Nearly Conformal Gauge Theories with Composite Higgs Mechanism

Julius Kuti

USQCD Collaboration Meeting

April 16, 2010

With Lattice Higgs Collaboration members:

Z. Fodor, K. Holland, D. Nogradi, C. Schroeder

Video Games in Technicolor

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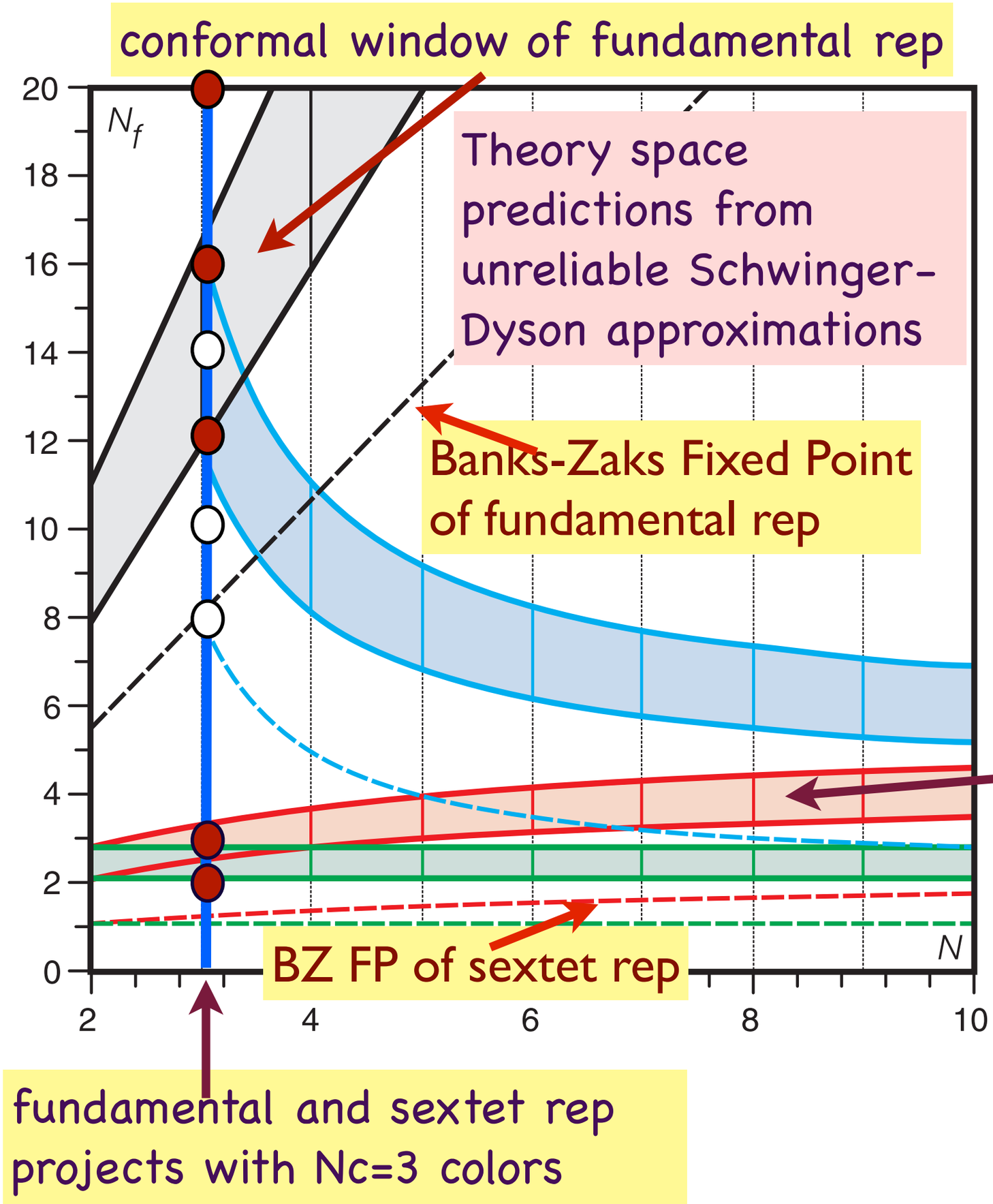
1. The SPC would appreciate to receive a more detailed breakdown of the resources required to address the various questions you raise in the proposal. In particular, the SPC wonders what resources are still needed to complete the Nf=12 calculations and what is needed to do the Nf=16 and 20 analysis.

2. It would be very helpful to receive information on the typical number of trajectories you need to generate to obtain the data you have shown in the proposal.



fundamental rep projects running: **Nf=8,10,12,14,16,20** dynamical staggered stout fermions

USQCD resources this year: 9M J/Psi core hours
(Far less than needed for the results presented here, or used on USQCD clusters)

New request: 13.9M J/Psi core hours and 0.6M GPU hrs

conformal window: 2-index symmetric rep (sextet)

sextet rep projects running: **Nf=2,3** dynamical staggered stout fermions

summary web page: http://www.physics.ucsd.edu/~nogradi/usqcd/

USQCD supported published results last year:

1. **Topology and higher dimensional representations.**
   Published in **JHEP 0908:084,2009**.
   e-Print: **arXiv:0905.3586** [hep-lat]

2. **Nearly conformal gauge theories in finite volume.**
   Phys.Lett.B681:353-361,2009.
   e-Print: **arXiv:0907.4562** [hep-lat]

3. **Chiral properties of SU(3) sextet fermions**
   e-Print: **arXiv:0908.2466** [hep-lat]

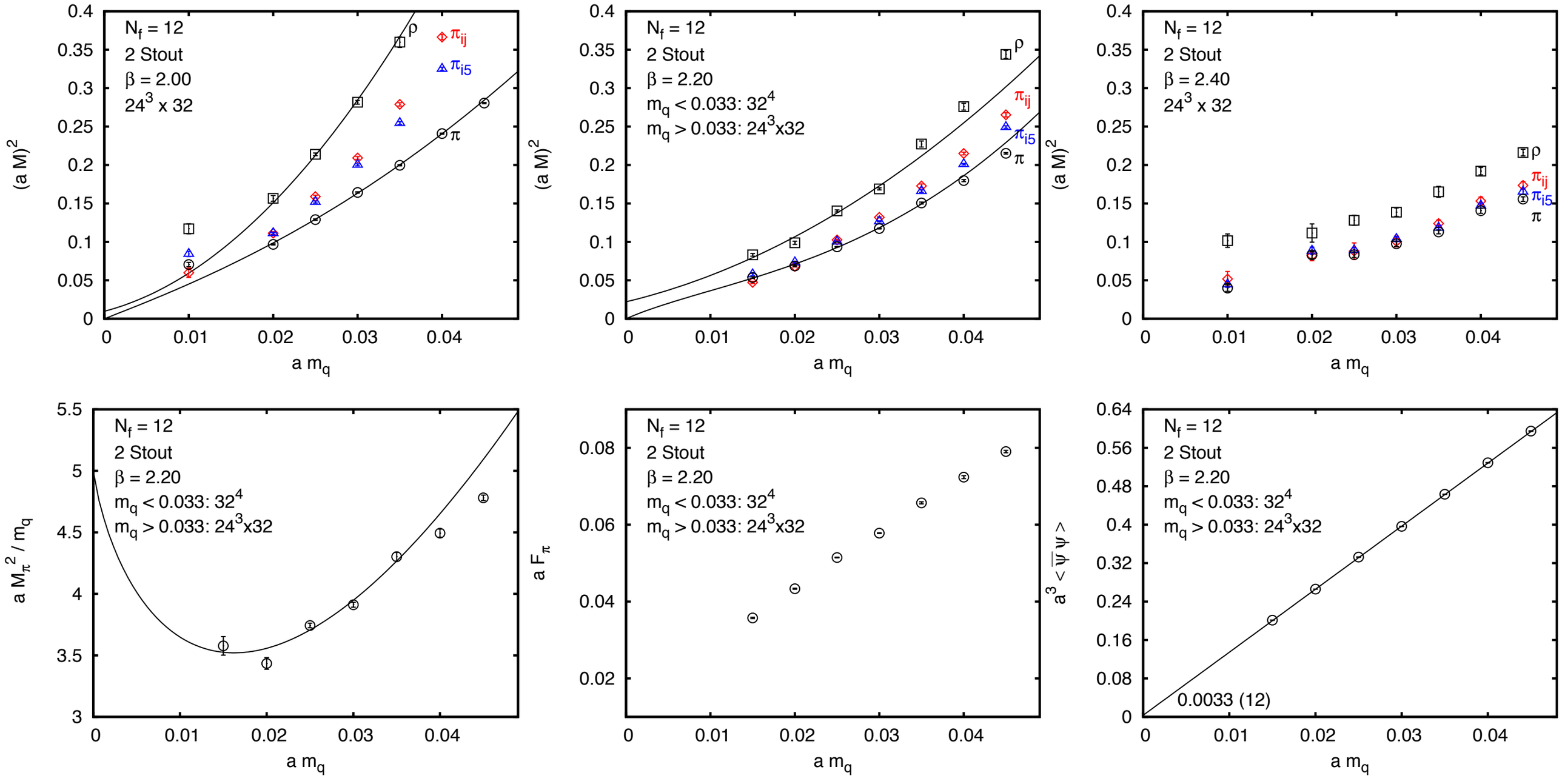
4. **Chiral symmetry breaking in nearly conformal gauge theories**
   e-Print: **arXiv:0911.2463** [hep-lat] **posted**

