The sexet model and the composite Higgs mechanism

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with Lattice Higgs Collaboration contributors:

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Chris Schroeder, Chik Him Wong

Outline

- Sextet model: simplest composite Higgs mechanism

- RG flows of lattice actions and crossovers

- Two RG based scaling strategies

- Are we at weak enough coupling?

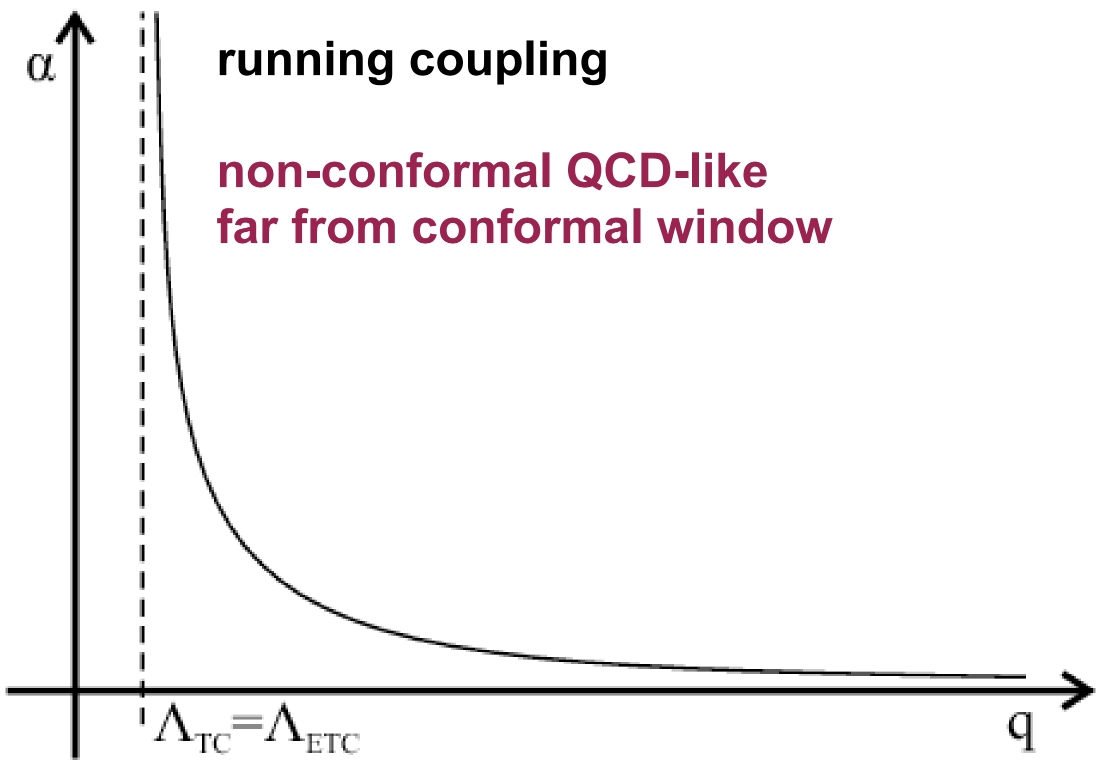
- New results on the Nf=2 sextet model with SU(3) gauge group

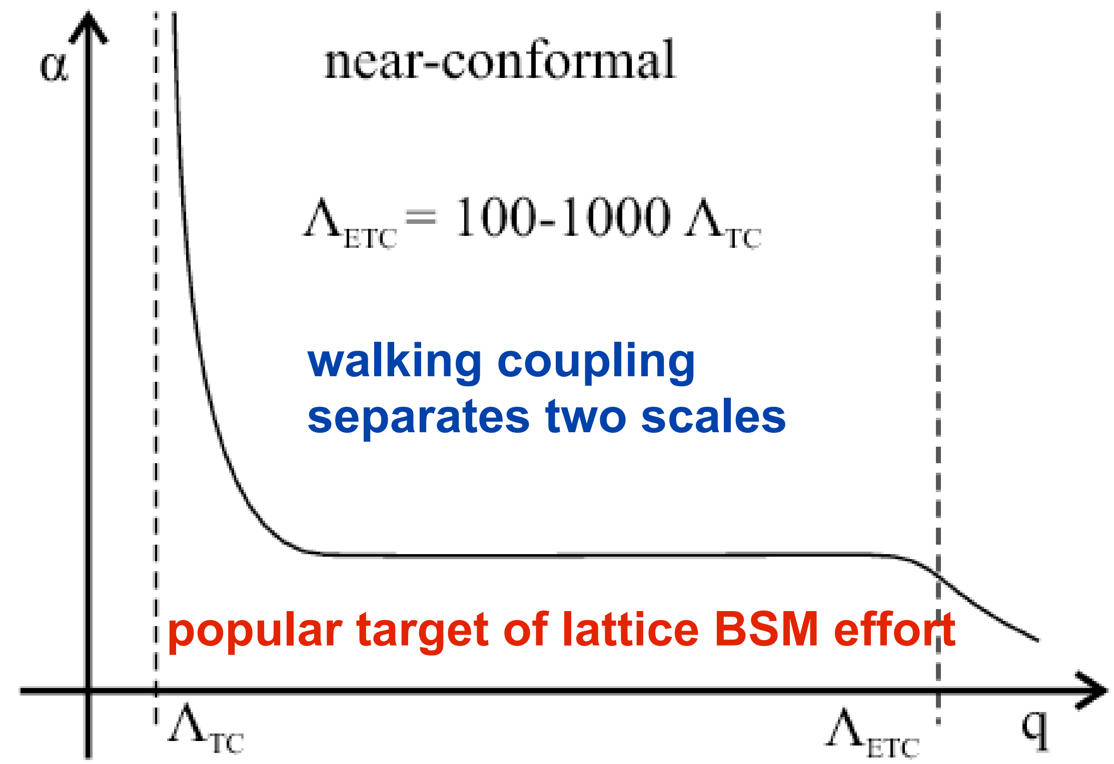
- What to expect from LHC phenomenology

- Summary and Outlook

composite Higgs? simplest example: Nf=2 SU(3) sextet representation

TC (ETC) language used   is it outside (but close to) conformal window?





- original Technicolor paradigm replaced with sextet SU(3) color rep:

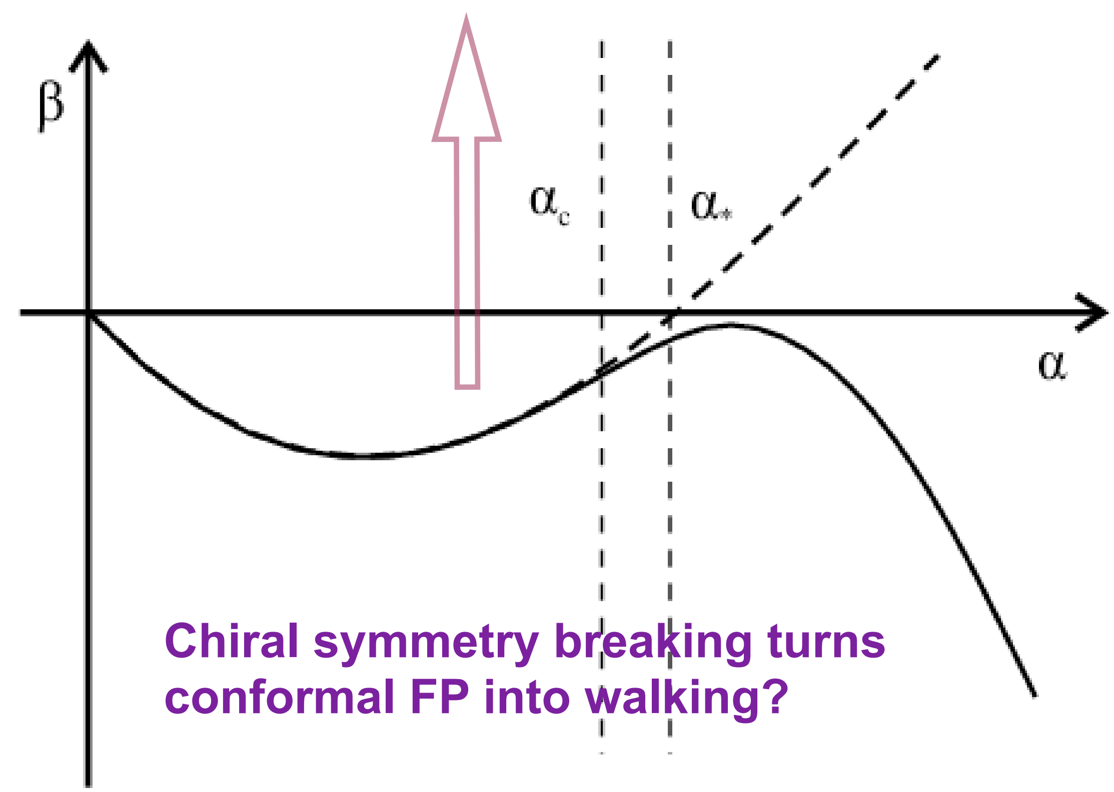
- one massless fermion doublet $\begin{bmatrix} u \\ d \end{bmatrix}$
  chiral SB with three Goldstone pions

→ longitudinal components of weak bosons

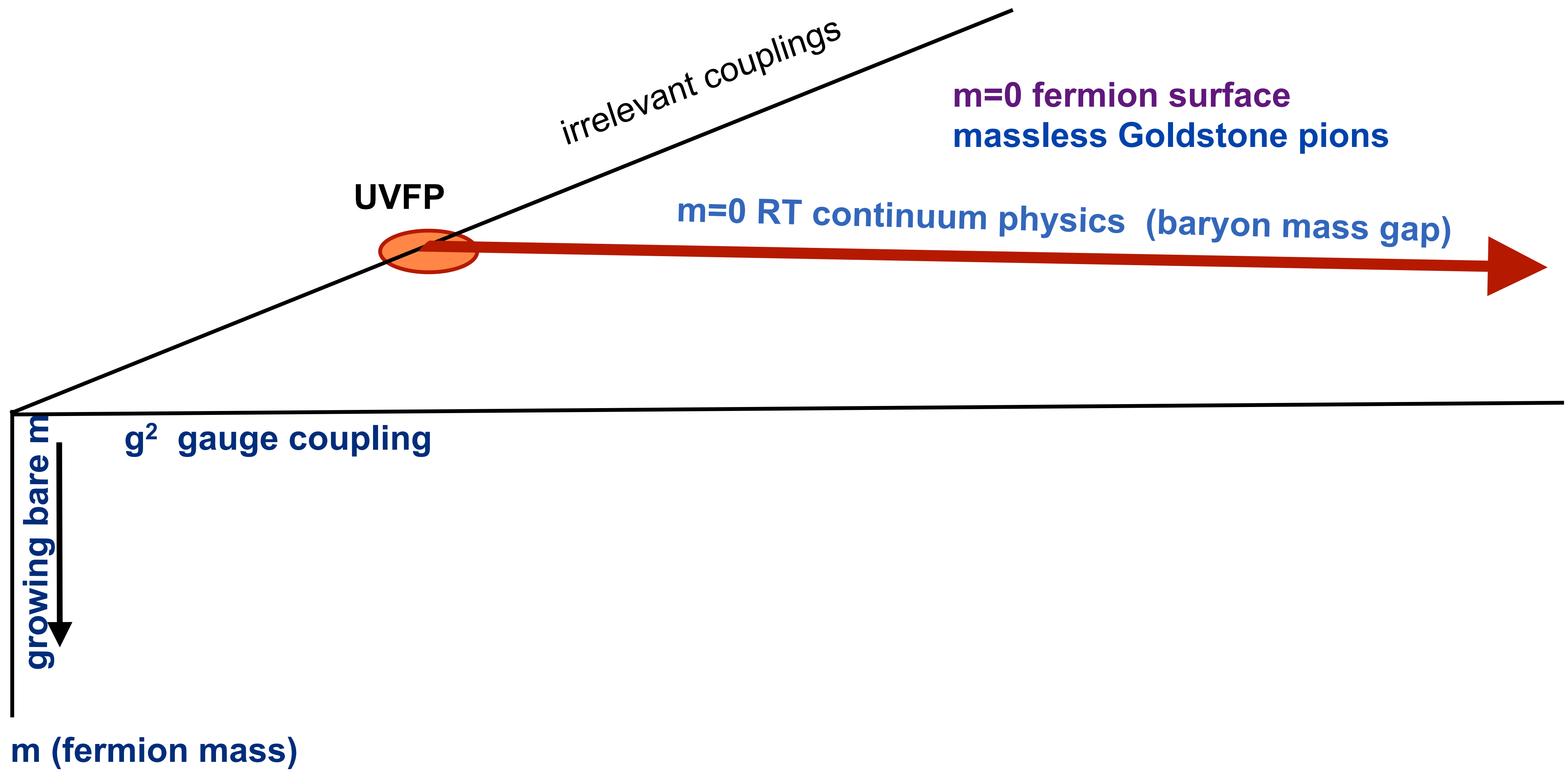
- composite Higgs mechanism
  scale of Higgs condensate ~ F=250 GeV

  $\Lambda_{TC} \sim TeV$

- conflicts with EW precision constraints?



QCD-like lattice navigation map and massless fermion surface



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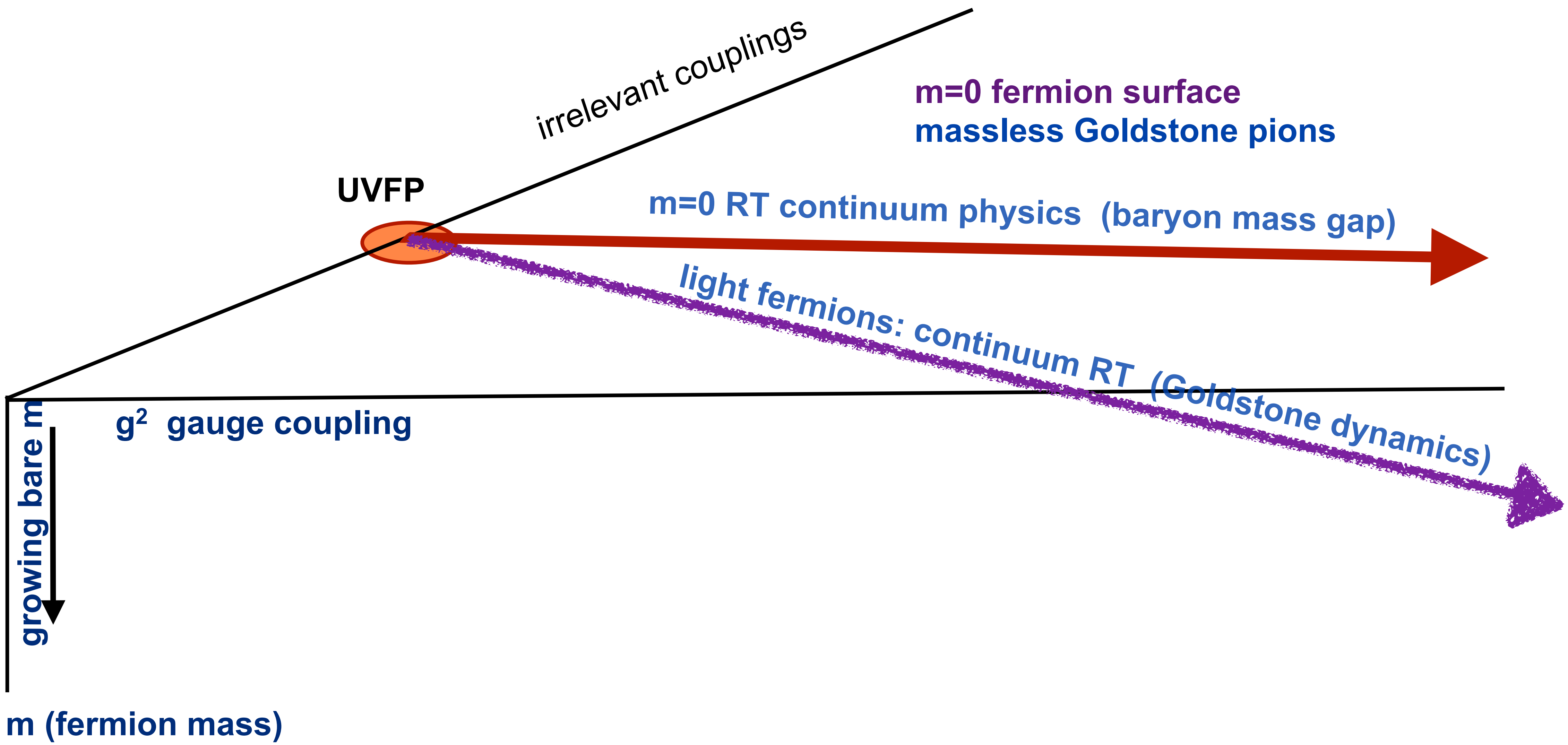

