Determination of the pseudoscalar decay constant from SU(2) with two fundamental flavors

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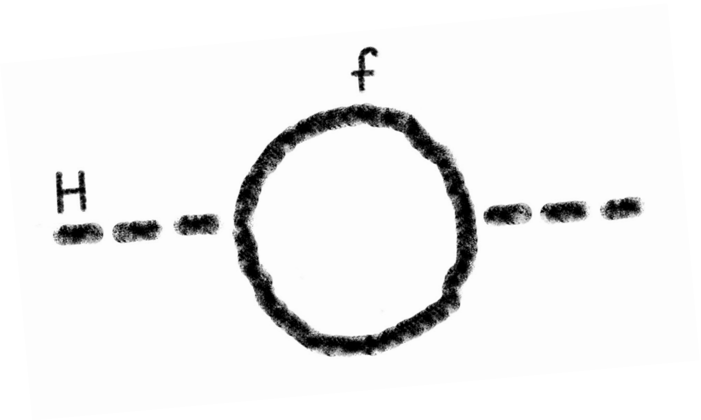
Structure

1. SU(2)/fundamental: Motivation from phenomenology
   Criteria on a composite Higgs theory
2. Lattice Setup
   Software, action, non-perturbative improvement
3. Analysis
   Evaluation of f_{PS}, renormalization, continuum extrapolation
4. Results
   Summary & Outlook

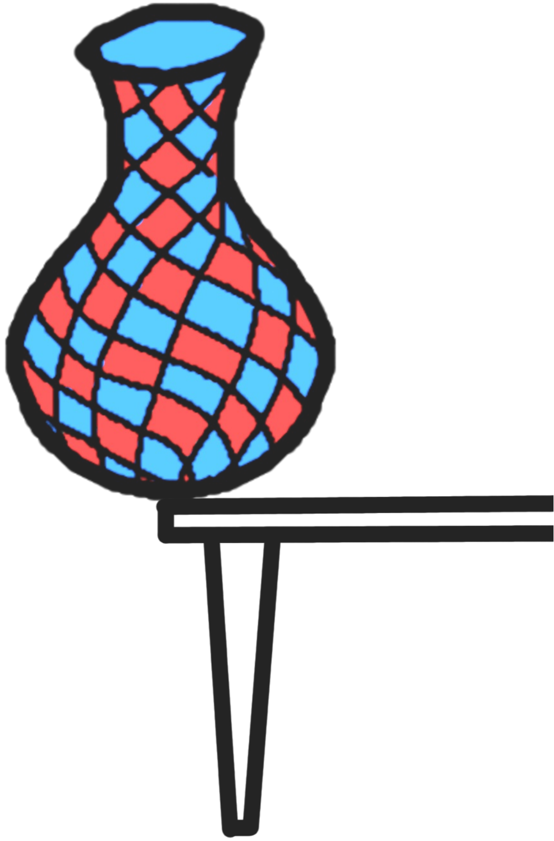
Motivation from phenomenology

Naturalness

Radiative corrections to the Higgs-mass



$$\Delta m_H^2 = \frac{|\lambda_f|^2}{8\pi}\Lambda_{\mathrm{UV}}^2$$



Is the Higgs really **elementary**?

See for example [S. P. Martin, 1998, hep-ph/9709356, Adv. Ser. Direct. High Energy Phys.] and references therein

Important inputs for experimentalists

Vacuum alignment θ

0 **Mixed realizations** $\pi/2$

Composite Higgs

Higgs is a pNGB

Technicolor

Higgs is a light resonance

The vacuum alignment is important to determine **oblique parameters**

See for example [Cacciapaglia, Pica, Sannino, 2020, 2002.04914 , Phys. Rept.] and references therein

[Ferretti, Karateev, 2014, 1312.5330, JHEP]
[Cacciapaglia, Pica, Sannino, 2020, 2002.04914 , Phys. Rept.] reviewed

SU(2) with two fundamental flavors

- [x] Asymptotic freedom
- [x] Singlet state consistent with the Higgs
- [x] Preservation of custodial symmetry

$$G_{SM} = SU(3)_c \times SU(2)_L \times U(1)_Y$$

$$\rho = \left(\frac{M_W}{M_Z \cos(\theta_W)}\right)^2 + \cdots$$

Protected by symmetry $SU(2)_L$. But

$$SU(2)_L \times U(1)_Y \to U(1)_{em}$$

What protects the ρ? A **custodial** $SU(2)_R$!

