Confining force in near-conformal gauge theories

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it’s the SM Higgs, stupid

ancient history (pre-2007): Lattice Higgs Collaboration

fundamental Higgs-Yukawa theories on the lattice

* Heavy Higgs/non-perturbative sector
* Triviality, vacuum (in)stability and Higgs bounds
* Limitations of non-asymptotically free theory

switched to near-conformal gauge theories (technicolor revised)

* Electroweak symmetry broken dynamically, new strong interaction
* asymptotically free, natural
* folklore: Higgs-free?

post July 4: now what?

how dead is dead?

last Friday, we heard from Guido Altarelli about the death of technicolor models

3 days later: back from the grave?

Agnolo Bronzini, *Resurrection*, Santissima Annunziata, Firenze

context

* space of 4d non-abelian gauge theories: Nf, Nc, representation

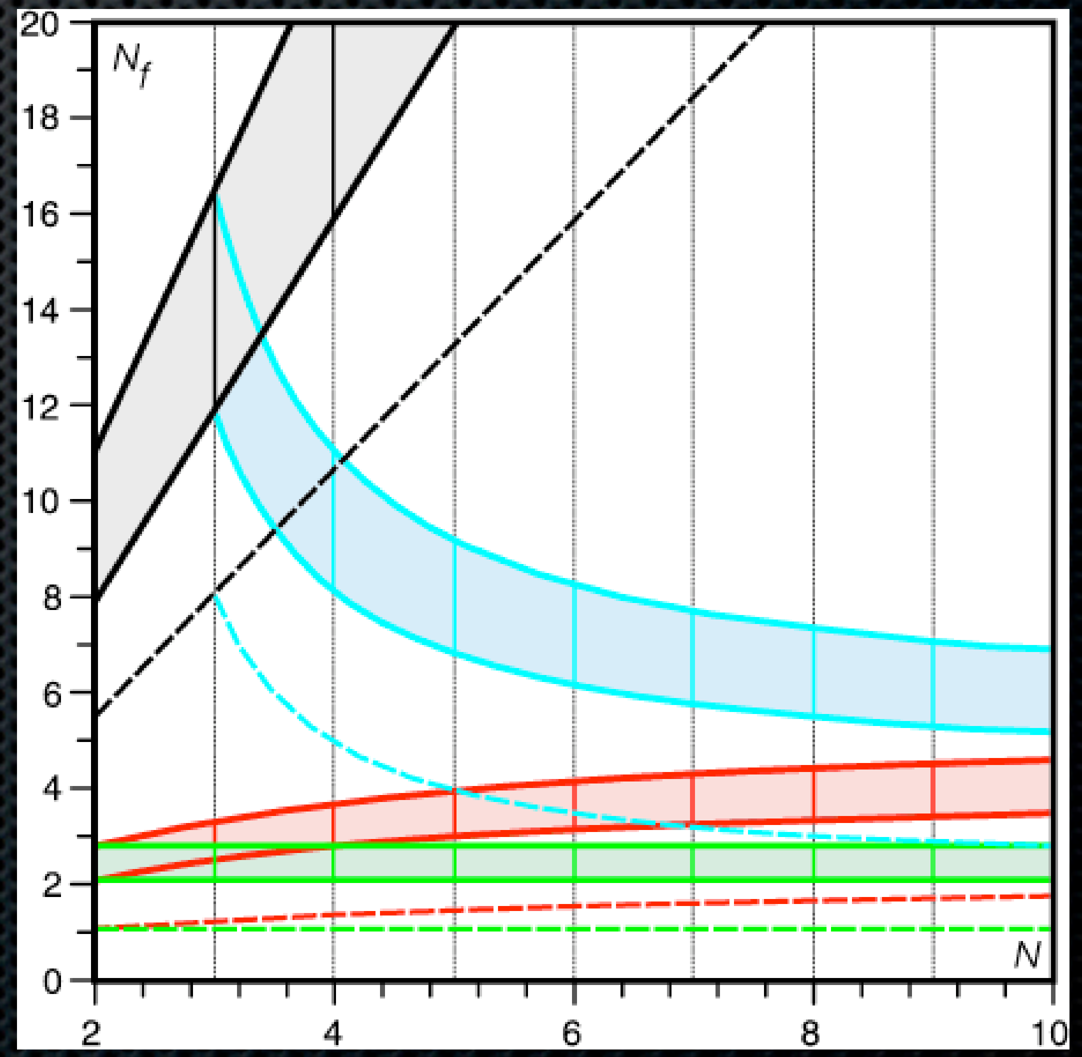
* keep asymptotic freedom

* which theories are conformal and do not break chiral symmetry spontaneously?

* could an almost-conformal theory play in role in Electroweak symmetry breaking?

* non-pertubative property: lattice essential, but which lattice observables to use?

* different theories, actions, observables, people, ...



Dietrich, Sannino, Tuominen, Appelquist, Shrock, ...

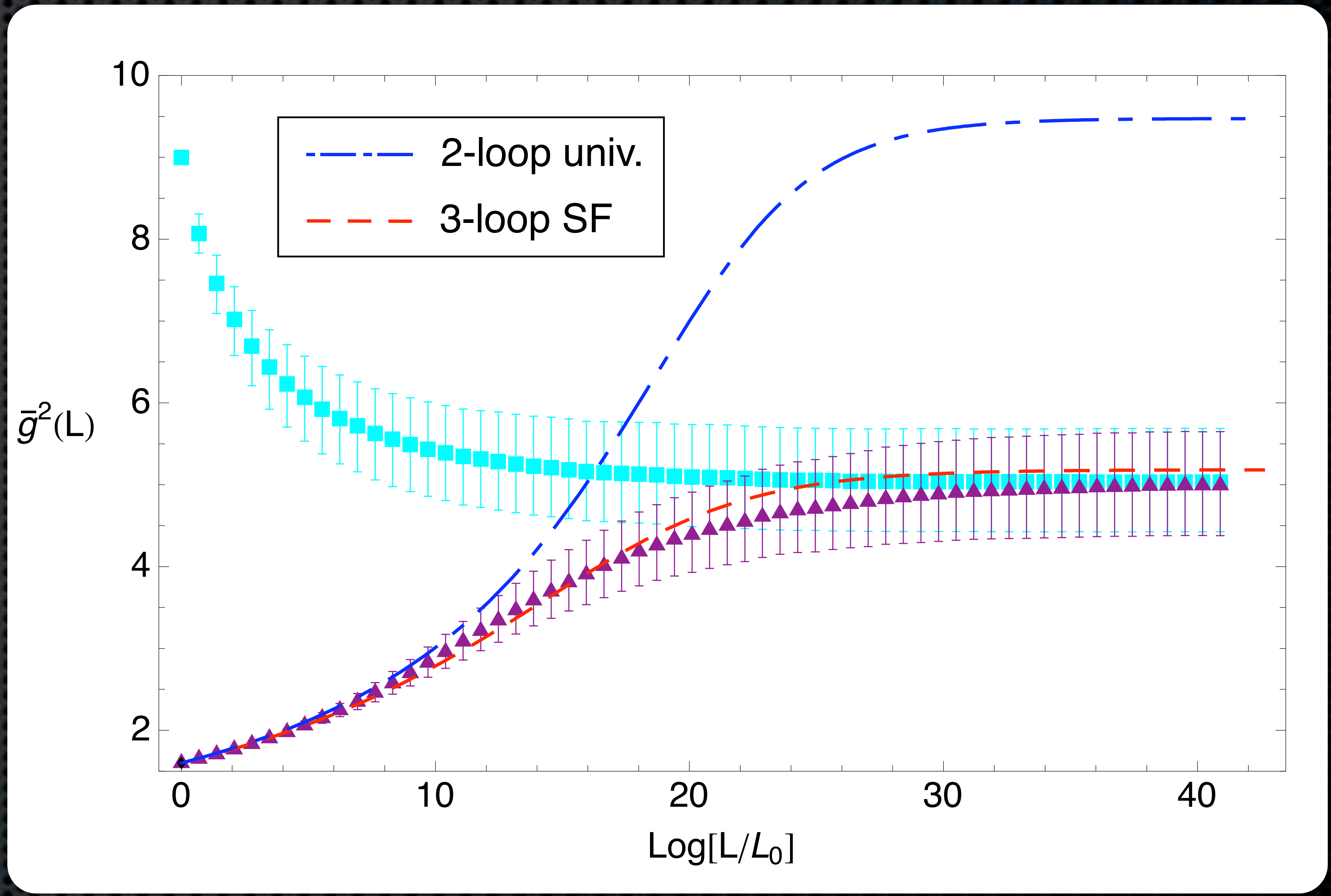
running coupling

early work: Appelquist, Fleming, Neil ‘07

Schroedinger functional renormalized coupling

SU(3) gauge theory
12 massless flavors
fundamental representation

evidence via simulations that renormalized coupling flows to infrared fixed point - conformal



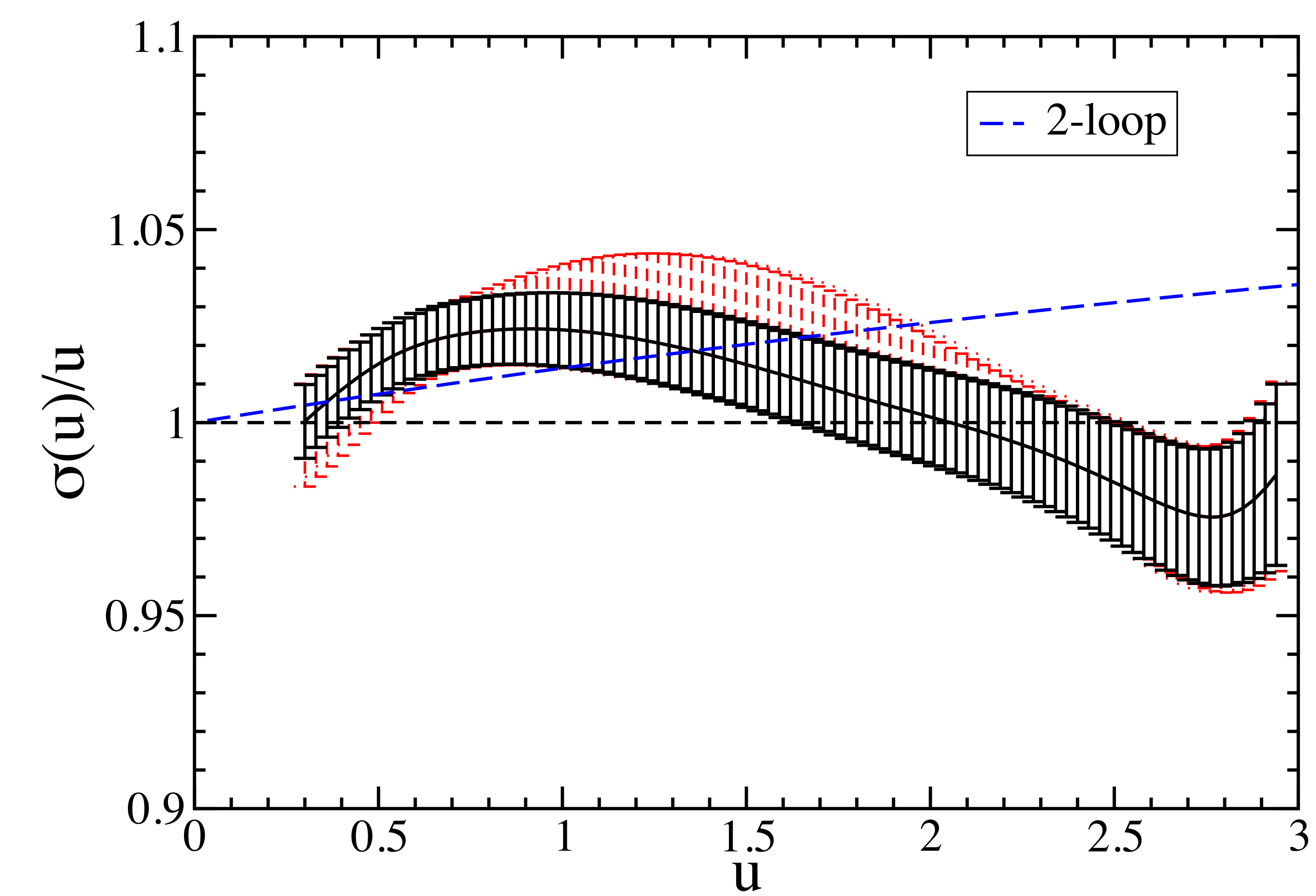
12 flavors expected to be conformal?

n-loop beta function
thermal degrees of freedom
Schwinger-Dyson

other renormalized coupling schemes

Twisted Polyakov loop scheme   de Divitiis et al '94

$$g^2_{\rm TPL} = \frac{1}{k}\frac{\langle \sum_{y,z} P_x(y,z,L/2a)P_x(0,0,0)^\dagger\rangle}{\langle \sum_{x,y} P_z(x,y,L/2a)P_z(0,0,0)^\dagger\rangle}.$$



Aoyama et al 2012

$$u = g^2_{\rm TPL}(L), \quad \sigma(u) = g^2_{\rm TPL}(1.5L)$$

SU(3) gauge theory
12 massless flavors
fundamental representation

also find evidence for infrared fixed point

other schemes:
ratios of square Wilson loops   Campostrini et al 94
quark potential V(r), force F(r)

12 flavors difficult

* Fodor et al: mass spectrum - spontaneous chiral symmetry breaking
* Jin & Mawhinney: finite-temperature chiral phase transition, not conformal
* Deuzeman et al: chiral symmetry not spontaneously broken
* Hasenfratz et al: Wilson RG flow shows fixed point
* Y.Aoki et al: mass spectrum - looks conformal

these inconsistencies prevent firm conclusion on phase of theory

being economic

* running coupling simulations, a la Schroedinger Functional
  - massless fermions, many lattice spacings to extrapolate to continuum, moderate lattice sizes

* mass spectrum simulations
  - several fermion masses, few lattice spacings, large lattice sizes for p-regime

each is expensive; doing both is prohibitive

recycle our mass spectrum runs

measure static quark potential V(r) and force F(r)

two theories

both SU(3)

