Precision determination of B_c and B_c^* meson decay constants from lattice QCD

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Work with

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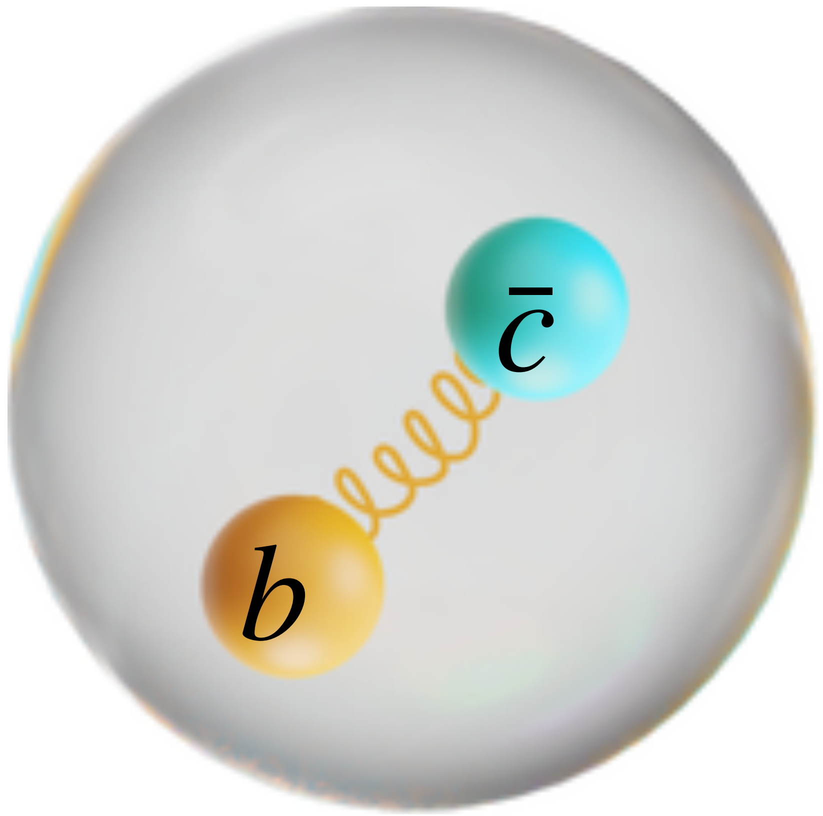
B_c meson

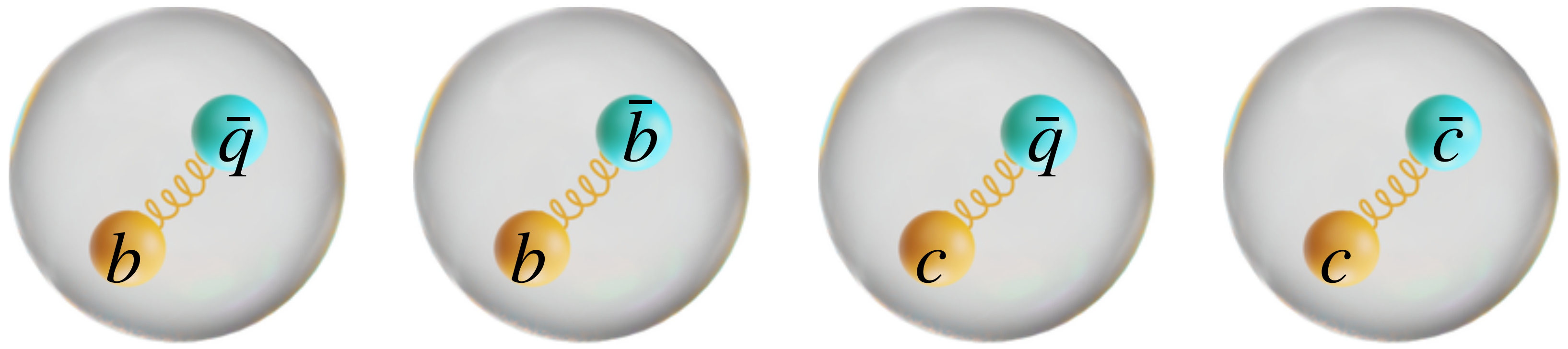


- Only meson composed of two different heavy quarks
- Unique laboratory for two-scale heavy-quark dynamics

- Large B_c samples at the LHC (More in future LHC, FCC)
- Precision studies of leptonic decays becoming feasible

- Purely leptonic decay, $\bar{B}_c \to l\bar{\nu}$, all hadronic effects encoded in a single decay constant
- Useful in accurate determinations of $|V_{cb}|$ (next slide)

Combines features of heavy-light mesons and heavy quarkonia
A unique heavy-heavy system connecting precision flavour physics and lattice QCD

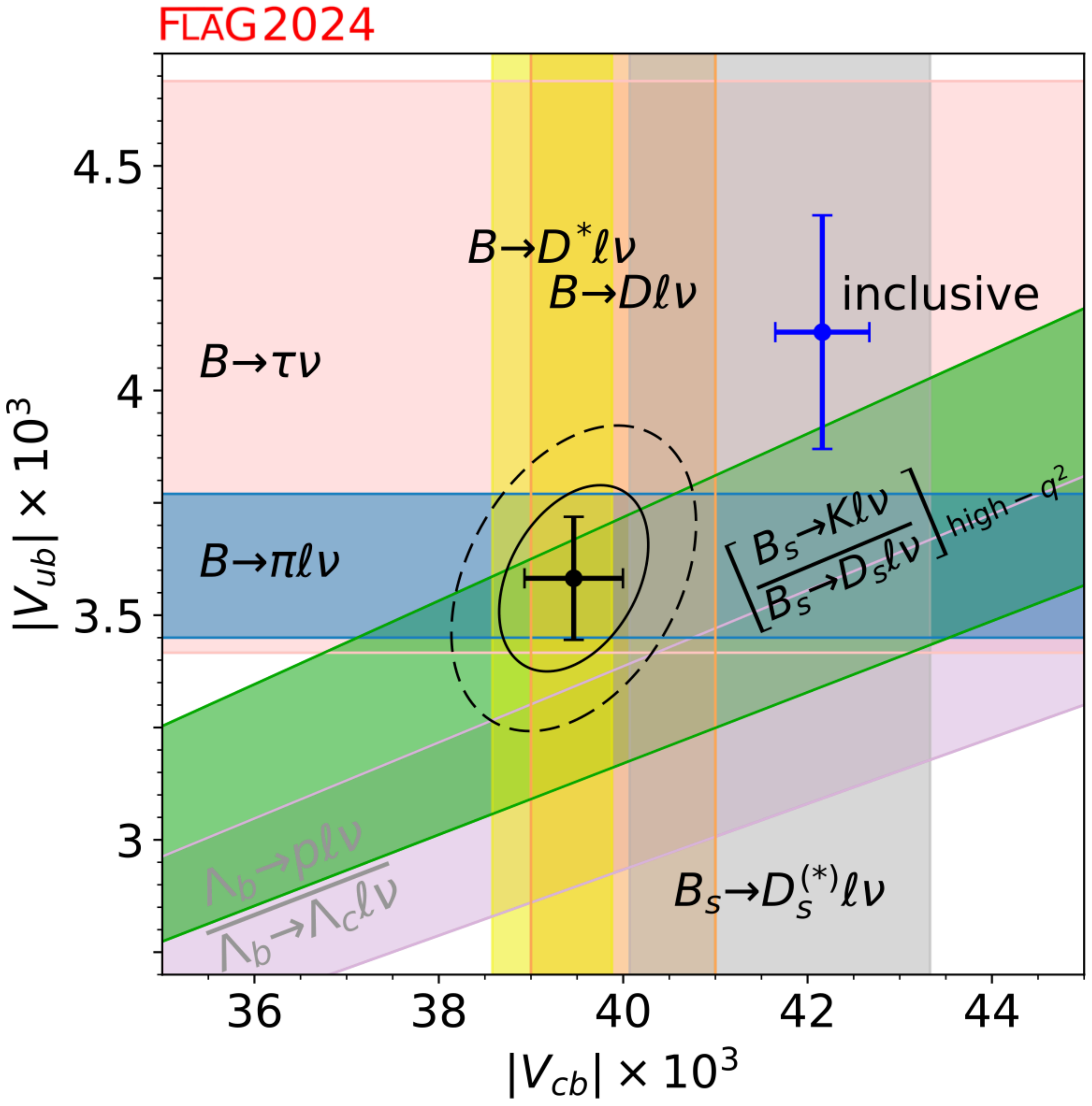


Why f_{B_c}?

