SU(2) gauge theory with many flavors of domain-wall fermions

- Introduction
- Setup
- Result of simulation: Nf=2, 4, 6, 8
- Summary/outlook

Hideo Matsufuru (KEK)

In collaboration with
Norikazu Yamada (KEK), Kei-Ichi Nagai (KMI, Nagoya U.)

Lattice 2014, 23 – 28 June 2014, Columbia Univ.

Introduction

- SU(2) gauge theory
  - Many works on confinement mechanism, finite temperature/density
  - Beyond standard model: technicolor, conformal window
- Chiral dynamics depending on gauge group and fermion repr.
  - Different symmetry breaking pattern

Fundamental	Adjoint
SU(2): SU(2Nf) → Sp(2Nf) SU(N) N>2: SU(Nf)xSU(Nf) → SU(Nf)	SU(N): SU(2Nf) → SO(2Nf)

  - Number of flavors
  - Finite temperature/density
  - Eigenvalue distribution

strategy

- Chiral symmetric fermion is better device
  - Overalp: best symmetry, high numerical cost, involved setup (Aoki phase, etc.) H.M., Kikukawa, Yamada, Nagai, Lattice 2010, 2009
  - Domain-wall: good properties, numerically feasible
    - approaches to overlap with large Ns
    - Residual mass probes chiral symmetry violation

Configuration

Domain-wall	Ovelap
- Topology changes	- Fixed topology
- Large lattice is possible	- p-regime/ε-regime

Mesurement

Domain-wall	Ovelap

- Spectroscopy
- Residual mass/breaking of G-W relation
- Eigenvalue/vectors

Present work

- Lattice actions:
  - Iwasaki gauge action
  - Standard domain-wall fermions: Nf=2, 4, 6, 8
- Survey of Nf-dependence with fixed setup
  - Applicability of domain-wall (and overlap) fermions
  - Confining/conformal feature ?
  - Static potential
  - Meson correlators/residual mass
  - Eigenmodes of domainwall/overlap fermion operators (underway)
- Fundamental setup: making basis for further studies
  - Finite T/μ, adjoint fermions
  - Comparion with improved domain-wall, dynamicsal overlap
  - Condition to access the ε-regime

Setup

- Lattice size: 16^3x32, Ns=16
- HMC
  - Domain-wall/Pauli-Villars
  - Omelyan integrator + multi-time step (2-level)
  - About 1000 tranjectories at each parameter set

Nf	beta	m
2	0.85	0.20, 0.10, 0.05
	0.90	0.20, 0.10, 0.05
4	0.85	0.20, 0.10, 0.05, 0.03
	0.90	0.20, 0.10, 0.05
6	0.80	0.20, 0.10, 0.05
	0.85	0.20, 0.10, 0.05
	0.90	0.20, 0.10, 0.05
8	0.80	0.20, 0.10, 0.05
	0.85	0.20, 0.10, 0.05

Domain-wall fermion

- Standard domain-wall fermion action

$$
\begin{aligned}
S_{DW} &= \sum_{x,s} \bar{\psi}(x,s) D_W(x,y;-M_0)\psi(y,s) \\
&\quad -\frac{1}{2}\sum_{x,s} \bar{\psi}(x,s)\left[(1-\gamma_5)\psi(x,s+1)+(1+\gamma_5)\psi(x,s-1)-2\psi(x,s)\right] \\
&\quad +m\left[\bar{\psi}(x,1)P_R\psi(x,L_s)+\bar{\psi}(x,L_s)P_L\psi(x,1)\right]
\end{aligned}
$$

$$
D_W(x,y;M) = M\delta_{x,y} - \frac{1}{2}\sum_{\mu=1}^{4}\left\{(1-\gamma_\mu)U_\mu(x)\delta_{x+\hat{\mu},y}+(1+\gamma_\mu)U_\mu^\dagger(x-\hat{\mu})\delta_{x-\hat{\mu},y}-4\delta_{x,y}\right\}
$$

- M_0: domain-wall height, m: fermion mass
- Ls: extent of 5-th direction
- Boundary conditions: $P_R\psi(s=0) = P_L\psi(s=L_s+1) = 0$
- 4D fermion field:

$$
\begin{aligned}
q(x) &= P_L\,\psi(x,s=1)+P_R\,\psi(x,s=L_s) \\
\bar{q}(x) &= \bar{\psi}(x,s=1)P_R+\bar{\psi}(x,s=L_s)P_L
\end{aligned}
$$

Resources/environment

- Machines
  - Hitachi SR16000, IBM Blue Gene/Q at KEK
  - φ at KMI, Nagoya Univ.

Code:

  - Bridge++ (C++)
    - Cf. S.Ueda's poster
  - Fortran code

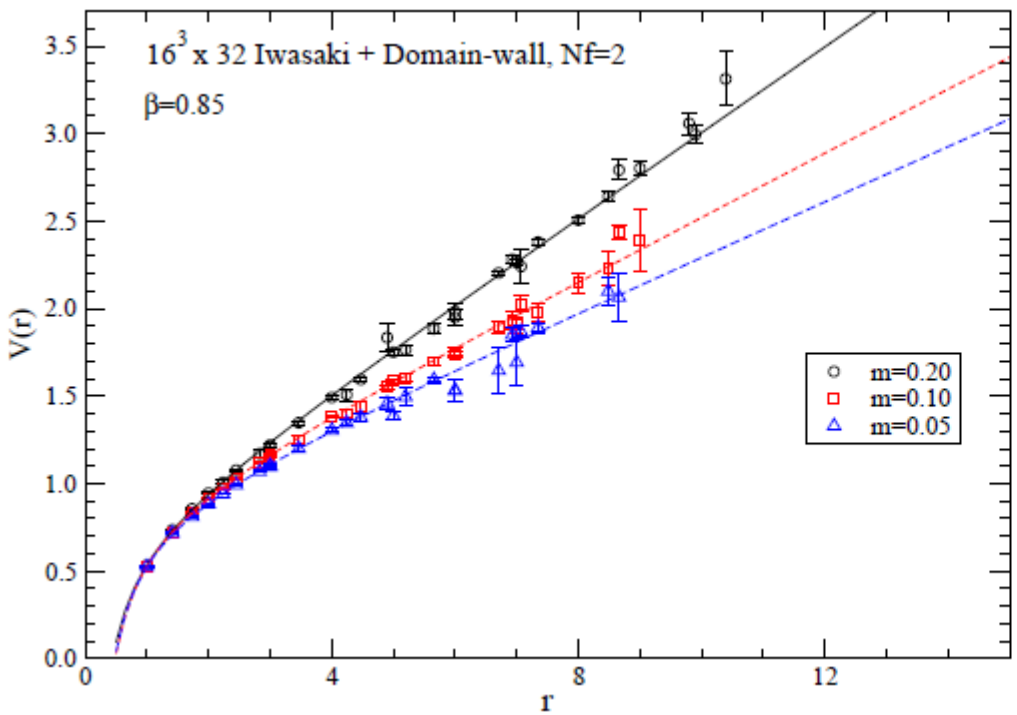
- JLDG (Japan Lattice Data Grid)
  - for fast data transfer

