Lattice Gauge Theory and the Large Hadron Collider

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Why are W, Z, $\ldots$ massive?

Coulomb interaction: $$V \propto \frac{1}{r}$$

comes from exchange of massless photons

Weak interactions: $$V \propto \frac{e^{-Mr}}{r}$$

where $M_W, M_Z \approx 100$ GeV (roughly 100 $\times$ proton mass).

Goal of LHC: find, if we can, what gives mass to W, Z, quarks and leptons.

Superconductivity

Inside a superconductor, magnetic field decays exponentially.

The superconducting state is made of electron pairs.

Collective back-reaction is so strong that photons become massive inside the superconducting medium.

Technicolor:

Masses of W, Z from a relativistic counterpart of superconductivity.

QCD vacuum as a superconductor

Chirality:

When moving almost at speed of light, quark's spin is parallel (u_L, d_L) or anti-parallel (u_R, d_R) to direction of motion.

QCD vacuum is filled with chiral condensate:

$$\langle \overline{\psi}\psi \rangle = \langle \overline{u}_L u_R + \overline{d}_L d_R + \overline{u}_R u_L + \overline{d}_R d_L \rangle$$

W, Z emitted/absorbed by u_L, d_L (and by their anti-particles), but not by u_R, d_R.

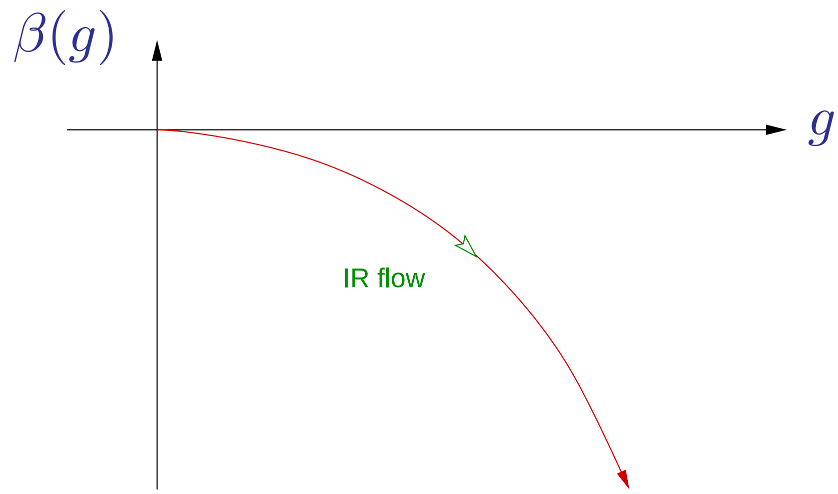
$\Rightarrow$ QCD vacuum acts as superconducting medium on W, Z.

Running couplings

When two (relativistic) electrons collide, their electric charge appears to grow very slowly with energy.

beta function: $$\beta(g) \equiv \mu \frac{\partial g}{\partial \mu} = -r \frac{\partial g}{\partial r}$$

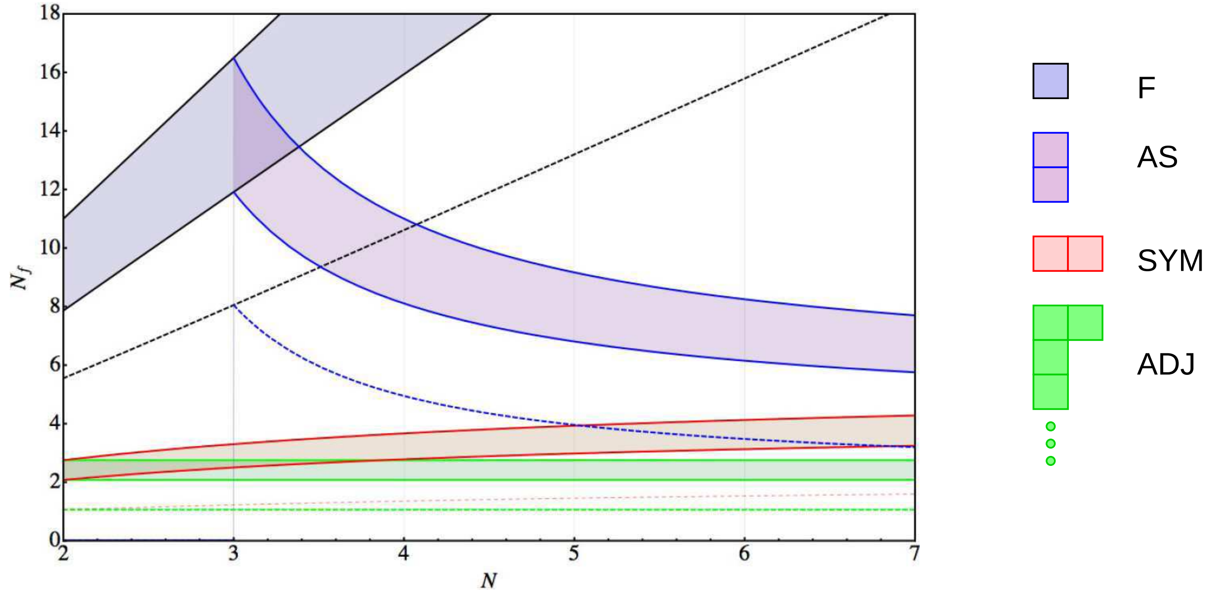
QCD – asymptotic freedom:



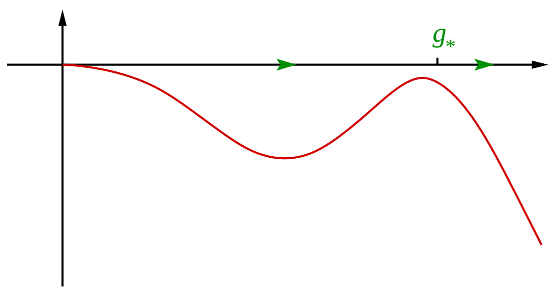
Technicolor

- If they were not massive already, QCD would give W, Z as mass.
- In reality, $M_{W,Z} \gg \Lambda_{QCD}$
- Technicolor: hypothetical QCD-like sector, with $\Lambda_{TC} \sim 1000\Lambda_{QCD}$ to give appropriate masses to W, Z.
- Can we also generate quark and lepton masses? (difficult: vast range of masses.)
- Heavier quark masses need larger $\langle\overline{\psi}\psi\rangle_{TC}$ without changing $M_{W,Z}$.
- This can happen if TC interaction gets weaker very slowly at energy scales above $\Lambda_{TC} \Rightarrow$ "Walking technicolor".

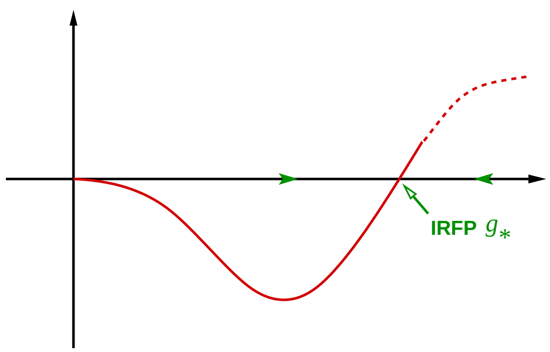