A precise determination of $|V_{cb}|$ is a central goal of precision flavor physics.

- Determined from inclusive and exclusive semileptonic B-meson decays
- A longstanding $2-3\sigma$ tension exists between the two determinations

- Exclusive determinations require precise hadronic form factors, making lattice QCD an essential theoretical input.
- A precise f_{B_c} strengthens unitarity bounds, leading to improved $B \to D^{(*)}$ form factors and a more precise exclusive determination of $|V_{cb}|$

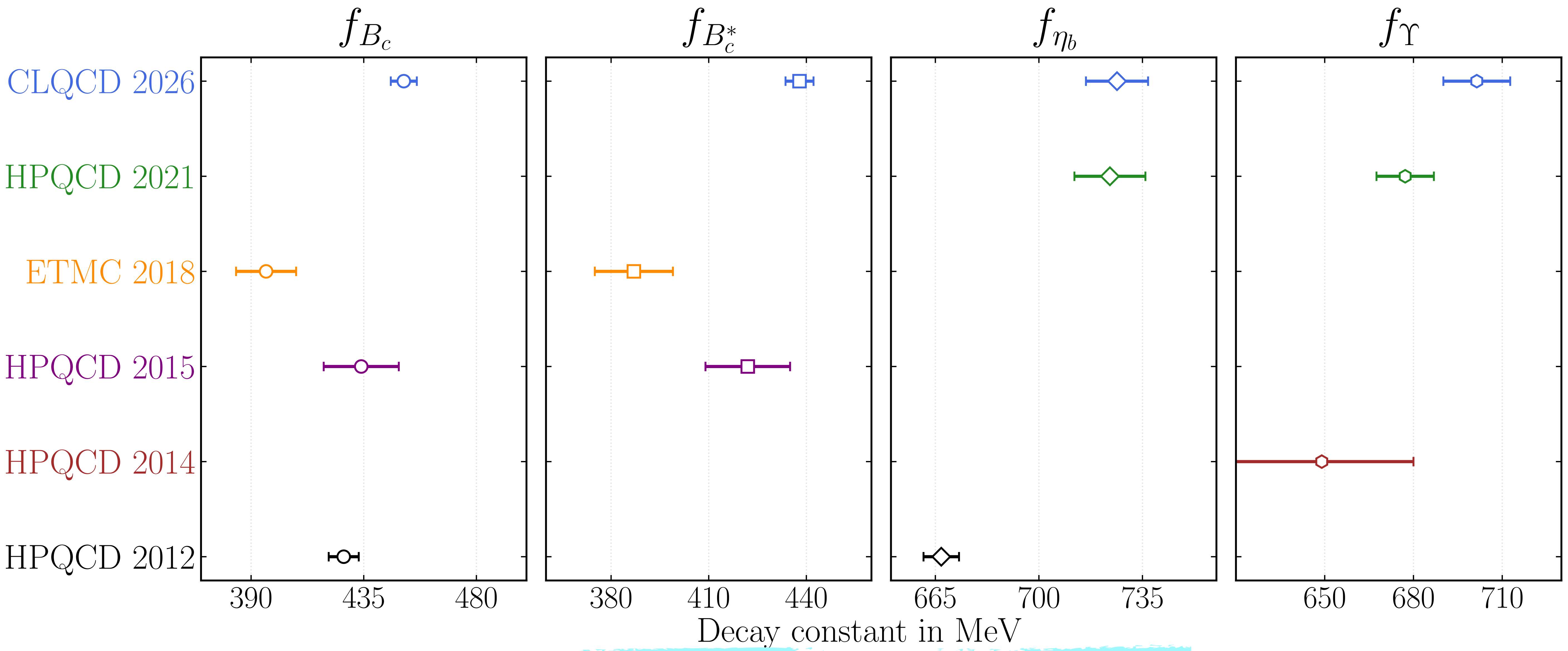


Our Setup

- $N_f = 2+1+1$ MILC HISQ ensemble, $96^3 \times 288$ lattice, $a \sim 0.0327\ fm$
- HISQ action for valence quarks as well
- Charm tuned to physical spin-averaged charmonium, bottom tuned to physical Υ
- 400 gauge configurations (so far), random color wall source to point sink setup

Targets of the work:

- Precise determination of f_{B_c} and $f_{B_c^*}$
- Results for tensor decay constant $f^T_{B_c^*}$
- Excited states using TGEVP (later part of the talk)



Lattice results so far

Why HISQ?

- Ultrafine lattice spacing ($a \sim 0.0327\ fm$) allows a fully relativistic treatment of the bottom quark, $am_b = 0.6223$, (also $am_c = 0.137$)
- Unlike coarser lattices, which often require specialized heavy-quark actions (e.g., NRQCD or RHQA), our ultrafine lattice allows the bottom quark to be simulated directly with the HISQ action
- Highly Improved Staggered Quark (HISQ) action significantly reduces heavy-quark discretization errors through higher-order improvement.
- Staggered fermions retain four continuum tastes per quark flavor, with meson operators classified by their spin–taste structure

$$\bar{\psi}\,\Gamma\,\psi \\ \downarrow \\ \bar{\chi}\left(\Gamma_S \otimes \Gamma_T\right)\chi$$

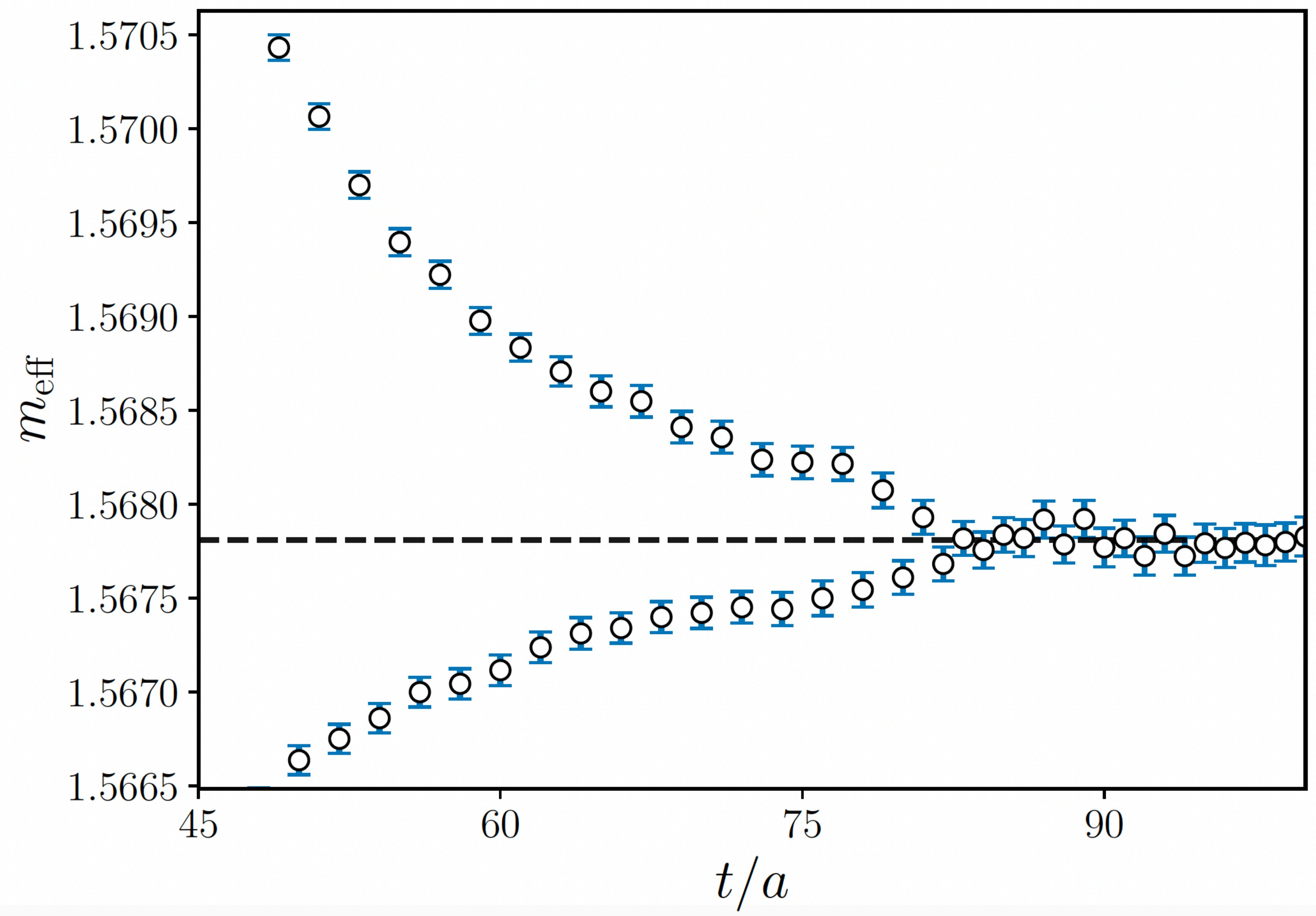
- Taste splitting effects suppressed (HISQ), ultrafine lattice spacing taste splitting expected to be small
- No mixed action effects, enables high-precision lattice calculations with controlled discretization errors