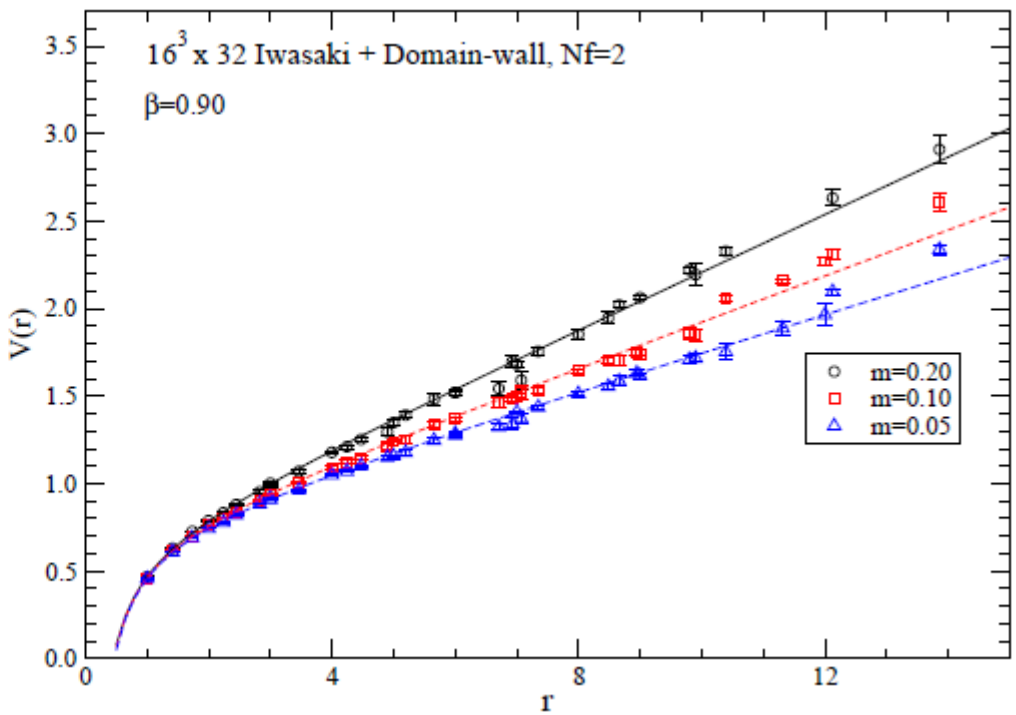
Japan Lattice Data Grid

Nf=2: static potential

Nf	beta	m
2	0.85	0.20, 0.10, 0.05
	0.90	0.20, 0.10, 0.05

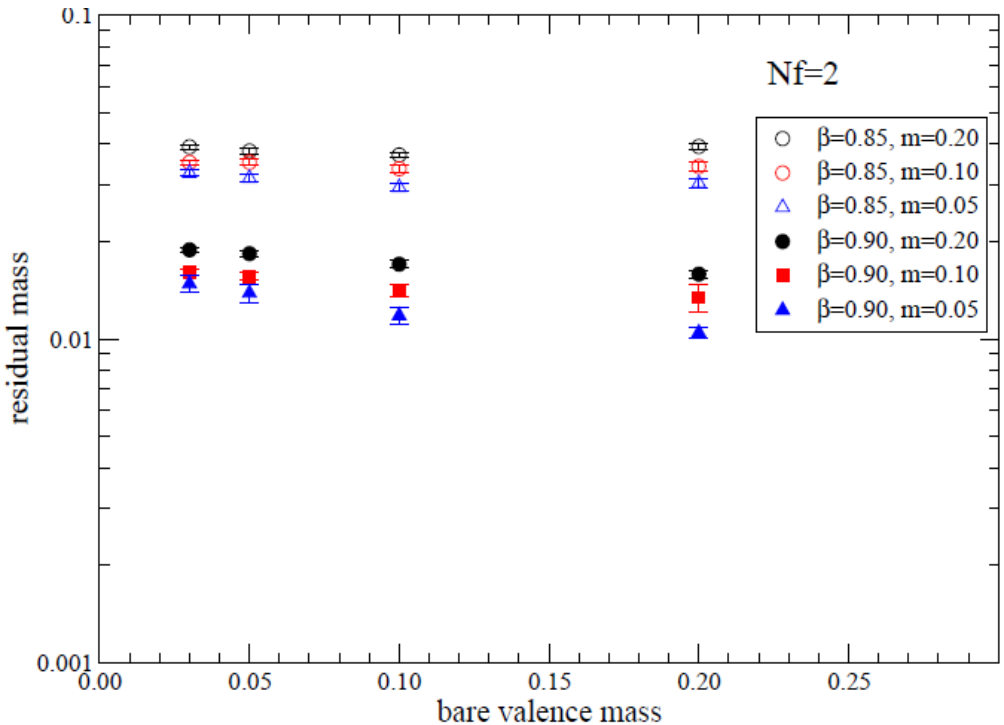
- Static potential
  - Fitted to $V(r) = \text{const} - A/r + \sigma r$
  - Sommer scale r_0 (or string tension) → "lattice spacing"