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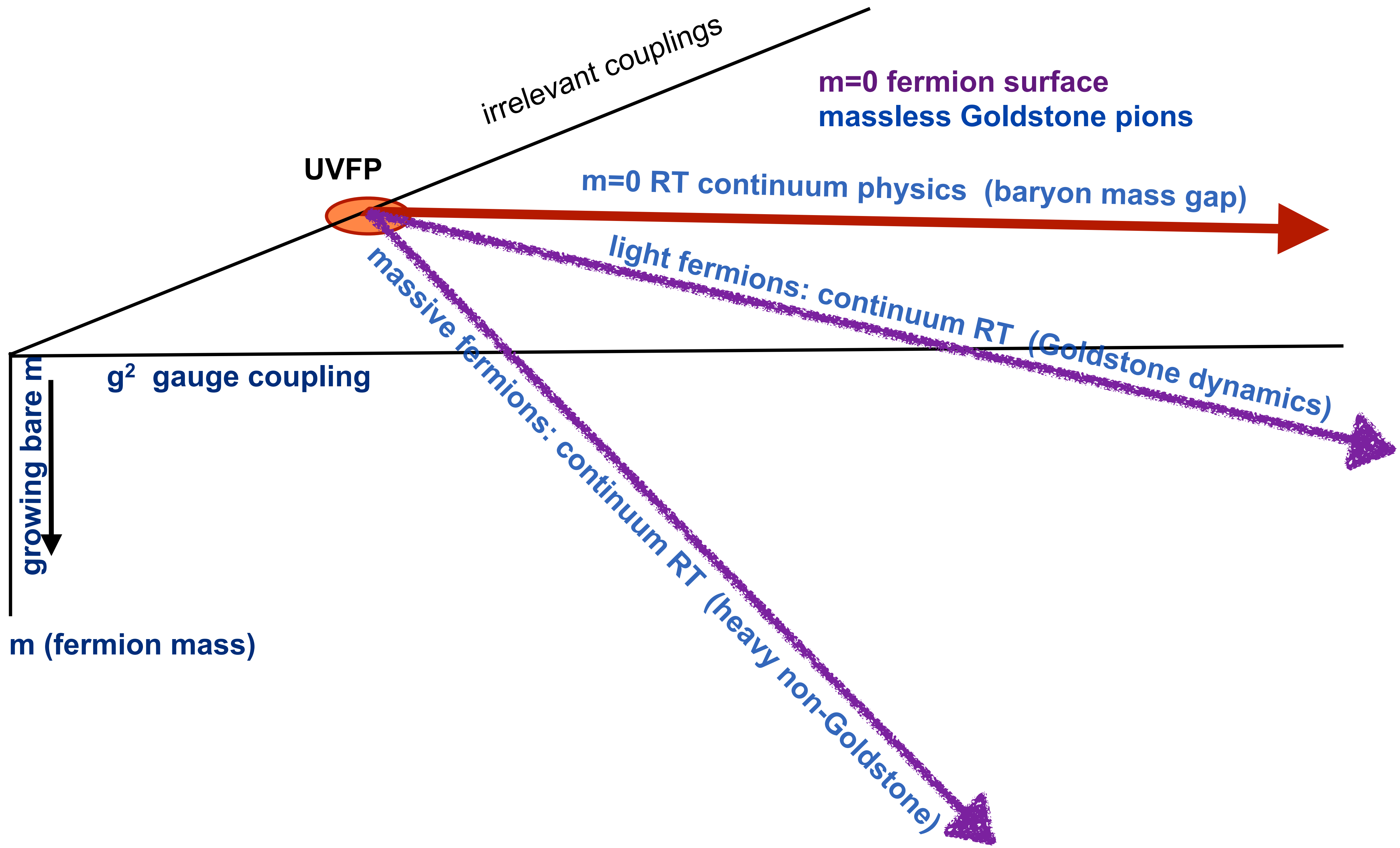

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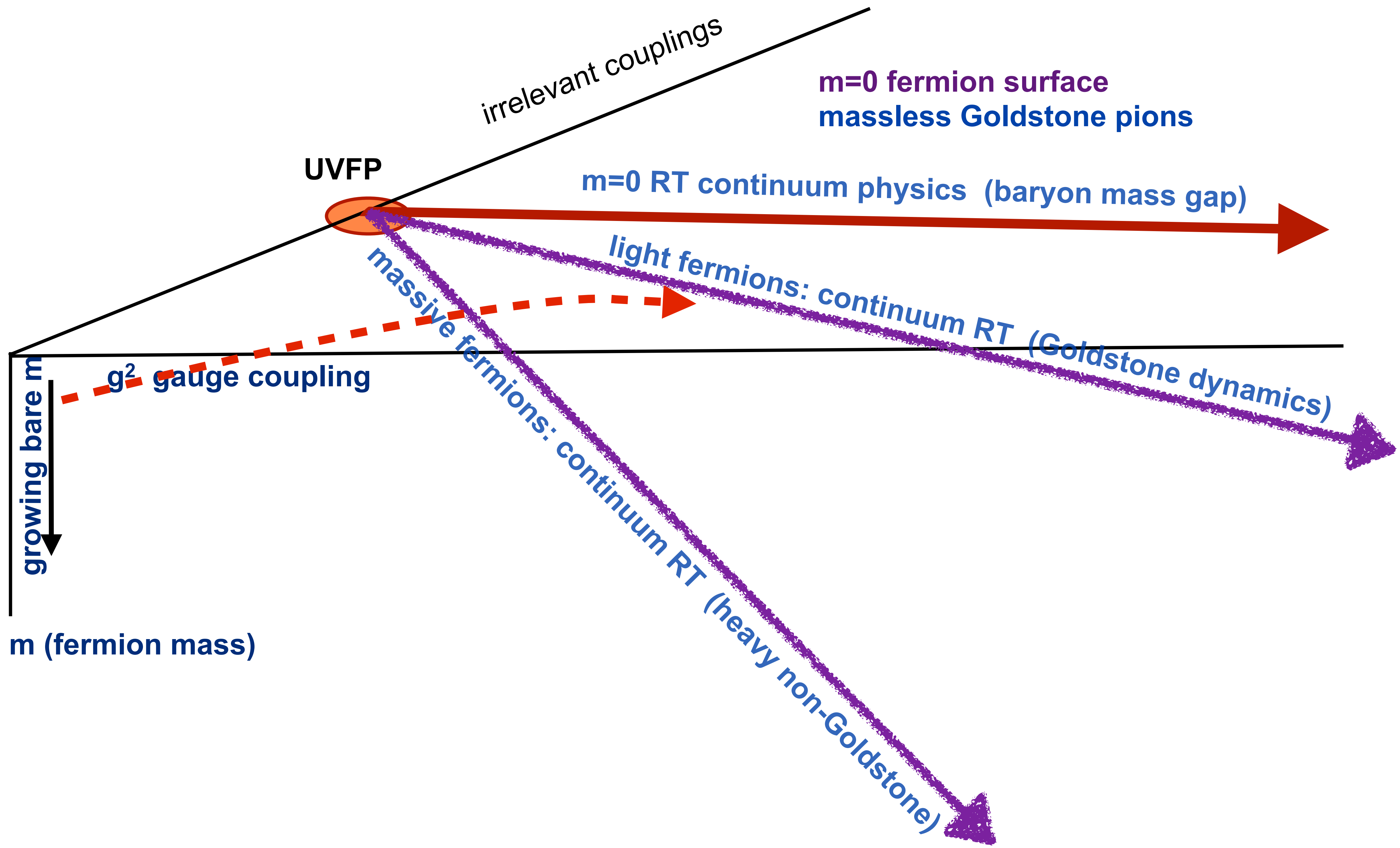

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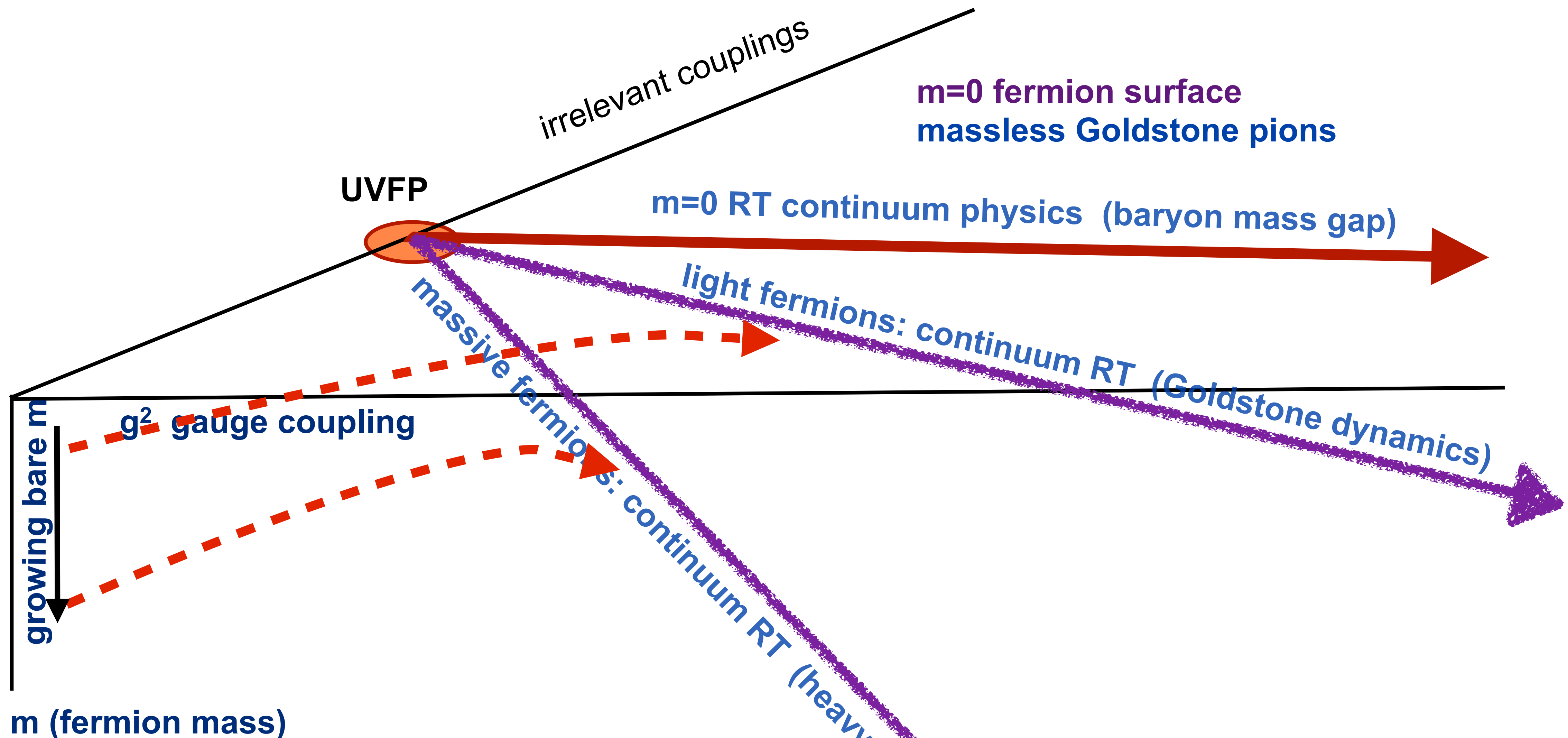

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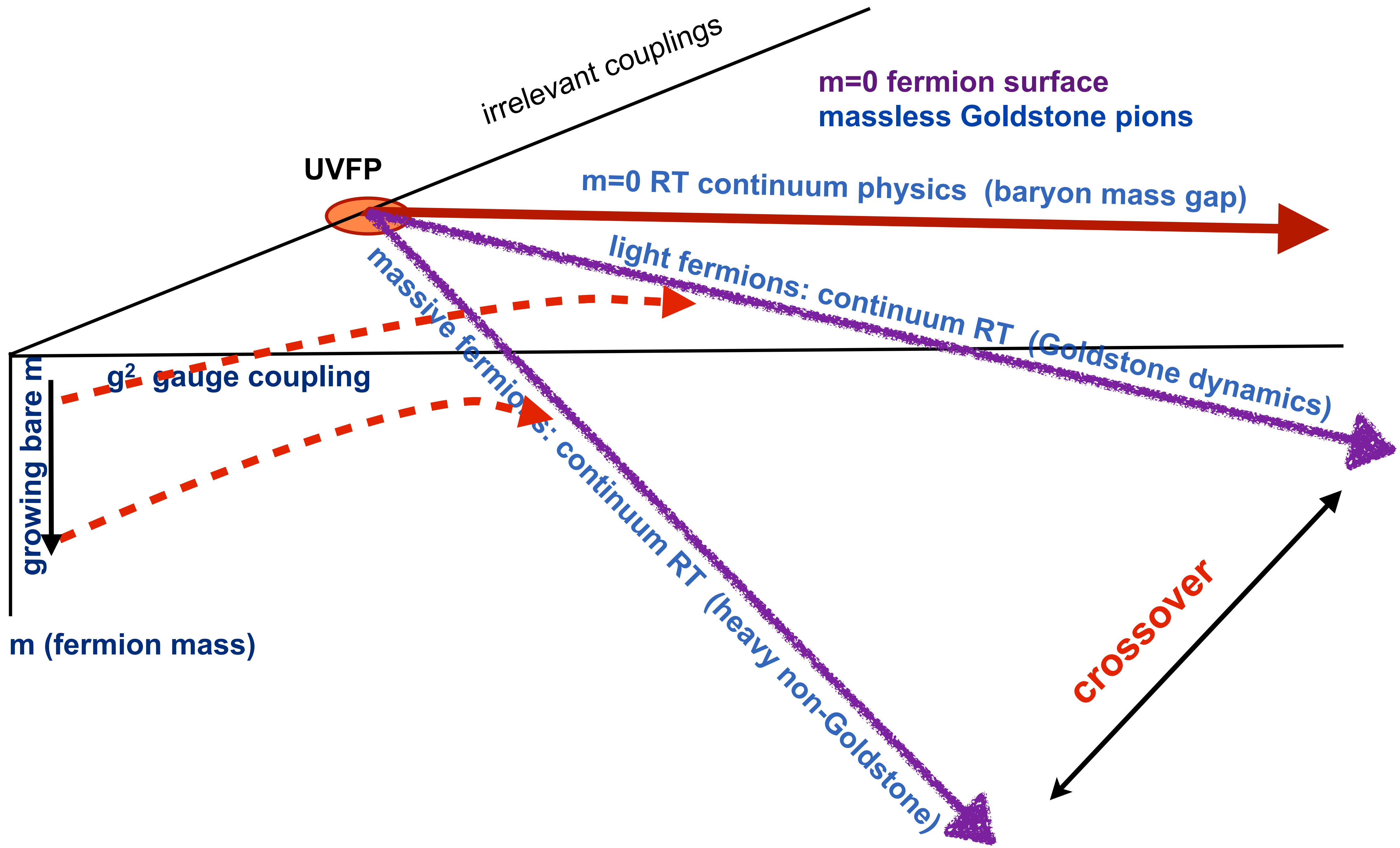
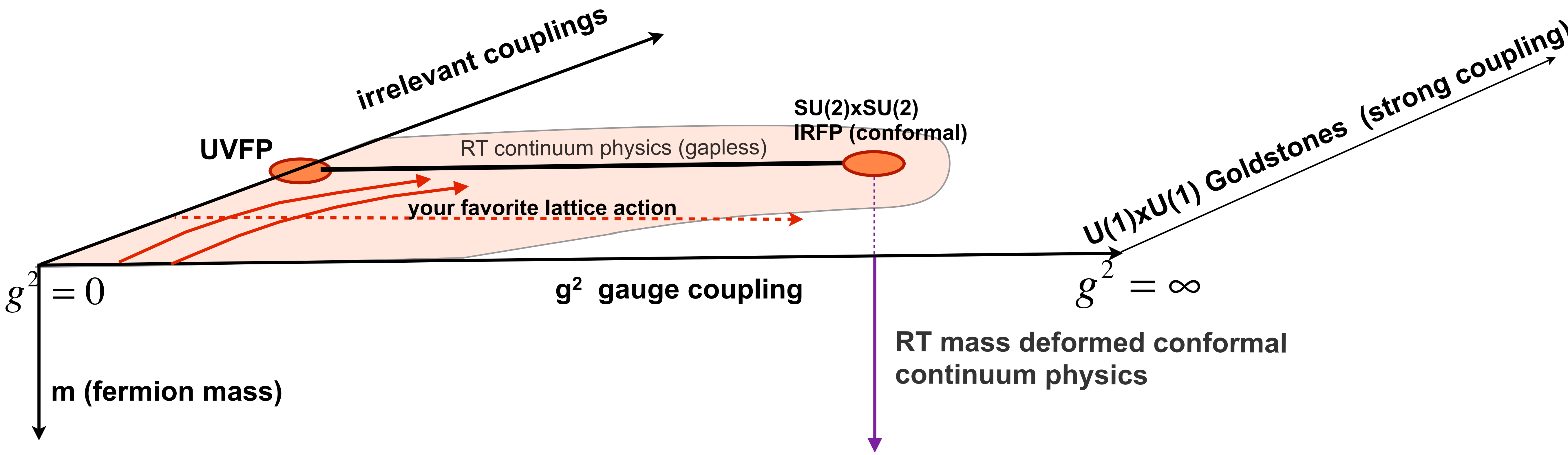


