Decay Constant of Vector Bc Meson and its Experimental Feasibility

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2209.15521; 2303.02692

In collaboration with Wei Tao and Zhen-Jun Xiao

5th Heavy Flavor and QCD Conf. @Wuhan   April 21, 2023

Content

➢ **Research Background**

➢ **Decay Constant of Bc* in EFT**

➢ **Decay Width of Bc* and its non-radiative decay modes**

➢ **Summary and Outlook**

> **Meson Puzzle:** Bc^+ ($\bar{b}c$) discovered in 1998, CDF @Fermi Lab)

1998, Bc(1S), 0⁻

51 years， ground meson

$E_0 \approx (6227 - m_b - m_c)\text{MeV}, \qquad \Delta E_0 \approx 60\text{MeV}$

Nonrelativistic system at femtoscale, similar to Hydrogen

> **LHCb made great progress to detect Bc decay modes**

Bottom decay ~20%，charm decay ~70%，both decay ~10%

B_c^+ DECAY MODES × B($\bar{b} \to B_c$)

B_c^- modes are charge conjugates of the modes below.

	Mode	Fraction (Γ_i/Γ)	Confidence level
Γ_1	$J/\psi(1S)\ell^+\nu_\ell$ anything	seen	
Γ_2	$J/\psi(1S)\mu^+\nu_\mu$	seen	
Γ_3	$J/\psi(1S)\tau^+\nu_\tau$	seen	
Γ_4	$J/\psi(1S)\pi^+$	seen	
Γ_5	$J/\psi(1S)K^+$	seen	
Γ_6	$J/\psi(1S)\pi^+\pi^+\pi^-$	seen	
Γ_7	$J/\psi(1S)a_1(1260)$	not seen	
Γ_8	$J/\psi(1S)K^+K^-\pi^+$	seen	
Γ_9	$J/\psi(1S)\pi^+\pi^+\pi^+\pi^-\pi^-$	seen	
Γ_{10}	$\psi(2S)\pi^+$	seen	
Γ_{11}	$J/\psi(1S)D^0K^+$	seen	
Γ_{12}	$J/\psi(1S)D^*(2007)^0K^+$	seen	
Γ_{13}	$J/\psi(1S)D^*(2010)^+K^{*0}$	seen	
Γ_{14}	$J/\psi(1S)D^+K^{*0}$	seen	
Γ_{15}	$J/\psi(1S)D_s^+$	seen	
Γ_{16}	$J/\psi(1S)D_s^{*+}$	seen	
Γ_{17}	$J/\psi(1S)p\bar{p}\pi^+$	seen	

PDG-2022

	Mode	Fraction (Γ_i/Γ)	Confidence level
Γ_{18}	$\chi_c^0\pi^+$		
Γ_{19}	$p\bar{p}\pi^+$		
Γ_{20}	D^0K^+		
Γ_{21}	$D^0\pi^+$		
Γ_{22}	$D^{*0}\pi^+$		
Γ_{23}	$D^{*0}K^+$		
Γ_{24}	$D_s^+\overline{D}^0$		
Γ_{25}	$D_s^+D^0$		
Γ_{26}	$D^+\overline{D}^0$		
Γ_{27}	D^+D^0		
Γ_{28}	$D_s^{*+}\overline{D}^0$		
Γ_{29}	$D_s^+\overline{D}^*(2007)^0$		
Γ_{30}	$D_s^{*+}D^0$		
Γ_{31}	$D_s^+D^*(2007)^0$	< 6.6 $\times 10^{-4}$	90%
Γ_{32}	$D^*(2010)^+\overline{D}^0$	< 3.8 $\times 10^{-4}$	90%
Γ_{33}	$D^*(2010)^+\overline{D}^0$, $D^{*+} \to D^+\pi^0/\gamma$	not seen	
Γ_{34}	$D^+\overline{D}^*(2007)^0$	< 6.5 $\times 10^{-4}$	90%
Γ_{35}	$D^*(2007)^+D^0$	< 2.0 $\times 10^{-4}$	90%
Γ_{36}	$D^*(2010)^+D^0$, $D^{*+} \to D^+\pi^0/\gamma$	not seen	
Γ_{37}	$D^+D^*(2007)^0$	< 3.7 $\times 10^{-4}$	90%
Γ_{38}	$D_s^{*+}\overline{D}^*(2007)^0$	< 1.3 $\times 10^{-3}$	90%
Γ_{39}	$D_s^{*+}D^*(2007)^0$	< 1.3 $\times 10^{-3}$	90%
Γ_{40}	$D^*(2010)^+\overline{D}^*(2007)^0$	< 1.0 $\times 10^{-3}$	90%
Γ_{41}	$D^*(2010)^+D^*(2007)^0$	< 7.7 $\times 10^{-4}$	90%
Γ_{42}	D^+K^{*0}	not seen	
Γ_{43}	$D^+\overline{K}^{*0}$	not seen	
Γ_{44}	$D_s^+K^{*0}$	not seen	
Γ_{45}	$D_s^+\overline{K}^{*0}$	not seen	
Γ_{46}	$D_s^+\phi$	not seen	
Γ_{47}	K^+K^0	not seen	
Γ_{48}	$B_s^0\pi^+$ / B($\bar{b} \to B_s$)	seen	

B_c^+ DECAY MODES × B($\bar{b} \to B_c$)

B_c^- modes are charge conjugates of the modes below.

Citation: J. Beringer et al. (Particle Data Group), PR **D86**, 010001 (2012) (URL: http://pdg.lbl.gov)

The following quantities are not pure branching ratios; rather the fraction $\Gamma_i/\Gamma \times$ B($\bar{b} \to B_c$).

