Setting the scale of HISQ ensembles

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On behalf of
the Fermilab lattice and MILC working group

Massachusetts Institute of Technology

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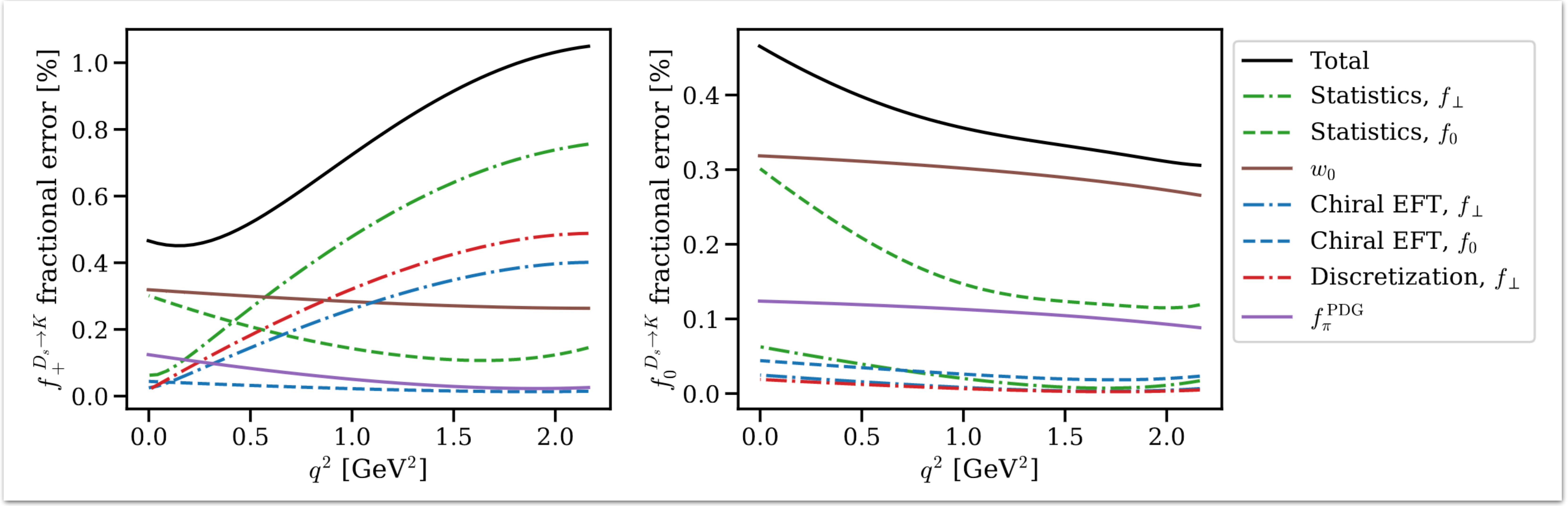
Scale setting for precision physics

For semileptonic D decay processes, the scale setting error is one of the dominant sources of uncertainties.



Fermilab Lattice and MILC. arXiv:2212.12648

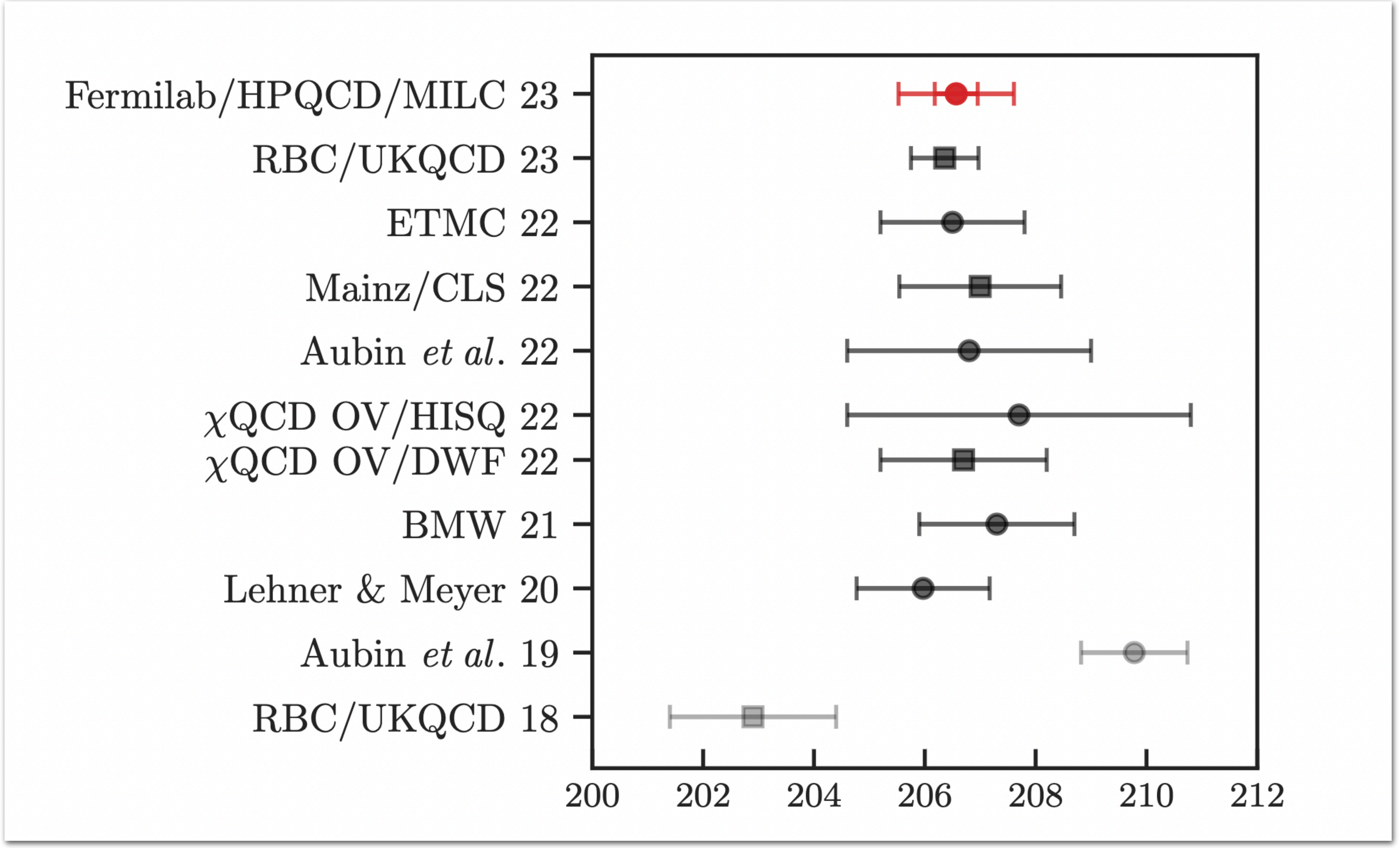
Error (%)	m_b/m_c	m_c/m_s	m_b/m_s	$m_{s,\overline{\mathrm{MS}}}$(2 GeV)	$\overline{m}_c$	$\overline{m}_b$	$\overline{\Lambda}_{\mathrm{MRS}}$
Statistics and EFT fit	0.10	0.09	0.11	0.43	0.31	0.29	4.6
Two-point correlator fits	0.07	0.01	0.08	0.07	0.05	0.00	1.3
Scale setting and tuning	0.02	0.14	0.16	0.18	0.03	0.02	0.2
Finite-volume corrections	0.00	0.02	0.01	0.01	0.01	0.00	0.0
Topological charge distribution	0.01	0.00	0.00	0.01	0.01	0.01	0.2
Electromagnetic corrections	0.12	0.11	0.01	0.01	0.08	0.00	0.0
α_s	0.01	0.00	0.01	0.56	0.75	0.18	2.9
$f_{\pi,\mathrm{PDG}}$	0.03	0.07	0.10	0.12	0.04	0.02	0.2

Fermilab Lattice, MILC, TUMQCD. arXiv:1802.04248

For quark masses, the scale setting error is also a dominant source of error.

