Strong Dynamics on the Lattice

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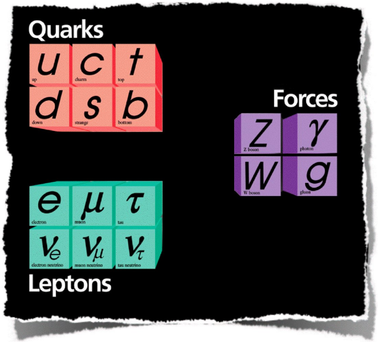
Edinburgh University

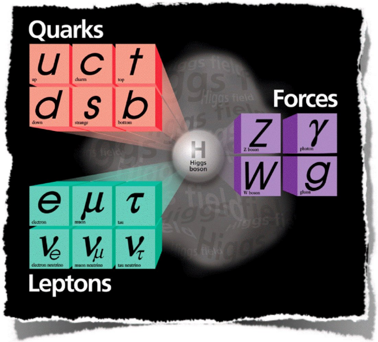
[0910.4535] - Francis Bursa, Luigi Del Debbio, Claudio Pica, Thomas Pickup

The Standard Model



- Standard Model is well verified experimentally
- Electroweak Symmetry breaking included (i.e. mass of Z/W bosons)
- But EWSB mechanism remains a mystery

The Higgs Mechanism



- Higgs mechanism will be tested at the LHC, but
  - Ad hoc: all fermion masses and mixings arbitrary parameters
  - Trivial: without new physics, higgs decouples
  - Unnatural: quadratically sensitive to Planck scale, so requires fine tuning
- So thought to be an effective description of a more fundamental theory, e.g. SUSY, Technicolor, ...

Technicolor

- SM without Higgs already has some EW symmetry breaking.
- Quark condensate gives M_W of the order of the pion decay constant:

$$\langle \overline{u}_L u_R + \overline{d}_L d_R \rangle \neq 0 \rightarrow M_W = \frac{gF_\pi}{2} \sim 30 MeV$$

- So why not have some more "techni-quarks" that form a condensate at a higher scale ($F_\pi^{TC} \sim 250 GeV \sim \Lambda_{TC}$)

Extended Technicolor

Quark Masses

$$\frac{\langle\overline{\Psi}\Psi\rangle_{ETC}\overline{\psi}\psi}{\Lambda_{ETC}^2}$$

FCNC

$$\frac{\overline{\psi}\psi\overline{\psi}\psi}{\Lambda_{ETC}^2}$$

- But naively scaling up QCD leads to a problem:
- Need large Λ_{ETC} to suppress Flavour Changing Neutral Currents
- Need small Λ_{ETC} to get physical quark masses

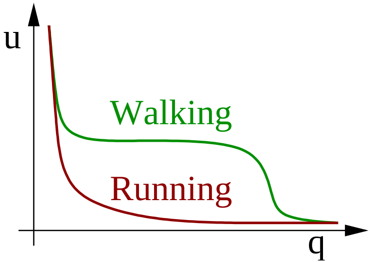
Walking Technicolor

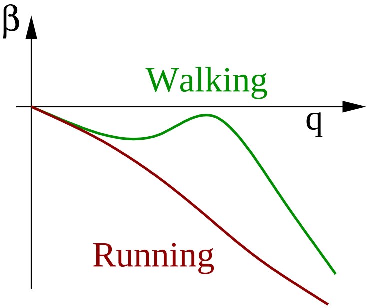
- If dynamics are not like QCD, $\langle\overline{\Psi}\Psi\rangle_{ETC}$ can be large:

$$\langle\overline{\Psi}\Psi\rangle_{ETC} = \langle\overline{\Psi}\Psi\rangle_{TC} exp\left(\int_{\Lambda_{TC}}^{\Lambda_{ETC}} \gamma(\mu) d\ln\mu\right)$$

