Lattice Parton Collaboration

北京航空航天大學 BEIHANG UNIVERSITY

Precision HQET LCDAs from Lattice QCD for Tightening B Decay Uncertainties

Qi-An Zhang

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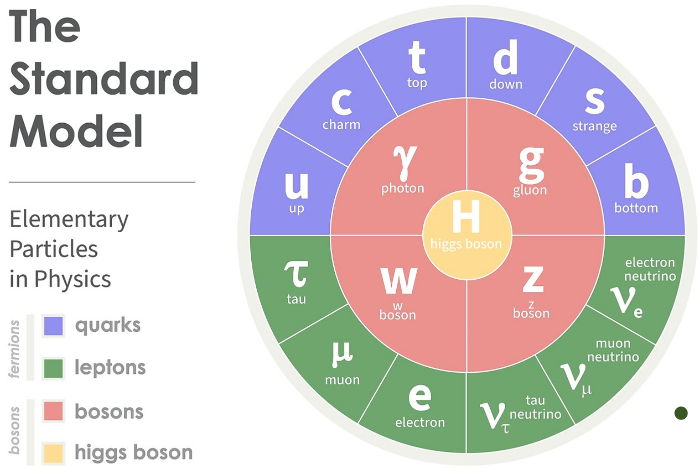
On behalf of Lattice Parton Collaboration (LPC)

