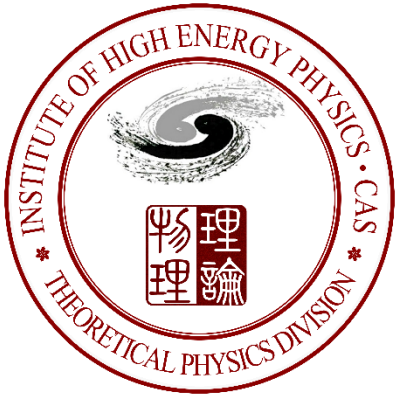
Precision calculation of $B \to V$ form factors in QCD



Jing Gao

Institute of High Energy Physics

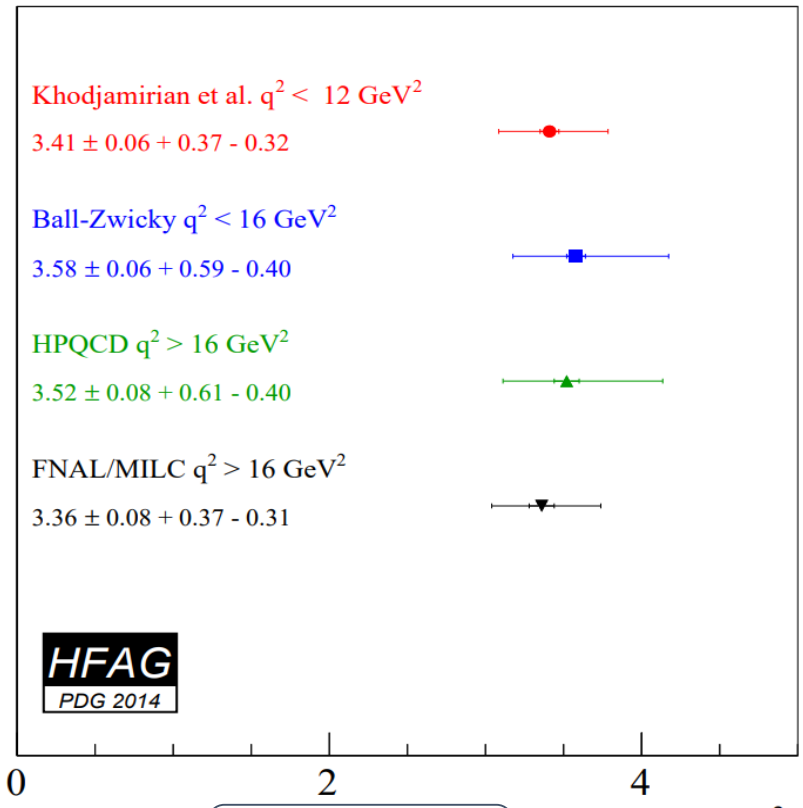
University of Chinese Academy of Science

Cooperators: Cai-Dian Lv, Yue-Long Shen, Yu-Ming Wang and Yan-Bing Wei

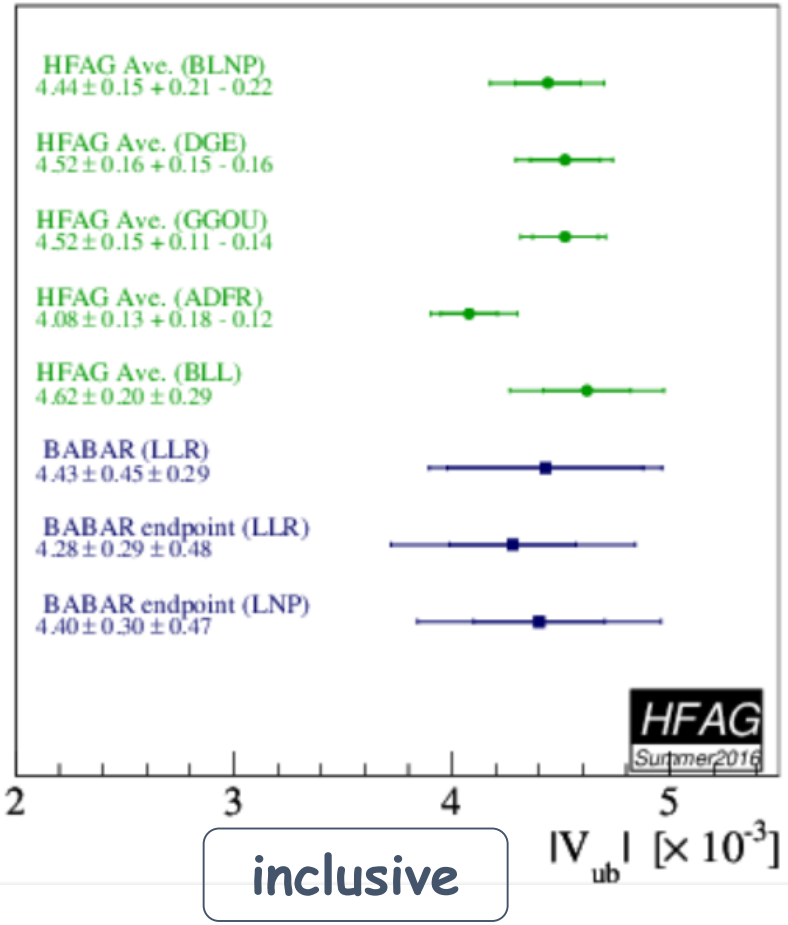
arXiv :1907.11092v1 [hep-ph]

