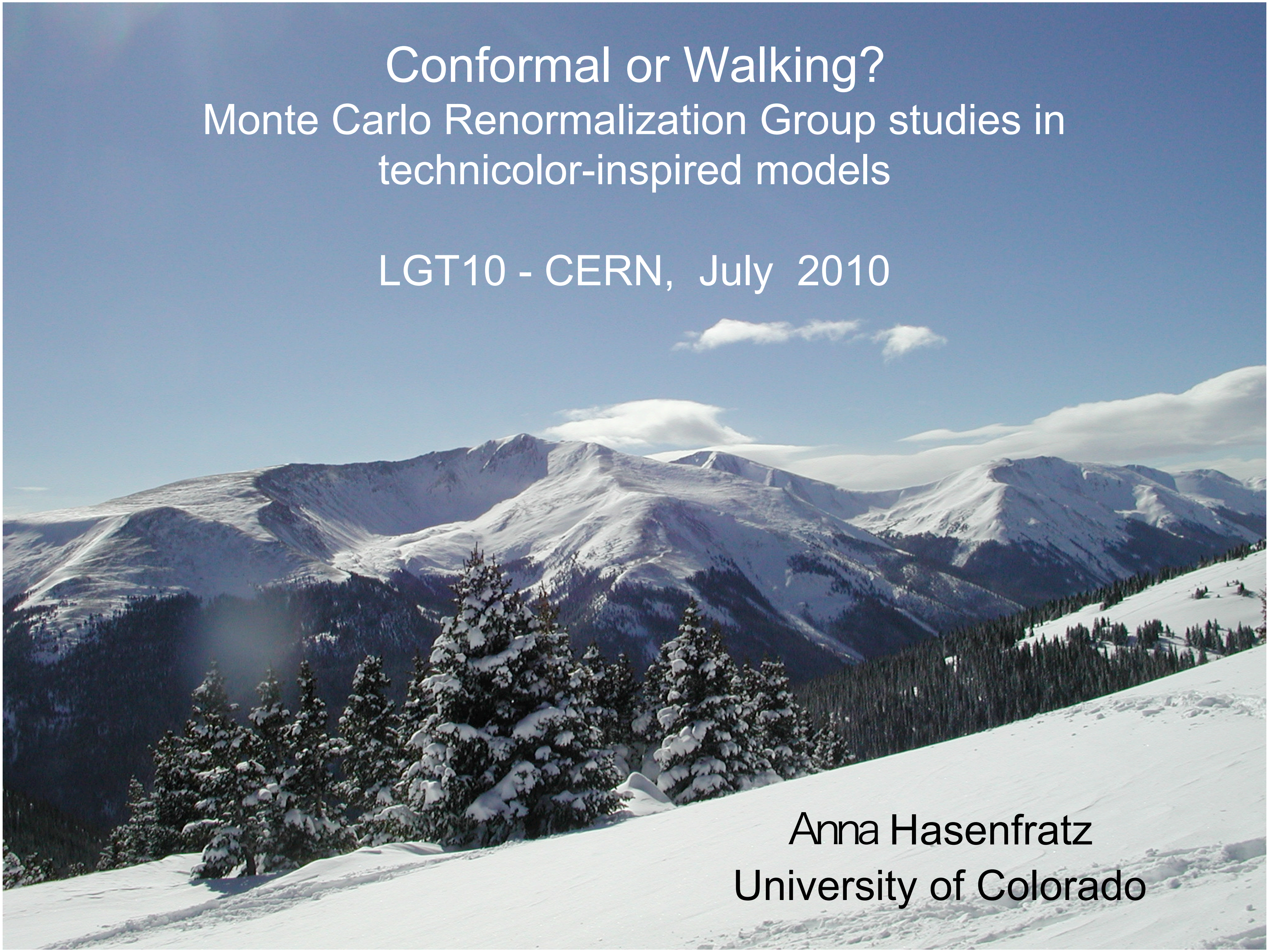


Conformal or Walking?

Monte Carlo Renormalization Group studies in technicolor-inspired models

LGT10 - CERN, July 2010

Anna Hasenfratz
University of Colorado

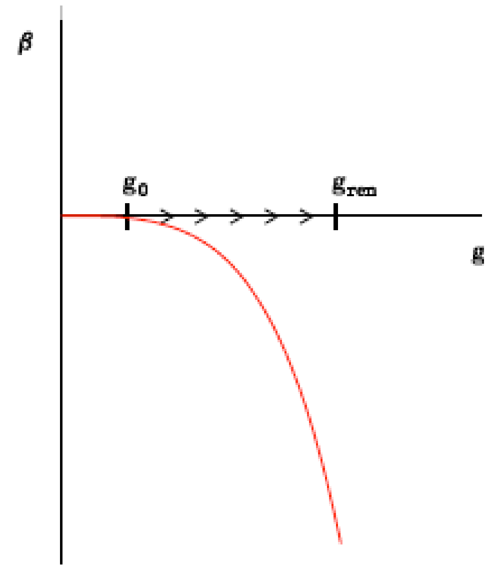
Beyond the Standard Model:
Technicolor-inspired electroweak symmetry breaking

The nature of electroweak symmetry breaking is one of the fundamental issues LHC could reveal. Some of the theoretical models require only a gauge theory with fermions:

Few fermions: QCD like

–Asymptotically free, chirally broken and confining

–Scaled-up QCD Technicolor does not satisfy electroweak precision tests

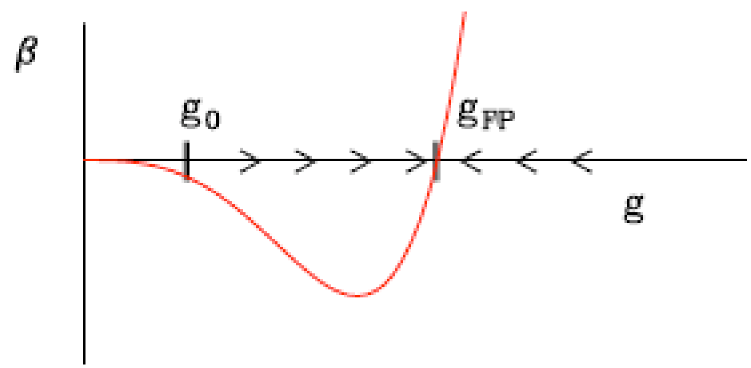


Beyond the Standard Model:
Technicolor-inspired electroweak symmetry breaking

The nature of electroweak symmetry breaking is one of the fundamental issues LHC could reveal. Some of the theoretical models require only a gauge theory with fermions:

More fermions: conformal systems

- –Asymptotically free
- –The gauge coupling develops an infrared fixed point and becomes an irrelevant operator.
- –Unparticles or ?