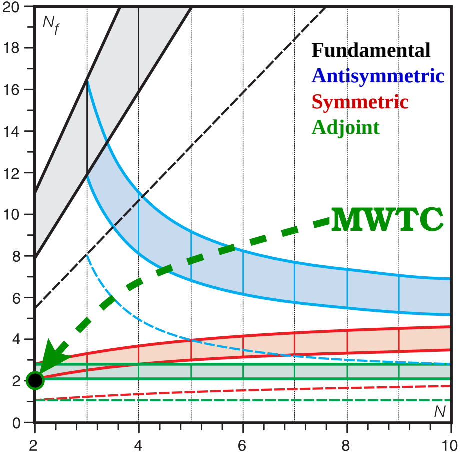
- If $\gamma(\mu)$ is large (~ 1) and approximately constant, i.e. walking coupling, then get large power enhancement
- $\langle\overline{\Psi}\Psi\rangle_{ETC} = \langle\overline{\Psi}\Psi\rangle_{TC}\left(\frac{\Lambda_{ETC}}{\Lambda_{TC}}\right)^{\gamma}$

Walking Technicolor



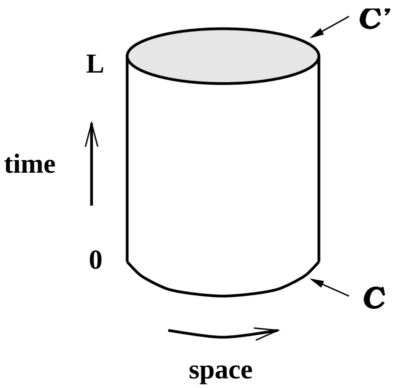


Minimal Walking Technicolor



- Simplest interesting model: MWT
- 2 dirac fermions transforming under the adjoint representation of SU(2)

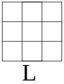
Schrodinger Functional



(LxLxL box with periodic b.c.)

- Finite size renormalisation scheme
- Can be defined in continuum and on lattice
- Scale $\mu \sim 1/L$

Step Scaling



- Step scaling - only need $L, 2L$
- $\overline{g}^2(\beta, L) = u$
- $u' = \overline{g}^2(\beta, 2L)$
- Now tune bare parameters until $\overline{g}^2(\beta', L) = u'$
- Repeat

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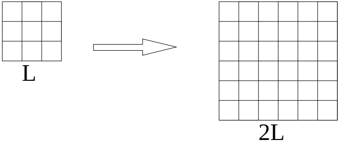

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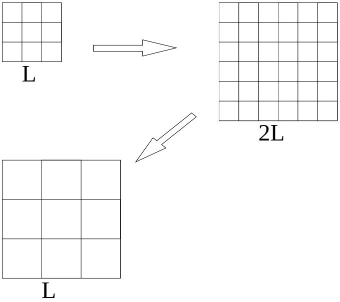

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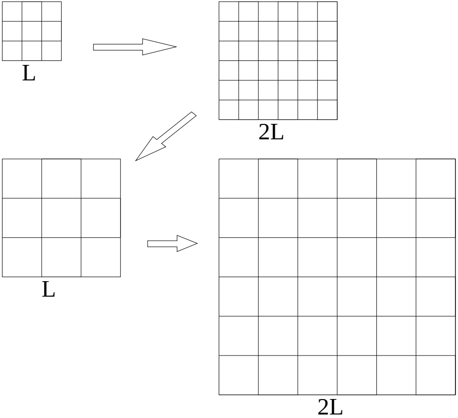

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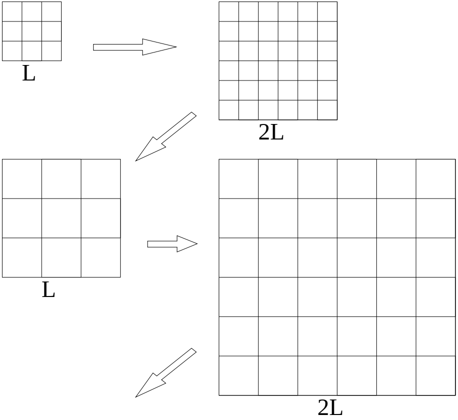

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Musical Analogy

- Step scaling - only need a violin and a cello
- Put finger somehwere on violin, play it.
- Put finger in the same place on cello, play it.
- Now move finger on violin until it makes the same sound as the cello.
- Repeat