Oscillating Correlators

- Staggered meson operators couple to both the desired state and its opposite-parity partner
- Consequently, the two-point correlation function contains oscillating contributions

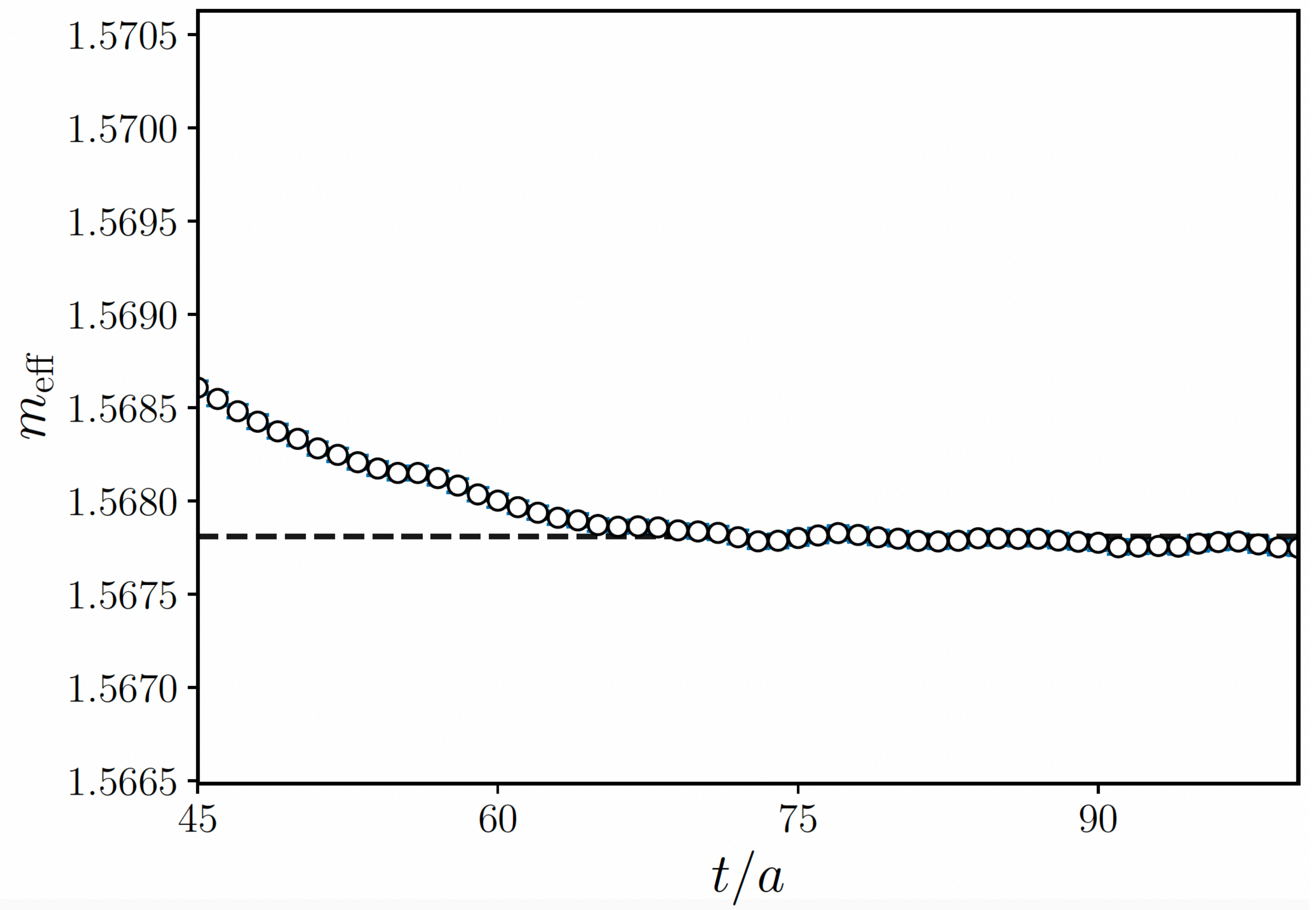
$$C(t) = \sum_n A_n \left(\exp(-E_n t) + \exp(-E_n(T-t))\right) - (-1)^t \sum_n B_n \left(\exp(-E_n^o t) + \exp(-E_n^o(T-t))\right)$$

Oscillating contributions produce an even-odd time-slice pattern



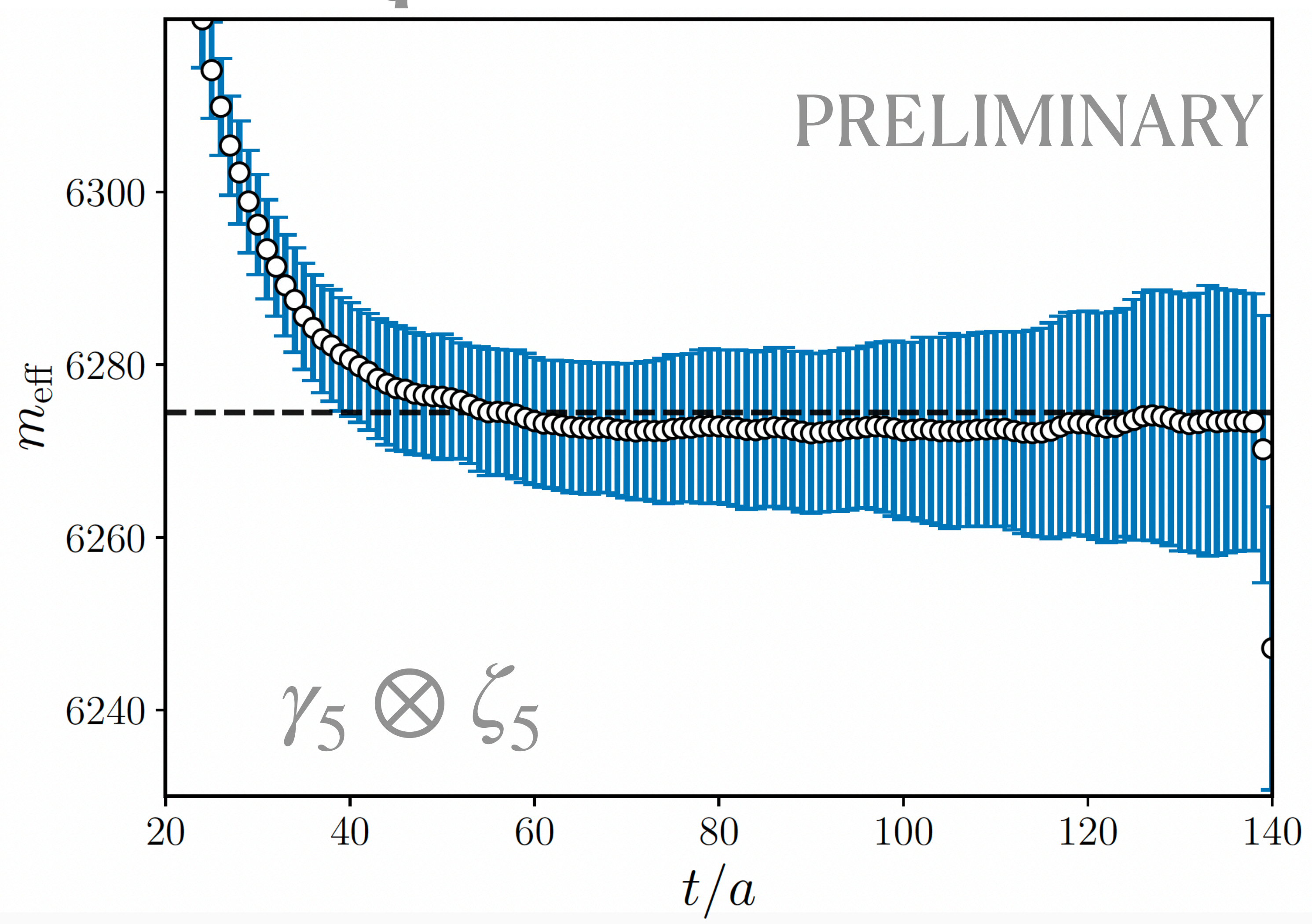
A three-point smoothing is applied to reduce these oscillations

