

$K\pi$ scattering as a step towards $B \rightarrow K^* \ell^+ \ell^-$ from Lattice QCD

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Electroweak

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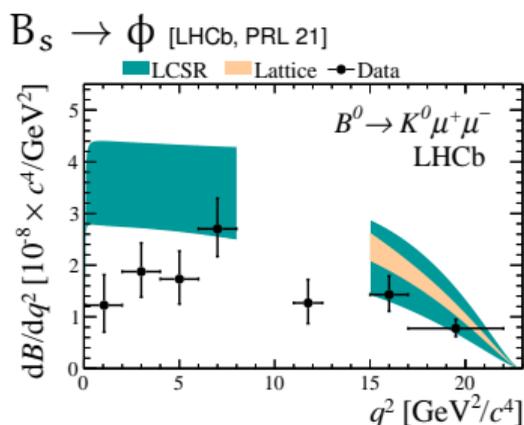
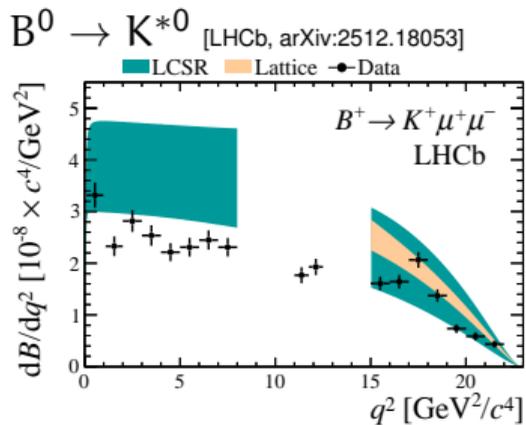
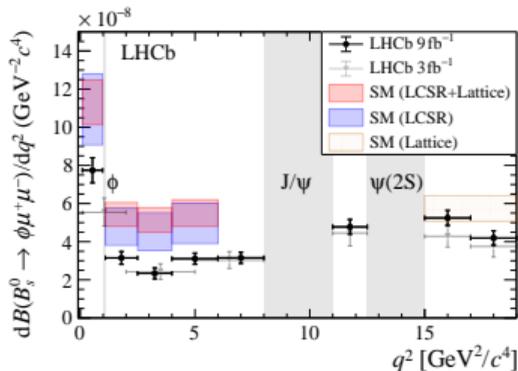
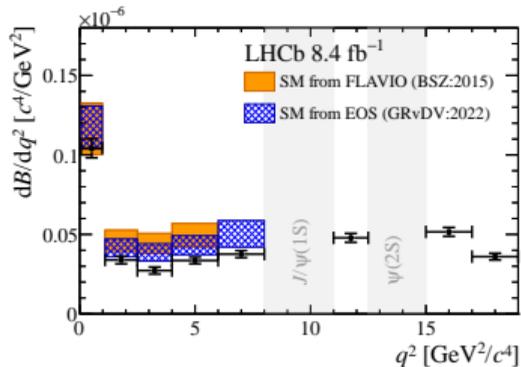
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B-ANOMALIES

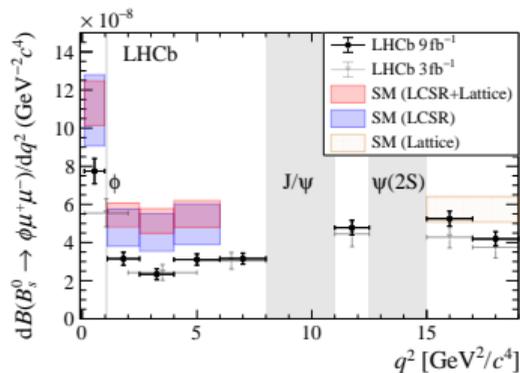
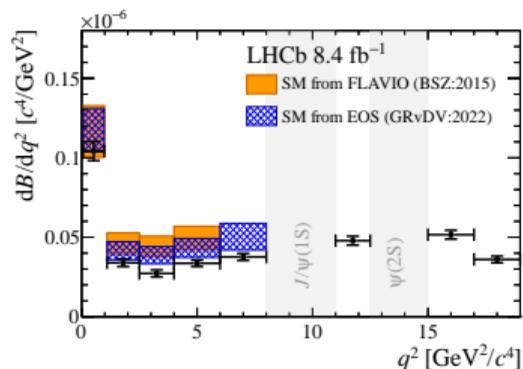