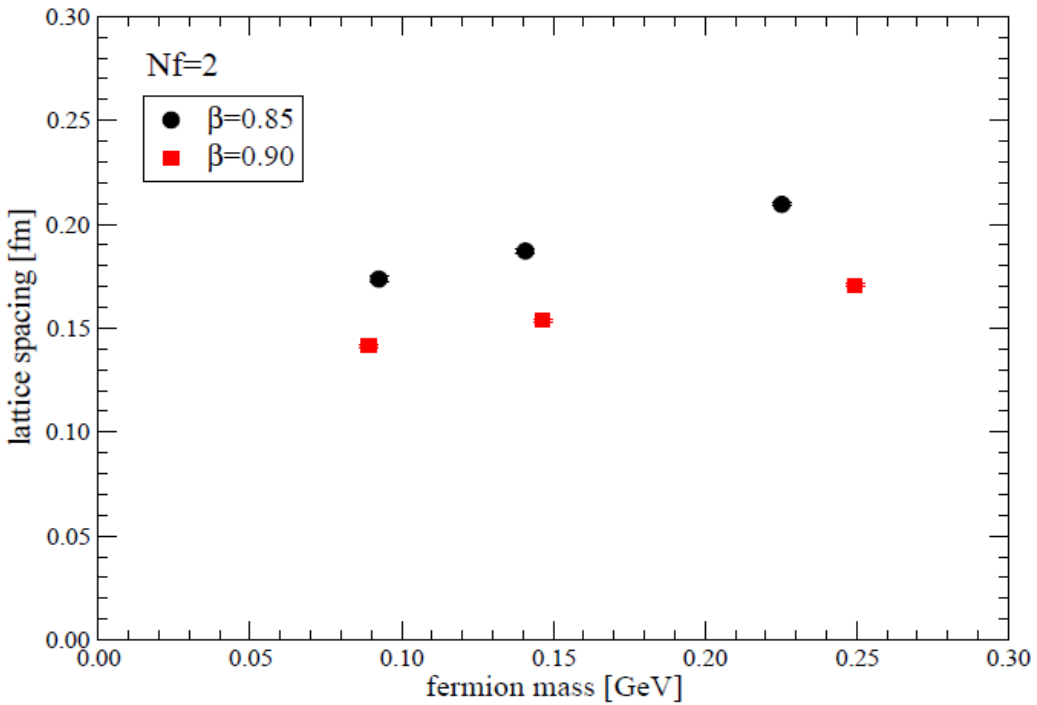




Nf=2: residual mass

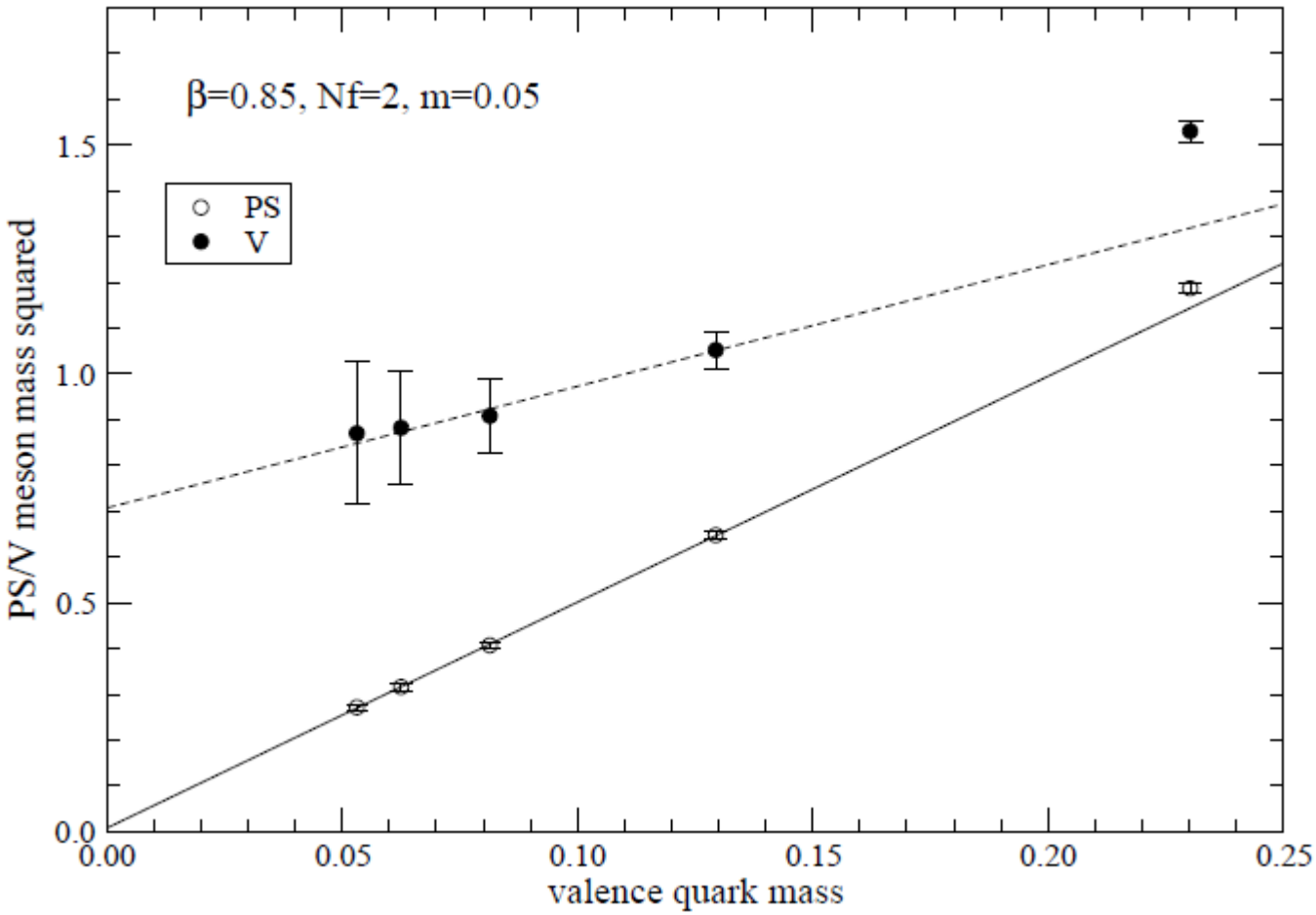
- Lattice spacing vs fermion mass (residual + bare)
- Extrapolation to massless limit seems successful
- To go below present residual mass, larger Ns or improved domain-wall are necessary