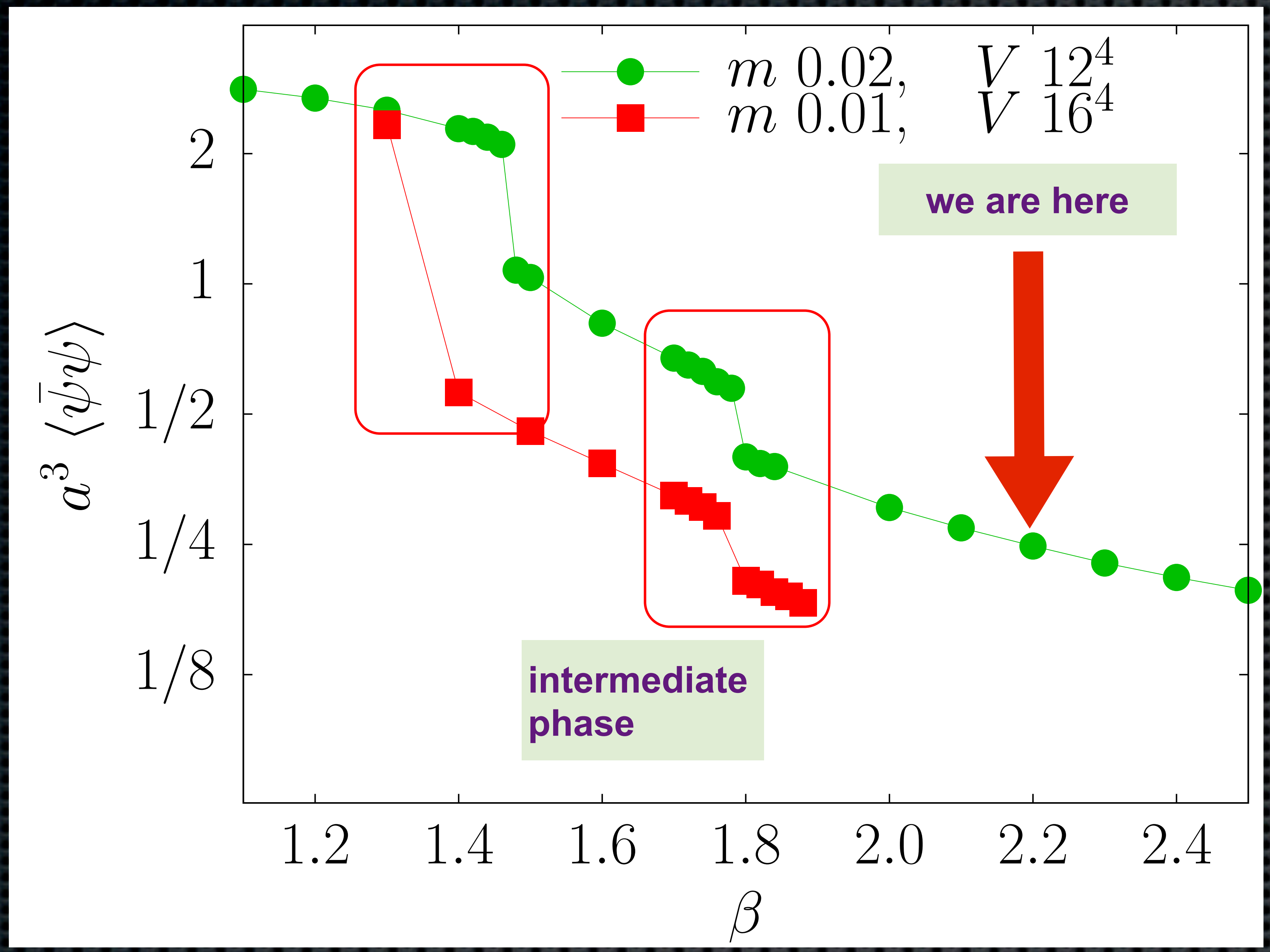
* 12 flavor fundamental
  - proven to be a difficult testbed
  - many studies, plenty to compare

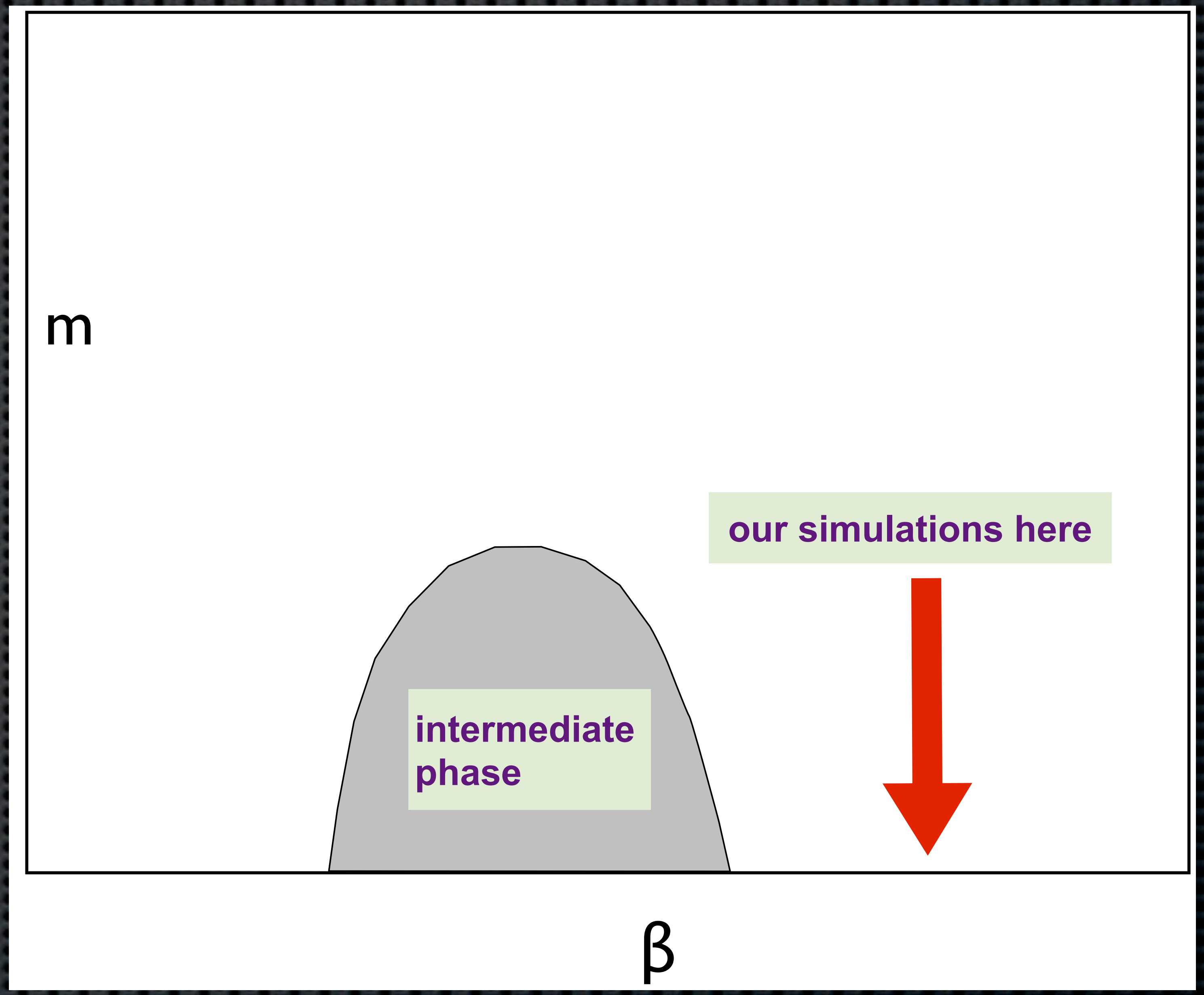
* 2-flavor 2-index symmetric (sextet)
  - exact match of GB's to W+/-, Z if chiSSB
  - fewer new d.o.f., less constrained
  - 3-flavor almost certainly conformal, 2-flavor only interesting #

will discuss both - not deja vu!

phase diagram

Nf=12 fundamental





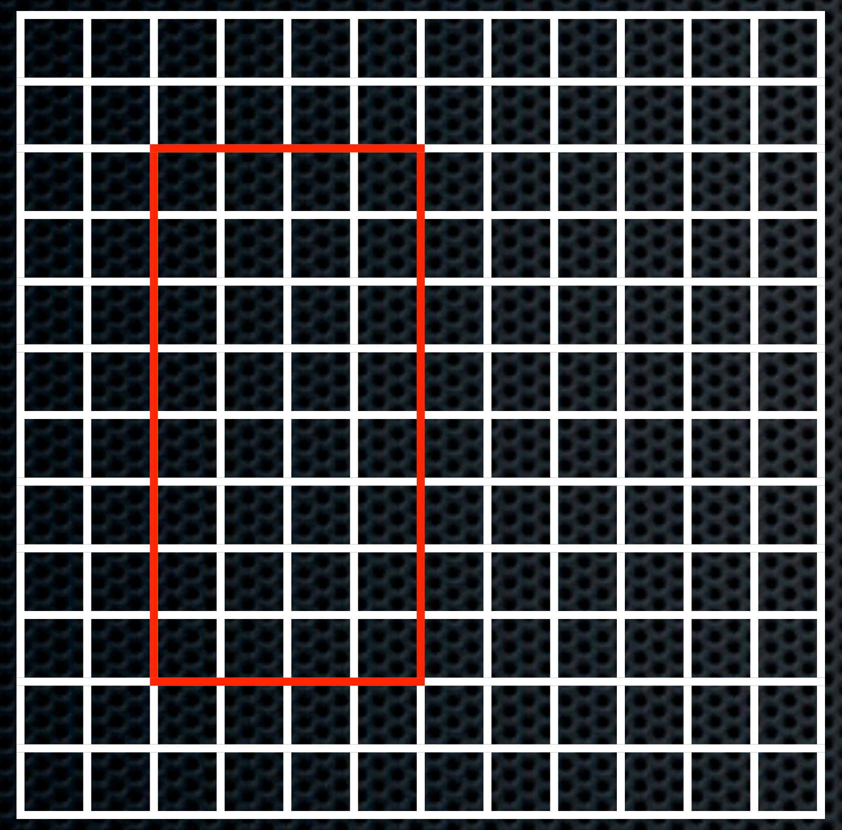
simulate at 1 bare coupling far away from bulk phase transitions, unusual phases

bulk transitions observed in other studies also

simulation details

* tree-level Symanzik-improved gauge action, stout-smeared staggered fermion
* relatively long runs: 1-2 thousand trajectories
* quark potential measurements: $48^3 \times 96, 40^3 \times 80, 32^3 \times 64$
* lightest pion mass $1/(m_\pi a) \approx 6 - 7$

4dim HYP-smeared time links



3dim APE-smeared space links

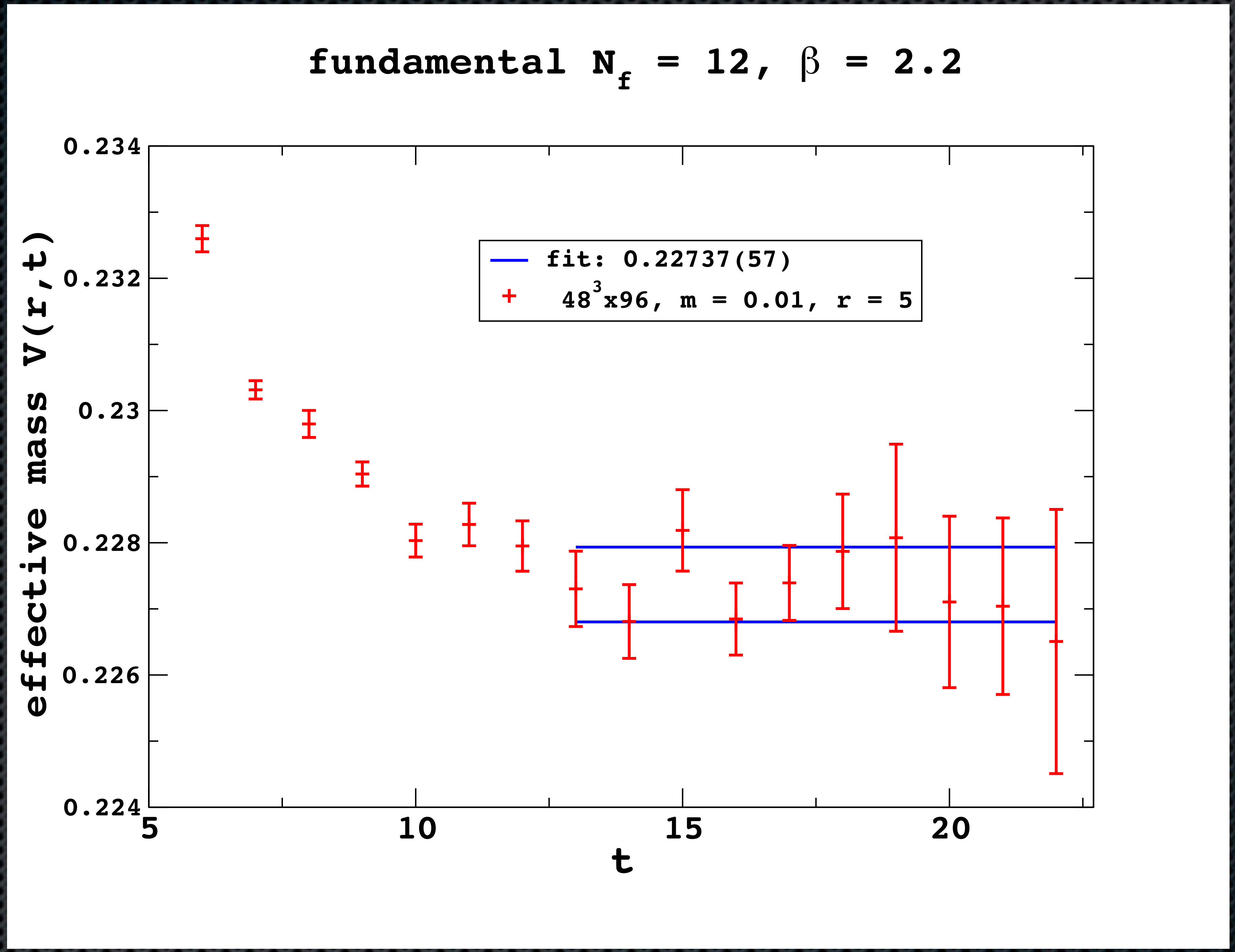
improve quark potential signal:

* HYP smear time-like links: reduce quark pair self-energy
* APE smear space-like links: build correlation matrix for Generalized Eigenvalue method

this talk: one diagonal of correlation matrix

* use Double Jackknife to estimate Covariance Matrix for chi-squared fitting of effective “mass”

effective “mass” example

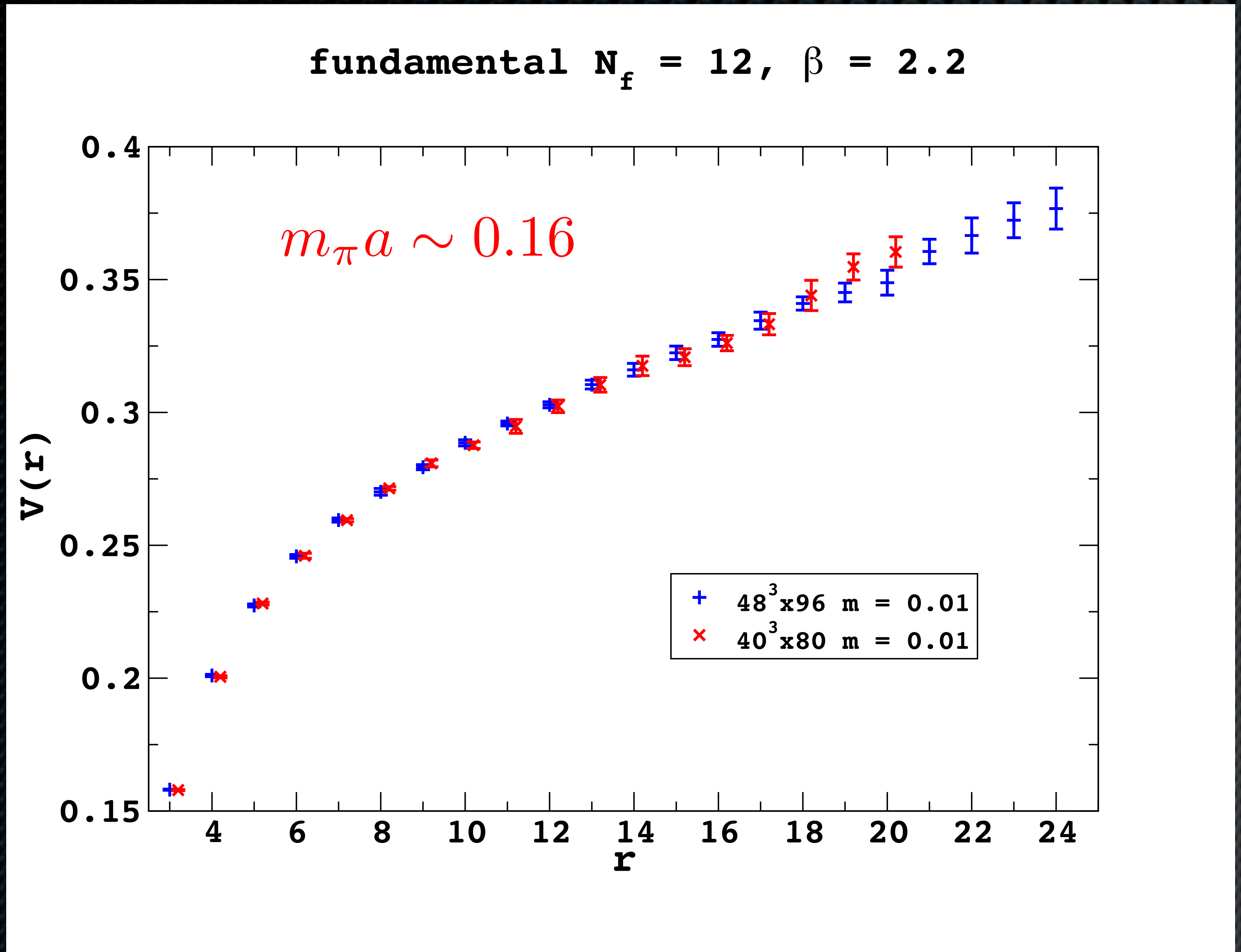


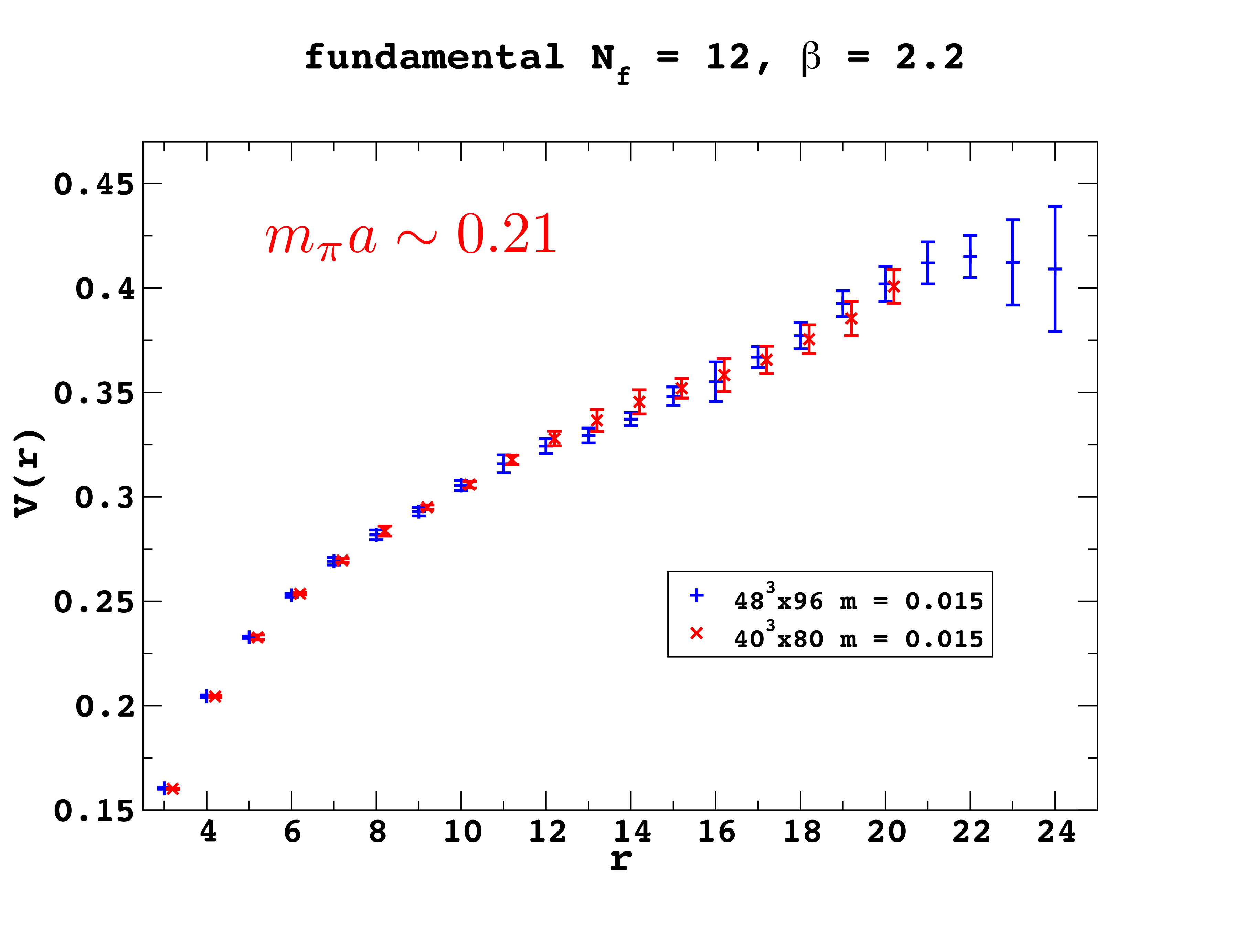
covariance matrix included in fitting, inner & outer jackknife

fit effective “mass” to constant V(r)

Del Debbio et al ’07

volume dependence 12-flavor



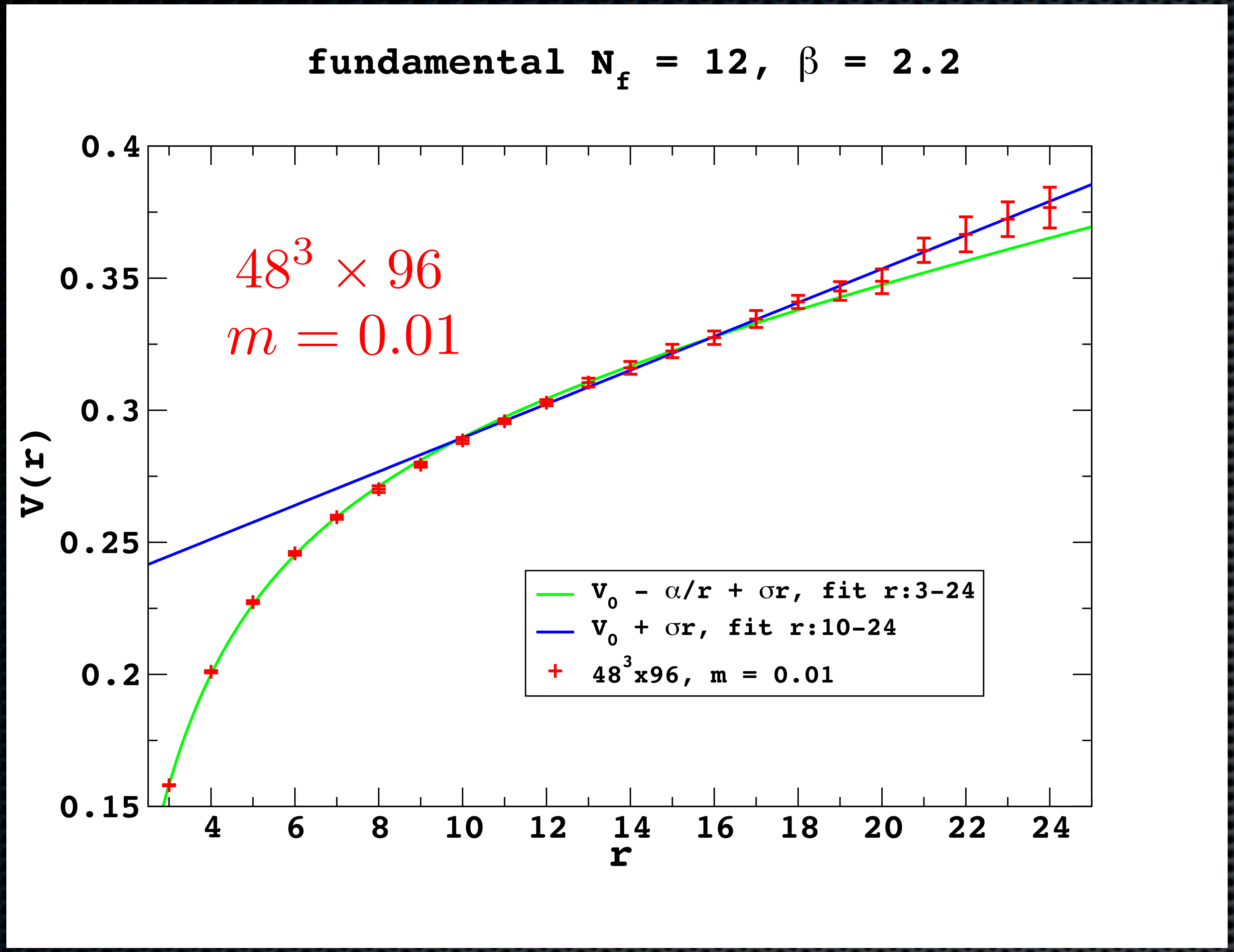


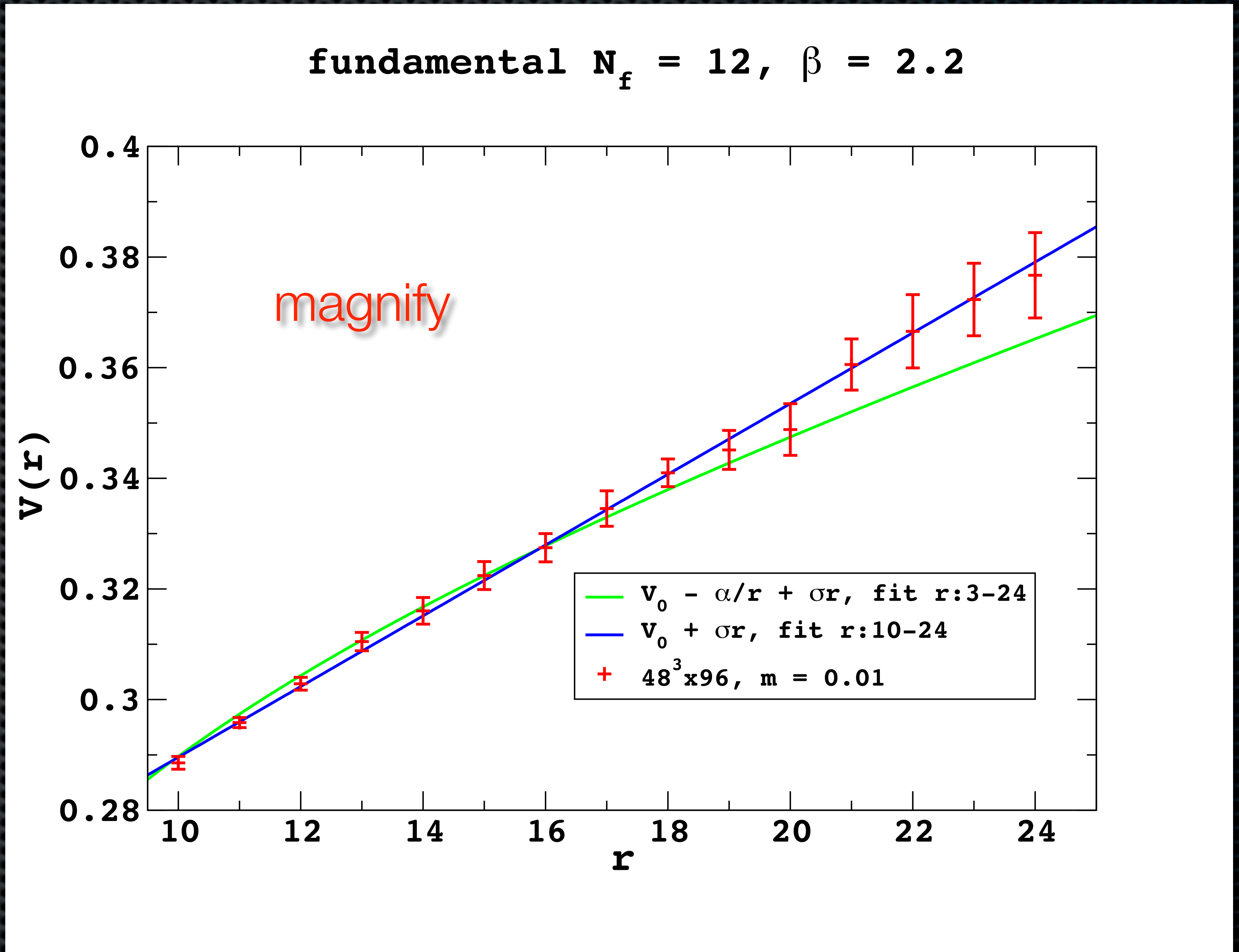
compare two large volumes at lightest pion mass at m=0.01 and 0.015

no volume dependence seen between $48^3 \times 96$ and $40^3 \times 80$

for larger masses m=0.02 and 0.025, sufficient to extract potential from $40^3 \times 80$

fit potential (light)