Motivation

$|V_{ub}|$ Puzzle ???



exclusive



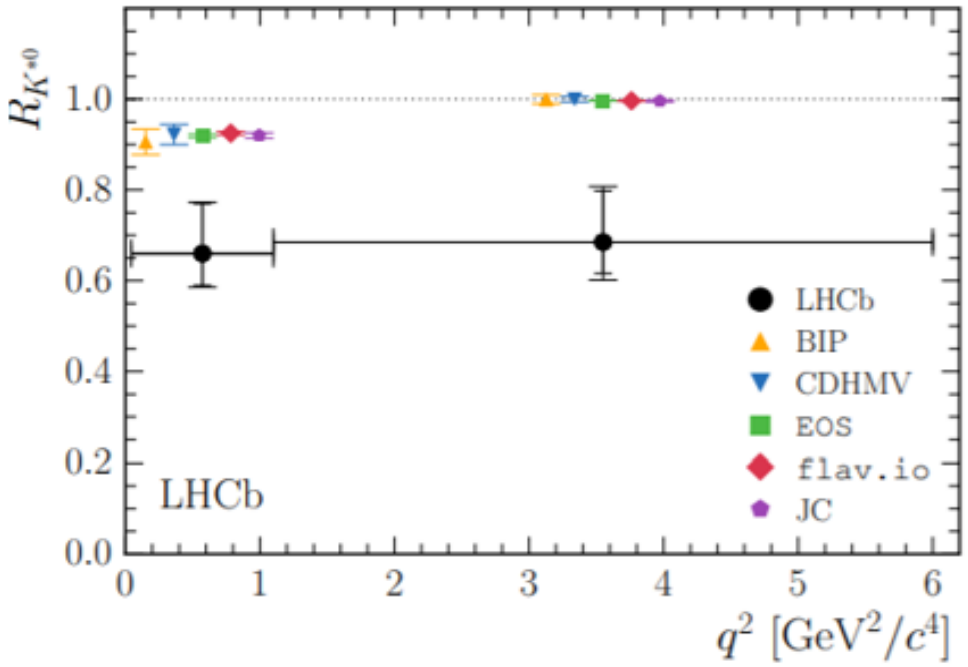
inclusive

2018 PDG $\begin{cases} V_{ub} = (3.70 \pm 0.10 \pm 0.12) \times 10^{-3} & LQCD \\ V_{ub} = (3.67 \pm 0.09 \pm 0.12) \times 10^{-3} & LCSR \end{cases}$

$$V_{ub} = (4.49 \pm 0.16^{+0.16}_{-0.17}) \times 10^{-3}$$

Motivation

Anomalies in FCNC processes $B \to K^* l^+ l^-$



- $R_{K^{*}} = \frac{\mathcal{B}(B \to K^* \mu^+ \mu^-)}{\mathcal{B}(B \to K^* e^+ e^-)}$ to test lepton flavor universality
- indicate the signal of new physics or ignore the QCD dynamics
- need more experimental data and theoretical efforts

LHCb-PAPER-2017-013, arXiv:1705.05802v2

Heavy to light form factor

- Definition $< V(p,\epsilon^*)|\bar{q}\Gamma b|B(p+q) >$
  - encode strong interaction effect
  - appear as non-perturbative parameter in the factorization theorem

M. Beneke and T. Feldmann, Nucl. Phys. B 592 (2001)

- Extract the CKM matrix element $|V_{ub}|$
  - processes $B \to \rho l \bar{\nu}_l \quad and \quad B \to \omega l \bar{\nu}_l$
- Rare B meson decay
  - process $B \to K^* \nu_l \bar{\nu}_l$
  - New physics beyond Standard Model

A. J. Buras, J. Girrbach-Noe, C. Nieho and D. M. Straub, JHEP 1502 (2015)

Theoretical method

- In low hadronic recoil region :

  LQCD
  - R. R. Horgan, Z. Liu, S. Meinel and M. Wingate, PoS LATTICE 2014 (2015)

- In the large hadronic recoil region :

  - QCDF
    - M. Beneke and T. Feldmann, Nucl. Phys. B (2001) [hep-ph/0008255]
  - SCET
    - F. De Fazio, T. Feldmann and T. Hurth, Nucl. Phys. B 733 (2006) [hep-ph/0504088]
    - F. De Fazio, T. Feldmann and T. Hurth, JHEP 0802 (2008) [arXiv:0711.3999 [hepph]]
    - M. Beneke and T. Feldmann, Nucl. Phys. B 685 (2004) [hep-ph/0311335]
  - LCSR
    - P. Ball and V. M. Braun, Phys. Rev. D 58 (1998) 094016 [hep-ph/9805422]
    - A. Khodjamirian, T. Mannel and N. Oen, Phys. Rev. D 75 (2007) 054013 [hepph/0611193]