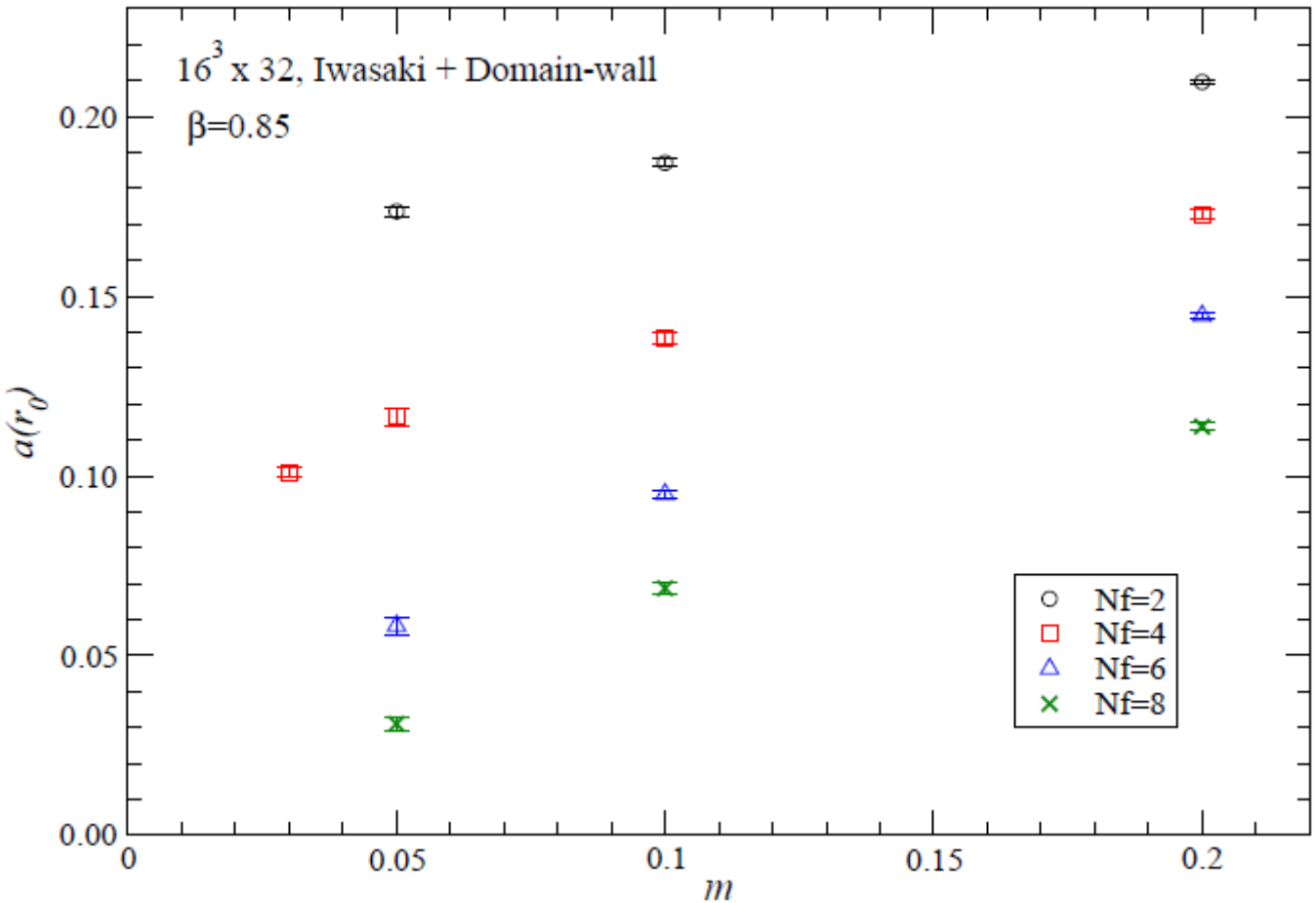


Nf=2: PS and V meson spectra

- Valence fermion mass dependence: similar behavior as SU(3) case

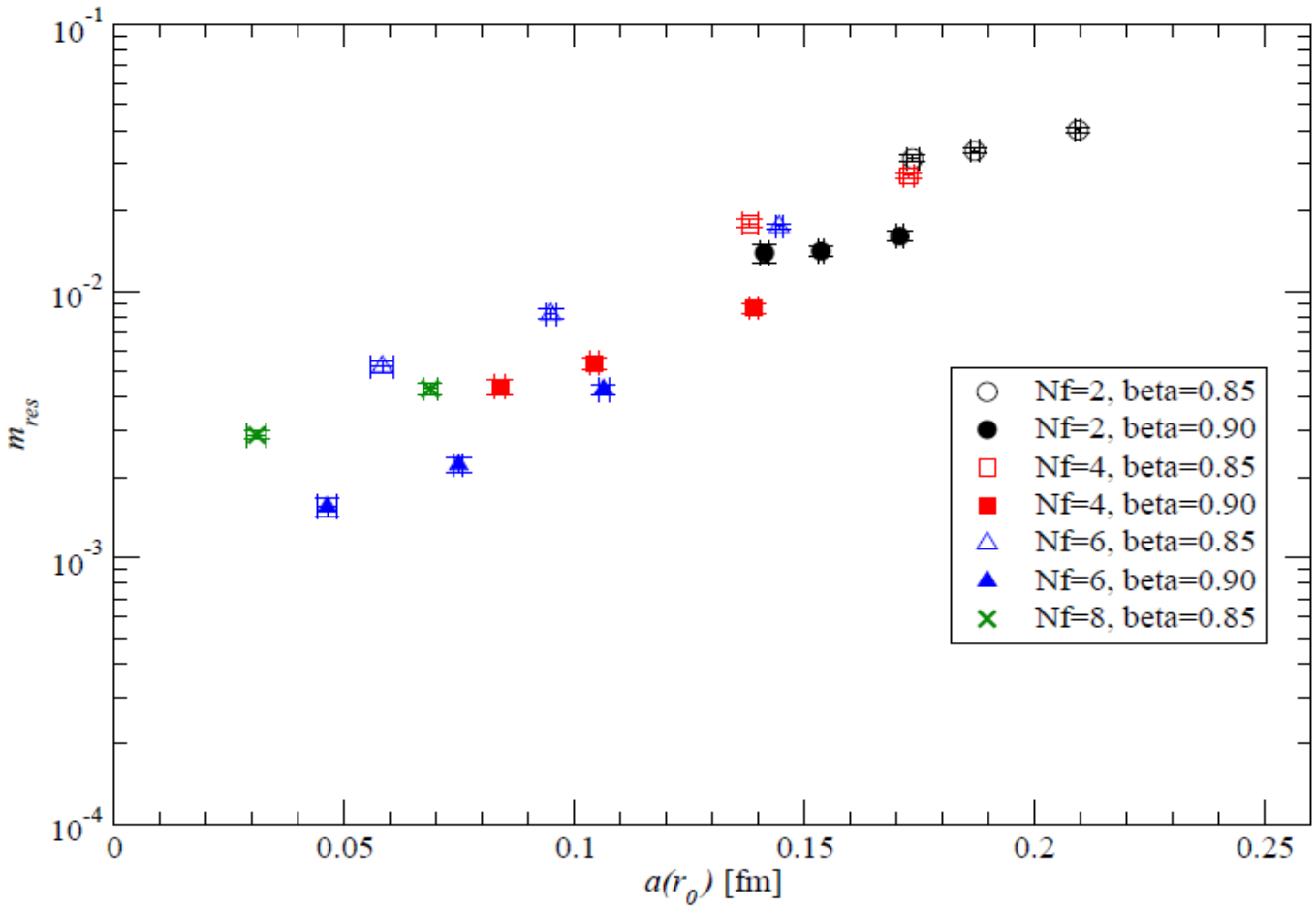


Nf-dependence of static potential



- Nf-dependence grows as Nf increases.
- For Nf=8 (and 6), confining feature seem to disappear at m=0.