$B^+ \rightarrow K^+$ [LHCb, JHEP 14]

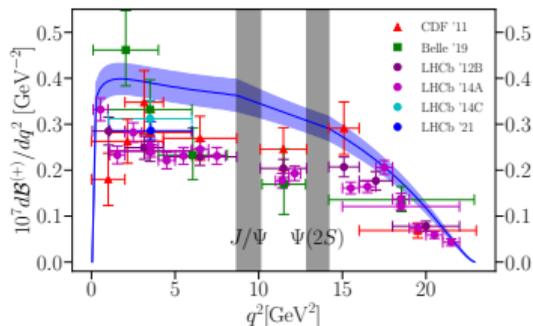
$B^0 \rightarrow K^0$ [LHCb, JHEP 14]

- Persistent tensions in $b \rightarrow s \ell^+ \ell^-$ modes
[Christoph Langenbruch, Zoltan Ligeti yesterday]
- Measurements also by CMS, Belle II [Meihong Liu yesterday]
- **Low** q^2 : LCSR region
High q^2 : lattice QCD
- Data systematically below SM expectations
- additionally reinforced by inclusive $B \rightarrow X_s \ell^+ \ell^-$ [Zihan Wang yesterday]

B-ANOMALIES

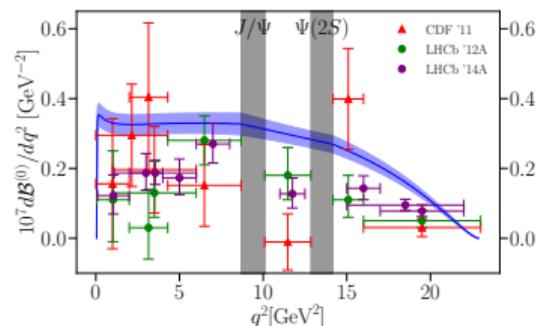


$B^0 \rightarrow K^{*0}$ [LHCb, arXiv:2512.18053]



$B^+ \rightarrow K^+$ [Parrot et al.; PRD 23]

$B_s \rightarrow \phi$ [LHCb, PRL 21]



$B^0 \rightarrow K^0$ [Parrot et al.; PRD 23]

- Recent lattice calculation: $B \rightarrow K \ell^+ \ell^-$

[HPQCD: Parrott et al., PRD 23]

- Includes form factors down to low q^2
- Lattice prediction reinforces the tension**
- Missing piece:

$$B \rightarrow K^*(\rightarrow K\pi) \ell^+ \ell^-$$

⇒ Goal: bring lattice QCD to this channel

LATTICE QCD: FIRST-PRINCIPLES QCD CALCULATIONS

Method: simulate QCD numerically in a finite box

- Discretise space-time on a grid
- Evaluate the QCD path integral using Monte Carlo
- Nonperturbative and systematically improvable

Controlled systematics:

- lattice spacing $a \rightarrow 0$ (continuum limit)
- box size $L \rightarrow \infty$ (infinite volume limit)
- quark masses \rightarrow physical values

\Rightarrow enables precision calculations of hadronic matrix elements



Source: Ben Jakober, Mazzochio (1984), p.33

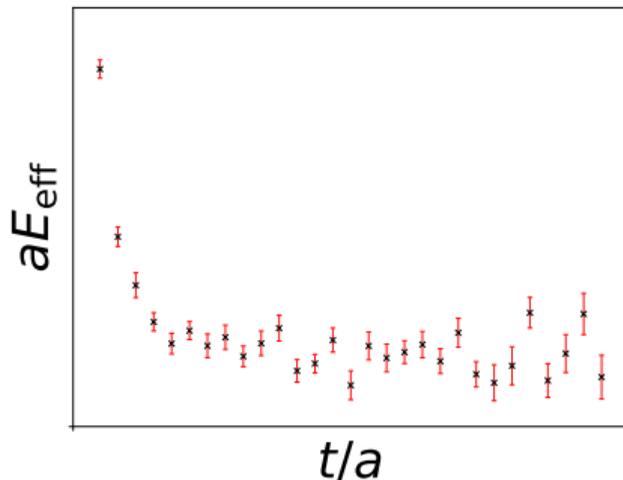
Basic observable: Euclidean correlation function