Beyond the Standard Model:
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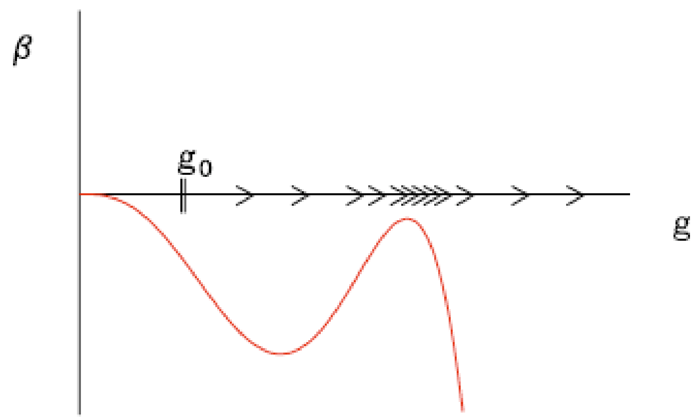
The nature of electroweak symmetry breaking is one of the fundamental issues LHC could reveal. Some of the theoretical models require only a gauge theory with fermions:

Just below the conformal window: walking



–AF, confining, chirally broken

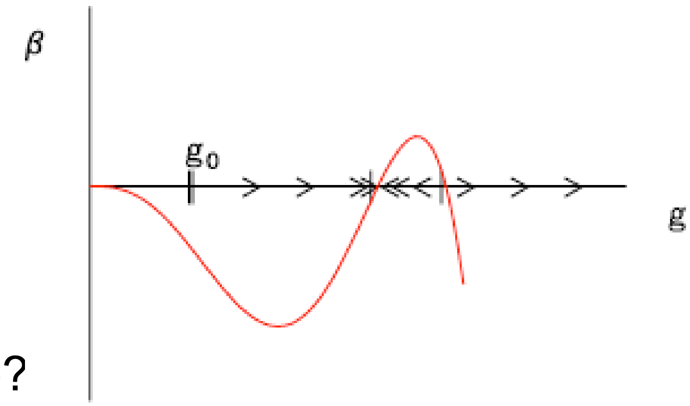
–The gauge coupling is walking

–Best option for technicolor **if** it has a large anomalous mass dimension across a large energy scale

Beyond the Standard Model:
Technicolor-inspired electroweak symmetry breaking

The nature of electroweak symmetry breaking is one of the fundamental issues LHC could reveal. Some of the theoretical models require only a gauge theory with fermions:

Fantasy? or Future?

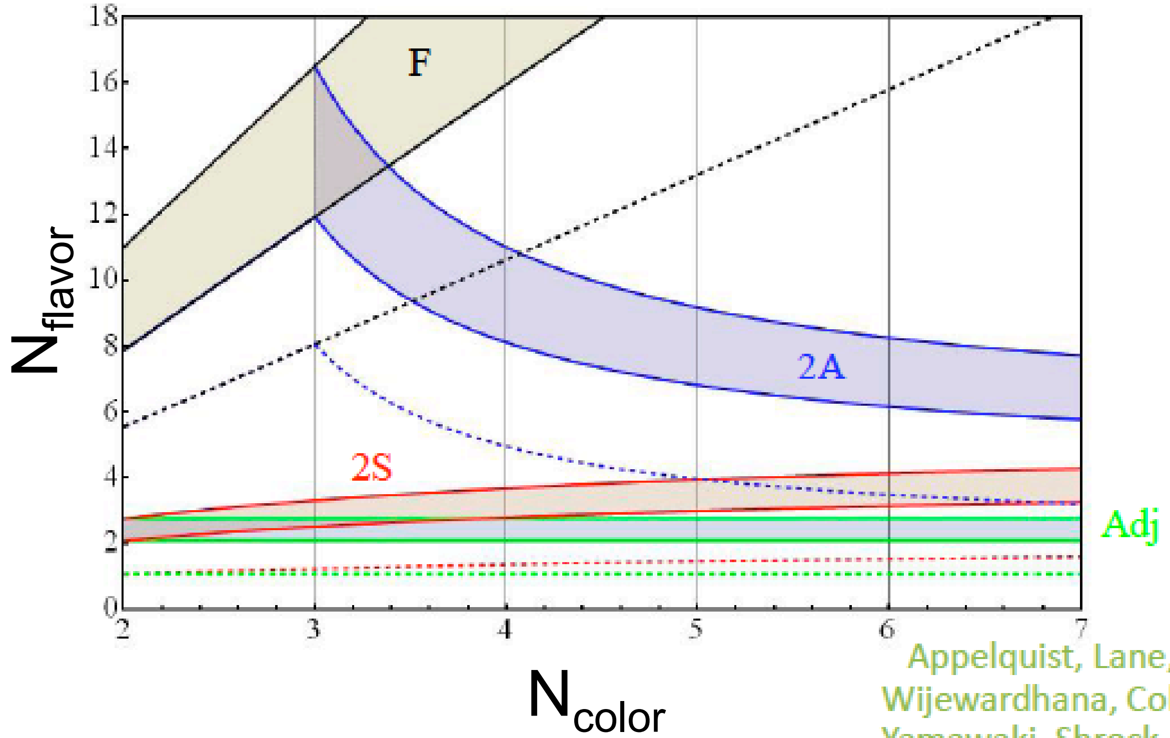


- –AF, conformal at weak coupling
- –Second FP (UV) at strong coupling:
  What kind of IR physics does it describe?
  Which operators are relevant?

(Kaplan et al)