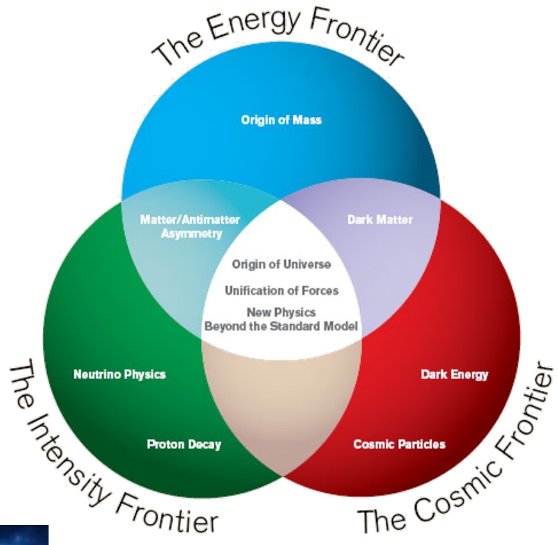
Apr. 26, 2026 @ 第八届全国重味物理与量子色动力学研讨会, 重庆

Motivation for Heavy Quark Physics

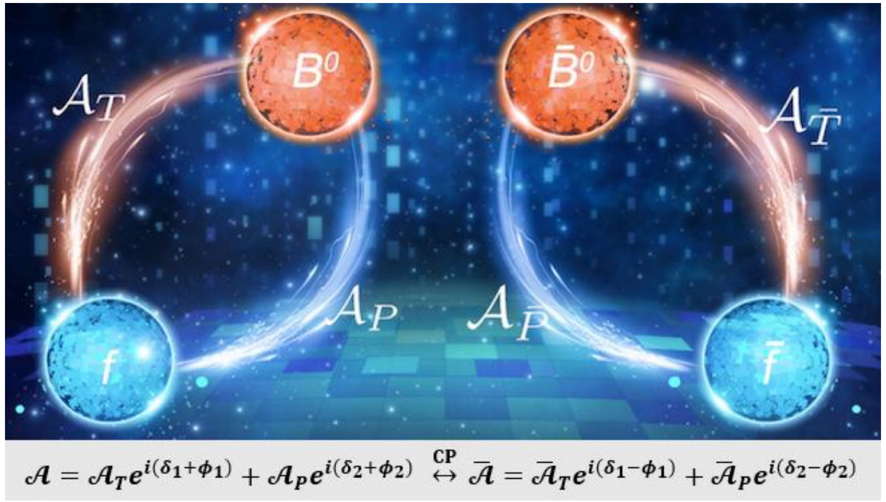
- Precisely testing standard model



- Indirect search for new physics



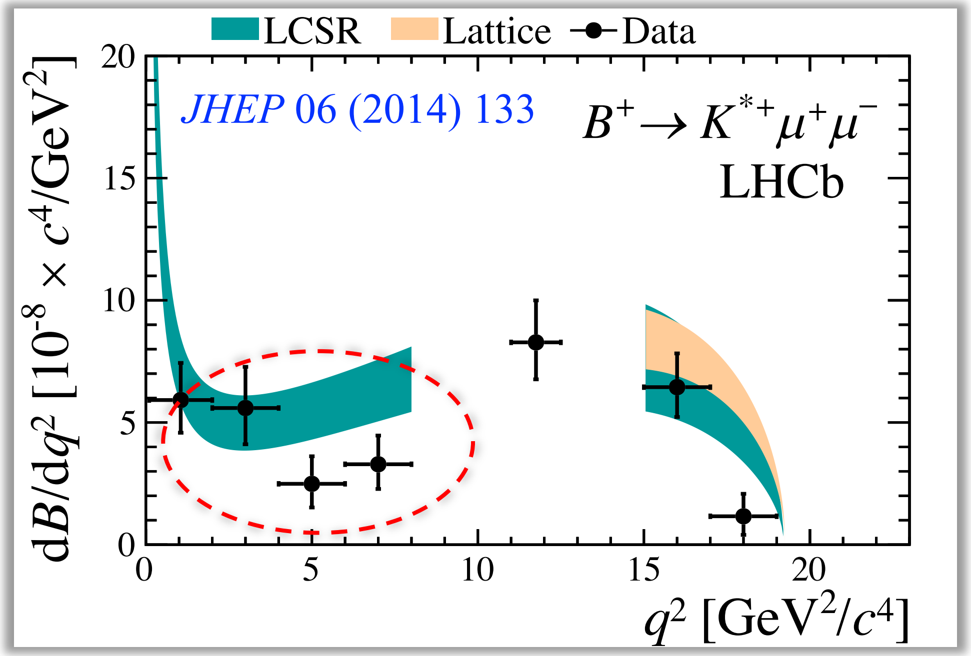
- Study on CP violation



Heavy Meson LCDA in the Precision Calculation

➢ FCNC processes $B \to K^* \ell\ell$

Gao, Lu, Shen, Wang, Wei, PRD 101 (2020) 074035



$$\mathcal{V}_{B\to K^*}(0) = 0.359^{+0.141}_{-0.085}\Big|_{\lambda_B}{}^{+0.019}_{-0.019}\Big|_{\sigma_1}{}^{+0.001}_{-0.062}\Big|_{\mu}{}^{+0.010}_{-0.004}\Big|_{M^2}{}^{+0.016}_{-0.017}\Big|_{s_0}{}^{+0.153}_{-0.079}\Big|_{\varphi_\pm(\omega)}.$$

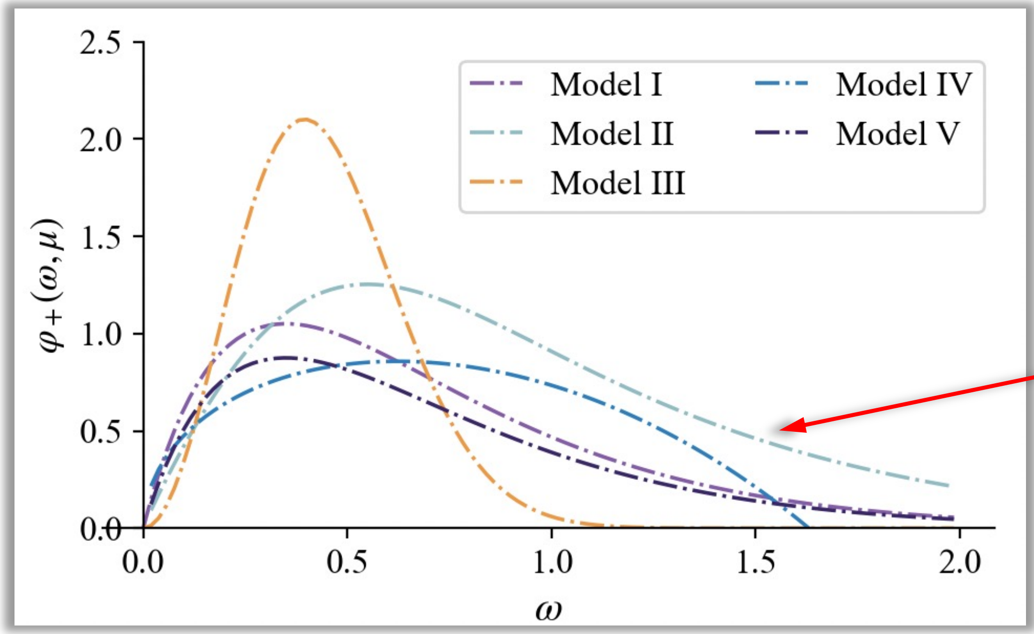
Dominant systematic uncertainties:

- Uncertainties of inverse moment;
- Model-dependence of heavy meson LCDA.

Model Parametrization of the Heavy Meson LCDA

➢ Models for B meson HQET LCDA:

Gao, Lu, Shen, Wang, Wei, PRD 101 (2020) 074035



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Dominant systematic uncertainties:

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- Model-dependence of heavy meson LCDA.

A Preliminary Study

北京航空航天大学
BEIHANG UNIVERSITY

Heavy Meson Profiles from First-Principle: Challenges, Advances, and Implementations

Qi-An Zhang

Beihang University (BUAA)

