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LCDA of vector meson from lattice QCD with large momentum effective theory

PRL.127.062002(2021)by LPC

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LaMET 2021 **2021/12/08**

Out line

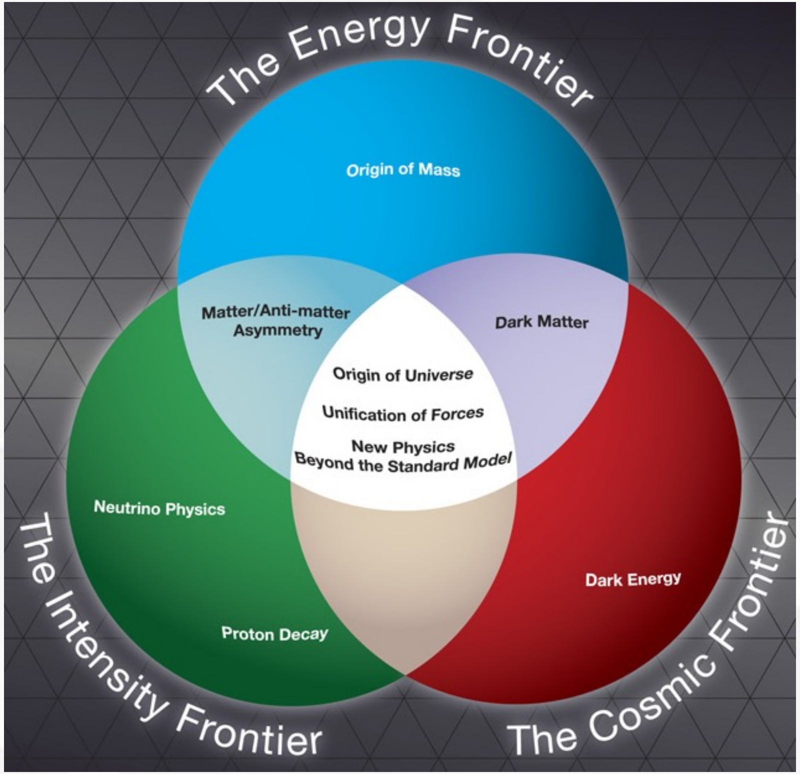
- Motivation
- LCDA by LaMET
- Numerical results
- Summary and Outlook

Motivation

New physics beyond Standard Model

- ➢ **Direct search: LHC, SPPC…**
- ➢ **Indirect test:**
  - **B factories (Rare decay)**
  - **Precision calculation**

Beyond SM: Three Frontiers



Motivation

Test of lepton universality with $B^0 \to K^{*0}\ell^+\ell^-$ decays #3

LHCb Collaboration • R. Aaij (CERN) et al. (May 16, 2017)

Published in: *JHEP* 08 (2017) 055 • e-Print: 1705.05802 [hep-ex]

pdf links DOI cite datasets 828 citations

Lepton Flavor Universality

Measurement of the Differential Branching Fraction and Forward-Backword Asymmetry for $B \to K^{(*)}\ell^+\ell^-$ #10

Belle Collaboration • J.-T. Wei (Taiwan, Natl. Taiwan U.) et al. (Apr, 2009)

Published in: *Phys.Rev.Lett.* 103 (2009) 171801 • e-Print: 0904.0770 [hep-ex]

pdf DOI cite 521 citations

Angular Analysis and P_5'

Angular analysis of the $B^0 \to K^{*0}\mu^+\mu^-$ decay using 3 fb^{-1} of integrated luminosity

LHCb Collaboration • Roel Aaij (CERN) et al. (Dec 14, 2015)

Published in: *JHEP* 02 (2016) 104 • e-Print: 1512.04442 [hep-ex]