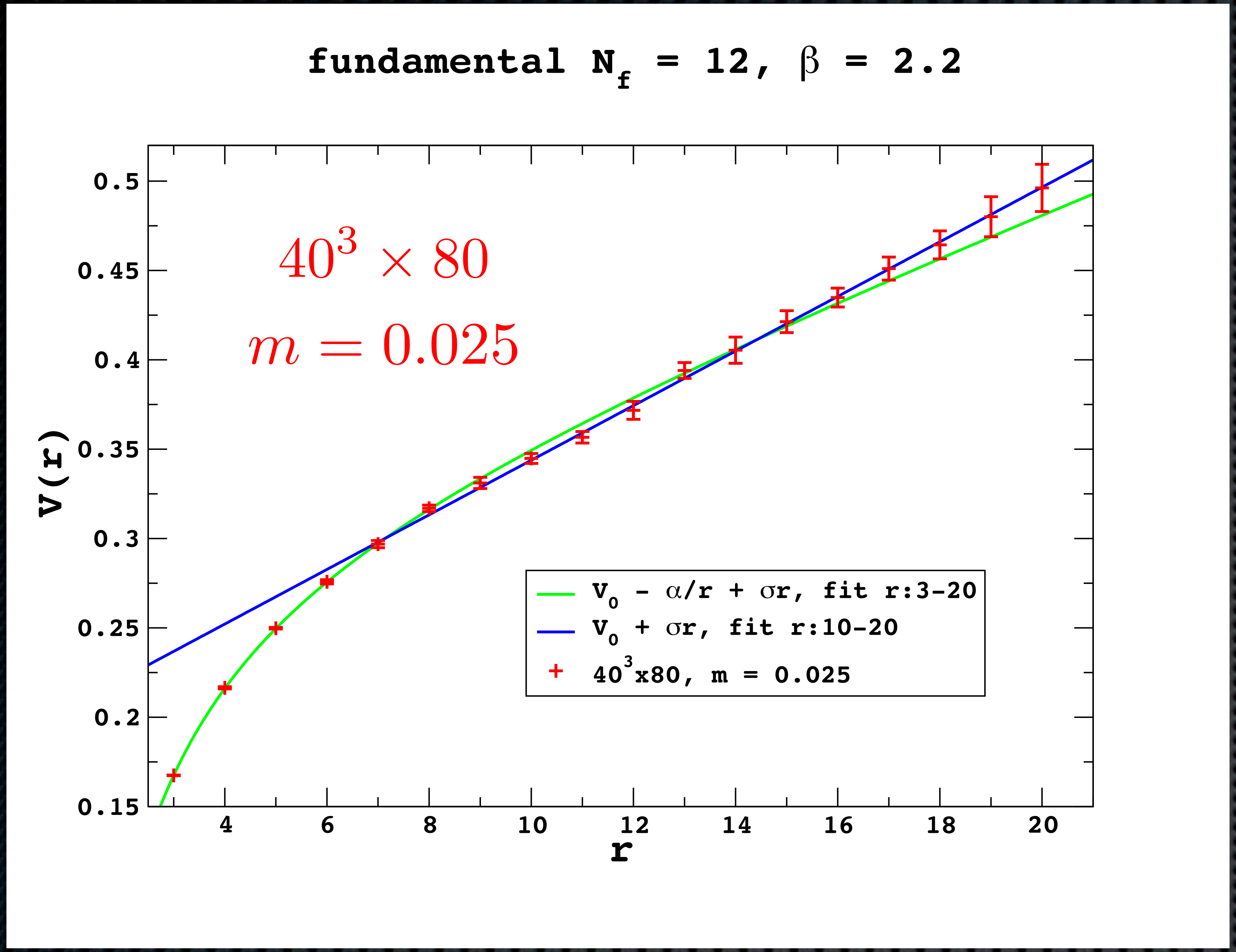


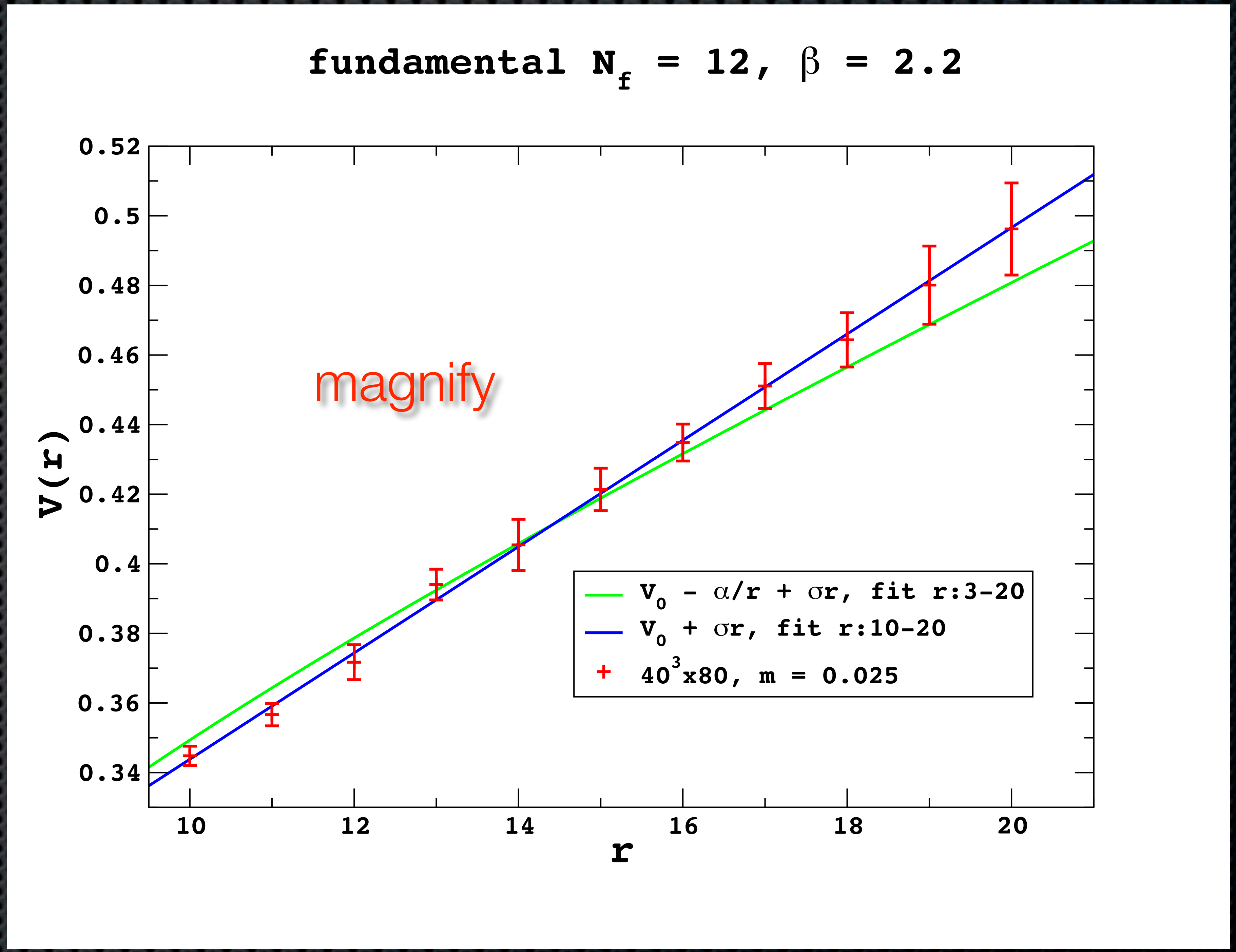
Two V(r) parametrizations

1. small and large r $V(r) = V_0 - \dfrac{\alpha}{r} + \sigma r$ $\chi^2/N = 32.8/19$
2. larger r only $V(r) = V_0 + \sigma r$ $\chi^2/N = 3.8/13$

data at larger r do not show much curvature - linear fit better?

fit potential (heavy)





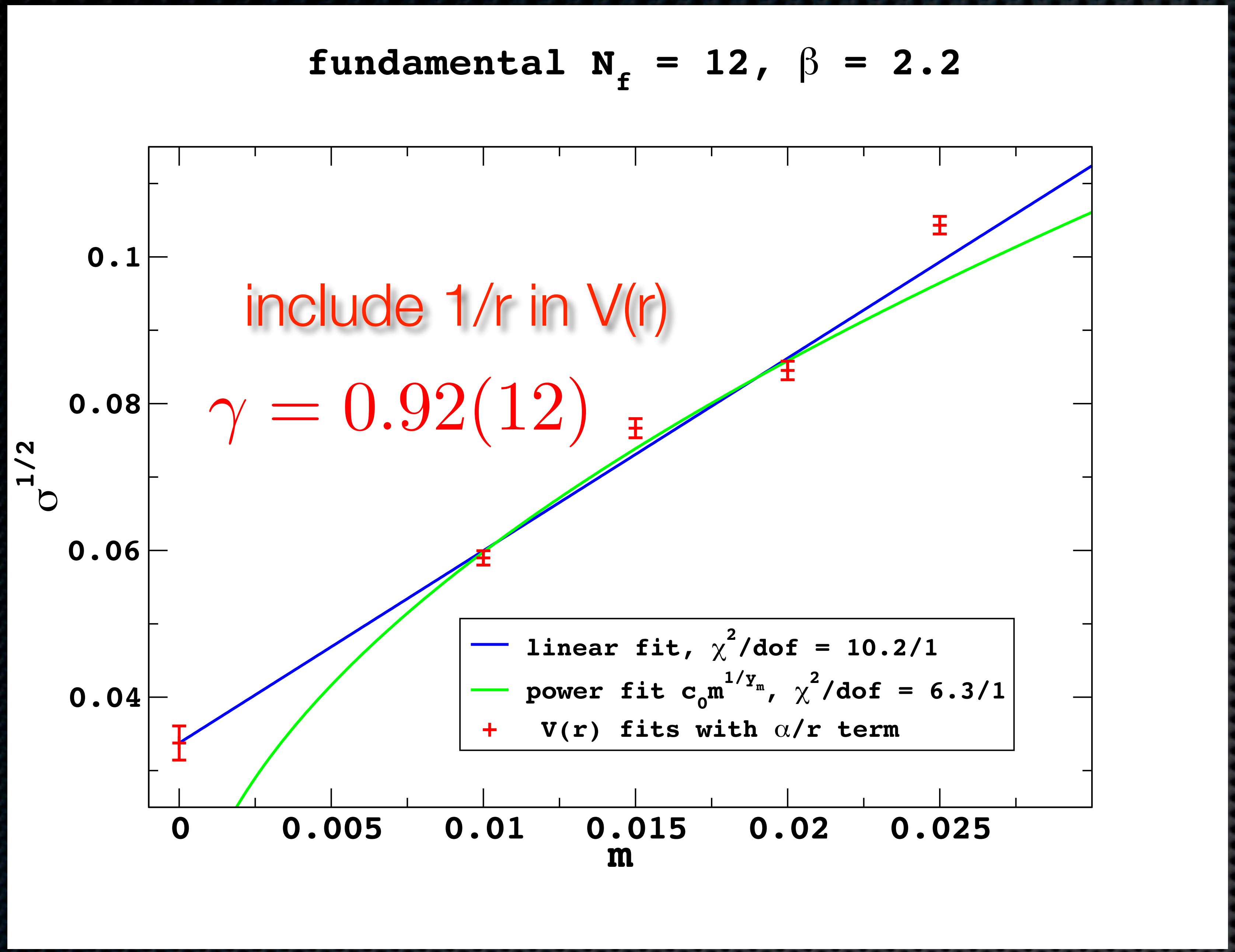
similar behavior at heaviest mass m =0.025 - little curvature in data at larger r