Nf-dependence of residual mass

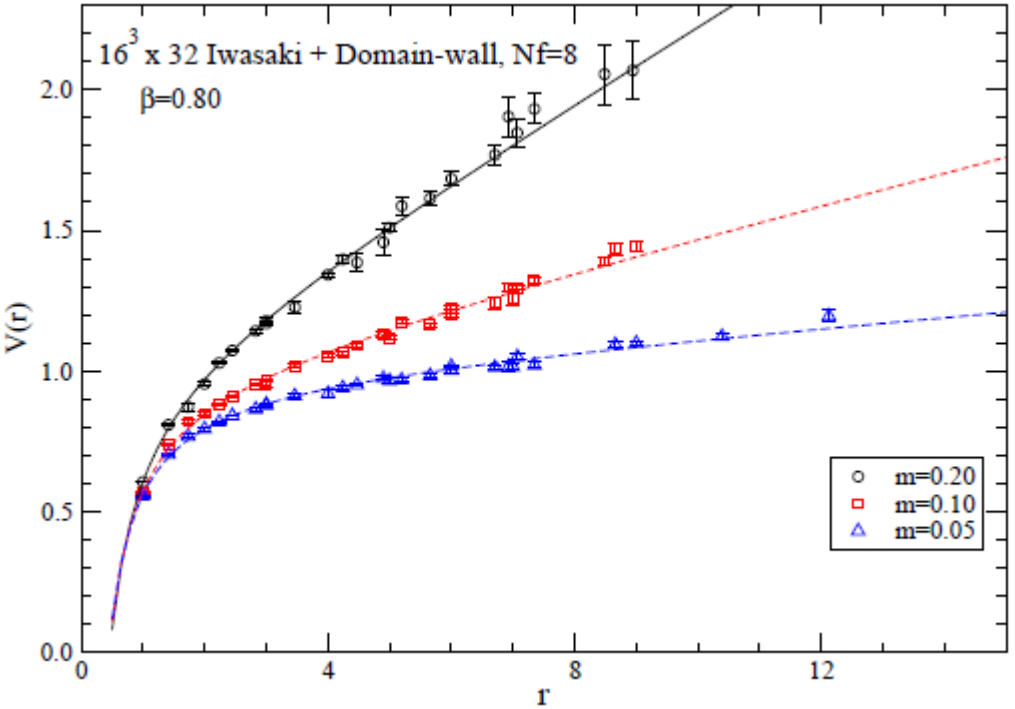


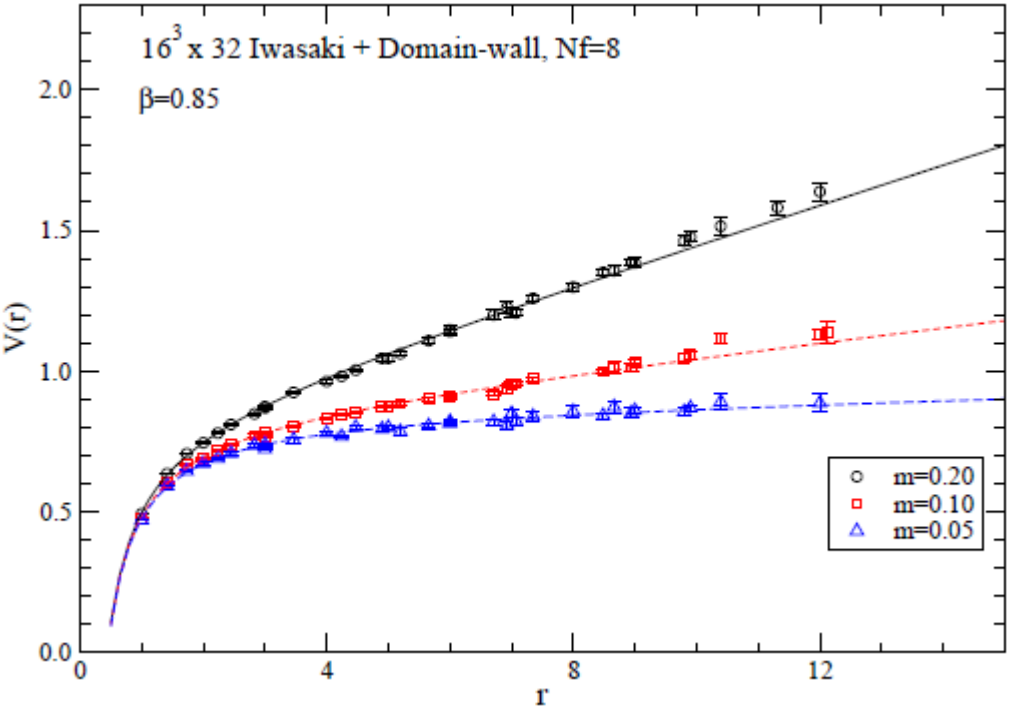
- General tendency: m_{res} decreases as lattice spacing increases

Nf=8: statix potential

Nf	beta	m
8	0.80	0.20, 0.10, 0.05
	0.85	0.20, 0.10, 0.05

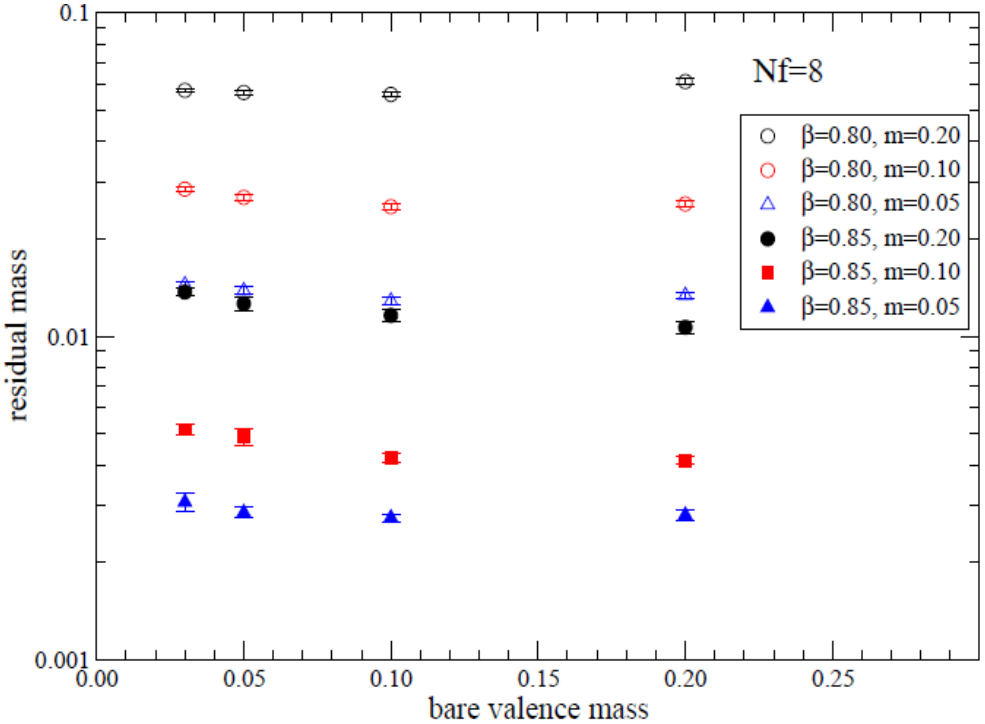
- Static potential
  - Bare mass dependence is large
  - String tension seems to vanish as m goes to zero