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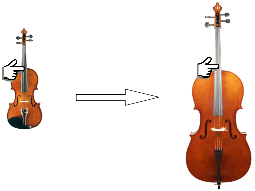

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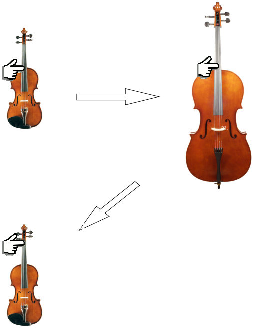

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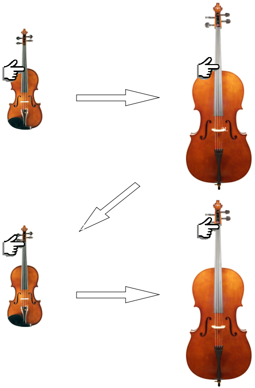

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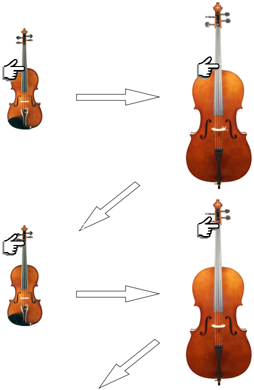

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- So need to repeat on a series of "guitars" with different fret spacings, and take the limit

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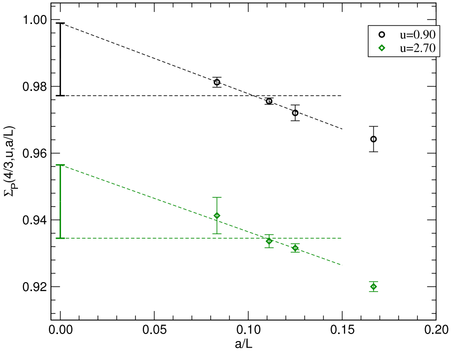
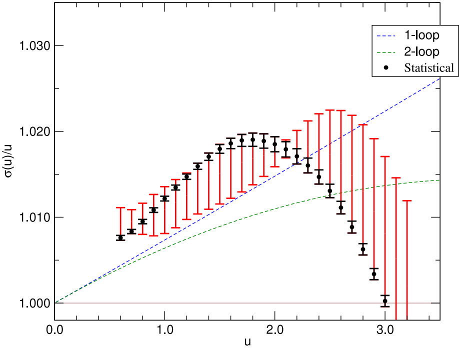
Continuum Exptrapolation



- Need to do this for various lattice spacings a
- Then extrapolate to $a = 0$

Running Coupling



- Coupling runs very slowly
- Looks like there may be a fixed point at $u \sim 3$
- But once we include systematic errors the signal is swamped

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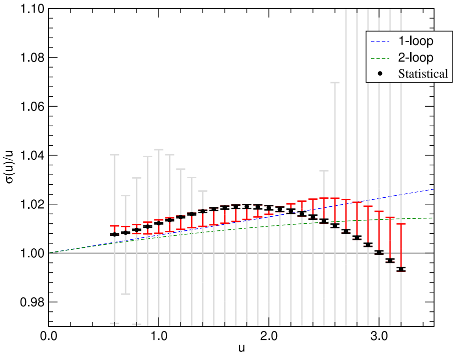

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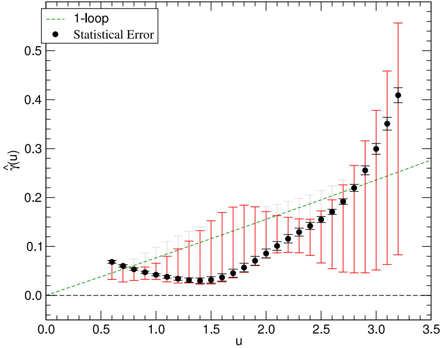
Mass Anomalous Dimension



- Anomalous dimension is better determined
- Consistent with one-loop prediction
- Smaller than desired for phenomenology
- But is sensitive to the location of the fixed point