$$C_2(t) = \langle O(t)O^\dagger(0) \rangle$$

Spectral decomposition:

$$C_2(t) = \sum_n |Z_n|^2 e^{-E_n t}$$

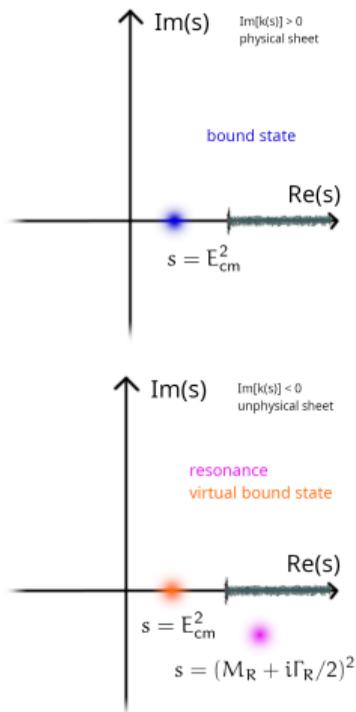
- excited states decay exponentially
 - large Euclidean time \Rightarrow ground state dominates
- \Rightarrow masses and matrix elements extracted from plateaus



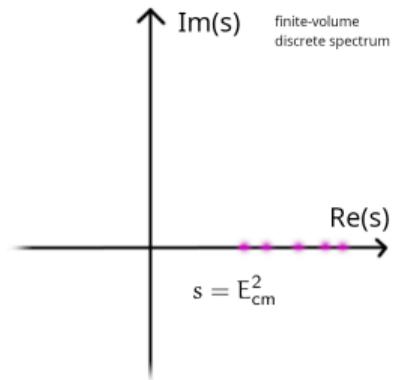
This works for stable particles.

But the K^* is a resonance.

RESONANCES ARE NOT ASYMPTOTIC STATES



Infinite volume:
poles in complex
energy plane



Finite volume: discrete
real spectrum

Key point

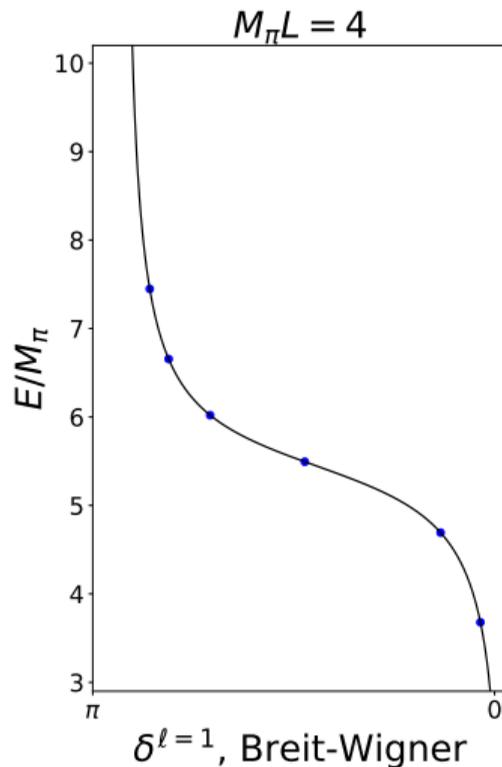
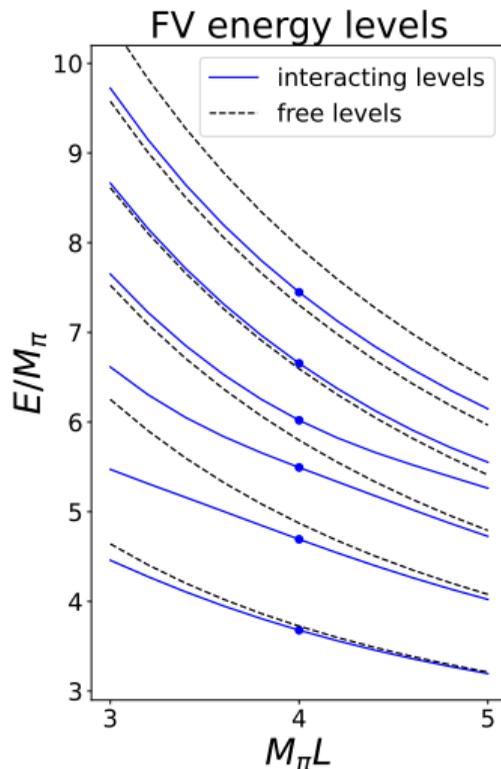
- Resonances = poles of amplitudes
- Finite volume gives only energy levels
- No cuts, sheets, or exposed poles