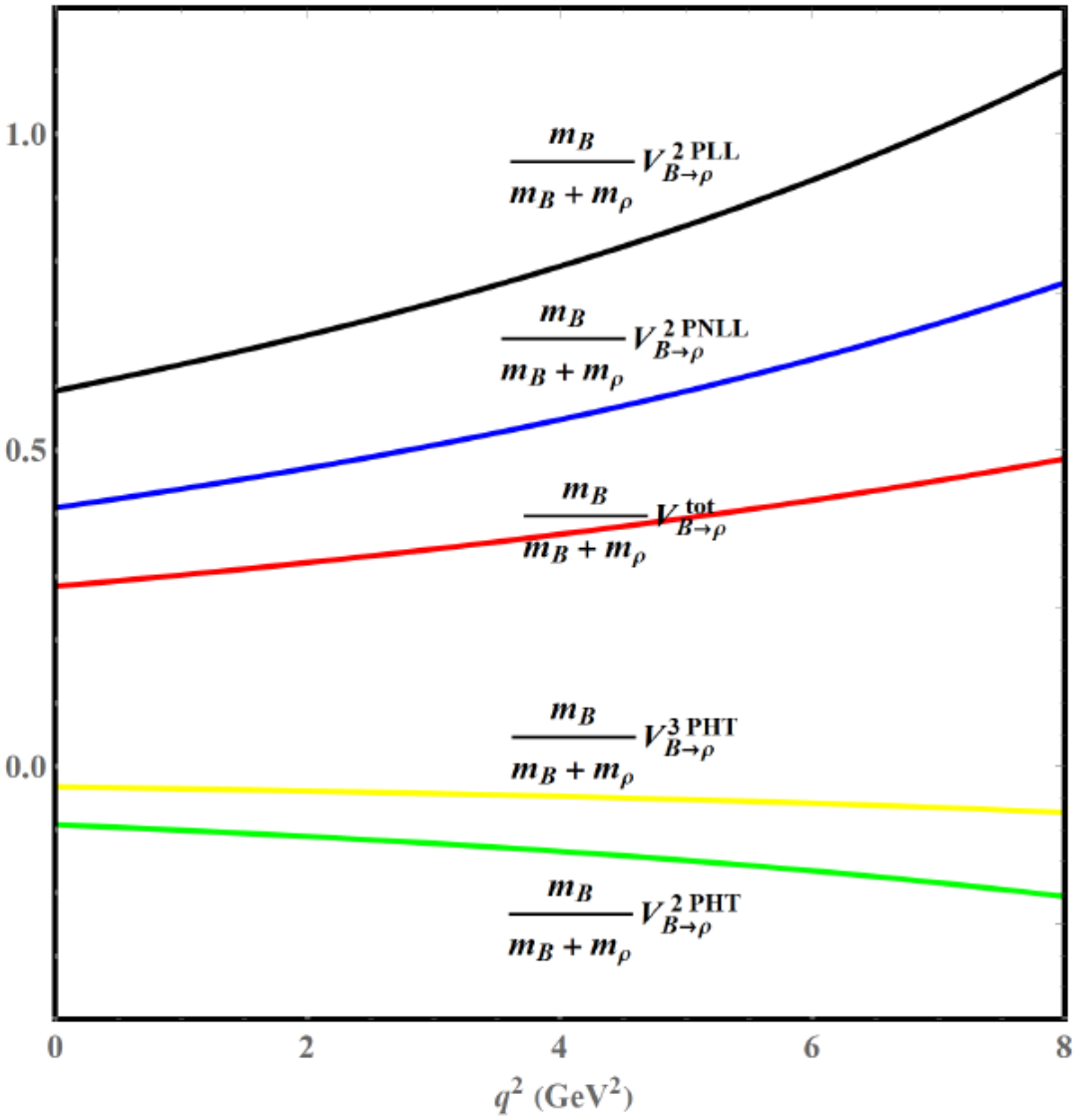
What we have done in this work

- Constructing the SCET sum rule (SCET+LCSR) for the form factors at NLO
- NLP correction at LO
  - Two-particle higher-twist B meson LCDA
  - Three-particle higher-twist B meson LCDA

$$c_V \langle V(p,\epsilon^*)|\bar{q}\,\gamma_\mu\, b|\bar{B}(p+q)\rangle = -\frac{2\,i\,V(q^2)}{m_B+m_V}\,\epsilon_{\mu\nu\rho\sigma}\,\epsilon^{*\nu}\,p^\rho\,q^\sigma$$