pdf links DOI cite datasets 717 citations

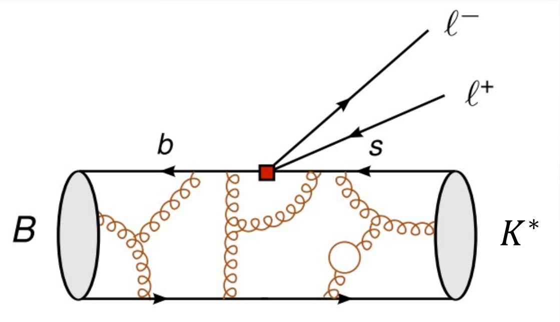
Forward-backward Asymmetry

Motivation

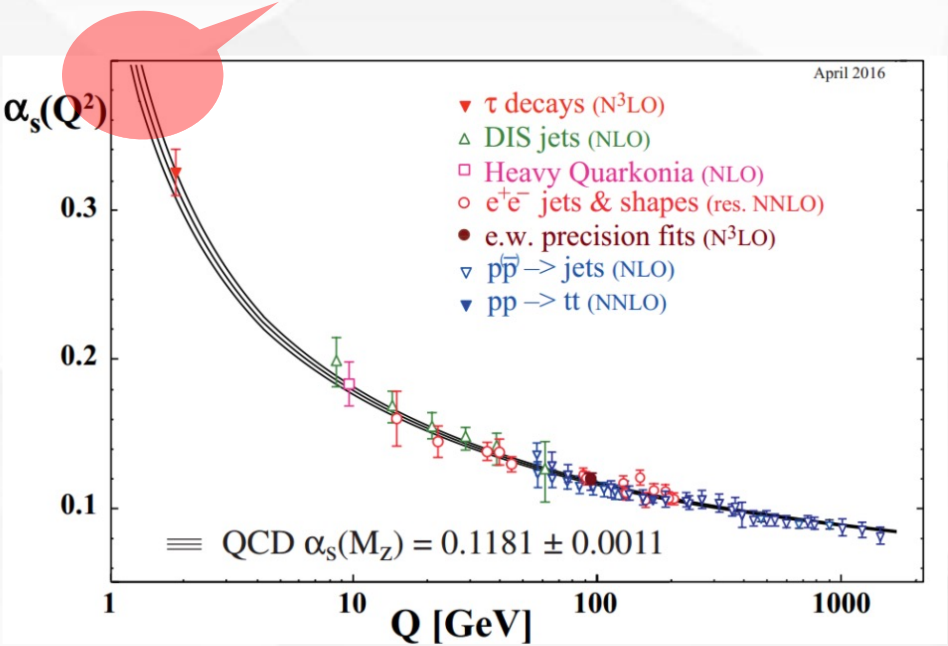
QCD factorization:

Separating the processes with different energy scales

Amplitudes = LCDAs ⊗ Hard kernel



Non-perturbative



LCDA in Lattice QCD

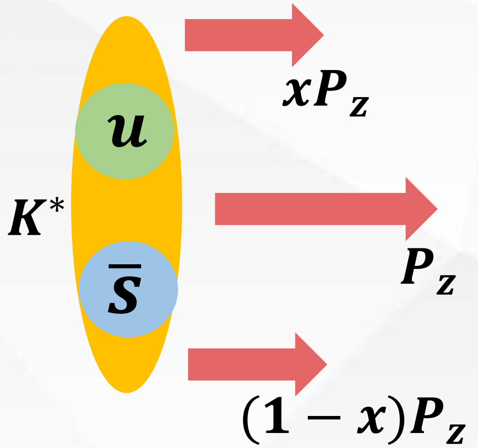
Target Vector Meson LCDA — defined via a meson-to-vacuum matrix element

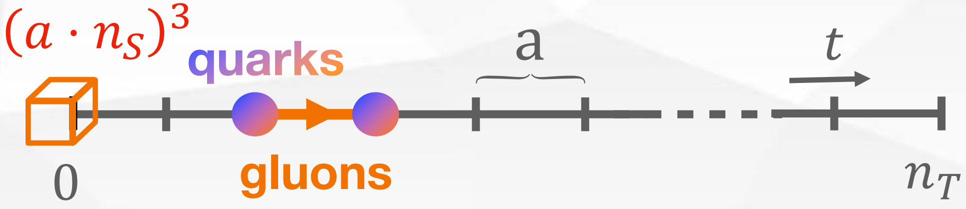
$$\int d\xi^- e^{-ixp^+\xi^-}\langle 0|\bar{\psi}_1(0)\not{n}_+ U(0,\xi^-)\psi_2(\xi^-)|V\rangle = f_V n_+\cdot\epsilon\Phi_{V,L}(x),$$

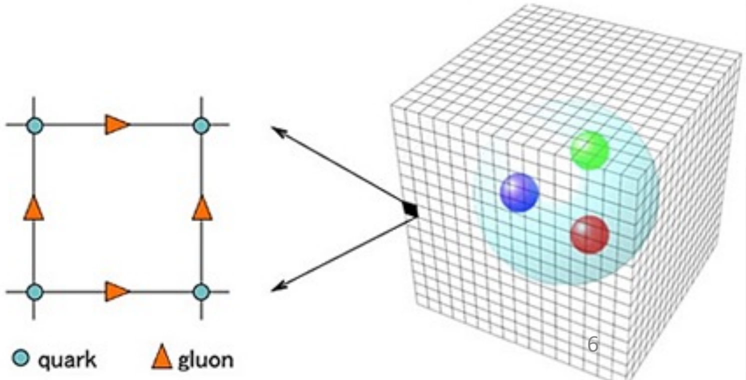
$$\int d\xi^- e^{-ixp^+\xi^-}\langle 0|\bar{\psi}_1(0)\sigma^{+\mu_\perp} U(0,\xi^-)\psi_2(\xi^-)|V\rangle = f_V^T[\epsilon^+ p^{\mu_\perp} - \epsilon^{\mu_\perp}p^+]\Phi_{V,T}(x),$$

$$U(0,\xi^-) = P\exp\left[ig_s\int_{\xi_-}^{0} ds n_+\cdot A(sn_+)\right]$$

polarization vector







LCDA in Lattice QCD

Method	Work	Meson	Mass	Lattice Spacing
OPE	V.M. Braun et al. (2015)	π	physical	(0.06,0.08)fm
	V.M. Braun et al. (2017)	ρ	physical	(0.06,0.08)fm
	G.S. Bali et al. (2019)_RQCD	π, K	combinations	5 (from 0.08 to 0.04)fm

Method	Work	Meson	Mass	Lattice Spacing
LaMET	J.H.Zhang et al. (2017)	π	310MeV-Pion	0.12fm
	R.Zhang et al.(2020)	π, K	310MeV-Pion	(0.06,0.09,0.12)fm
	LPC (2021) this work	K^*, ϕ	physical	(0.06,0.09,0.12)fm