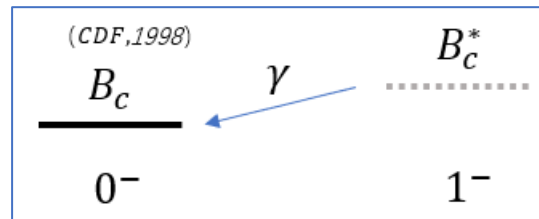|	Mode
Γ_1	$J/\psi(1S)\ell^+\nu_\ell$ anything
Γ_2	$J/\psi(1S)\pi^+$
Γ_3	$J/\psi(1S)\pi^+\pi^+\pi^-$
Γ_4	$J/\psi(1S)a_1(1260)$
Γ_5	$D^*(2010)^+\overline{D}^0$

PDG-2012

5 个衰变道

Vector Bc*(1⁻)

➢ **Excited Bc states below BD threshold major decay to ground Bc state**

➢ **Hyperfine splitting between Bc*(1S) and Bc(1S): around 60MeV**

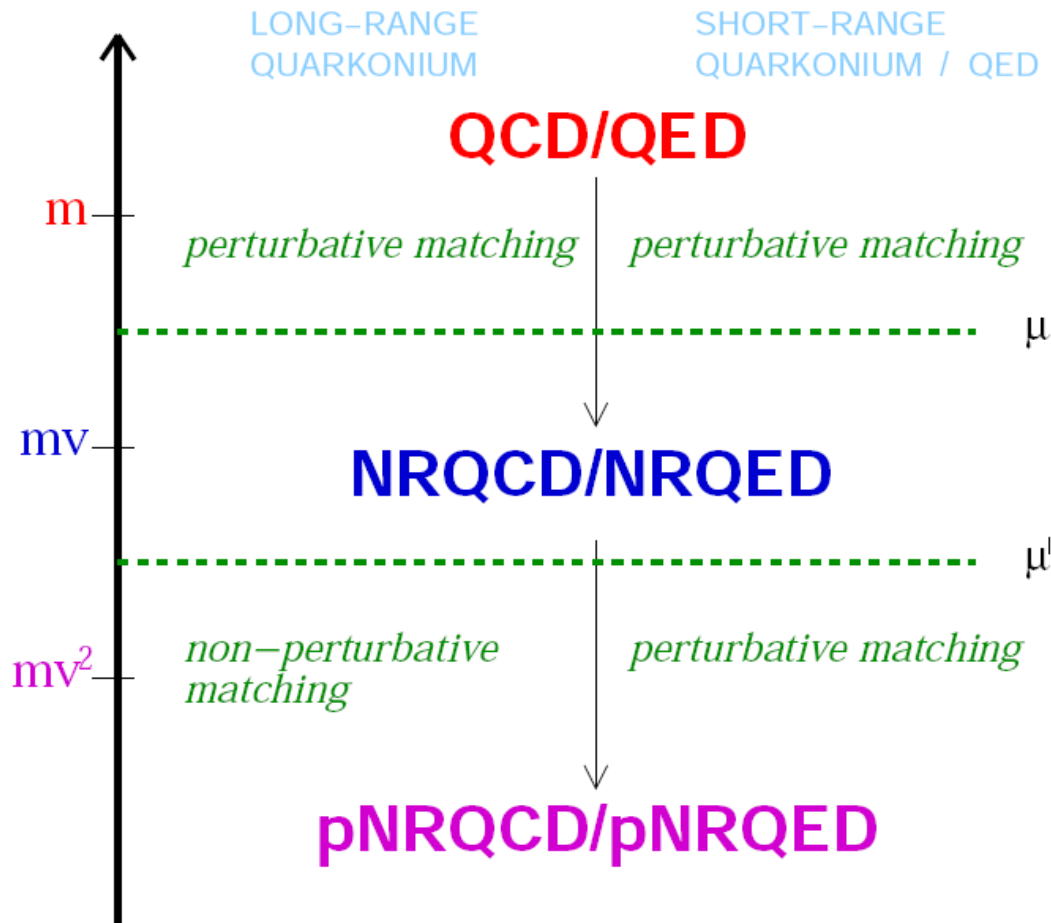➢ **Bc* (1S) major (99.99%) electromagnetic decays to Bc(1S)**

➢ **However, 60MeV photon is hard to detect at LHC**

> **Nonrelativistic EFT in QCD/QED**

$$\alpha_s(mv) \quad \sim \quad v$$

$$v^2 \approx 0.1 \text{ for the } \Upsilon$$

LONG–RANGE QUARKONIUM   SHORT–RANGE QUARKONIUM / QED

QCD/QED

m — *perturbative matching* | *perturbative matching*

- - - - - - - - - - - - - - - μ

NRQCD/NRQED

mv —

- - - - - - - - - - - - - - - μ'

mv^2 — *non–perturbative matching* | *perturbative matching*

pNRQCD/pNRQED

Bodwin-Braaten-Lapage-1995

Pineda-Soto-Brambilla-Vairo-2000

P. Pietrulewicz

Decay Constant of Bc*

➤ **Bc* decay constants in QCD**

$$\left\langle 0 \left| \bar{b}\gamma^\mu c \right| B_c^*(P, \varepsilon) \right\rangle = f_{B_c^*}^v m_{B_c^*} \varepsilon^\mu,$$

(a) LO
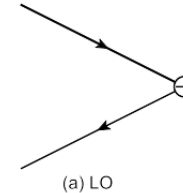
➤ **Bc* decay constants in NRQCD**

$$f_{B_c^*}^v = \sqrt{\frac{2}{m_{B_c^*}}} \underbrace{C_v(m_b, m_c, \mu_f)}_{\text{mathing coefficients}} \underbrace{\left\langle 0 \left| \chi_b^\dagger \sigma \cdot \varepsilon \psi_c \right| B_c^*(\mathbf{P}) \right\rangle (\mu_f)}_{\text{NRQCD LDMEs}} + \mathcal{O}(v^2)$$

➤ **Matching Formulae**

$$Z_J Z_{2,b}^{\frac{1}{2}} Z_{2,c}^{\frac{1}{2}} \Gamma_J = C_J \tilde{Z}_J^{-1} \tilde{Z}_{2,b}^{\frac{1}{2}} \tilde{Z}_{2,c}^{\frac{1}{2}} \tilde{\Gamma}_J$$

$\tilde{Z}_J$:NRQCD $\overline{\text{MS}}$ current renormalization constants

Calculation procedure

➢ **Feynman Diagrams & Amplitudes**
  (Packages: FeynArts / QGraf)

➢ **Feynman Amplitudes Simplification：Trace & Contraction**
  (Packages: FeynCalc / FormCalc / FormLink)

➢ **Feynman Integrals Reduction**
  (Packages: Apart(Feng) / FIRE/Kira /…)

➢ **Feynman Master Integrals Calculation:**
  (Packages: AMFlow(Ma et al) / FIESTA /…)