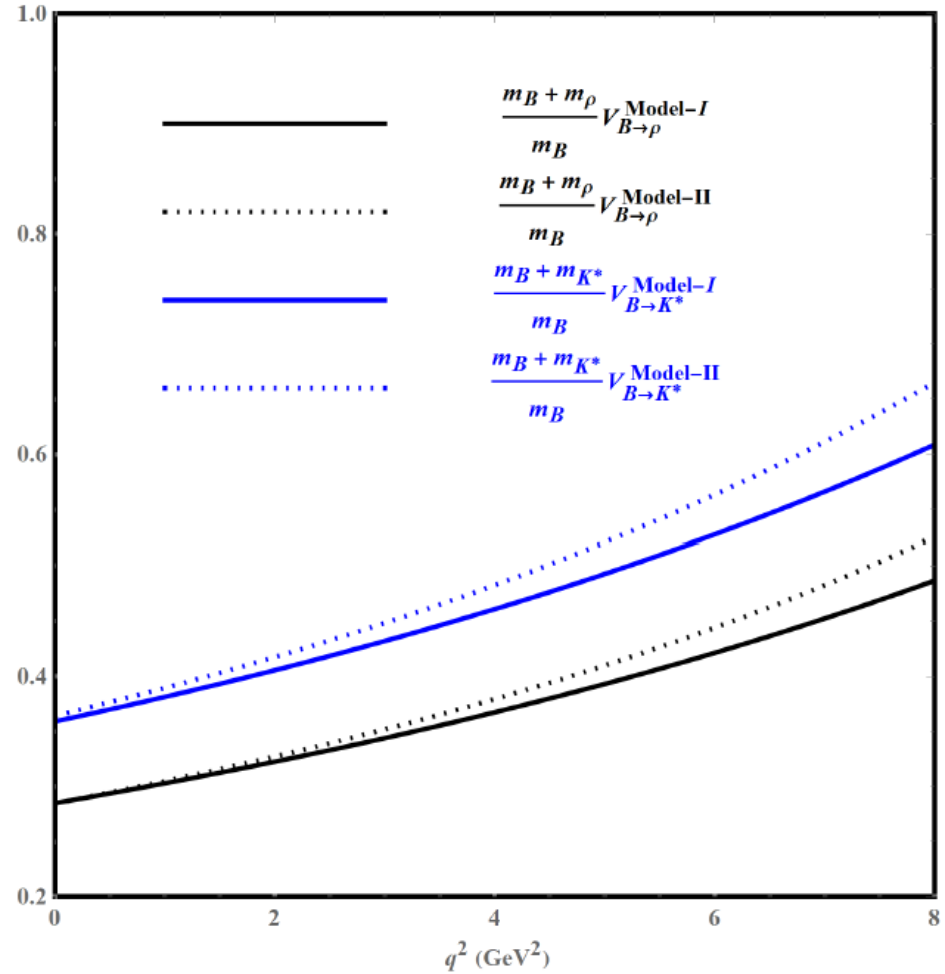
$$c_V \langle V(p,\epsilon^*)|\bar{q}\,\gamma_\mu\,\gamma_5\, b|\bar{B}(p+q)\rangle = \frac{2\,m_V\,\epsilon^*\cdot q}{q^2}\,q_\mu\,A_0(q^2)$$ + other Lorentz structures

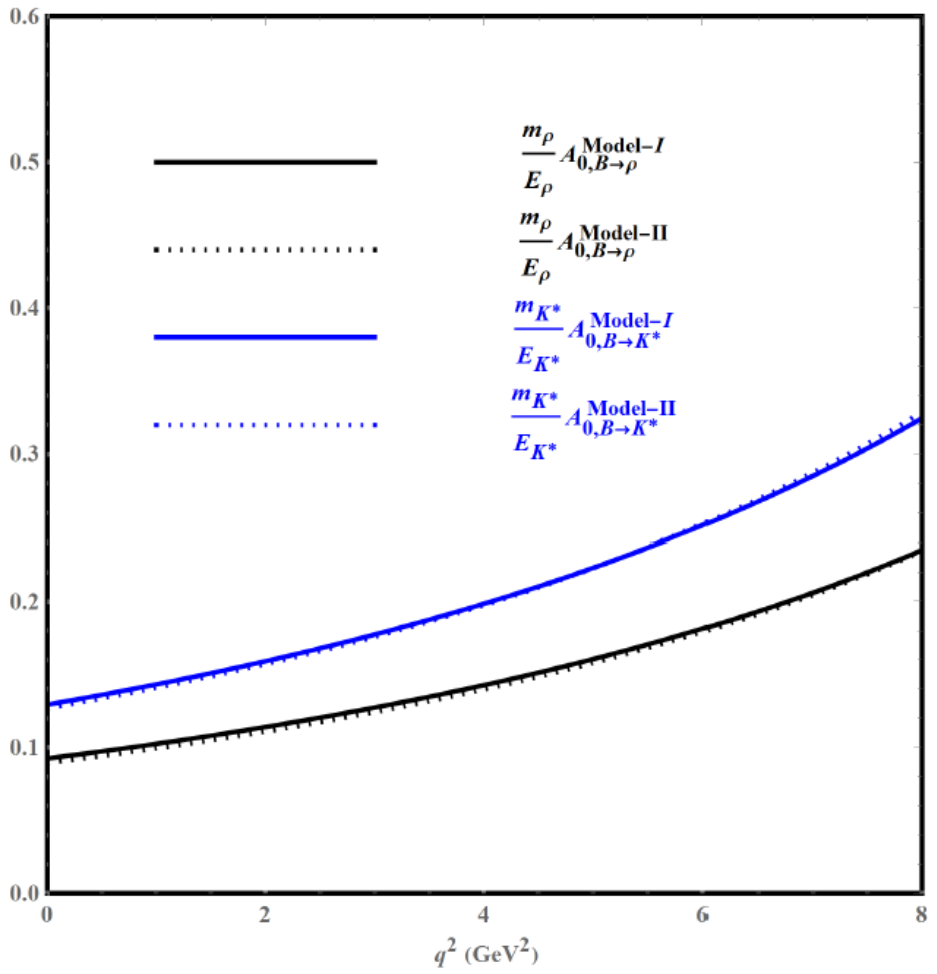
Higher-order and higher-twist corrections