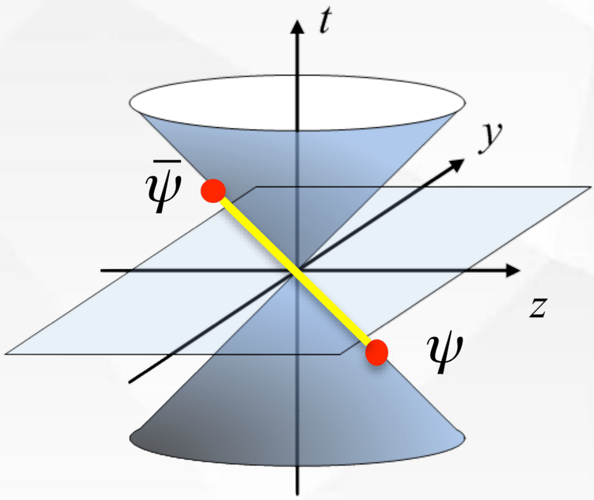
Large-Momentum effective theory

Define a new matrix element with an equal-time correlator, named quasi-PDF/DA:

$$\tilde{q}(x, P^z, \mu) = \int \frac{dz}{4\pi} e^{ixP^z z} \langle 0|\overline{\psi}(z)\gamma_t \exp\left(-ig\int_0^z dz' A^z(z')\right)\psi(0)|V\rangle$$

Can be calculated on lattice directly!

X. Ji. Parton Physics on a Euclidean Lattice, Phys.Rev.Lett. 110, 262002 (2013).



For large P^z, the leading power of quasi-PDF/DA under the expansion of $\Lambda^2, M^2/(P^z)^2$ can be factorized into PDF/DA:

$$\tilde{q}(x, P^z, \mu) = \int \frac{dy}{|y|} C(x, y, P^z, \mu) q(y, \mu) + \mathcal{O}\left(\frac{\Lambda^2, M^2}{(P^z)^2}\right)$$

LCDA in LaMET

- ✓ MILC, clover
- ✓ 0.06, 0.09, 0.12fm
- ✓ 1.29, 1.72, 2.15GeV

Bare DA matrix element with

↓

Renormalized matrix element: hybrid scheme based on RI/MOM

↓ Fourier Transformation with Extrapolation

Quasi-DA in Momentum space

↓ Inverse matching procedures:

$$\phi_{LC}(y) = \int dx\, C^{-1}(x, y, P_z, \mu, \mu_R)\,\widetilde{\phi_Q}(x)$$

$\overline{MS}$ LCDA

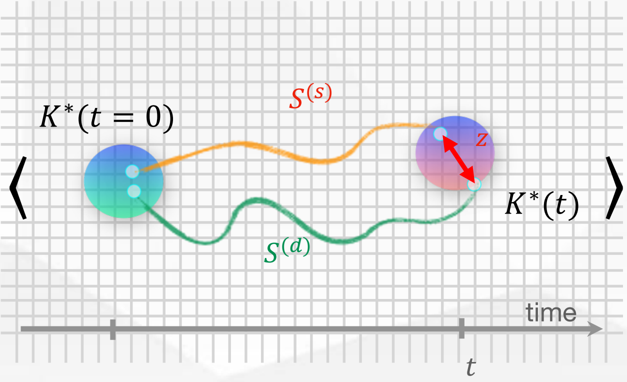
Bare matrix element

- **The bare equal-time correlations on the lattice:**

$$\langle 0 \,|\, \bar{\psi}_1(0)\gamma^t\, U(0,\vec{z})\psi_2(\vec{z})\, |V\rangle \;=\; H(z)\epsilon^t f_V$$

Gauge link

Quasi DA



- **The two-point correlation function defined on the lattice:**

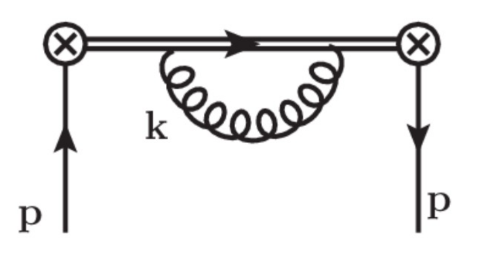
$$C_2^m(z,\vec{P},t) \;=\; \int d^3w\, e^{-i\vec{P}\cdot\vec{w}}\langle 0|\bar{\psi}_1(\vec{w},t)\Gamma_1\, U(\vec{w},\vec{w}+\vec{z})\psi_2(\vec{w}+\vec{z},t)\bar{\psi}_2(0,0)\Gamma_2\, \psi_1(0,0)|0\rangle$$

K^* related to Twist2: ***Longitudinal***: γ_t ***Transverse***: $\boldsymbol{\sigma}_{(z,x)}$

