B-meson LCDA and power corrections

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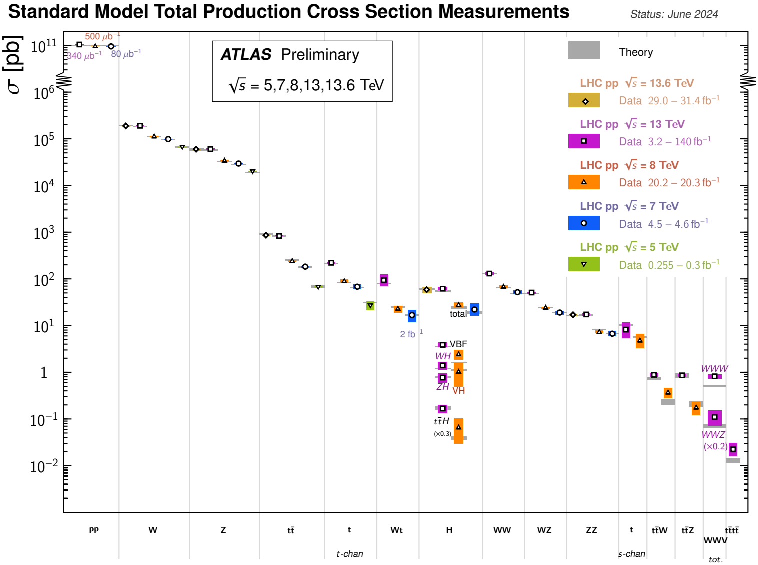
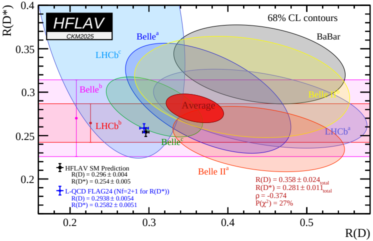
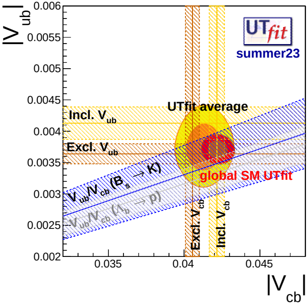
Collider Physics



New physics beyond the SM

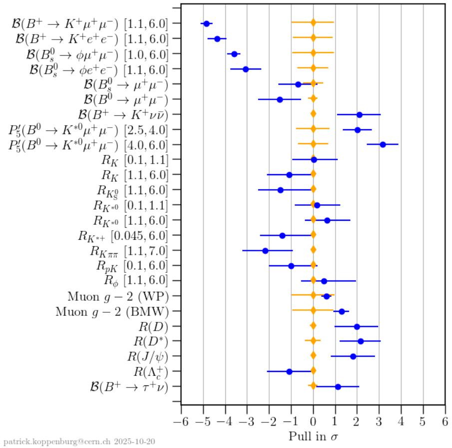
- Indirect search: flavour physics
- LHC, Belle-II
- HL-LHC





- CPV: $\Lambda_b^0 \to pK^-\pi^+\pi^-$ [LHCb, 25'], [Wang and Yu, 24']
- $R(D^{(*)})$: [Wang, **YBW**, Shen and Lü, 17']
- $\left|V_{ub/cb}\right|$: [Shen and **YBW**, 21']

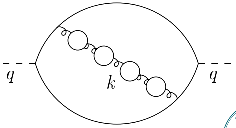
B Physics



- Multi-scale problem:

B LCDA $\sim \mathcal{O}(\Lambda)$

- Power correction:
  - $$\frac{\Lambda}{m_b} \sim \mathcal{O}(20\%)$$
  - IR renormalons [Beneke, 98']



Expansions in B decays

The perturbation expansion and power expansion

$$\alpha_s \sim \Lambda/m_b \sim 20\%$$

$\mathcal{A}$	LL (α_s)	NLL	NNLL
LP	**LP@LL**	**LP@NLL**	**LP@NNLL**
NLP	NLP@LL	NLP@NLL	
NNLP	NNLP@LL		

$$20\% \begin{cases} \text{LP@NLL} \\ \text{NLP@LL} \end{cases}$$

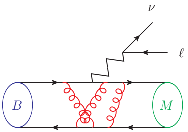
$$4\% \begin{cases} \text{LP@NNLL} \\ \text{NLP@NLL} \\ \text{NNLP@LL} \end{cases}$$