- $\mathrm{LP@NLL} - \mathrm{LP@LL} \sim (25-30)\%$
- $\frac{\mathrm{2PHT@LO}}{\mathrm{2PNLL}} \sim$ (20-30)%
- 3PHT correction is $\mathcal{O}(10\%) and\ \mathcal{O}(2\%)$ enhancement for transverse and longitudinal form factor

Model dependence of form factor



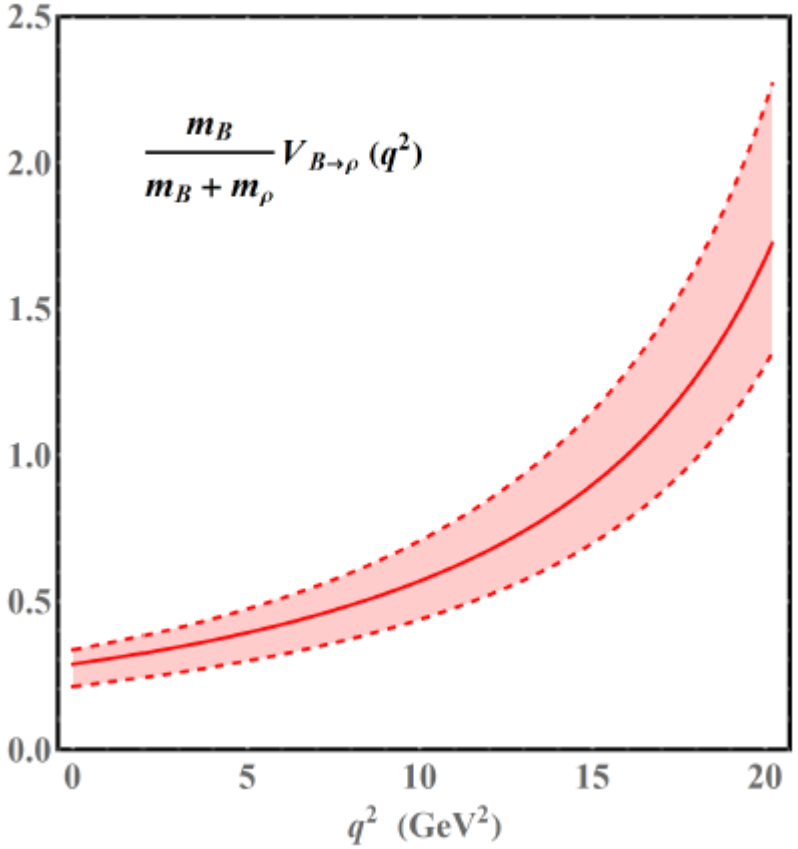


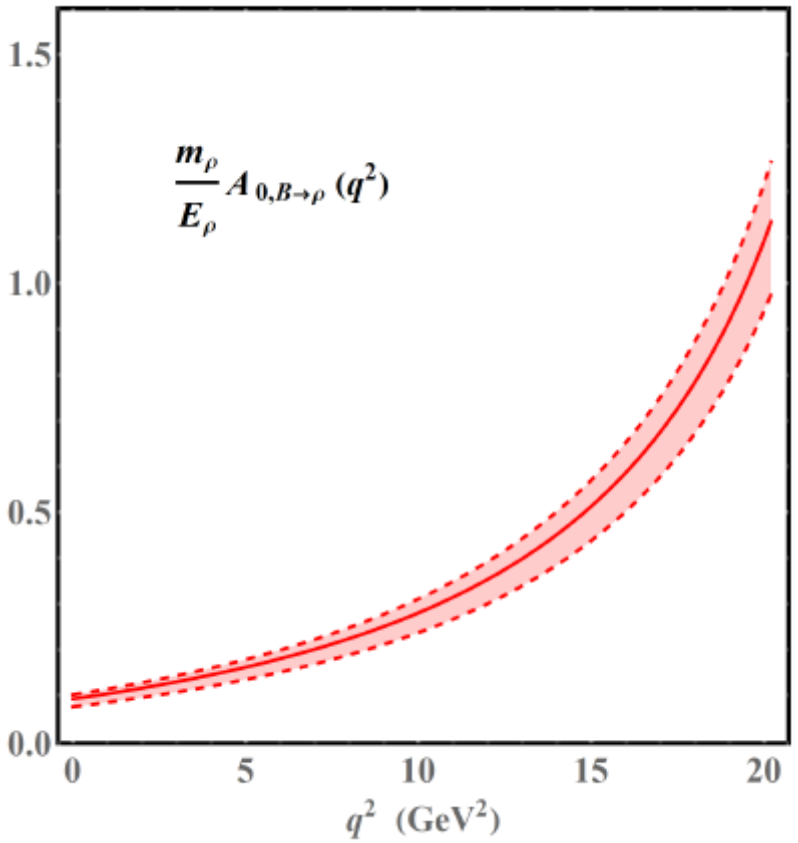
- I : exponential model II : local dual model
- $B \to \rho, K^*$ form factor