Hybrid renormalization on RI/MOM

Matrix element

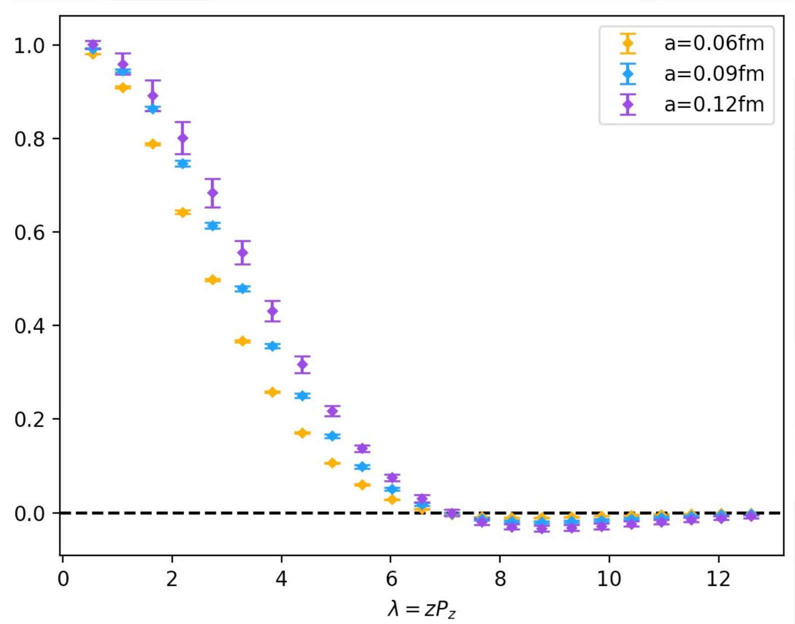
$$\langle P|\bar{\psi}(0)U(0,z)\psi(z)|P\rangle$$



$$M(z) \sim \exp\left(-\frac{C(\alpha)z}{a}\right) f(z)$$

Linear divergence from self-energy of gauge link

DA bare matrix elements: $e^{\frac{izP_z}{2}} H_\pi(z)$

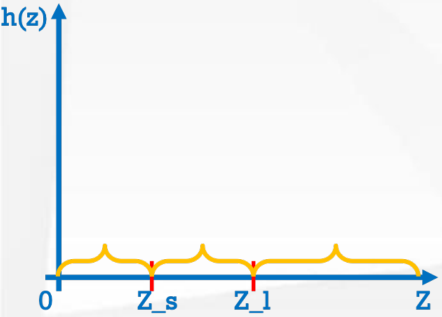


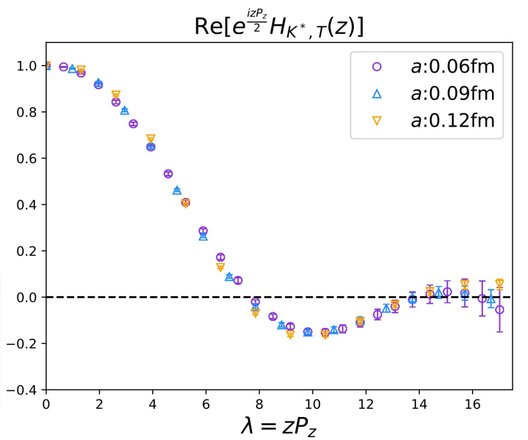
Hybrid renormalization on RI/MOM

- **$(0 \le |z| \le Z\_s)$, RI/MOM renormalization**
- **$(Z\_s \le |z| \le Z\_l)$, modified mass renormalization**

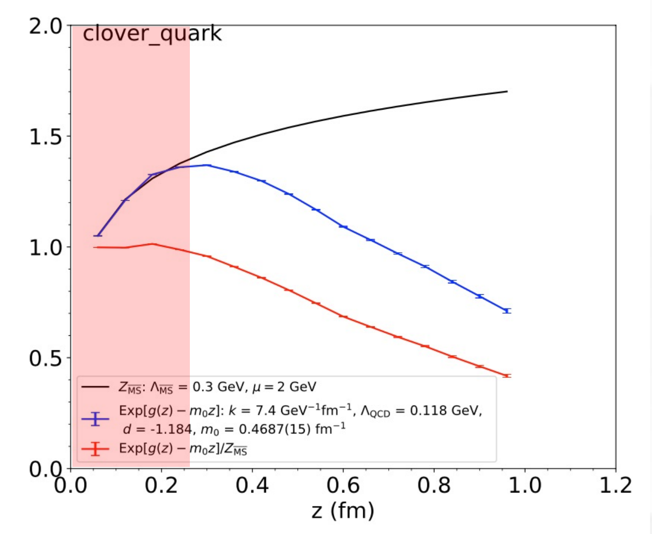
$$C_2 = C_0 e^{-(1+c_2 ln\frac{z}{z_s})\{(\underbrace{\frac{m_{-1}}{a}+m_0}_{\delta m})*z+c_1\ln(z)\}}$$

X.~Ji, et al. NPB.964.115311(2021)





Effective range for RI/MOM



Y.K.Huo, Y.Su et al. NPB.969.115443(2020)

Extrapolation

➢ (|z|≥ Z_l), **physics-based extrapolation**

- Asymptotic behavior at x~0,1:

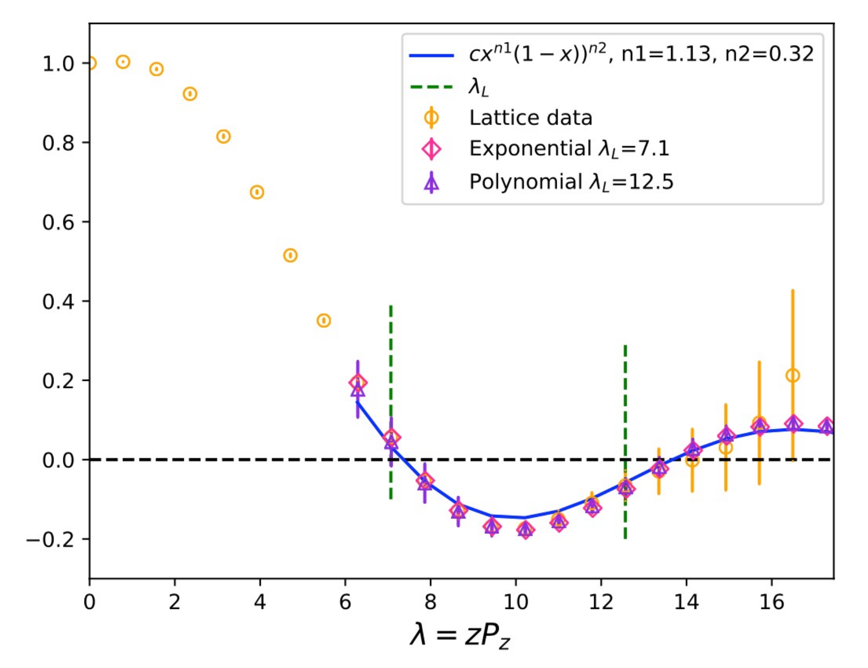
$$\psi(x) \sim x^a(1-x)^b$$

- Coordinate space:

$$h(\lambda) = \int_0^1 dx e^{ix\lambda} x^a (1-x)^b$$

- At large λ

$$\tilde{H}(z, P_z) = \left[\frac{c_1}{(-i\lambda)^a} + e^{i\lambda}\frac{c_2}{(i\lambda)^b}\right] e^{-\frac{\lambda}{\lambda_0}}$$



Numerical results

- 2+1+1 flavors of highly improved staggered quarks (HISQ) action gen-erated by MILC collaboration.

- 3 lattice spacings(0.06, 0.09, 0.12)fm on physical mass(K^*: 0.89GeV, ϕ: 1.02GeV) with $P_z = \{1.29, 1.72, 2.15\}$GeV.

Ensemble	a(fm)	$L^3 \times T$	Clover	$m_\pi(MeV)$	$m_{\eta_s}(MeV)$	Measurements
a12m130	0.1213	$48^3 \times 64$	1.05088	140	670	970(cfg)×64
a09m130	0.0882	$64^3 \times 96$	1.04239	140	670	730×96
a06m130	0.0574	$96^3 \times 192$	1.03493	140	670	570×128

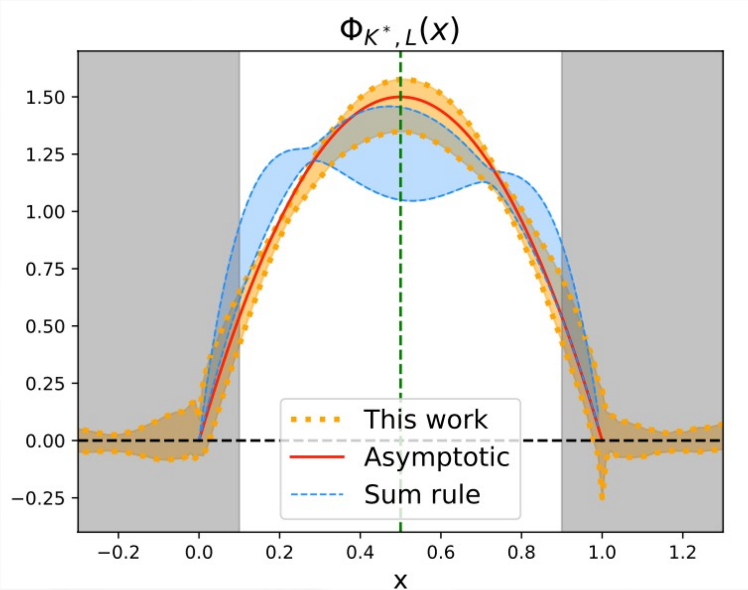
Numerical results

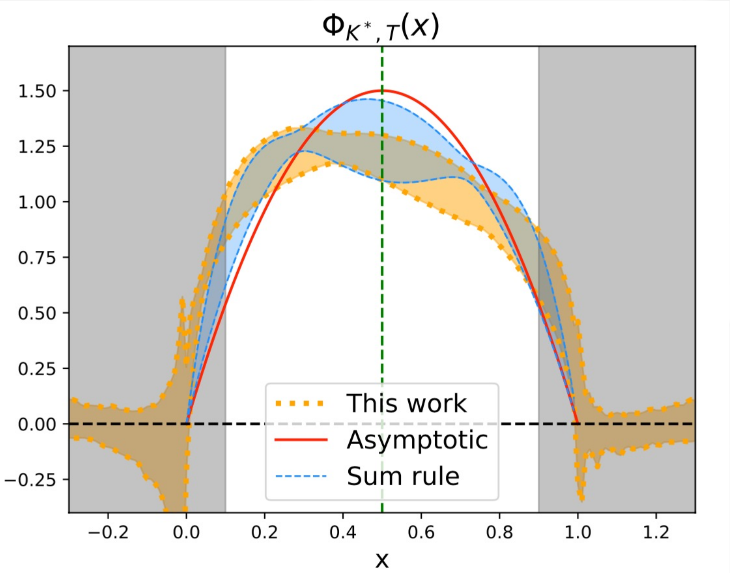
$$q(y, P^z, \mu) = \int dx C^{-1}(x, y, P^z, \mu)\tilde{q}(x, \mu) + \mathcal{O}\left(\frac{\Lambda_{QCD}^2}{(yP^z)^2}, \frac{\Lambda_{QCD}^2}{((1-y)P^z)^2}\right)$$

