2-flavour SU(2) Gauge Theory with Exponential Clover Fermions

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Standard Model Challenges

SM Experimental Challenges

- Muon $g-2$
- Dark Matter
- Neutrino Masses

SM Theoretical Challenges

- **Naturalness and Hierarchy Problems**
- **Triviality**
- 28 unexplained input parameters, origin of generations, ...

Models of particle physics where the Higgs boson is composite are proposed to tackle the NP/HP and triviality.

Composite Higgs Models

- Introduce a new sector into the SM, to give a dynamical origin to the electroweak spontanous symmetry breaking
- The Higgs emerges as either a pseudo-Nambu-Goldstone boson or as a light scalar resonance. These are not mutually exclusive, and the amount of mixing between the two scenarios is controlled by the vacuum misalignment angle θ.
- Scattering processes involving a potential new strong sector are expected to be testable at the LHC, for example in the vector boson channel.

> "...ICFA reconfirms the international consensus on the importance of a Higgs Factory as the highest priority for realizing the scientific goals of particle physics ..."
>
> — International Committee on Future Accelerators, 2022

Research Aims

Long Term Goal

Understand how the properties of resonances in the composite Higgs scenario would change the observable Higgs boson phenomenology at the LHC.

$SU(2)$ with 2 Fundamental Flavours

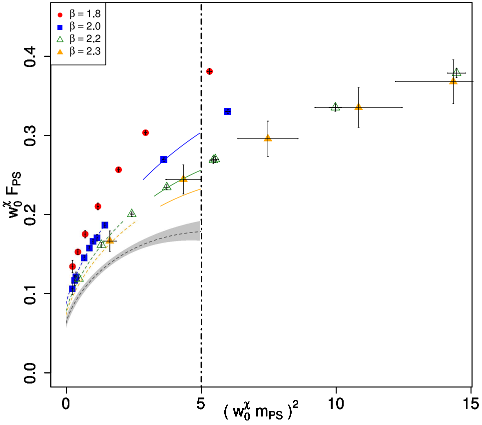
Continuum Theory

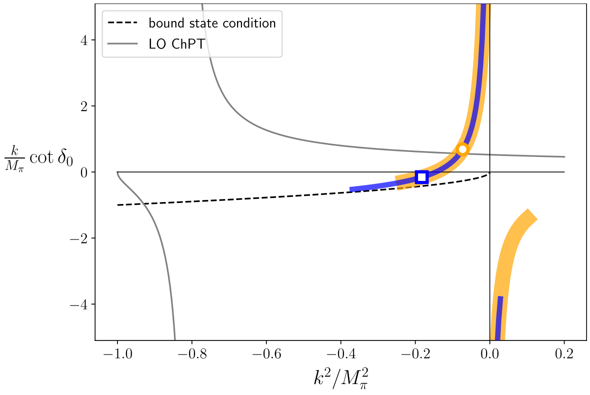
$$\mathcal{L} = -\frac{1}{4}F^a_{\mu\nu}F^{\mu\nu}_a + \overline{\mathfrak{u}}(i\gamma^\mu D_\mu - m)\mathfrak{u} + \overline{\mathfrak{d}}(i\gamma^\mu D_\mu - m)\mathfrak{d}$$

- Pseudoreal fundamental representation gives rise to the flavour symmetry breaking structure $SU(4)_f \to Sp(4)_f$
- Can build testable composite Higgs models which are not excluded by experiment.

Previous Work

Previous spectroscopic results [1602.06559] were plagued with order-a effects. In addition, the singlet state was shown to be stable up to $\frac{m_v}{m_{ps}} < 2.5$ in [2107.09974], so this is the threshold we are aiming at.