$$C(t) = \sqrt{C(t)\sqrt{C(t-1)C(t+1)}}$$



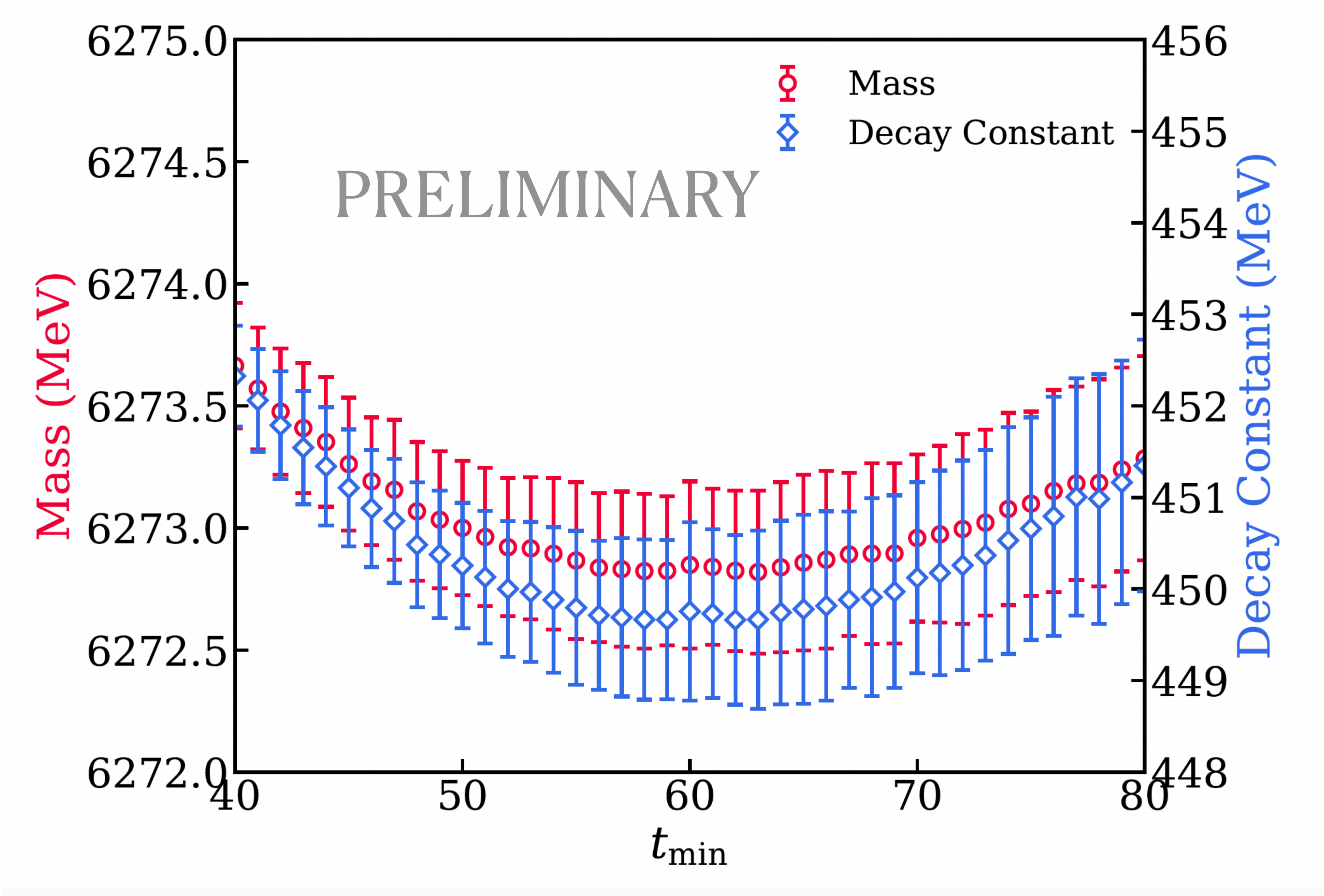
B_c signal

Effective mass constructed from smoothed correlators and shown without bootstrap/jackknife uncertainties to highlight the signal quality