Large momentum expansion breaks done in end point region:

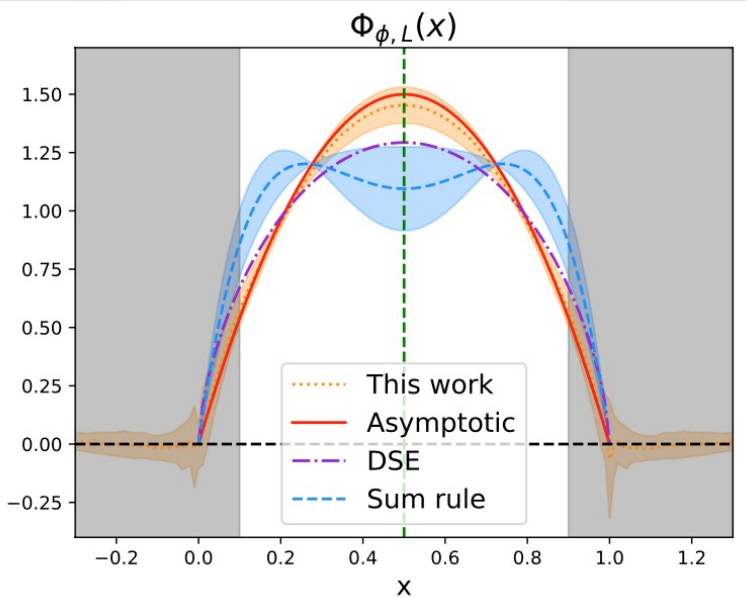
$xP^z \sim \Lambda_{QCD}$; $(1-x)P^z \sim \Lambda_{QCD}$;   For $P^z_{max} = 2.15 GeV$, reliable region: (0.1, 0.9)

K^* LCDA

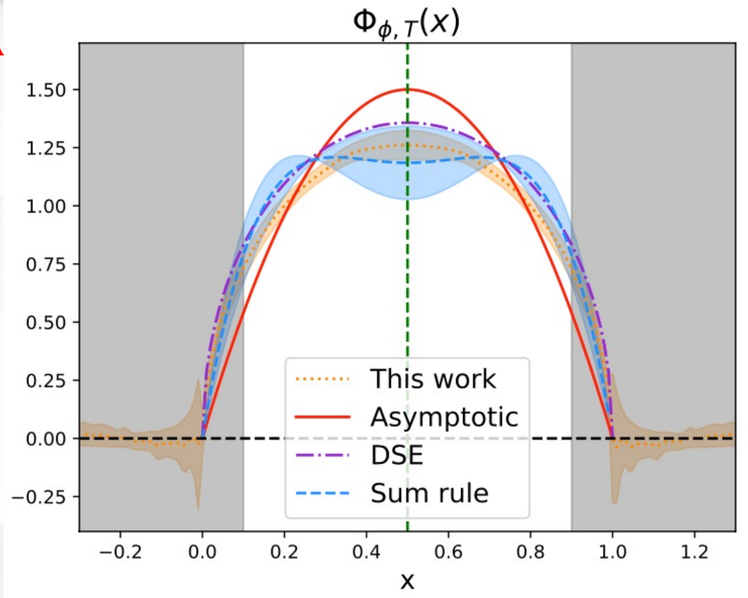




Numerical results



ϕ LCDA



Gegenbauer moments:

Gegenbauer moments	a_1	a_2	a_4
K^*, L	-0.005(07)(07)	0.015(10)(08)	0.013(09)(09)
K^*, T	-0.074(06)(07)	0.181(07)(12)	0.064(07)(06)
ϕ, L	−−	0.018(09)(09)	0.007(10)(20)
ϕ, T	−−	0.128(03)(21)	0.044(04)(08)