5. **Calculating the running coupling in strong electroweak models**
   e-Print: **arXiv:0911.2934** [hep-lat]

I will also discuss unpublished new analysis

Nf=12 chiral symmetry breaking pattern and running coupling require continued investigations

Nf=12 NLO chiral analysis in p-regime:



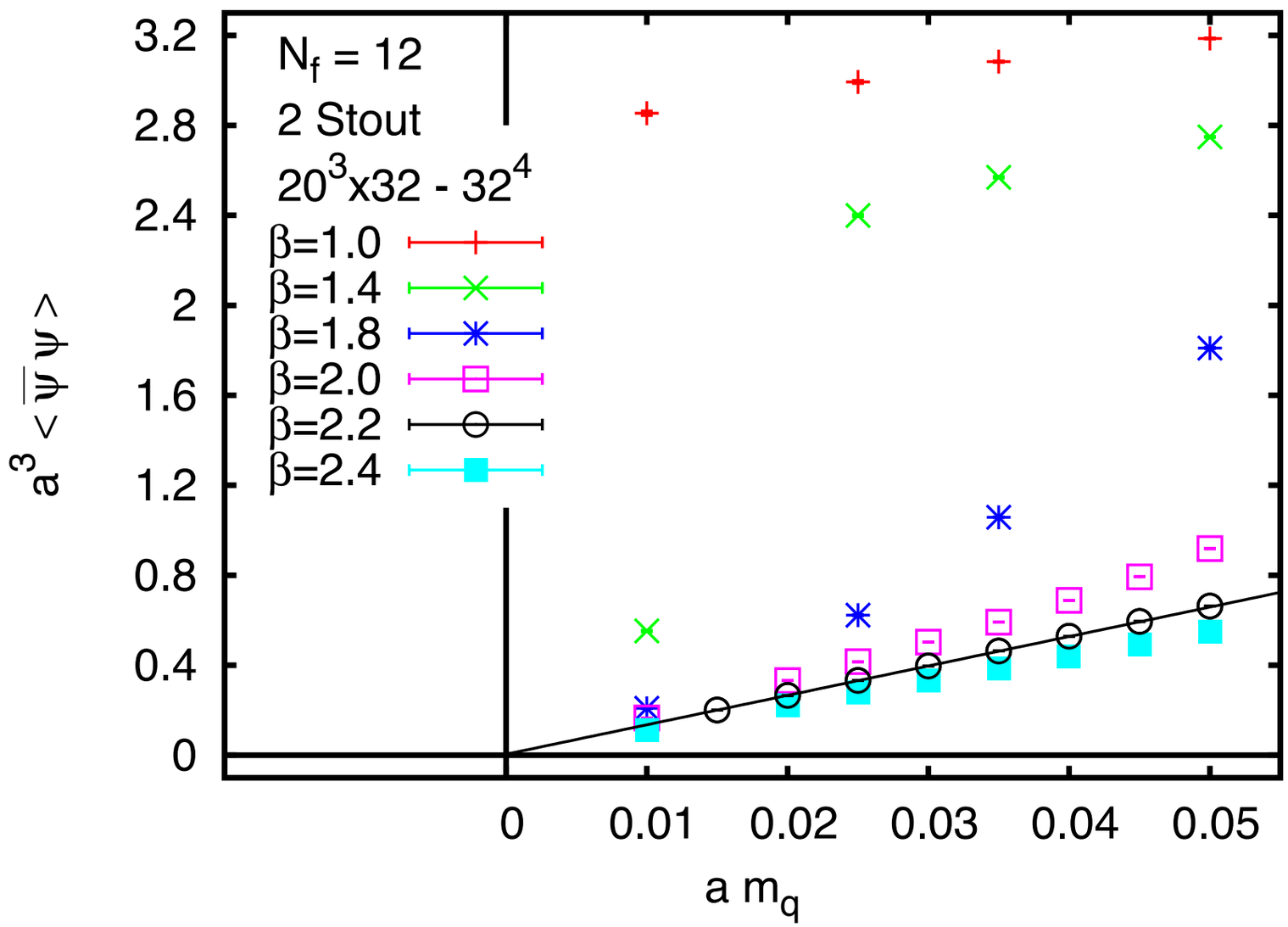
Similar pattern to Nf=9 case!

All features exhibit chiral symmetry breaking

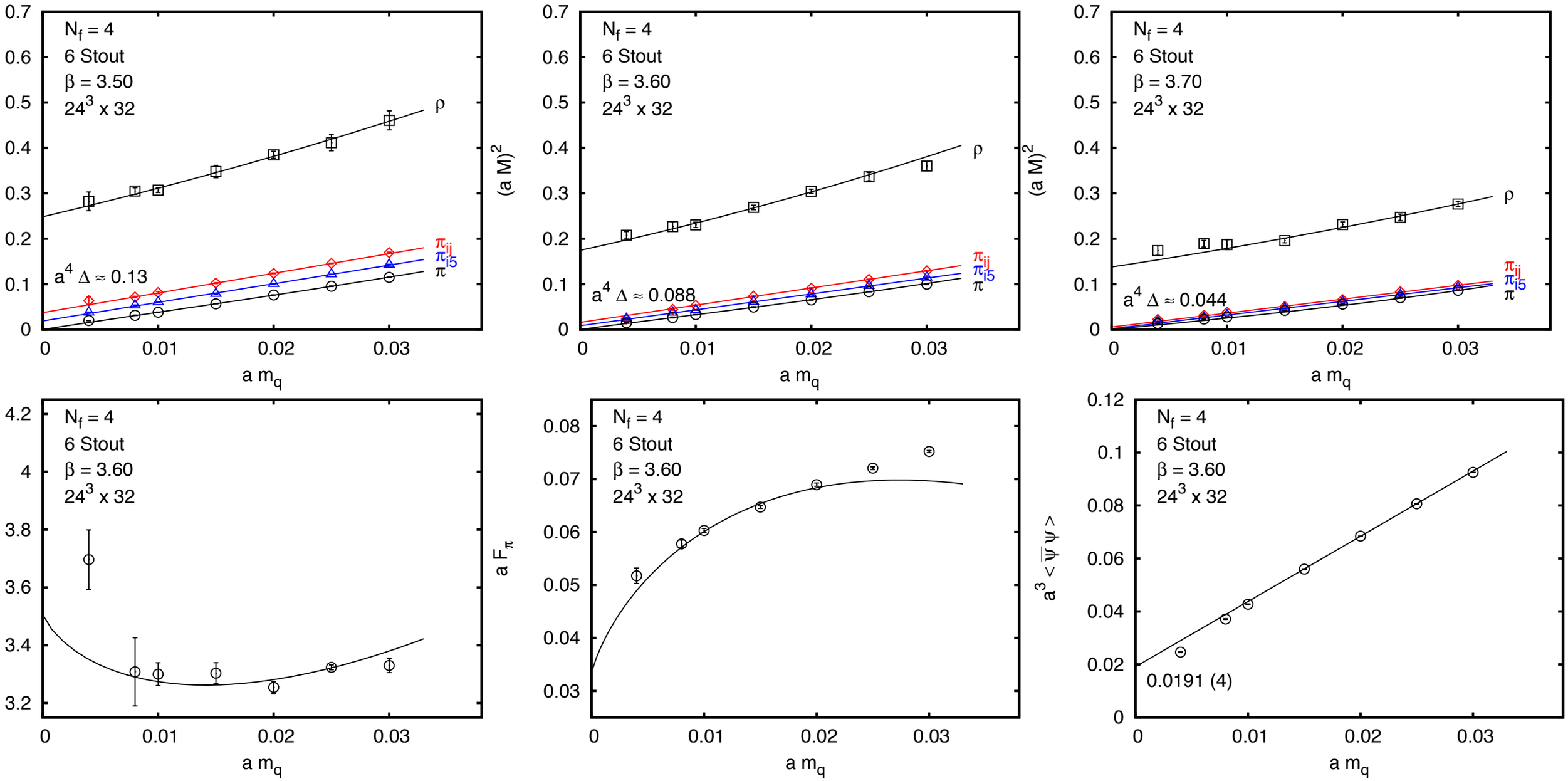
Columbia group's results consistent with this

Nf=12 runs are away from strong to weak coupling crossover region on the weak coupling side!