Roadmap for the conformal window

S-D type calculations



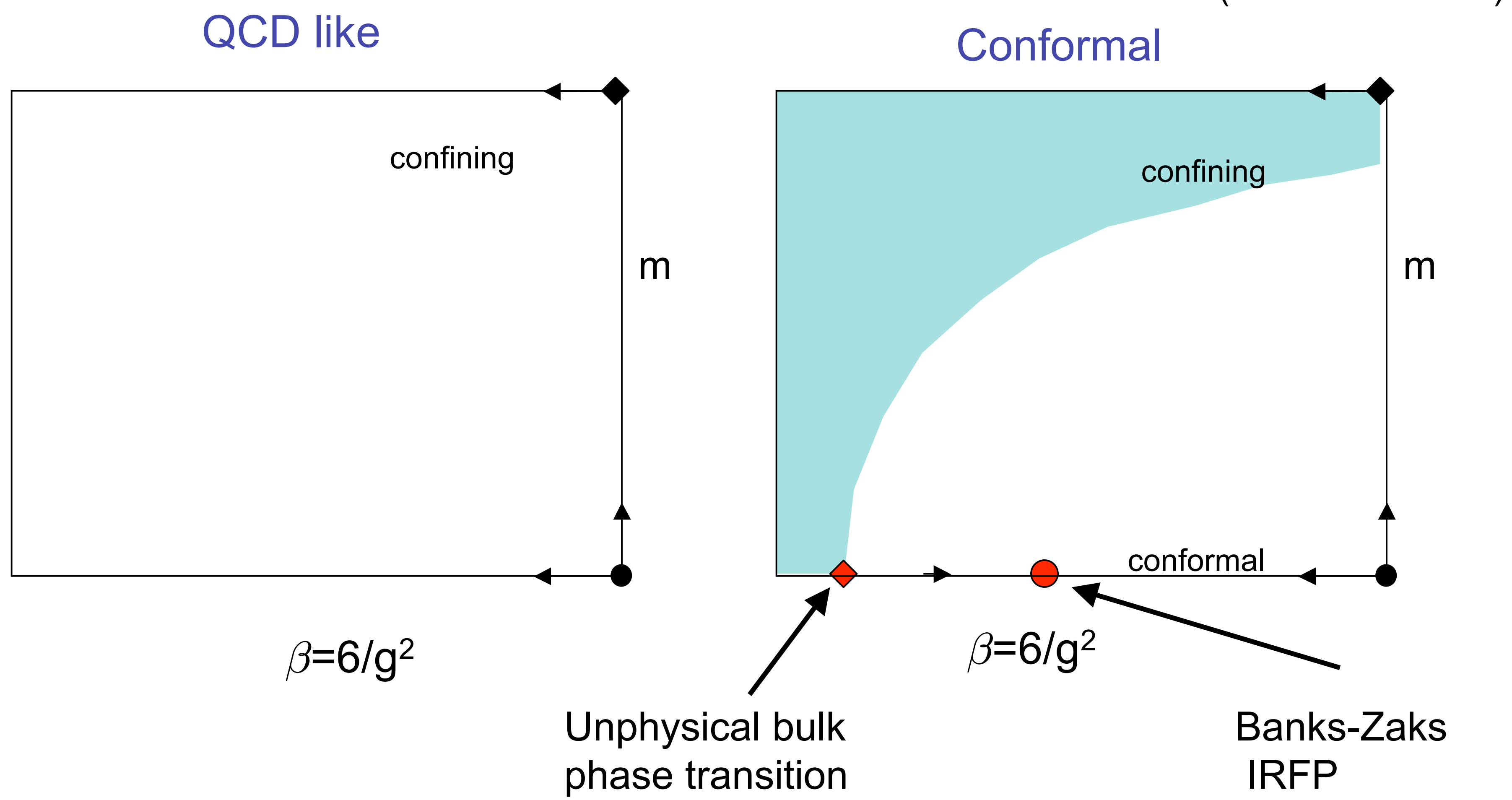
Shaded areas are conformal

Appelquist, Lane, Mahanta, Wijewardhana, Cohen, Georgi, Yamawaki, Shrock, Dietrich, Sannino, Tuominen

Needs non-perturbative verification!

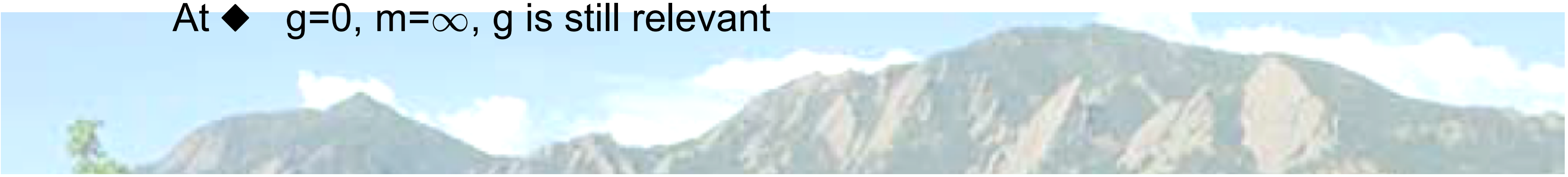
The lattice phase diagram

(arrows: UV to IR)



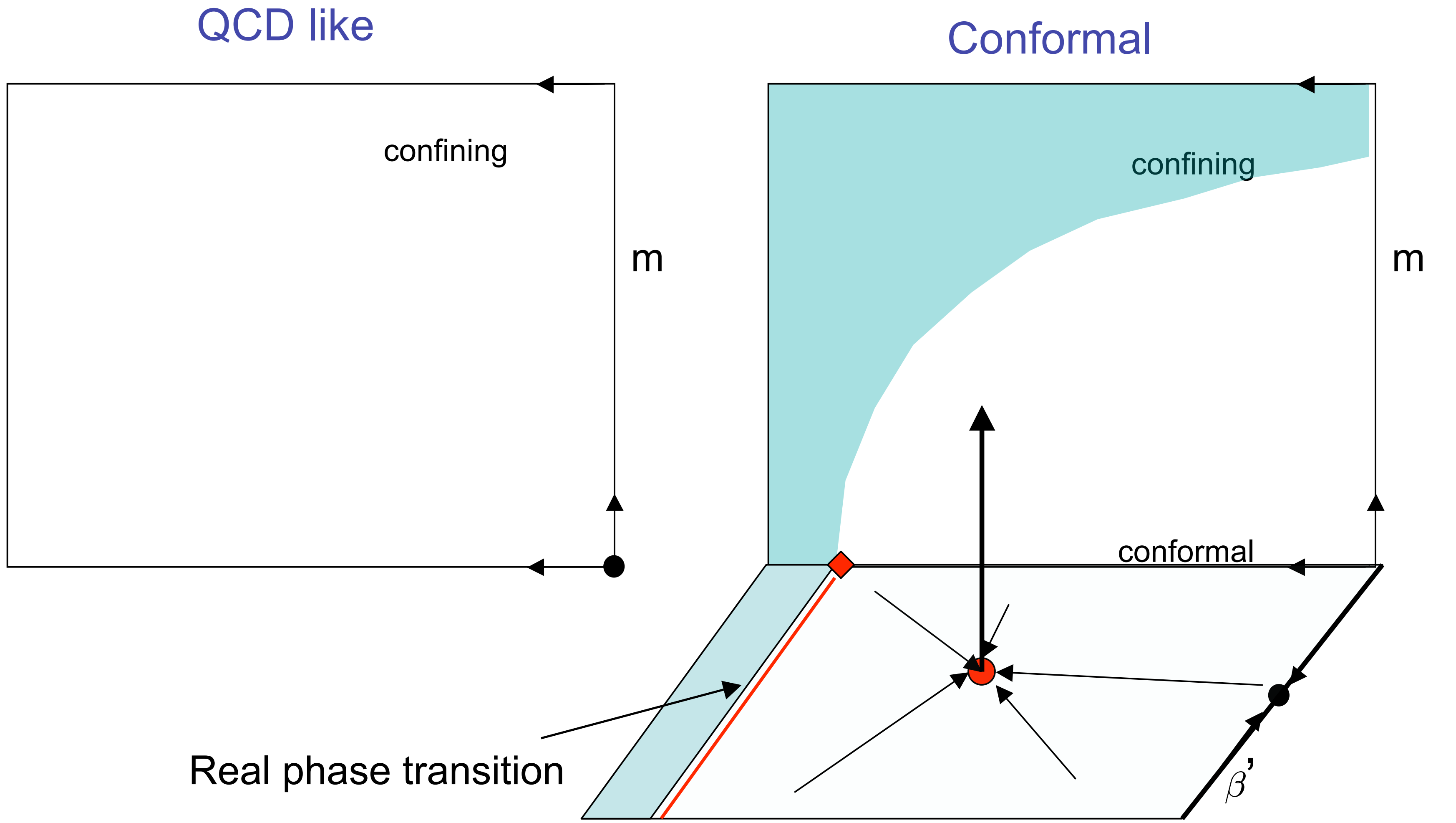
At ● g=0, m=0, both couplings are relevant

At ◆ g=0, m=∞, g is still relevant



The lattice phase diagram

(arrows: UV to IR)