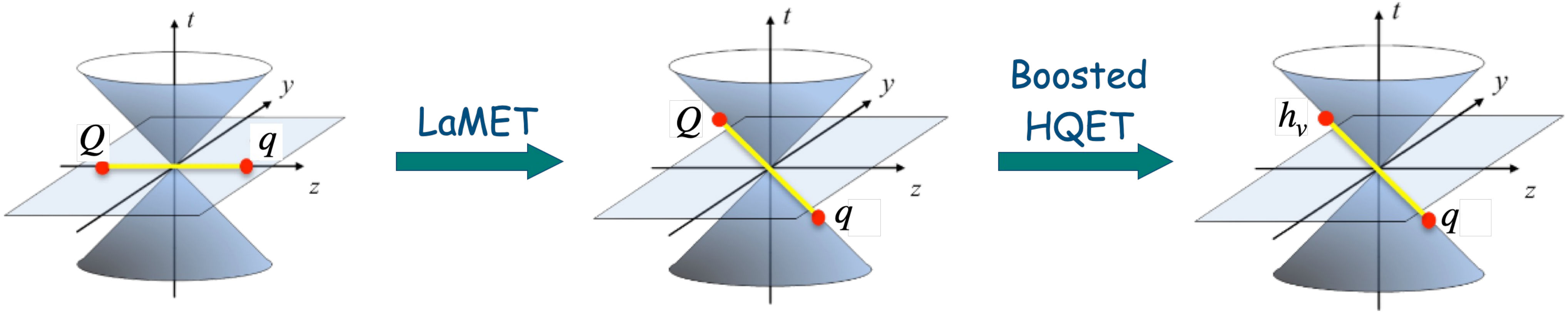
Apr. 21, 2025 @ 第七届全国重味物理与QCD研讨会, 南京

首次成功的格点QCD尝试

Toward the First-Principle Calculation of Heavy Meson LCDAs

Heavy Quark LaMET

LPC, Phys.Rev.D 111 (2025), L111503; PRD111 (2025), 034503



P^z / m_H / Λ_{QCD}

- Quasi-DA
- LQCD calculable
- $\Lambda_{QCD} \ll m_H \ll P^z$

m_H / Λ_{QCD}

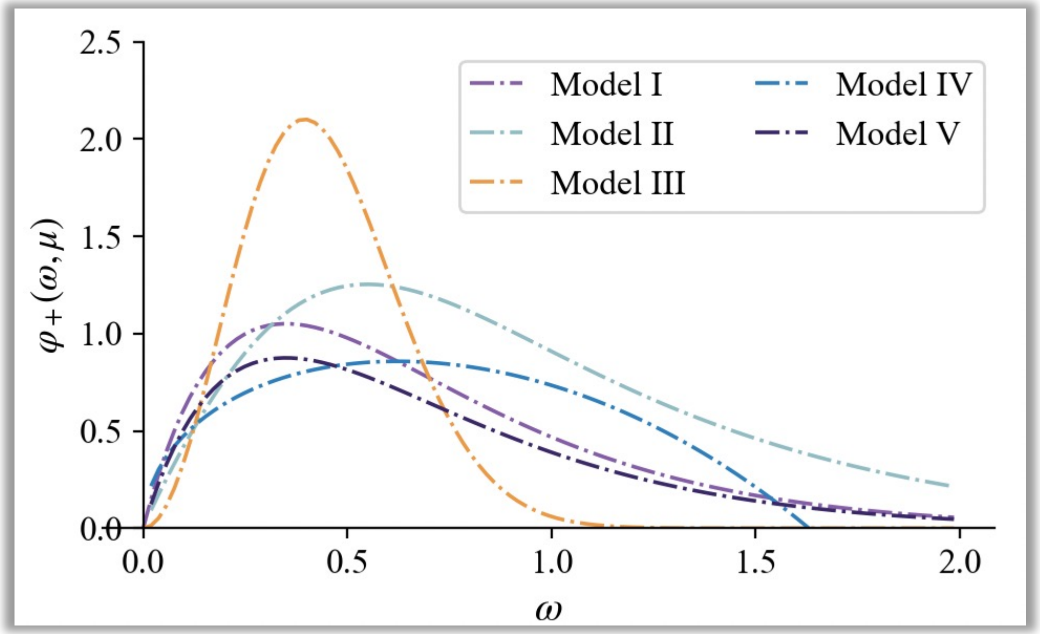
- LaMET
- Integrate out P^z
- QCD LCDA

Λ_{QCD}

- Boosted HQET
- Integrate out m_Q
- HQET LCDA

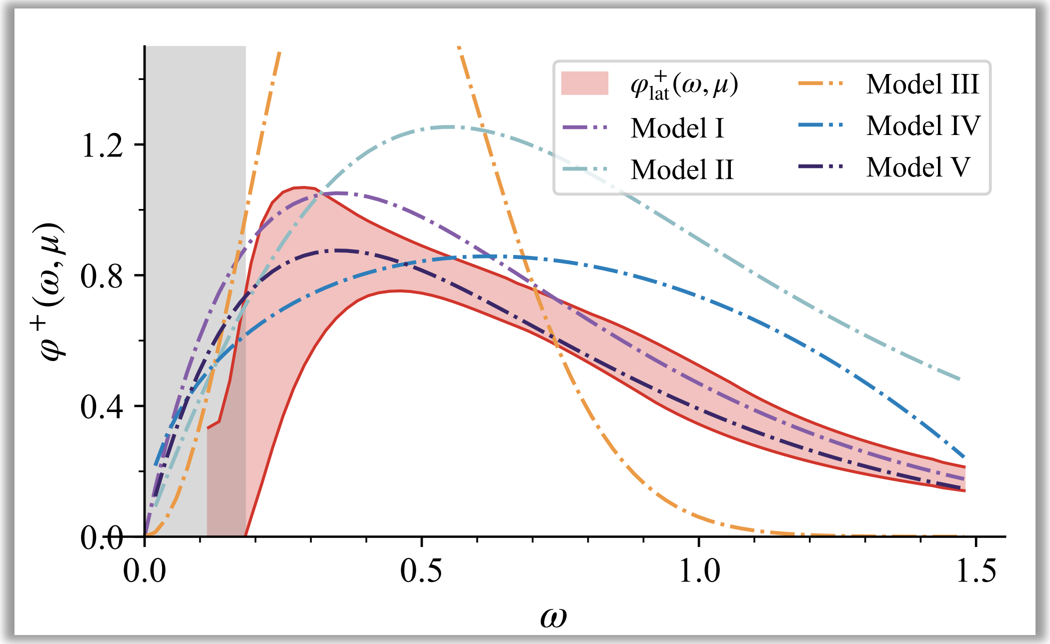
Toward the First-Principle Calculation of Heavy Meson LCDAs