Varying $N_c, \; N_f$



Dietrich & Sannino
PRD 2007

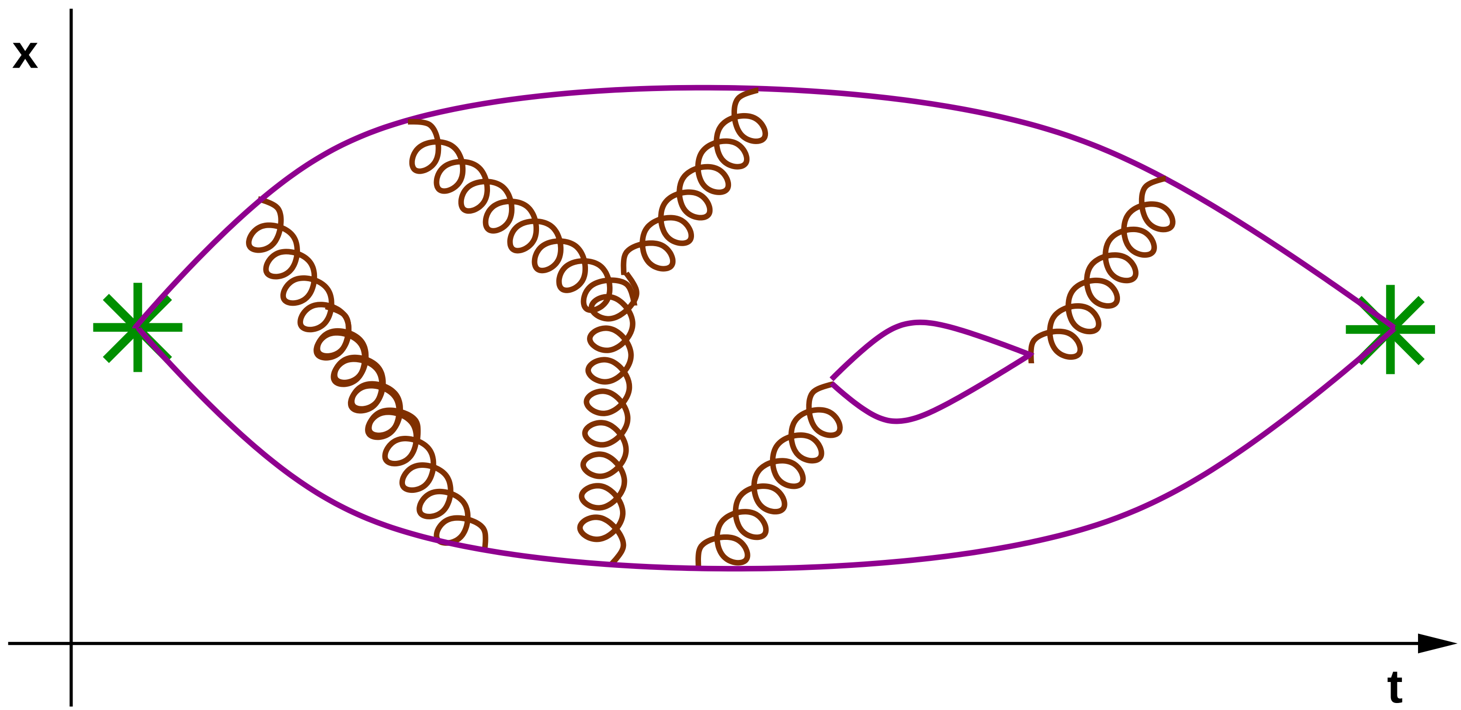


Walking technicolor



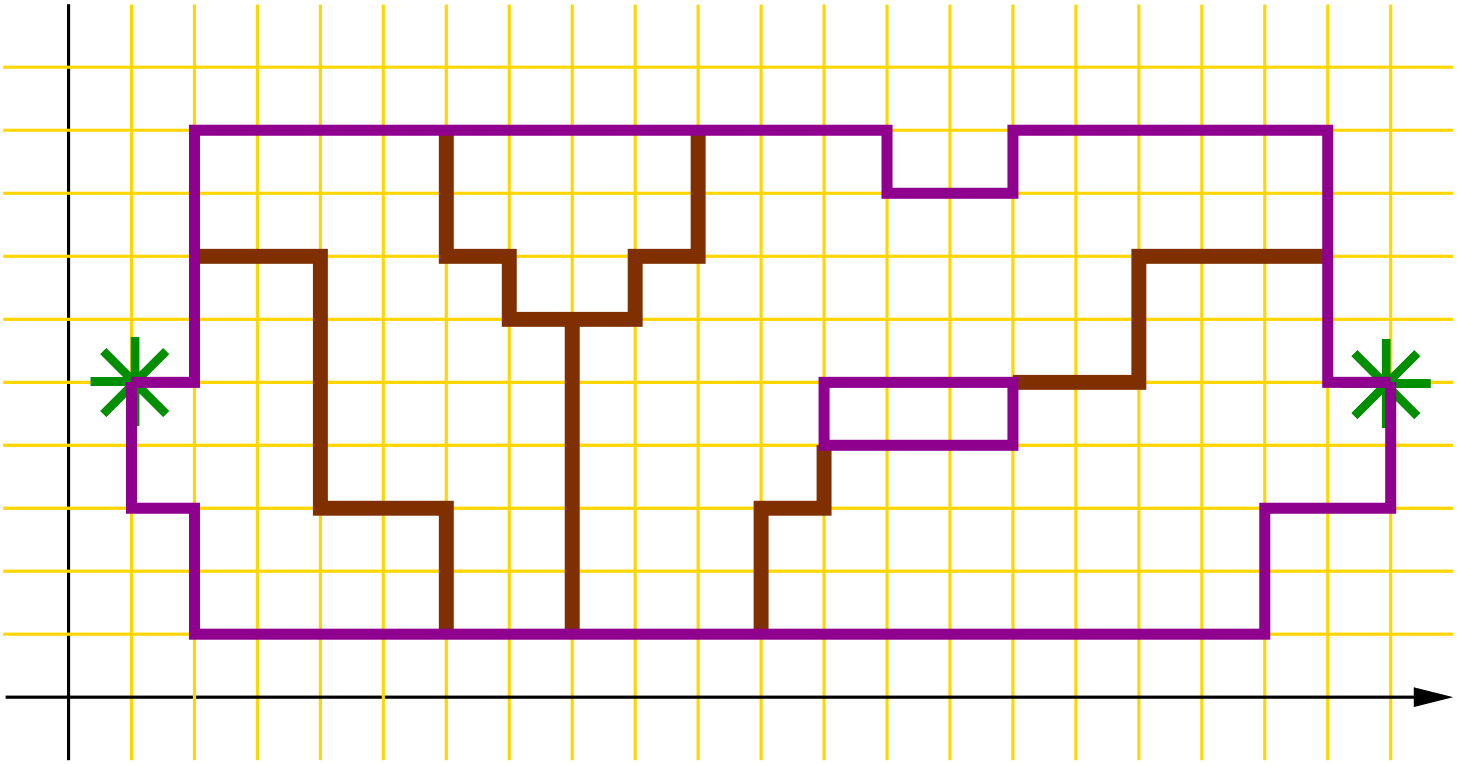
Infra-red fixed point

Lattice gauge theory



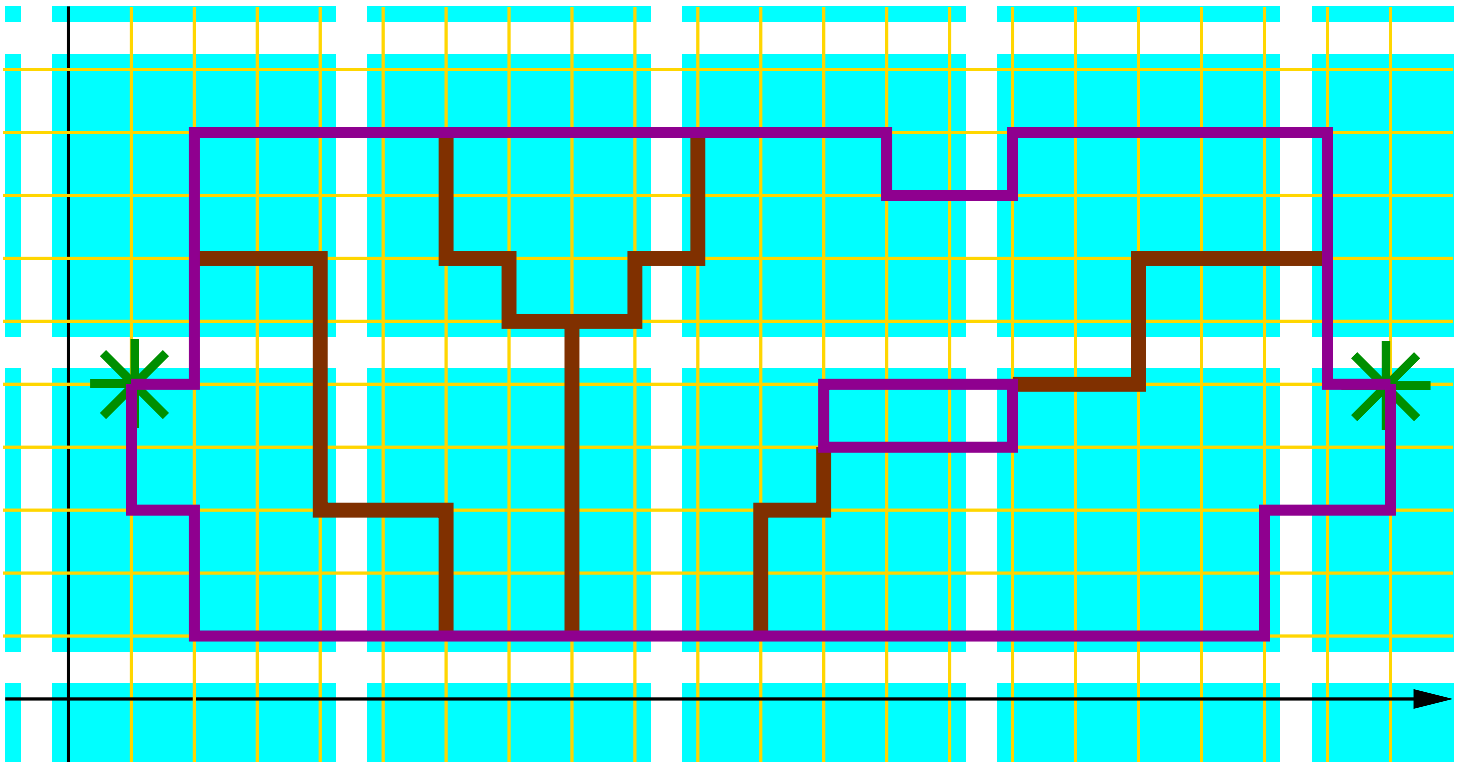
propagation of meson (quark-antiquark pair)