A Systematic and Efficient Method to Compute Multi-loop Master Integrals   #1

Xiao Liu (Peking U. and Peking U., SKLNPT), Yan-Qing Ma (Peking U. and Peking U., SKLNPT and Peking U., CHEP and CICQM, Beijing), Chen-Yu Wang (Peking U. and Peking U., SKLNPT) (Nov 27, 2017)

Published in: Phys.Lett.B 779 (2018) 353-357 • e-Print: 1711.09572 [hep-ph]

📄 pdf   🔗 DOI   ⊟ cite   🔲 claim   🔖 reference search   🕙 84 citations

AMFlow: A Mathematica package for Feynman integrals computation via auxiliary mass flow   #2

Xiao Liu (Peking U., SKLNPT and Oxford U., Theor. Phys.), Yan-Qing Ma (Peking U., SKLNPT and Peking U., CHEP and CICQM, Beijing) (Jan 27, 2022)

Published in: Comput.Phys.Commun. 283 (2023) 108565 • e-Print: 2201.11669 [hep-ph]

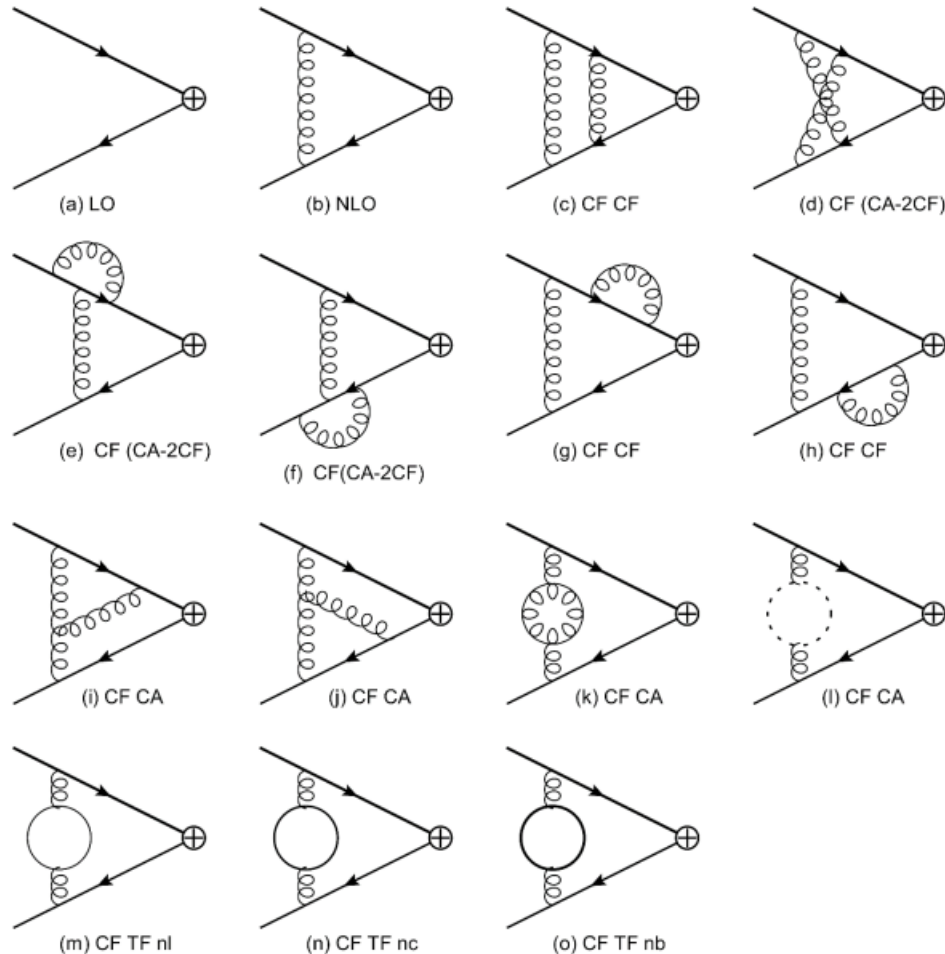📄 pdf   🔗 DOI   ⊟ cite   🔲 claim   🔖 reference search   🕙 63 citations

See Prof. Ma Yanqing's talk tomorrow

> **Feynman diagram up to two-loop order accuracy**

(a) LO   (b) NLO   (c) CF CF   (d) CF (CA-2CF)

(e) CF (CA-2CF)   (f) CF(CA-2CF)   (g) CF CF   (h) CF CF

(i) CF CA   (j) CF CA   (k) CF CA   (l) CF CA

(m) CF TF nl   (n) CF TF nc   (o) CF TF nb

> **Matching coefficients at two loop**   Tao-Zhu-Xiao, 2209.15521

$\mu_f \in [1.5, 1.2, 1]$GeV, $\mu \in [6.25, 4.75, 3]$GeV, $m_b \in [5.25, 4.75, 4.25]$GeV, $m_c \in [2, 1.5, 1]$GeV

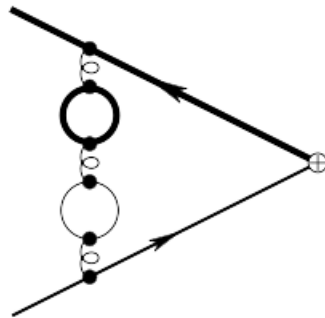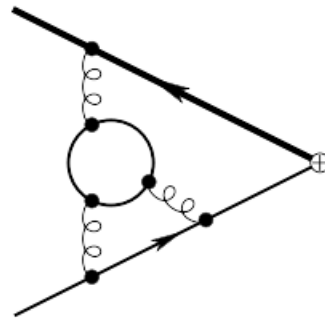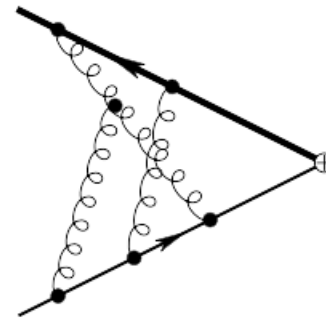|	LO	NLO	NNLO
C_p	1	$0.9117^{-0+0.0072+0.0061-0.0156}_{+0-0.0160-0.0064+0.0263}$	$0.7897^{-0.0310+0.0206+0.0119+0.0149}_{+0.0253-0.0482-0.0133-0.0141}$
C_v	1	$0.8697^{-0+0.0107+0.0061-0.0156}_{+0-0.0236-0.0064+0.0263}$	$0.7363^{-0.0234+0.0230+0.0106+0.0117}_{+0.0191-0.0526-0.0117-0.0121}$