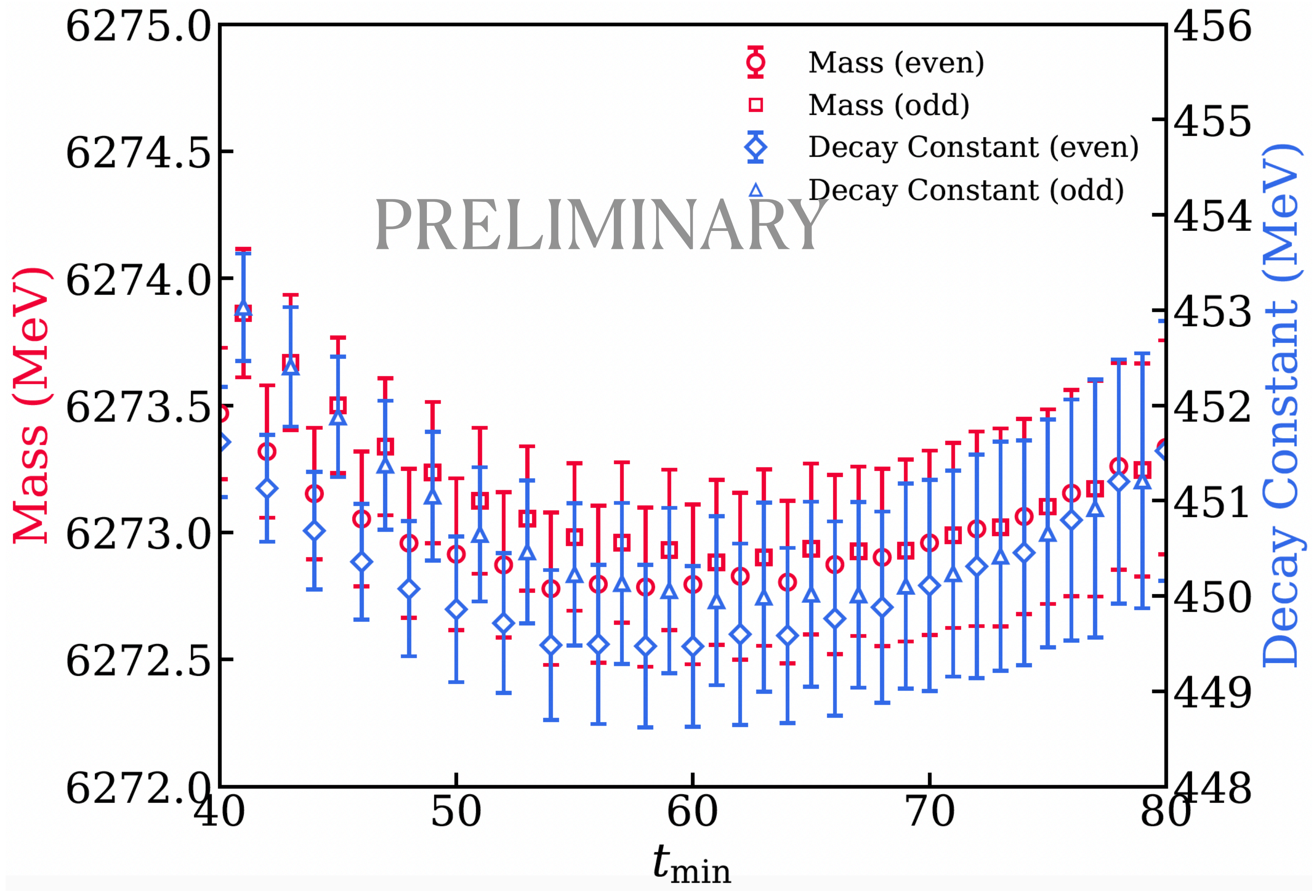


$$f_{ps} = \left(m_{q_1} + m_{q_2}\right)\sqrt{\frac{2A}{E^3}}$$

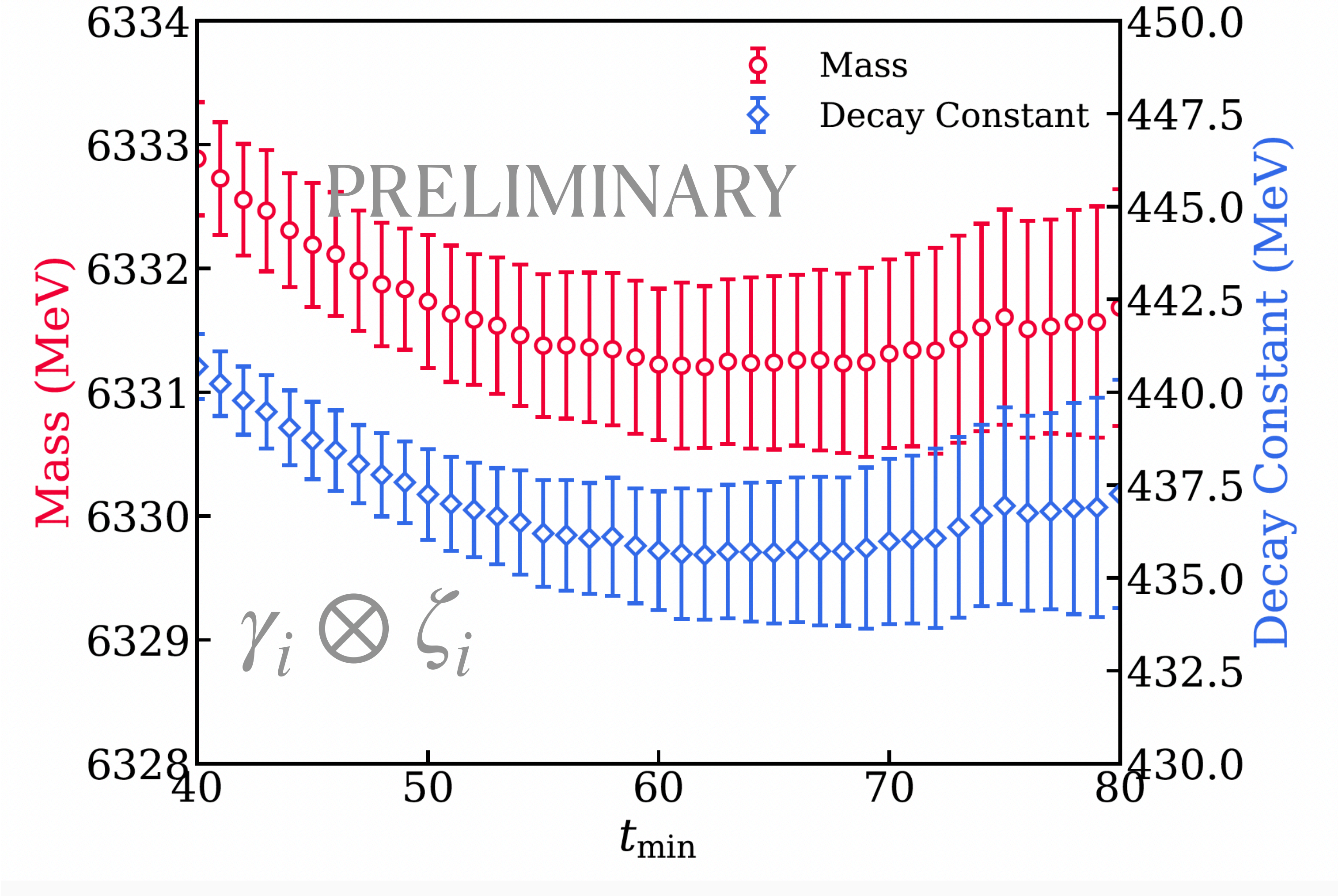
A naive check to verify that no information is lost through smoothing



Oscillating ansatz becomes increasingly noisy at large Euclidean times, single exponential fits to smooth data



B_c^* signal

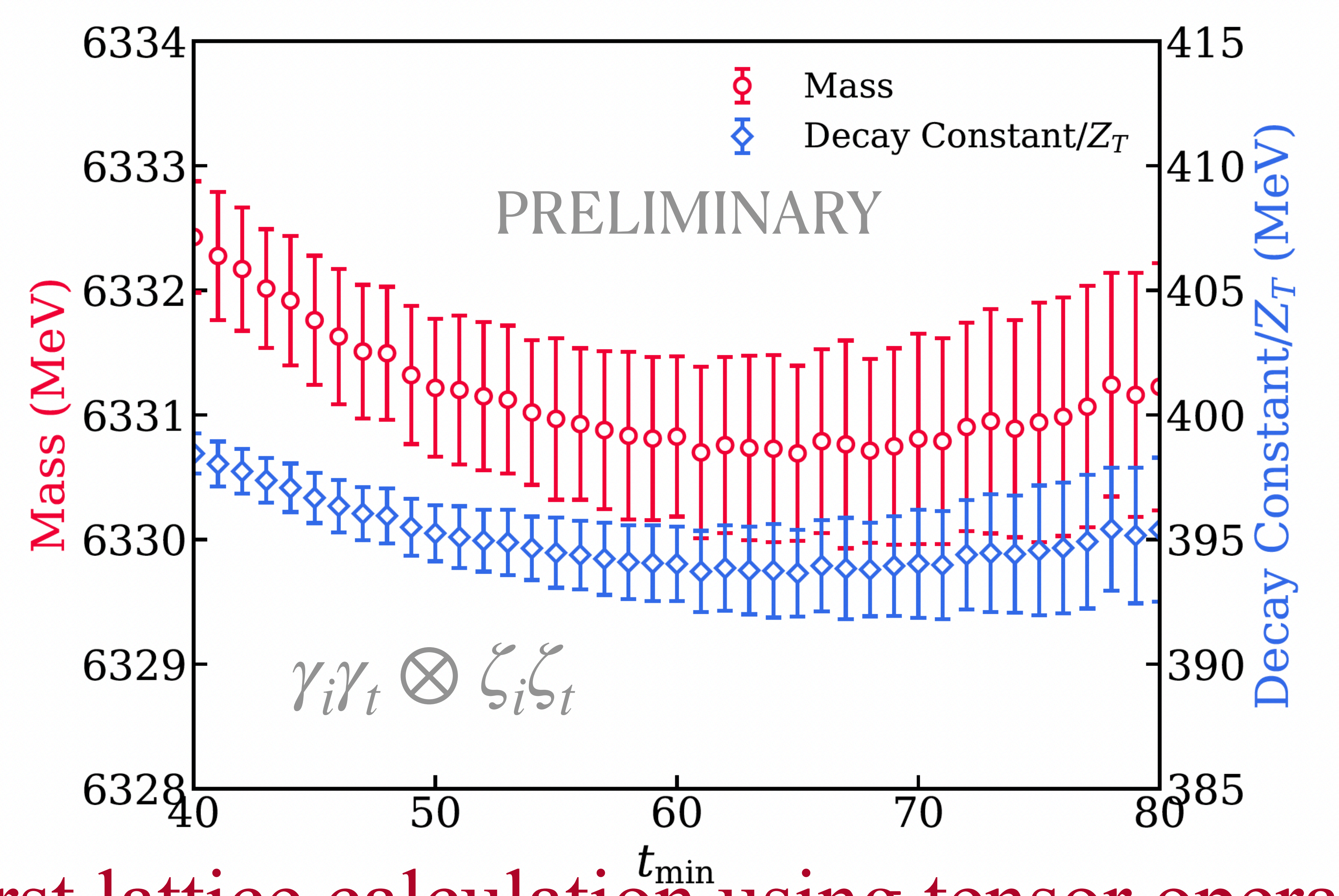


- Preliminary $B_c^* - B_c$ splitting (through ratio): 59.07(30) MeV
- We also report B_c^* using tensor interpolating operators
- Tensor currents, absent at tree level in the Standard Model, provide a sensitive probe of physics beyond the Standard Model