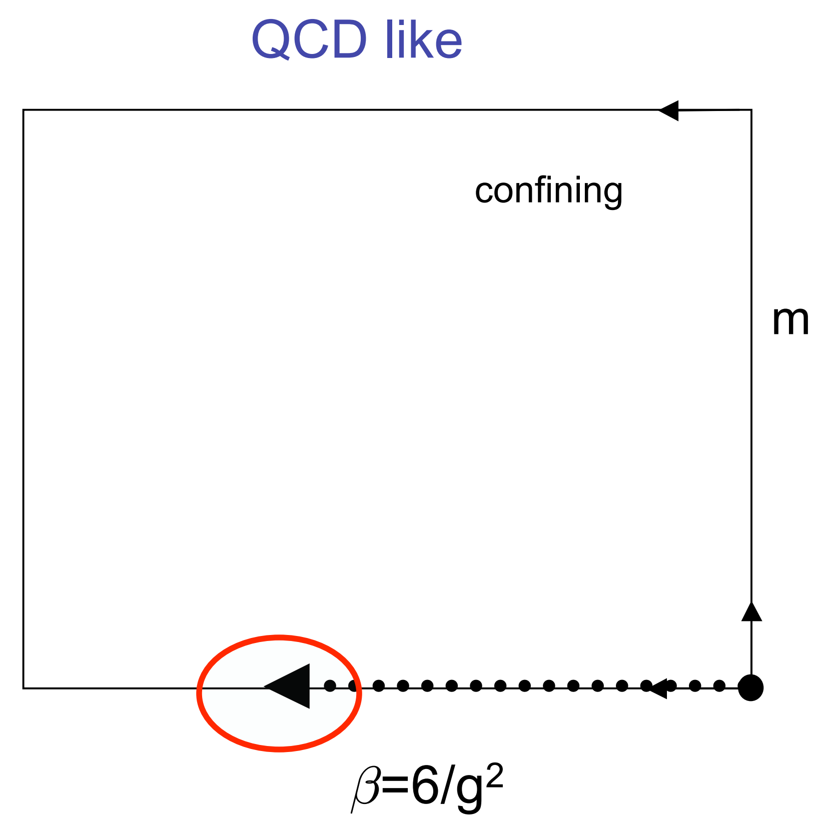


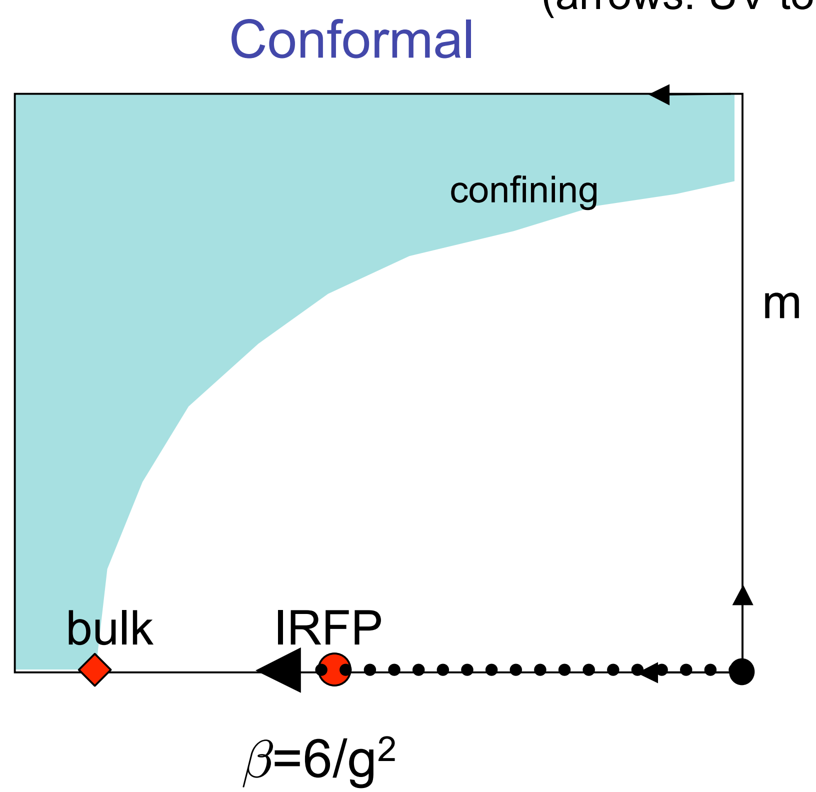
Existence of IRFP is universal;
Its location is RG dependent

At ● IRFP only the mass is relevant

How can we distinguish QCD-like and conformal systems?

(arrows: UV to IR)





Lattice simulations can connect the perturbative FP and strong coupling

- Found IRFP ? Done ✔
- No IRFP? Show that it is confining before a bulk transition is reached

Connecting weak and strong coupling:

the bare differential step scaling function

$$s_b(\beta) = \beta - \beta' \quad \text{where} \quad \xi(\beta) = \xi(\beta')/2 \qquad (\beta = 2N_c/g_0^2)$$

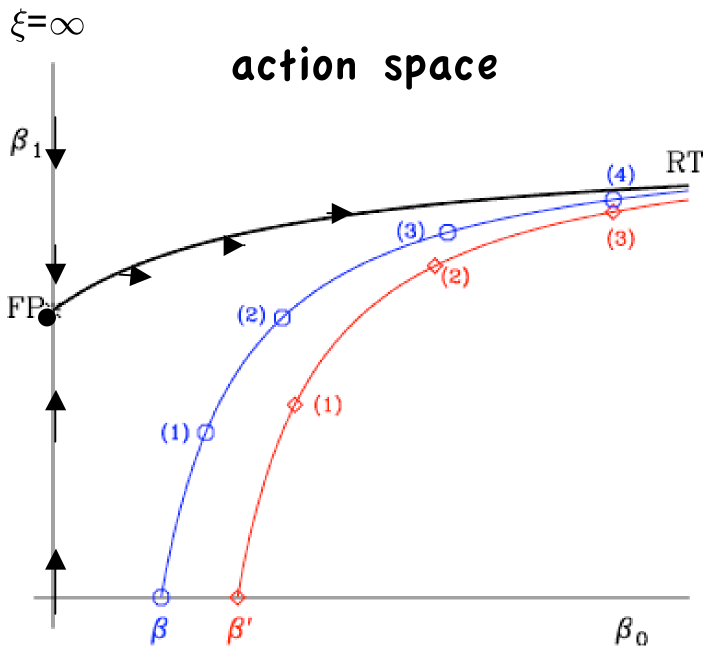
ξ is the correlation length defined by some physical mass.

Sensible definition when ξ is finite

s_b is universal only as far as ξ is

- Can be measured directly or
- Through some running coupling(the Schrodinger functional formalism) or
- **Use RG flow** : $s_b(\beta)$ is the "projection" of the RG flow to a lower dimensional coupling space

Step scaling function around a UVFP

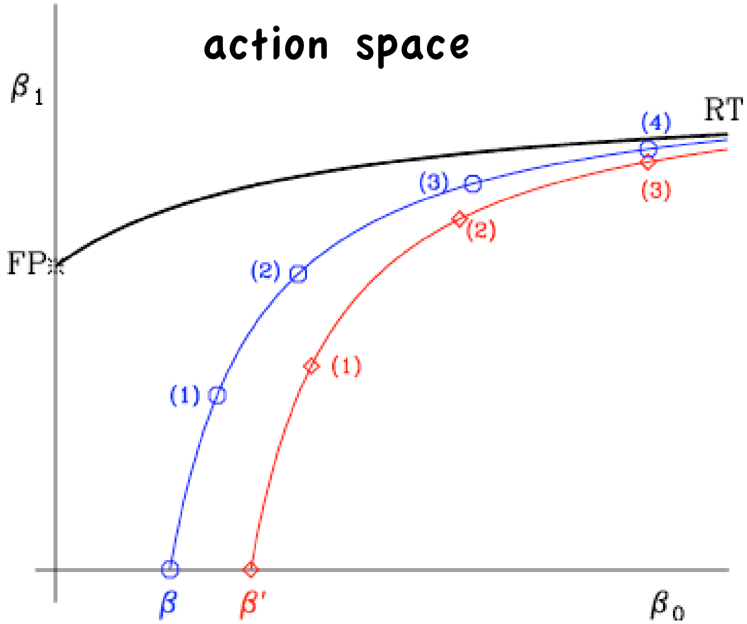


- Do simulations at β and β'(m=0)
- RG block and compare the blocked actions
- if $S(\beta^{(n)}) = S(\beta'^{(n-1)})$ --> $a(\beta)=a(\beta')/2$

  the step scaling function is

$$s_b(\beta) = \lim_{n_b \to \infty} (\beta - \beta')$$

Calculating $s_b(\beta)$ with MCRG



Two actions are identical if all operator expectations values agree

⇓

Match operators (local expectation values) after several blocking steps

- The location of the FP on the critical surface depends on the RG transformation
- Tuning free parameters in the RG transformation can pull the FP and its RT close, reducing systematical errors (optimization)

Along a relevant direction $s_b(\beta)$ is universal (up to lattice artifacts)

The step scaling function in a conformal system

In the chiral limit $\xi = \infty$ everywhere !