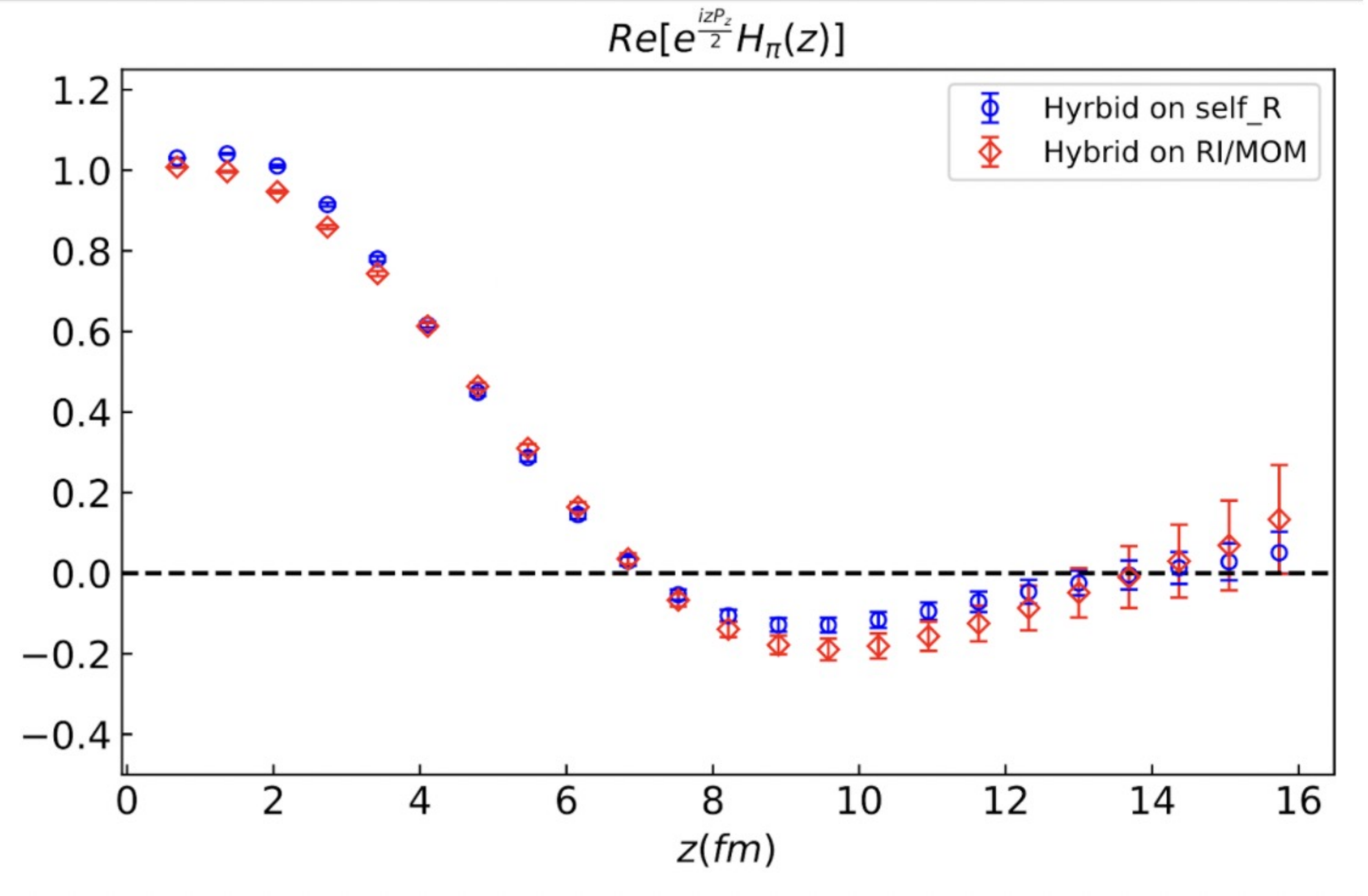
Summary and Outlook

- **We calculate the K^*/ϕ LCDAs on lattice using LaMET:**
  - **First lattice calculation of LCDAs of vector mesons K^*/ϕ**
  - **Firstly adopt the hybrid renormalization scheme to avoid extra nonperturbative effects.**

- **More reliable prediction:**
  - **Hybrid scheme on self renormalization**
  - **Matching in coordinate space**
  - **Lattice calculation on larger P_z, smaller a**
  - **Other methods ...**

Thank You !

Back up



$Re[e^{\frac{izP_z}{2}}H_\pi(z)]$
Hyrbid on self_R
Hybrid on RI/MOM
1.2
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
0
2
4
6
8
10
12
14
16
z(fm)

Matching form Quasi to LCDA

$$\tilde{q}(x,P^z,\mu) = \int \frac{dy}{|y|} C\left(\frac{x}{y}, yP^z, \mu\right) q(y,\mu) + \mathcal{O}\left(\frac{\Lambda_{QCD}^2}{(yP^z)^2}, \frac{\Lambda_{QCD}^2}{((1-y)P^z)^2}\right)$$