Before 2025



- Only models

LQCD result, 2025

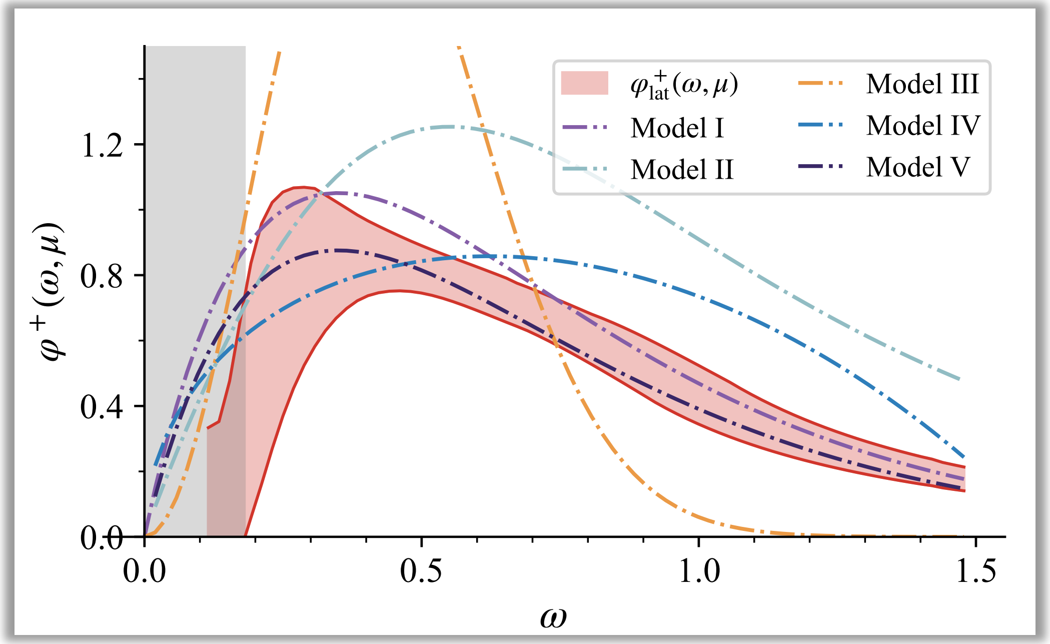


- LQCD, but still preliminary

LPC, Phys.Rev.D 111 (2025), L111503; PRD111 (2025), 034503

Toward the Precision Calculation of Heavy Meson LCDAs

LQCD result, 2025



LPC, Phys.Rev.D 111 (2025), L111503; PRD111 (2025), 034503

- Only single lattice spacing ⇒ Continuum limit
- Unphysical mass ⇒ Chiral extrapolation
- Leading power ⇒ Power corrections?

LaMET:

$$\frac{\Lambda_{\rm QCD}^2}{(yP^z)^2} \sim \frac{0.4^2}{(4y)^2} < 1\%$$

$$\frac{m_D^2}{(P^z)^2} \sim \frac{2^2}{4^2} \simeq 25\%$$

bHQET:

$$\frac{\Lambda_{\rm QCD}}{m_D} \sim \frac{0.4}{2} \simeq 20\%$$

Recap: LaMET vs. Lattice OPE

- In the lattice OPE calculation of heavy meson LCDAs, the largest scale is m_H
- But only the lowest moments can be accessed
- The power correction $\mathcal{O}(m_D^2/(P^z)^2)$ can be benchmarked by the OPE moments

	LaMET	OPE
Output	x-dependent partonic distributions of LCDAs	A finite number of moments of LCDAs
Pros	1) Direct access to the full x-dependence of partonic distributions 2) Enables direct comparison with global fits and phenomenology	1) No need for large hadron momentum 2) Low moments can be determined precisely 3) QCD sum-rule constraints provide useful consistency checks
Cons	1) Requires large hadron momentum P^z 2) Requires better control of discretization effects, signal-to-noise degradation, and excited-state contamination	1) Higher moments are more difficult (larger noise, operator mixing, and more complicated renormalization) 2) Unable to directly determine the full partonic distributions

Precision Calculation of Heavy Meson LCDAs

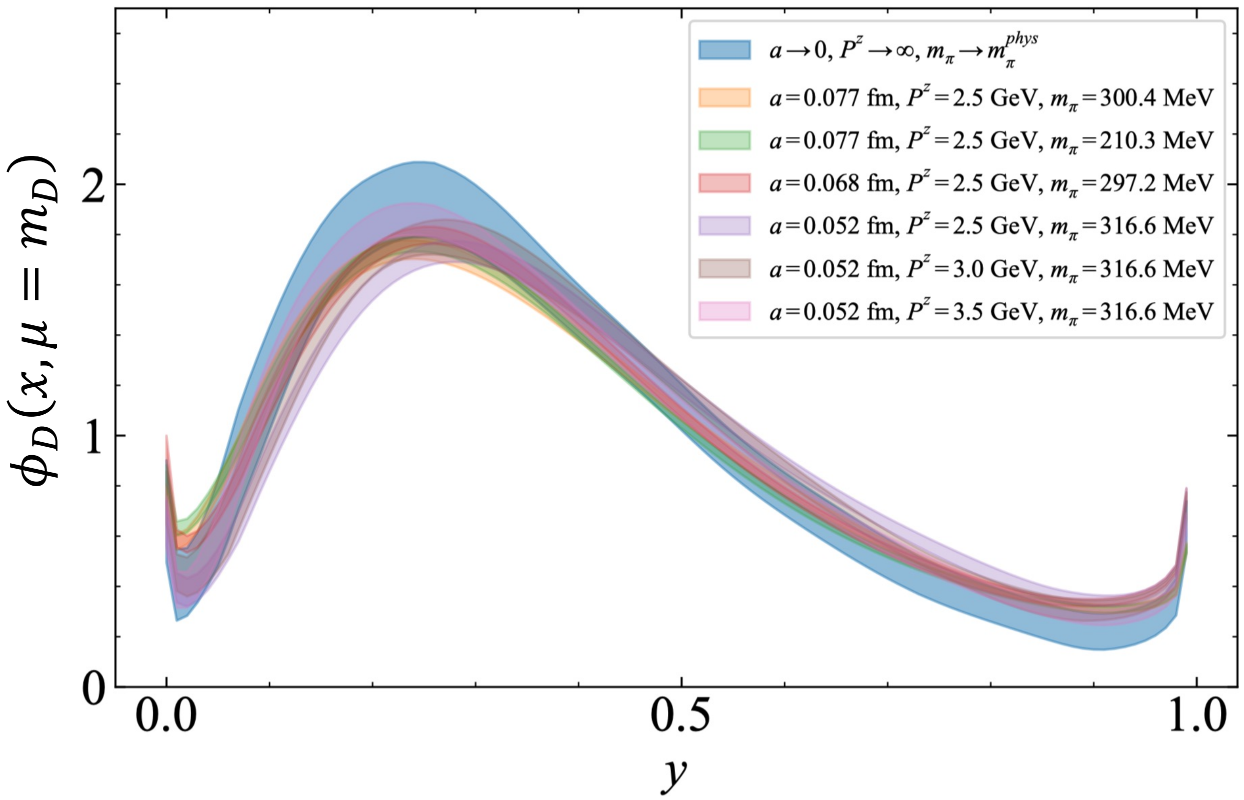
Ensemble	a (fm)	$L^3 \times T$	m_π (MeV)	m_D (MeV)	$n_{\mathrm{cfg}} \times n_{\mathrm{meas}}$ LaMET	$n_{\mathrm{cfg}} \times n_{\mathrm{meas}}$ OPE moment $\langle \xi \rangle$	$n_{\mathrm{cfg}} \times n_{\mathrm{meas}}$ OPE moment $\langle \xi^2 \rangle$
C24P29	0.1053	$24^3 \times 72$	292.7(1.2)	1885.7(3.6)	—	50 × 16	440 × 16
C48P14		$48^3 \times 96$	135.5(1.6)	1864.8(3.2)			304 × 48
F32P30	0.0775	$32^3 \times 96$	303.2(1.3)	1887.9(1.3)	900 × 102	50 × 16	231 × 16
F32P21		$32^3 \times 64$	210.9(2.2)	1869.3(3.1)	459 × 128	—	—
G36P29	0.0683	$36^3 \times 108$	295.1(1.2)	1873.1(1.0)	656 × 86	50 × 16	117 × 16
H48P32	0.0519	$48^3 \times 144$	317.2(0.9)	1882.4(0.8)	550 × 108	50 × 16	111 × 16