$s_b(\beta)$ can be defined through the RG flow

$$s_b(\beta) = \beta - \beta' \quad \text{where} \quad S^{(n)}(\beta) = S^{(n-1)}(\beta')$$

$s_b(\beta)$ can be defined through a running coupling as well

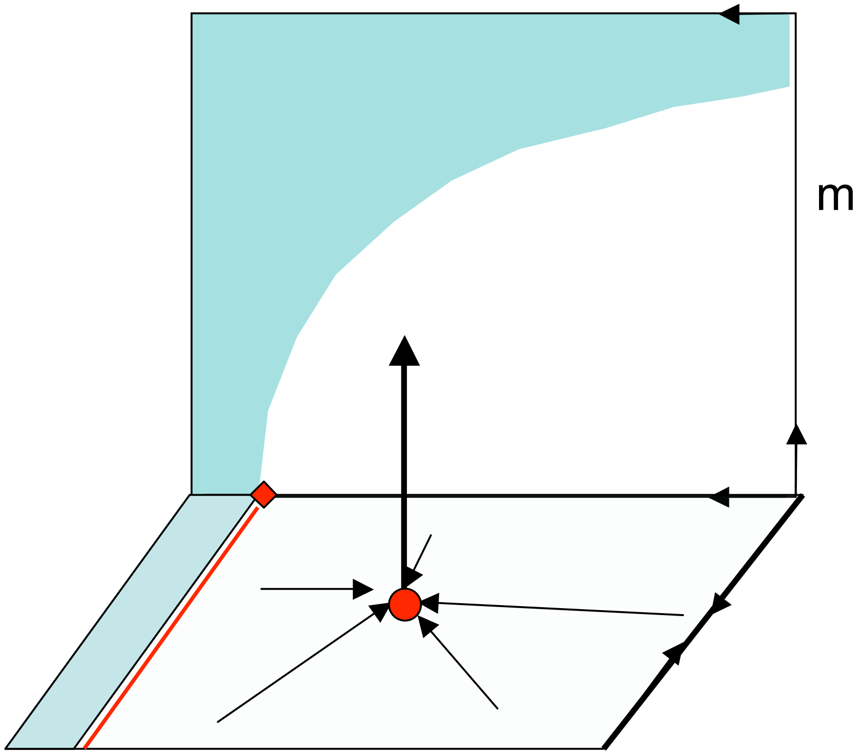
$$g^2(\beta;L) = g^2(\beta';L/2) \qquad (\beta=2N_c/g_0^2)$$

Calculate $g^2(\beta;L)$ using Schrodinger functional or potential or something else

RG flow lines around an IRFP

On the critical surface (m=0) around an IRFP the flows converge to the FP when $n_b \to \infty$

With finite n_b the flow picks up the slowest flowing operator



The location of the IRFP depends on the RG transformation

$s_b(\beta)$ along an irrelevant direction depends on the blocking (scheme dependence)

This could be a signal for non-QCD-like behavior

Matching of 2 relevant operators

- Matching around a FP with 2 relevant operators require tuning of 2 parameters (β and m)

OR

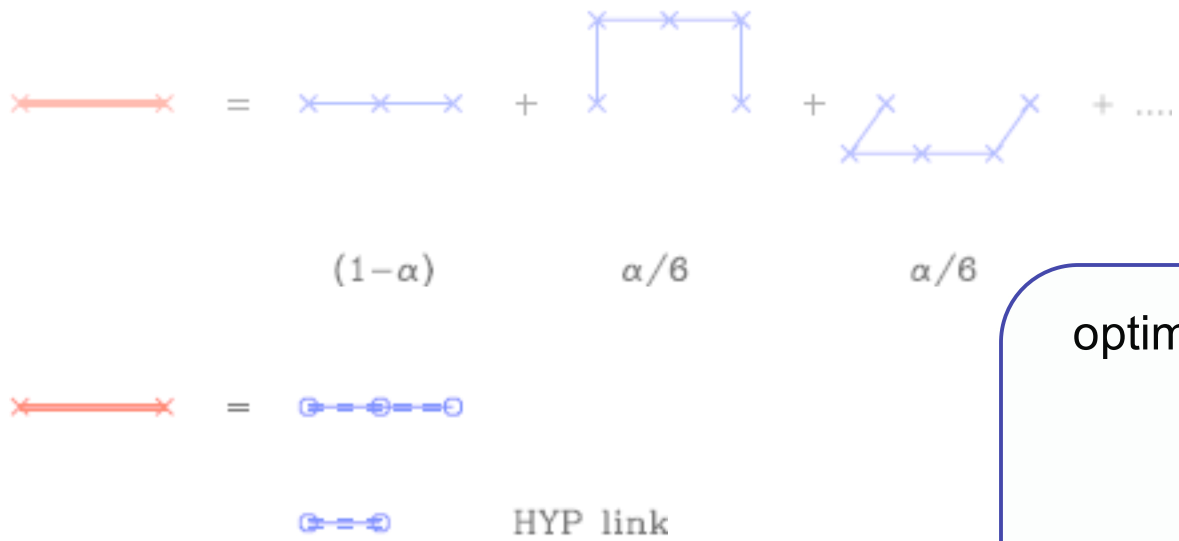
- Set one operator to its critical value (m=0) and tune only in the other one (β) $\rightarrow s_b$
- Next fix s_b and tune m $\rightarrow \gamma_m$

The 3 Renormalization Group transformations

A real space block transformation averages out the UV modes leading to the renormalized trajectory that describes perfect actions

Original

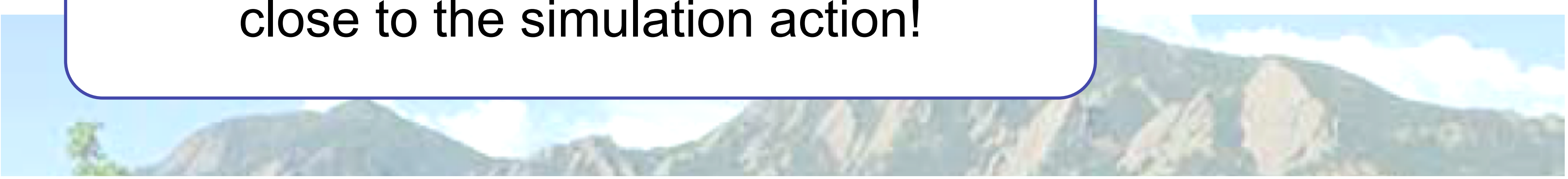
HYP



optimize with α

optimize with α_1
(play with α_2, α_3)

Optimization is essential to pull the FP/RT close to the simulation action!