Lattice Setup

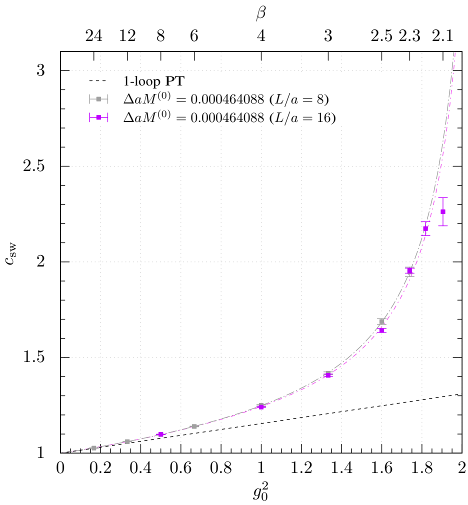
- Plaquette Gauge Action
- Exponential Clover Wilson Fermions [1911.04533]

$$M_0 + C_{SW}\frac{i}{4}\sigma_{\mu\nu}\hat{F}_{\mu\nu} \;\rightarrow\; M_0 \exp\left[\frac{C_{SW}}{M_0}\frac{i}{4}\sigma_{\mu\nu}\hat{F}_{\mu\nu}\right].$$

  - Enforces the diagonal part of the Wilson-Dirac operator to be positive and gapped above zero, enhancing numerical stability.
  - $O(a)$ improvement once C_{SW} is tuned non-perturbatively.
- Set the scale for the ensembles using the Wilson gauge flow.
- Simulations performed in the HiRep suite [github.com/claudiopica/HiRep]

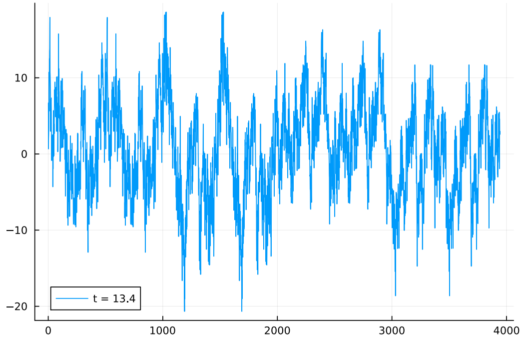
Tuning of C_{SW}

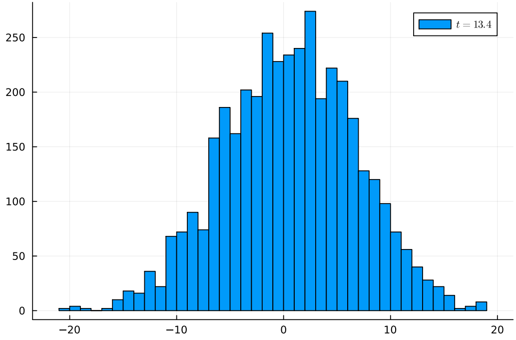
- **Non-perturbative** tuning of C_{SW} via Schrodinger functional simulations
- A vast amount of our time spent tuning (hundreds of thousands of trajectories)
- Find a value for k_{crit} by tuning $M = M_0$, and then find C_{SW} at k_{crit} by tuning $\Delta M = \Delta M_0$.



Ensembles

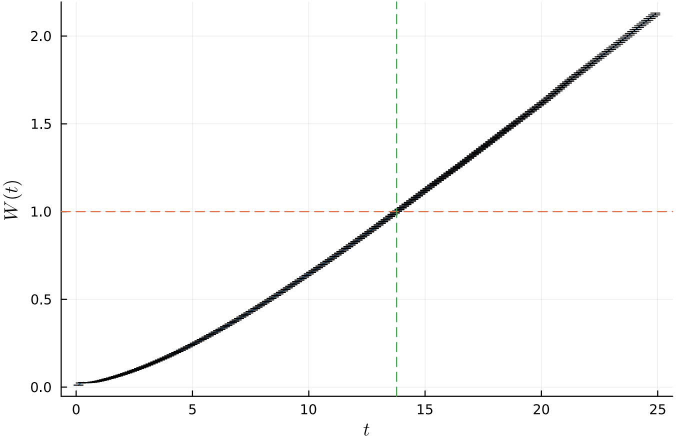
- All ensembles used have $Lm_{ps} > 5$
- Used lattice spacings $\beta = 2.2, 2.3$
- Shown below is the topological charge for an ensemble at our finest lattice spacing $\beta = 2.3$.