lattice navigation map and the critical (conformal) surface

Symanzik improved gauge action

staggered fermions with 2 stout smearing steps

massless fermions on critical surface



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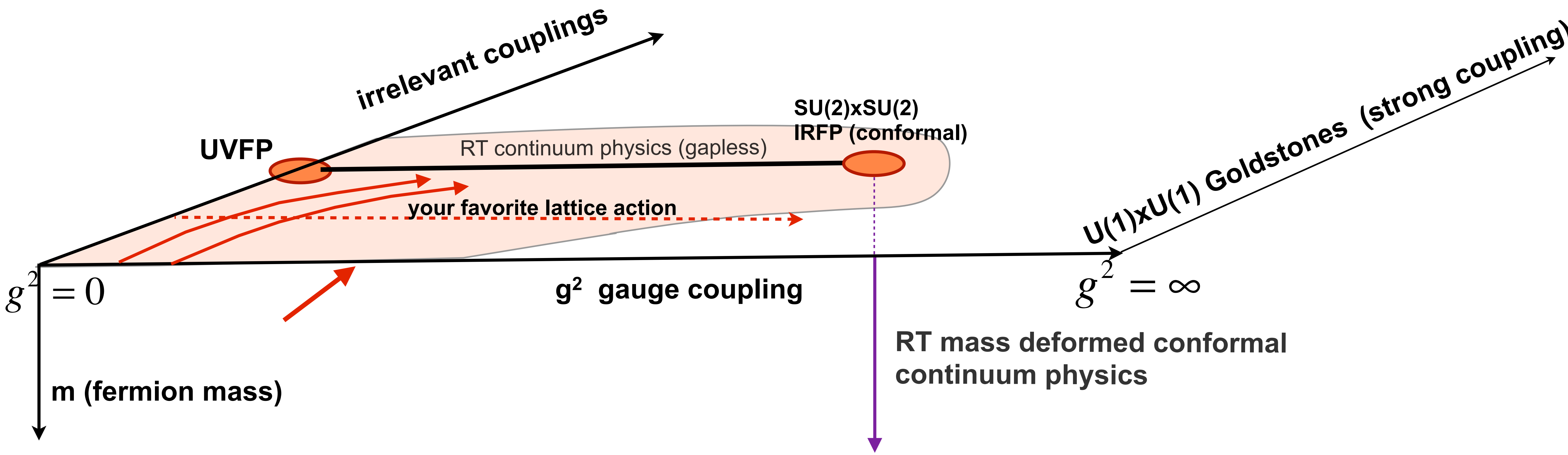

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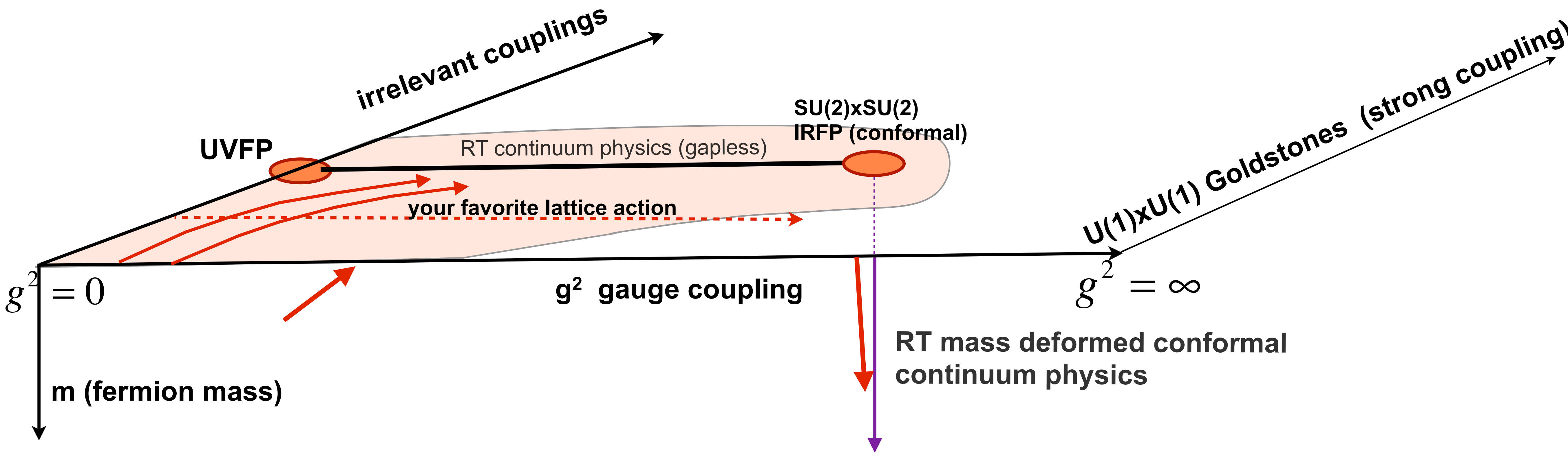

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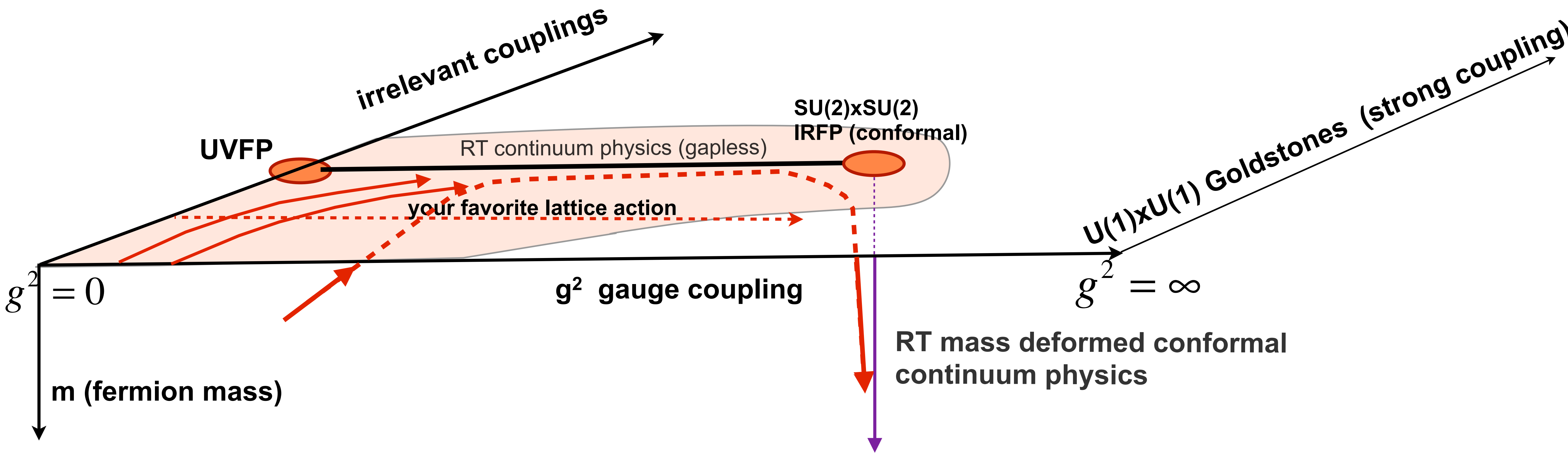

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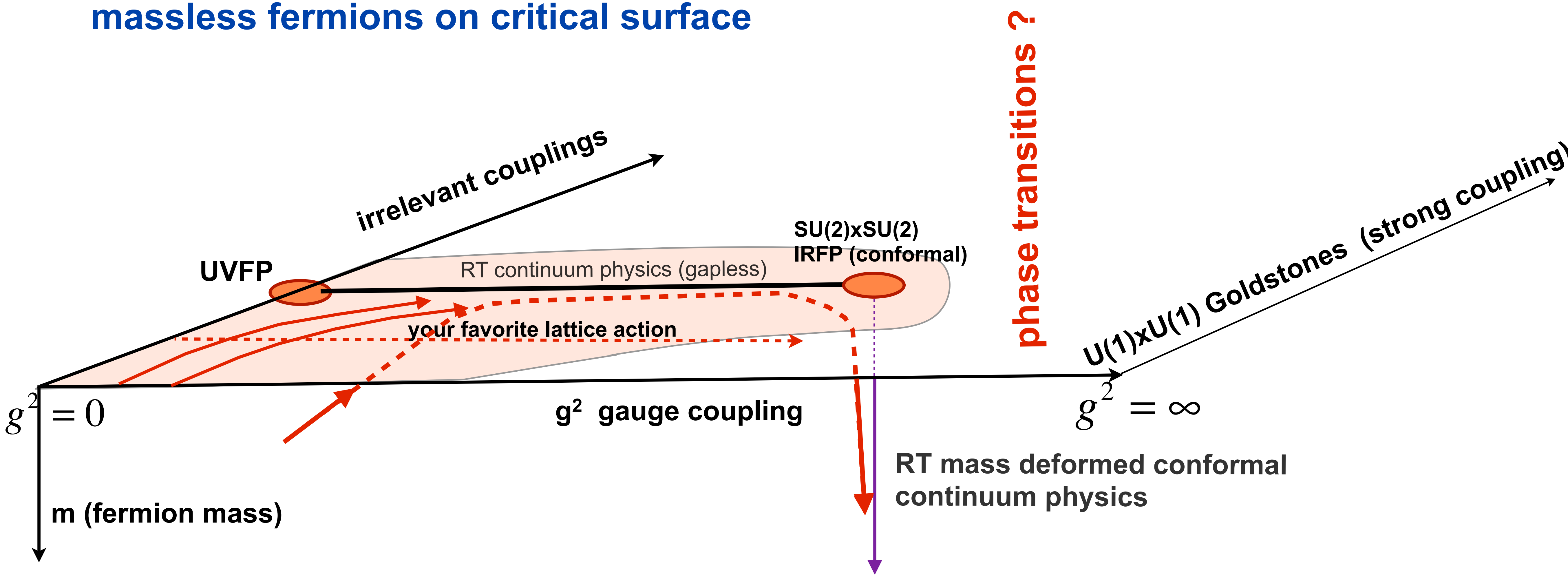

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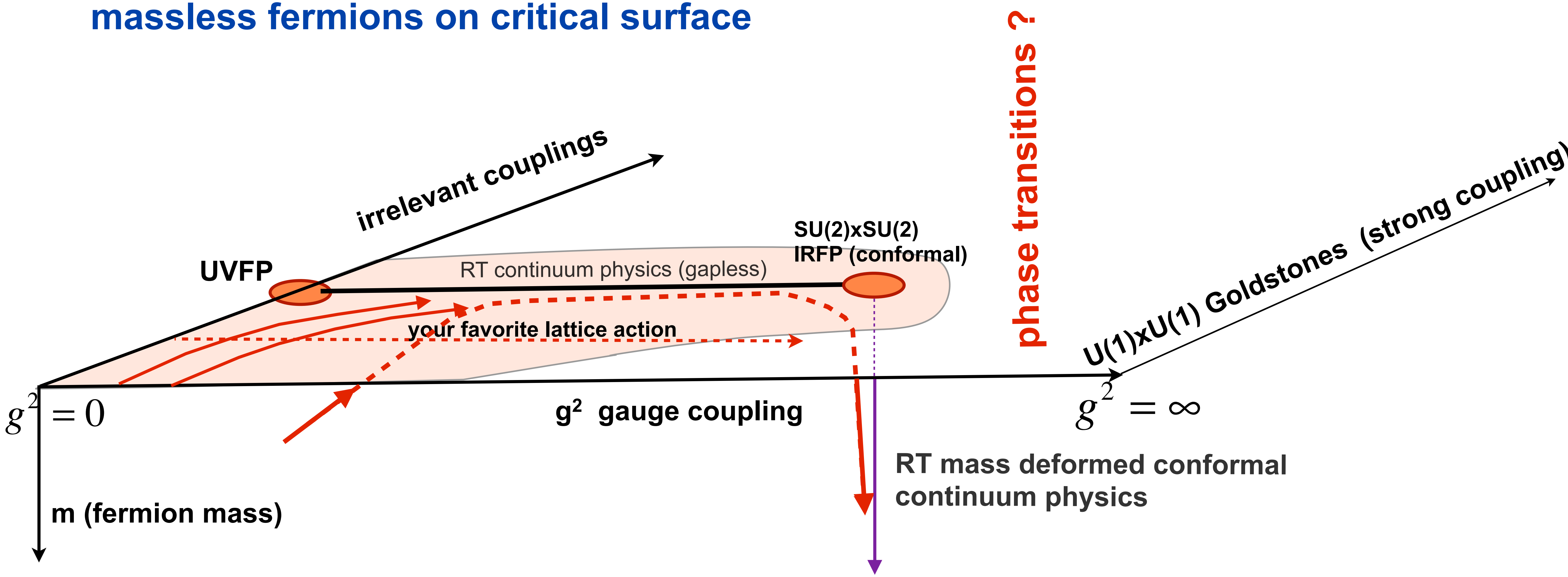


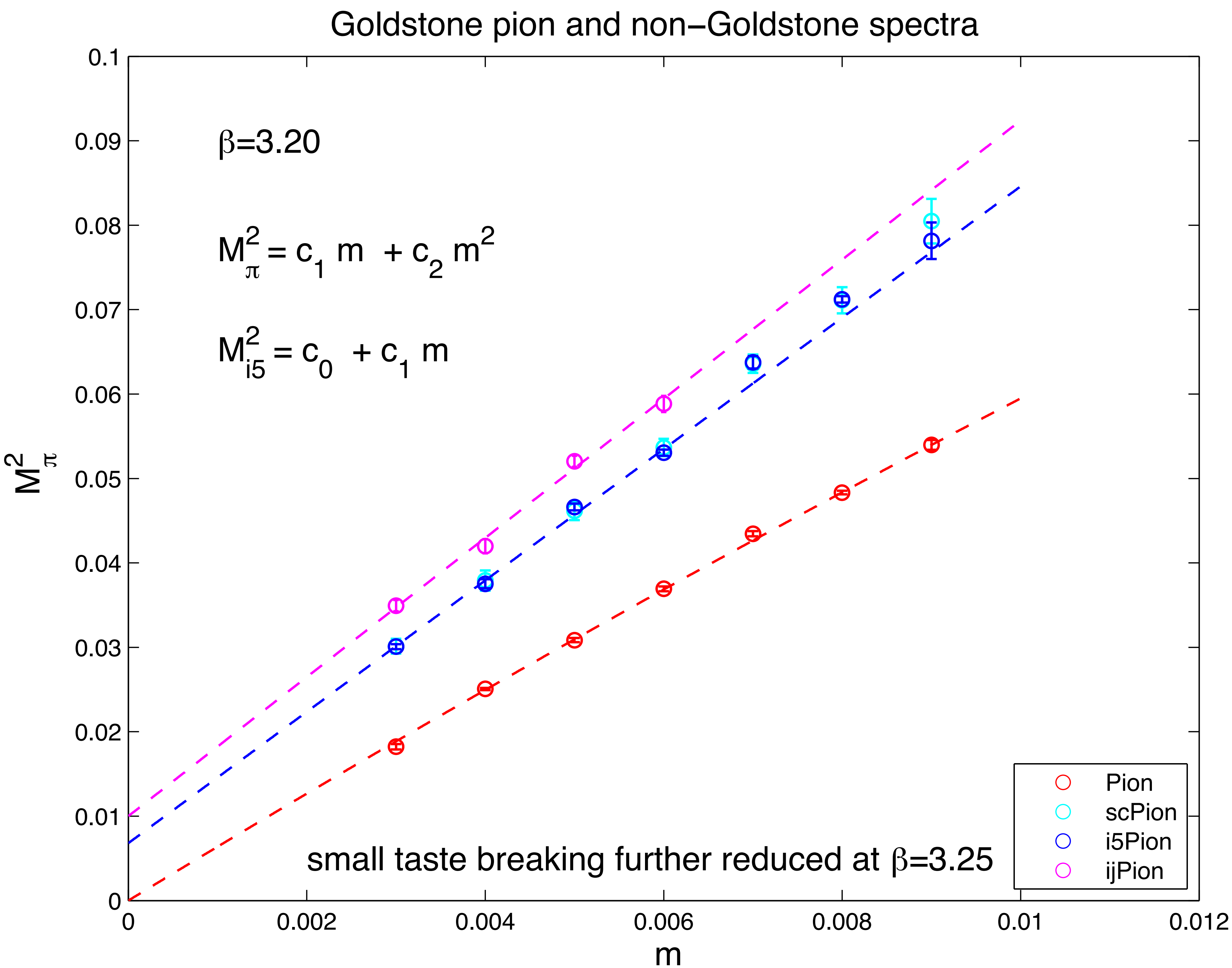
m=0 bulk phase at weak coupling? chiral SB?

will determine the physics of the m=0 surface and the (non)existence of IRFP

Nf=2 sextet bulk phase structure ?

are we sitting in the weak coupling phase when β=3.2 ?