μ dependence for matching coefficients
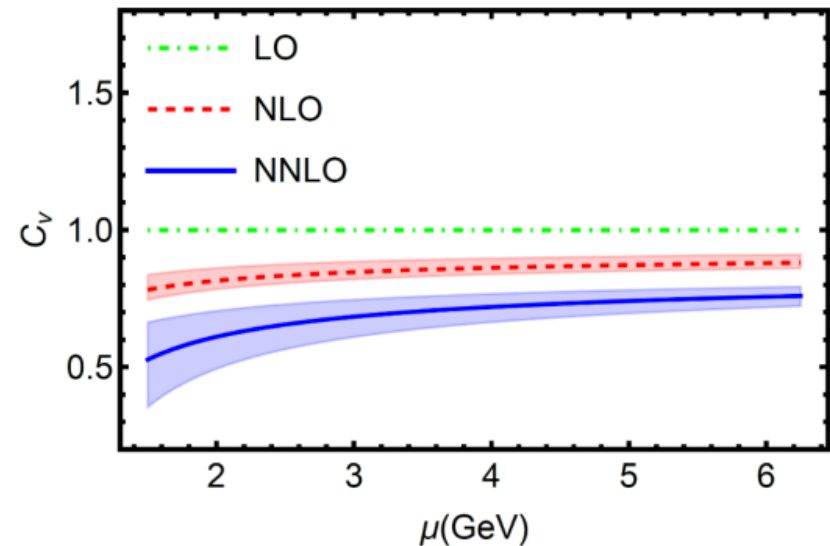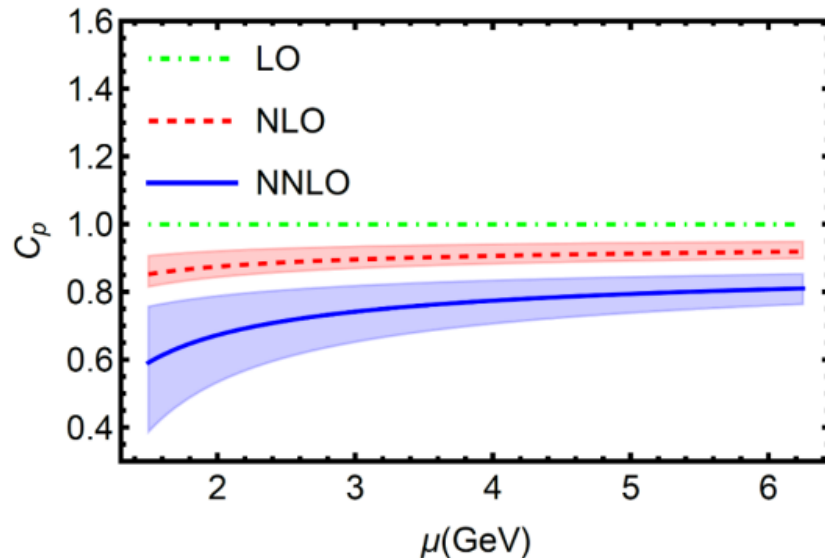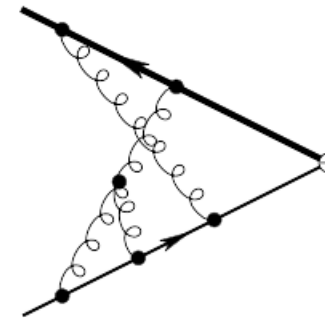
> **Typical diagrams up to three-loop**
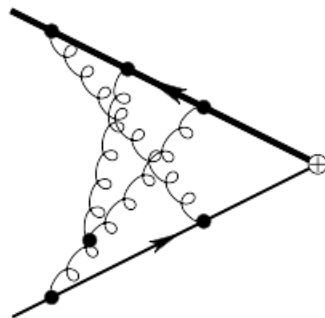

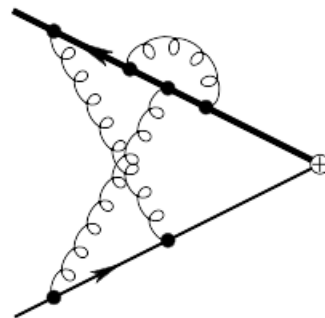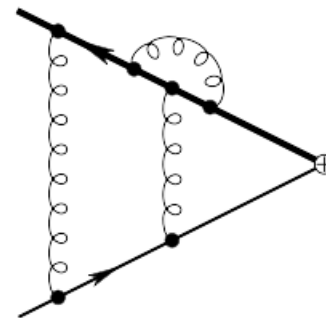(a) TF nb TF n1 CF

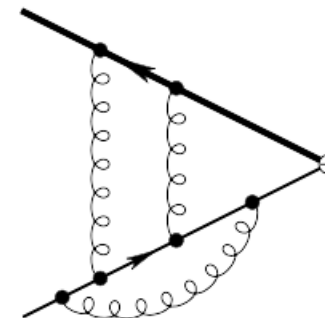(b) TF nc (CA − 4CF) CF

(c) CA (CA − 2CF) CF

(d) CA (CA − 2CF) CF

(e) CA (CA − 2CF) CF

(f) (CA − 2CF) (CA − 2CF) CF

(g) (CA − 2CF) CF CF

(h) (CA − 2CF) (CA − 2CF) CF

LO:1, NLO:1, NNLO:11, N^3LO:268

➢ **Matching coefficients for vector current(state-of-art)**

$$\mathcal{C} = 1 - 2.29 \left(\frac{\alpha_s^{(n_l)}}{\pi} \right) - 35.44 \left(\frac{\alpha_s^{(n_l)}}{\pi} \right)^2 - 1686.27 \left(\frac{\alpha_s^{(n_l)}}{\pi} \right)^3 + \mathcal{O}(\alpha_s^4),$$

for $n_l = 3, n_c = 1, n_b = 0,$

Sang-Zhang-Zhou, arXiv:2210.02979

➢ **Matching coefficients for pseudoscalar current(state-of-art)**

$$\mathcal{C}(x_{\text{phys}}) = 1 - 1.62623 \left(\frac{\alpha_s^{(n_l)}(m_r)}{\pi} \right) - 6.51043 \left(\frac{\alpha_s^{(n_l)}(m_r)}{\pi} \right)^2 - 1520.59 \left(\frac{\alpha_s^{(n_l)}(m_r)}{\pi} \right)^3 + \mathcal{O}(\alpha_s^4)$$