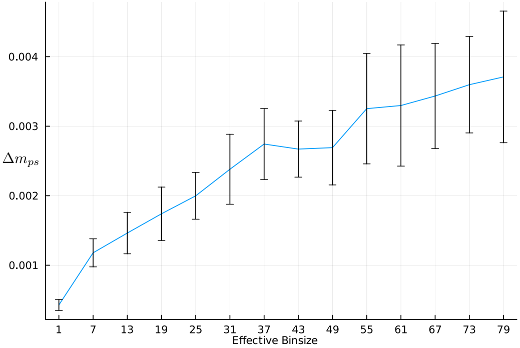
Wilson Flow

- Very precise way of defining a relative scale between ensembles
- We use $W(t) := t\mathcal{E}'(t)$, $W(w_0^2) = 1.0$ to set the scale.

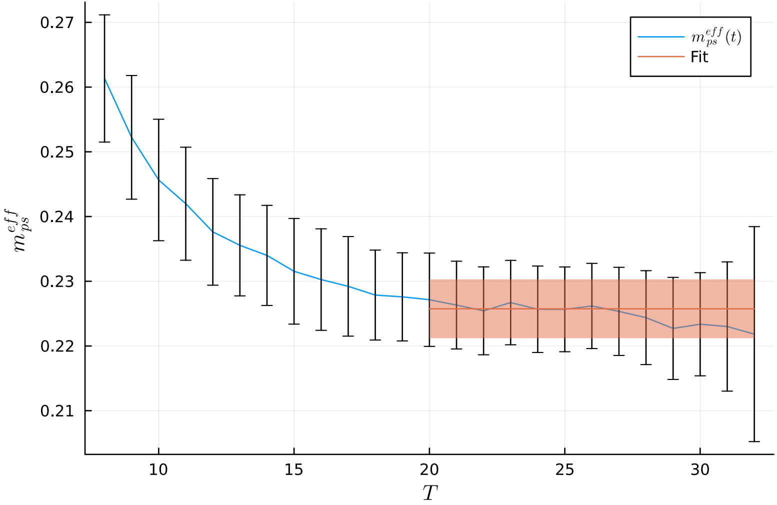


Errors and Autocorrelations

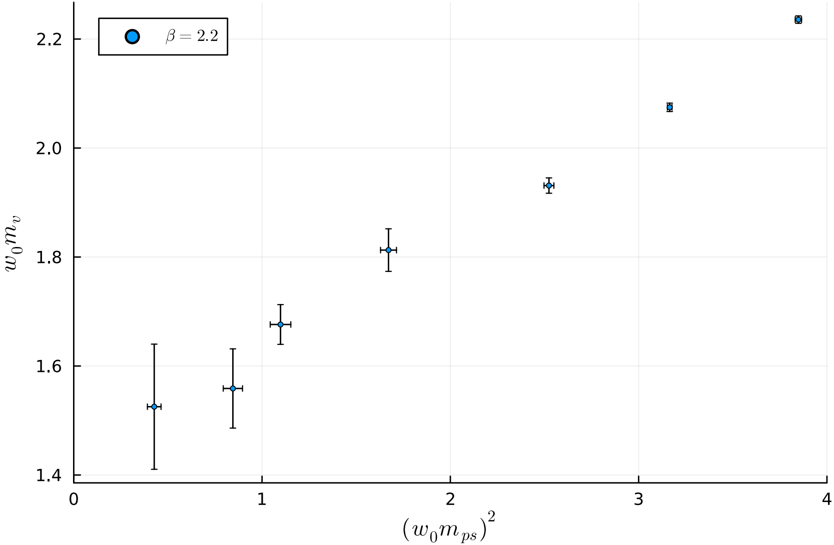
- Use effective bins to remove autocorrelations
- Tuning the correct binsize is expensive and requires three levels of bootstrap, and for short runs can be temperamental
- In the future, want to estimate errors in a more robust way, such as the Γ-method.