$B \to \rho$ form factor in entire kinematical region

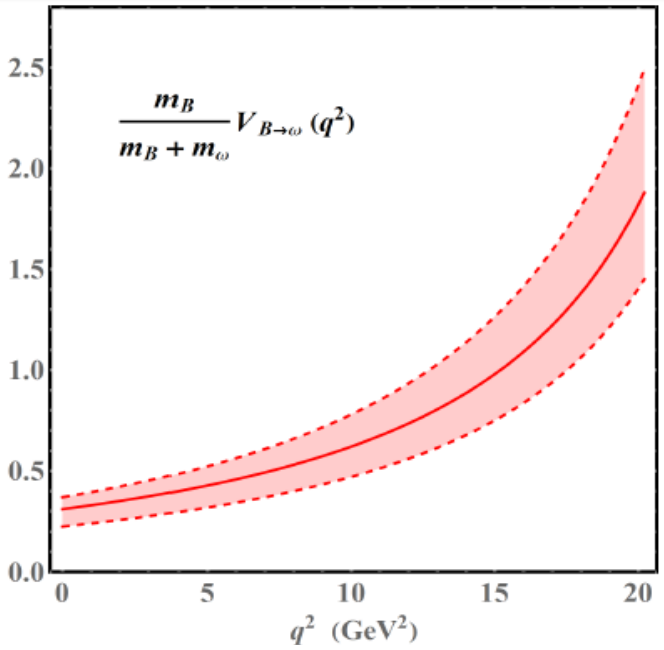
- BCL version of the z-series expansion

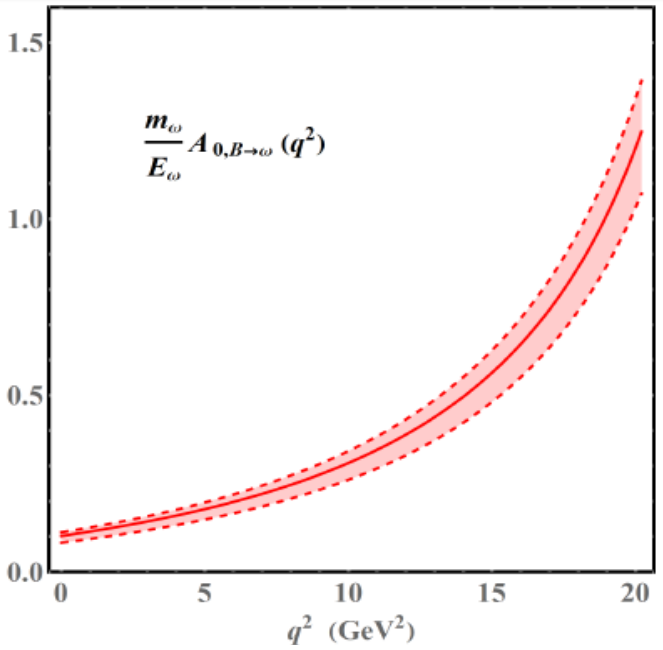
$$F^i_{B\to V}(q^2) = \frac{F^i_{B\to V}(0)}{1 - q^2/m^2_{i,\,\mathrm{pole}}} \left\{ 1 + \sum_{k=1}^{N} b^i_k \left[z(q^2, t_0)^k - z(0, t_0)^k \right] \right\}$$