(most of the results)



taste breaking is comparable to HISQ performance when M_{rho} is matched

at beta=3.25 we see considerably reduced splitting

Nf=2 sextet bulk phase structure ?

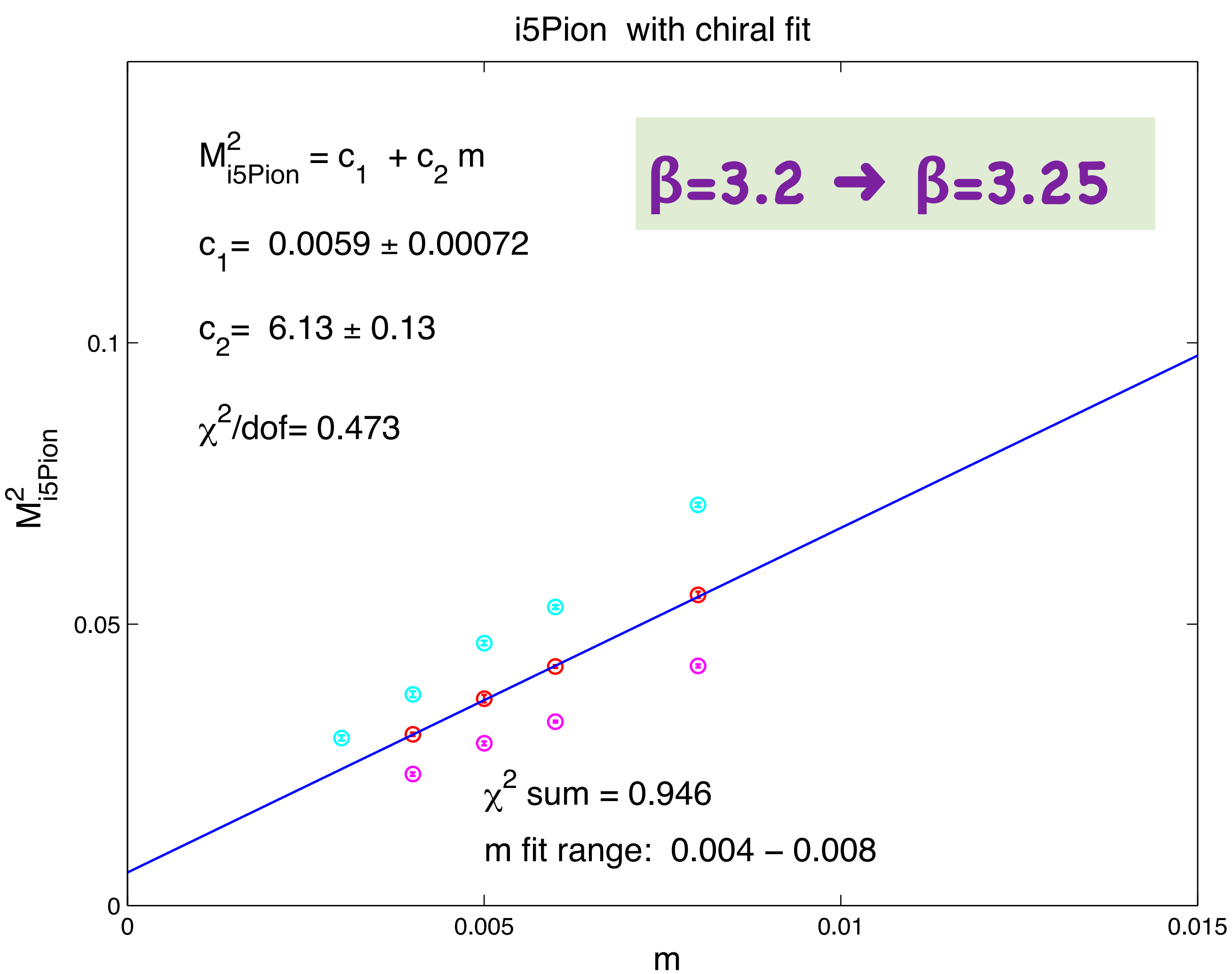
are we sitting in the weak coupling phase when β=3.2 ?

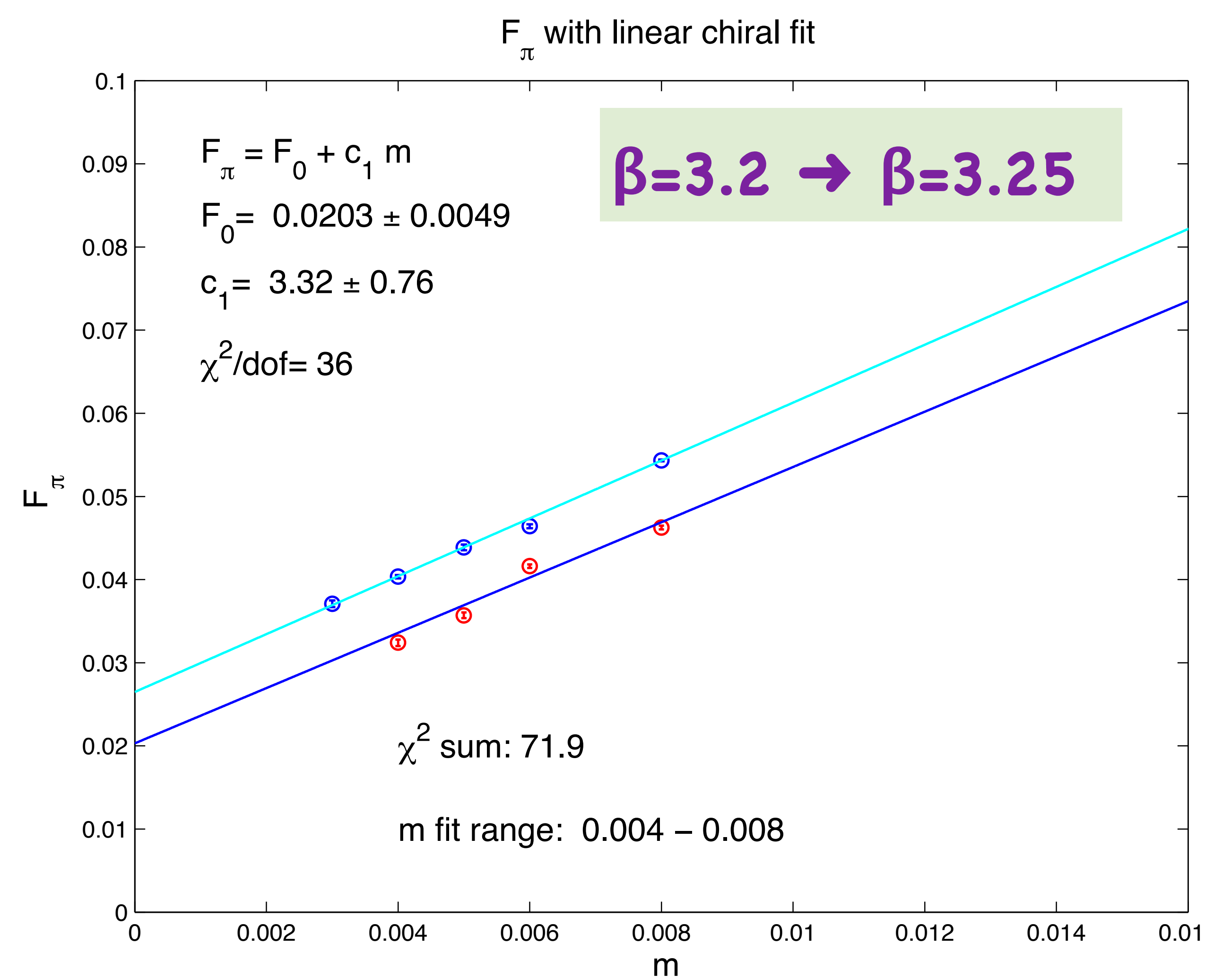
(most of the results)

new data: β=3.2 ➜ β=3.25

(non)Goldstone splittings and spectroscopy like in weak coupling QCD

full scan of bulk phase in progress to re-confirm chiSB phase





status of SU(3) Nf=2 sextet model analysis

our group: mass-deformed theory close to m=0 critical surface and m -> 0 limit:

- two strategies complement: (1) inf volume mass deformed chiral or conformal
  (2) finite volume mass-deformed FSS

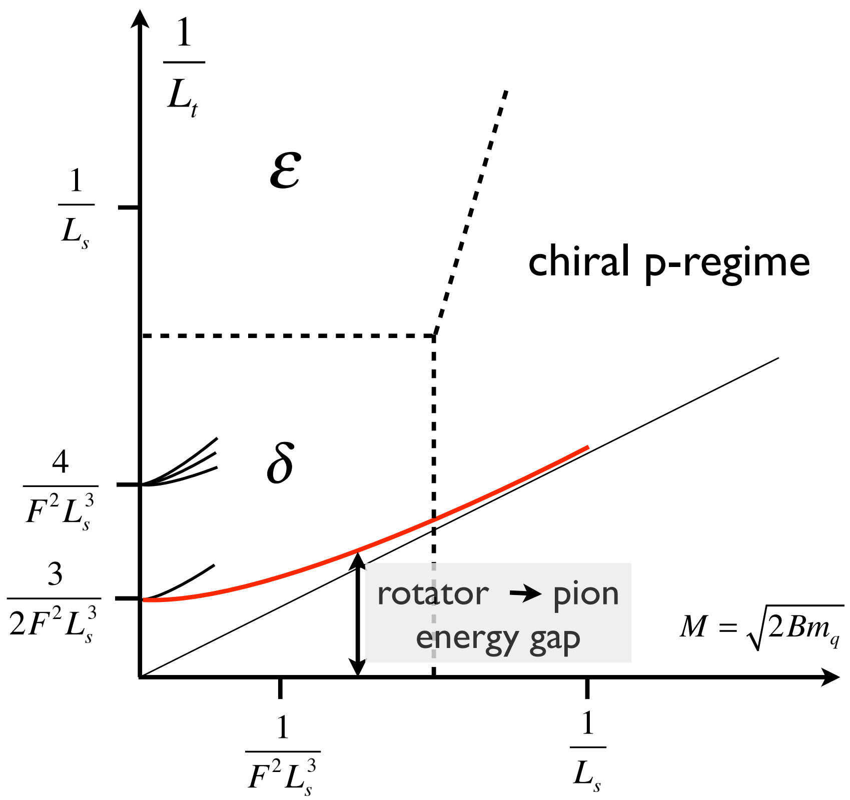
- direct access to effective anomalous dimension γ if conformal

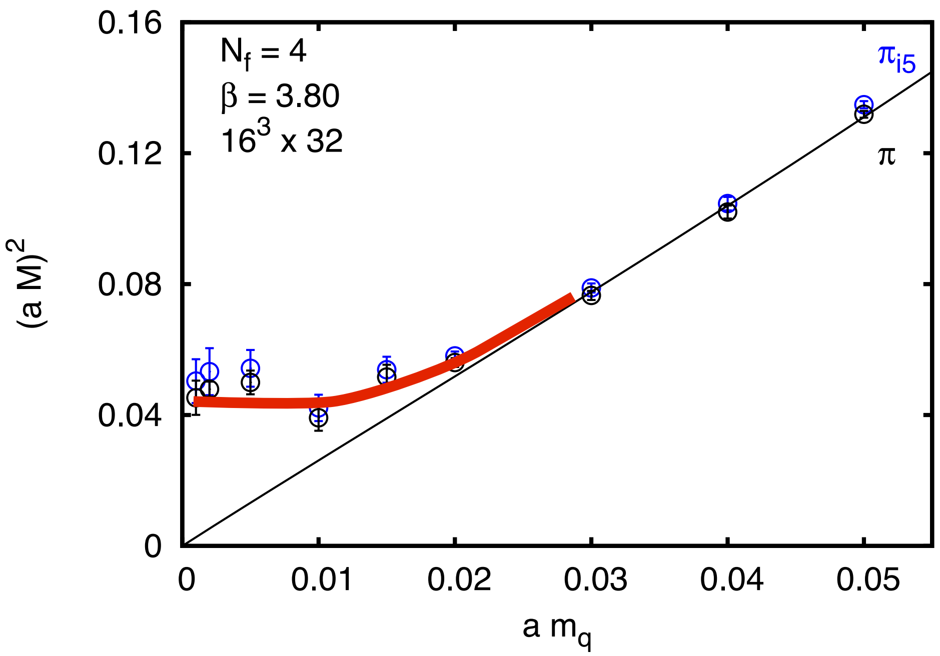
- similar to tests of RG scaling laws of moments of current correlator functions
  (m=0 and m≠0 RG with running coupling and running; $\gamma(\mu)$ exponent in progress)

- we will work with chiSB hypothesis which is consistent with all data

- conformal tests badly failed so far - additional conformal FSS tests in the works
  will be illustrated for Nf=12 (Ricky Wong's talk)

mass deformed chiral regime in finite volume below conformal window:





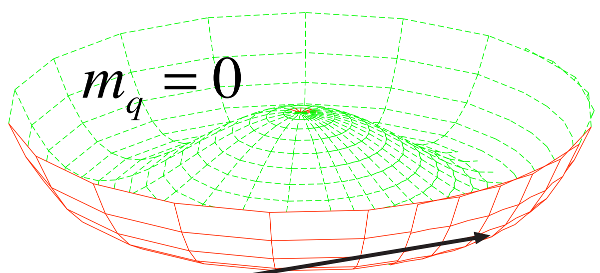
Goldstone dynamics is different in each regime

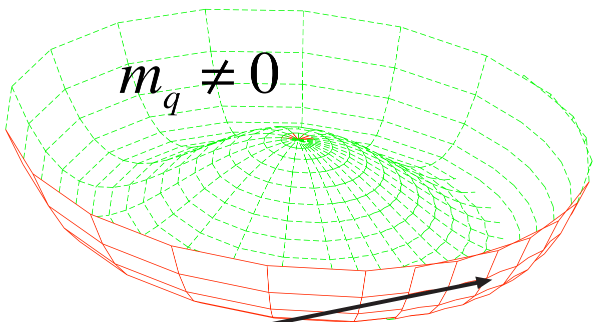
We study δ and ε-regimes (RMT)

and p-regime (probing chiral loops)

complement each other

interpretation of rotator levels in $m_q \to 0$ limit:

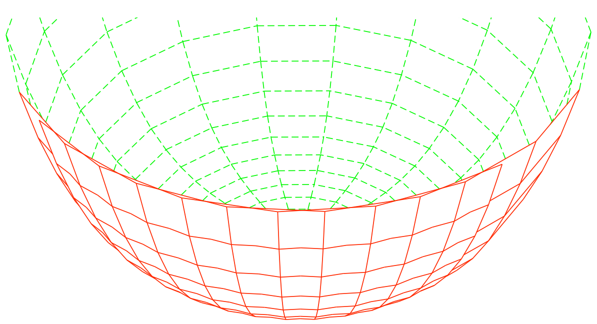




Veff: chiral condensate in flavor space

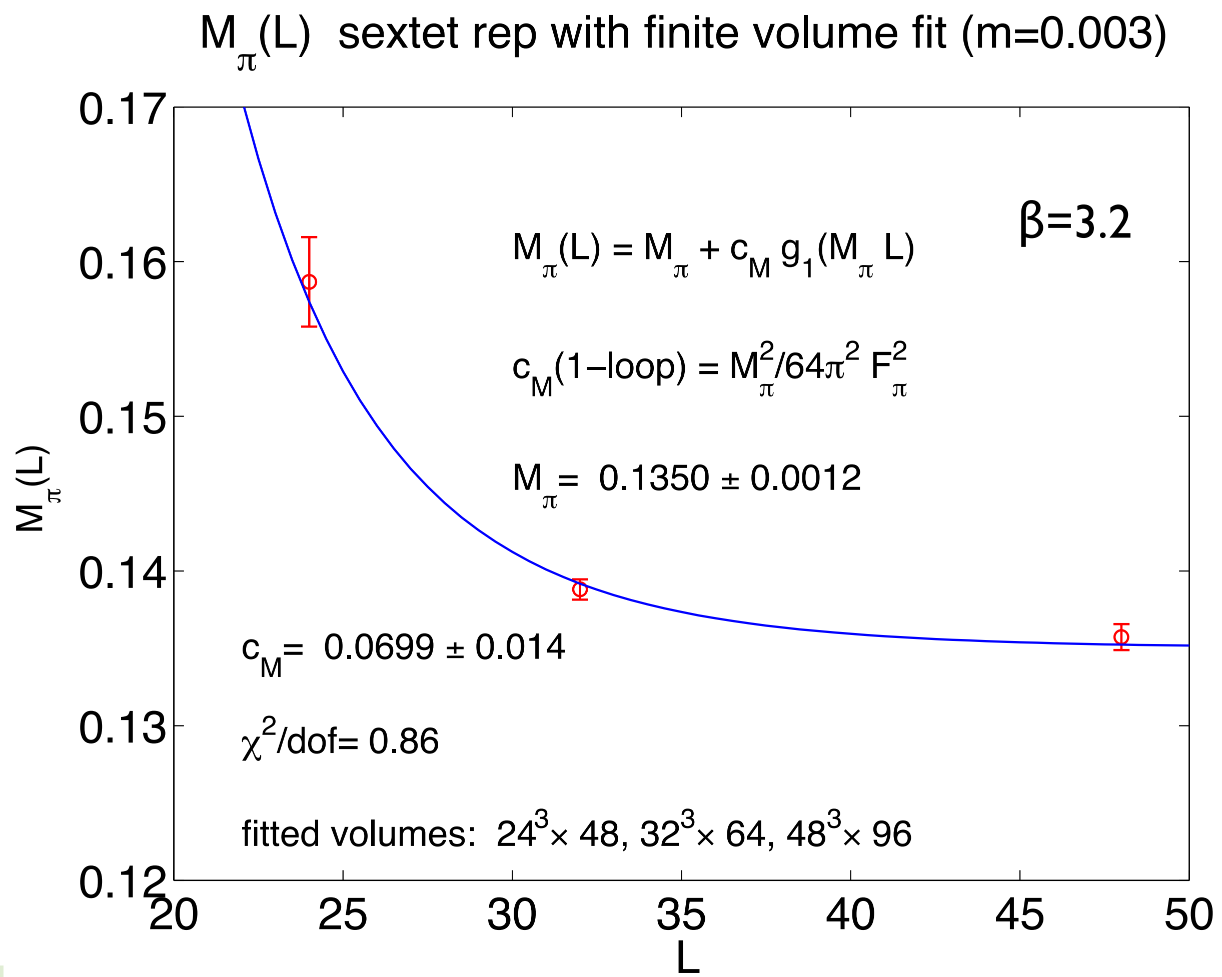
arbitrary orientation of condensate

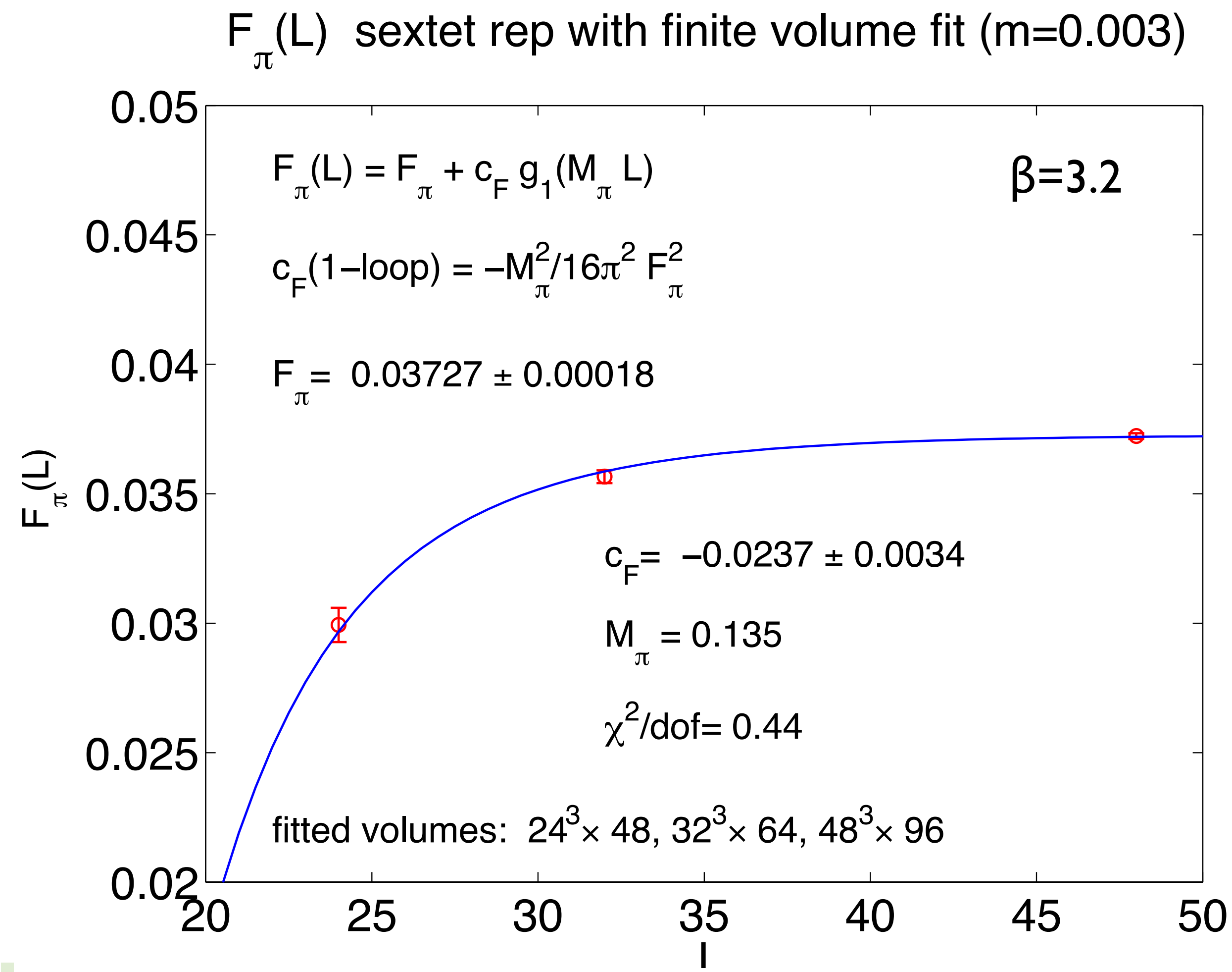
tilted condensate



Not to misidentify rotator gaps as evidence of chirally symmetric phase !

Our sextet simulations are in the p-regime β=3.2 (and β=3.25)





strategy 1: L→∞ extrapolation first

mass-deformed theory

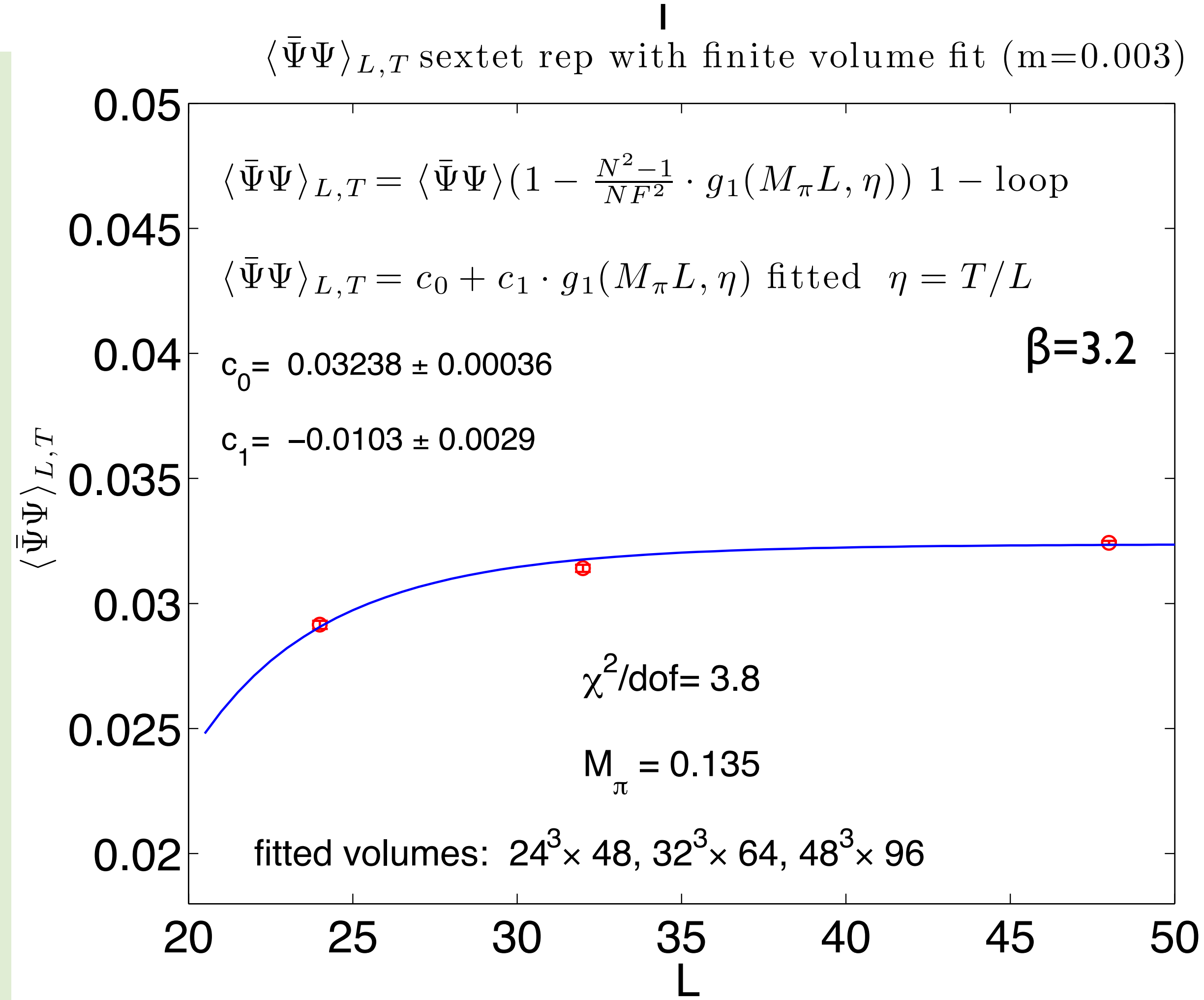
close to m=0 critical surface

L→∞ extrapolated chiral and conformal scaling tests in sextet model

for L·Mπ > 5

less than one percent L correction

C_M and C_F signs correct, values are off by factor of 3-4 (similar in QCD)



Strategy I: L=∞ extrapolation first and scaling mass-deformed test

Chiral hypothesis (in)complete analysis on both sides **Conformal hypothesis**

sextet model is close to chiral log regime

$$(M_\pi^2)_{NLO} = (M_\pi^2)_{LO} + (\delta M_\pi^2)_{1-loop} + \underbrace{(\delta M_\pi^2)_{m^2}}_{\sim m^2} + \underbrace{(\delta M_\pi^2)_{a^2 m}}_{\sim a^2 m} + \underbrace{(\delta M_\pi^2)_{a^4}}_{\sim a^4}$$

$$(M_\pi^2)_{LO} = 2B\cdot m + a^2\Delta_B$$ **kept cutoff term in B see LO a² term**

would require more data

$$(\delta M_\pi^2)_{1-loop} = [(M_\pi^2)_{LO} + a^2]^2 \ln(M_\pi^2)_{LO}$$

$$\boxed{M_\pi^2 = c_1 m + c_2 m^2 \ + \text{logs}}$$ **fitted function for Goldstone**

$$\boxed{M_{nuc} = c_0 + c_1 m \ + \ \text{logs}}$$ **nucleon states, rho, a1, higgs, ...**

$$(F_\pi)_{LO} = F,\quad (\delta F_\pi)_{1-loop} = [(M_\pi^2)_{LO} + a^2]\ln(M_\pi^2)_{LO}$$

chiral log regime was not reached in fermion mass range

$$(\delta F_\pi)_{m^2} \sim m,\quad (\delta F_\pi)_{a^2 m} = a^2$$

kept cutoff term in F

$$\boxed{F_\pi = F + c_1 m + \text{logs}}$$ **fitted function**

$$\boxed{\langle\bar\psi\psi\rangle = \langle\bar\psi\psi\rangle_0 + c_1 m + c_2 m^2 + \text{logs}}$$ **chiral condensate**

$$\boxed{M_\pi = c_\pi \cdot m^{1/y_m},\qquad y_m = 1+\gamma}$$

leading conformal scaling

functional form for all hadron masses

$$\boxed{F_\pi = c_F \cdot m^{1/y_m},\qquad y_m = 1+\gamma}$$

universal critical exponent

$$\boxed{\langle\bar\psi\psi\rangle = c_\gamma \cdot m^{(3-\gamma)/y_m} + c_1 m}$$ Del Debbio et al.

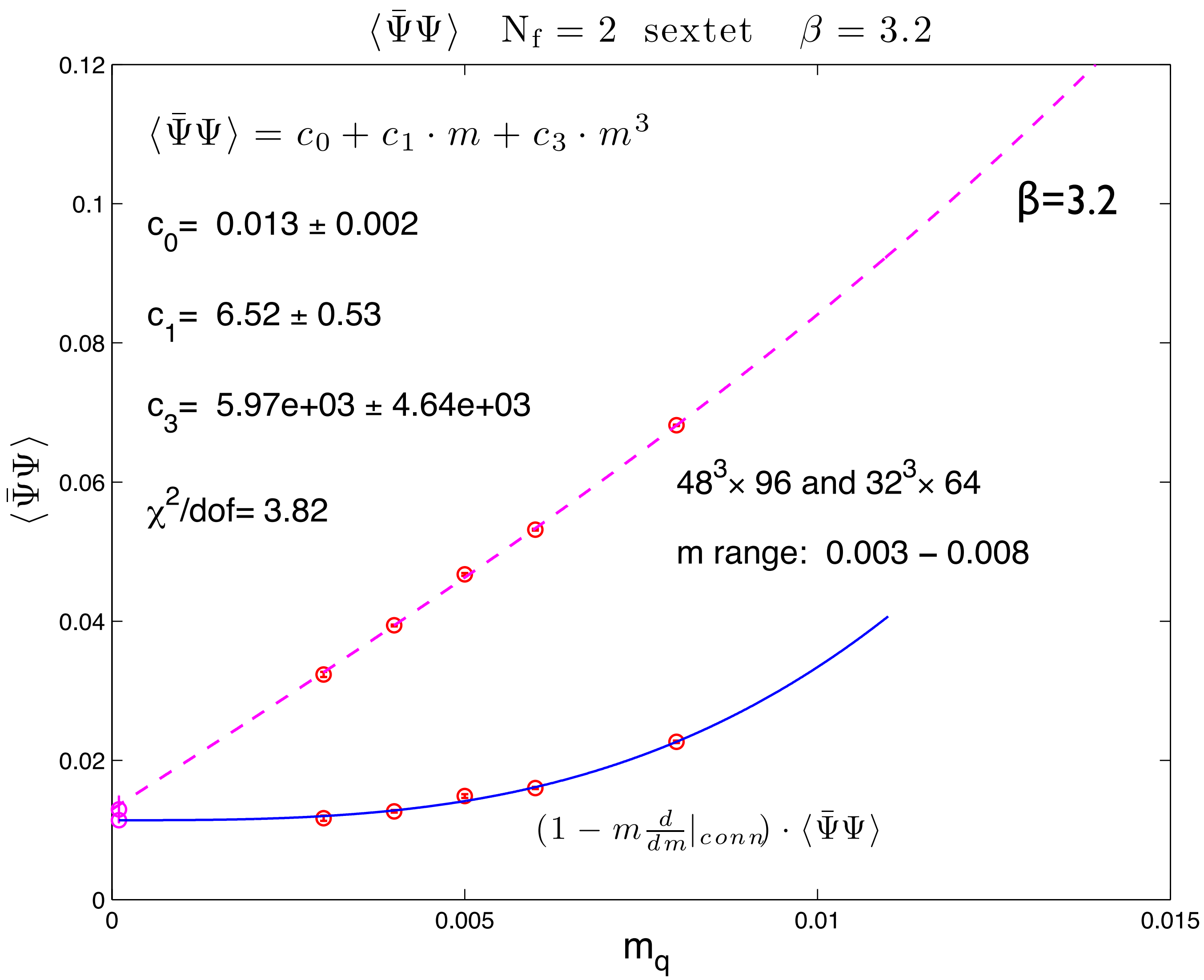
recent improvements (Patella) from Dirac spectrum