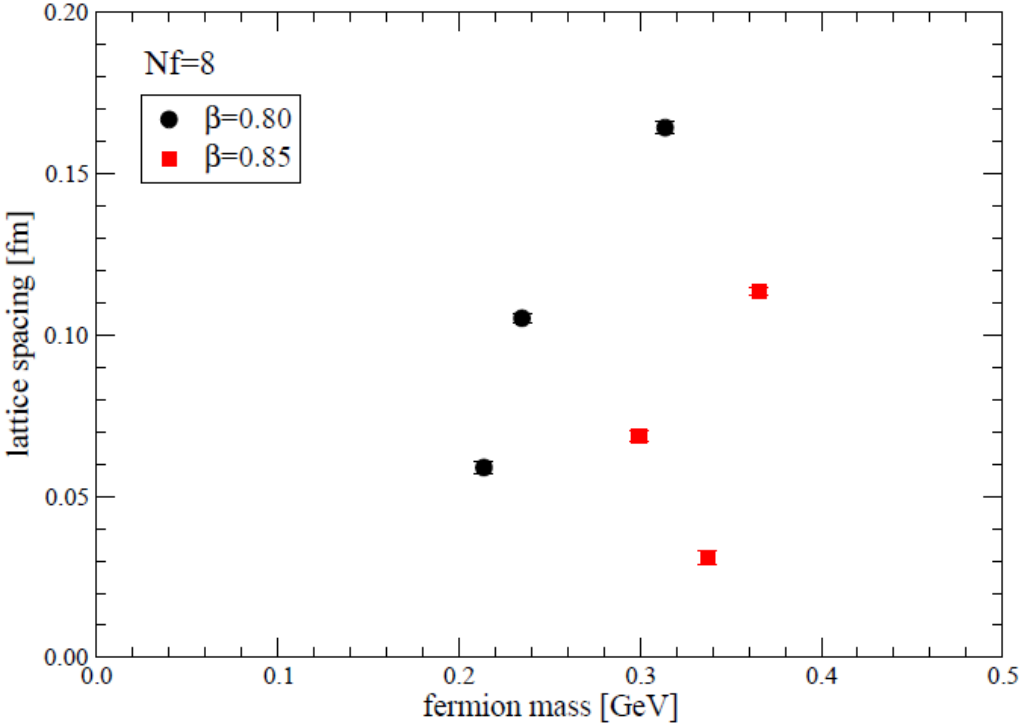




Nf=8: scale vs residual mass

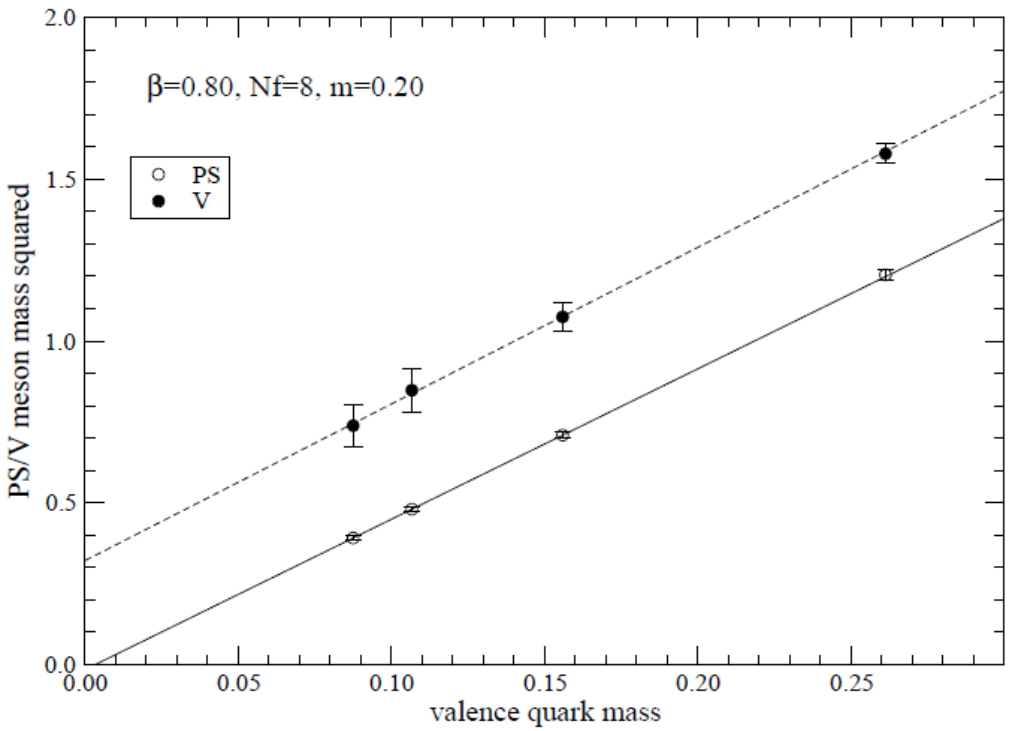
- Scale vs scaled residual mass: massless limit is hardly taken