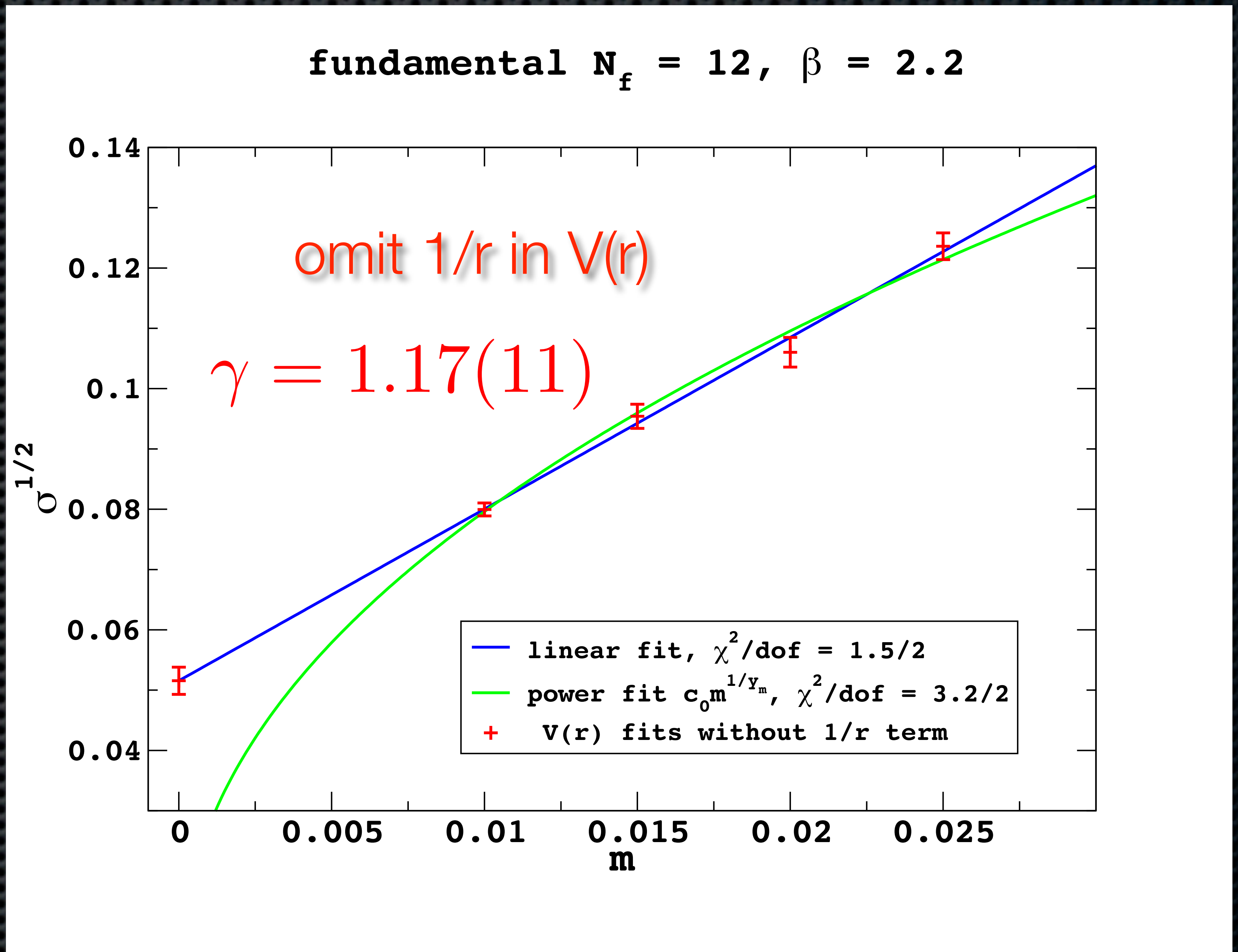
two parametrizations

$$V(r) = V_0 - \frac{\alpha}{r} + \sigma r \qquad \chi^2/N = 16.2/15$$

$$V(r) = V_0 + \sigma r \qquad \chi^2/N = 2.1/9$$

fit string tension





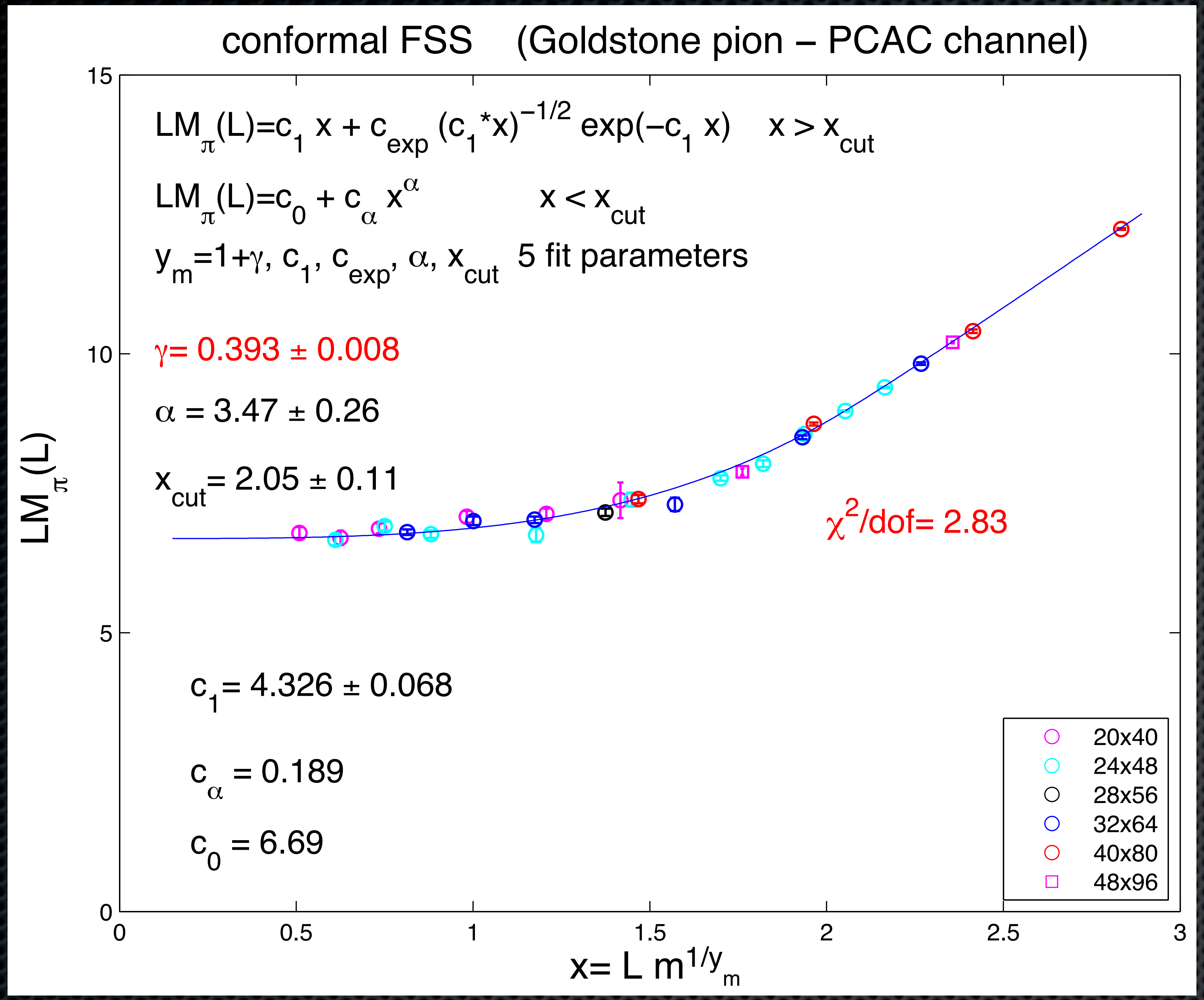
non-conformal $\sigma^{1/2} = \sigma_0^{1/2} + a_1 m$ conformal $\sigma^{1/2} = c_0 m^{1/y_m}, \quad y_m = 1 + \gamma$

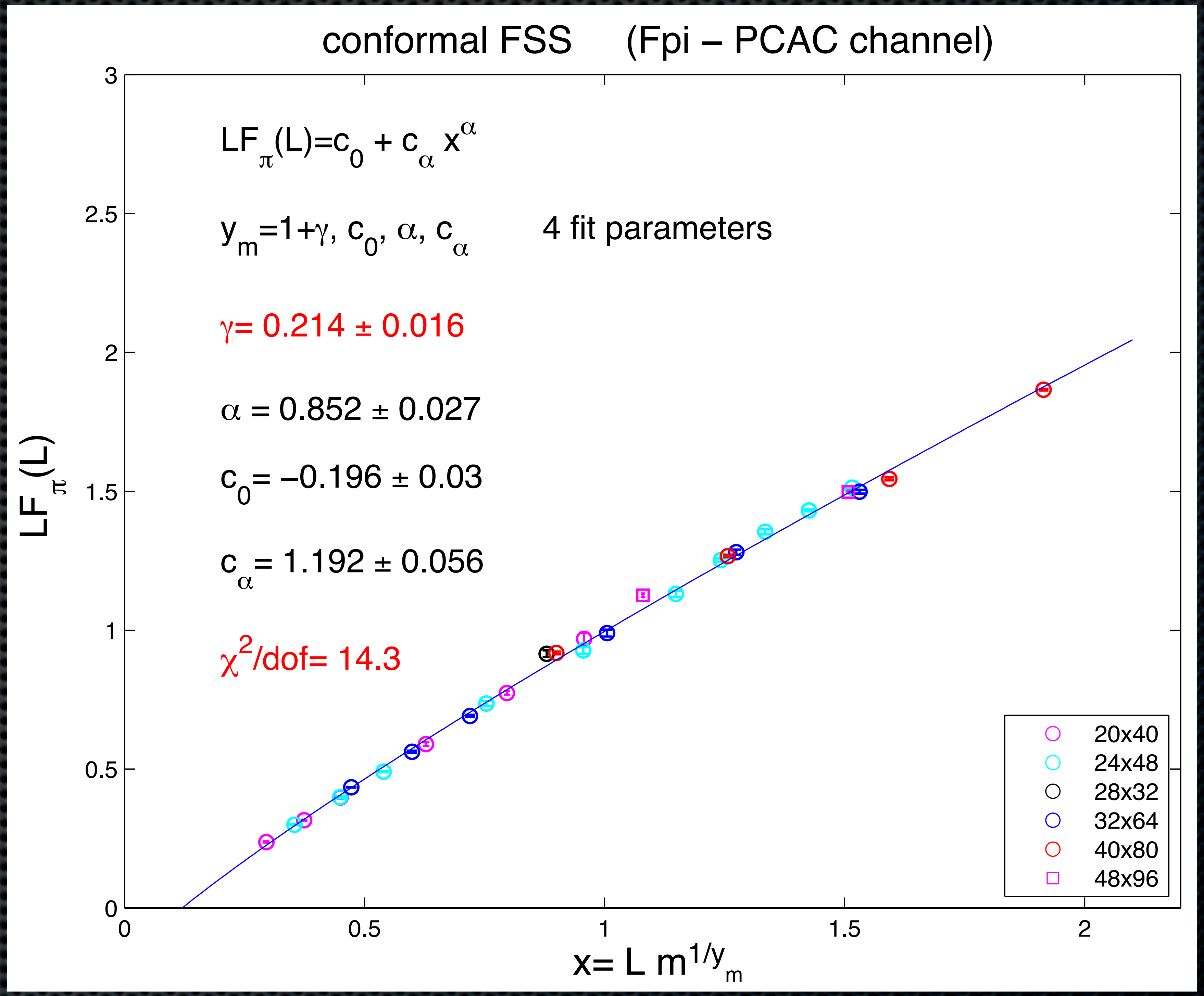
* fit V(r) with 1/r : neither form describes all 4 mass data
* fit V(r) without 1/r : both forms can fit all 4 mass data

gamma exponent values inconsistent with spectroscopy $\gamma \sim 0.2 - 0.4$

non-conformal linear fits: clear non-zero chiral limit

12-flavor mass spectrum





conformal fits of mass spectrum data, many states

include volume-dependence: finite-size scaling (FSS)

states do not yield universal value gamma conformal failure

force F(r)

is linear fit of potential justified?

$$F(r) = \frac{dV}{dr} = C_F \frac{\alpha_{qq}(r)}{r^2}$$

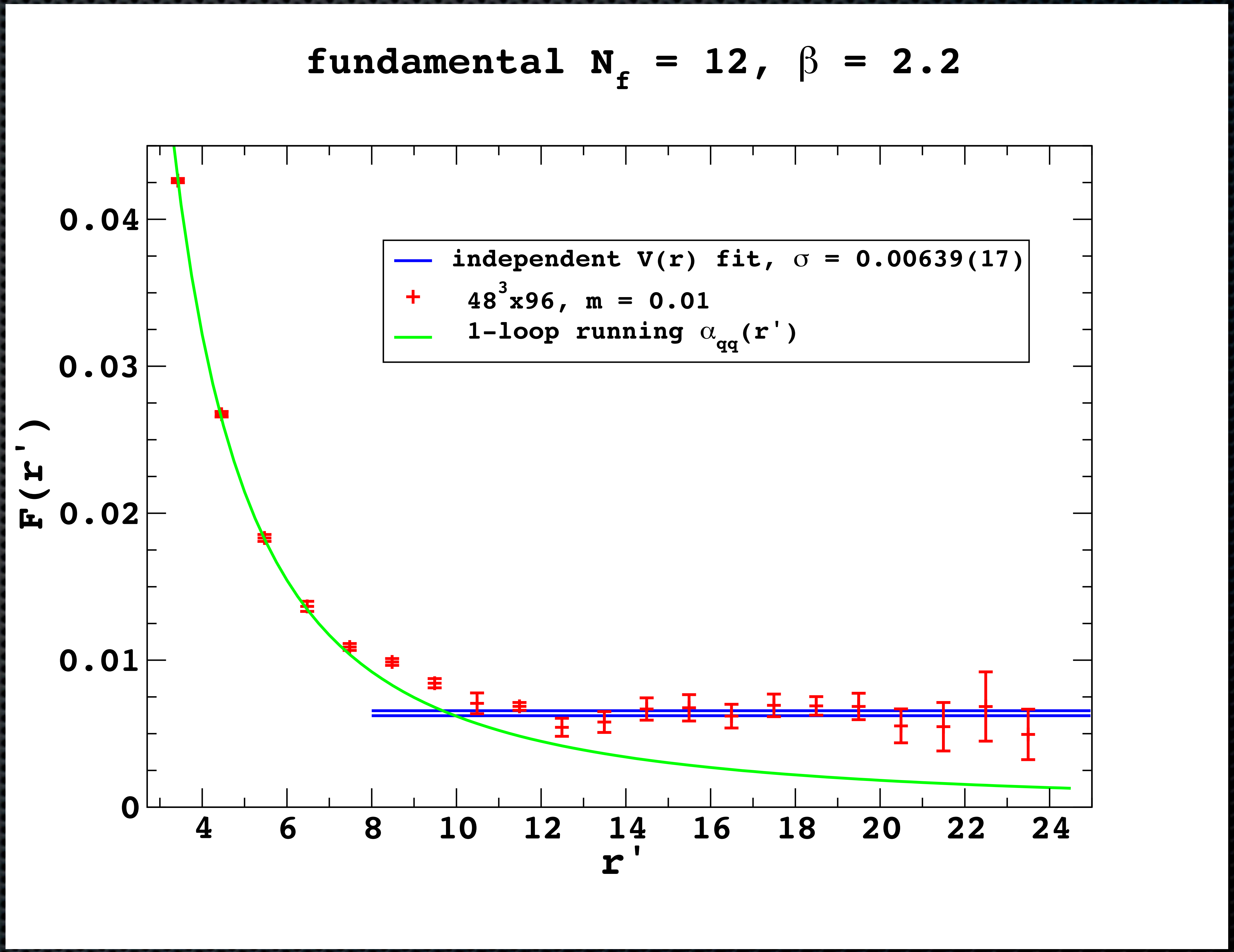
extract directly from effective “force”