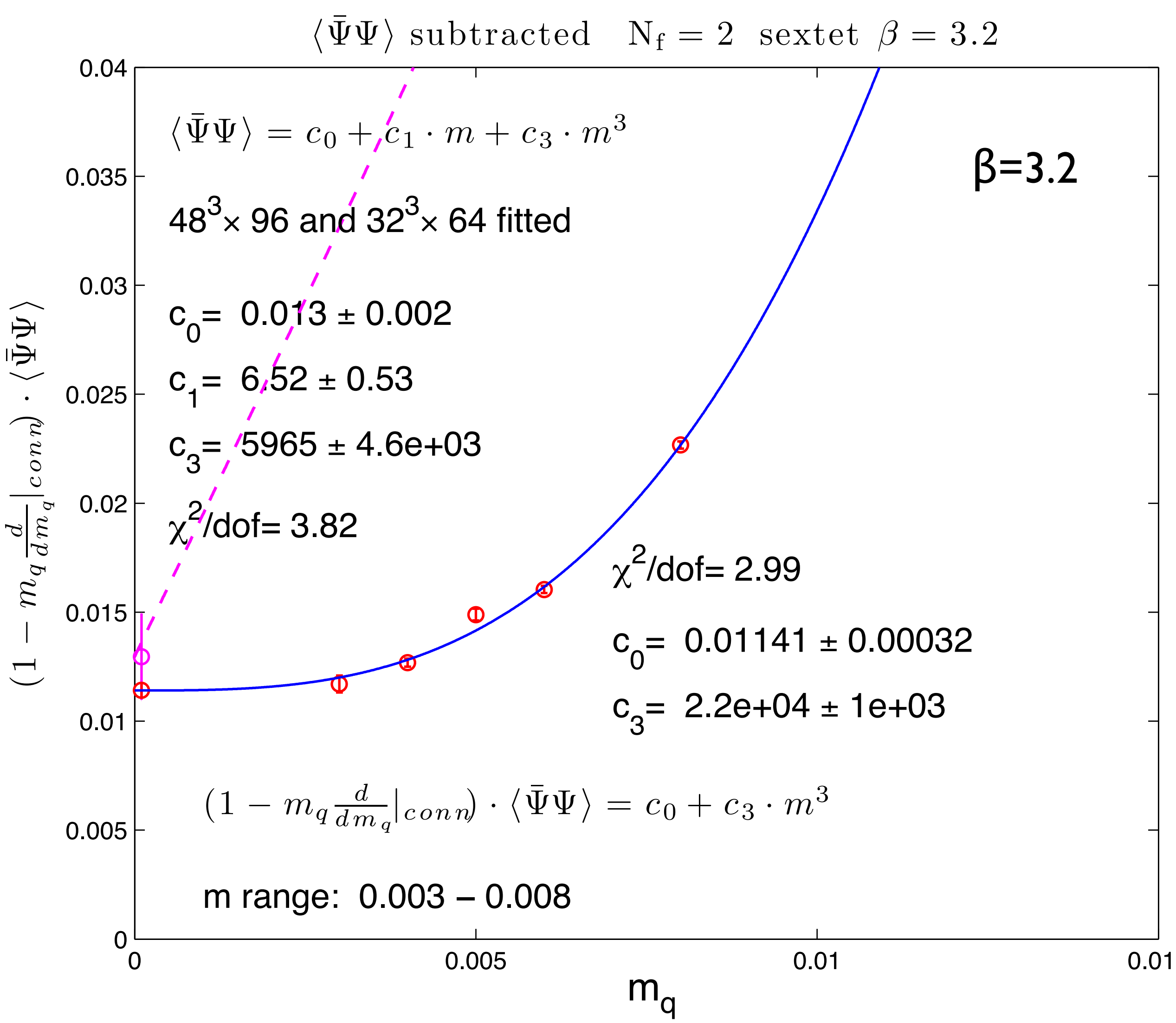
based on Giusti and Luscher

conformal scaling violation analysis?

fails in sextet model

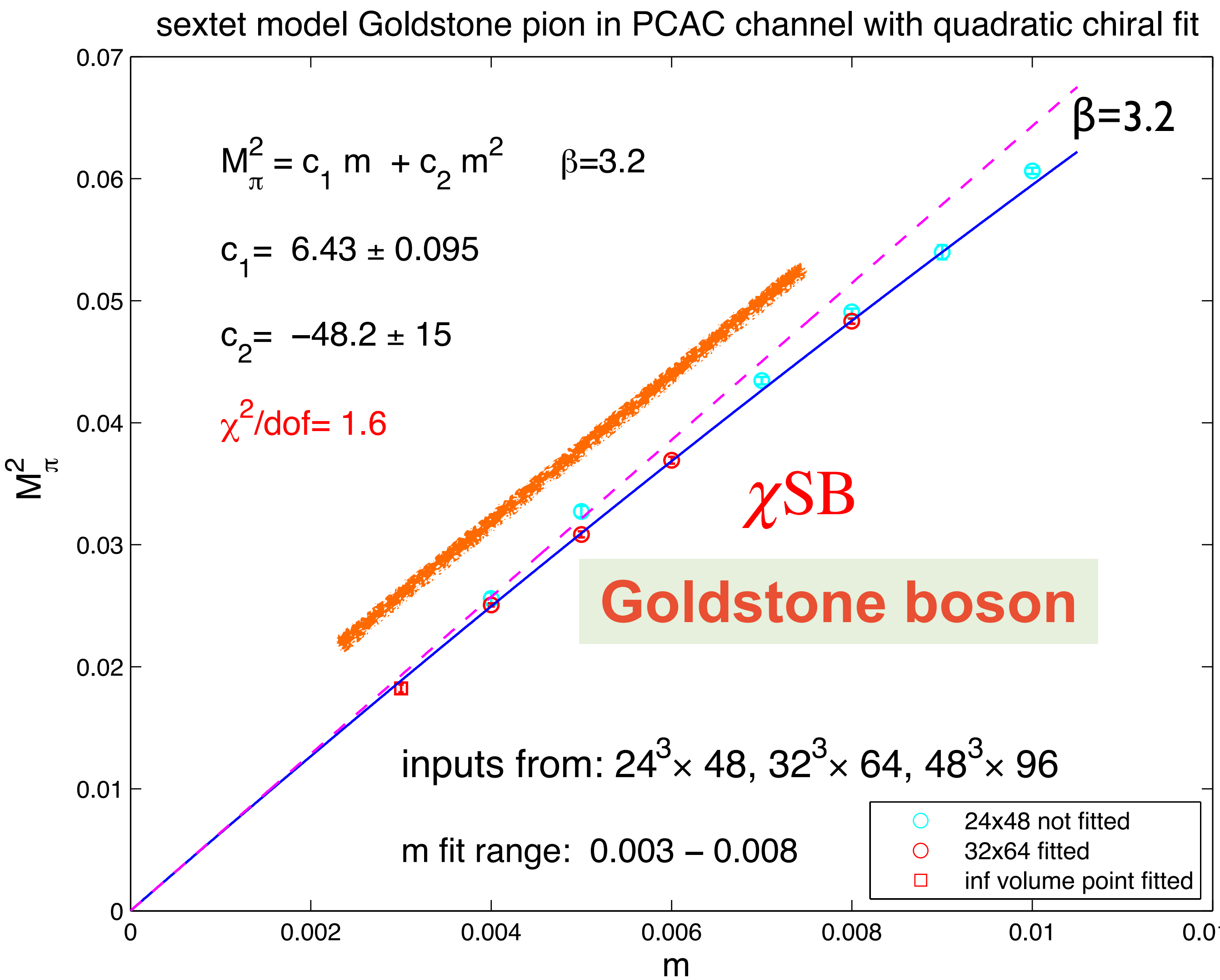
Nf=2 SU(3) sextet chiral condensate

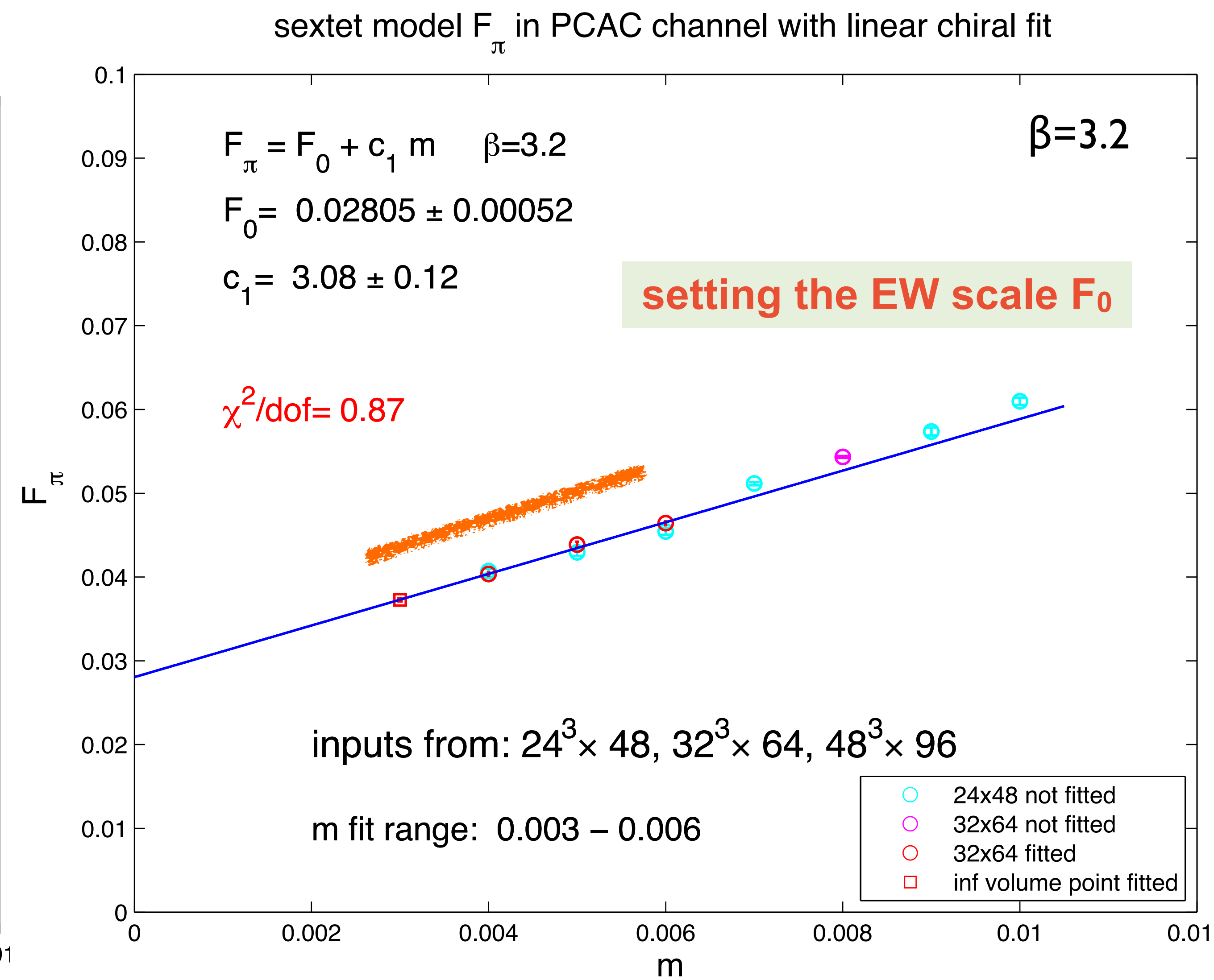




- two independent determinations of the chiral condensate
- consistently non-vanishing in chiral limit
- all sextet results are treated as inf volume (m=0.003 is extrapolated in Ls)