Small chiral condensate



Nf=12 different from Nf=4 textbook-like NLO chiral analysis in p-regime:

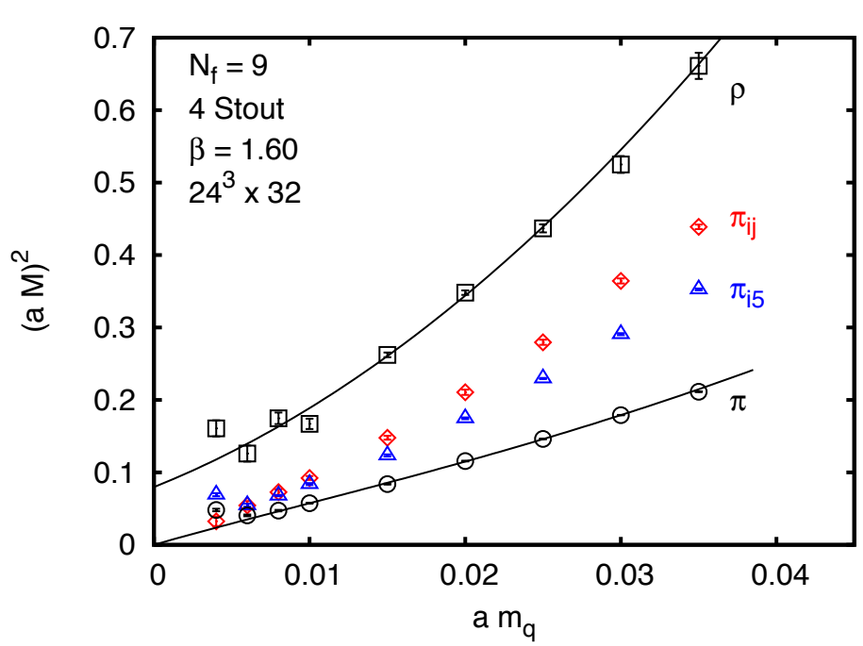


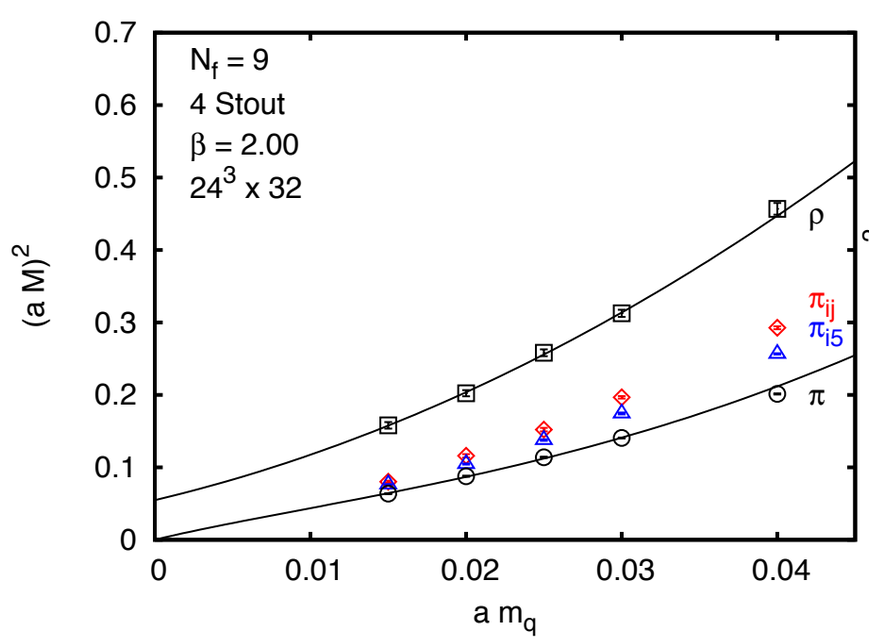
$$\mathcal{L}_\chi^{(4)} = \frac{F^2}{4}\mathrm{Tr}(\partial_\mu\Sigma\partial_\mu\Sigma^\dagger) - \frac{1}{2}B\,m_q\,F^2\mathrm{Tr}(\Sigma + \Sigma^\dagger) \;+V_\chi^{(6)}$$

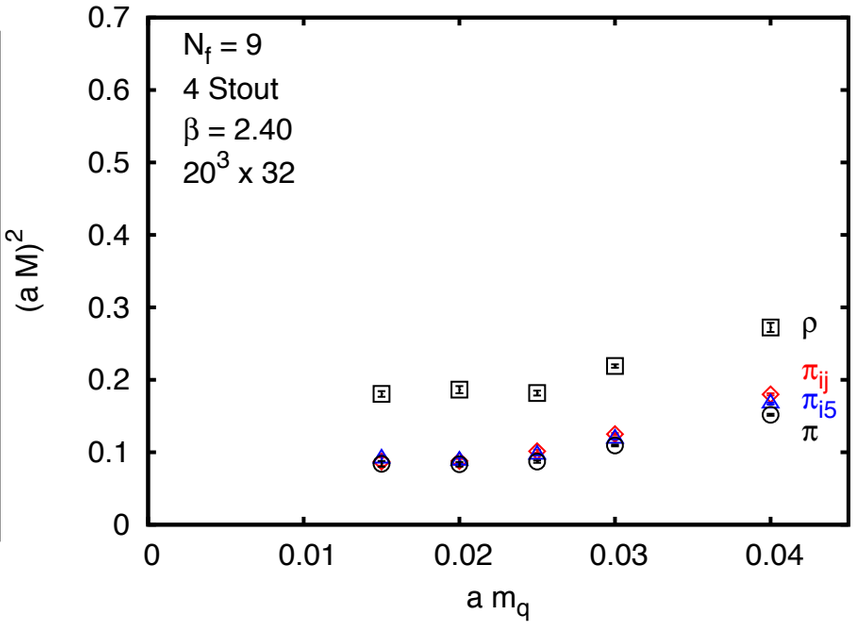
$$M_\pi(T_a)^2 = 2Bm_q + a^2\Delta(T_a) + O(a^2 m_q) + O(a^4)$$

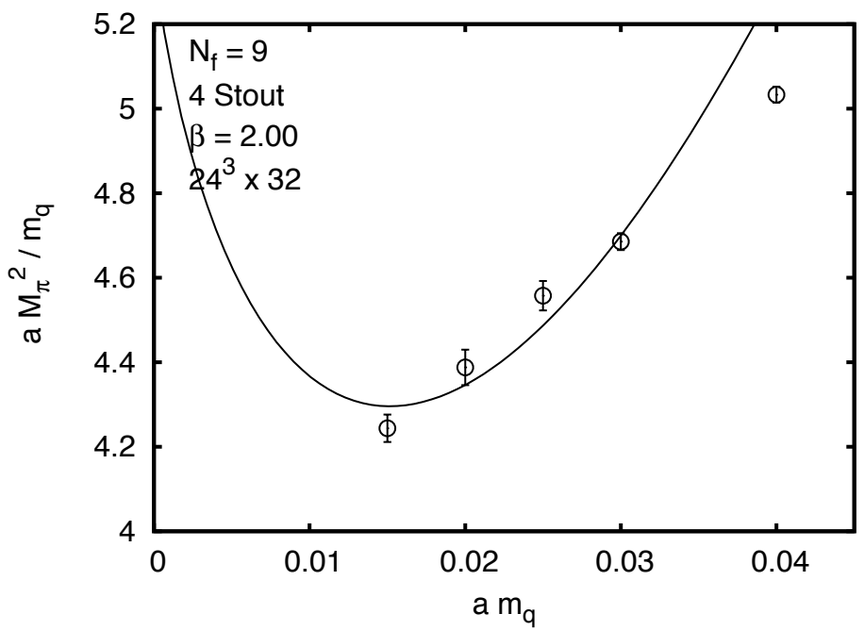
$$\begin{aligned}
\Delta(\xi_5) &= 0\,, \\
\Delta(\xi_\mu) &= \frac{8}{F^2}(C_1 + C_2 + C_3 + 3C_4 + C_5 + 3C_6)\,, \\
\Delta(\xi_{\mu 5}) &= \frac{8}{F^2}(C_1 + C_2 + 3C_3 + C_4 - C_5 + 3C_6)\,, \\
\Delta(\xi_{\mu\nu}) &= \frac{8}{F^2}(2C_3 + 2C_4 + 4C_6)\,.
\end{aligned}$$