Scale setting for muon g-2

Precision scale setting on HISQ to constrain the leading order HVP to muon g-2



$$\frac{\Delta a_{hvp}}{a_{hvp}} \approx 2\left(\frac{\Delta\Lambda}{\Lambda}\right)$$

M. Della Morte et al. [arXiv:1705.01775]()

A sub-percent scale determination, **accounting for all systematics**, is needed.

Connected light quark contribution to the intermediate window observable

Fermilab Lattice, HPQCD, MILC. [arXiv: 2301.08274]()

Gradient flow scales on HISQ

Gradient flow scales

- Smoothening procedure, Lüscher, 1006.4518:

$$\frac{dV_{x,\mu}}{dt} = -\left\{\partial_{x,\mu} S^f(t)\right\} V_{x,\mu}, \quad V_{x,\mu}(t=0) = U_{x,\mu},$$

where the flow action $S^f = S_{Wilson}$ or $S^f = S_{Symanzik}$

- Scale setting:

$$t^2 \langle S^o(t) \rangle \Big|_{t=t_0} = Const \quad \text{or} \quad \left[t \frac{d}{dt} t^2 \langle S^o(t) \rangle \right]_{t=w_0^2} = Const,$$

where the observable $S^o = S_{clover}$ or $S^o = S_{Wilson}$ or $S^o = S_{Symanzik}$

Improving the lattice gradient flow

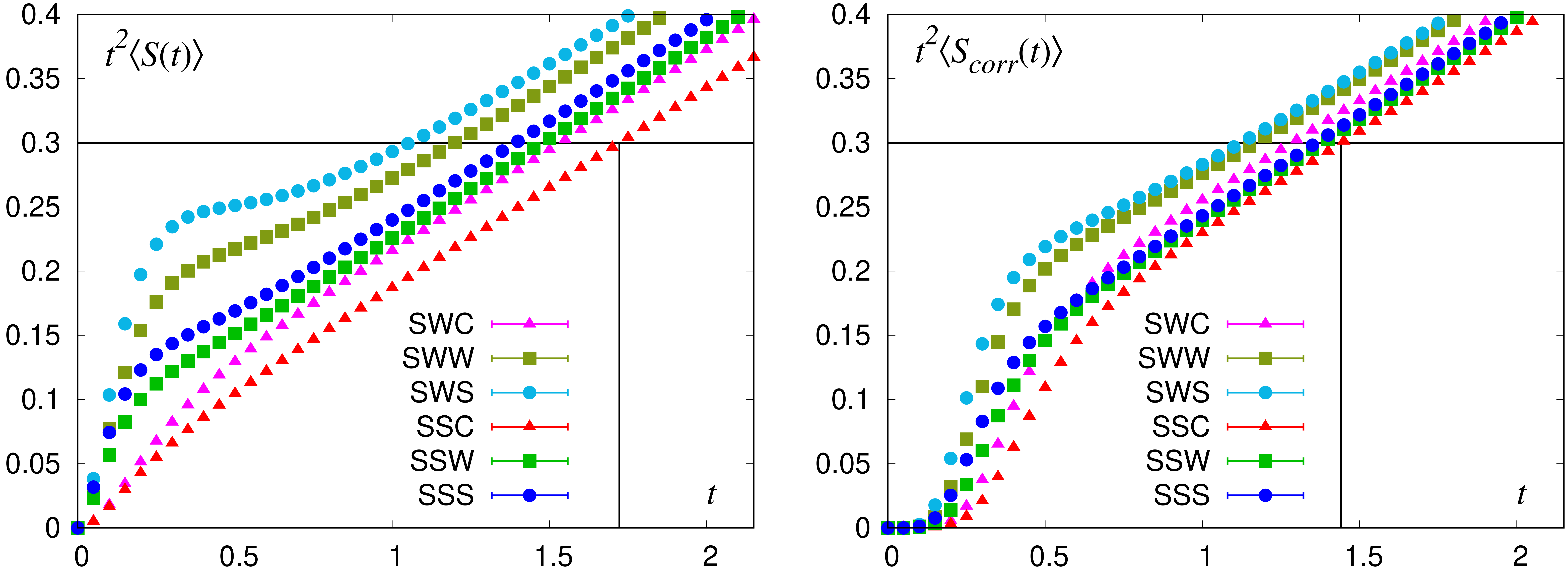
For a given combination of the dynamical action, flow action and the observable the leading discretization effects can be canceled at tree level, Fodor et al, 1406.0827:

$$t^2 S(t) \quad \rightarrow \quad t^2 S_{corr}(t) = \frac{t^2 S(t)}{1 + \sum_{m=1}^{4} C_m (a^{2m}/t^m)}$$

Parameters of the calculation

- Two flows: Wilson, Symanzik
- Observable: Clover, Wilson, Symanzik
- Tree-level corrections
- Fourth-order commutator-free Lie group integrator, 2007.04225, 2101.05320
- Integrate the flow at two step sizes 0.05, 0.025
- The flow on all MILC HISQ ensembles at $a \approx 0.09$ fm, 0.12 fm and 0.15 fm is completed, $a \leqslant 0.06$ fm is ongoing on USQCD and non-USQCD resources
- Computing time in 2023-2024 is requested for the retuned CalLat physical pion mass $a \approx 0.09$ fm ensemble the incorporated in several MILC projects