$$f_V = Z_V \sqrt{\frac{2A}{E}}$$

Z_V: PRD 102, 054511 (2020) HPQCD

We are currently investigating the determination of Z_V

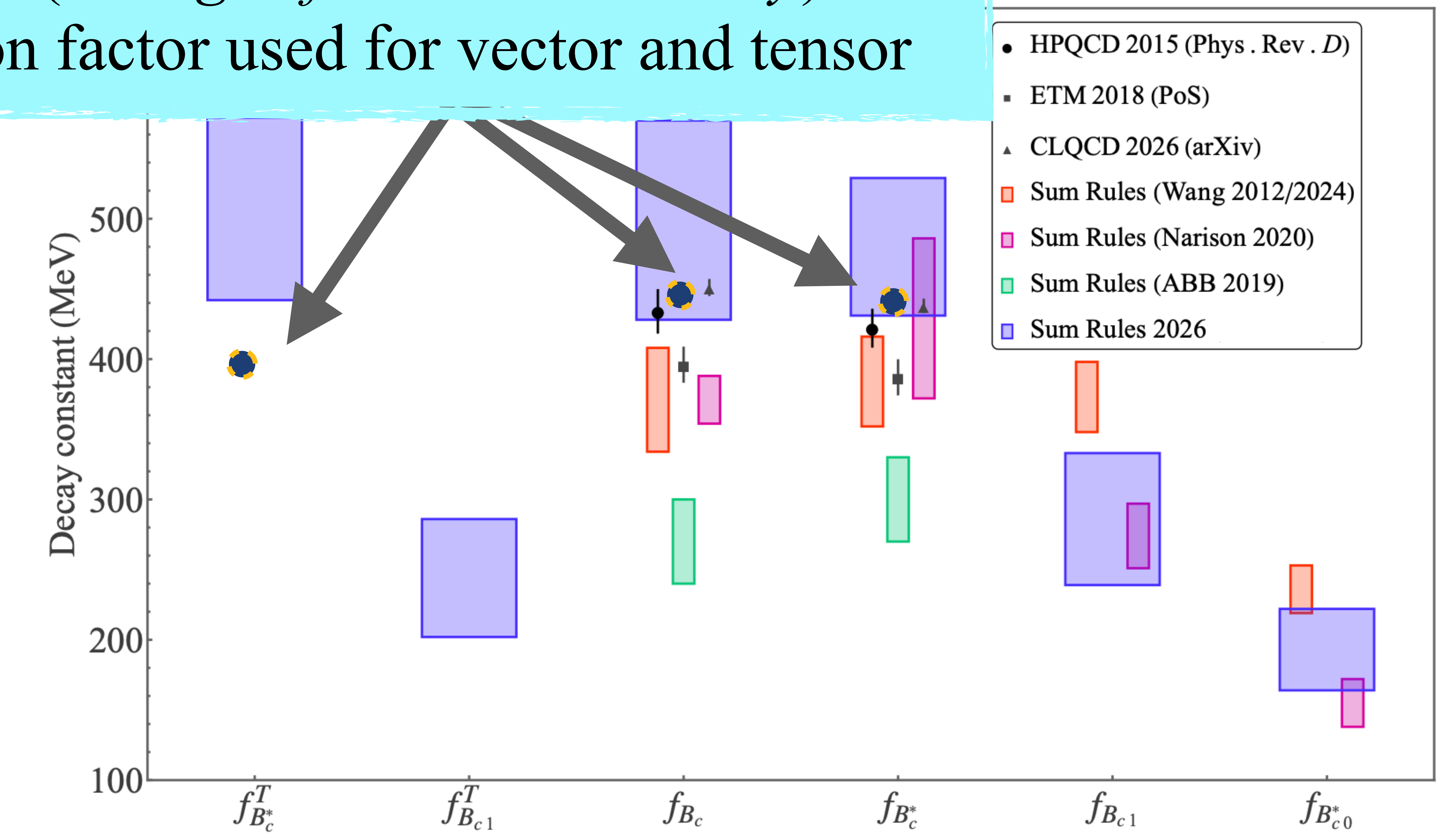


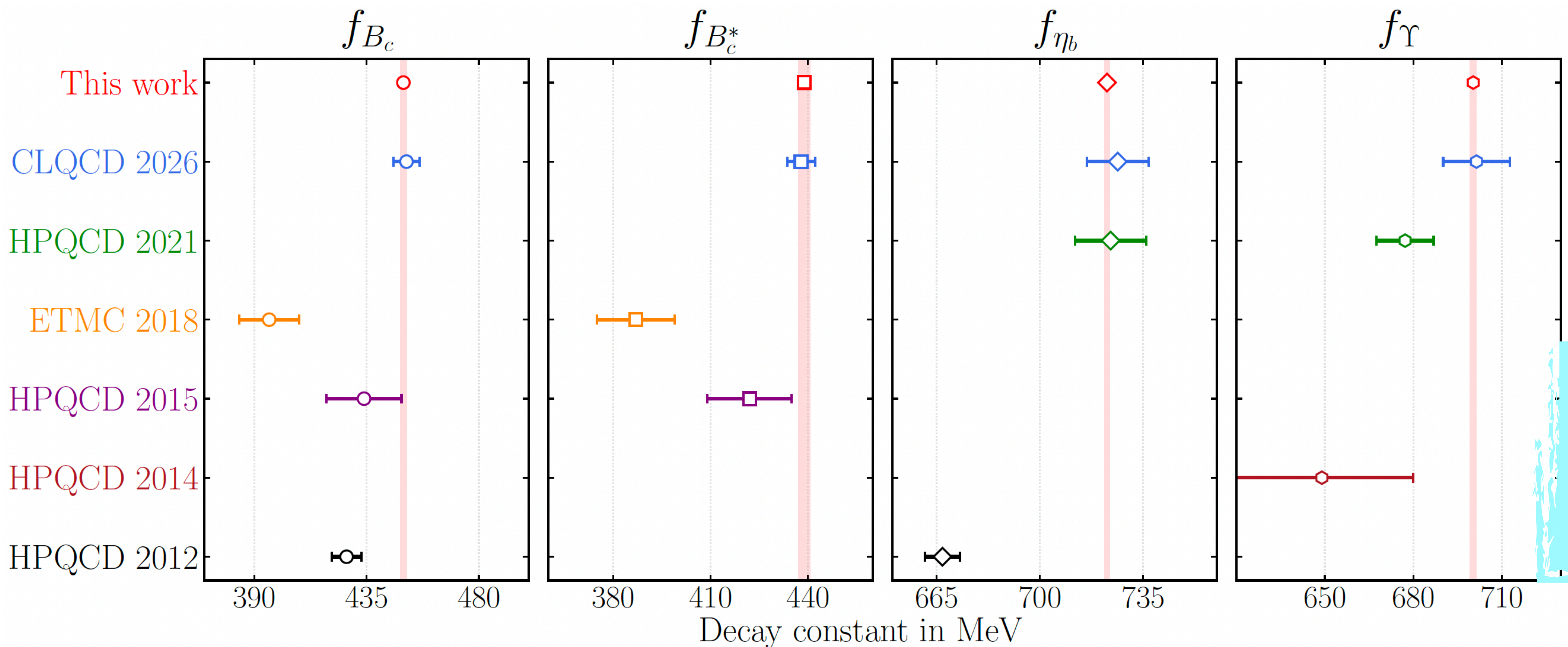
First lattice calculation using tensor operators; currently investigating renormalisation factor

Results

Our data points (*enlarged for better visibility*)
No renormalisation factor used for vector and tensor

Hadron	Mass [in MeV]	f/Z [in MeV]
η_c	2983.55(30)	396.41(81)
η_b	9404.07(14)	722.76(68)
B_c	6272.85(34)	449.76(97)
B_c^*	6331.22(61)	438.82(161)
B_c^* (tensor)	6330.82(64)	394.02(150)
Υ	9458.14(18)	700.30(79)
Υ (tensor)	9458.27(17)	646.47(70)





A recent pheno calculation
arXiv:2606.25733[hep-ph]
Reina, Gubernari, Wüthrich

No renormalisation factor used here for B_c^*, Υ

No systematics yet!!

Extracting More ...