HQET LCDA of heavy meson

The leading-twist heavy-meson HQET LCDA [Grozin and Neubert, 96']

$$\langle H_v|\bar{h}_v(0)\not{n}_+\gamma^5 q_s(tn_+)|0\rangle = -i\widetilde{f}_H(\mu)\, n_+\cdot v\int_0^\infty d\omega\, e^{i\omega t n_+\cdot v}\varphi_+(\omega)$$

HQET LCDA: appears in exclusive B decays

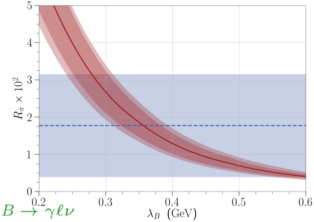


- $B \to \pi K \cdots$
- $B \to D^{(*)}\ell\nu \cdots$
- $B \to \gamma\ell\nu \cdots$

LQCD: $am_b \gtrsim 1$ [FLAG, 24']

- Effective b quark action
- Quark mass extrapolation

First inverse momentum $\lambda_B \sim \mathcal{O}(\Lambda_{\text{QCD}})$: NOT well determined



[Belle, 18']: $B \to \gamma\ell\nu$

Study of HQET LCDA

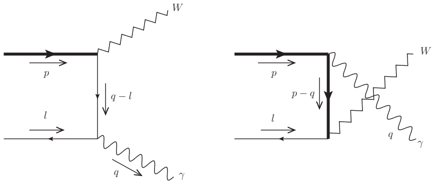
HQET LCDA: non-perturbative physics

- Inverse moments: [Wang and Shen, 18'], [Beneke, Braun, Ji, and **YBW**, 18'], [Belle, 18'], [Galda, Neubert and Wang, 22'], [Han, et al., 24']
- EOM [Kawamura, Kodaira, Qiao and Tanaka, 02'], [Lü, Shen, Wang and **YBW**, 18']
- RG evolution properties: [Braun, Ji and Manashov, 19'], [Galda and Neubert, 20'], [Cui, Shen, Wang and **YBW**, 23']
- generalized LCDA [Beneke, Böer, Toelstede, and Vos, 22'], [Qin, Shen, Wang and Wang, 22'], [Huang, Ji, Shen, Wang and Wang, 23']

Determination of λ_B

- Extract from the experiments: clean process $B \to \gamma \ell \nu$, $W \to B\gamma$
- Calculate with LQCD, inverse problem approach

$B \to \gamma \ell \nu$

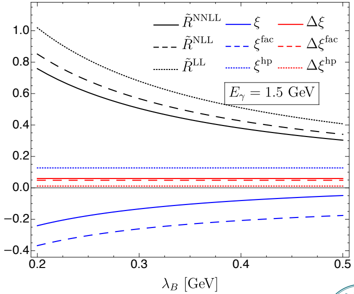


[Wang and Shen, 18'], [Beneke, Braun, Ji, and **YBW**, 18'], [Galda, Neubert and Wang, 22'], [Cui, Shen, Wang, and **YBW**, 23']

Decay form factor

$$F_{V/A}(E_\gamma) = R(E_\gamma) + \Big[\xi(E_\gamma) \pm \Delta\xi(E_\gamma)\Big]$$

- Factorizable contributions: higher-twist B-meson LCDA, QCD $\to$ HQET: b quark field
- Non-factorizable contributions: hadronic structure of the photon



[Cui, Shen, Wang, and **YBW**, 23']

$$\langle H_v | \bar{h}_v(0) \not{n}_+ \gamma^5 q_s(tn_+) | 0 \rangle = -i\widetilde{f}_H(\mu)\, n_+ \cdot v \int_0^\infty d\omega\, e^{i\omega t n_+ \cdot v} \varphi_+(\omega)$$

Exclusive B decays: B-meson HQET decay constant $\widetilde{f}_B$:

$$\widetilde{f}_B(\mu) = K^{-1}(\mu) f_B$$

QCD decay constant f_B calculated with LQCD [FLAG].

$B \to \gamma \ell \nu$

$$\langle H_v | \bar{h}_v(0) \not{n}_+ \gamma^5 q_s(t n_+) | 0 \rangle = -i \widetilde{f}_H(\mu)\, n_+ \cdot v \int_0^\infty d\omega\, e^{i\omega t n_+ \cdot v} \varphi_+(\omega)$$

Exclusive B decays: B-meson HQET decay constant $\widetilde{f}_B$:

$$\widetilde{f}_B(\mu) = K^{-1}(\mu) f_B$$

QCD decay constant f_B calculated with LQCD [FLAG].