$$F(r', t) = V(r+1) - V(r, t)$$

improve force: $r' \neq r + 1/2$

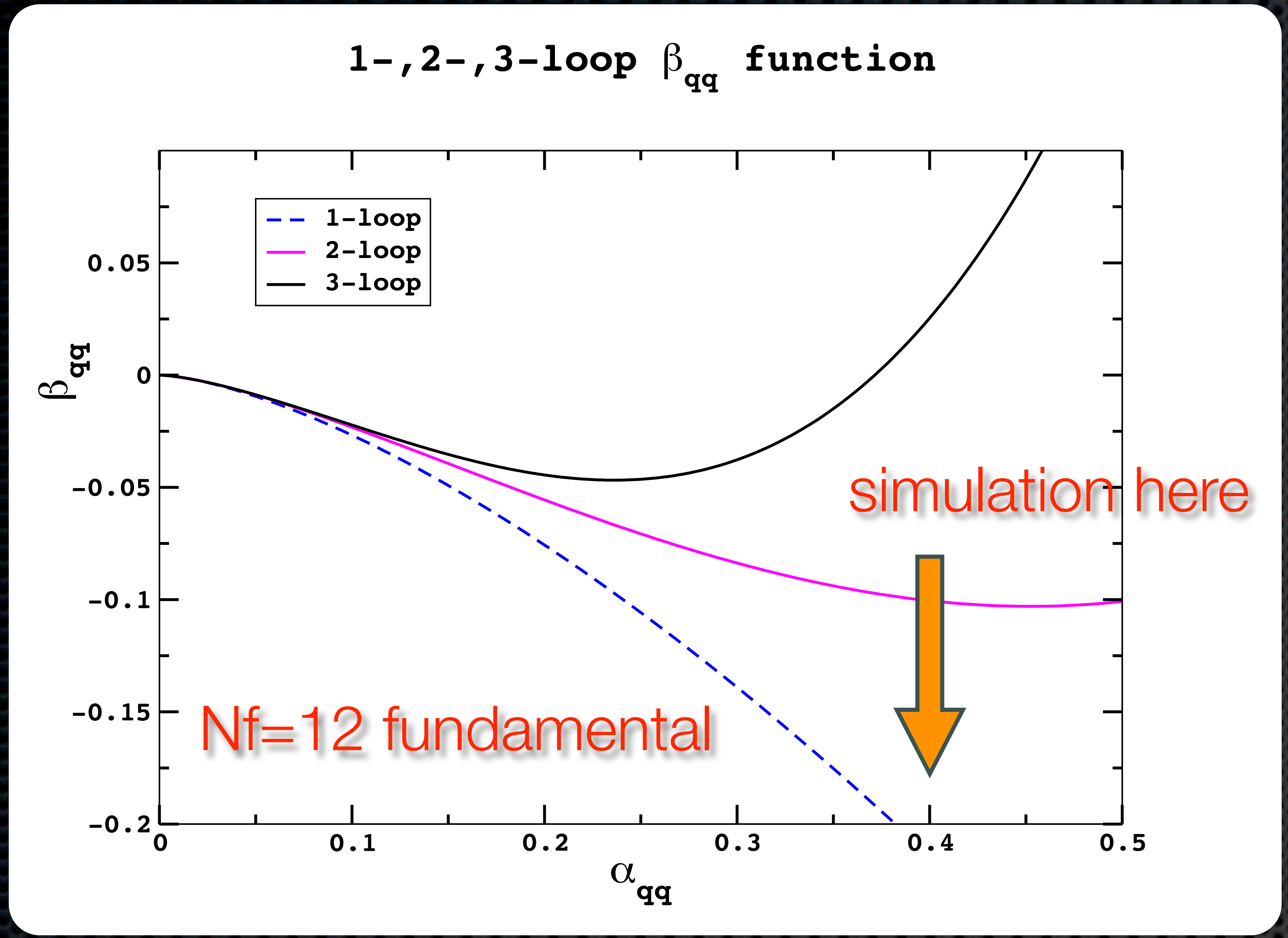
covariance matrix in t and r

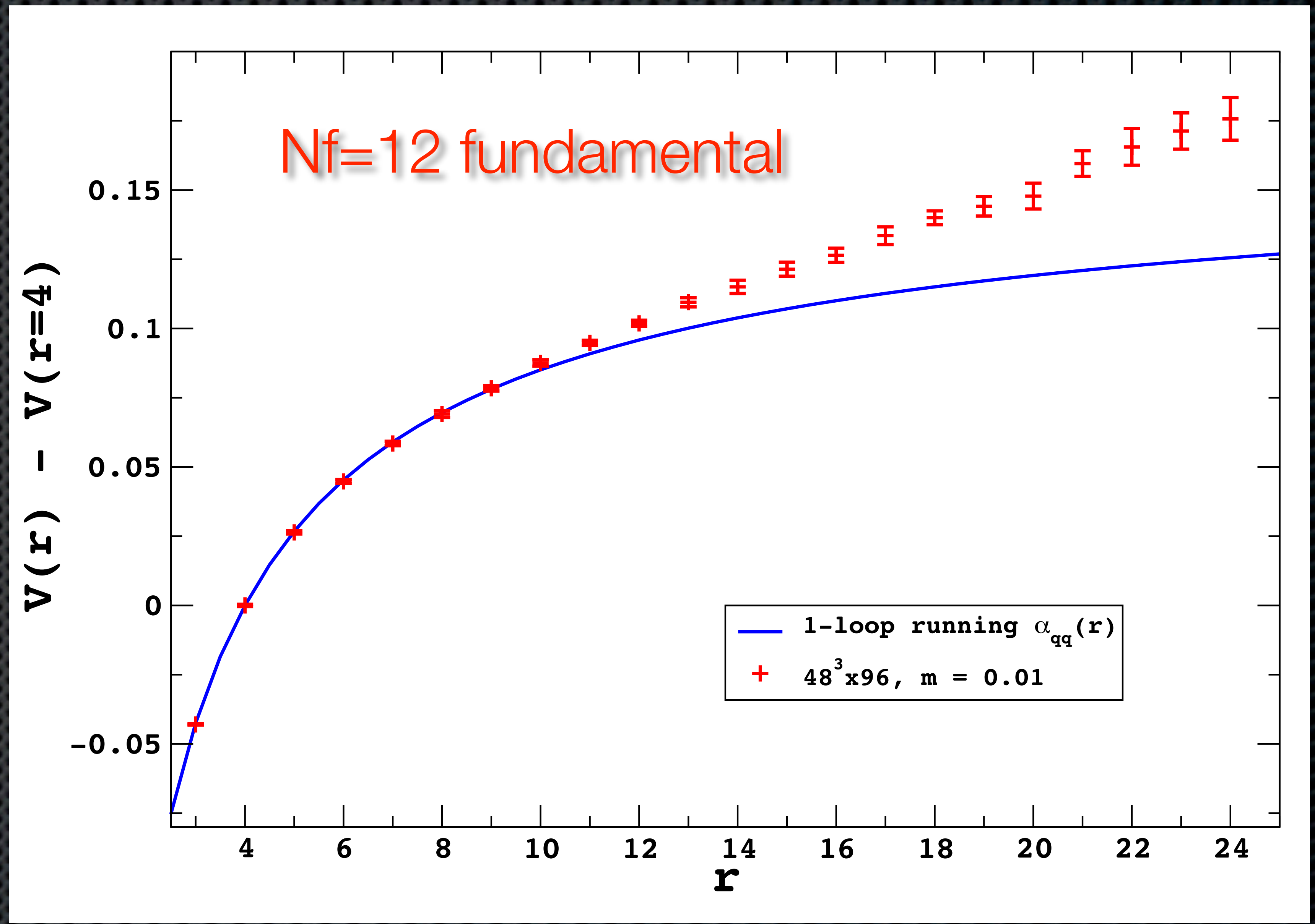
if confining, force should flow to string tension at large distance - confirmed



coupling does not show IR fixed point

running coupling





3-loop QQ scheme, fundamental rep

IR fixed point $\alpha^*_{qq} = 0.371$

$$F(r) = \frac{dV}{dr} = C_F \frac{\alpha_{qq}(r)}{r^2}$$

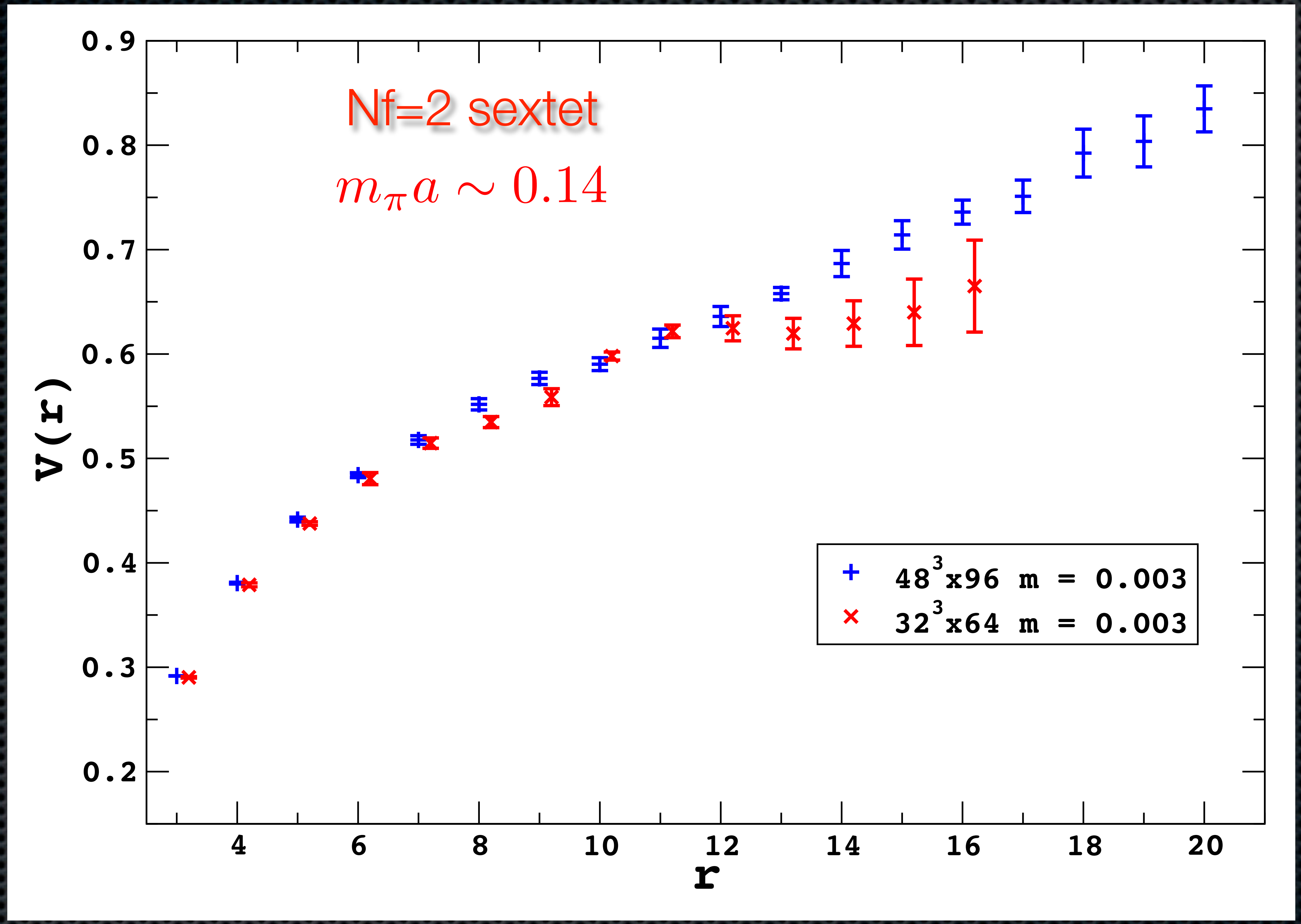
direct measurement from V(r):

$$\alpha_{qq}(r = 4.457...) = 0.393(11)$$

pert thy prediction: $V(r) - V(r_0) = C_F \int_{r_0}^{r} \frac{\alpha_{qq}(r')}{r'^2} dr'$