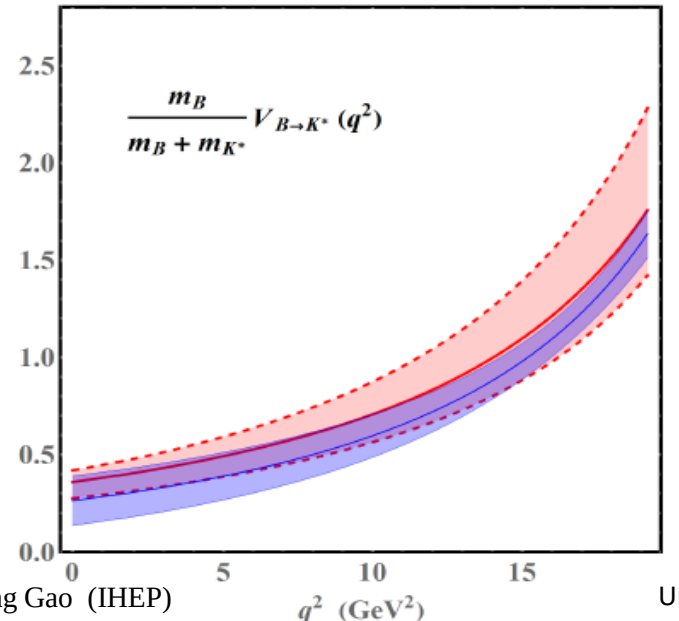


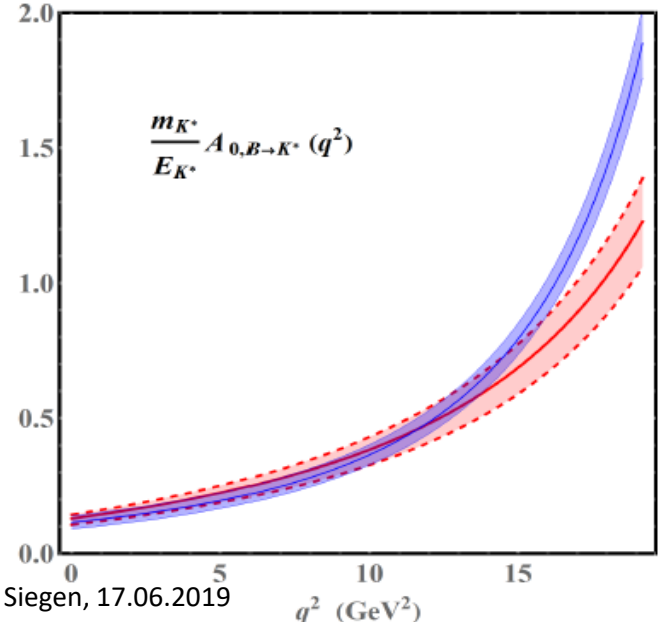


B → ω, K^* form factor in entire kinematical region





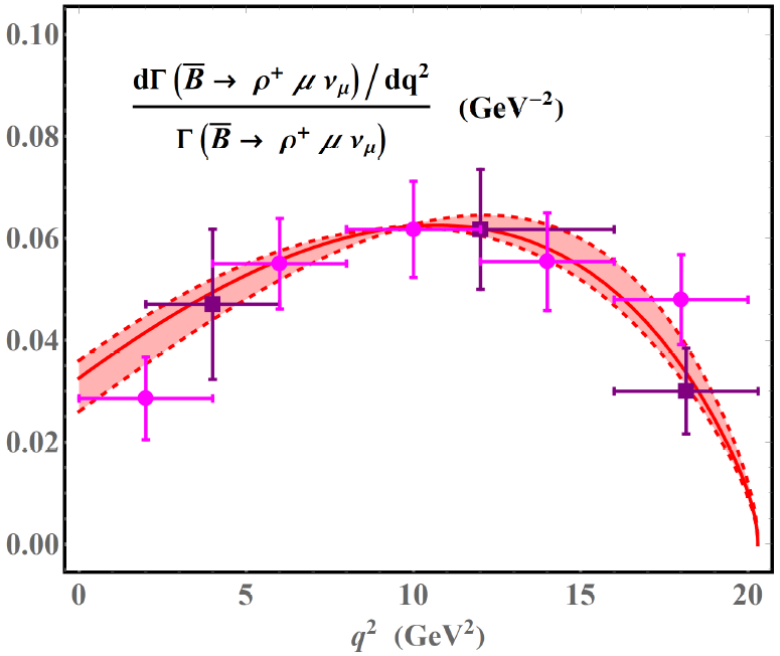




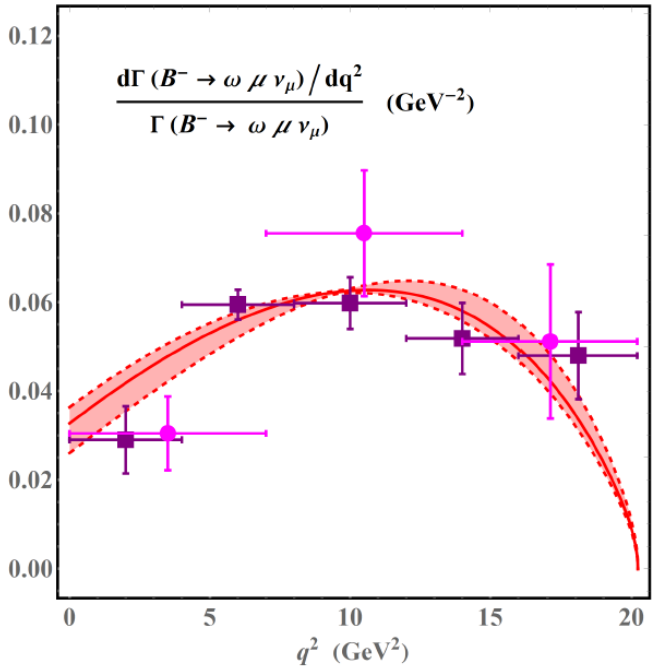
Semileptonic $B \to (\rho, \omega) l \bar{\nu}_l$