Action density vs flow time, $a \approx 0.12$ fm



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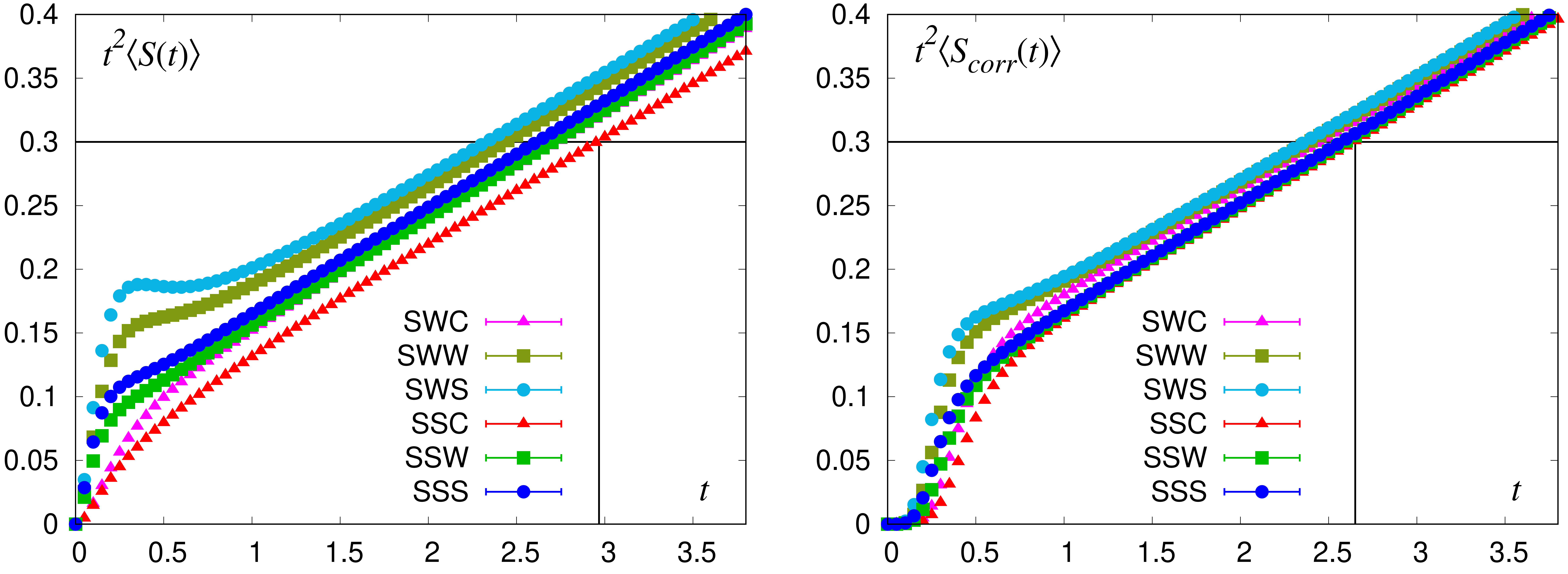
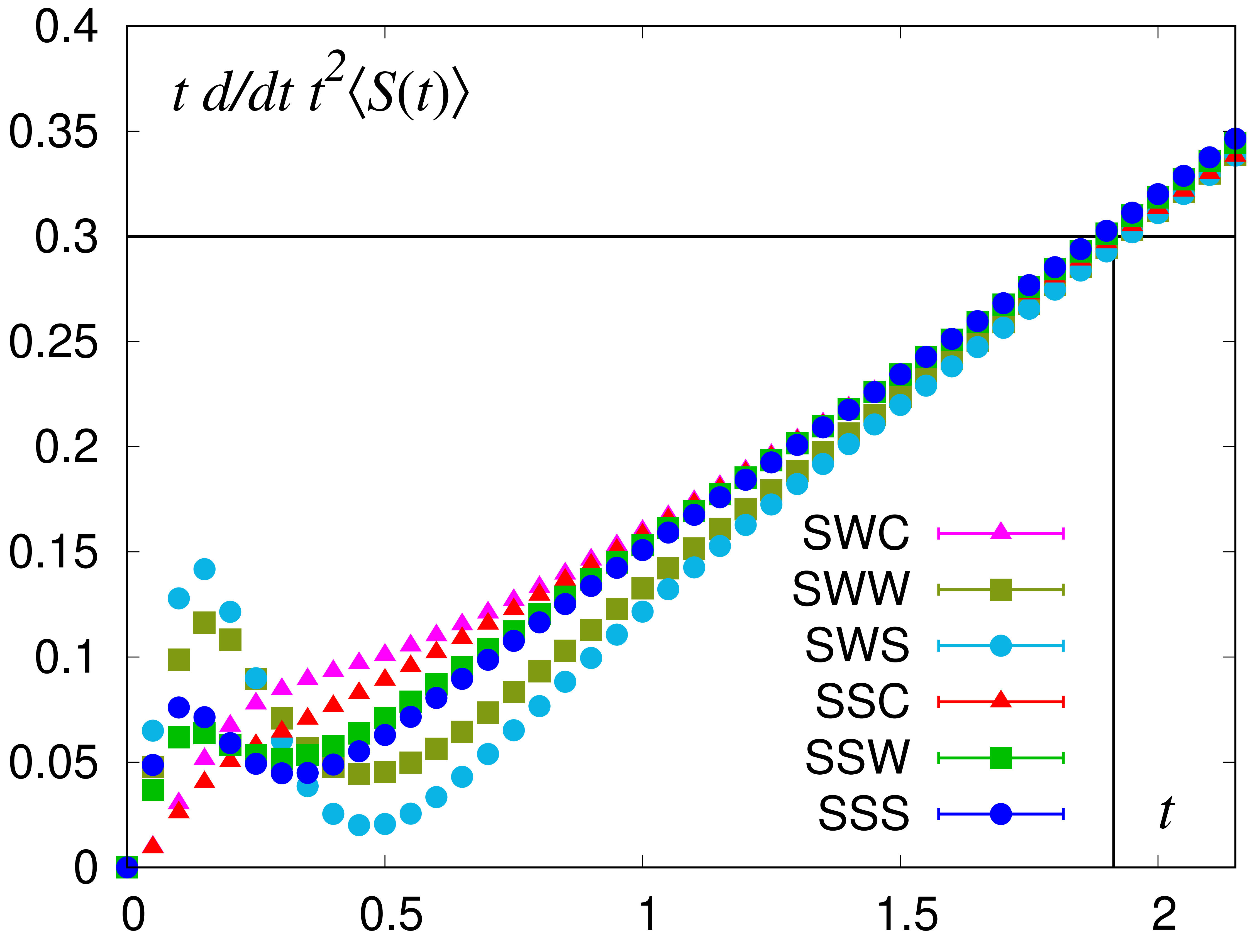
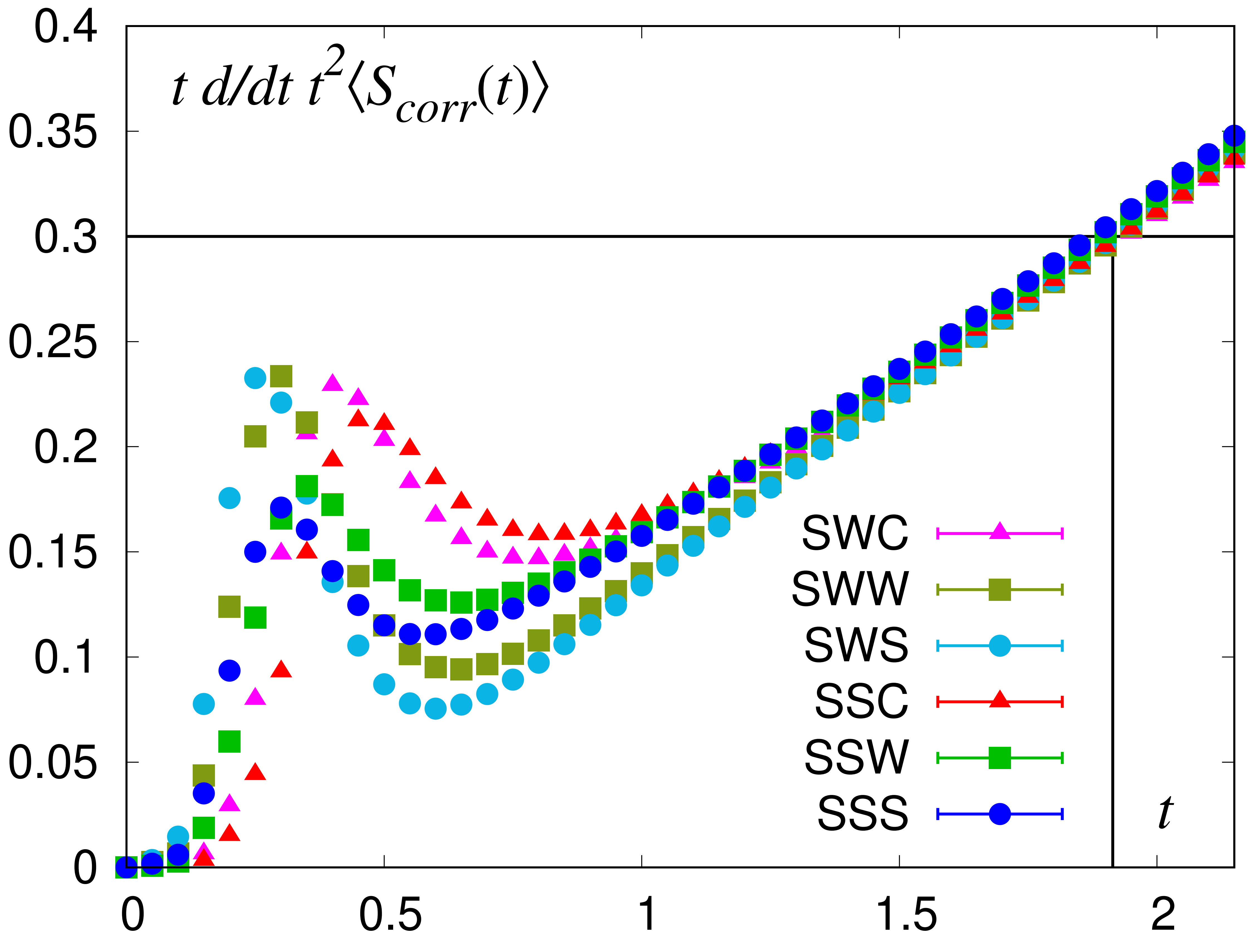
Action density vs flow time, $a \approx 0.09$ fm

