Approaching the conformal window:

Systematic study of the particle spectrum in SU(2) field theory with $N_f = 2, 4$ and 6 fundamental fermions.

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Technicolor

- Idea: explain EW symmetry breaking by a new force
  - $SU(N)$ gauge field + N_f massless fermions
  - EW symmetry broken by a chiral condensate
  - Higgs composite: solves fine tuning problem
- Fermion masses from extended TC
  - Motivation for non-QCD like running
  - Walking: $g \sim g_*$ over large scale separation
  - Infrared fixed point (IRFP): $\beta = \mu \frac{dg}{d\mu}$ is zero at g_*
- IRFP at strong coupling

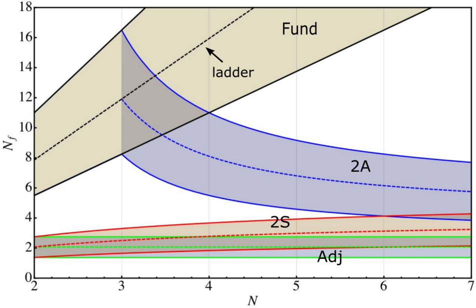
  $\Rightarrow$ Perturbative analysis not valid

  $\Rightarrow$ Lattice simulations required

Conformal window

$=$ Range of N_f where IRFP exists

- Walking coupling: near the lower edge of the conformal window?
- Below conformal window: chiral symmetry breaking



Ref. [Sannino, Tuominen]

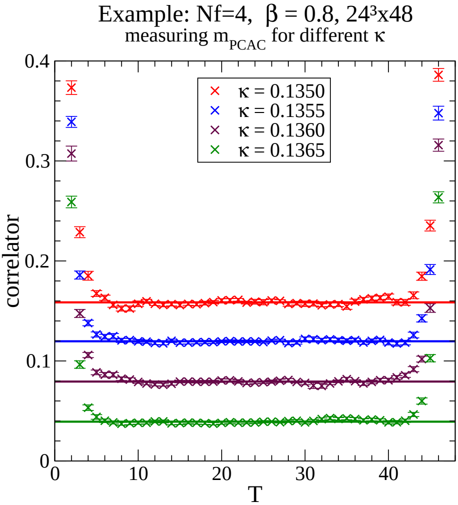
- Hadron spectrum: when $m_Q \to 0$
  - Pions massless as $m_\pi \propto m_Q^{1/2}$ $\to$ QCD-like chiral symmetry breaking
  - All states massless as $M \propto m_Q^{\frac{1}{1+\gamma(g_*^2)}}$ $\to$ IRFP

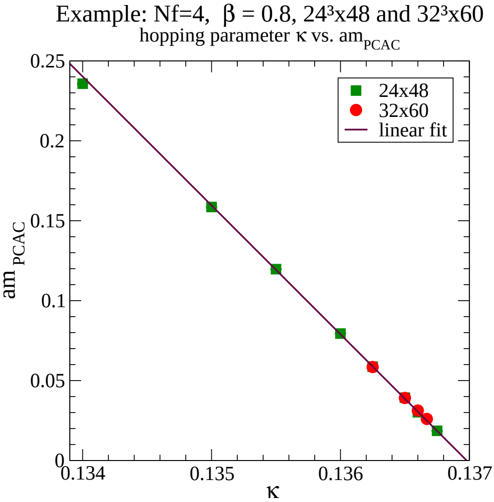
$SU(2)$ theory with $N_f = 2$, 4 and 6 fundamental fermions

Approaching conformal window

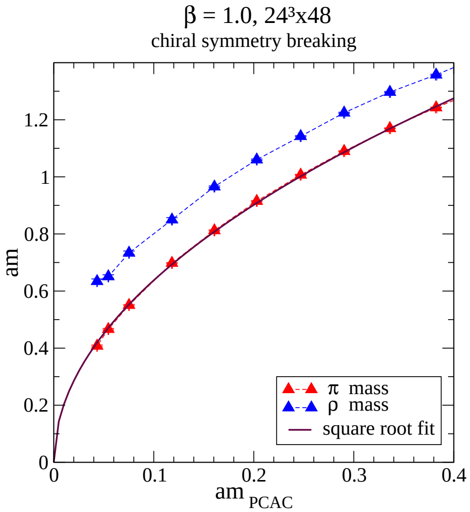
- $N_f = 2$, 4 evidence for chiral symmetry breaking is found, but $N_f = 6$ is unclear [Karavirta et al. (2011), Appelquist et al. (2013)]
- Our goal: to study hadron spectrum and scale-setting, when approaching the conformal window.
- Method: using
  - HEX smeared Wilson clover action for fermions
  - thin link Wilson + stout link Wilson for gauge fields
- Lattice size: $24^3 \times 48$, and $32^3 \times 60$ for small am_Q
- Number of configurations: 80-200
- Scale setting with gradient flow