\Rightarrow **lattice QCD accesses resonances only indirectly through finite-volume spectra**

HOW RESONANCES APPEAR IN LATTICE SPECTRA

- Finite-volume energies are not resonance masses
- Free two-particle levels: **dashed lines**
- Interactions shift the spectrum: **solid lines**
- These shifts encode the scattering amplitude (Lüscher formalism)

Resonances show up as shifts — not as states



Resonances and long-distance effects enter both as:

Final states

- $K \rightarrow \pi\pi$
- $D \rightarrow K\pi, \pi\pi, KK$
- $B \rightarrow (\rho \rightarrow \pi\pi)\ell\nu, B \rightarrow (K^* \rightarrow K\pi)\ell^+\ell^-$

Intermediate states

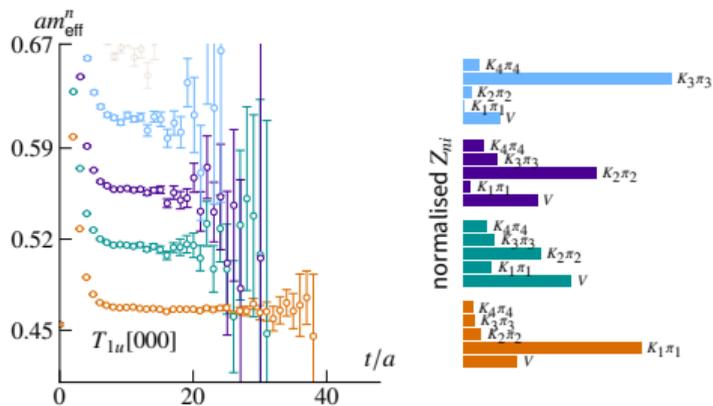
- $K-\bar{K}$ mixing and rare kaon decays
- long-distance contributions in $D-\bar{D}$ mixing
- hadronic vacuum polarization ($\pi\pi$ for $g - 2$)

Recent progress: $B \rightarrow \rho \ell\nu$ on the lattice [Leskovec et al., PRL 2025]

\Rightarrow **next target:** $B \rightarrow K^*(\rightarrow K\pi)\ell^+\ell^-$

K^* ON THE LATTICE (FINITE VOLUME)

- K^* is **QCD unstable** \Rightarrow in finite volume it mixes with $K\pi$ (and other states) with the same quantum numbers.
- **Variational method (GEVP)**: finds eigenvectors $v^{(n)}$ that optimally isolate a given finite-volume level n .
- This defines an **optimized state** to use in 3-point functions
- Next step: relate finite-volume matrix elements to **infinite-volume amplitudes** (Lellouch–Lüscher).



[Boyle, FE et al., PRL 25], [Boyle, FE et al., PRD 25]