Lattice gauge theory



Discretize space-time into a lattice

Lattice gauge theory



Parallel-processing numerical (Monte Carlo) simulations

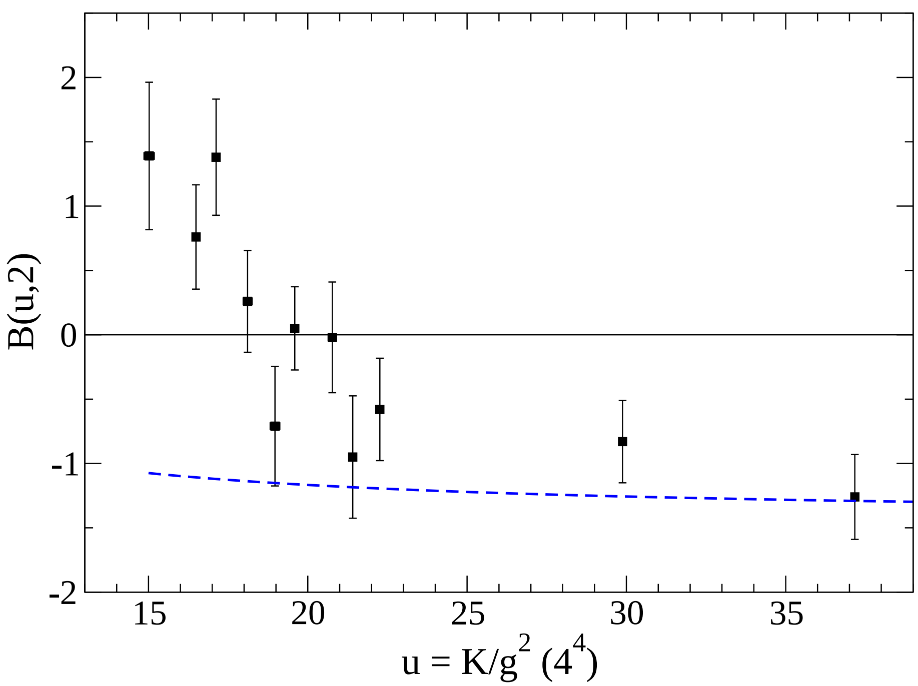
Discrete beta function I

What we do:

SU(3) with two fermions in the sextet (two-index symmetric) representation.

bare parameters: β (coupling constant), κ (mass)