~ 100K !

- ✓ Multi lattice spacings: Continuum extrapolation.
- ✓ Multi pion masses: Chiral extrapolation.
- ✓ Large statistic.
- ✓ LaMET + Lattice OPE for QCD LCDA.

QCD LCDA of D Meson from LaMET

➢ Full distribution of D meson QCD LCDA from LaMET:



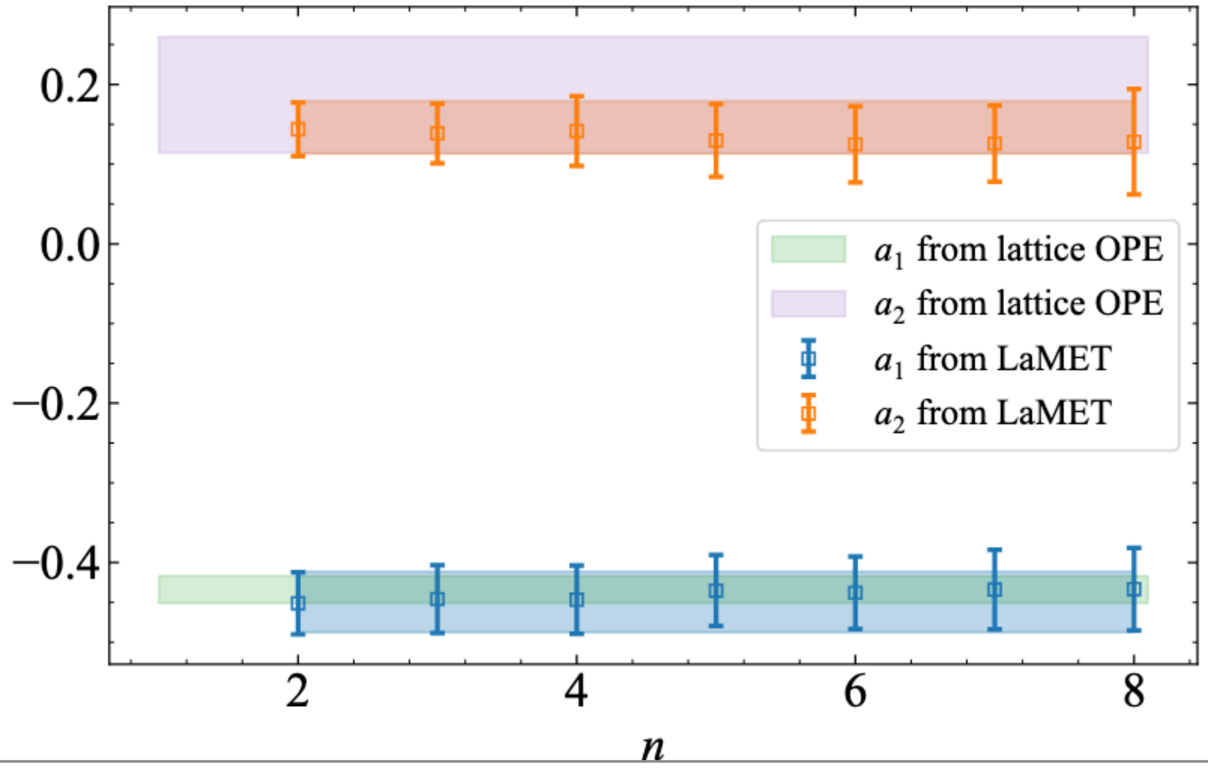
- Peak region: $y \sim \mathcal{O}(\Lambda_{\rm QCD}/m_H)$
- Tail region: $y \sim \mathcal{O}(1)$
- End-point region: $(yP^z \lesssim \Lambda_{\rm QCD}) \cup (P^z \lesssim m_D)$

- Gegenbauer moments can be extracted from the full distribution

Benchmark the Full Distributions from moments

- Gegenbauer moments a_1 and a_2 from LaMET and Lattice OPE:

$$\phi(x,\mu) = 6x(1-x)\left[1 + \sum_{n=1}^{\infty} a_n(\mu) C_n^{(3/2)}(2x-1)\right]$$