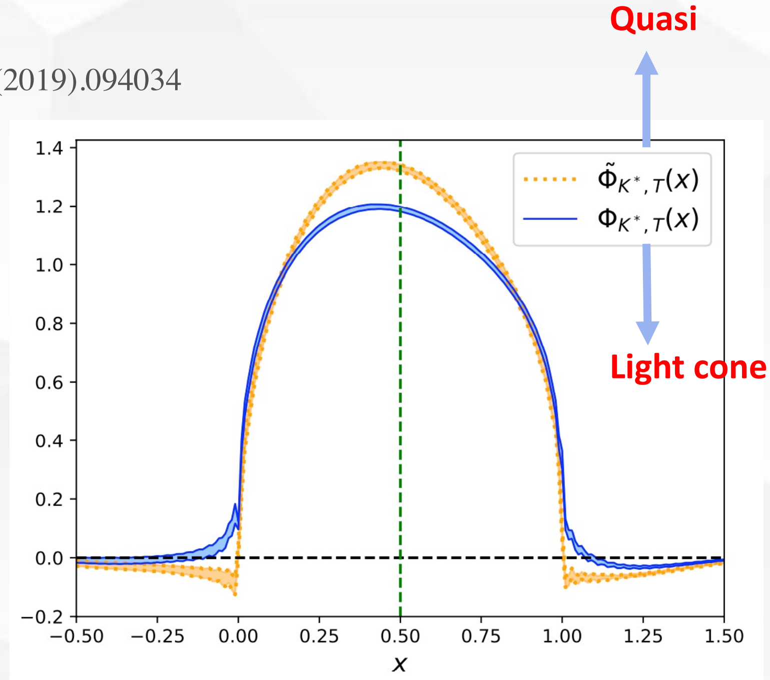
Matching kernel

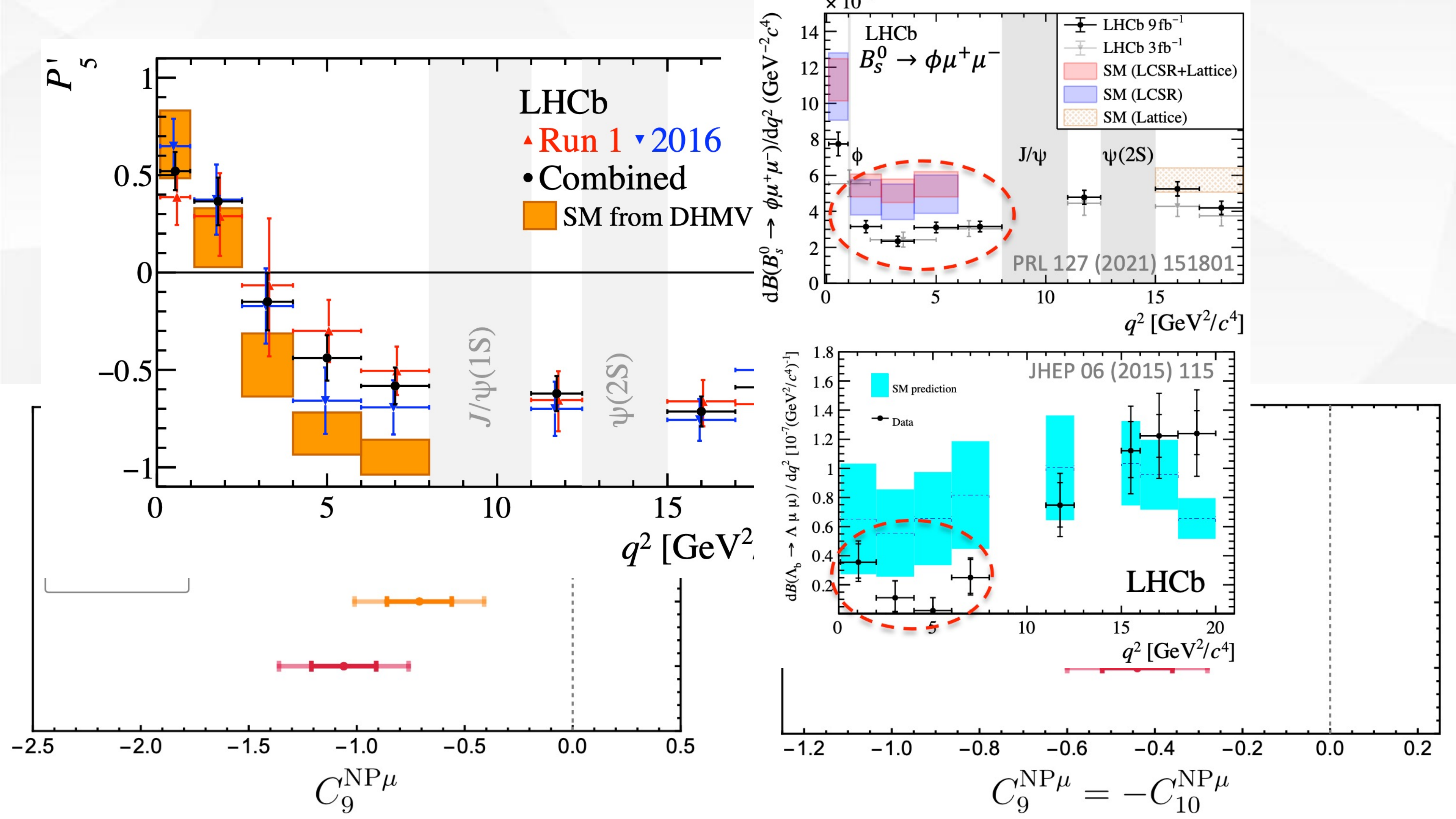
—Y.S.Liu, Q.A.Zhang et.al PRD99(2019).094034

Delta function
Plus function → **Discretization**

$$[q] = \left[C^{-1}\left(\frac{x}{y}, yP^z, \mu\right)\right] * [\tilde{q}]$$

500*500





P'_5
LHCb
Run 1
2016
Combined
SM from DHMV
$J/\psi(1S)$
$\psi(2S)$
q^2 [GeV^2
LHCb
$B_s^0 \to \phi\mu^+\mu^-$
LHCb 9 fb^{-1}
LHCb 3 fb^{-1}
SM (LCSR+Lattice)
SM (LCSR)
SM (Lattice)
ϕ
J/ψ
ψ(2S)
PRL 127 (2021) 151801
$\mathrm{d}B(B_s^0 \to \phi\mu^+\mu^-)/\mathrm{d}q^2$ (GeV$^{-2}c^4$)
q^2 [GeV$^2/c^4$]
JHEP 06 (2015) 115
SM prediction
Data
LHCb
$\mathrm{d}B(\Lambda_b \to \Lambda\mu\mu)$ / dq^2 [10^{-7}(GeV$^2/c^4$)$^{-1}$]
q^2 [GeV$^2/c^4$]
$C_9^{\mathrm{NP}\mu}$
$C_9^{\mathrm{NP}\mu} = -C_{10}^{\mathrm{NP}\mu}$