V(r) data increase fast with r - no sign of IRFP

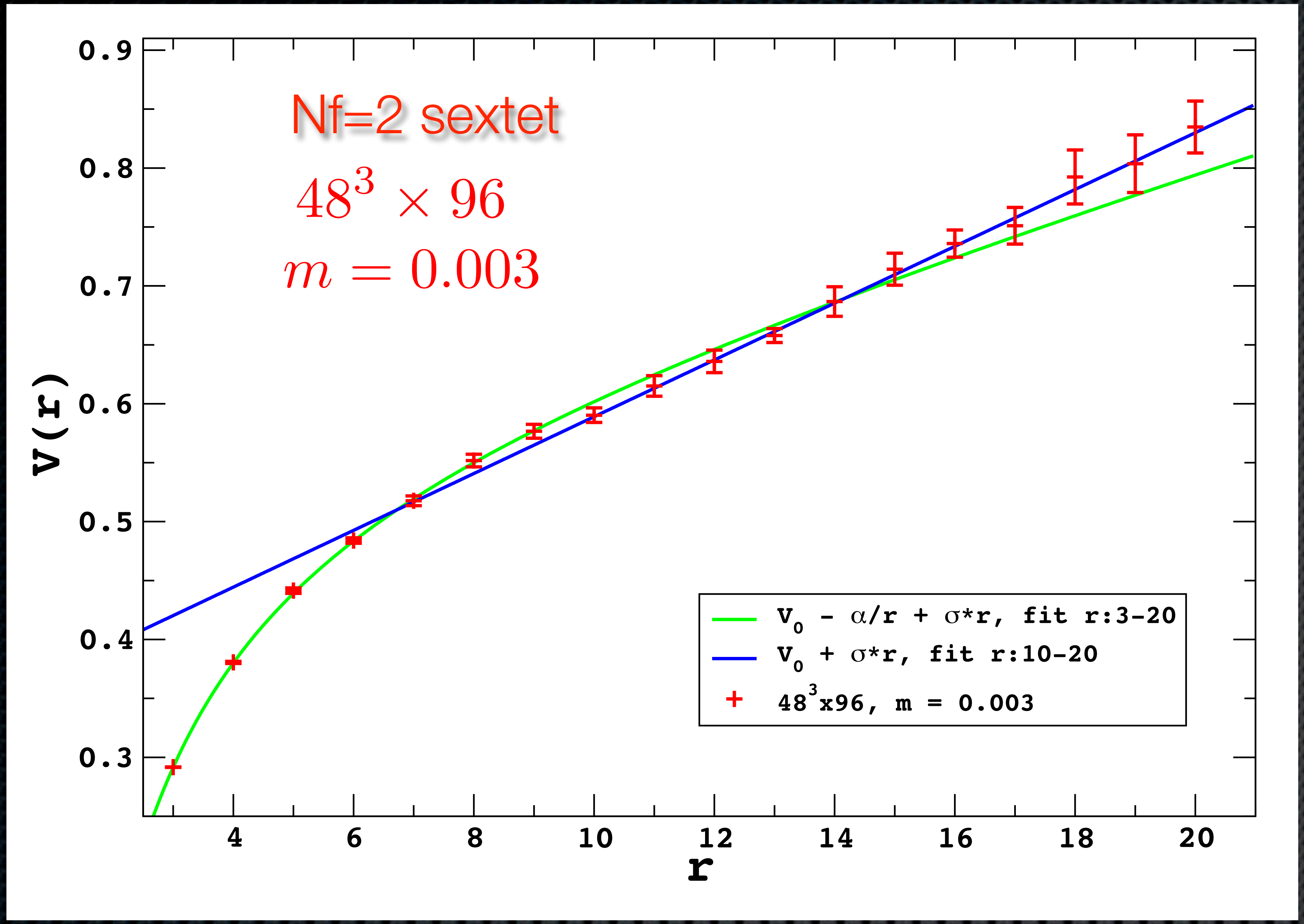
2-flavor sextet

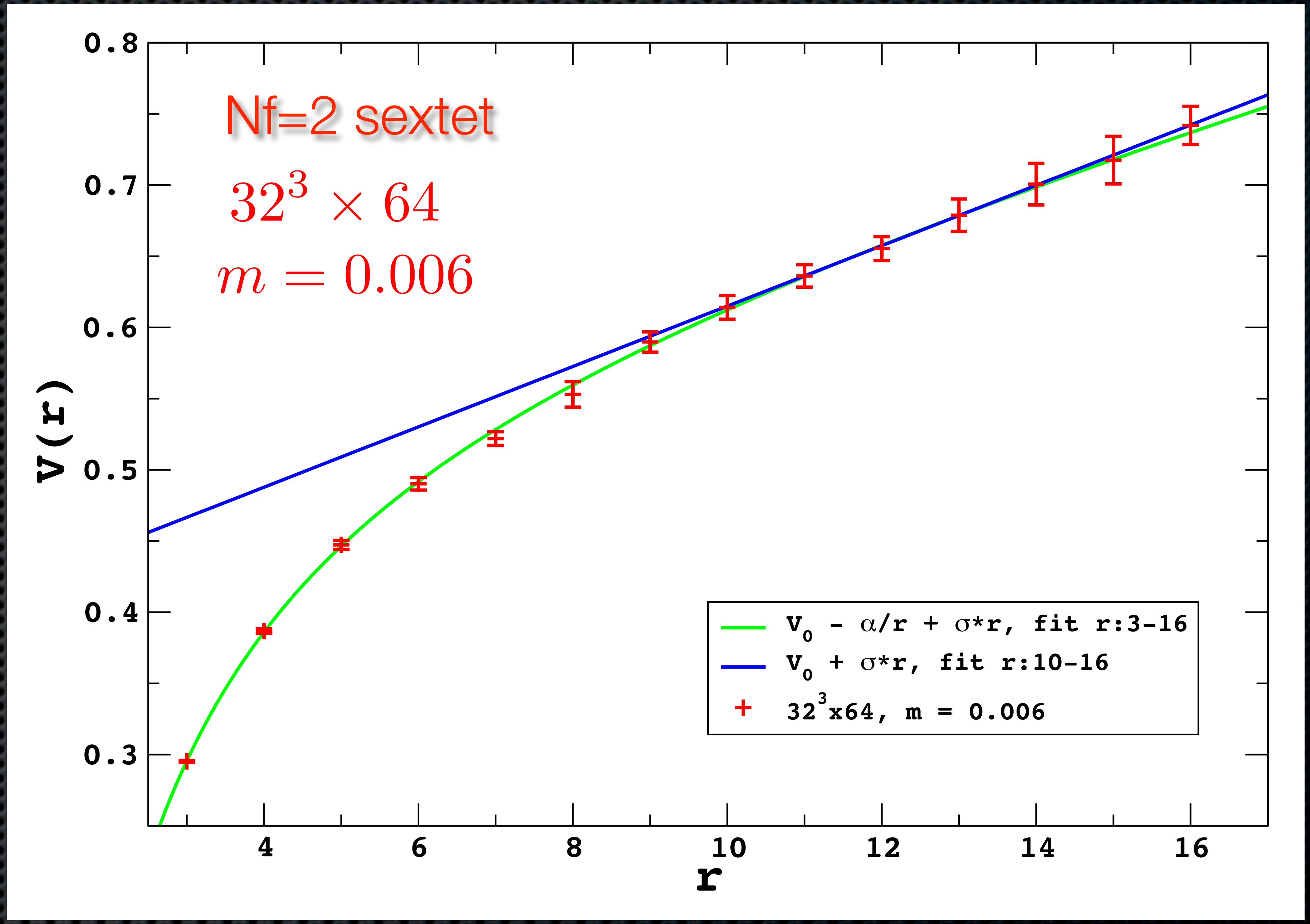


only 1 very large volume run $48^3 \times 96$ remainder of runs $32^3 \times 64$

do not have clear evidence that L=32 sufficient for heavier masses

fit potential

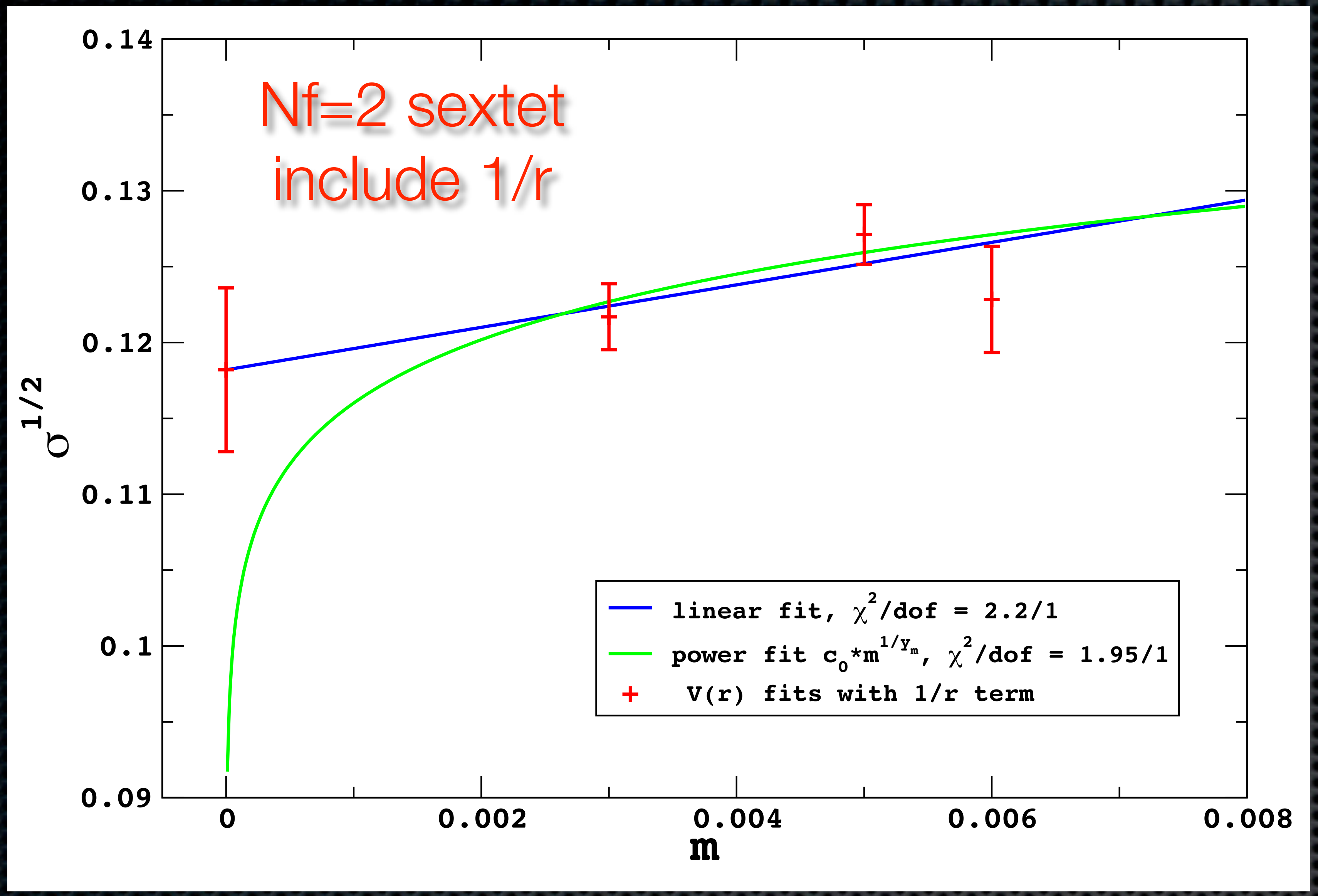


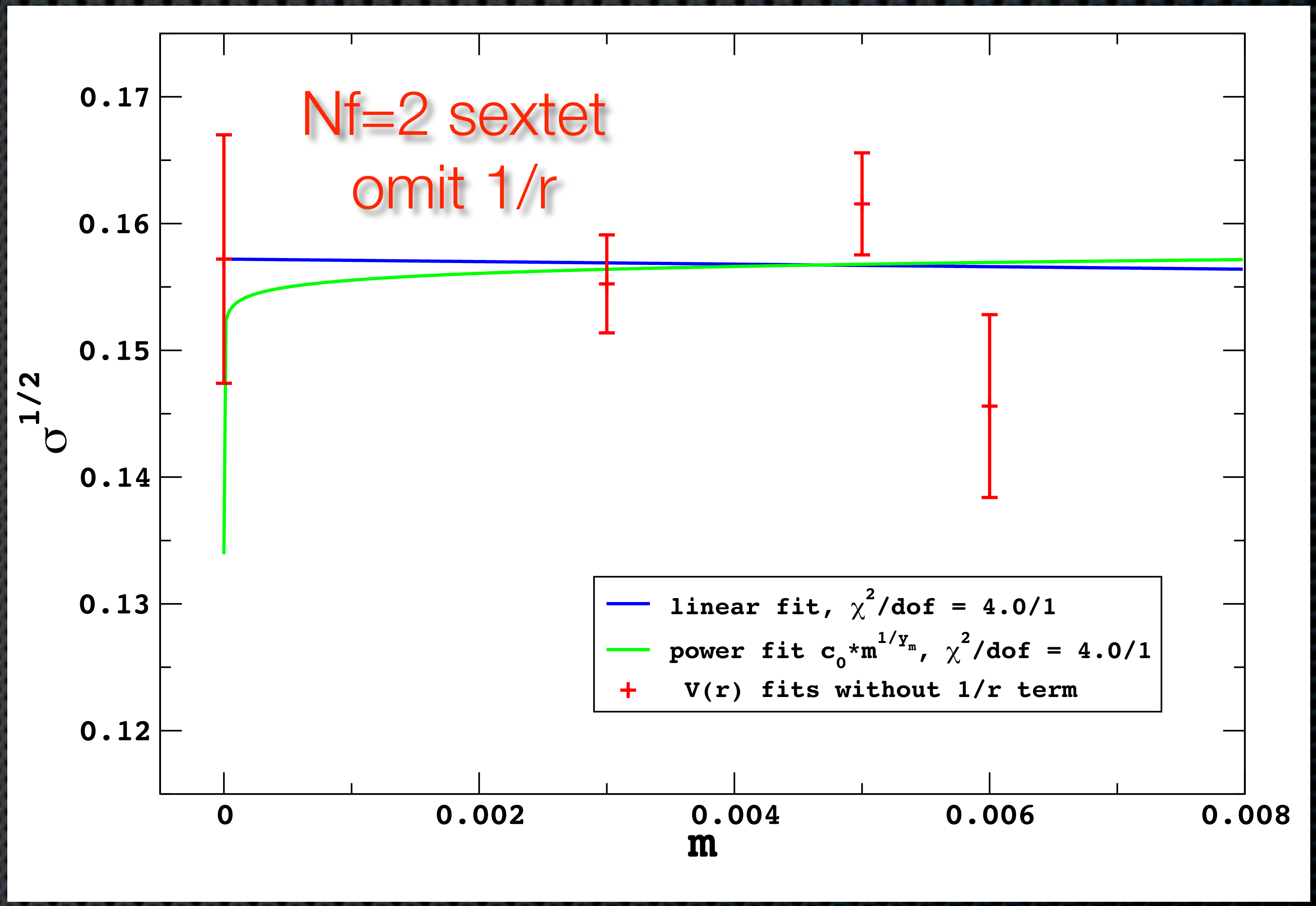


like fundamental: fit V(r) with & without 1/r term - 2 parametrizations

again, V(r) data at larger r show little curvature

fit string tension





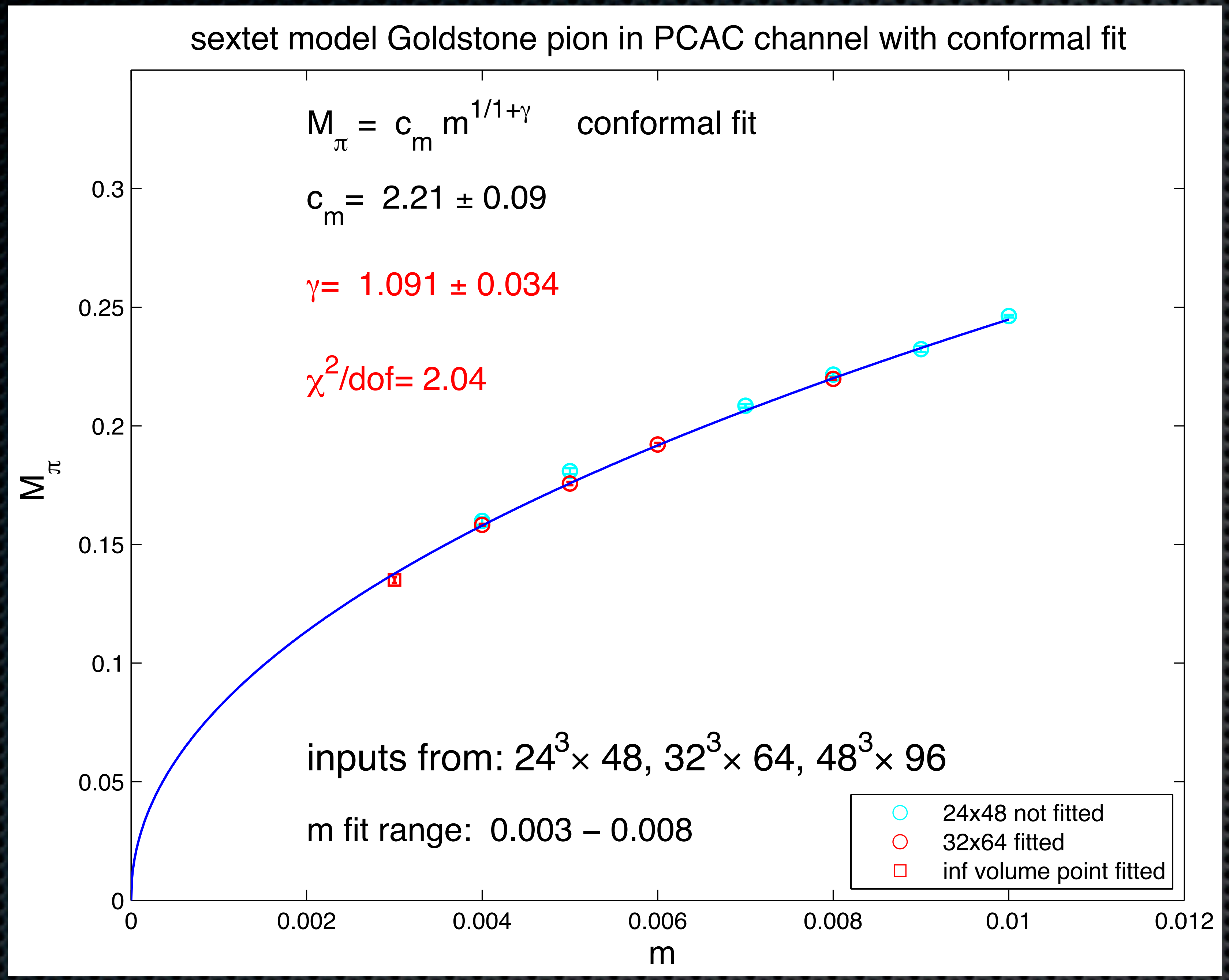
both parametrizations: string tension has little mass dependence