- So far, we have focused on single-exponential fits to extract the ground-state properties
- However, correlation functions contain richer spectral information
- Can be accessed using advanced spectral extraction techniques

Using these methods, we

- get a validation of our ground states numbers
- can validate the impact of excited-state contamination
- get faster convergence and improved numerical stability

- We use TGEVP for further analysis

- Lanczos, Wagman (PRL 134 (2025) 24, 241901)
- Prony GEVM, Ostmeyer, Sen, Urbach (EPJA 61, 26 (2025))
- Transfer Matrix GEVP, Chakraborty, Sood, Radhakrishnan, Mathur (PRD 112 (2025) 7, 074506)

TGEVP Setup

Truncated Krylov Subspace $\mathscr{K}_m$

$$\mathscr{K}_m \equiv \{ |\chi\rangle, \hat{\mathscr{T}} |\chi\rangle, \hat{\mathscr{T}}^2 |\chi\rangle, \ldots, \hat{\mathscr{T}}^m |\chi\rangle \},$$
for $2m - 1 \leq n_T$

Transfer Matrix T^m_{ij}

$$T^m_{ij} = \langle v_i | \hat{\mathscr{T}} | v_j \rangle = C(i+j+1)/\sqrt{C(2i) \times C(2j)}$$

One time step ahead, encodes transfer matrix action on Krylov basis

Overlap Matrix V^m_{ij}

$$V^m_{ij} = \langle v_i | v_j \rangle = C(i+j)/\sqrt{C(2i) \times C(2j)}$$

Encodes overlaps between the Krylov basis states using correlator values

Solve the Generalised Eigenvalue Problem

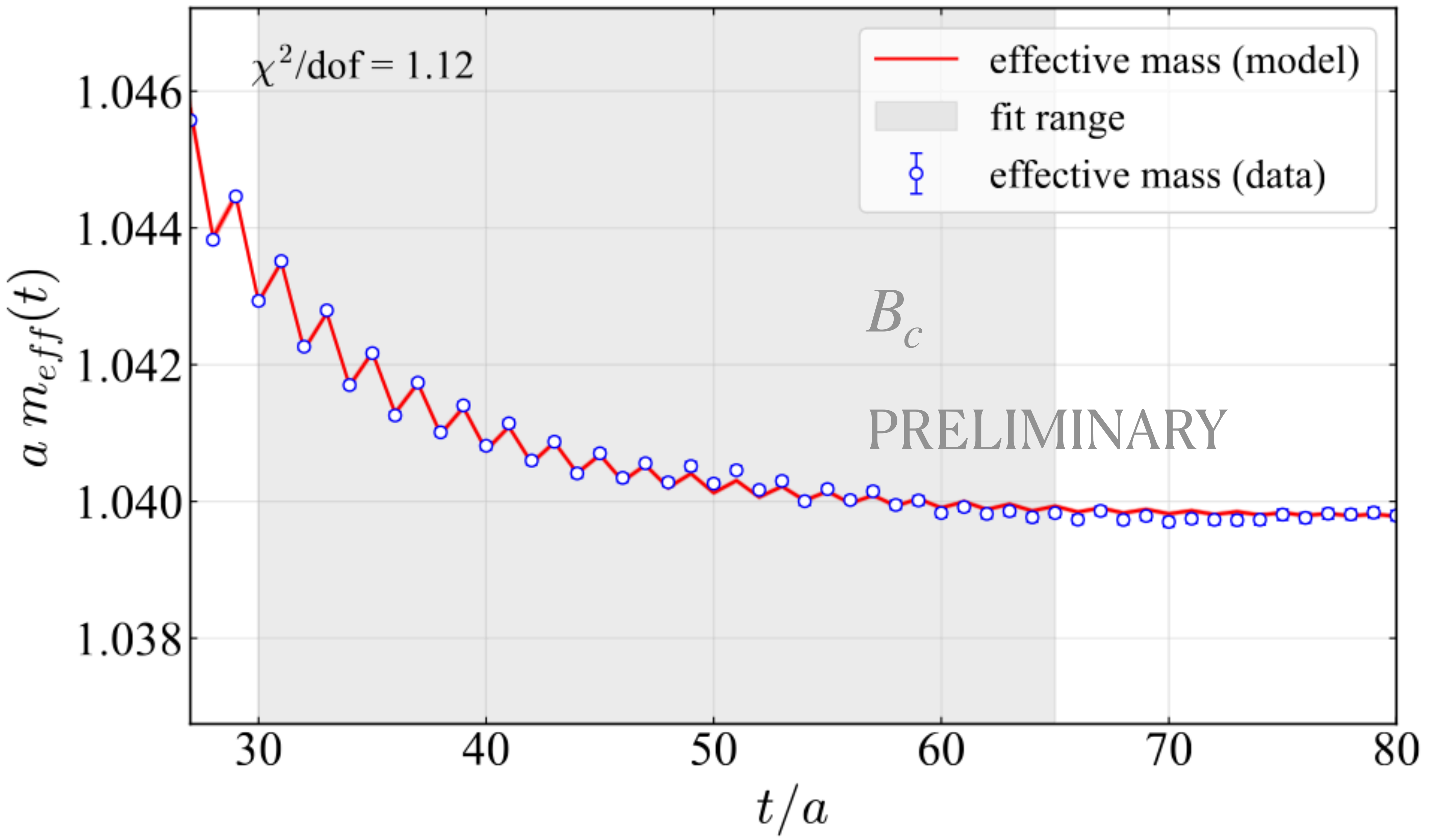
$$T^m x^m_n = \lambda^m_n V^m x^m_n \qquad E^m_n = -\log \lambda^m_n$$

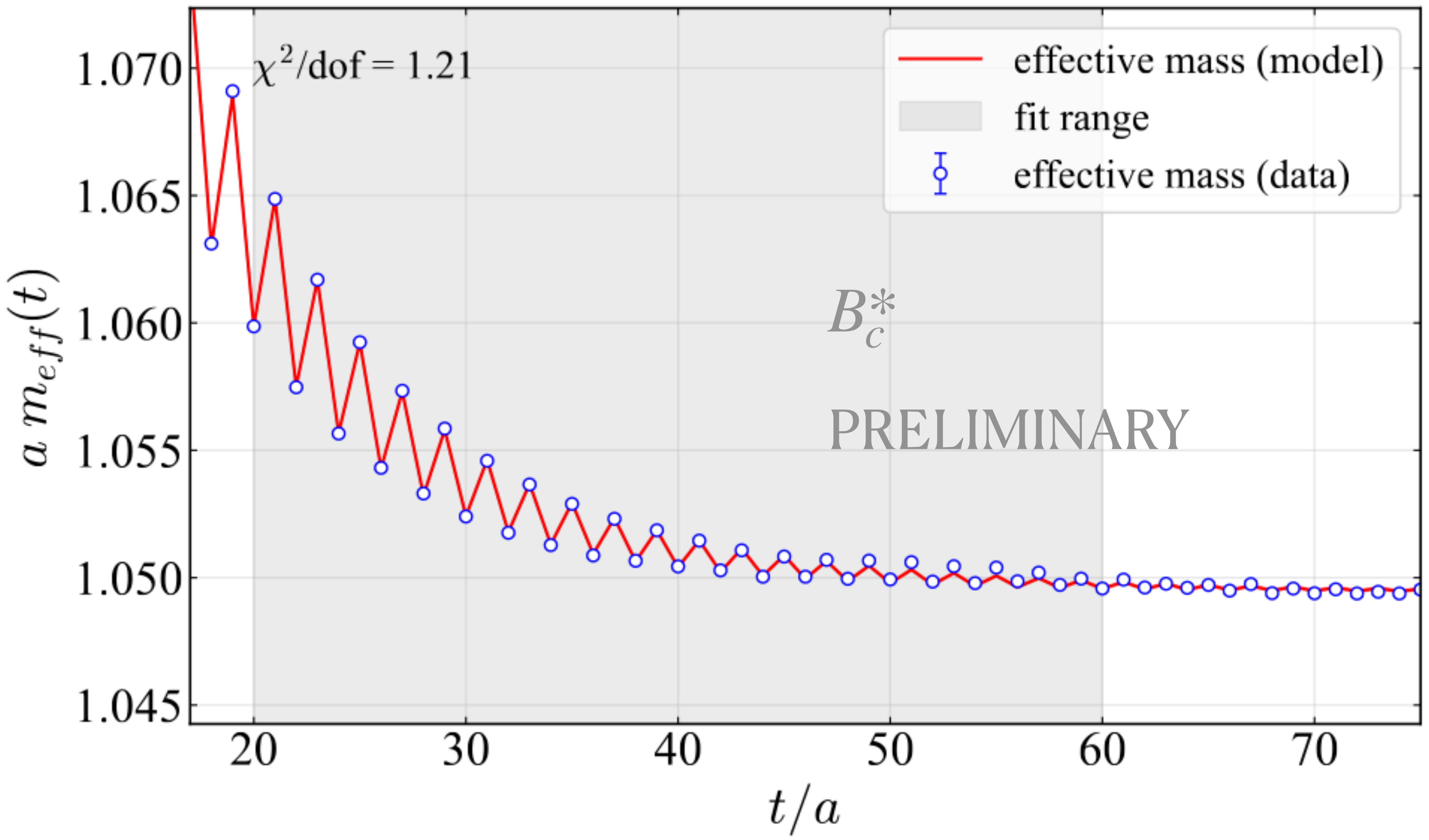
T^m and V^m are positive definite $\rightarrow$ λ_n's are real and positive $0 < \lambda^m_n \leq 1$