LaMET

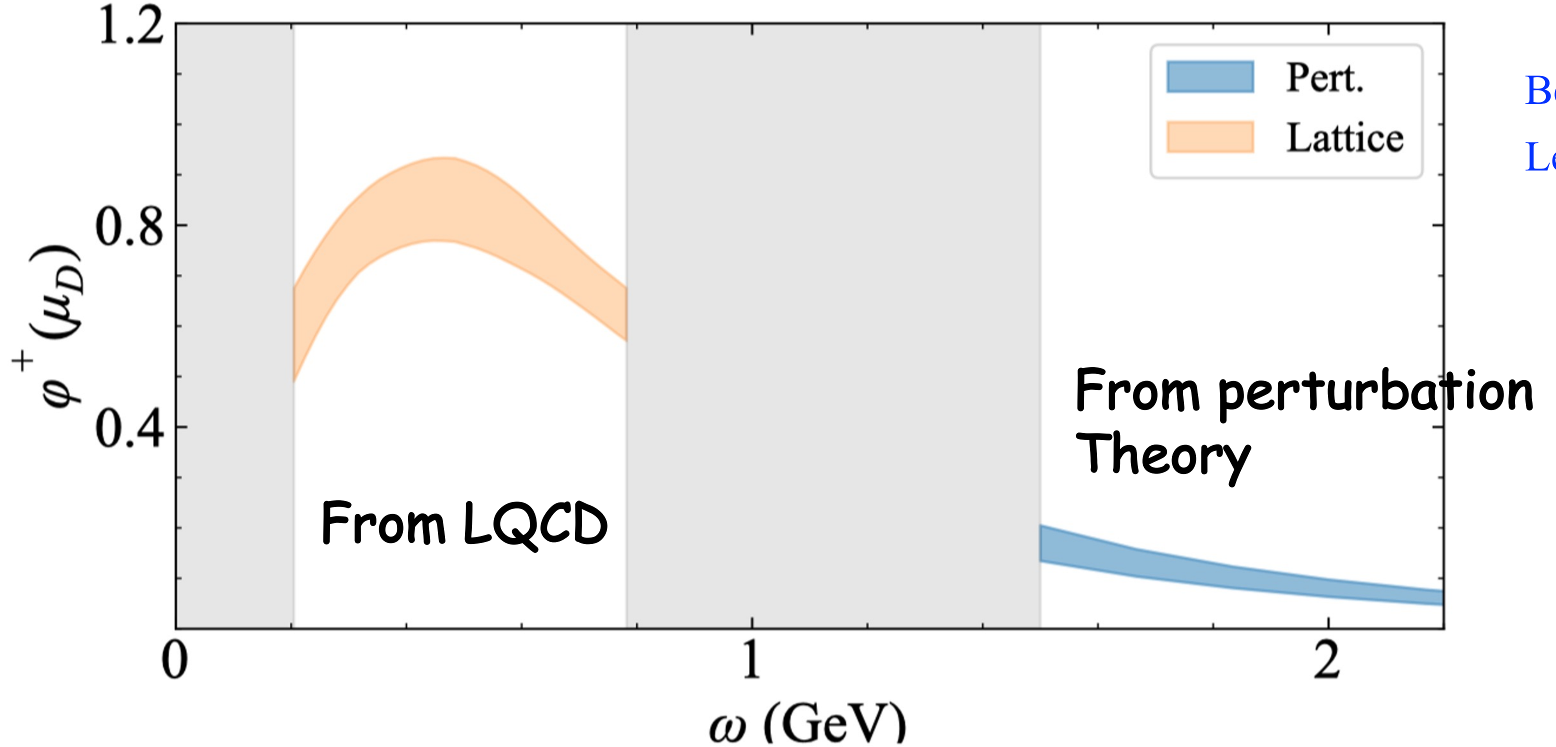
$$a_1^{\mathrm{LaMET}}(\mu) = -0.450(38),$$
$$a_2^{\mathrm{LaMET}}(\mu) = 0.146(33),$$

OPE

$$a_1^{\mathrm{OPE}}(\mu) = -0.434(17),$$
$$a_2^{\mathrm{OPE}}(\mu) = 0.183(73),$$

Prediction for the HQET LCDA

$$\varphi^+(\omega,\mu) = \begin{cases} \frac{1}{m_H}\left[1 - \frac{\alpha_s C_F}{4\pi}\left(\frac{1}{2}\ln^2\frac{\mu^2}{m_H^2} + \frac{1}{2}\ln\frac{\mu^2}{m_H^2} + \frac{3}{2}\ln\frac{\mu^2}{m_Q^2} + \frac{\pi^2}{12} + 4\right) + \mathcal{O}\left(\alpha_s^2\right)\right]\phi(\frac{\omega}{m_H},\mu), & \omega \sim \Lambda_{\rm QCD} \\ \frac{\alpha_s C_F}{\pi\omega}\left[\left(\frac{1}{2} - \ln\frac{\omega}{\mu}\right) + \frac{4\bar{\Lambda}}{3\omega}\left(2 - \ln\frac{\omega}{\mu}\right)\right] + \mathcal{O}\left(\alpha_s^2\right), & \omega \sim m_H \end{cases}$$



Beneke, Finauri, Vos, Wei, JHEP 09, 066 (2023)

Lee, Neubert, PRD 72, 094028 (2005)