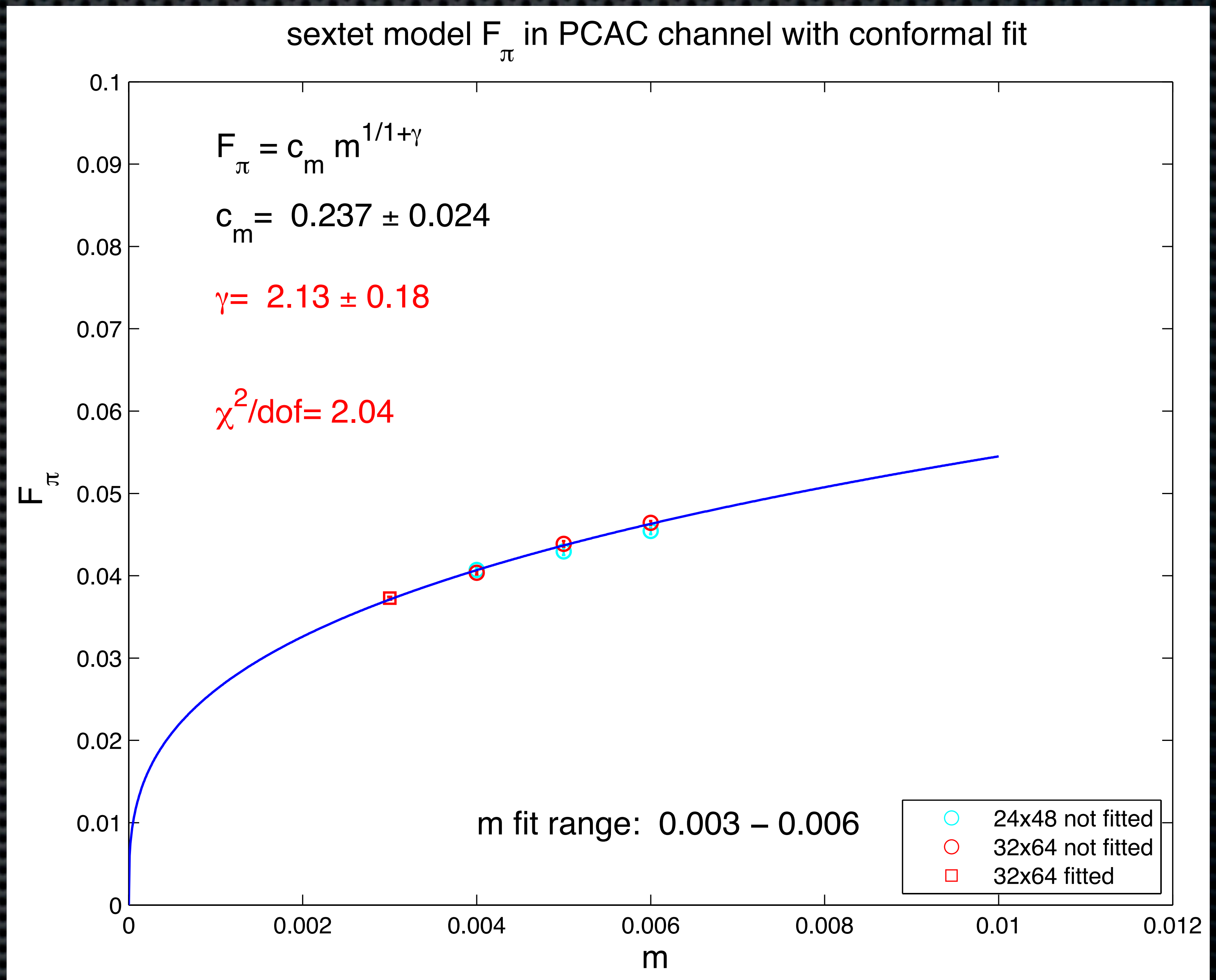
conformal fit: $\sigma^{1/2} = c_0 m^{1/y_m}, \quad y_m = 1 + \gamma$

include 1/r: $1/y_m = 0.051(39)$ omit 1/r: $1/y_m = 0.005(59)$ unacceptable

linear fits almost constant, looks like clear non-zero chiral limit

sextet mass spectrum





conformal fits already have strong tension

states do not agree on universal gamma value

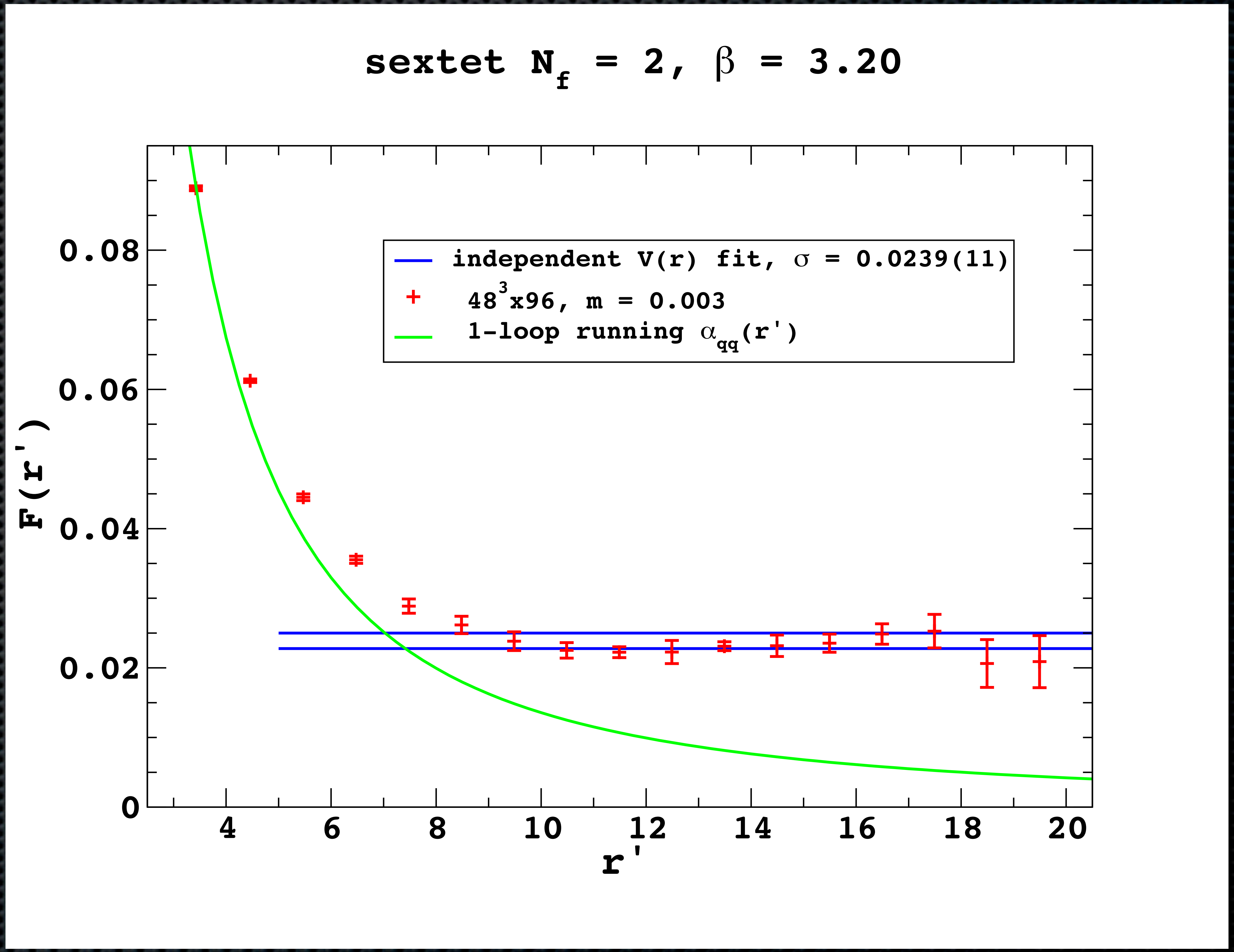
string tension adds to conformal failure

force

independent measurement of force F(r)

again, flows to string tension

consistent with independent V(r) fit



summary

* 12-flavor fundamental
  - conformal fit gamma inconsistent with spectroscopy
  - linear extrapolation to chiral limit gives non-zero string tension
  - potential runs faster that pert theory, do not see IR fixed point
  - theory looks non-conformal

* 2-flavor sextet
  - ditto
  - even stronger inconsistency in conformal fits
  - theory looks even more non-conformal

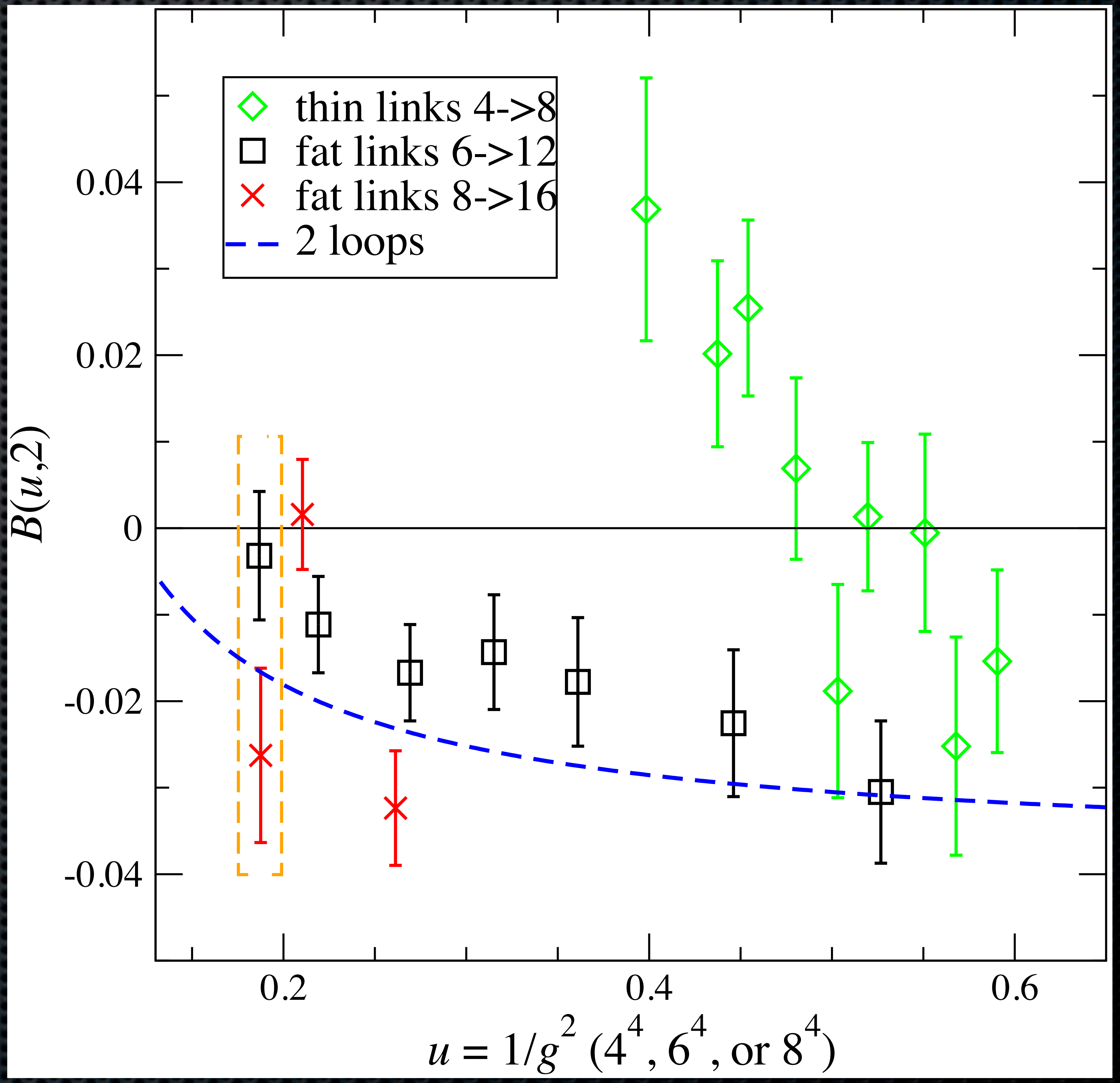
* highest priority: light composite scalar?

sextet running coupling

Schroedinger Functional scheme

infrared fixed point or near-zero of beta-fn?

how close to conformality is the model?



DeGrand, Shamir & Svetitsky