Lattice Setup

Lattice Simulation Setup

Exp. Clover: [A. Francis et. al., 2020, 1911.04533, Comput. Phys. Commun.]
HiRep: [Del Debbio, Patella, Pica, 2010, 0805.2058, Phys. Rev. D]
GPUs: [Martins et. al., 2024, 2405.19294, EuroPLEx2023]

Non-perturbative improvement: Exponential clover

- Improved stability
- SU(3) suggests smaller O(a^2) -effects

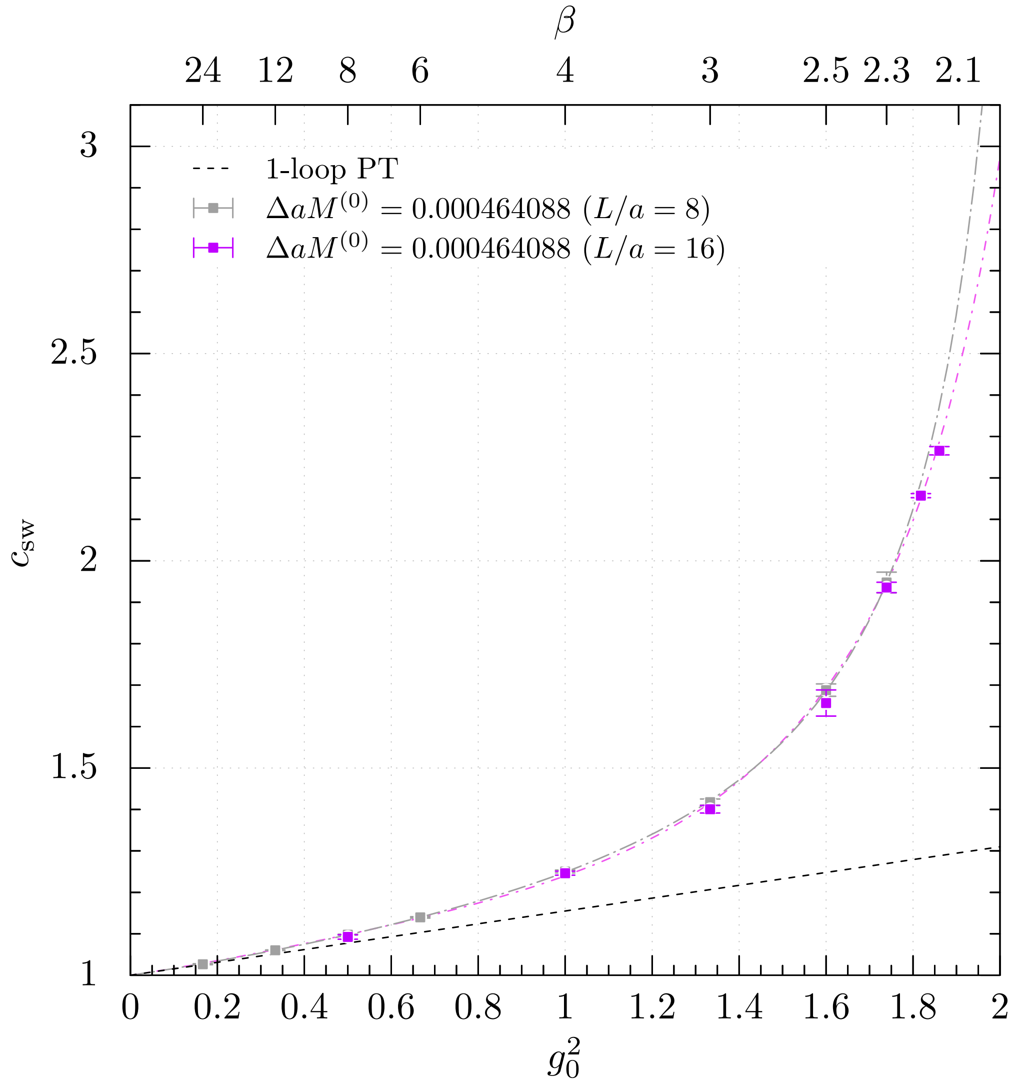
SU(2) gauge group with 2 mass degenerate Wilson fermions