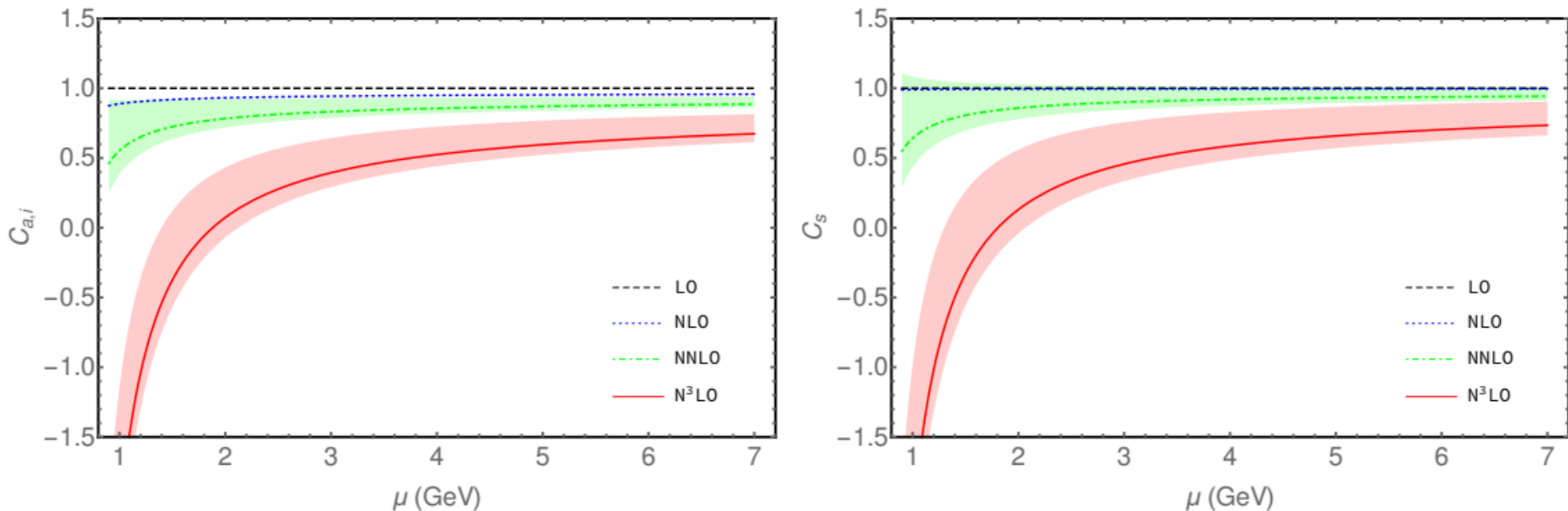Feng-Jia-Mo-Pan-Sang-Zhang, arXiv:2208.04302

Results for axial-vector and scalar

➢ **Matching coefficients for axial-vector and scalar up to three loop**

Nonconvergence behaviors also in other two currents

Tao-Xiao-**Zhu**, arXiv: 2303.02692

Sub-leading Contribution

> **Relativistic corrections**

$$\langle 0|\overline{Q_1}\gamma^5 Q_2 |Q_2\overline{Q_1}\rangle_{\text{QCD}}$$

$$= \sqrt{2M_H}\left[C_0^P \left\langle 0\left|\chi_1^\dagger\psi_2\right| Q_2\overline{Q_1}(\mathbf{p})\right\rangle_{\text{NRQCD}} + C_2^P \left\langle 0\left|(\mathbf{D}\chi_1)^\dagger\cdot\mathbf{D}\psi_2\right| Q_2\overline{Q_1}(\mathbf{p})\right\rangle_{\text{NRQCD}} + \cdots \right]$$

Employing EOM: $\left\langle 0\left|(\mathbf{D}\chi_1)^\dagger\mathbf{D}\psi_2\right| Q_2\overline{Q_1}(\mathbf{p})\right\rangle = -2m_r E\left\langle 0\left|\chi_1^\dagger\psi_2\right| Q_2\overline{Q_1}(\mathbf{p})\right\rangle.$

$$f_{B_c^*} = 2\sqrt{\frac{N_c}{m_{B_c^*}}}\left[\mathcal{C}_v + \frac{d_v E_{B_c^*}}{12}\left(\frac{8}{M} - \frac{3}{m_r}\right)\right]|\Psi_{B_c^*}(0)|,$$

$$f_{B_c} = 2\sqrt{\frac{N_c}{m_{B_c}}}\left[\mathcal{C}_p - \frac{d_p E_{B_c}}{4m_r}\right]|\Psi_{B_c}(0)|,$$

> Wave function at origin

For Power-law potential

$$V(r) = Ar^a + C$$

Exact solution

$$|\psi_\mu^n(0)|^2 = f(n,a)(A\mu)^{3/(2+a)}$$

Scale relation

$$|\Psi_{B_c^*}(0)| = |\Psi_{J/\psi}(0)|^{1-y} |\Psi_\Upsilon(0)|^y,$$

$$y = y_c = \ln((1 + m_c/m_b)/2)/\ln(m_c/m_b)$$

Collins-Imbo-King-Martell, PLB 393 (1997) 155–160

$$|\psi_1(0)|^2 = |\psi_1^{(0)}(0)|^2 \left(1 + \sum_{k=1}^n f_k a_s^k\right).$$

$$\left|\psi_1^{(0)}(0)\right|^2 = \frac{(m_b C_F \alpha_s)^3}{8\pi},$$

$$E_1^{(0)} = -\frac{1}{4} m_b (C_F \alpha_s)^2,$$

Beneke-Kiyo-Marquard-Penin-Piclum-Seide-Steinhauser, PRL. 112, 151801 (2014)