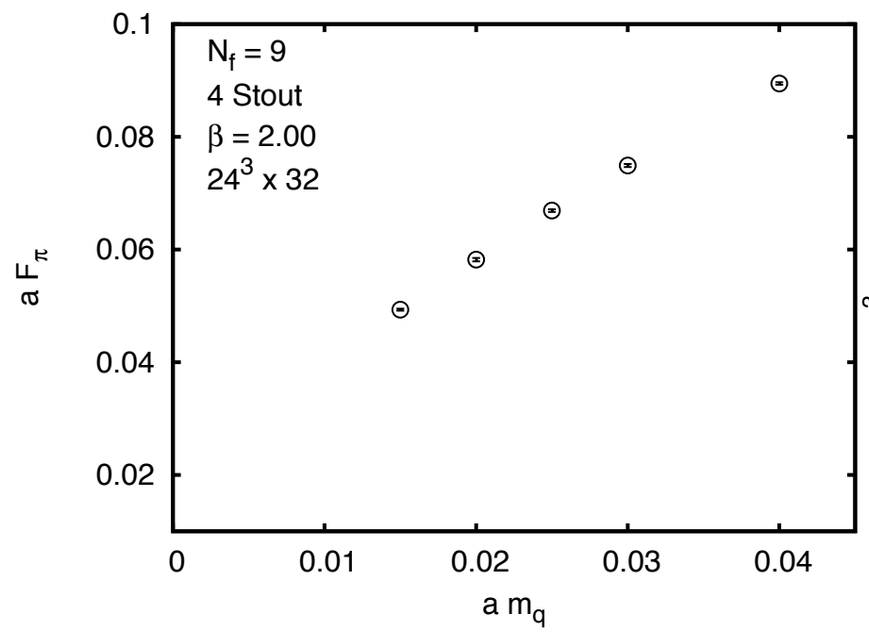
But Nf=12 is quite similar to Nf=9 NLO chiral analysis in p-regime:

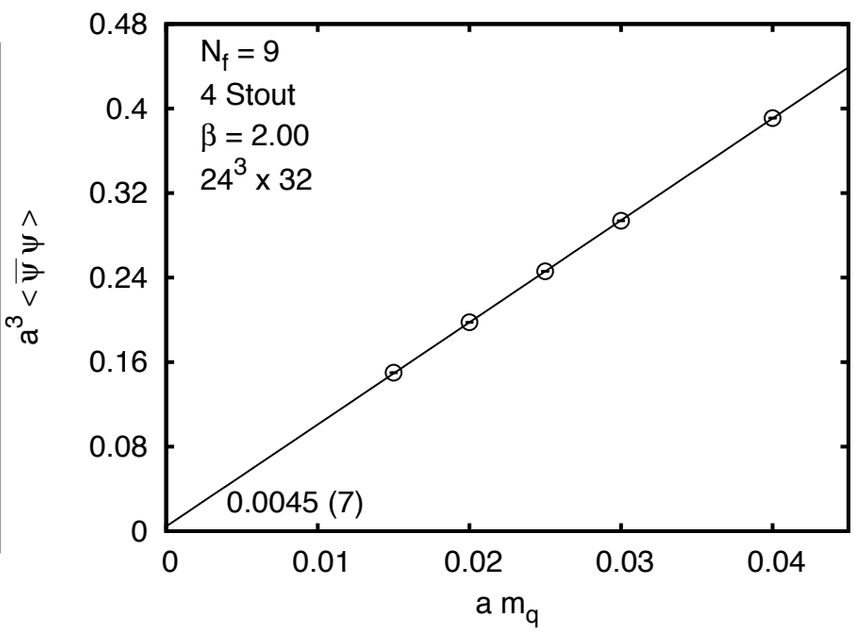












Further hints for chiral symmetry breaking: running coupling (?) and A1-Rho splitting (?)

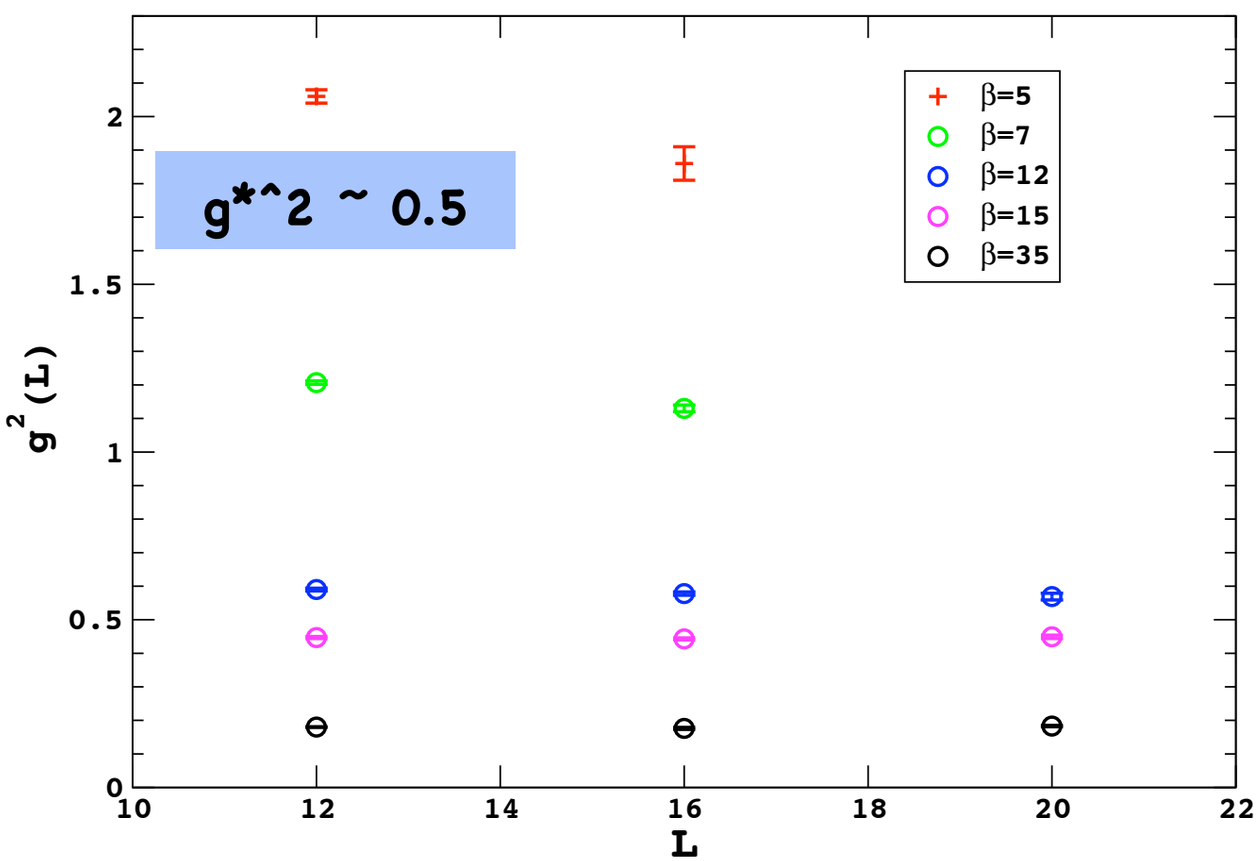
Our running coupling methods (important to have 3 methods)

SF, MCRG, Wilson loops (including $\alpha_W(R)$, V(R), F(R))

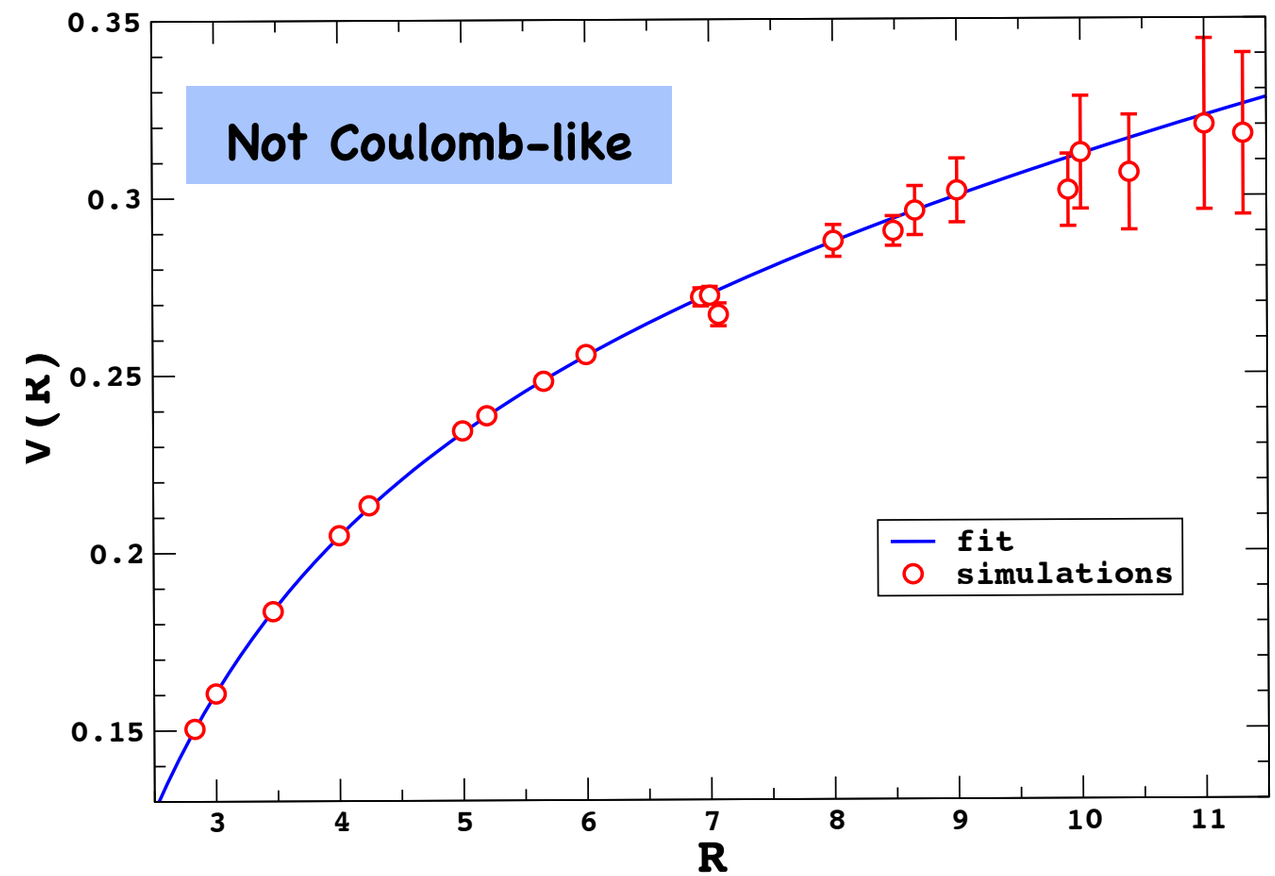
We use Wilson loop ratios, V(r) potential, and F(r) force to get the running coupling g(R) in several schemes Looks promising