Measuring am_{PCAC} and defining κ_{crit}

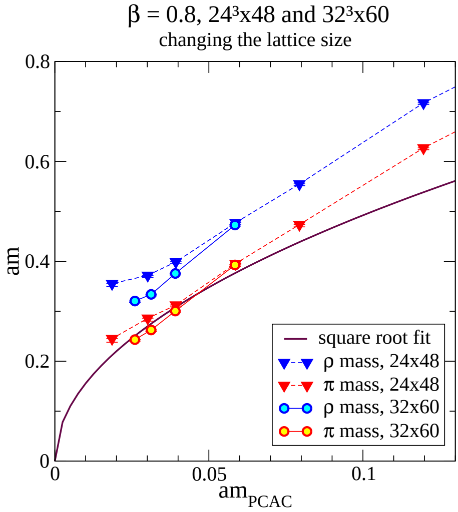


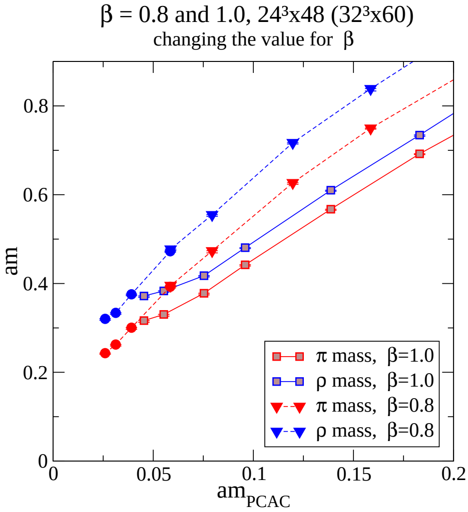


Hadron spectrum: $N_f = 2$ (preliminary results)

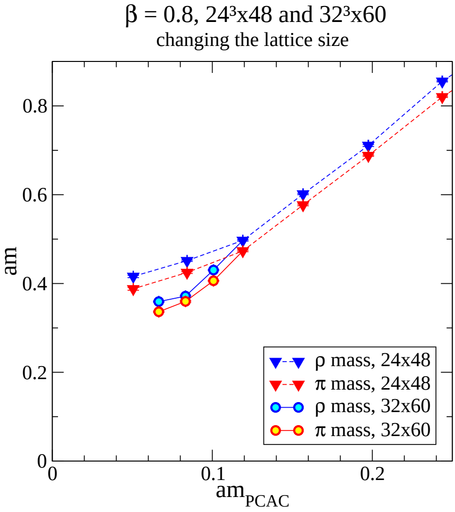


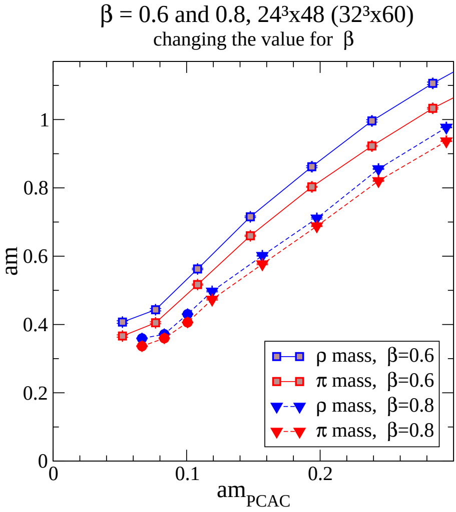
Hadron spectrum: $N_f = 4$ (preliminary results)





Hadron spectrum: $N_f = 6$ (very preliminary results)

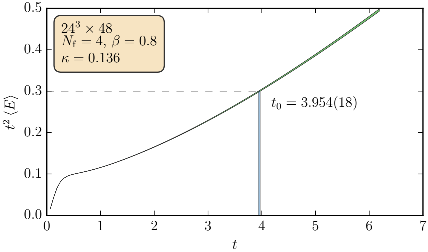




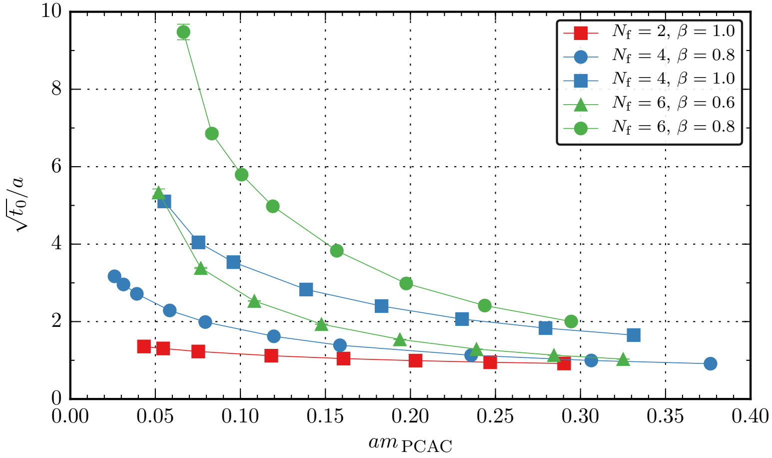
Wilson flow: t_0, w_0

- Scale-setting:
  - Required to predict dimensional quantities in physical units
  - Determine accurately the relative physical lenght scale of different simulations