➢ Hyperfine splitting for beauty-charm family

$$(\Delta M)_{i\bar{j}} = 32\pi\alpha_s(2\mu_{i\bar{j}})|\Psi_{i\bar{j}}(0)|^2/9m_i m_j ,$$

$$\Delta M_{c\bar{b}} = \alpha_s(2m_r)x^{1-2q}\left(\frac{\Delta M_{c\bar{c}}}{\alpha_s(m_c)}\right)^{1-q}\left(\frac{\Delta M_{b\bar{b}}}{\alpha_s(m_b)}\right)^q .$$

$$\Delta M_{c\bar{b}(1S)} = 63.8^{+5.5}_{-8.4}(q)^{+1.2}_{-1.2}(exp)\,\text{MeV},$$

$$\Delta M_{c\bar{b}(2S)} = 26.4^{+2.1}_{-3.3}(q)^{+1.5}_{-1.7}(exp)\,\text{MeV},$$

$$\Delta M_{b\bar{b}(1S)} = 62.3 \pm 3.2 \,\text{MeV}$$

$$\Delta M_{b\bar{b}(2S)} = 24 \pm 4 \,\text{MeV}$$

CMS 2019

$$\Delta M_{c\bar{b}(2S)} = 29.1 \pm 1.5(stat) \pm 0.7(syst)\,\text{MeV}$$

LHCb 2019

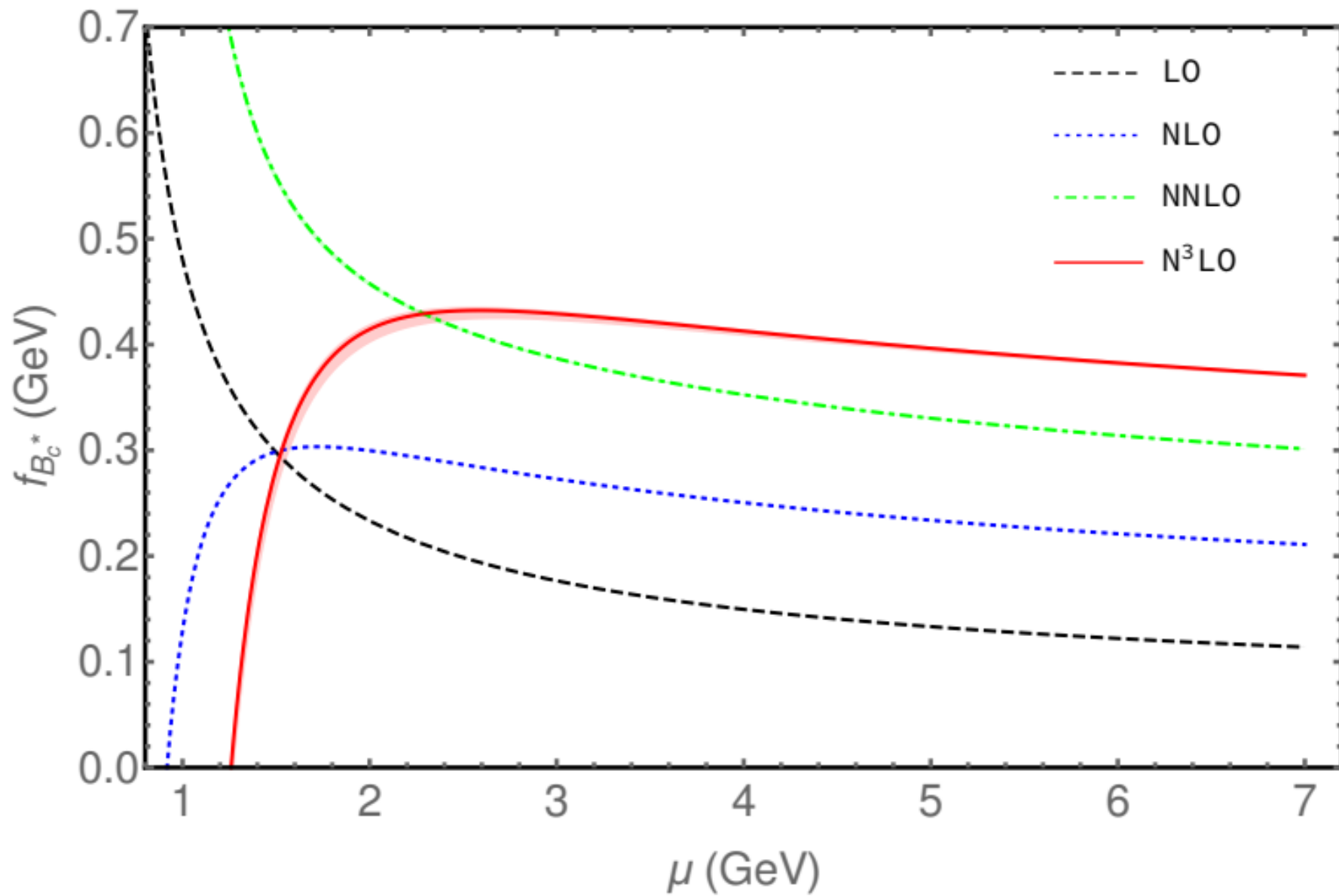$$\Delta M_{c\bar{b}(2S)} = 31.0 \pm 1.4(stat) \pm 0.0(syst)\,\text{MeV}$$

HPQCD lattice results

$$\Delta M_{c\bar{b}(1S)} = 54 \pm 4 \,\text{MeV}$$

Vector Bc* decay constant

TABLE I: The N^3LO predictions for the pure leptonic branching ratios $\mathcal{B}(B_c^{*+}(B_c^+) \to l^+\nu_l)$ with $l = (e, \mu, \tau)$. The three uncertainties come from $q \in [0.3, 0.4]$, $\mu_f \in [0.4, 7]$GeV, $\mu \in [2.2, 7]$GeV, respectively.