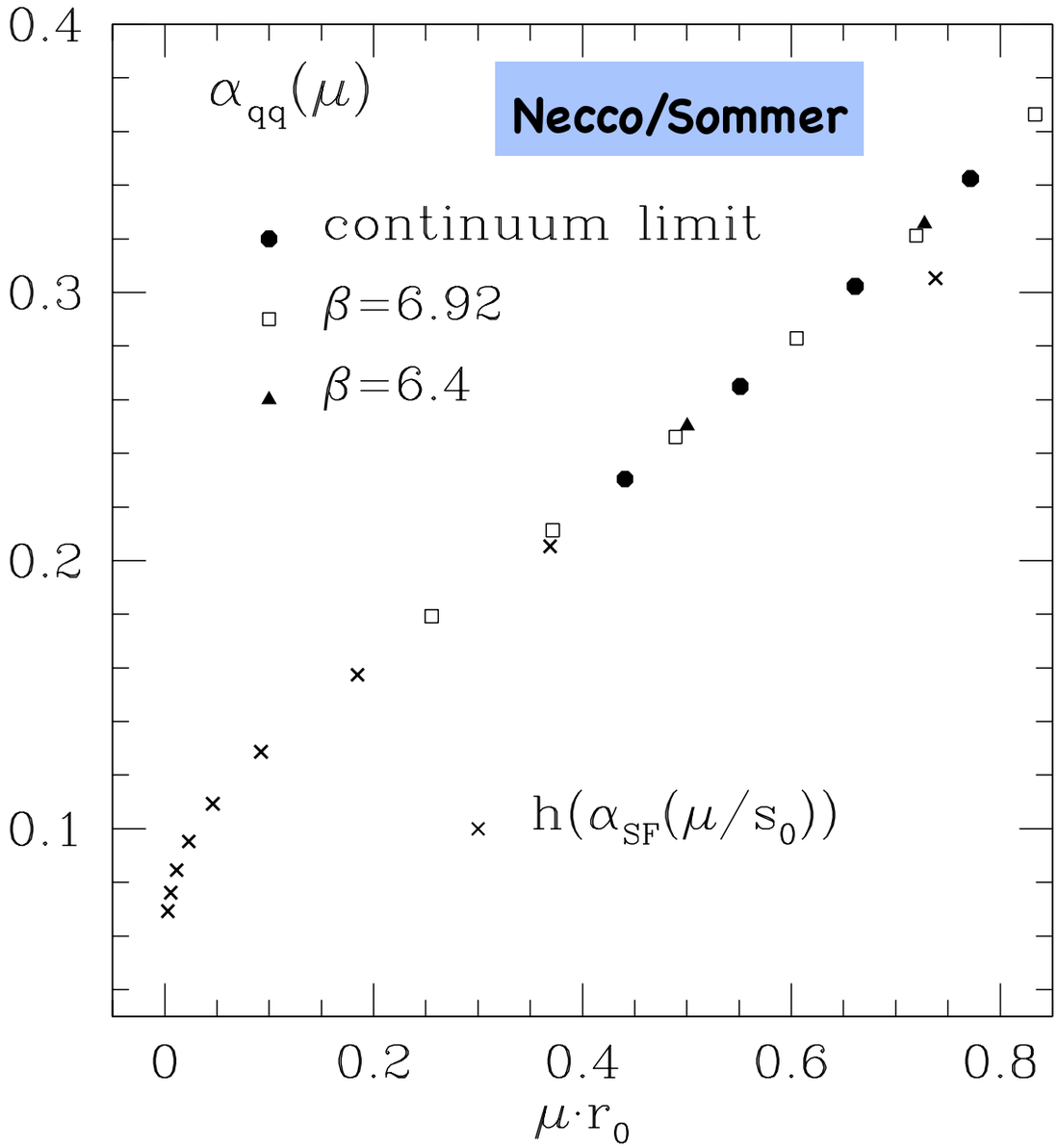
We are running with R, or with L when R/L fixed (different schemes)