Pros and Cons

- Pros:
  - Measured running of coupling and mass
  - Full control of systematic errors
- Cons:
  - Systematic errors swamp our signal!
- How can we do better?
  - Work harder: More computer time
  - Work smarter: Improved technique

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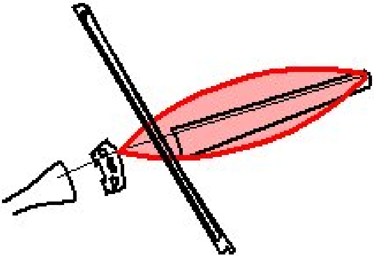

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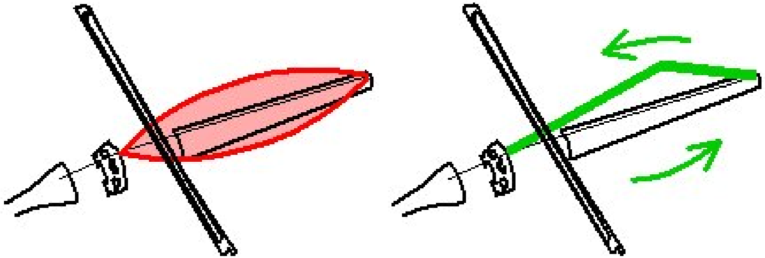

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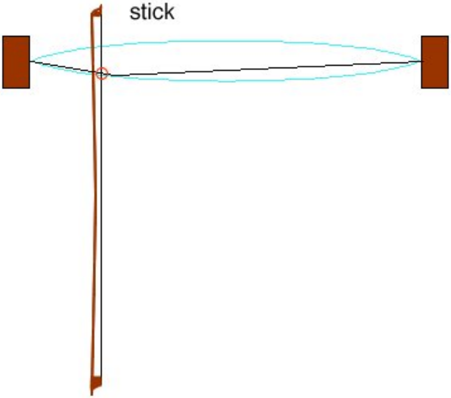

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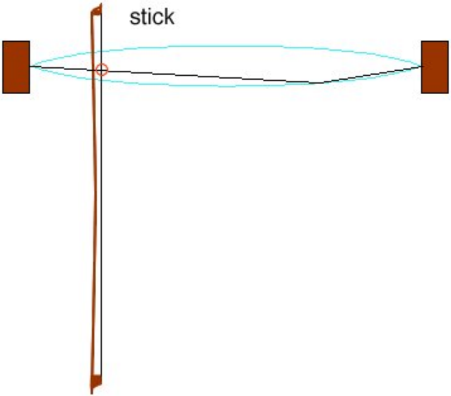

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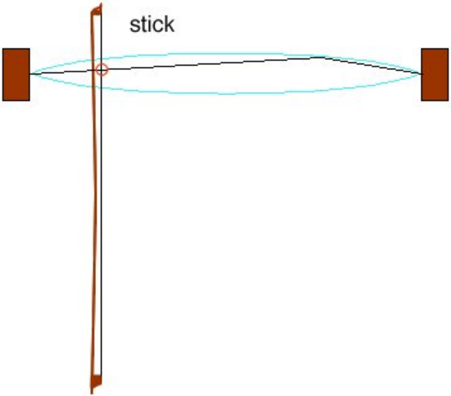

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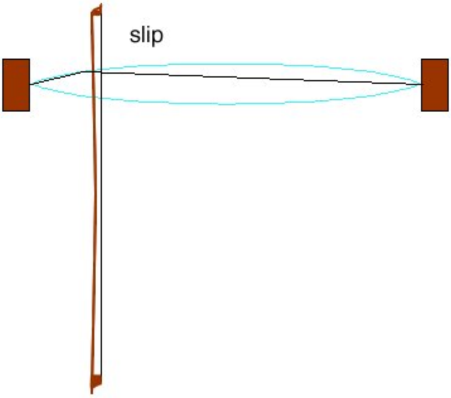