EXPLORATORY CALCULATION: $B \rightarrow K^*(\rightarrow K\pi) \ell^+ \ell^-$

- **Setup:**

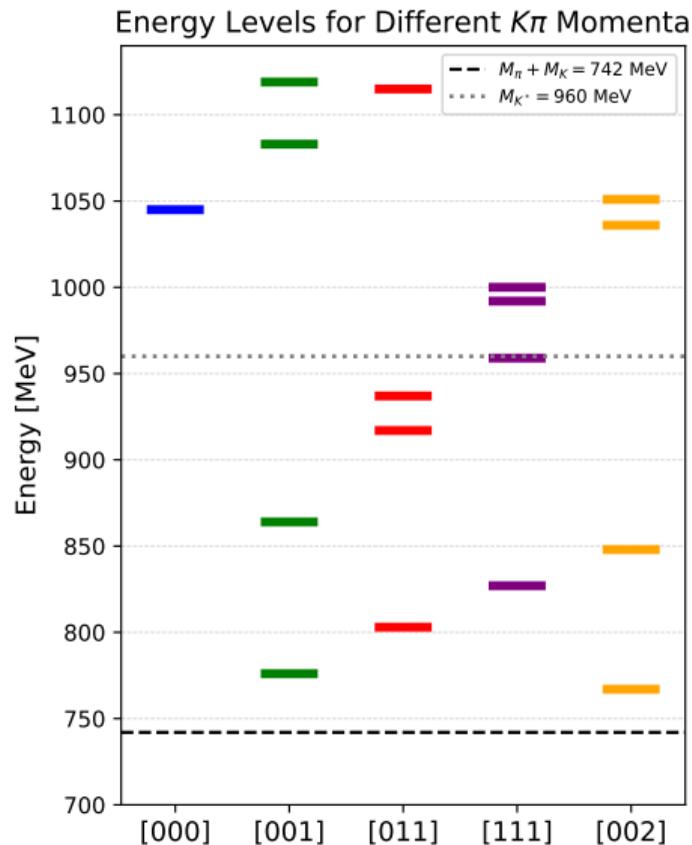
- Resonant K^* on RBC/UKQCD DWF ensemble
- $M_\pi = 232$ MeV, $M_K = 510$ MeV

- **Heavy sector:**

- 3 DWF heavy quarks, $m_c \leq m_h \lesssim 0.5 m_b$
- RHQ heavy quark tuned to $m_h = m_b$
- [Alejandro Vaquero yesterday]

- **Methodology:**

- Using efficient all-to-all techniques (distillation) to construct complete sets of $K\pi$ two- and three-point functions.



Method: distillation [Peardon et al.; PRD 09] [Morningstar et al.; PRD 11]

- Efficient construction of multi-hadron operators
- Essential for treating resonances on the lattice

Weak decays require local currents

- local operators break part of the distillation efficiency

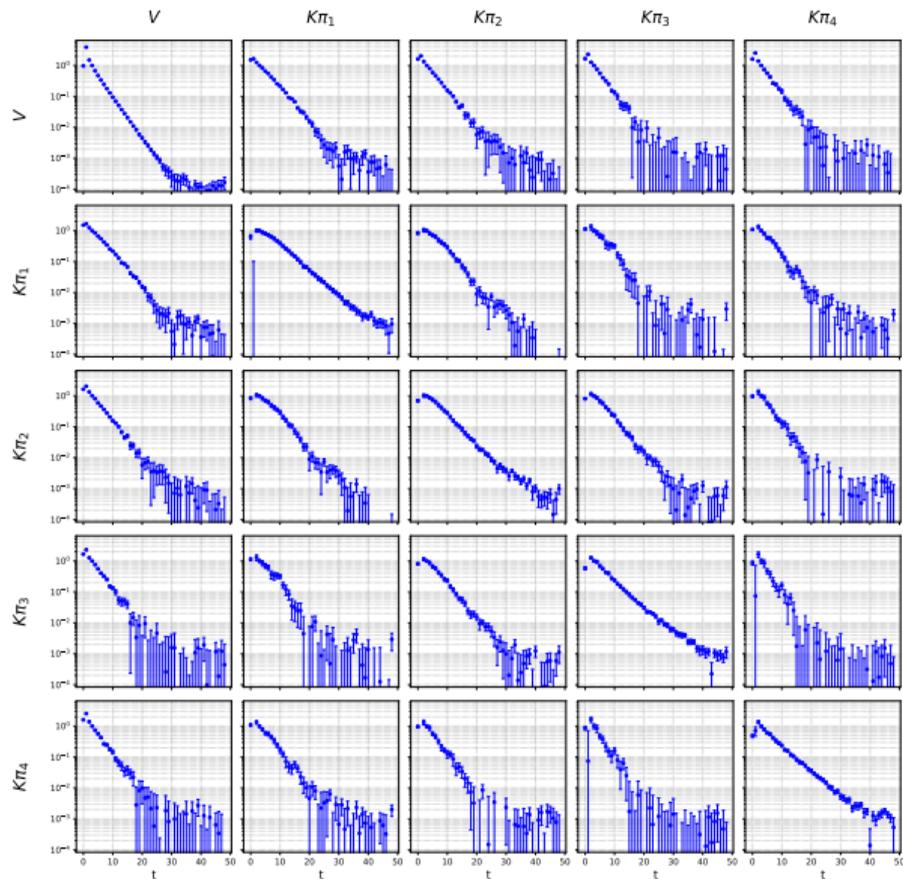
Cost in this project

- buffering unsmeared vectors for several configurations
- $\Rightarrow \sim 500$ **TB temporary storage**
- significant data production effort