- Wilson flow
  - very precise, cheap and straightforward
  - t_0: solve $t_0^2 \langle E(t_0) \rangle = 0.3$
    - $E(t)$ = continuum-like action density at flow time t
  - w_0: solve $t \frac{d}{dt}(t^2 \langle E(t) \rangle)|_{t=w_0^2} = 0.3$

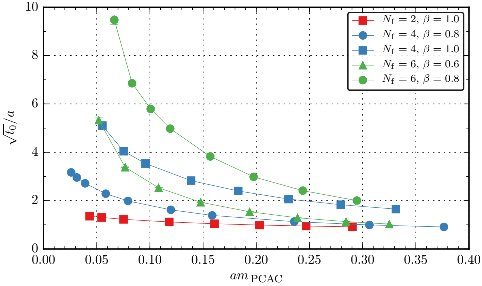


Wilson flow: $\sqrt{t_0}$ (preliminary results)



Wilson flow: $\sqrt{t_0}$ (preliminary results)

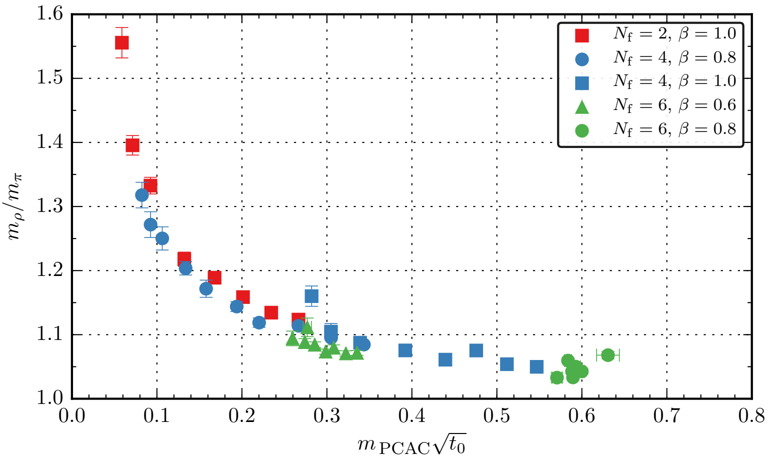
- $\sqrt{t_0}/a$ grows as
  - N_f is increased
  - β is increased (weaker bare coupling)
- If IRFP: $\sqrt{t_0}/a \to \infty$ as $am_{PCAC} \to 0$
  - fixed point at $N_f = 6$?
- $N_f = 2, 4$: finite value as $am_{PCAC} \to 0$



- Keeping $\sqrt{t_0}$ fixed: Bigger $\sqrt{t_0}/a$ means smaller lattice spacing $\to$ physical quark masses heavier

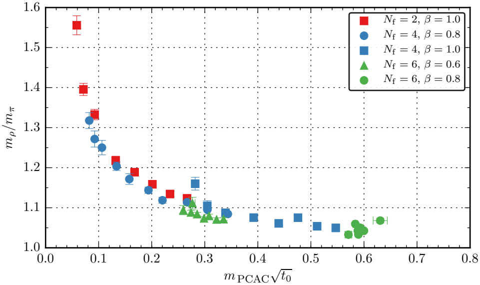
$\Rightarrow$ Near the conformal window: *very* strong lattice coupling is needed to avoid small volume squeeze

Results in physical units (preliminary results)



Results in physical units (preliminary results)

- If chiral symmetry breaking: $m_\rho/m_\pi \to \infty$ as $m_{PCAC} \to 0$
  - Case for $N_f = 2$ and 4
- $N_f = 6$ interesting:
  - $\beta = 0.8$: looks like IRFP?
  - $\beta = 0.6$: m_ρ/m_π grows along "universal" curve $\to$ chiral symmetry breaking?



$\Rightarrow$ Next: study $N_f = 8$ (which has IRFP, next talk by Leino) to see how it behaves

- Smaller m_{PCAC} can be reached by:
  - Smaller am_{PCAC} and bigger lattice (expensive)
  - Decreasing β

Conclusions and outlook

- m_Q dependence of the $\sqrt{t_0}$ scale becomes stronger as N_f is increased
- Volume squeezes quicker than expected $\rightarrow$ requires very strong couplings
- Difficult to reach the chiral regime even at Nf=4
- Hint for chiral symmetry breaking at Nf=6?

- Bigger lattices for smaller quark masses
- More values of β in $N_f = 6$ case
- Simulating $N_f = 8$
- Defining the glueball masses and the string tension
- Measure the decay constant
- In future: scalar measurement