HiRep on CPUs and GPUs

Non-perturbative Improvement

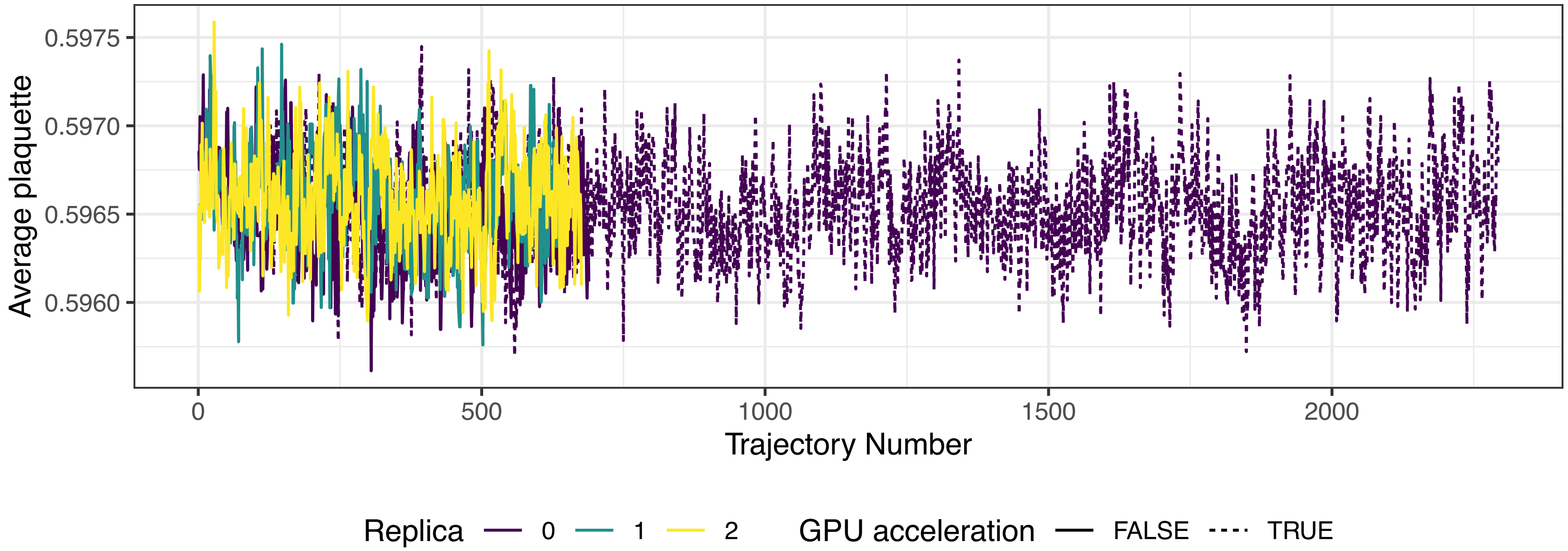
Using Schrödinger-Functional ensembles

[L. S. Bowes et. al., 2024, 2401.00589, PoS] + one additional point



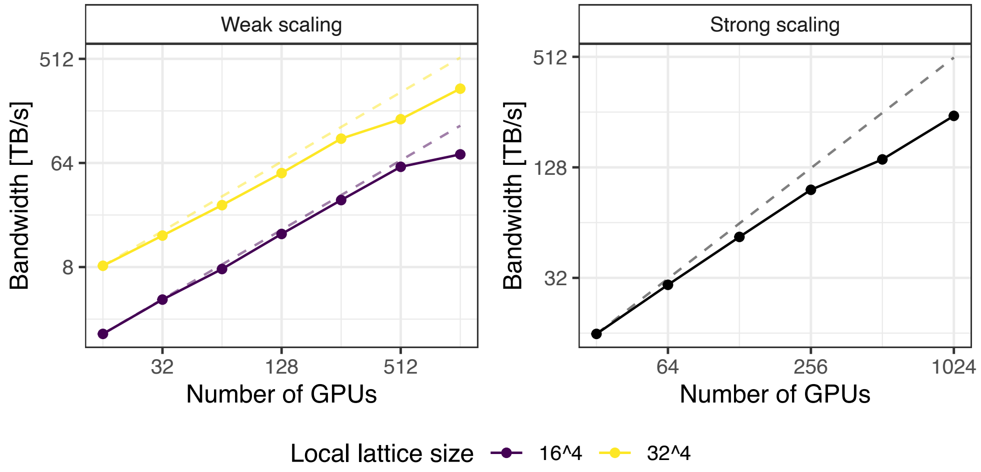
GPU ensembles

at $M_V/M_{PS} \approx 1.5$



Computational Budget
CPU (DIaL3, AMD EPYC 7742)
1 node (128 cores)
~ 1h / traj

GPU (LUMI-G, AMD MI250x)
1 node (4 GPUs)
~ 6 mins / traj



See poster on HiRep on GPUs

Analysis

Twisted mass

During measurements include a chirally rotated (*twisted mass*) term