Branching ratios	N^3LO
$\mathcal{B}(B_c^{*+} \to e^+\nu_e)$	$\left(3.85^{+0.29-0.07-1.35}_{-0.46+0.03+0.37}\right) \times 10^{-6}$
$\mathcal{B}(B_c^{*+} \to \mu^+\nu_\mu)$	$\left(3.85^{+0.29-0.07-1.35}_{-0.46+0.03+0.37}\right) \times 10^{-6}$
$\mathcal{B}(B_c^{*+} \to \tau^+\nu_\tau)$	$\left(3.40^{+0.25-0.06-1.19}_{-0.41+0.03+0.33}\right) \times 10^{-6}$
$\mathcal{B}(B_c^+ \to e^+\nu_e)$	$\left(1.91^{+0.15-0.19-0.70}_{-0.23+0.12+0.22}\right) \times 10^{-9}$
$\mathcal{B}(B_c^+ \to \mu^+\nu_\mu)$	$\left(8.18^{+0.63-0.83-2.99}_{-1.00+0.52+0.94}\right) \times 10^{-5}$
$\mathcal{B}(B_c^+ \to \tau^+\nu_\tau)$	$\left(1.96^{+0.15-0.20-0.72}_{-0.24+0.12+0.23}\right) \times 10^{-2}$

$$\Gamma_{\text{tot}}(\check{B}_c^*) = 60\text{eV}$$
$$\tau_{B_c} = 0.51\text{ps.}$$

arXiv: 2304.XXXXX

➢ **Bc* (1S) major (99.99%) electromagnetic decays to Bc(1S): M1 transition**
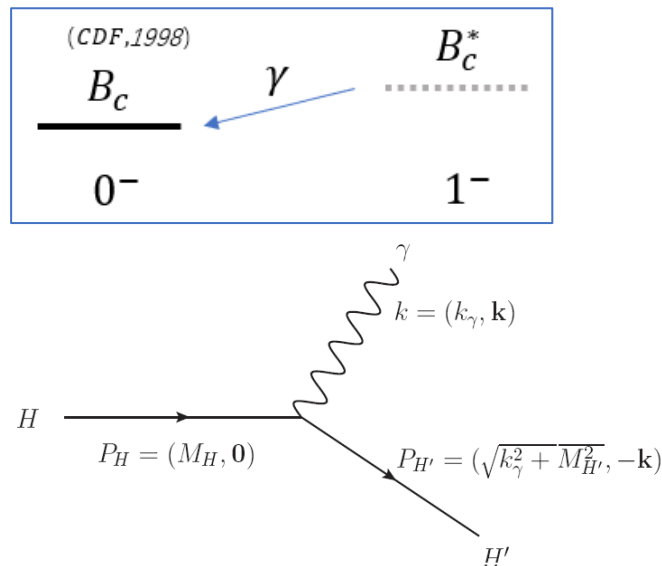
$$\mathcal{L}_\varphi = \varphi^\dagger \left(iD_0 + \frac{\mathbf{D}^2}{2m} + \frac{\mathbf{D}^4}{8m^3} \right) \varphi$$
$$+ g\varphi^\dagger \left(\frac{c_F}{2m}\boldsymbol{\sigma} \cdot \mathbf{B} + i\frac{c_s}{8m^2}\boldsymbol{\sigma}\cdot[\mathbf{D}\times,\mathbf{E}] + \frac{c_D}{8m^2}[\mathbf{D}\cdot,\mathbf{E}] \right) \varphi$$
$$+ ee_Q\varphi^\dagger \left(\frac{c_F^{em}}{2m}\boldsymbol{\sigma} \cdot \mathbf{B}^{em} + i\frac{c_s^{em}}{8m^2}\boldsymbol{\sigma}\cdot[\mathbf{D}\times,\mathbf{E}^{em}] + \frac{c_D^{em}}{8m^2}[\mathbf{D}\cdot,\mathbf{E}^{em}] \right) \varphi$$
$$+ ee_Q\varphi^\dagger \left(\frac{c_{W1}^{em}}{8m^3}\{\mathbf{D}^2,\boldsymbol{\sigma} \cdot \mathbf{B}^{em}\} - \frac{c_{W2}^{em}}{4m^3}\mathbf{D}^i\boldsymbol{\sigma} \cdot \mathbf{B}^{em}\mathbf{D}^i \right) \varphi$$
$$+ ee_Q\varphi^\dagger \left(\frac{c_{p'p}^{em}}{8m^3}[(\boldsymbol{\sigma} \cdot \mathbf{D})(\mathbf{B}^{em} \cdot \mathbf{D}) + (\mathbf{D} \cdot \mathbf{B}^{em})(\boldsymbol{\sigma} \cdot \mathbf{D})] \right) \varphi$$
$$+ ee_Q\varphi^\dagger \left(i\frac{c_M^{em}}{8m^3}\{\mathbf{D}\cdot,\{\mathbf{D}\times,\mathbf{B}^{em}\}\} \right) \varphi \,,$$

$$|H(\mathbf{P},\lambda)\rangle^{(0)} = \int d^3R \int d^3r\, e^{i\mathbf{P}\cdot\mathbf{R}}\mathrm{Tr}\left\{ \phi_{H(\lambda)}^{(0)}(\mathbf{r})\mathrm{S}^\dagger(\mathbf{r},\mathbf{R})|US\rangle \right\} ,$$
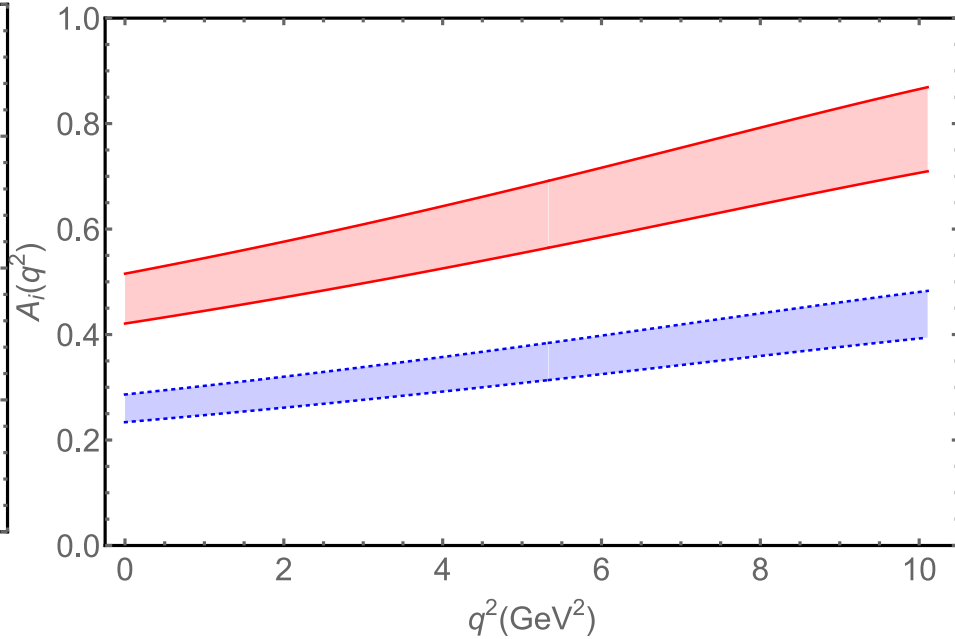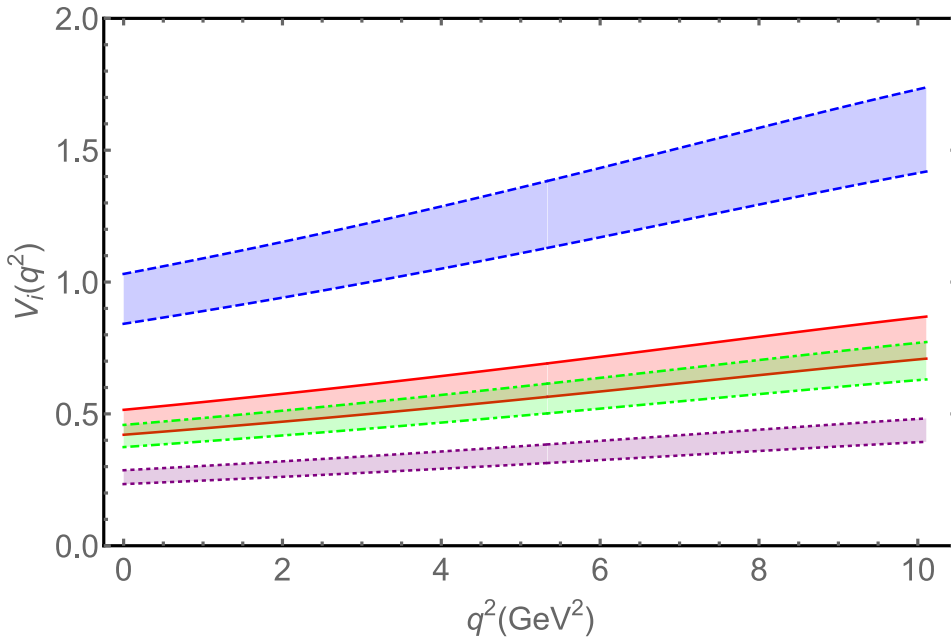
$$\Gamma(B_c^*(1S)) \approx \Gamma(B_c^*(1S) \to B_c(1S) + \gamma) \sim 54eV$$