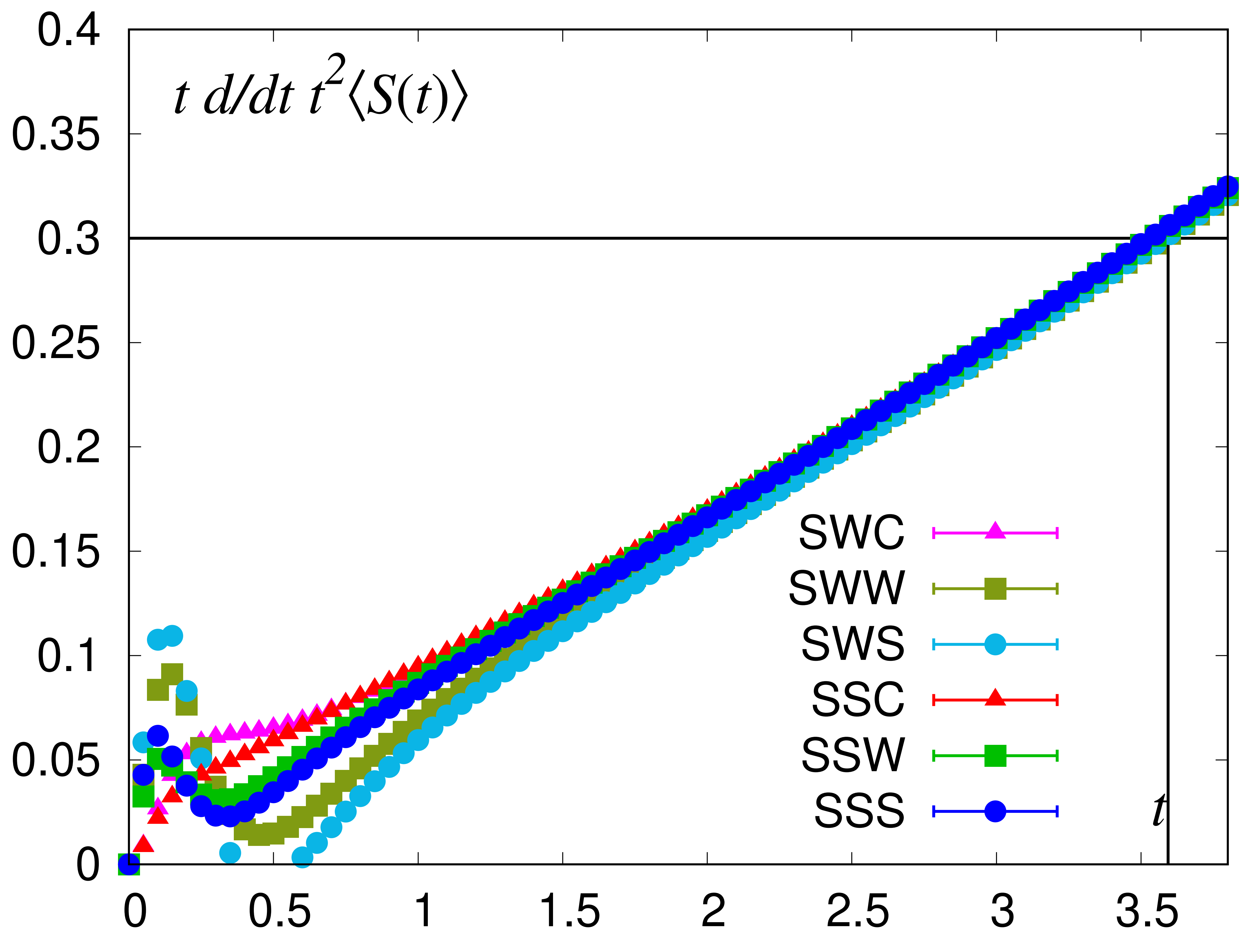


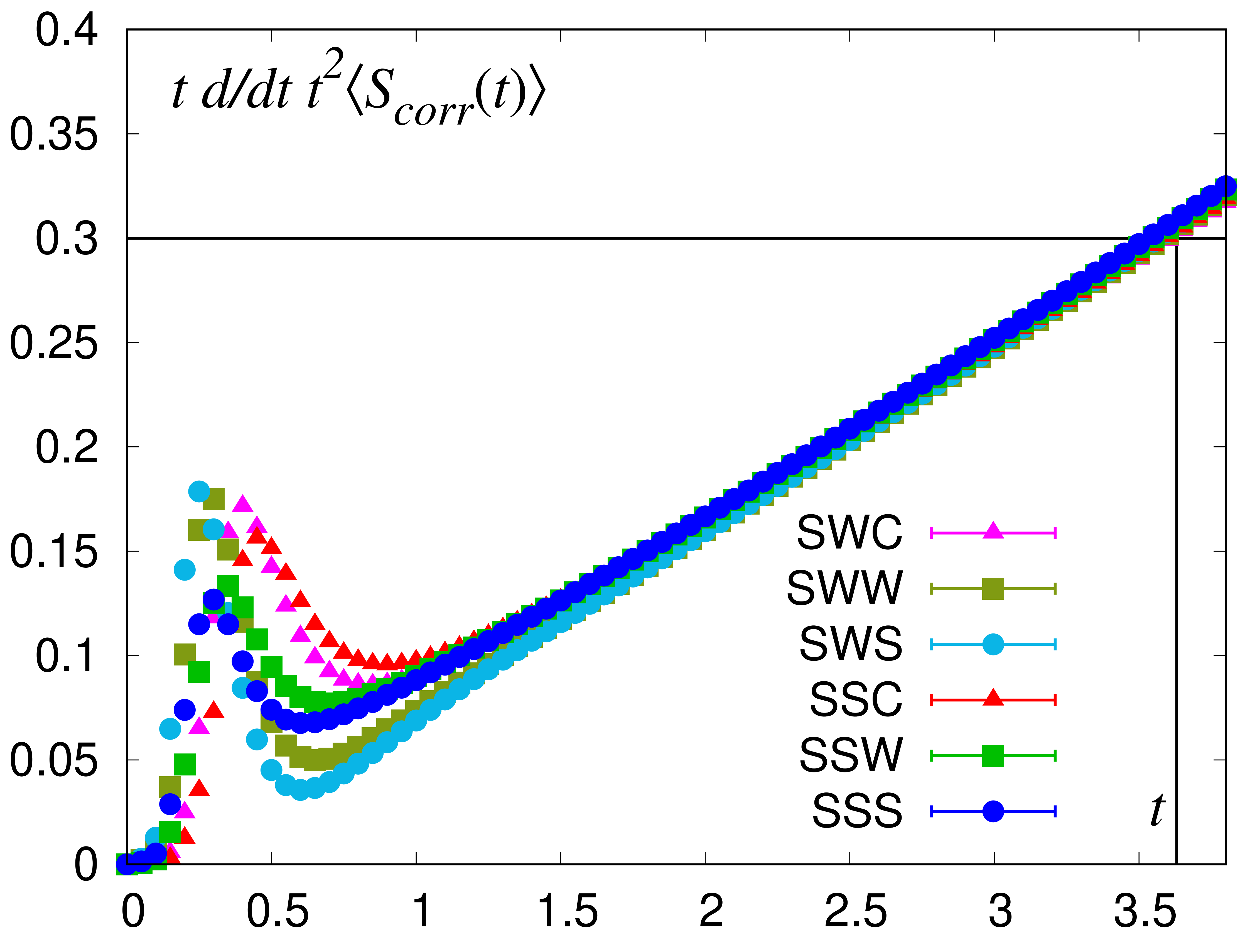
Action density vs flow time, $a \approx 0.12$ fm