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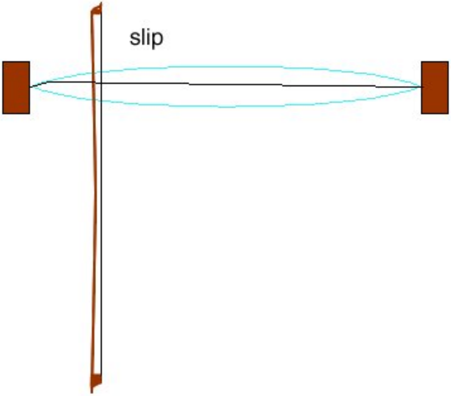

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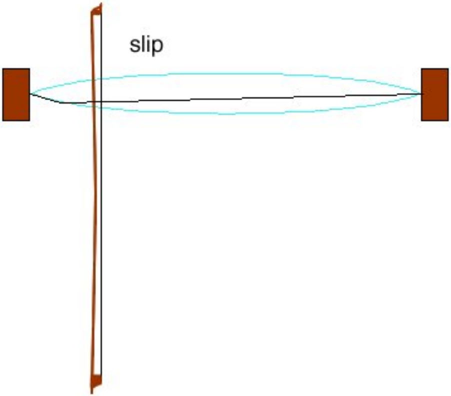

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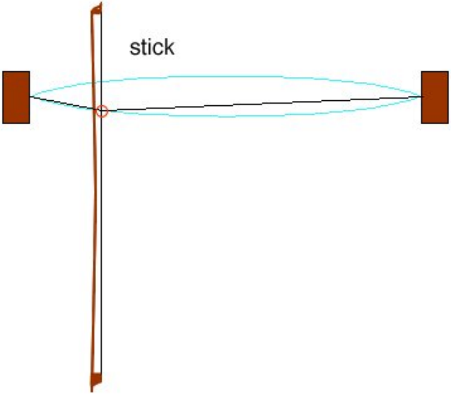

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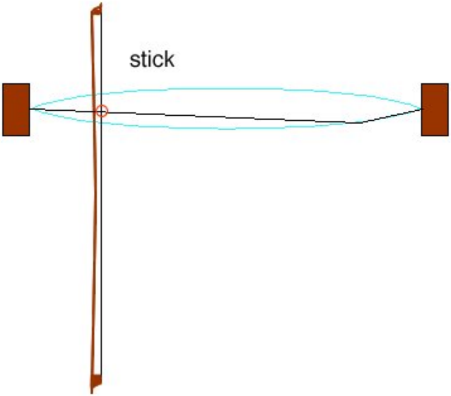

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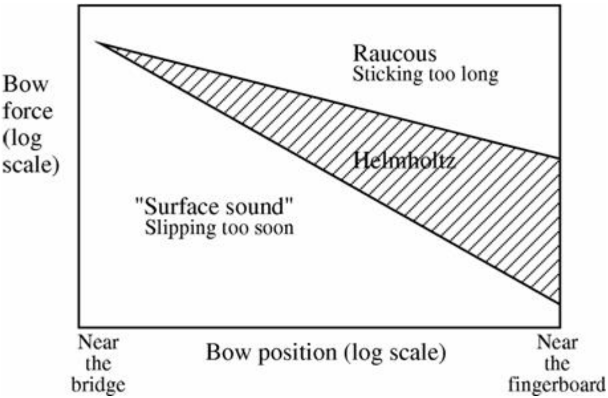
Bow force (log scale)
Raucous
Sticking too long
Helmholtz
"Surface sound"
Slipping too soon
Near the bridge
Bow position (log scale)
Near the fingerboard

Improvement

- Many ways to discretise the action
- We used the simplest, with scaling errors $O(a)$
- Could use an improved action, with scaling errors $O(a^2)$
- This would significantly reduce the systematic error in the continuum extrapolation - our main source of errors.

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Conclusion

- We present the first measurement of the mass anomalous dimension in MWT.
- This is a phenomenologically important quantity, but is sensitive to the location of a fixed point, which we need better statistics and/or techniques to determine well.
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- Scaling studies: Schrodinger Functional scaling studies, Monte Carlo Renormalisation Group methods, Spectral studies, . . .

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(Final) Musical Analogy