➢ **However, around 60MeV photon is hard to detect at LHC**

Bc* decays to J/psi form factors

$$\langle J/\psi\,(\epsilon',p')\,|\bar{b}\gamma_\mu c|\,B_c^*\,(\epsilon,p)\rangle = -\,(\epsilon\cdot\epsilon'^*)\left[P_\mu V_1\left(q^2\right) - q_\mu V_2\left(q^2\right)\right] - (\epsilon\cdot q)\,\epsilon_\mu'^* V_3\left(q^2\right) + (\epsilon'^*\cdot q)\,\epsilon_\mu V_4\left(q^2\right)$$

$$+\,\frac{(\epsilon\cdot q)\,(\epsilon'^*\cdot q)}{M^2 - M'^2}\left[\left(P^\mu - \frac{M^2 - M'^2}{q^2}q^\mu\right)V_5\left(q^2\right) + \frac{M^2 - M'^2}{q^2}q^\mu V_6\left(q^2\right)\right],$$

$$\langle J/\psi\,(\epsilon',p')\,|\bar{b}\gamma_\mu\gamma_5 c|\,B_c^*\,(\epsilon,p)\rangle = i\varepsilon_{\mu\nu\alpha\beta}\epsilon^\alpha\epsilon'^{*\beta}\left[\left(P^\nu - \frac{M^2 - M'^2}{q^2}q^\nu\right)A_1\left(q^2\right) + \frac{M^2 - M'^2}{q^2}q^\nu A_2\left(q^2\right)\right]$$

$$+\,\frac{i\varepsilon_{\mu\nu\alpha\beta}P^\alpha q^\beta}{M^2 - M'^2}\left[\epsilon'^*\cdot q\epsilon^\nu A_3\left(q^2\right) - \epsilon\cdot q\epsilon'^{*\nu}A_4\left(q^2\right)\right]$$

$$+\,i\varepsilon_{\rho\nu\alpha\beta}\epsilon^\rho\epsilon'^{*\nu}P^\alpha q^\beta\left[P^\mu A_5\left(q^2\right) - q^\mu A_6\left(q^2\right)\right],$$

$\ell = e, \mu$	This work	Chang-Wang-Zhu-Li(2020)	Wang et al(2018)	Dai-Zhang-Oset(2018)
$B_c^{*+} \to J/\psi + \ell^+ + \nu_\ell$	$(2.10 - 3.15) \times 10^{-7}$	$\left(5.44^{+4.46}_{-2.49}\right) \times 10^{-7}$	5.37×10^{-7}	2.91×10^{-7}

	This work	Yang-Wang-Huang-Chang-Sun(2022)	Liu-Wan(2022)
$B_c^{*+} \to J/\psi + \pi^+$	$(1.86 - 2.79) \times 10^{-8}$	5.8×10^{-8}	2.4×10^{-8}

$$\mathcal{B}(B_c^{*+} \to \mu^+ \nu_\mu) \qquad \left(3.85^{+0.29-0.07-1.35}_{-0.46+0.03+0.37}\right) \times 10^{-6}$$

➢ **Cross section ~100nb at LHC from single parton scattering**
Chang-Wu, EPJC 38,267(2004)
increased up to ~ μb if consider the double parton scattering

➢ **around hundreds of Jpsi+pi and thousands of Jpsi+mu+nv events for 10fb⁻¹ data.**   **Future LHCb 300fb⁻¹**

➢ **…**   **See Prof. He Jibo's talk**

Summary and Outlook

- ✓ Convergent Bc* decay constant up to three-loop accuracy is obtained;
- ✓ Bc* decay width is studied (~50-60eV) from its radiative decay; $B_c^{*+}(1S) \to B_c^+(1S) + \gamma$
- ✓ Hunting for vector Bc* meson possibly by non-radiative decay modes

Outlook

$$B_c^{*+}(1S) \to \mu^+ + \nu_\mu \qquad B_c^{*+}(1S) \to J/\psi + X$$

- ➤ Nontrivial high-order calculation of wave function in un-equal mass cases
- ➤ Rare Decays for Bc meson family at LHC/CEPC/Super-Z

Thank you a lot!