Nf=16 Creutz coupling running



N_f=12, 2-stout 32^3x64, β=2.2, m=0.015



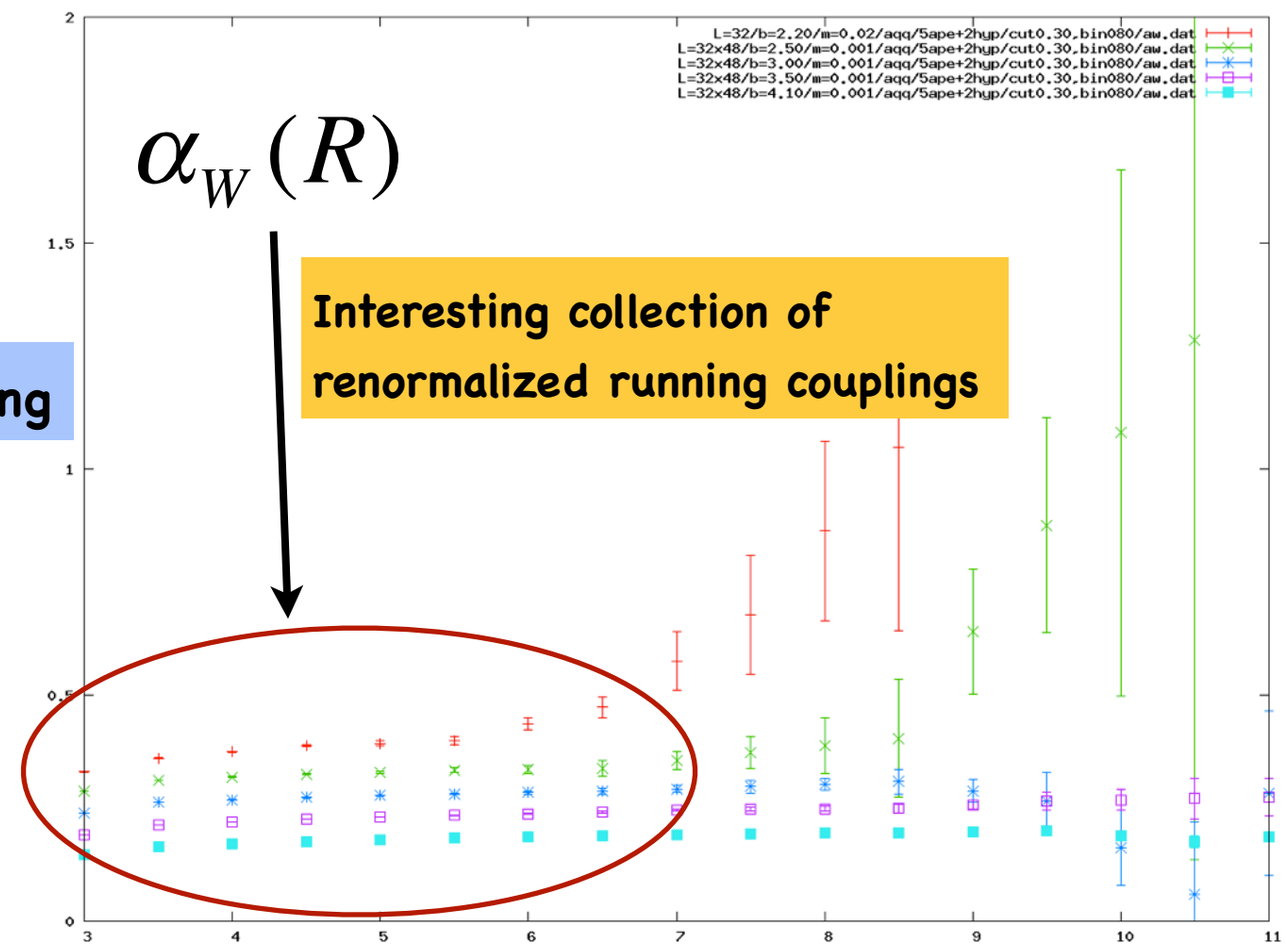


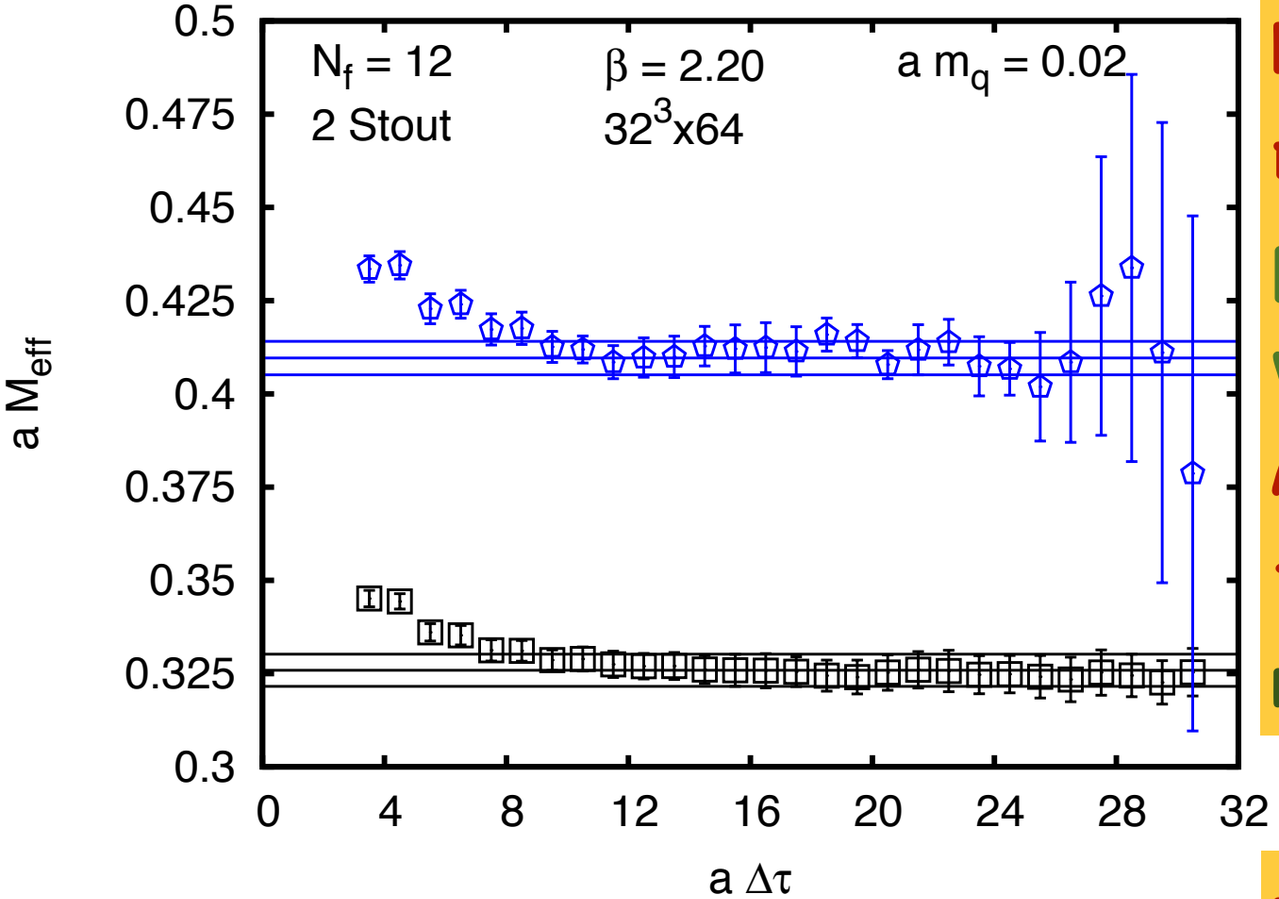
Very difficult to resolve fixed point from walking

Running coupling from force and SF running nicely match for Nf=0 and Nf=2

We have difficulties to match data from the Force/Creutz running coupling and the Yale SF running at Nf=12 in the relevant coupling range

Will requires further careful studies



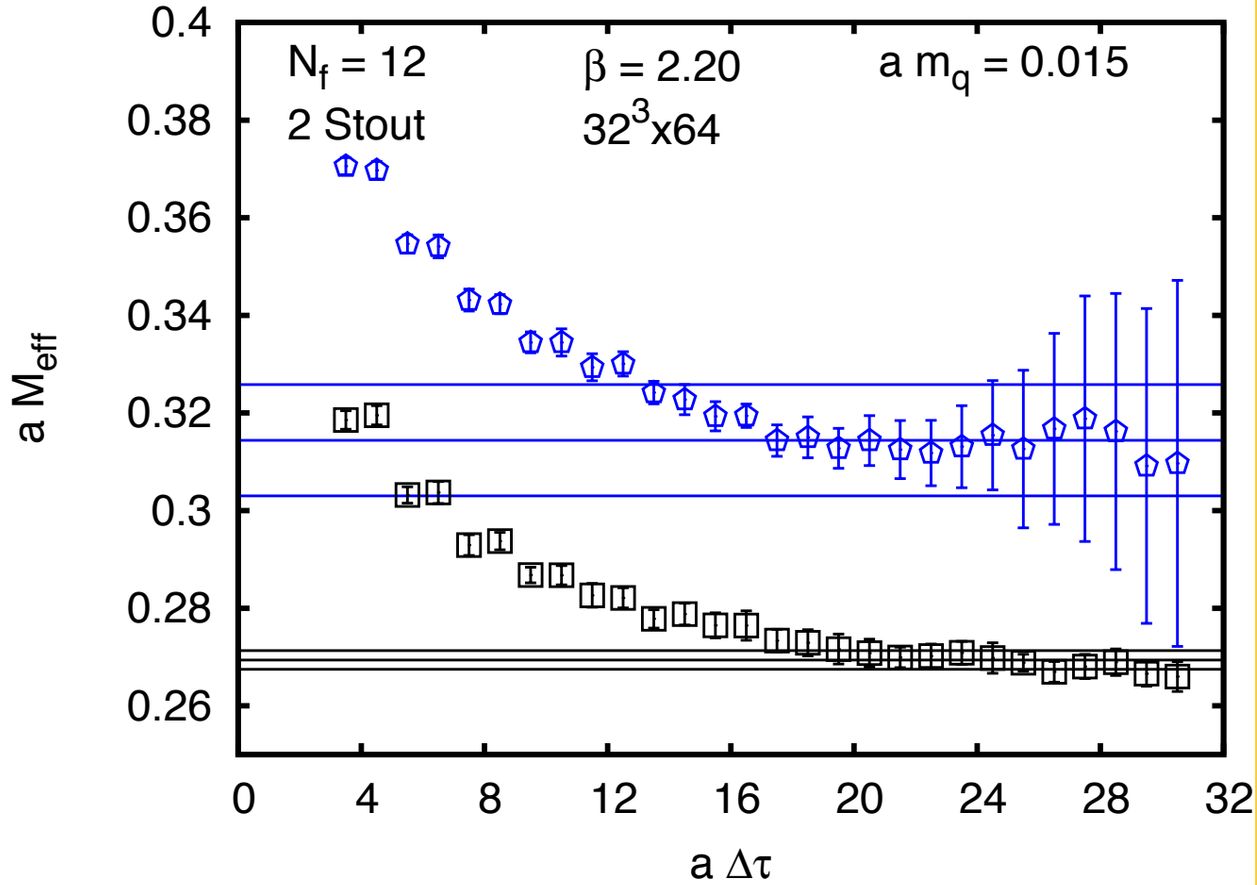


Nf=12 mq=0.015, 0.02

rho-A1 splitting

pulled out from single correlator with two parity partners

Approximately 3,000 thermalized trajectories of unit length (bare minimum we should always have)



Nf=12 mq=0.01 benchmark

32^3x64 with 3K trajectories:

~ 300K 9q core hours

20 Gflops on 9q nodes in eight cores

approximately scales to 48^3x96 (3K trajectories):

~ 1.5 M 9q core hours

Nf=12

For test of chiral symmetry breaking and chiral limit extrapolations: We propose to add one run at beta=2.2 with mq=0.01 on 48^3x96 lattice generating 3K trajectories

cost: 3M J/Psi core hours

This lattice would match our existing Ls=24^36 runs and the 32^3x64 runs for several tests of the running coupling

For scaling tests: We propose to add two runs at beta=2.0 with mq=0.01, mq=0.015 and one run at beta=2.4 with mq=0.02 on 32^3x64 lattices with 3K trajectories

cost: 1.8M J/Psi core hours

For test of SF Yale results of running coupling: We plan to run KS fermions at mq=0.001 at four beta values on 32^3x64 lattices

cost: 2.4M J/Psi core hours The largest lattice size dominates

Total Nf=12 budget: 7.2M J/Psi core hours

Nf=16

Femto physics with tunneling vacua is relevant (and probably dominant):