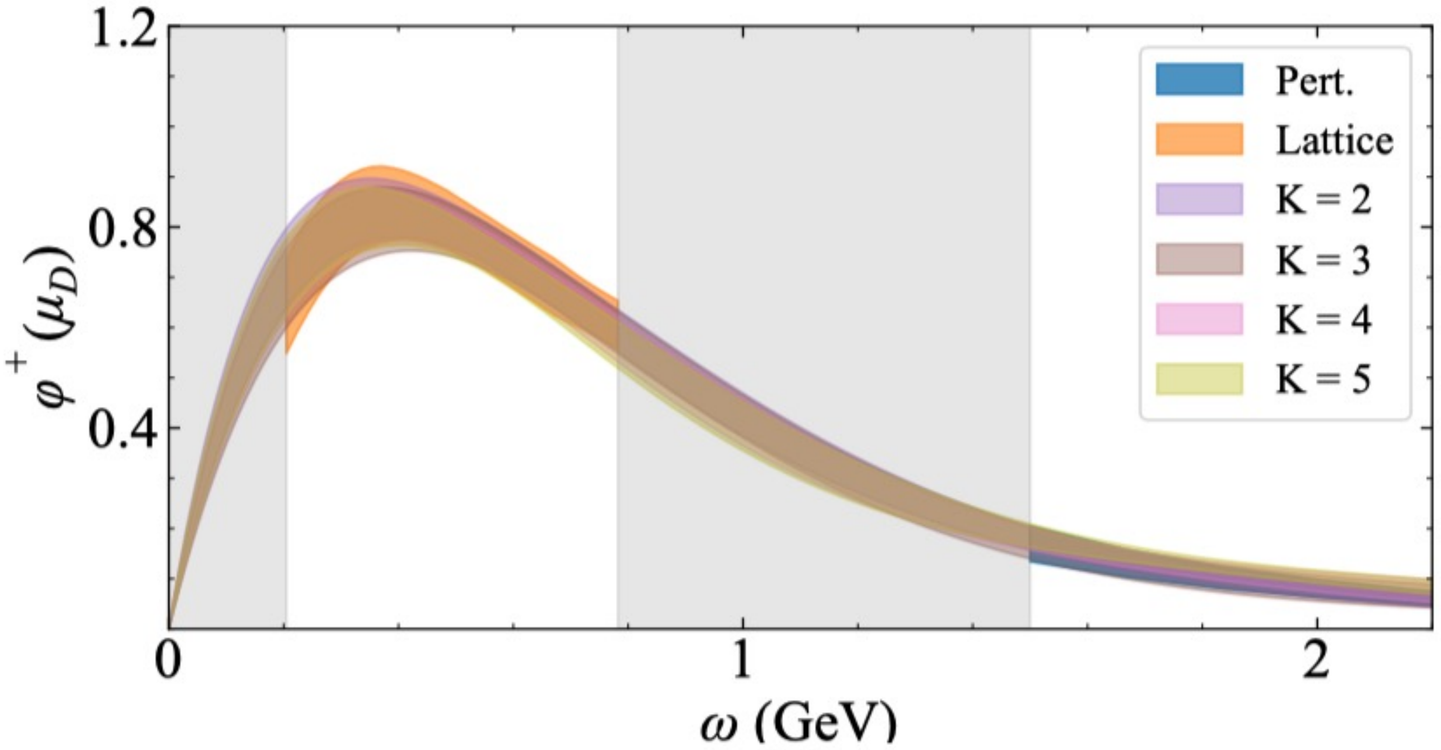
Full distribution is still not accessible!

Prediction for the HQET LCDA

- Rebuild the full distribution of the HQET LCDA from a **model-independent parametrization:**

$$\varphi^+(\omega,\mu) = \frac{\omega e^{-\omega/\omega_0}}{\omega_0^2} \sum_{k=0}^{K} \frac{a_k(\mu)}{1+k} L_k^{(1)}(2\omega/\omega_0),$$

Feldmann, Lughausen, Dyk, JHEP10, 162 (2020)