$$D_{TM}(m, \mu_0) = D_{expclover}(m) + i\gamma_5\mu_0$$

Tuning $M_{PS}^{sea} = M_{PS}^{valence}$ and $m_{PCAC} = 0$ allows omission of renormalization constants in f_{PS}

Bare tm mass parameter

$$f_{PS} = \frac{2\mu_0\langle 0|P|\pi\rangle_{bare}}{M_{PS}^2}$$

[Hernández, Pena, Romero-López, 2019, 1907.11511, Eur. Phys. J. C]
[Shindler, 2008, 0707.4093, Phys. Rept.] and references therein

Twisted mass

Bare tm mass parameter

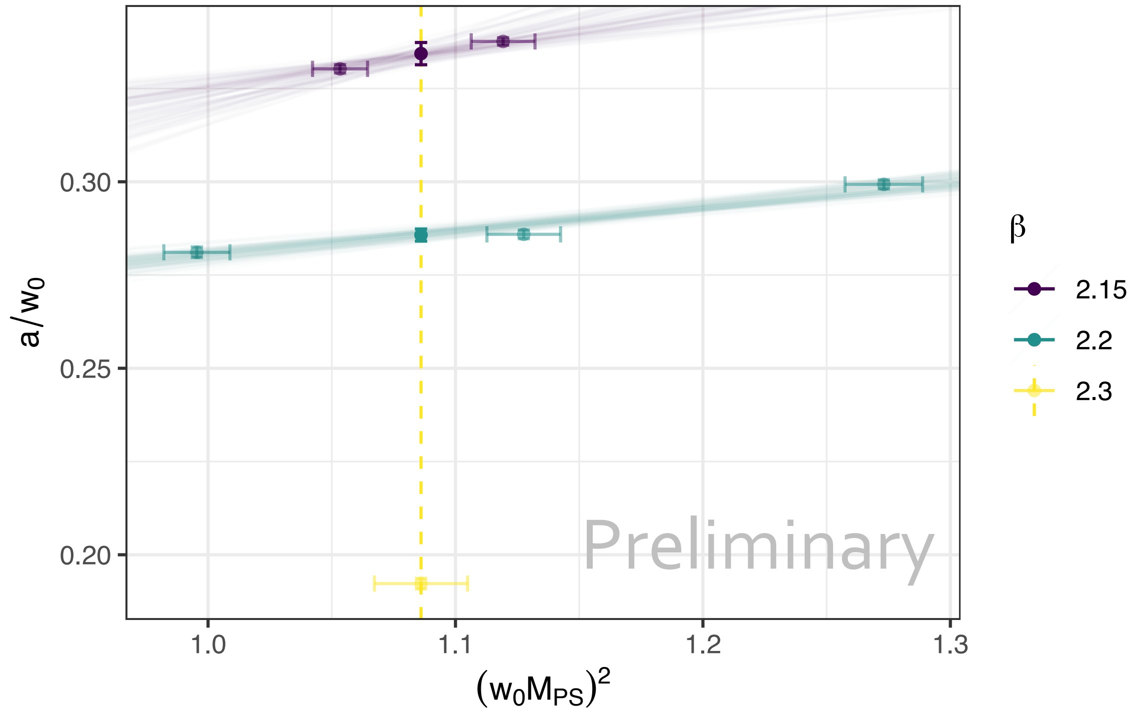
$$D_{TM} = D_{expclover} + i\gamma_5\mu_0, \qquad f_{PS} = \frac{2\mu_0\langle 0|P|\pi\rangle_{bare}}{M_{PS}^2}$$