We would like to run at three beta values with mq=0.001 on 24^3x128 lattices generating 3K trajectories for the conformal energy spectra ~1/L

cost: 1.3M J/Psi core hours

Nf=20

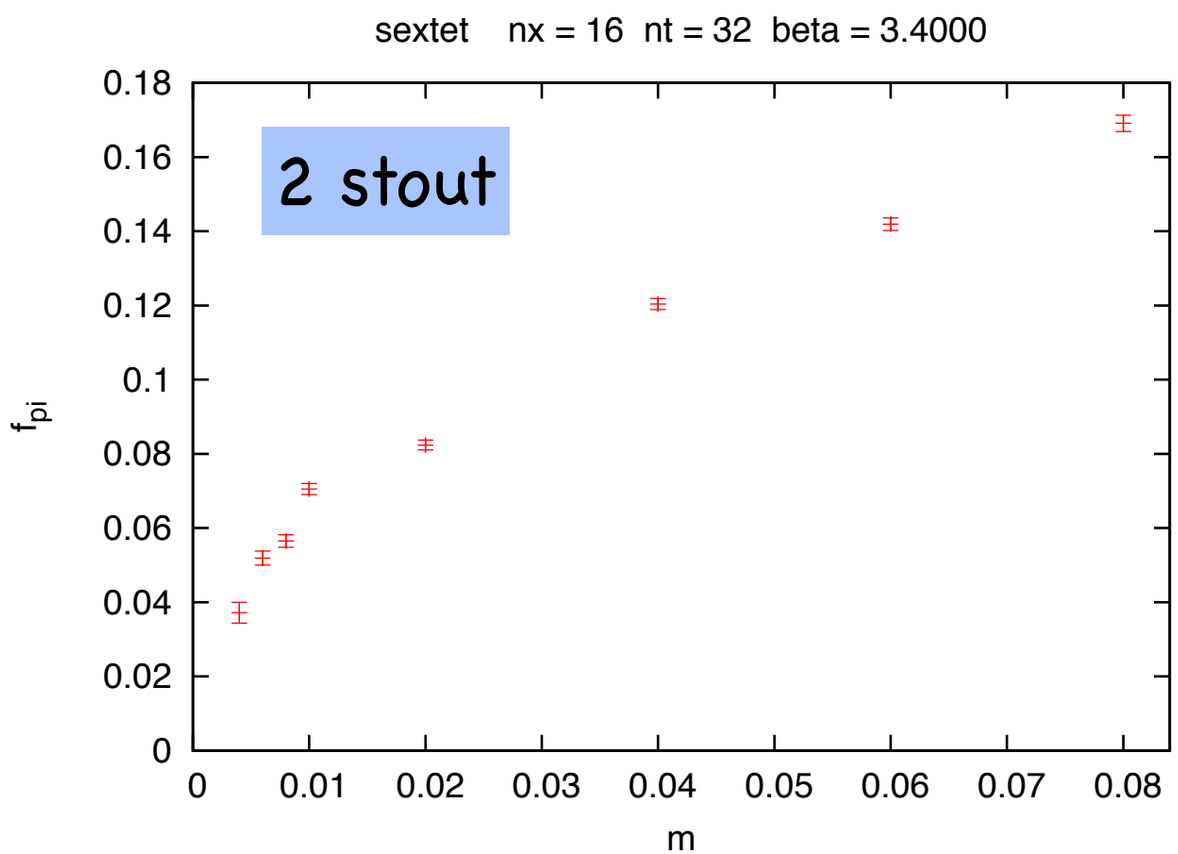
Femto physics with tunneling vacua is relevant (and probably dominant):

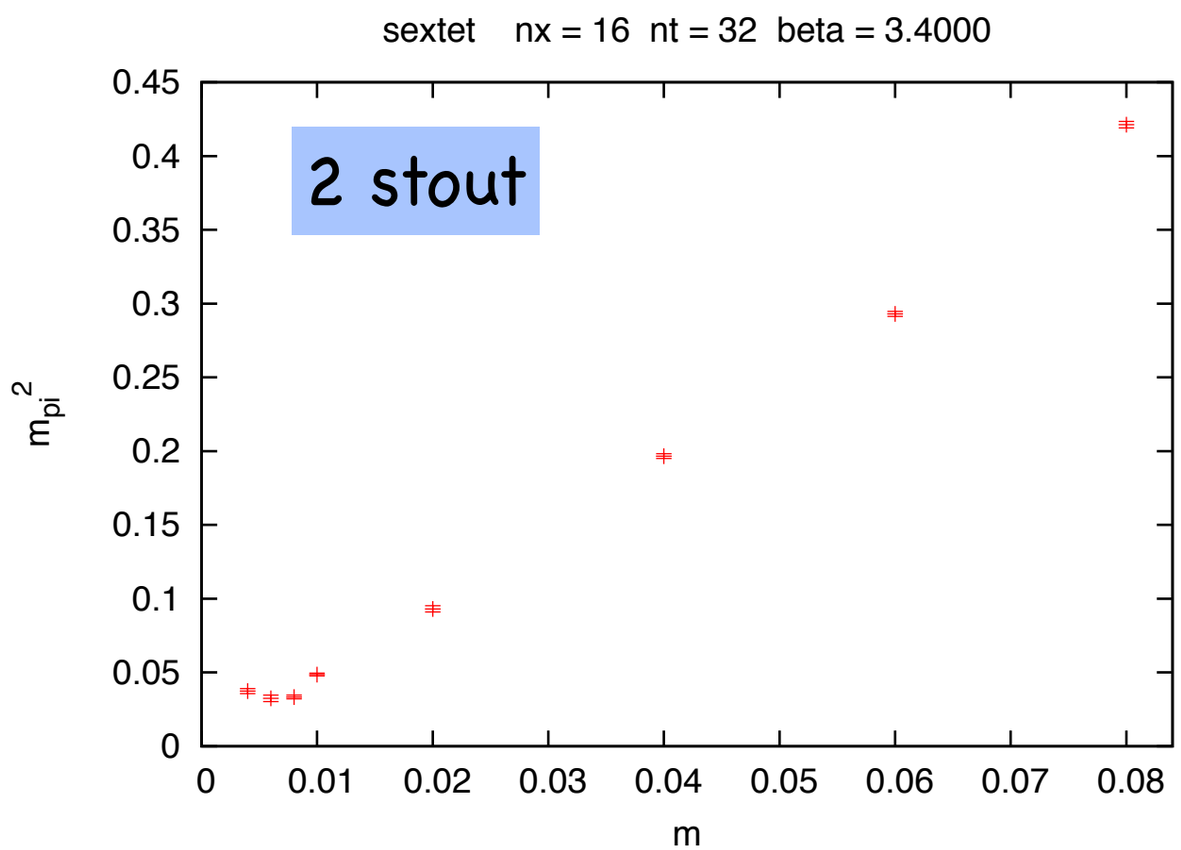
We would like to run at three beta values with mq=0.001 on 24^3x128 lattices generating 3K trajectories for the trivial energy spectra ~1/L