Tune to massless quarks $\kappa_c(\beta)$, measure renormalized coupling



$$B = \frac{K}{g^2(2L)} - \frac{K}{g^2(L)}$$

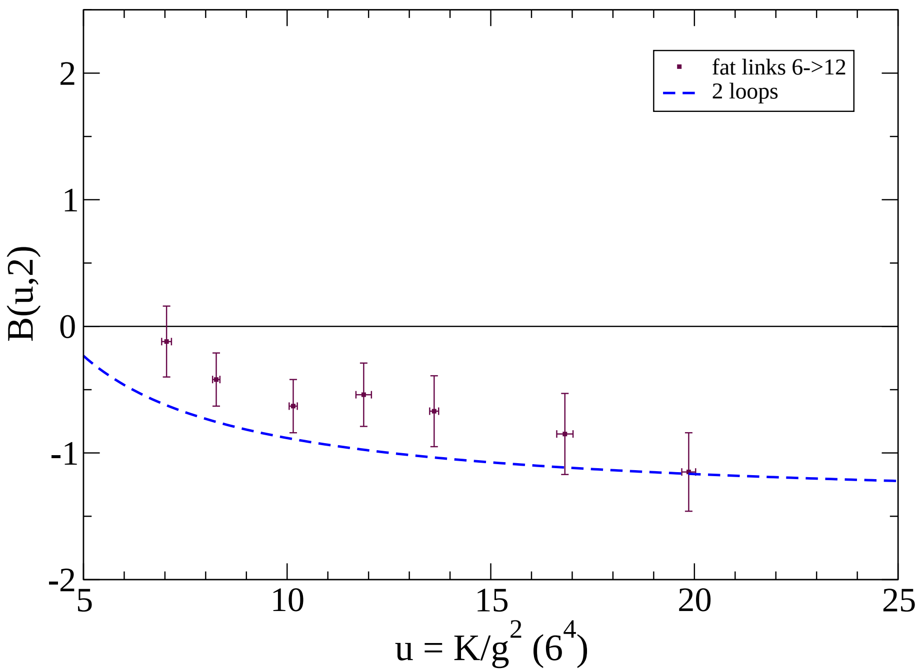
where $L = 4 \times$ lattice spacing

$K = 37.7..$

IRFP at $g^2 \approx 2$!

Discrete beta function II

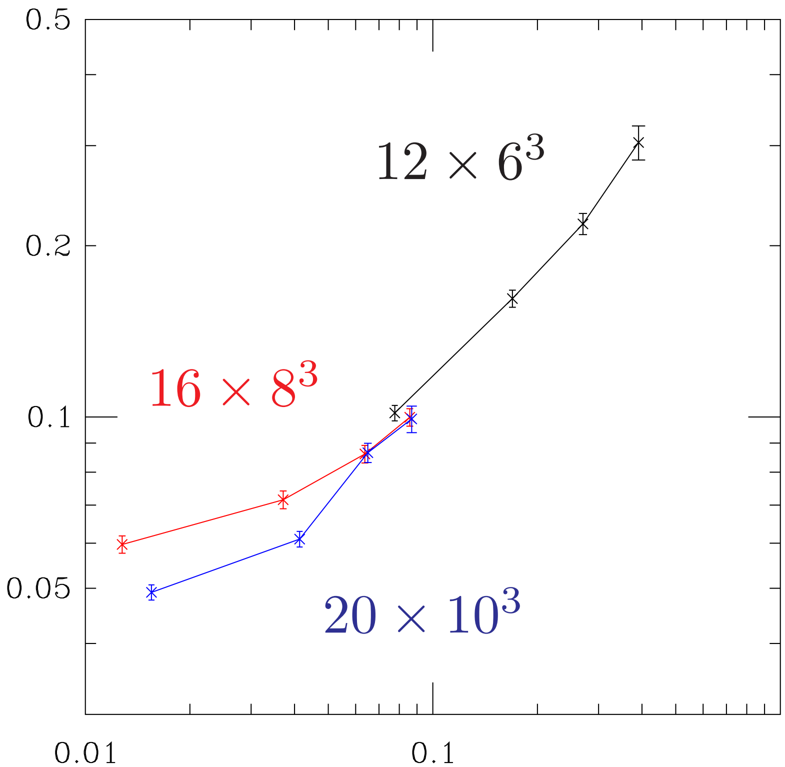
Bigger lattice $(6^4 \rightarrow 12^4)$, better lattice action



- Walking? conformal?
- Can't go to smaller β (massless quarks: $\beta > \beta_c$ only)
- required $\sim 500,000$ core-hours on Teragrid
- next year: $8^4 \rightarrow 16^4$

Finite size scaling

Condensate vs. quark mass on a loglog plot



- linear behavior

⇒ critical exponent

- Need large(r) volumes to probe critical point

Future

- Phase diagram
- Spectrum
- Scaling study of Discrete Beta Function
- Finite size scaling and critical exponents