Renormalization factor Z_A only necessary for slightly mistuned ensembles

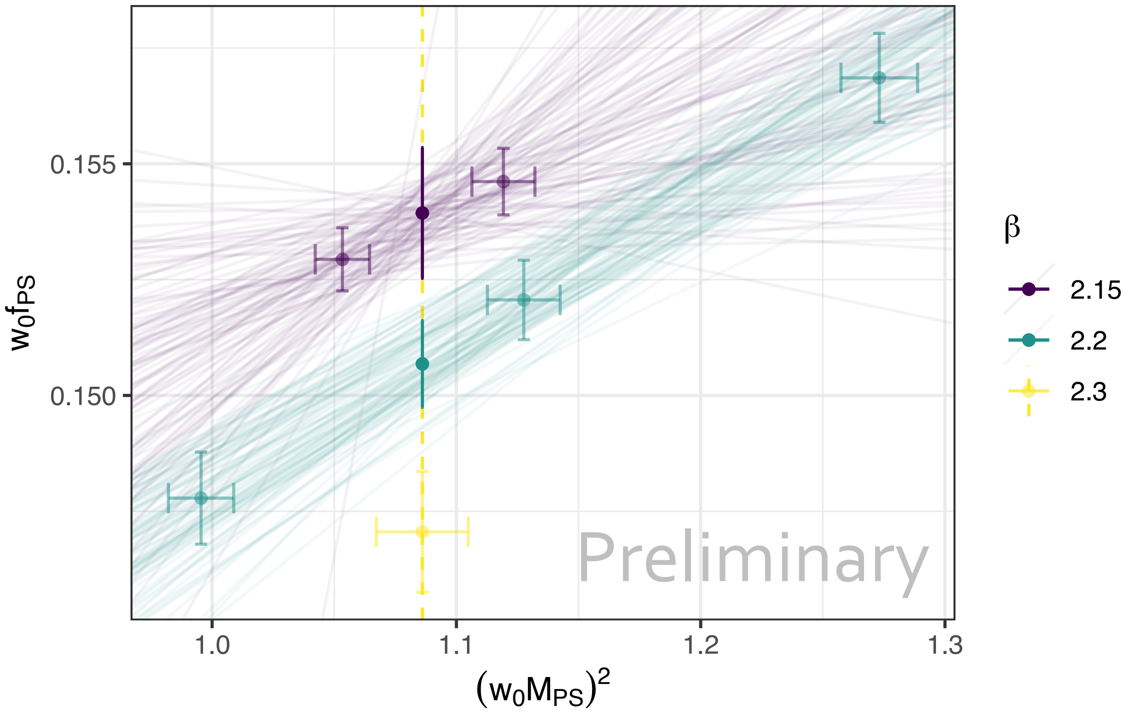
$$af_{PS} \rightarrow af_{PS}\sqrt{1 + \left(\frac{Z_A m_{PCAC}}{a\mu_0}\right)}$$