Summary: 2- lattice matching MCRG

- Works with bare couplings - sufficient to study the phase diagram
- Can be optimized by tuning the free parameter(s) of the RG transformation
- Finite volume effects are largely controlled
- Requires relatively small statistics
- Has a lot of built-in consistency checks
  - compare several blocking levels
  - compare several operators
  - compare different RG transformations

Some results:

- SU(3) pure gauge (test)
- SU(3) gauge + N_f=8,16 and 12 fundamental flavors

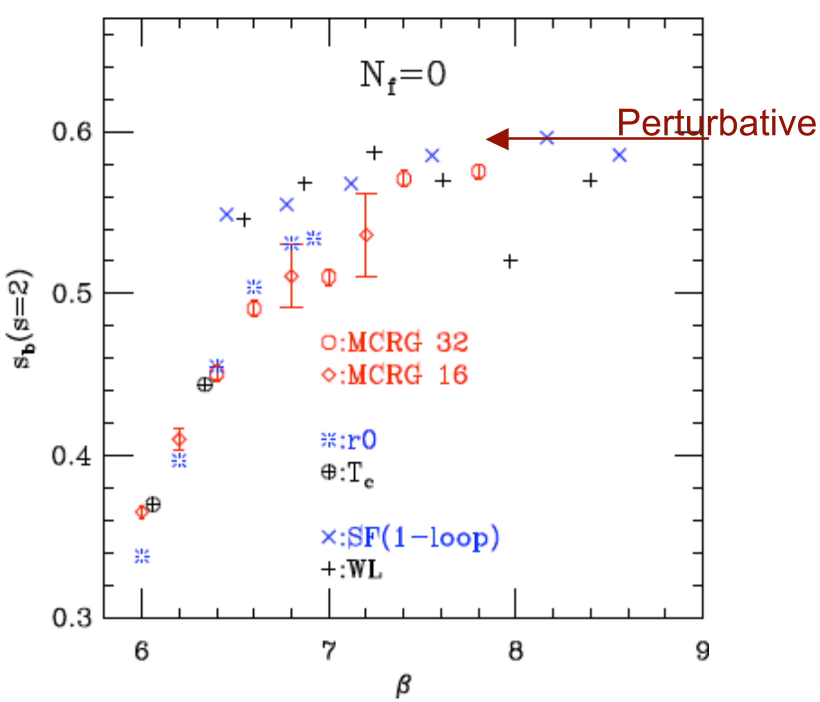
All with nHYP smeared staggered fermions (no rooting!)
Wilson plaquette gauge action

Warning: $s_b>0$ when $\beta(g)<0$!

SU(3) pure gauge : test case

The bare step scaling function can be calculated in many ways

- physical observables r_0, T_c
- Schrodinger fn; Wilson loop ratios,
- RG matching: $32^4 \to 16^4$ and $16^4 \to 8^4$

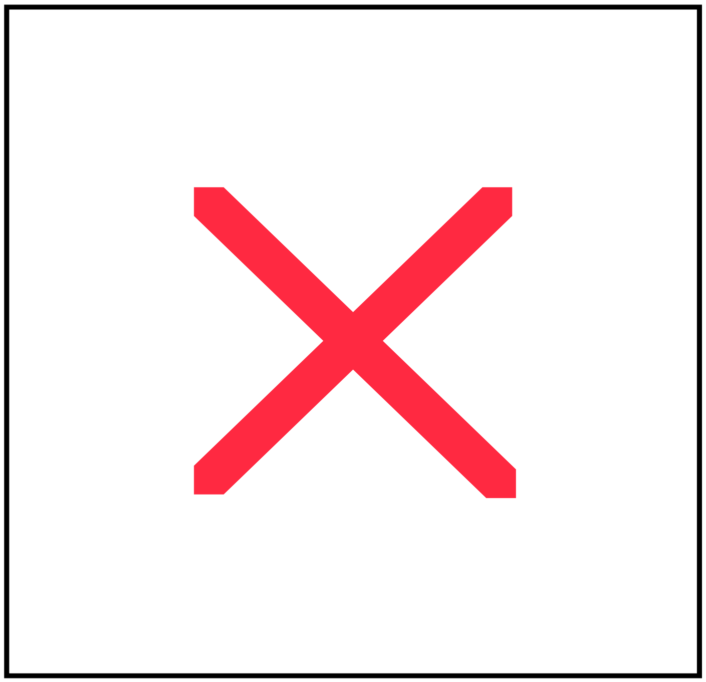


- Good agreement between r_0, T_c and MCRG
- $32^4 \to 16^4$ and $16^4 \to 8^4$ are consistent with ~0.02 accuracy
- Both SF and MCRG approach the perturbative value
- Since at β=6 we can test confinement, we know there is no physical IRFP

Compare different RG transformations:

When the flow is governed by a UVFP, $s_b(\beta)$ is universal (up to lattice corrections).

Compare 3 different RG transformations:

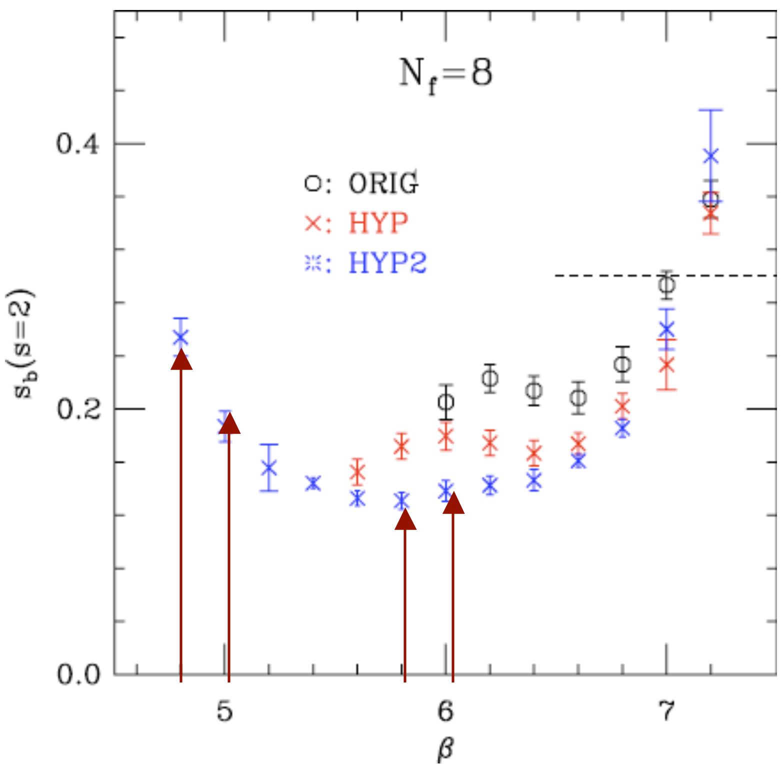


Excellent agreement between the 3 RG blockings
→ attractive region of a UVFP

N_f=8 flavors

Expected to be QCD-like: analytical & numerical results

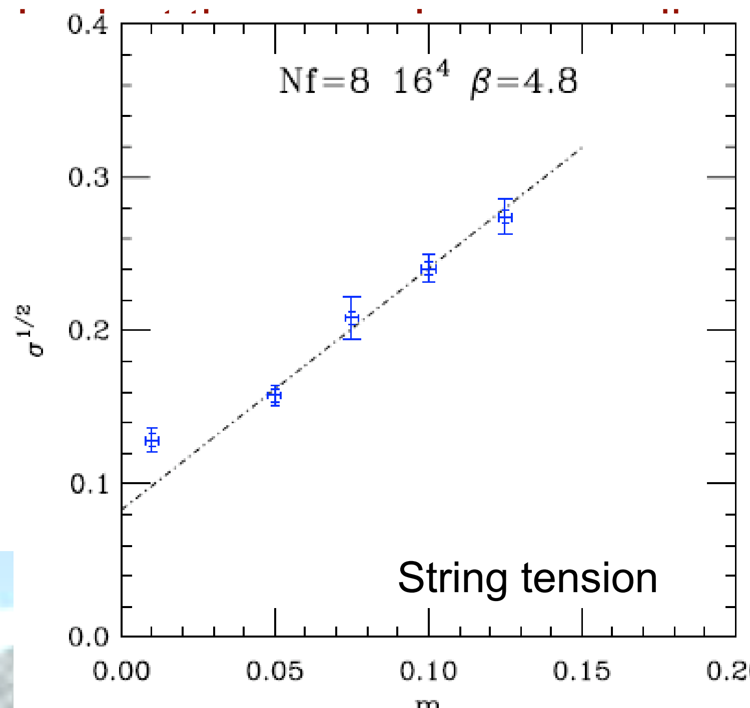
Compare the different RG transformations (m≈0)

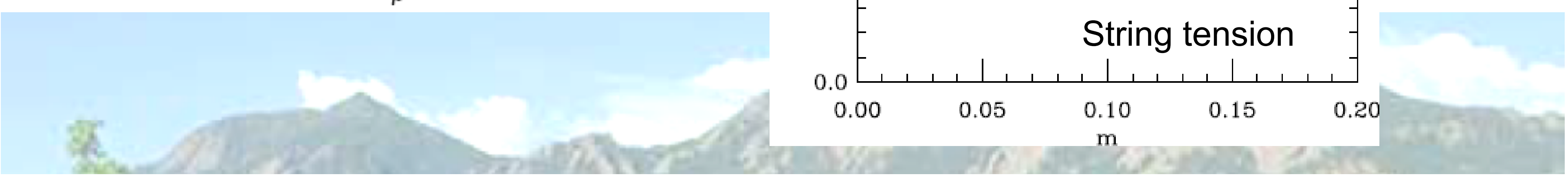


s_b>0 everywhere - no IRFP

Is it confining?

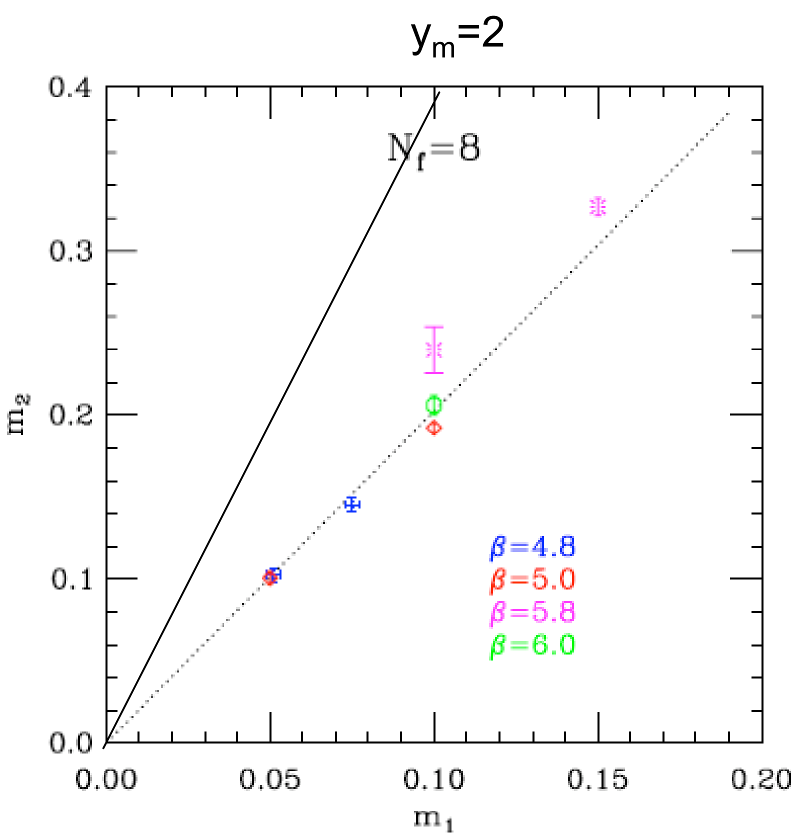
nsion





N_f=8 flavors, anomalous mass

4 different couplings (β=4.8,5.0,5.8,6.0), optimal RG from m=0 data



$m_2 = m_1\, 2^{-1/y_m}$

$\gamma_m = y_m - 1$

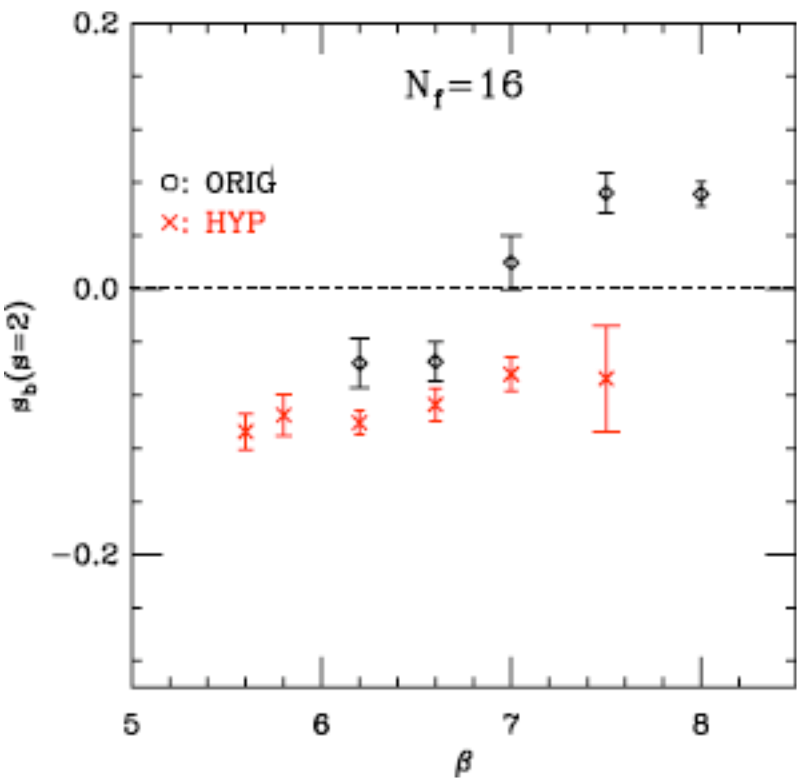
All 4 β values predict similar value

$\gamma_m = 0.02(5)$

close to free field exponent

N_f=16 flavors

$16^4 \to 8^4$ MCRG



ORIG blocking shows $s_b(\beta)$=0 around β=7.0

HYP blocking has an IRFP around β=10.0

Different block transformations predict different $s_b(\beta)$=0 but they both show a positive RG β function

N_f=12 flavors

Some history:

- The analytic works predicts N_f=12 is just above the conformal window
- Yale group found an IRFP at fairly strong coupling, using Schrodinger functional method, unimproved action
- Groningen/INF group identified a bulk phase transition characteristic to a conformal system and claim chiral symmetry at weaker coupling
- Two groups (San Diego and Columbia) have studied the spectrum of the model with improved and unimproved actions. Both see QCD-like behavior, though at stronger gauge couplings.