The relation receive
power corrections
[Becher, Neubert and Petrov, 00']

$$\bar{q}\, \gamma^\alpha Q \cong \sum_{i=1,2} C_i(\mu)\, J_i + \frac{1}{2m_Q} \sum_{j=1}^{10} B_j(\mu)\, Q_j$$

$$f_B = K(\mu) \widetilde{f}_B(\mu) + \mathrm{NLP}$$

Two loop renormalization of heavy light currents at order 1/m(Q) in the heavy quark expansion

Thomas Becher (Cornell U., LNS), Matthias Neubert (Cornell U., LNS), Alexey A. Petrov (Cornell U., LNS)

Dec, 2000

16 pages

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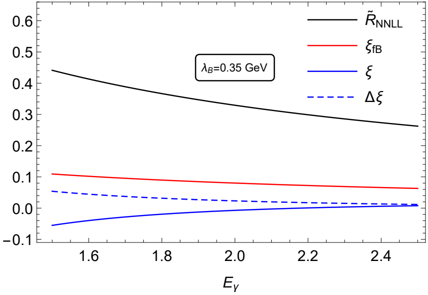
$B \to \gamma \ell \nu$

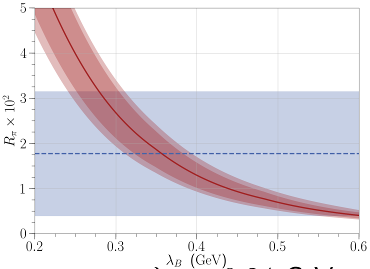
Power correction in f_B

$\Rightarrow$ 20% increase to $F_{V/A}$

$\Rightarrow$ 40% increase to decay width

[Liu, Su and **YBW**, in progress]



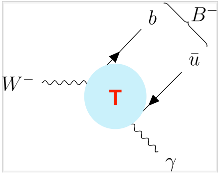


[Belle, 18']: $\lambda_B > 0.24$ GeV

Also affect the exclusive extraction of $|V_{ub}|$ and $|V_{cb}|$.

$W \to B\gamma$

Rare decay $W^- \to B^-\gamma$: B-meson QCD LCDA
[Grossman, König and Neubert, 15']



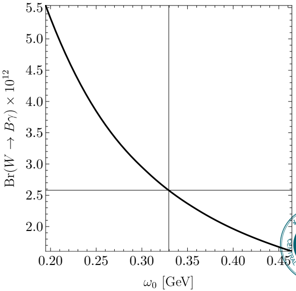
Match from QCD LCDA to HQET LCDA [Ishaq, Jia, Xiong and Yang, 19'], [Zhao, 19'], [Beneke, Finauri, Vos and **YBW**, 23'], [Deng, Wang, **YBW** and Zeng, 24']

$$\phi_{\mathrm{QCD}}(u) = \mathcal{J}(u,\omega) \otimes \varphi_{\mathrm{HQET}}(\omega)$$

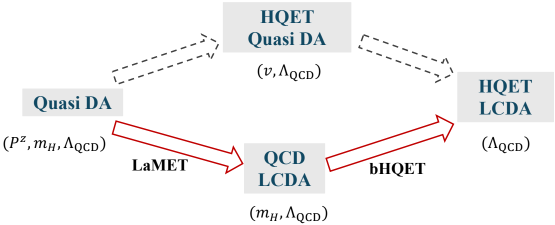
Our result: with $\ln \Lambda_{\mathrm{QCD}}/m_Q$ resummation

$$\mathrm{Br} = (2.58 \pm 0.21_{\mathrm{in}}\,{}^{+0.05}_{-0.08}\,{}_{\mu_h}\,{}^{+2.95}_{-0.98}\,{}_{\lambda_B}) \cdot 10^{-12}$$

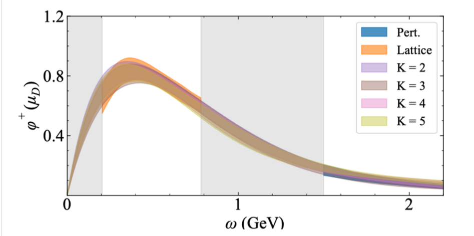
30% increase



LaMET [Ji, 13']



From QCD LCDA to HQET LCDA

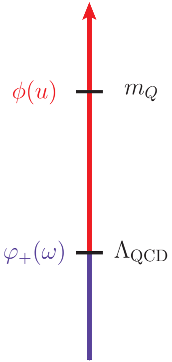


First inverse moment [LPC Collaboration, 26'] $\lambda_B = 0.347(21)$ GeV

Indirect study of HQET LCDA

From QCD LCDA to HQET LCDA

$$\phi(u) = \mathcal{J}(u,\omega) \otimes \varphi_+(\omega)$$



The heavy meson QCD LCDA [Braun and Filyanov, 89']

$$\langle H(p_H)|\bar{Q}(0)\not{n}_+\gamma^5 q(tn_+)|0\rangle = -if_H n_+\cdot p_H \int_0^1 du\, e^{iutn_+\cdot p_H}\,\phi(u)$$