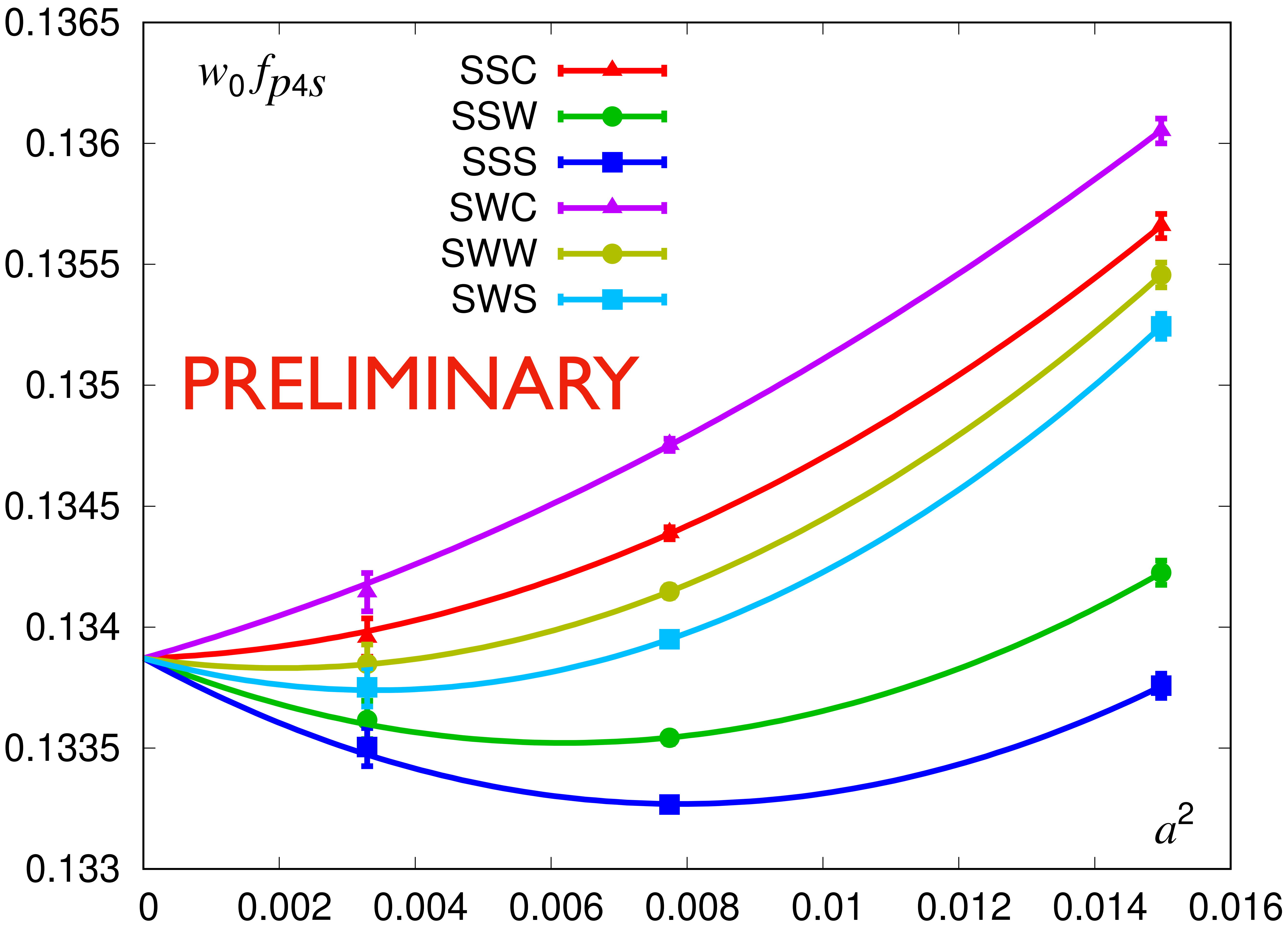


Action density vs flow time, $a \approx 0.09$ fm





Simple continuum extrapolation

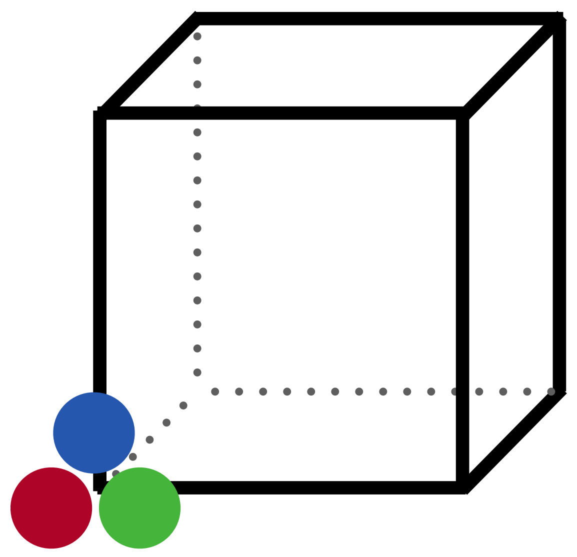


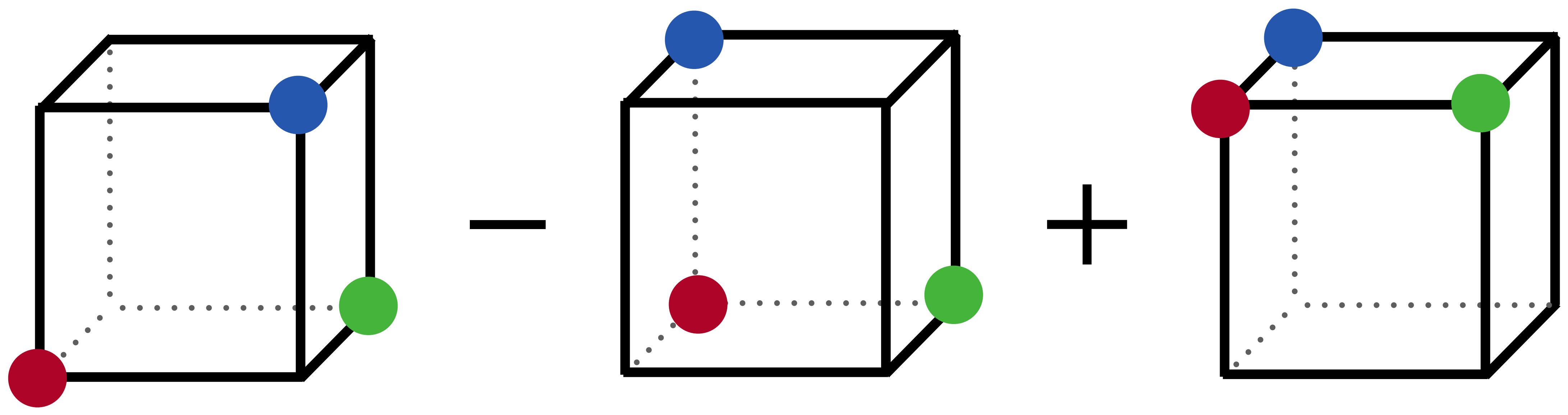
- Simultaneous fit for all six available flow/observable combinations on the physical pion $a \approx 0.06$, 0.09 and 0.12 fm ensembles
- Quadratic in a^2, 18 data points, 13 parameters with common intercept

Ω Baryons on HISQ

Details of aM_Ω on HISQ