Nf=2 SU(3) sextet chiral fits of M_π and F_π



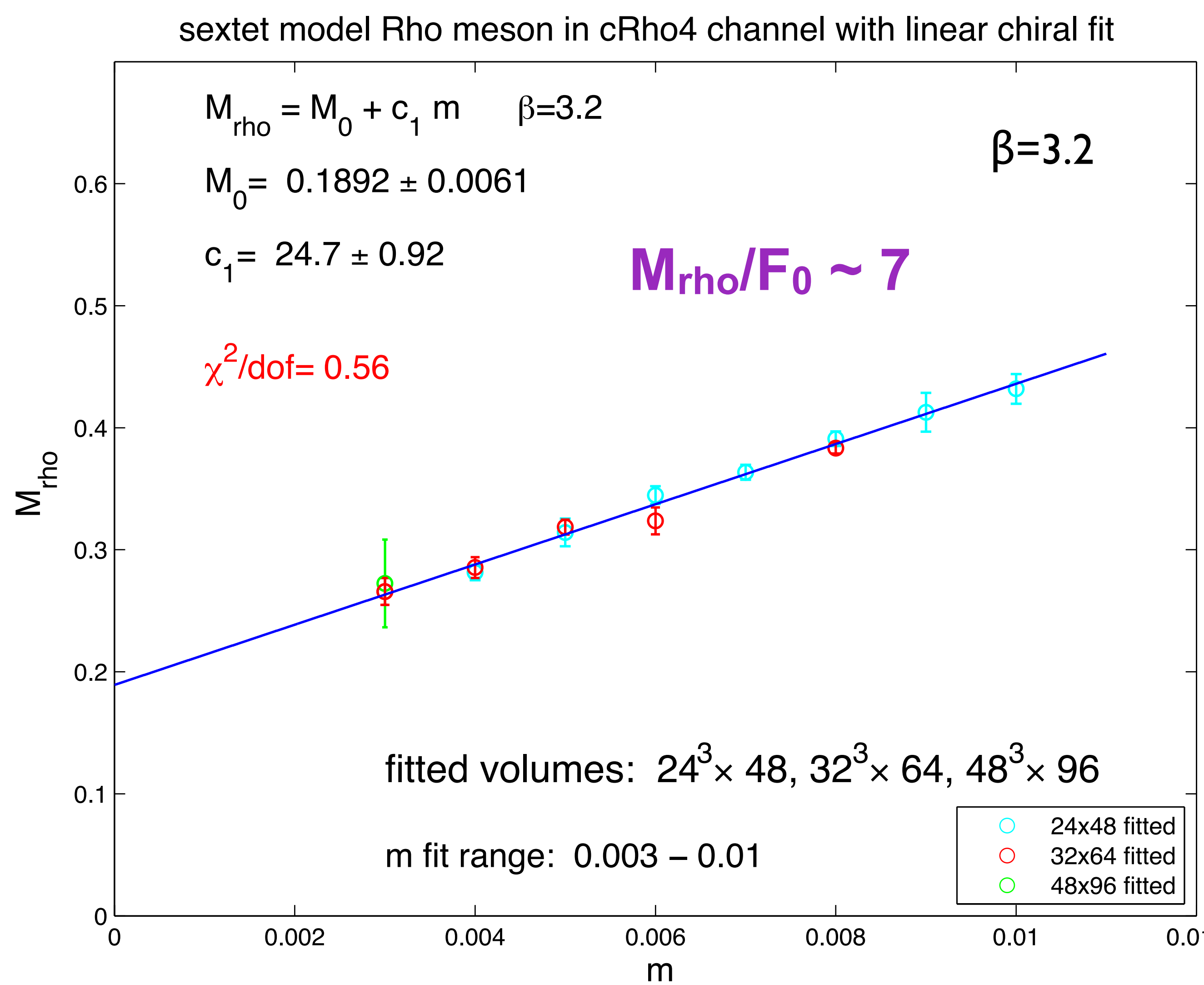


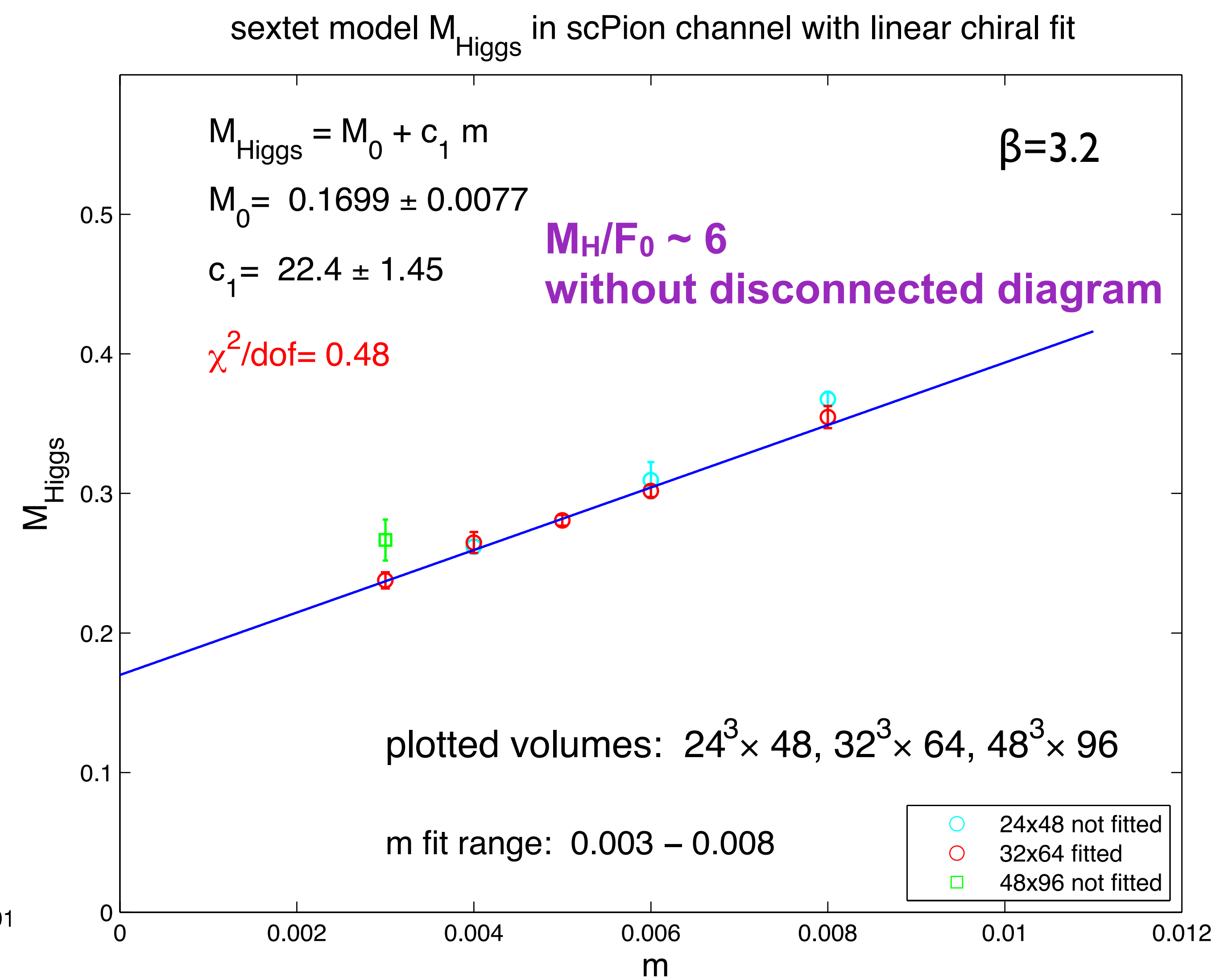
m=0.003-0.006 range close to chiral log regime

Nf=2 helps: SU(2) flavor analysis QCD-like

log detection will require more precise data (pqsChiPT works but not well-tested)

Nf=2 SU(3) sextet chiral fits M_ρ and M_H





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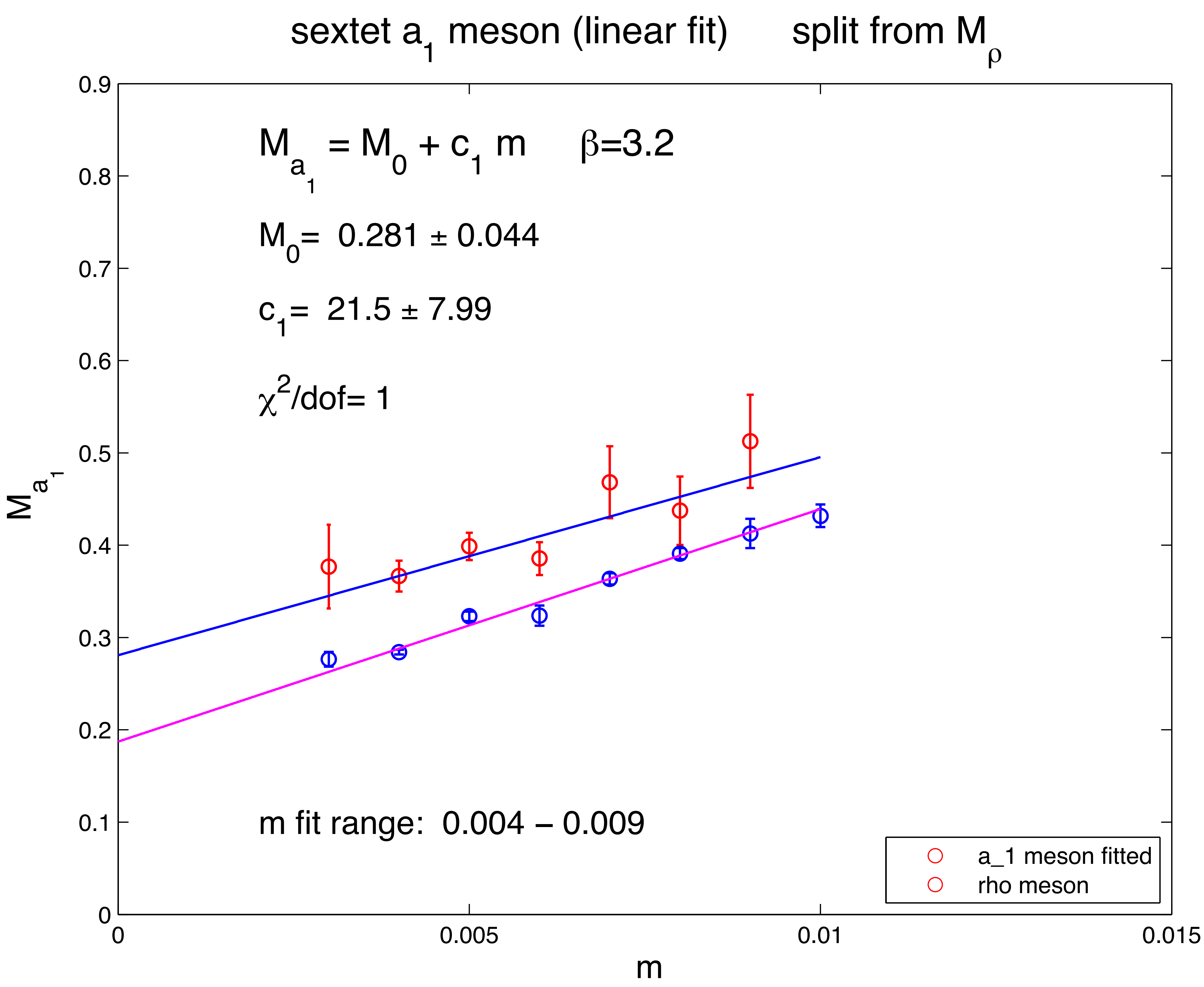
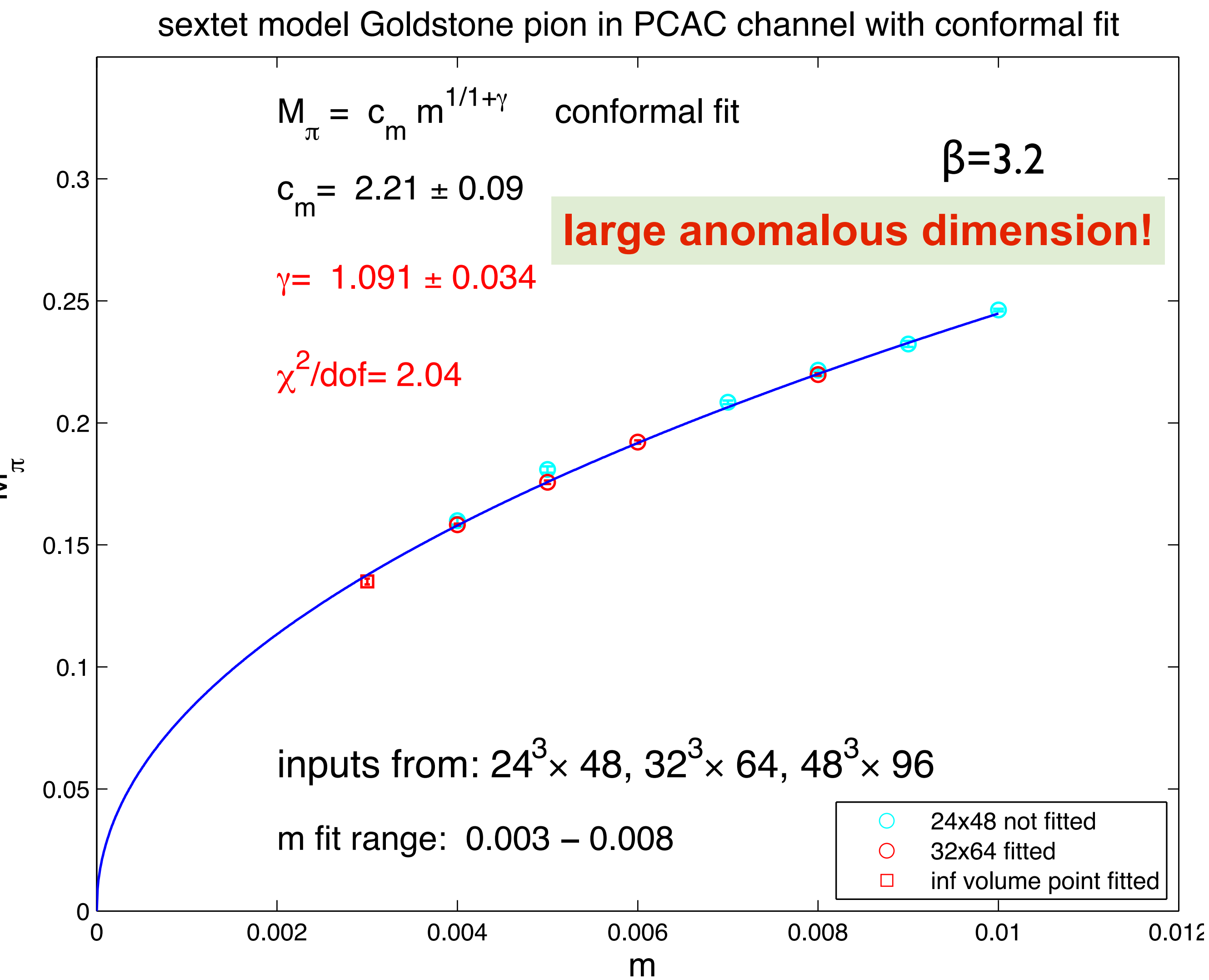
a1-rho split in m=0 limit requires more precise data:

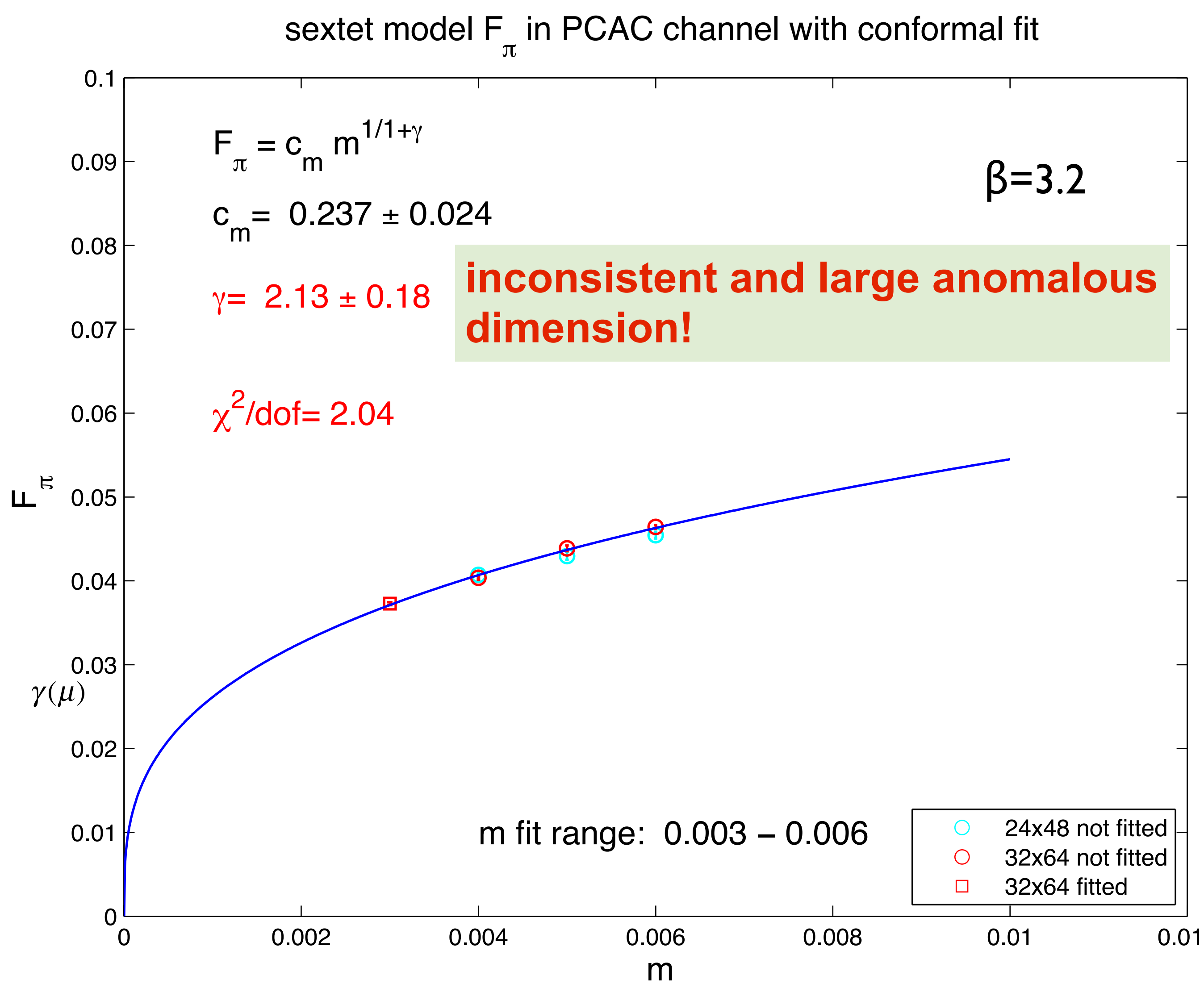


further Nf=2 SU(3) sextet model tests ?

- $L=\infty$ conformal scaling tests ✓
- conformal FSS tests — will be shown in Nf=12 model
- confining force in chiral limit ? — Kieran Holland's talk

conformal hypothesis breaks down in global fits:





inconsistent large critical exponents γ forced by chiral behavior
in far infrared

it is not the running $\gamma(\mu)$ at some scale μ!