- ✓ Renormalization
- ✓ Automatic O(a)-improvement

Pseudoscalar Decay Constant f_{PS}



Interpolation to reference mass: Lattice spacing



Lattice $48{\times}24^3$, $M_{PS}L = 6.7$ to 8.4

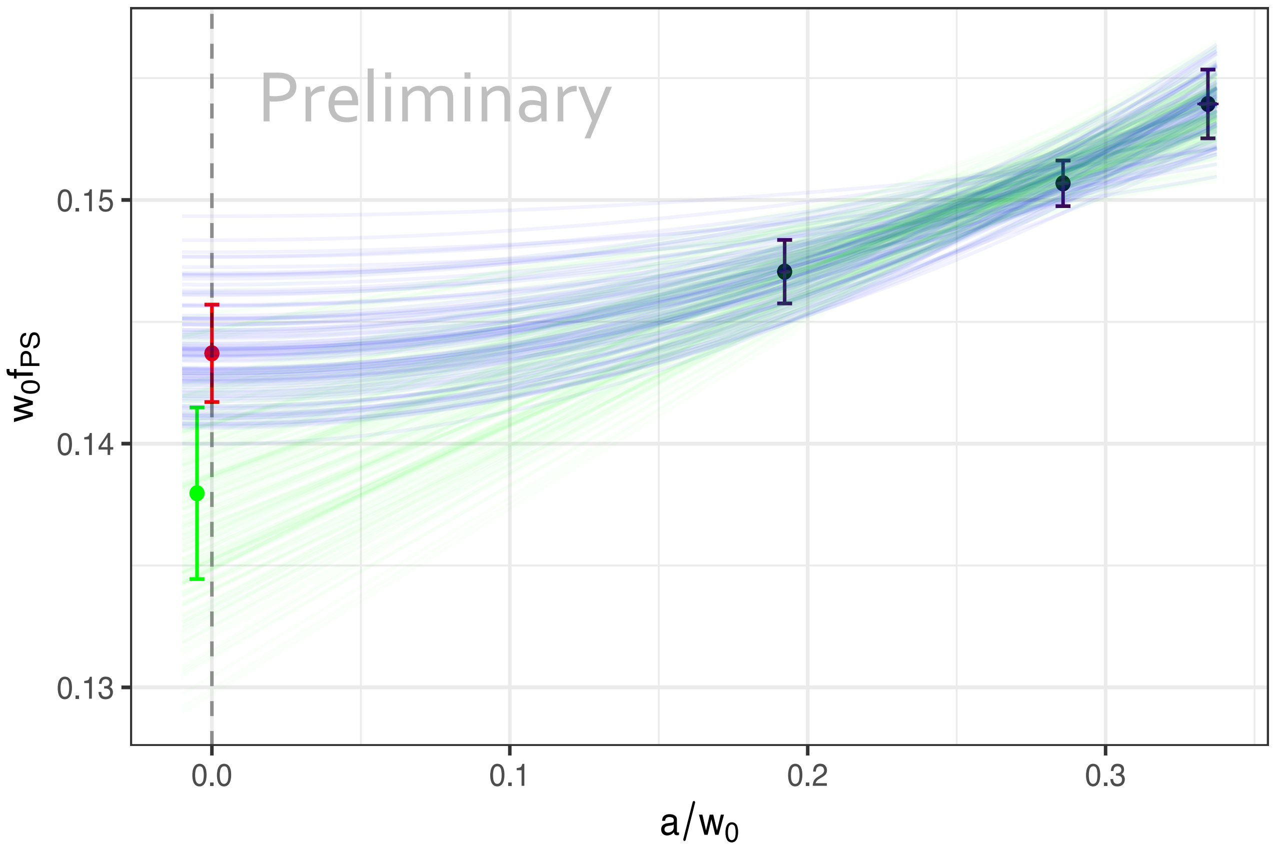
Reference lattice 36^4, $M_{PS}L = 7.2$

Smearing radius $r \leq 0.4L$

Results

Continuum limit

- Another point missing for proving that the effects are O(a^2)
- Result from linear behavior almost agrees with the result from quadratic fits
- Discretization effects are <10%
- Previously: NP-renormalized f_{PS} + Wilson fermions ≈ 30%



$w_0 f_{PS}$=0.1436(19) at $(w_0 M_{PS})^2$=1.09(2)

$$O(a^2) = 0.089(20)\frac{a^2}{w_0^2}$$

Summary & Outlook

- We took the continuum limit for f_{PS} at fixed $w_0 M_{PS}$
- We see only small $O(a^2)$-effects and achieved high precision

Questions

- One more point to really understand the continuum limit scaling?
- Larger and chiral ensembles on the GPU?