- So far only computed on **physical-mass ensembles $a \approx$ 0.15, 0.12, 0.09, and 0.06 fm**. Cheap to compute on most ensembles
- Three Ω baryon tastes, three interpolators. J. Bailey. arXiv:hep-lat/0611023, C. Hughes, Y. Lin, A. Meyer. arXiv:1912.00028
- Two types of sources, **wall and Gaussian smeared sources**, to better constrain the excited-state contamination

$O_{\Omega,1} =$ 

$O_{\Omega,2} =$ 

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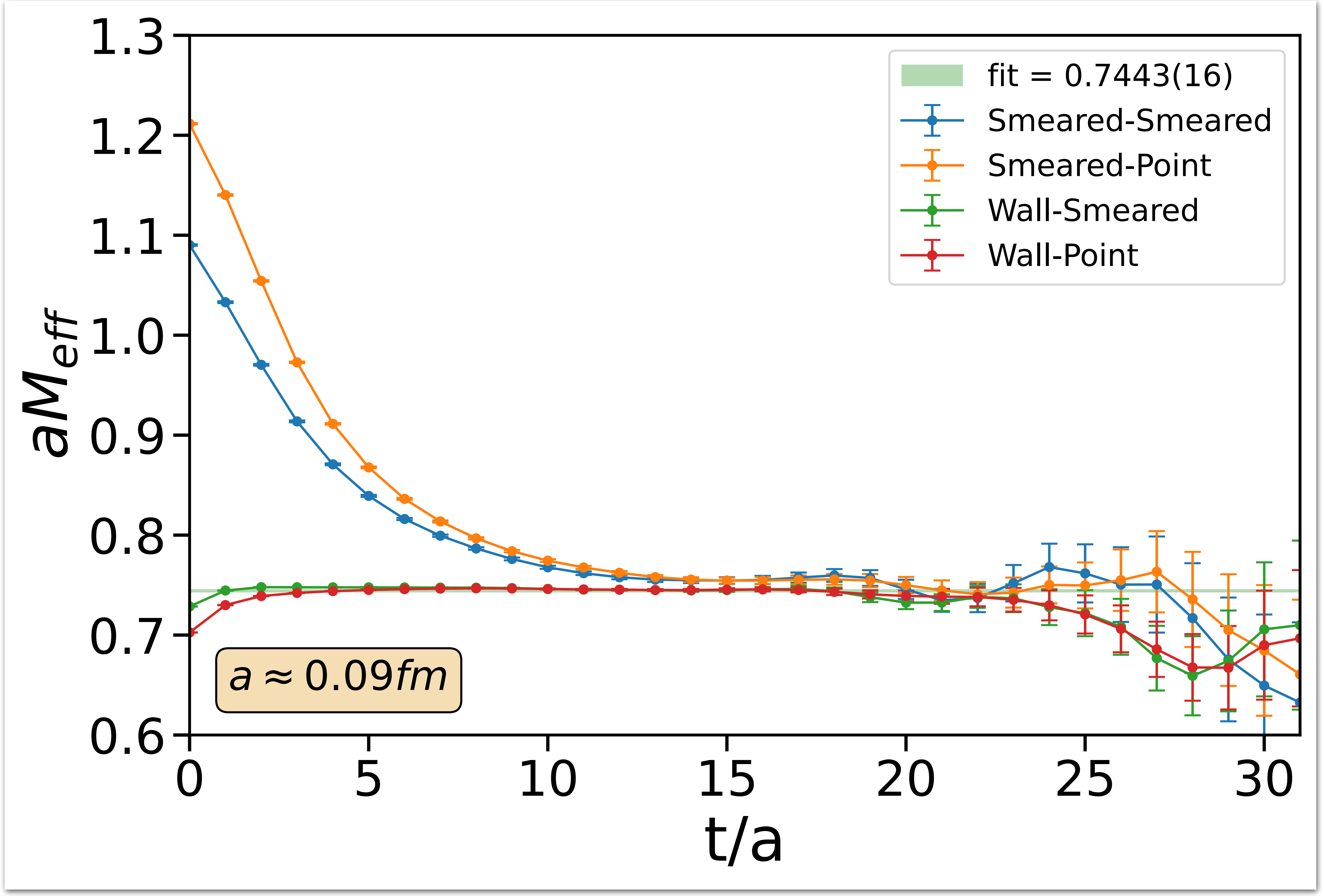
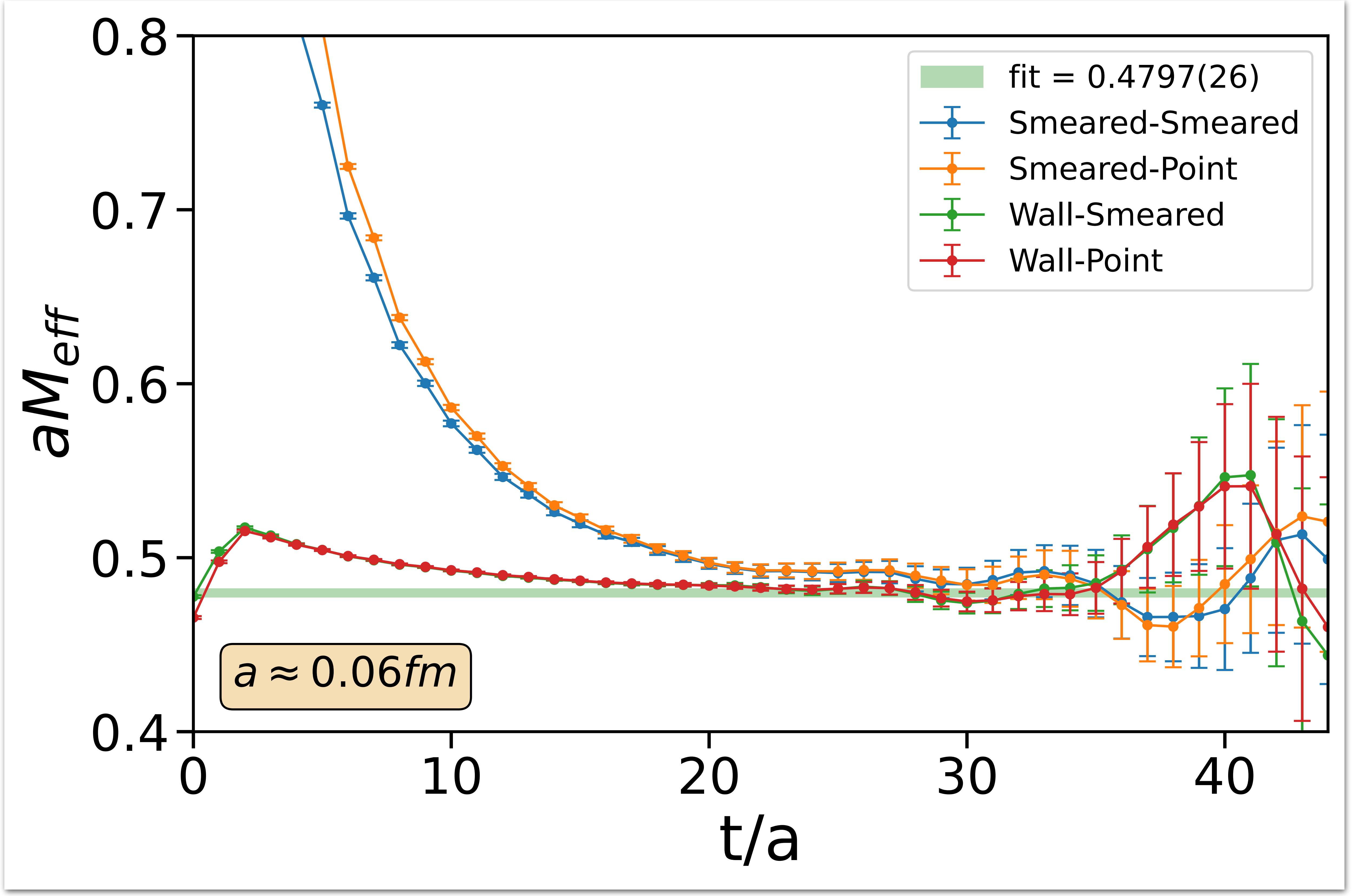
aM_Ω, $a \approx 0.09,\ 0.06$ fm physical masses