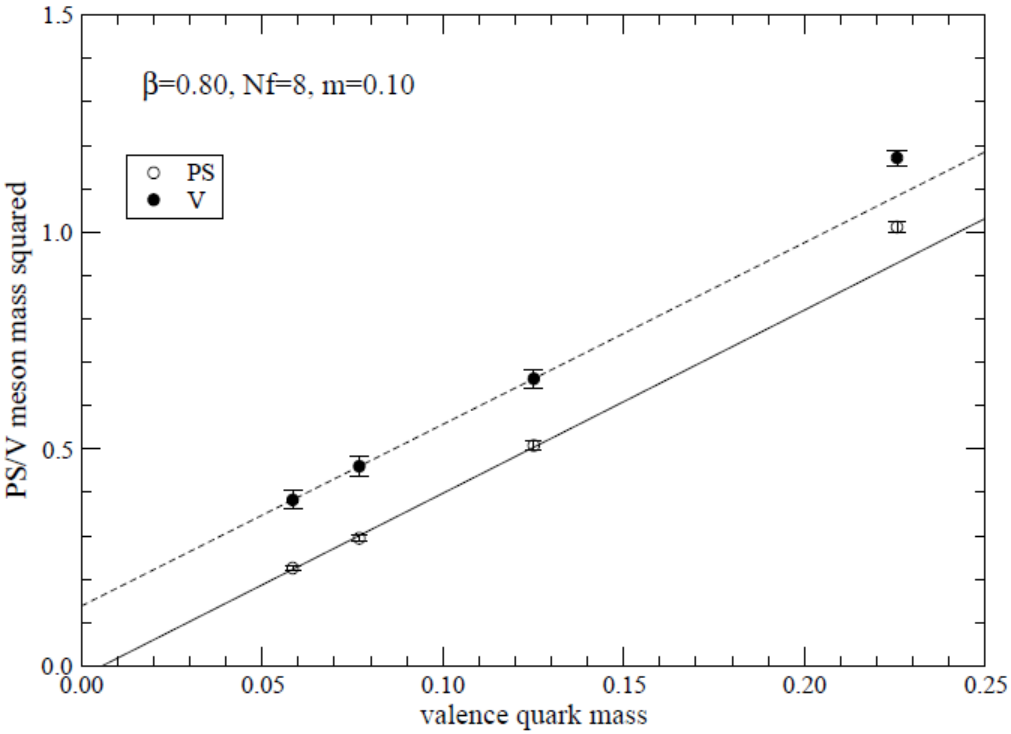




Nf=8: PS and V meson masses

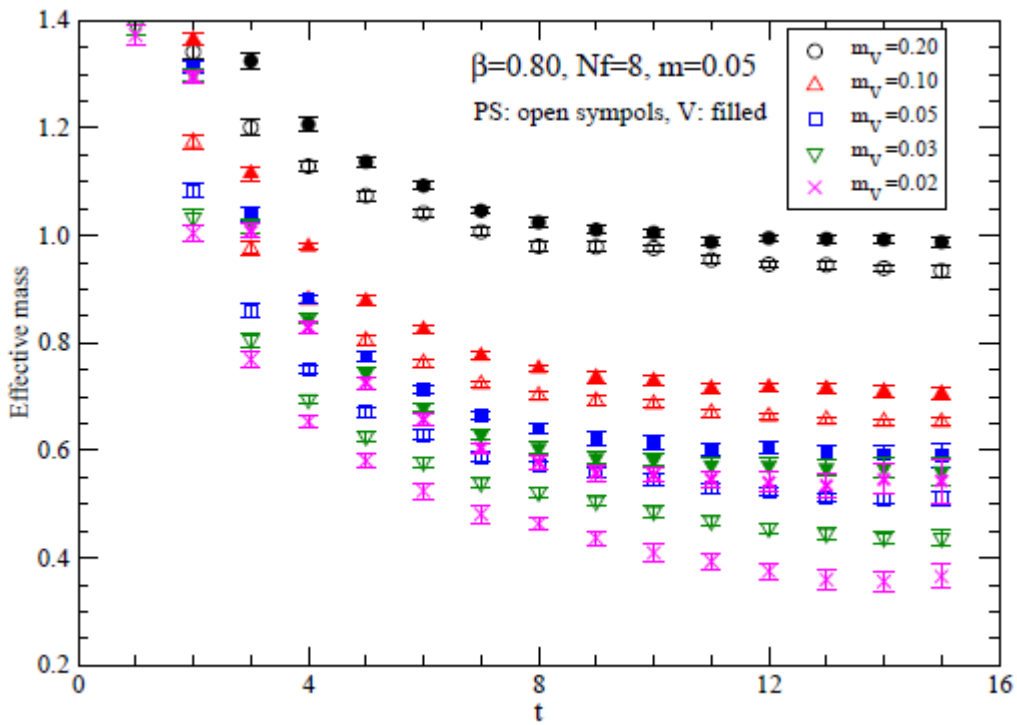
- Meson spectrum at β=0.80 (β=0.85 shows similar results)
- PS-V splitting tends to decrease as m decreases: scale is also largely changed
- Finite size effect: to be quantified

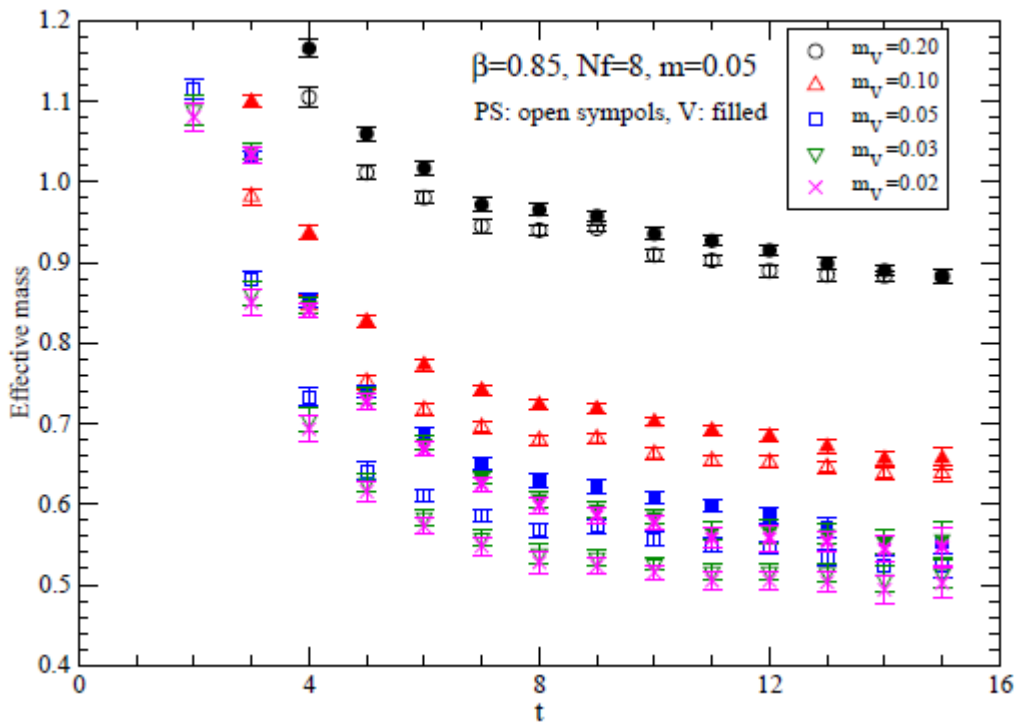




Nf=8: PS and V meson masses

- For m=0.05 at β=0.80 and 0.85
- Local-local correlator seems not to reach plateau
- To be confirmed with wall-source correlators