Outlook

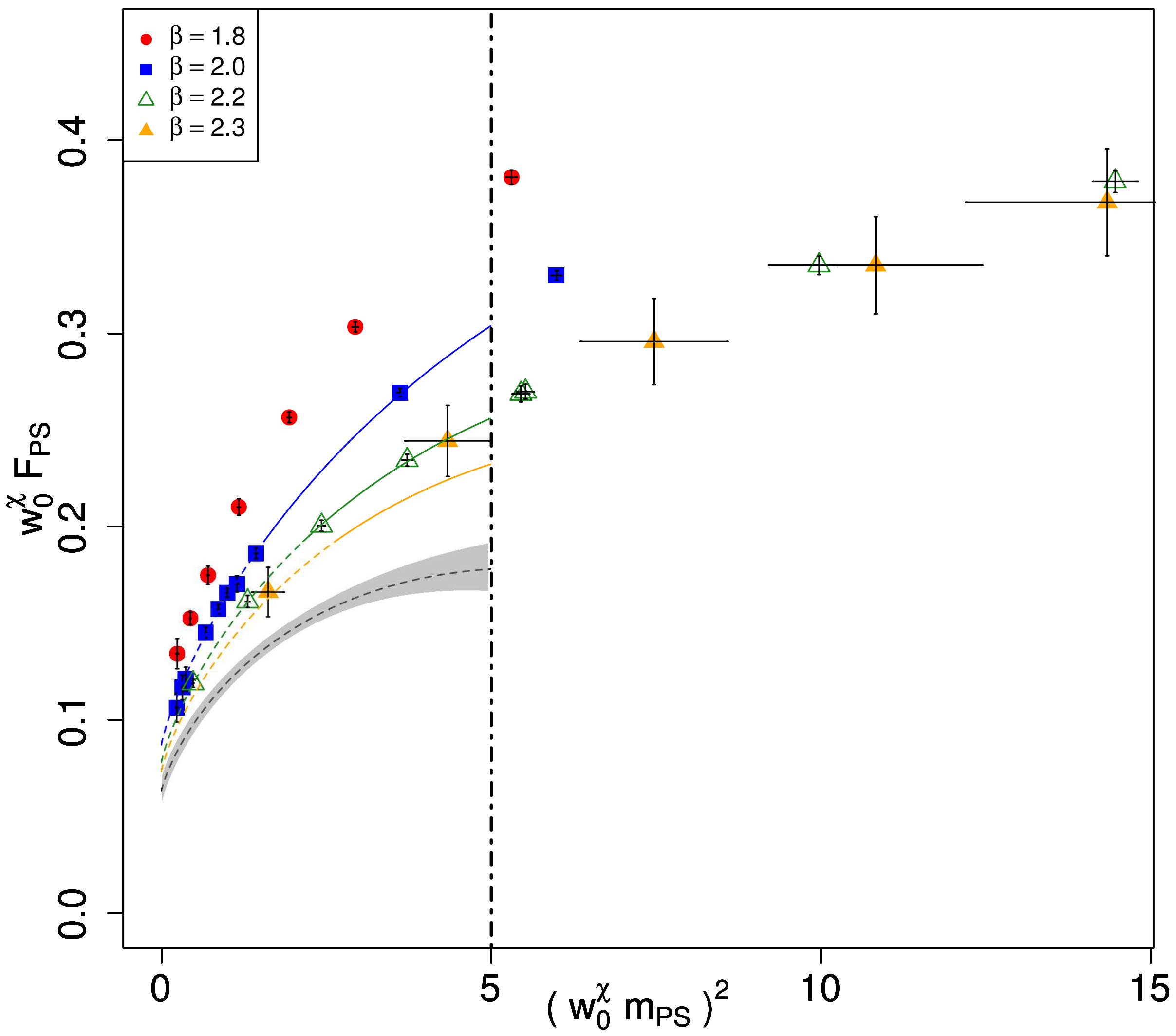
- Stay tuned for more really chiral simulations and a full scattering analysis

Backup

Ensemble Overview

Lattice	β	m	w_0/a	aM_{PS}	af_{PS}
48×24^3	2.15	−0.2645	3.028(11)	0.3390(14)	0.05051(14)
48×24^3	2.15	−0.2624	2.962(9)	0.3572(18)	0.05220(19)
48×24^3	2.2	−0.269	3.558(18)	0.2804(13)	0.04154(19)
48×24^3	2.2	−0.2657	3.498(15)	0.3036(16)	0.04348(17)
48×24^3	2.2	−0.26	3.341(14)	0.3377(16)	0.04695(21)
36^4	2.3	−0.29	5.201(39)	0.2004(9)	0.02827(14)

Previous results from [1602.06559]



In the given region, the discretization effects are at 30% of the total f_{PS}, now we achieve < 10%