- Extract CKM matrix element $|V_{ub}|$

$$\frac{d^2\Gamma(B \to V\,\ell\,\bar{\nu}_\ell)}{dq^2\,d\cos\theta} = \frac{G_F^2\,|V_{ub}|^2}{256\,\pi^3\,m_B^3}\,\frac{q^2}{c_V^2}\,\lambda^{1/2}(m_B^2, m_V^2, q^2)\left\{\sin^2\theta\;|H_0(q^2)|^2 + (1-\cos\theta)^2\,\frac{|H_+(q^2)|^2}{2} + (1+\cos\theta)^2\,\frac{|H_-(q^2)|^2}{2}\right\}$$



$$|V_{ub}| = \left(3.05\,^{+0.67}_{-0.52}\big|_{\text{th.}}\,^{+0.19}_{-0.20}\big|_{\text{exp.}}\right) \times 10^{-3}$$

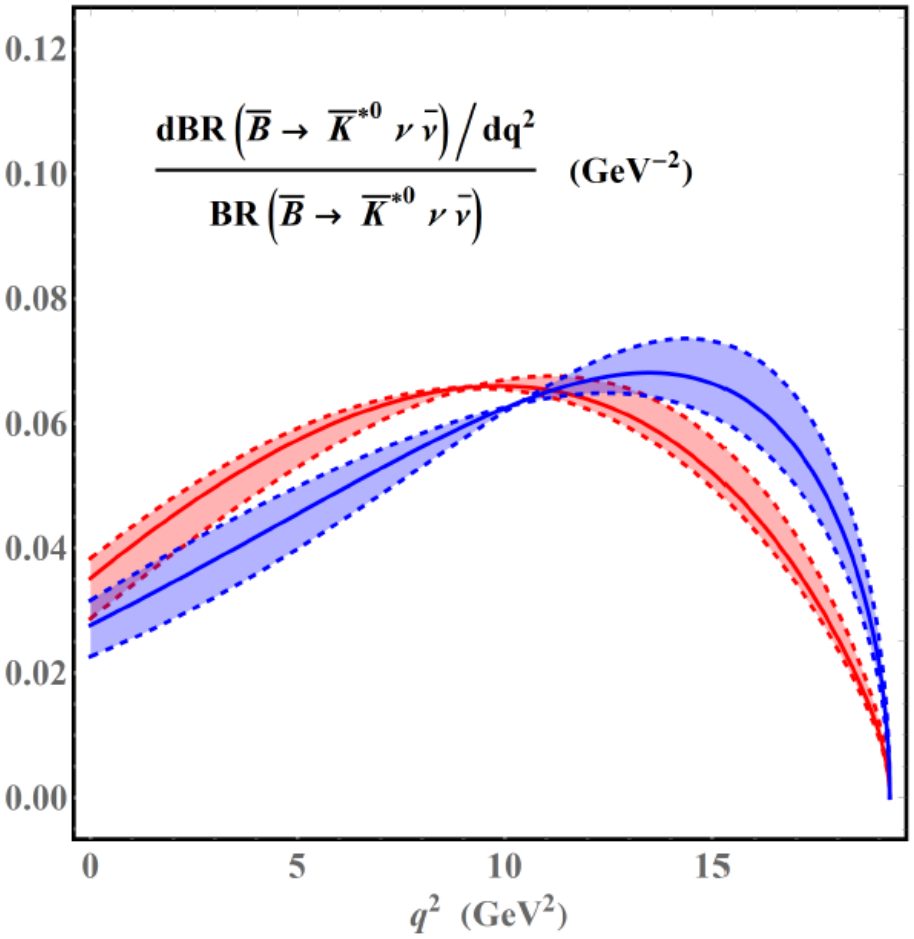


$$|V_{ub}| = \left(2.54\,^{+0.56}_{-0.40}\big|_{\text{th.}}\,^{+0.18}_{-0.19}\big|_{\text{exp.}}\right) \times 10^{-3}$$

Rare exclusive $B \to K^* \nu_l \bar{\nu}_l$

- Comparison for the future Belle II data

$$\Delta\mathcal{BR}(q_1^2, q_2^2) = \tau_{B0} \int_{q_1^2}^{q_2^2} dq^2 \frac{d\Gamma(B \to K^* \nu_\ell \bar{\nu}_\ell)}{dq^2}$$



- understand strong interaction dynamics
- Search for exotic particle X in the dark matter context

J. Buras, J. Girrbach-Noe, C. Nieho and D. M. Straub, JHEP (2015) [arXiv:1409.4557 [hep-ph]]

Conclusion and Prospect

- $B \to \rho, \omega, K^*$ form factors within SCET sum rule
  - ➢ LP@NLO correction
    - light-quark mass contribution is not suppressed
  - ➢ NLP@LO : higher-twist B meson LCDA correction up to twist-6
    - Two-particle B meson LCDA (longitudinal FFs ≈ transverse FFs)
    - Three-particle B meson LCDA (longitudinal FFs < transverse FFs)
  - ➢ CKM matrix element $|V_{ub}| = \left(3.05\,^{+0.67}_{-0.52}\big|_{\text{th.}}\,^{+0.19}_{-0.20}\big|_{\text{exp.}}\right) \times 10^{-3}$
  - ➢ Predict observable ΔBR for new physics
- ➢ A complete NLL QCD resummation
- ➢ Higher-dimensional HQET matrix element

Thanks for your attention !