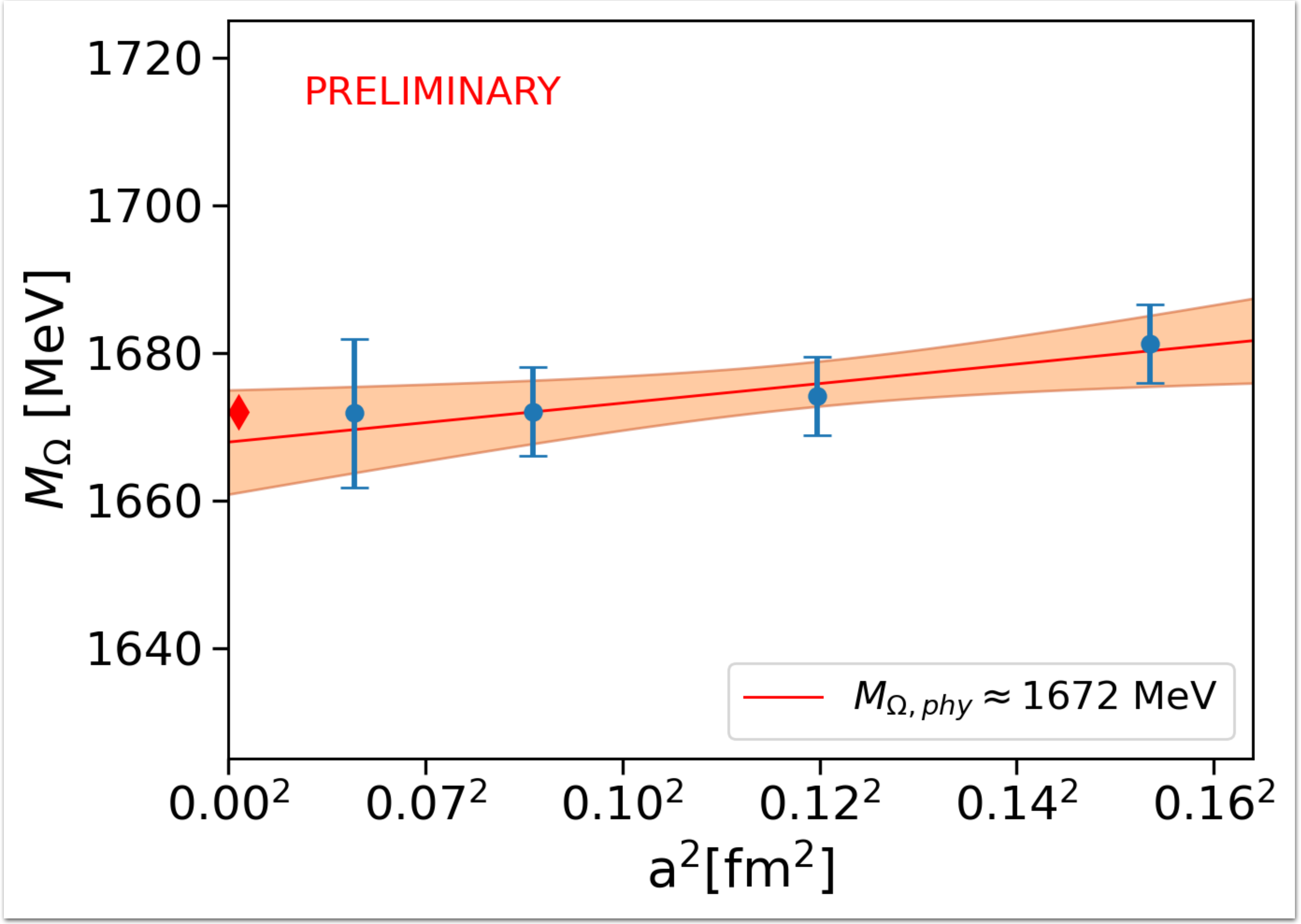




error ≈ 0.2%

error ≈ 0.5%

Simple continuum extrapolation of M_Ω

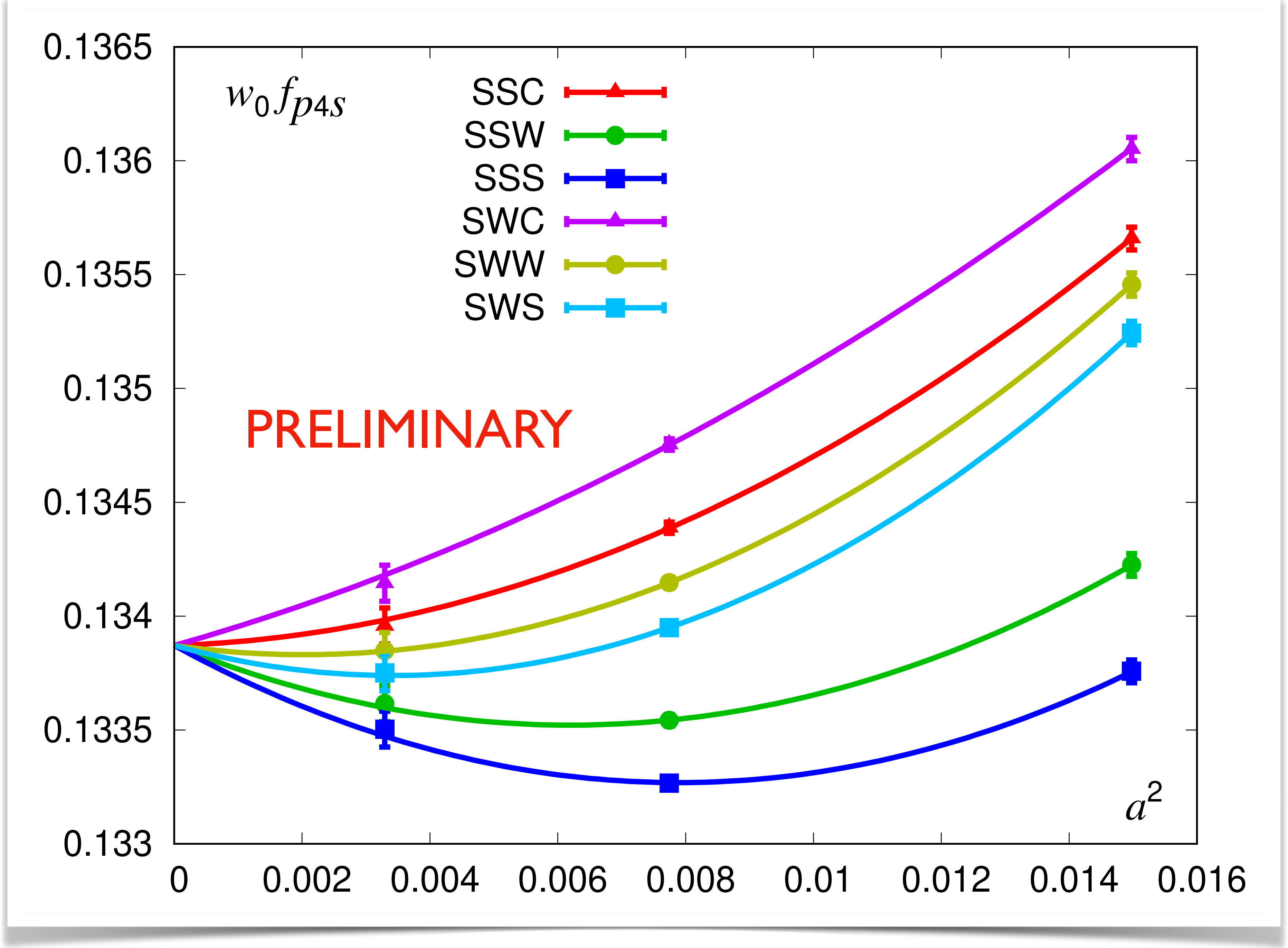


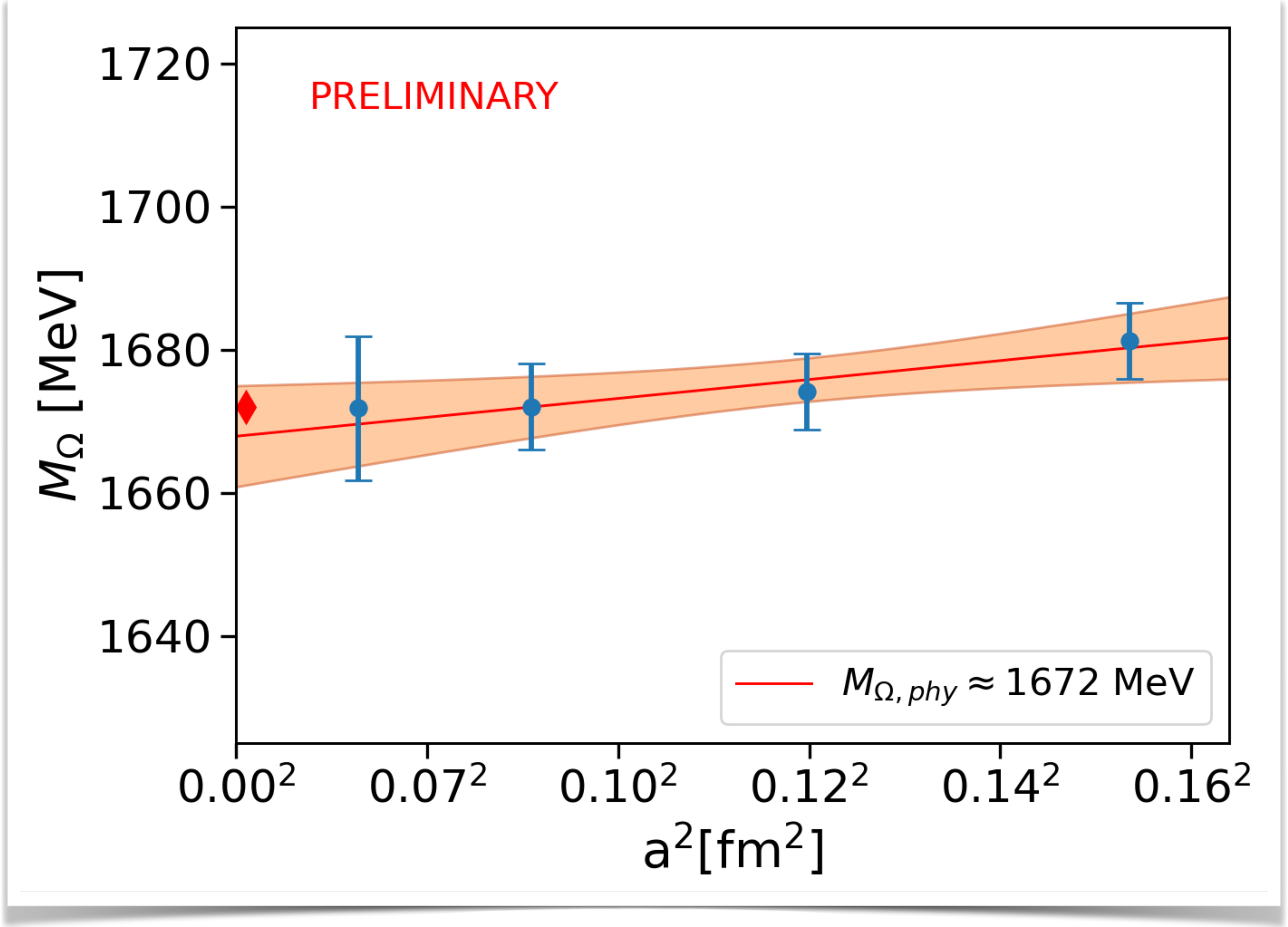
- Preliminary fit result:

  $M_\Omega = 1668(7)$ **MeV**

- **error ≈ 0.4%** — on par/ better with the current best lattice determinations
- More statistics are being added
- **Systematic errors** are important

Summary and outlook





- Perform measurements of the retuned a ≈ 0.09 fm from CalLat
- Continue accumulating statistics on a ≤ 0.06 fm ensembles with external resources

- Constraining the isospin breaking effects on a ≈ 0.12, 0.09 fm ensembles
- Continuing accumulating statistics