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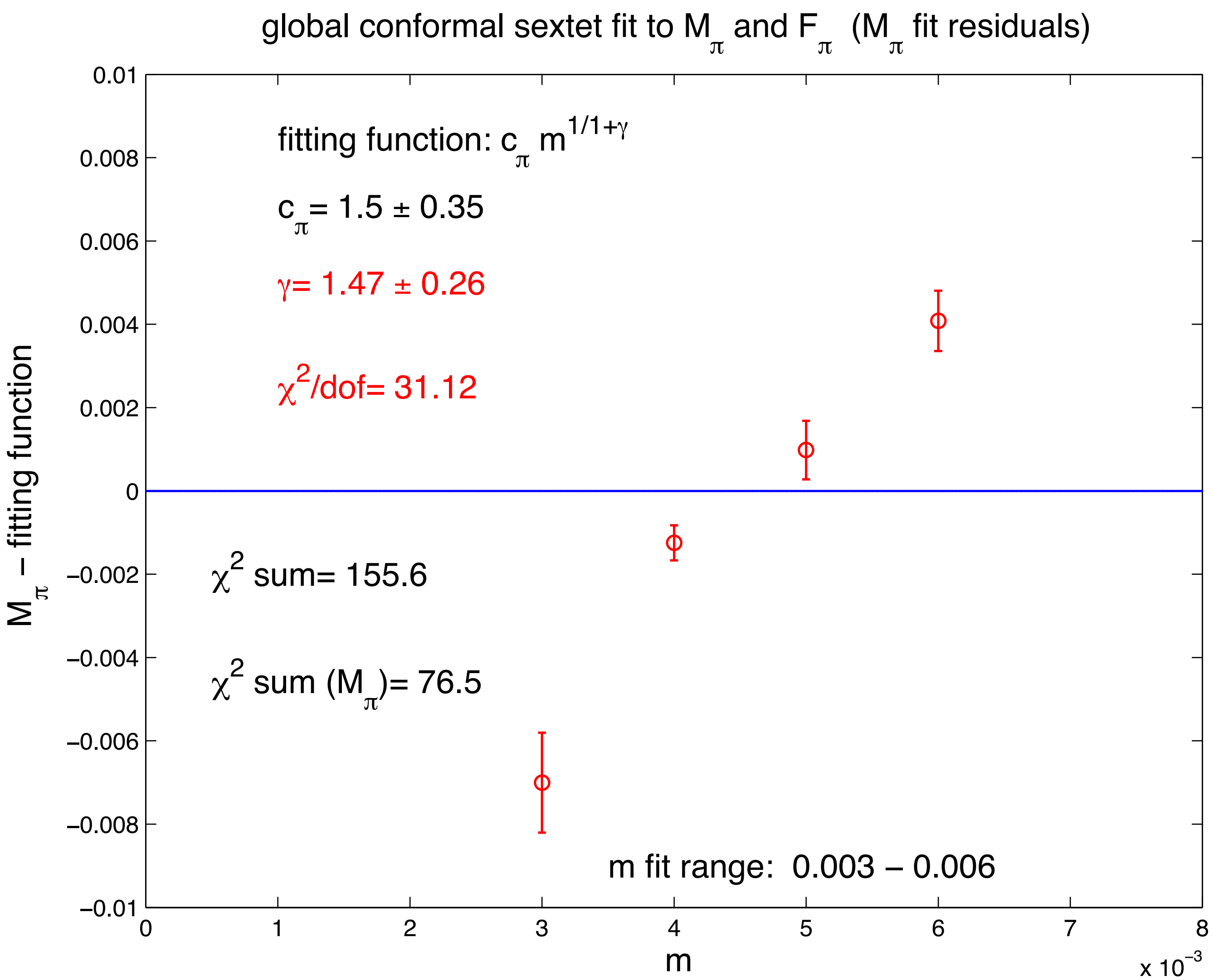
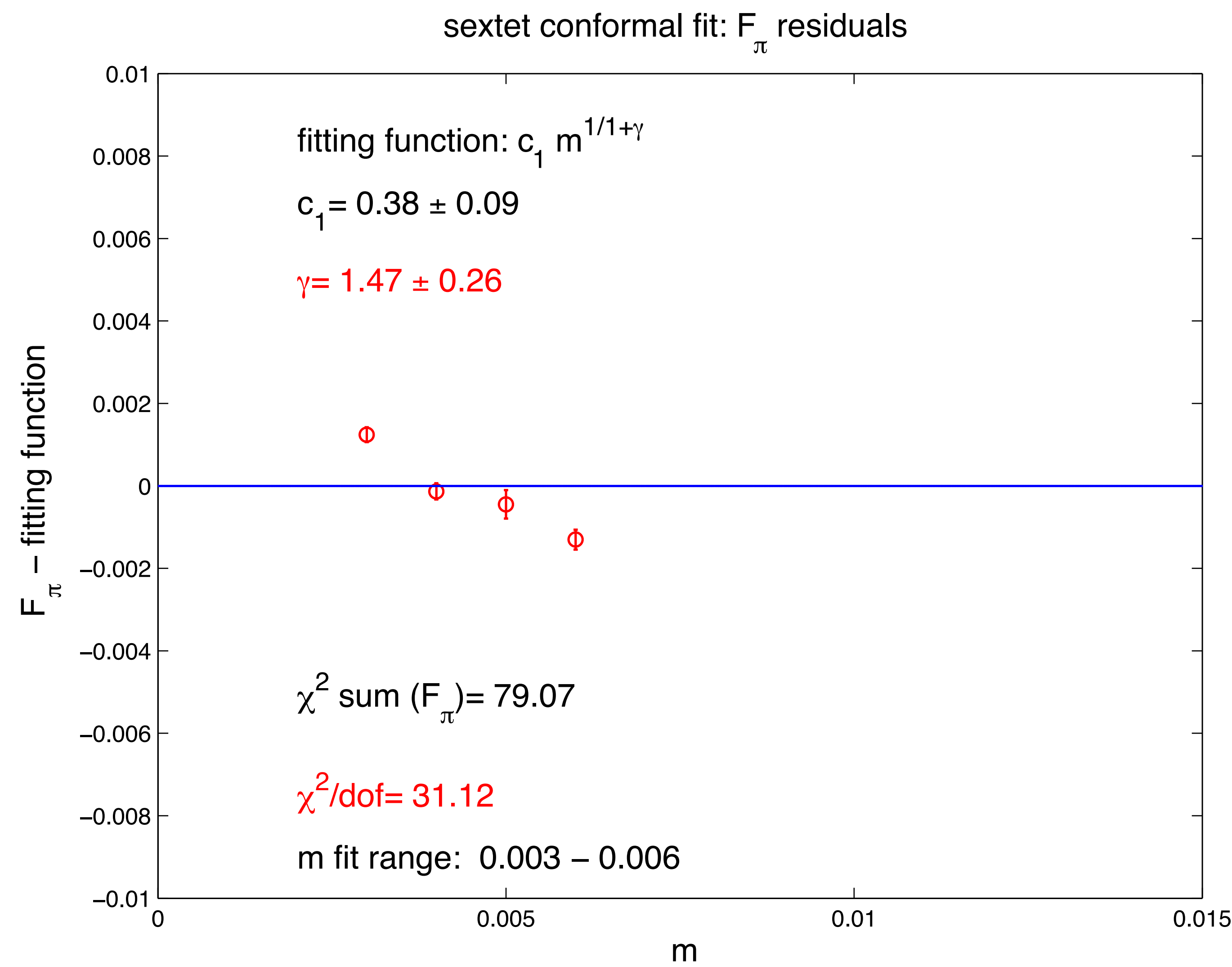




large and inconsistent critical exponents γ

are we close enough to the critical surface?

methods developed in SU(3) Nf=12 fundamental rep:

1. conformal scaling test with FSS heavy use of RG theory

$$LM = f(x) + L^{-\omega} g(x)$$

$$x = m^{1/1+\gamma} L$$

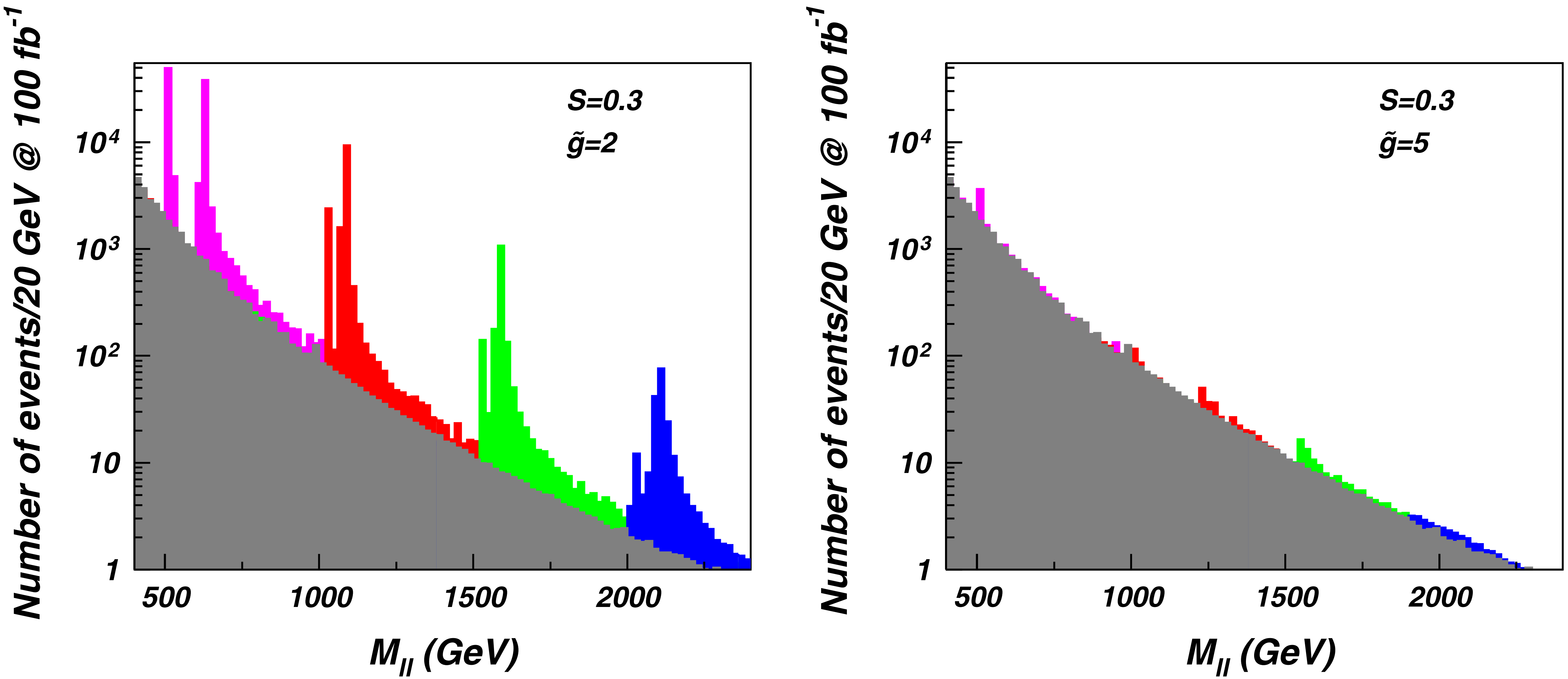
$$\omega = \beta'(g^*)$$

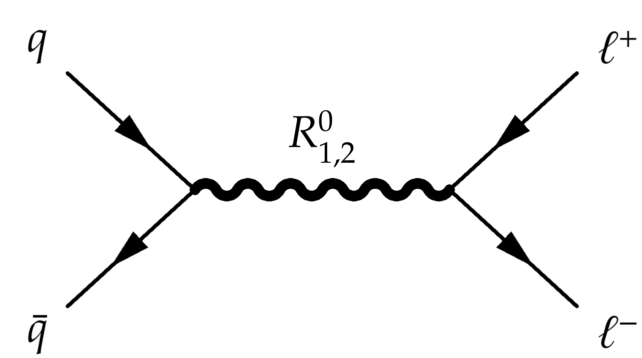
2. confining force and its critical m=0 limit Holland's talk

Time for LHC phenomenology

We are doing LHC phenomenology based on MadGraph and FeynCalc (Sannino et al)

Drell-Yen production of composite vector bosons on the TeV scale





Feynman diagram of TeV scale new vector meson production

Nf=2 SU(3) sextet model summary:

- No inconsistency with χSB in Nf=2 SU(3) sextet model

- We find inconsistency with conformal symmetry in all L=∞ like tests

- Effective large anomalous dimension inconsistent and forced (γ is in 1-2 range)

- Kogut and Sinclair: looking for finite temperature χSB phase transition

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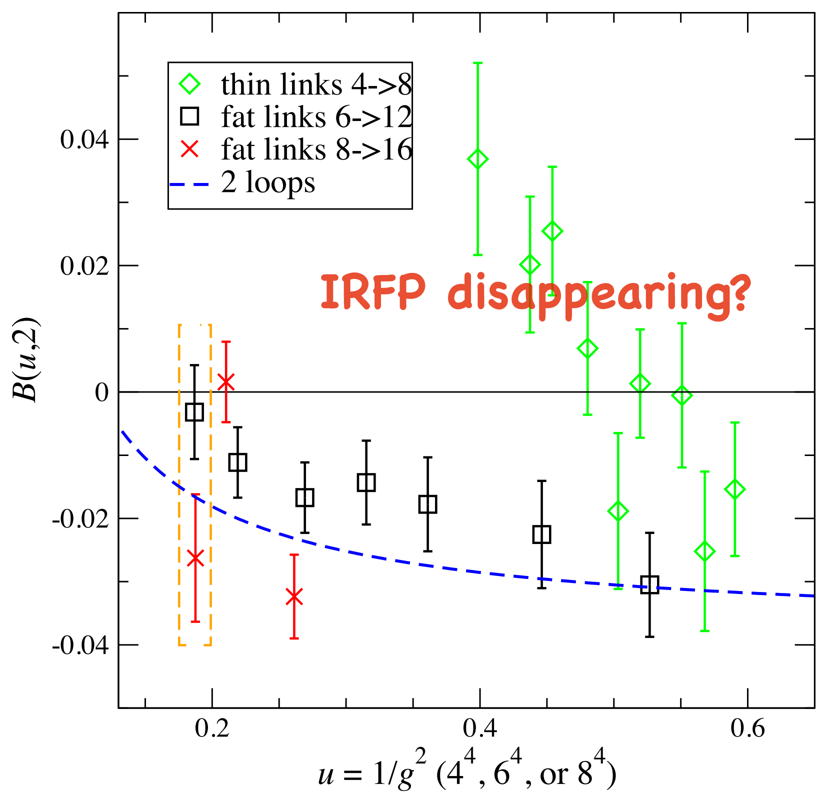
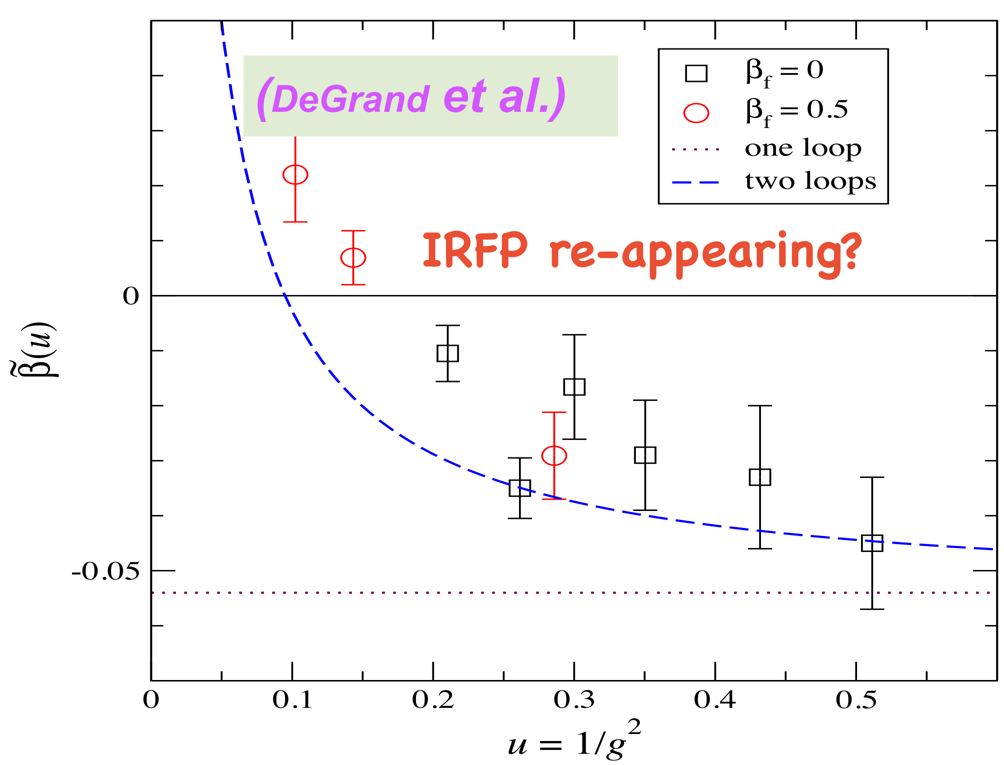
- DeGrand et al. find: Nf=2 sextet beta function might have an IRFP zero?
- model has small anomalous dimension ?

$\gamma(\mu) < 0.45$ controversy, if conformal; if χSB what is $\gamma(\mu)$?





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  γ(μ) < 0.45 controversy, if conformal; if χSB what is γ(μ) ?

- The Nf=2 sextet model with SU(3) color is an interesting candidate for the composite Higgs mechanism

- Viability requires: confirmation, our own running couplings (see Nogradi's talk from Wilson flow and Holland's talk on the F(R) force), the S-parameter, and composite Higgs physics with LHC phenomenology. What will happen on July 4th?