If N_f=12 is conformal,

Could the spectral measurements be in the strong coupling phase?

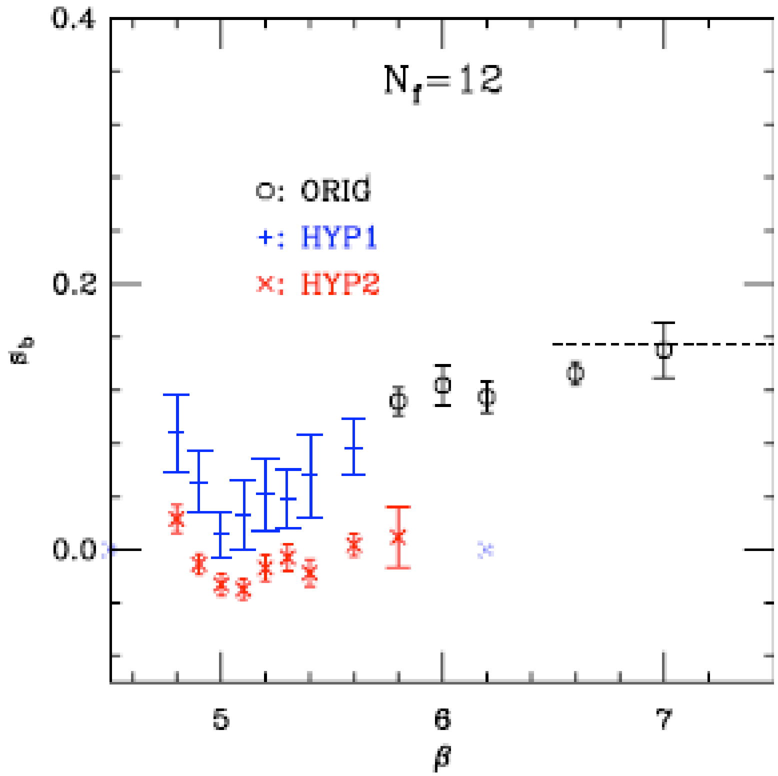
If N_f=12 is QCD-like,

The unimproved actions used with Schrodinger functional could be unreliable

We expect a universal result from all actions. The existence of the conformal phase near g=0 is universal, even if the locations of the phase transitions, fixed points are not.

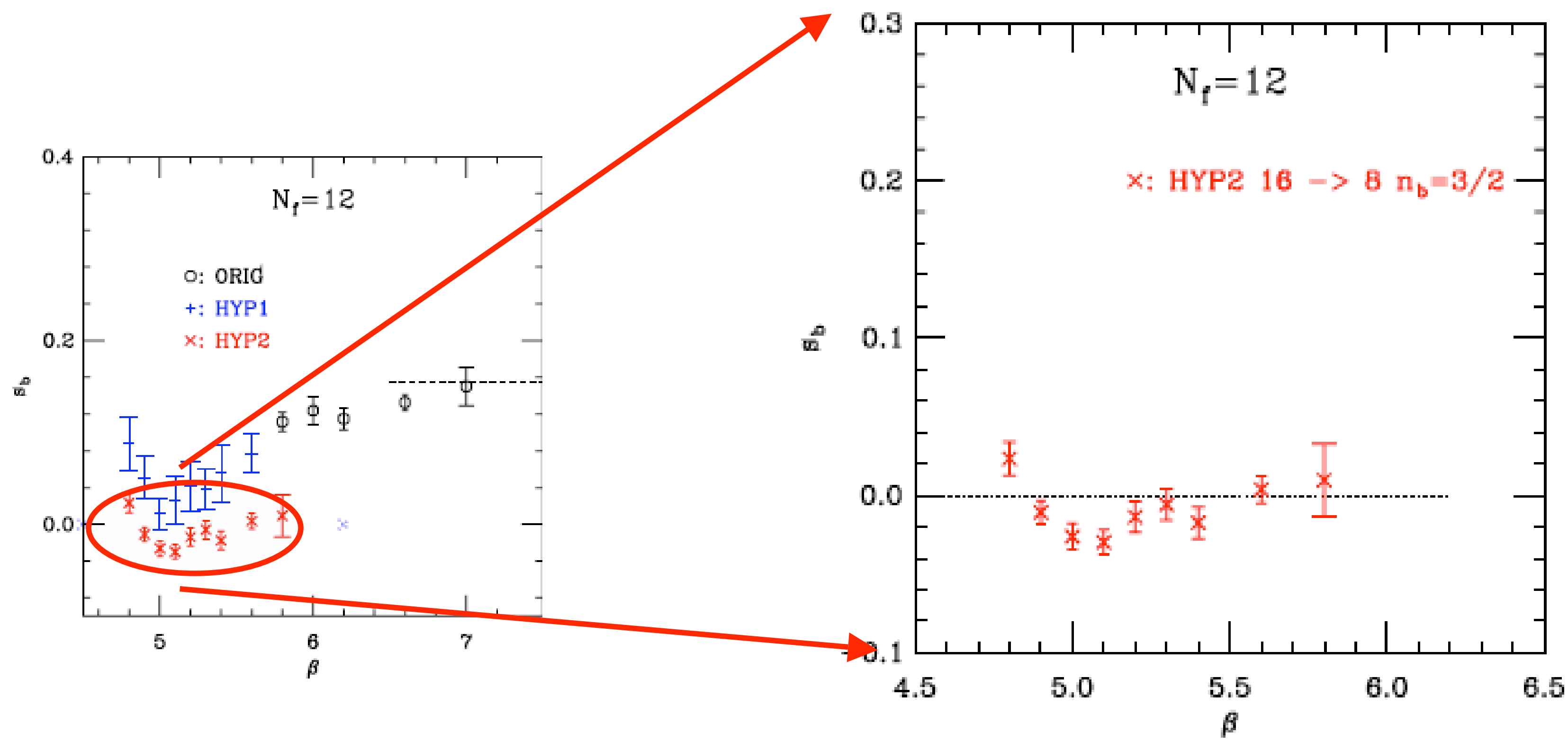
N_f=12 flavors with MCRG

Use the same techniques as before; $16^4 \to 8^4$, m=0.0025 or 0.01



- Orig/HYP blockings predicts different $s_b(\beta)$ functions
- HYP2 hovers around 0 -- likely IRFP
- String tension vanishes at β=4.4 on 16^4 volumes, but lattice artifacts are large and the volume is small

Look at closer



- There is no phase transition at the second zero
- 32^4 ->16^4 matching shows large
  - finite volume
  - finite n_b effects

Summary: N_f=12 flavors

- It is a difficult system

Conclusion

MCRG is an effective alternative method to study the phase structure and scaling properties of lattice QFT's

- The method is very universal, straightforward to implement for any other system
- Can be used to predict anomalous mass dimensions as well

N_f=0-8,16 as expected. N_f=12 is difficult

What is next?

- Could the different groups come up with a consistent picture for N_f=12?
- SU(2) gauge, other fermion representations can be studied the same way

- Maybe it is time to go beyond fermion-gauge systems