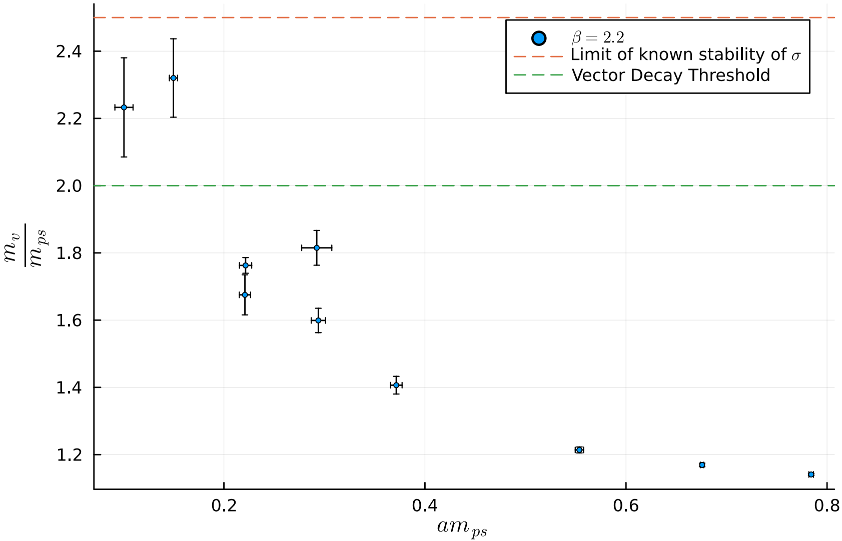
Effective Masses



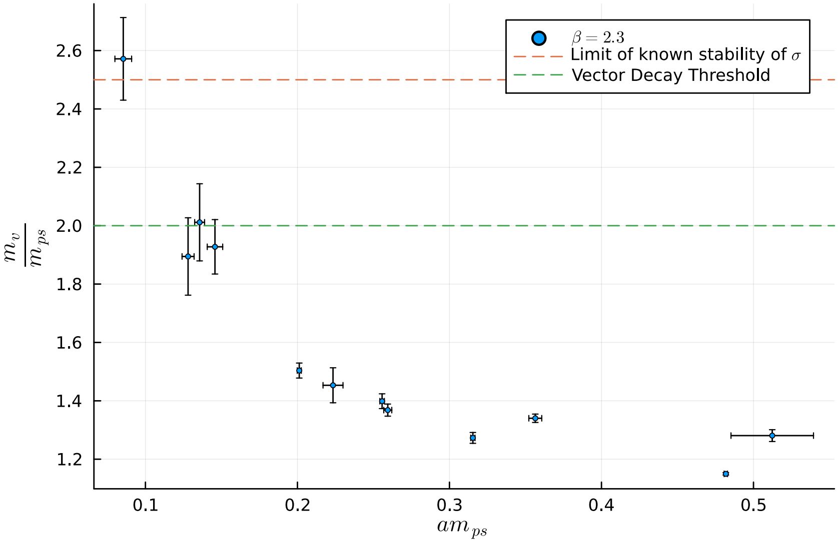
Vector mass against pseudoscalar mass squared



Ratio of vector mass to pseudoscalar mass at $\beta = 2.2$



Ratio of vector mass to pseudoscalar mass at $\beta = 2.3$



Conclusions

- We are working on obtaining more data at more values of β, and soon we will be able to take the continuum limit at fixed pion mass.
- We are now clearly in a region where the decays of the vector meson and the sigma resonance can be studied, which is phenomenologically very exciting. This is what we will now be undertaking. Thank you for listening!

Backup: Tuning of C_{SW}