TGEVP Results

$$C(t) = \sum_n A_n \left(\exp(-E_n t) + \exp(-E_n(T-t))\right) - (-1)^t \sum_n B_n \left(\exp(-E_n^o t) + \exp(-E_n^o(T-t))\right)$$

Ansatz incorporates four non-oscillating and three oscillating states





Ground-state information obtained from the late-time region is used to constrain fits at early times, where excited-state contributions are significant

TGEVP Results

Hadron	State	Mass [in MeV]	f/Z [in MeV]
η_c	1S	$2983.83\,(^{+0.17}_{-0.17})$	$395.91\,(^{+0.51}_{-0.59})$
	2S	$3665\,(^{+55}_{-60})$	–
η_b	1S	$9406.77\,(^{+0.10}_{-0.09})$	$723.07\,(^{+0.40}_{-0.41})$
	2S	$9989\,(^{+47}_{-49})$	–
B_c	1S	$6274.40\,(^{+0.20}_{-0.19})$	$449.47\,(^{+0.54}_{-0.58})$
	1P (0^+)	$6708\,(^{+11}_{-14})$	–
	2S	$6854\,(^{+63}_{-58})$	–
B_c^*	1S	$6332.67\,(^{+0.38}_{-0.39})$	$438.81\,(^{+1.11}_{-1.12})$
	1P (1^+)	$6745\,(^{+15}_{-16})$	–
B_c^* (tensor)	1S	$6332.47\,(^{+0.43}_{-0.44})$	$394.15\,(^{+1.08}_{-1.04})$
	1P (1^+)	$6744\,(^{+15}_{-17})$	–
Υ	1S	$9460.88\,(^{+0.11}_{-0.11})$	$700.63\,(^{+0.51}_{-0.54})$
	1P (χ_{b1})	$9897.4\,(^{+8.4}_{-7.9})$	–
	2S	$10016\,(^{+32}_{-32})$	$465\,(^{+45}_{-47})$
Υ (tensor)	1S	$9460.98\,(^{+0.11}_{-0.11})$	$646.94\,(^{+0.45}_{-0.47})$
	1P (χ_{b1})	$9901.6\,(^{+8.2}_{-9.1})$	–
	2S	$10001\,(^{+31}_{-33})$	–

TGEVP numbers

Hadron	Mass [in MeV]	f/Z [in MeV]
η_c	2983.55(30)	396.41(81)
η_b	9404.07(14)	722.76(68)
B_c	6272.85(34)	449.76(97)
B_c^*	6331.22(61)	438.82(161)
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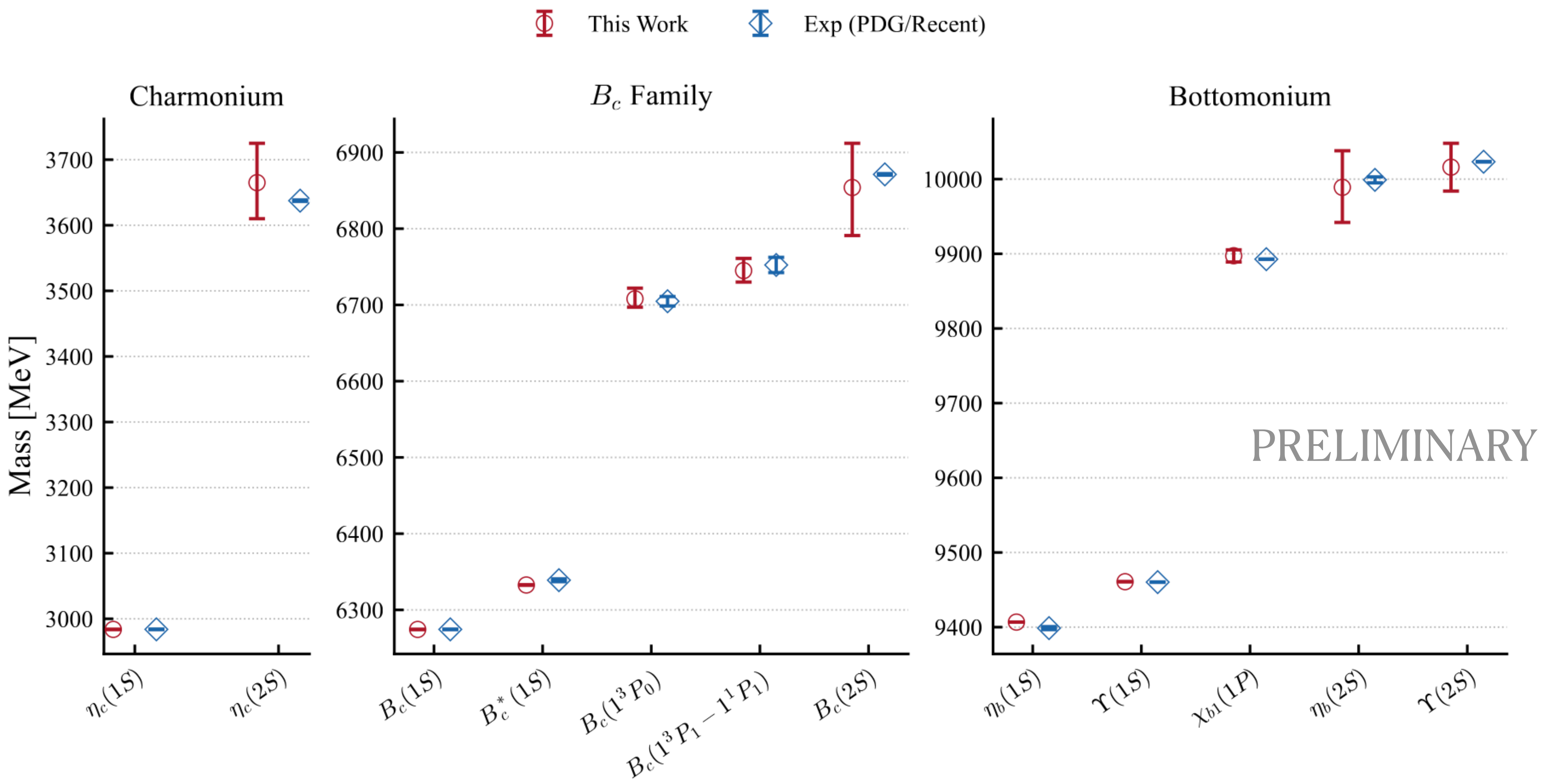
Single exponential fits

1-2 MeV difference in some cases
t_{min} dependence ….
TGEVP more clean?……

Summary TGEVP



- Excited-state decay constants: work in progress (more statistics and systematics underway)

- Excited-state spectrum is well established in lattice QCD
- Single-operator TGEVP provides a complementary cross-check of excited-state contamination and extraction

Summary

- [x] Performed a high-precision lattice QCD calculation of the B_c meson family decay constants using fully relativistic $N_f = 2 + 1 + 1$ HISQ ensembles

- [x] Obtained preliminary results:

$$f_{B_c} = 449.76(97)(?)\ MeV, f_{B_c^*}/Z = 438.82(161)(?)\ MeV, f^T_{B_c^*}/Z = 394.02(150)(?)\ MeV$$

- [x] Implemented TGEVP to strengthen extraction of ground-state and enable a systematic study of excited-state properties

- [ ] To increase statistics by analyzing more configurations; investigate renormalisation factors

- [ ] A complete systematic error budget for ground- and excited-state B_c spectroscopy

Thanks to the MILC Collaboration, especially Steven Gottlieb, for providing the configurations

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THANK YOU

LATTICE 2026

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