The leading-twist heavy-meson HQET LCDA [Grozin and Neubert, 96']

$$\langle H_v|\bar{h}_v(0)\not{n}_+\gamma^5 q_s(tn_+)|0\rangle = -i\widetilde{f}_H(\mu)\, n_+\cdot v \int_0^\infty d\omega\; e^{i\omega tn_+\cdot v}\varphi_+(\omega)$$

Power corrections: preliminary

At NLP in Λ/m_b, we have [Lu, **YBW** and Zhang, in progress]

$$\widetilde{O}_1 = \bar{h}_v(0)\,\frac{i\overleftarrow{\not{D}}}{2m_Q}\,\not{n}_+\,\gamma_5\, q(nt_+)$$

From EOM, need three-particle B-meson LCDA

$$\begin{aligned}\partial_x^\rho\,\bar{q}(x)\Gamma[x,0]h_v(0) &= \partial^\rho\,[\bar{q}(x)\Gamma[x,0]h_v(0)] - \bar{q}(x)\Gamma[x,0]D^\rho\,h_v(0)\\ &\quad + i\int_0^1 du\,\bar{u}\,\bar{q}(x)[x,ux]g_s\,x_\sigma\,G^{\sigma\rho}(ux)[ux,0]\Gamma h_v(0)\end{aligned}$$

Higher power HQET Lagrangian O_{kin} [Neubert, 93']

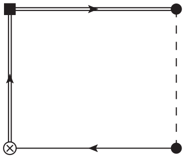
$$\widetilde{O}_{\mathrm{kin}} = \frac{1}{2m_Q}\int d^4x\,T\{\widetilde{O}_{\mathrm{LP}}\,,O_{\mathrm{kin}}\},\qquad O_{\mathrm{kin}} = \bar{h}_v(iD)^2 h_v$$

Nonperturbative matrix elements of the operators.

Contribution form $\widetilde{O}_1$

$$\varphi_+^1(\omega;\mu) = \frac{1}{2m_Q}\left\{ \left(\bar{\Lambda}-\omega\right)\varphi_+(\omega;\mu) + \Phi_H(\omega;\mu) + \phi_3(\omega)\ \text{term}\right\}$$

Local duality model for $\widetilde{O}_{\text{kin}}$ from QCD sum rules



$$\varphi_+^{\text{kin}}(\omega;\mu) = \frac{1}{2m_Q}\left\{\frac{3}{2}\,\omega_0\,\varphi_+(\omega;\mu) - \frac{3}{4}\,\frac{\omega^3+\omega\left(4\omega_0^2-\omega^2\right)\theta(2\omega_0-\omega)}{\omega_0^3}\right\}$$

Finally we obtain the power corrections

$$\phi(u;\mu) = m_H\,\frac{\widetilde{f}_H(\mu)}{f_H}\left\{\varphi_+ + \varphi_+^1 + \varphi_+^{\text{kin}}\right\}(um_H;\mu) + \mathcal{O}\left(\alpha_s^2, \alpha_s/m_Q, 1/m_Q^2\right)$$

Summary

※ Power correction in f_B matching and application to $B \to \gamma \ell \nu$

- 40% increase of decay width

※ Match QCD LCDA to the HQET LCDA

- Application in $W \to B\gamma$ decay
- LaMET quasi DA: $\lambda_B = 0.347(21)\ \mathrm{GeV}$
- Power correction at tree level

Thank you!

Evolution of the LCDAs: φ_+ and ϕ

Two-step evolutions: $\Lambda_{\rm QCD} \to m_Q \to Q$

$\Lambda_{\rm QCD}$ $\quad$ m_Q $\quad$ Q

$\phi(m_Q) = \mathcal{J} \otimes \varphi_+(m_Q)$ $\quad$ ERBL $\quad$ $\phi(Q)$

$\varphi_+(\Lambda_{\rm QCD})$ $\quad$ LN $\quad$ $\varphi_+(m_Q)$

$\phi(m_Q) \to \phi(Q)$:
evolve of the Gegenbauer moments

$$\frac{a_n(\mu_h)}{a_n(\mu)} = \left(\frac{\alpha_s(\mu_h)}{\alpha_s(\mu)}\right)^{\frac{\gamma_n}{2\beta_0}}$$