cost: 1.3M J/Psi core hours

Total Nf=16,20 budget: 2.6M J/Psi core hours

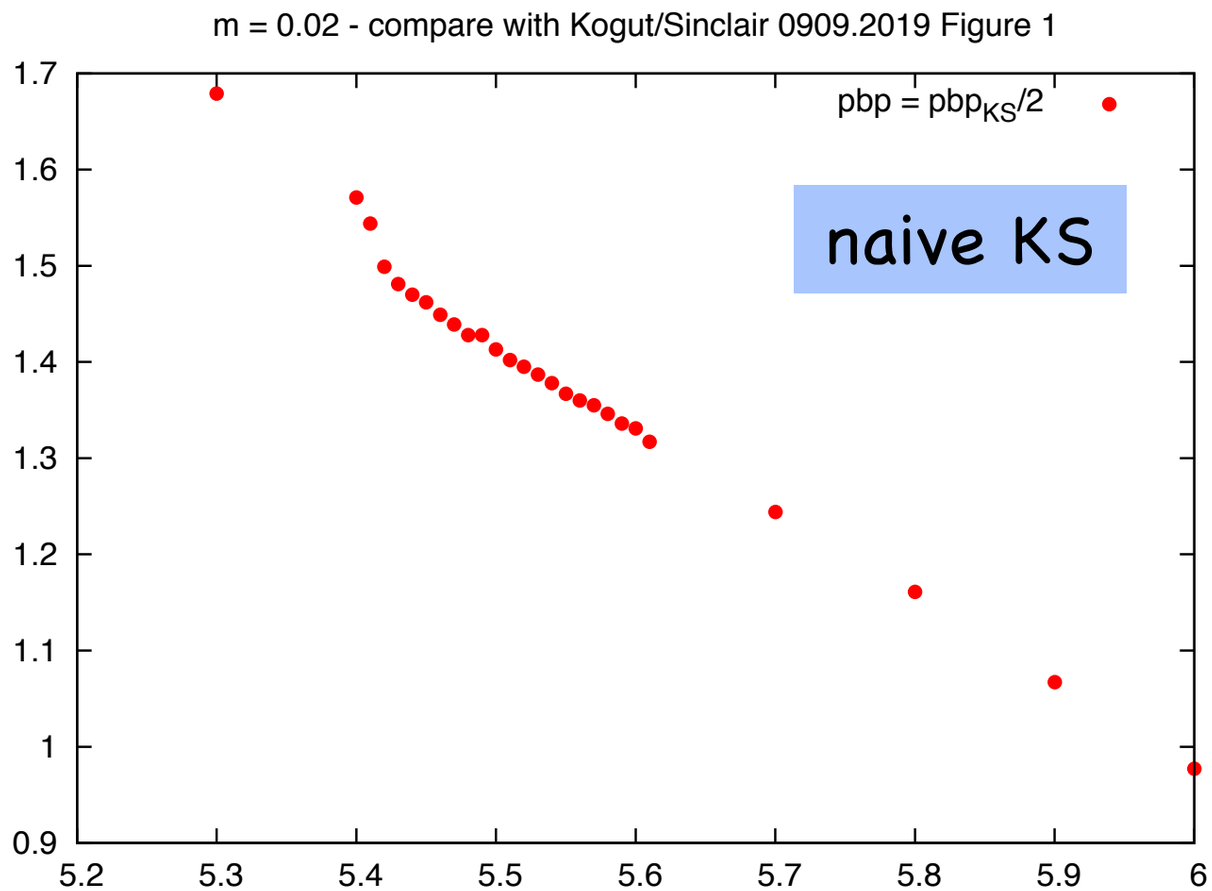
Sextet representation with Nf=2

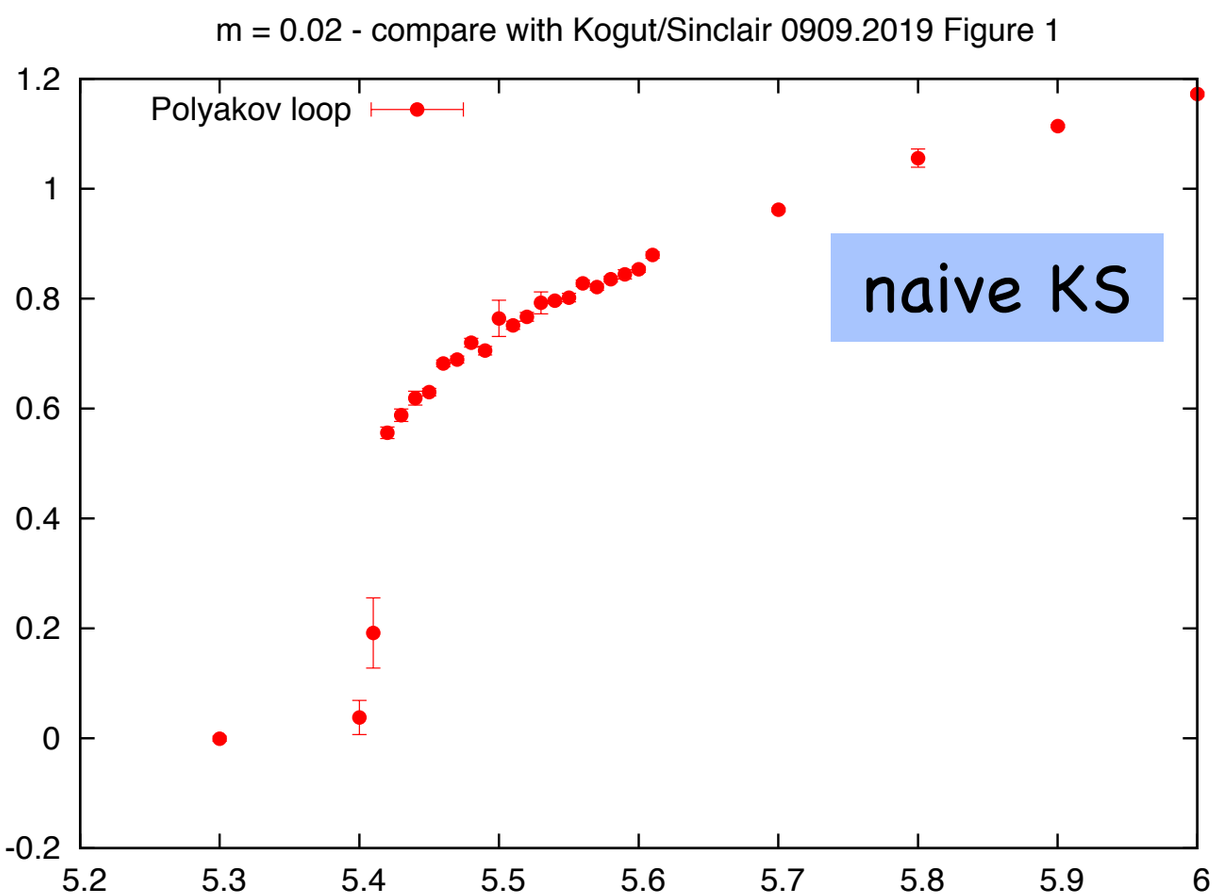




Goldstone spectrum and Fpi-> chirally broken

Will be easy 2 flavor analysis





Code reproduces Kogut-Sinclair results with the 2 stout steps disabled

Budget of sextet project with Nf=2,3:

For test of Nf=2 chiral symmetry breaking and chiral limit extrapolations:

We propose to run at beta=3.2,3.4,3.6 with mq=0.01,0.02,0.03 on 32^3x64 lattices generating 3K trajectories each

cost: 5.4M J/Psi core hours

This lattice would match our existing Ls=16^32 runs

Several tests of the running coupling are needed in the sextet model:

propose to run at beta=3.2,3.4,3.6,4.0,4.5 with mq=0.001 up to 32^3x64 lattices generating 3K trajectories each

cost: 3M J/Psi core hours + 3M J/Psi core hours for the Nf=3 runs inside the conformal window

Total Nf=2,3 sextet budget: 11.4M J/Psi core hours

Cluster budget of all plans: 21.2 M J/Psi core hours

almost factor 2 more than what we asked for in proposal cluster time and still underestimates needs for what we are planning to do (for example, critical slowdown at mq=0.001 for chiral runs always turns out worse then benchmarks indicate before thermalization)

Hope to make up for all the "misunderestimations" with GPU computing

3. The SPC also wonders what makes it necessary to split calculations with fermions in the fundamental representation into a portion that is done on GPUs and another portion that is done on clusters.

4. We are also interested in your experience with running on, and coding for, the GPU cluster.

We are supported by the Wuppertal hardware/software infrastructure

We built on Wuppertal software library:
Fodor, Szabo, Katz

Very limited use of Wuppertal hardware

We are USQCD !!

GPU Hardware

CUDA code:
Kalman Szabo
Sandor Katz
Chris Schroeder
Daniel Nogradi

GTX 280
Flops: single 1 Tflop, double 80 Gflops
Memory 1GB, Bandwidth 141 GBs^{-1}
230 Watts, $350

Our new DYNQCD software mostly by Szabo, Nogradi, Schroeder

For code development:
Small UCSD Tesla cluster
ARRA funded by DOE
waiting for Fermi cards

Tesla 1060
Flops: single 1 Tflop, double 80 Gflops
Memory 4GB, Bandwidth 102 GBs^{-1}
230 Watts, $1200

Tesla 1070
Flops: single 4 Tflops, double 320 Gflops
Memory 16GB, Bandwidth 408 GBs^{-1}
900 Watts, $8000

Nf=12 mq=0.01 benchmark comparison between GPU and CPU

32^3x64 with 3K trajectories:

~ 300K 9q core hours

~ 15 K GTX 285 hours

~ 20 Gflops on 9q nodes

approximately scales to 48^3x96

(3K trajectories):

~ 1.5 M 9q core hours

~ 75 K GTX 285 hours

However, benchmarks are not full RHMC code comparisons

CPU is used in double precision sums and error checking and a few other parts of the RHMC code

Full code is going to move gradually into the new Fermi GPU cards which have error checking and high speed double precision

Writing GPU CUDA code is challenging (fighting Amdahl's law ?)
(production workflow is quite different: many Gflops but slow configuration generation on single GPU to sit out thermalization before you stream on GPU farm)

Staggered stout in fundamental rep runs on GPU
sextet rep staggered code is only running in CPU

Operationally the JLAB GPU cluster set up is great

Fermi cards with error correction and fast double precision may be game changers

Early Fermi benchmark tests at JLAB are complicated and somewhat tentative

Going parallel within node (4 GPU) or across nodes challenging

5. The SPC would like to receive a statement of your group regarding the common data and source code sharing policy of USQCD.

All lattice configurations we generate are available to USQCD including the ones we generated in Wuppertal!

All software we develop from USQCD sources is shared. Wuppertal based software has to be discussed with original non-USQCD developers.