Payoff: broad physics reach

- $B \rightarrow K^* \ell^+ \ell^-$ ($b \rightarrow s$)
- $B_s \rightarrow K^* \ell^+ \ell^-$ ($b \rightarrow d$)
- $D \rightarrow \rho \ell^+ \ell^-$ ($c \rightarrow u$)
- $B \rightarrow \rho \ell \nu$ ($b \rightarrow u$)
- $K\gamma \rightarrow K\pi$ ($s \rightarrow s, d \rightarrow d$)
- $\pi\gamma \rightarrow \pi\pi$ ($d \rightarrow d$)

TWO-POINT CORRELATION FUNCTIONS $K^* \leftrightarrow K\pi$

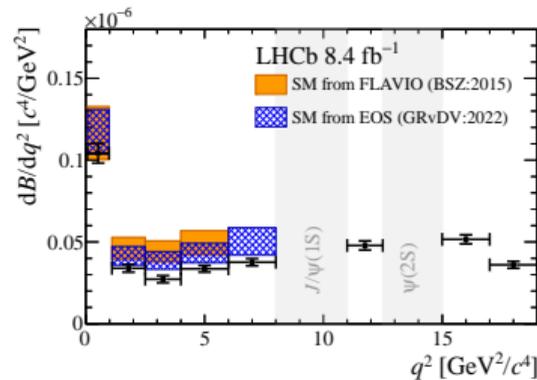


- first look at data: Two-point correlation functions
- rest frame, 5×5 matrix (symmetrized)
- eight configurations, 24 source times
- target statistics: 30 – 50 configurations
- 3 bins per config treated as independent - **statistics still preliminary**

KINEMATIC AND FORMAL CHALLENGES AHEAD

- Lattice calculations most reliable near q_{\max}^2
($\mathbf{p}_B = \mathbf{p}_{K^*} = 0$)
- Reaching low q^2 demands large $|\mathbf{p}_{K^*}|$
- On this $48^3 \times 96$, $a^{-1} = 2.7$ GeV lattice, $q^2 = 0$ would require $\mathbf{p}_{K^*} \sim [8, 8, 8]$ — **unfeasible**
- At such momenta E_{K^*} exceeds multi-hadron thresholds \Rightarrow finite-volume formalism no longer applicable
- Nearby charmonium resonances complicate region; first lattice steps towards control, using spectral reconstruction: [Frezzotti et al., arXiv:2508.03655]

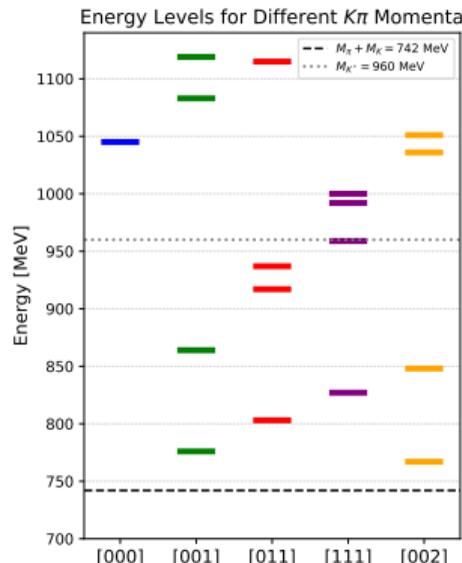
\Rightarrow Current focus: **high- q^2 regime** where lattice control is strongest, but extending towards **low q^2** remains crucial for understanding B anomalies



[LHCb, arXiv:2512.18053]

OUTLOOK

- **New exploratory lattice study** of heavy-meson decays into **resonant final states**
- K^* **spectrum** from two-point functions using distillation
- two-point data for first configurations available, target 30 – 50 configurations
- Three-point data under analysis
- **Versatile setup:** same distillation data covers a broad range of $b \rightarrow s$, $b \rightarrow d$, $b \rightarrow u$, and $c \rightarrow u$ transitions
- **Dual heavy-quark approach:** RHQ at m_b and DWF interpolation up from m_c



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