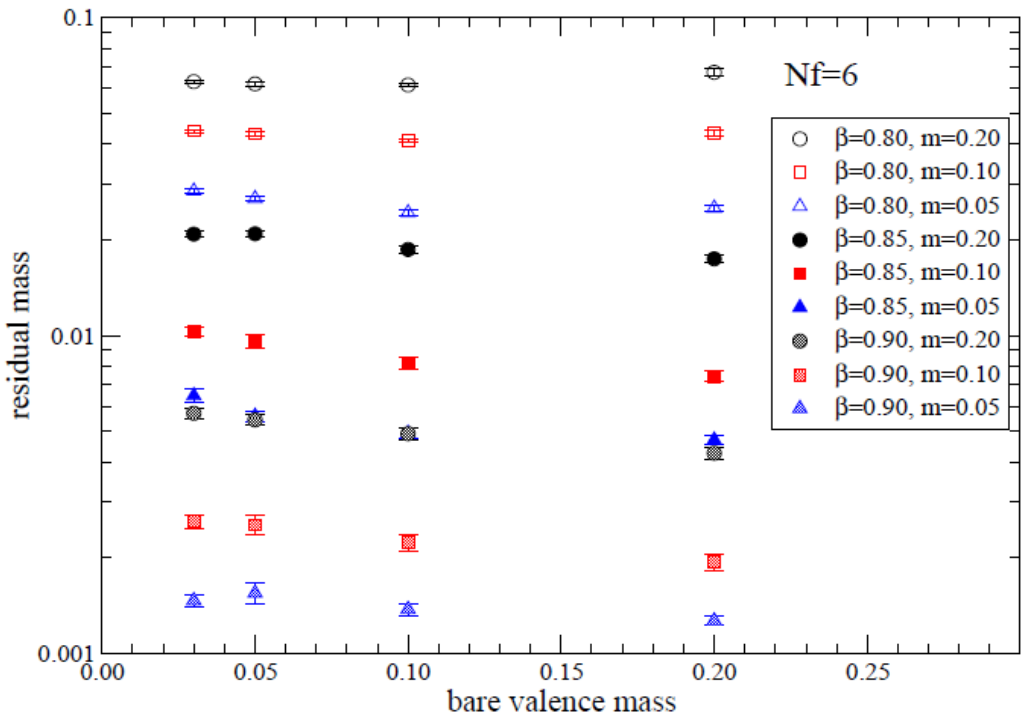


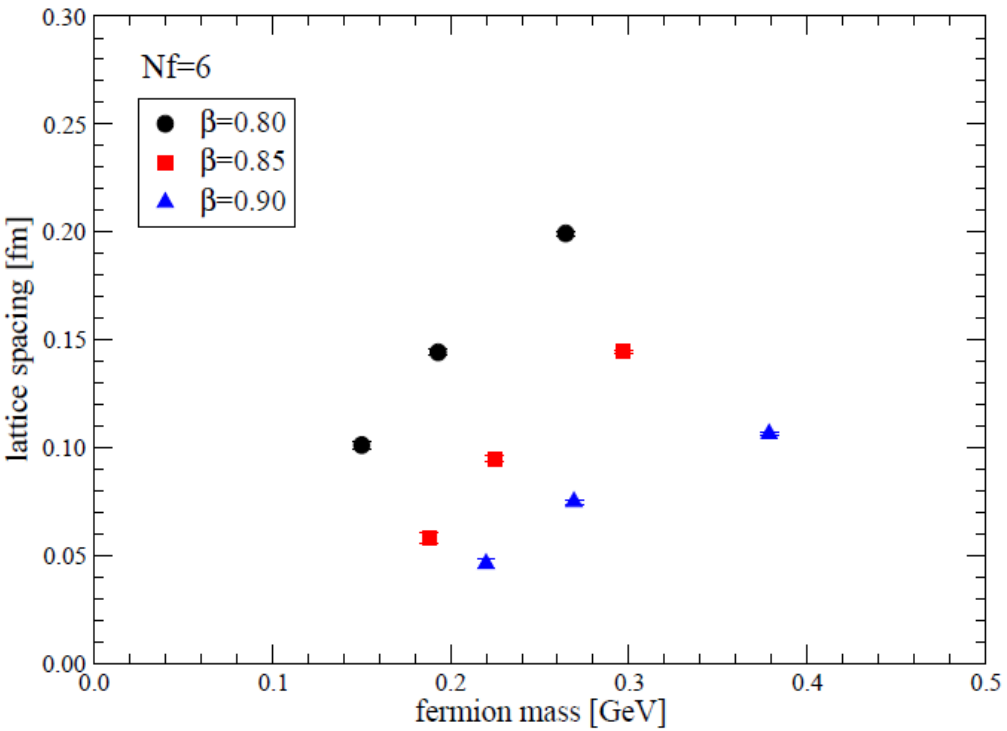


Nf=6: scale vs residual mass

- Residual mass shows ordinary behavior
- Lattice scale (string tension) vs scaled fermion mass:

  Massless limit hardly to take: confining feature disappear as m→0



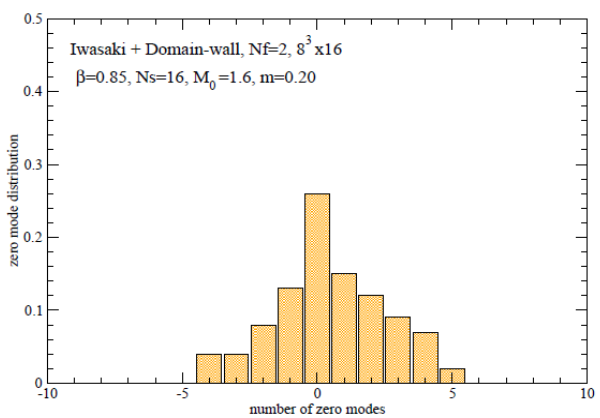


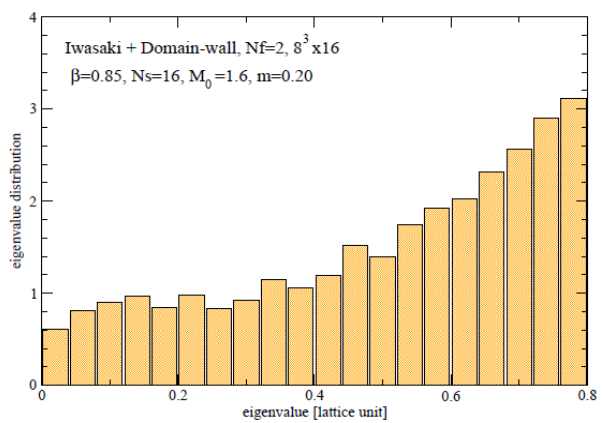
To do

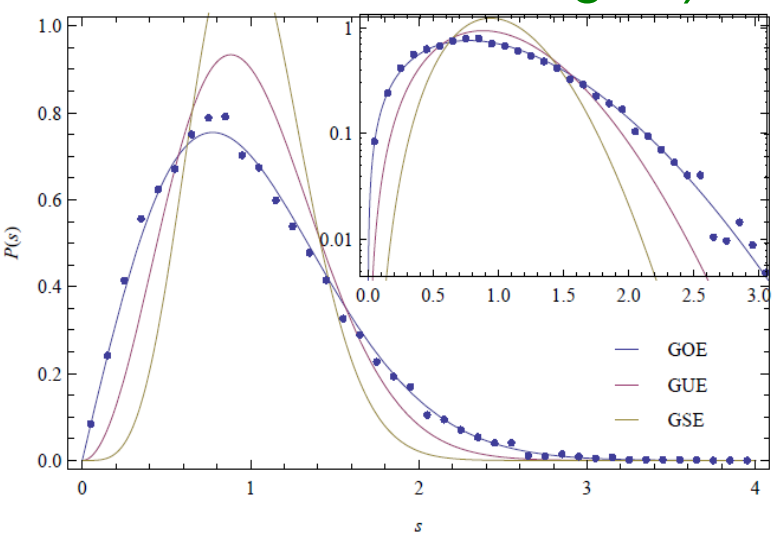
- So far analysis based on confining/chral symmetry broken phase were applied
- Analysis to test conformality such as hyperscaling is planned
- Locality of domainwall/overlap fermion to be confirmed
- Method to improve signals needed for other channels
- Eigenmodes of domainwall/overlap fermion operators

(in collaboration with S.M.Nishigaki)

Figures from Lattice 2013 proceedings
(8^3x16 lattice, Nf=2)







Summary/outlook

- Summary
  - SU(2) gauge theory with domainwall fermions of Nf=2,4,6,8
  - Nf=8: confining feature tends to disappear at small m
  - Nf=6 is similar, but no unusual behavior in PS and V meson spectra
  - Detailed analyses underway

- Outlook
  - finite temperature/density
  - Residual mass: better to dcrease → optimal domainwall ?
  - Other gauge group, fermion repr. : adjoint fermions
  - Dynamical overlap (fixed topology) in epsilon-regime