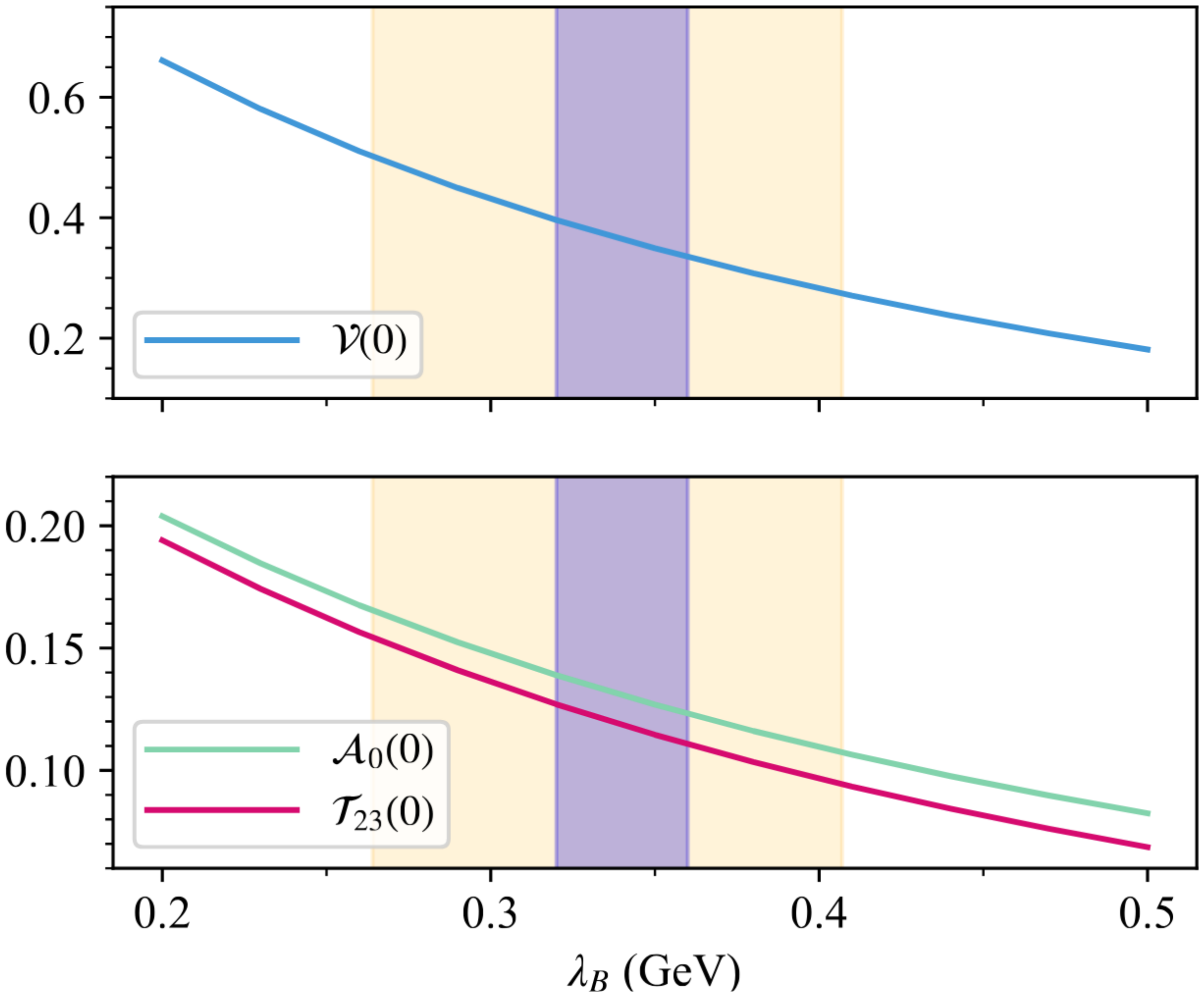


- Agree well with the data.
- With full distributions, further phenomenological discussions can be preformed.

Inverse and inverse-logarithmic moments

μ	Reference (Method)	λ_B (GeV)	$\sigma_B^{(1)}$	
1 GeV	This work	0.347(21)	1.723(69)	
	Ref. [18] (LQCD)	0.376(63)	1.66(13)	PRD111 (2025), 034503
	Ref. [29] (Experiment)	> 0.24	–	PRD98 (2018), 112016
	Ref. [15] (QCD sum rule)	$0.343^{+0.064}_{-0.079}$	1.4(4)	PRD101 (2020), 074035
	Ref. [6] (QCD sum rule)	0.46(11)	1.4(4)	PRD69 (2004), 034014
	Ref. [30] (QCD sum rule)	0.383(153)	–	JHEP10 (2020), 043
	Ref. [14] (OPE)	0.48(11)	1.6(2)	PRD72 (2005), 094028
	Ref. [5] (Asymptotic behavior)	0.35(15)	–	PRD55 (1997), 272290
	Ref. [31] (Global Fit)	0.338(68)	–	PLB848 (2024), 138345

B→K* Form Factors in LCSR with Updated Inverse Moments



- In PRD101 (2020), 074035: (orange band)

$$V(0) = 0.359^{+0.141}_{-0.085}, \quad A_0(0) = 0.129^{+0.035}_{-0.021},$$
$$T_{23}(0) = 0.116^{+0.036}_{-0.022},$$

- With our updated λ_B: (purple band)

$$V(0) = 0.362^{+0.034}_{-0.029}, \quad A_0(0) = 0.131^{+0.008}_{-0.008},$$
$$T_{23}(0) = 0.119^{+0.008}_{-0.008}.$$

We thank Yu-Ming Wang for his code to calculate the B → V form factors in LCSRs, *PRD 101 (2020) 074035*

$W \to D\gamma$ and $W \to B\gamma$ rare decays with updated QCD LCDA

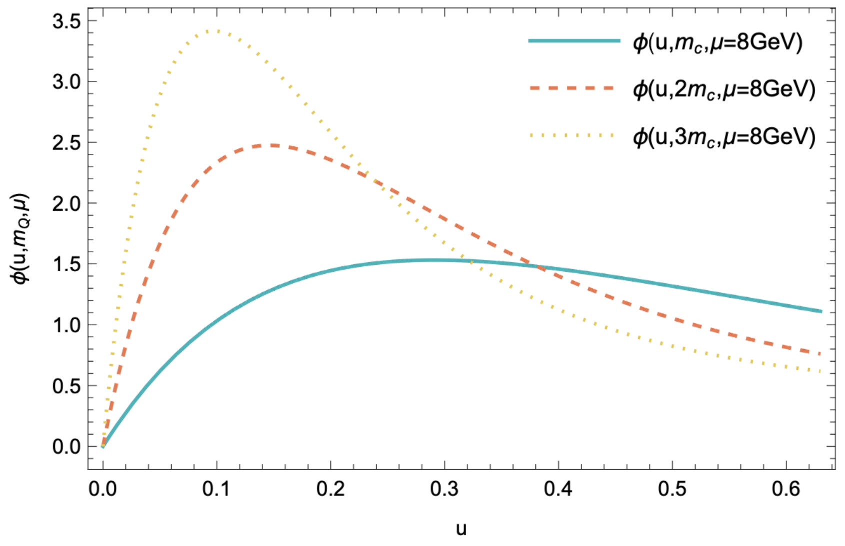
- Rare radiative decay branching ratios of $W \to D\gamma$: Beneke, Finauri, Vos, Wei, JHEP 09, 066 (2023)

$$\mathcal{B}(W \to D\gamma) = (1.07 \pm 0.10_I {}^{+0.06}_{-0.07}{}_\mu \pm 0.21_L) \times 10^{-9},$$

- Evolute to the B meson QCD LCDA with the m_Q-RGE of heavy meson LCDAs:

Wang, Xu, **QAZ**, Zhao, arXiv:2411.07101 [hep-ph]

$$\left[m_Q \frac{\partial}{\partial m_Q} - u \frac{\partial}{\partial u} - 1 - \gamma(m_Q, \mu)\right] \phi(u, \mu; m_Q) = 0$$



- Branching ratios of $W \to B\gamma$:

$$\mathcal{B}(W \to B\gamma) = (2.08 \pm 0.17_I {}^{+0.19}_{-0.22}{}_\mu \pm 0.25_L) \times 10^{-12}$$

Summary and Outlook

2025，南京，第七届重味物理和QCD研讨会

The factorization formula for heavy meson LCDAs has been established. Preliminary lattice QCD results are now available, awaiting for more systematic lattice QCD investigations.

2026，重庆，第八届重味物理和QCD研讨会

- Based on HQLaMET framework, we present a precise calculation of HQET LCDAs.
- Continuum limit ✔, physical-mass ✔
- Power corrections 🕒

- Precise lattice calculations will deliver essential nonperturbative inputs for precision heavy quark phenomenology.

Thanks for your attention