Precision study of inclusive B -> $X_{d(s)}$ll decays

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T. Huber, QQ, K. Vos, 1806.11521
T. Huber, T. Hurth, J. Jenkins, E. Lunghi, QQ, K. Vos, in preparation

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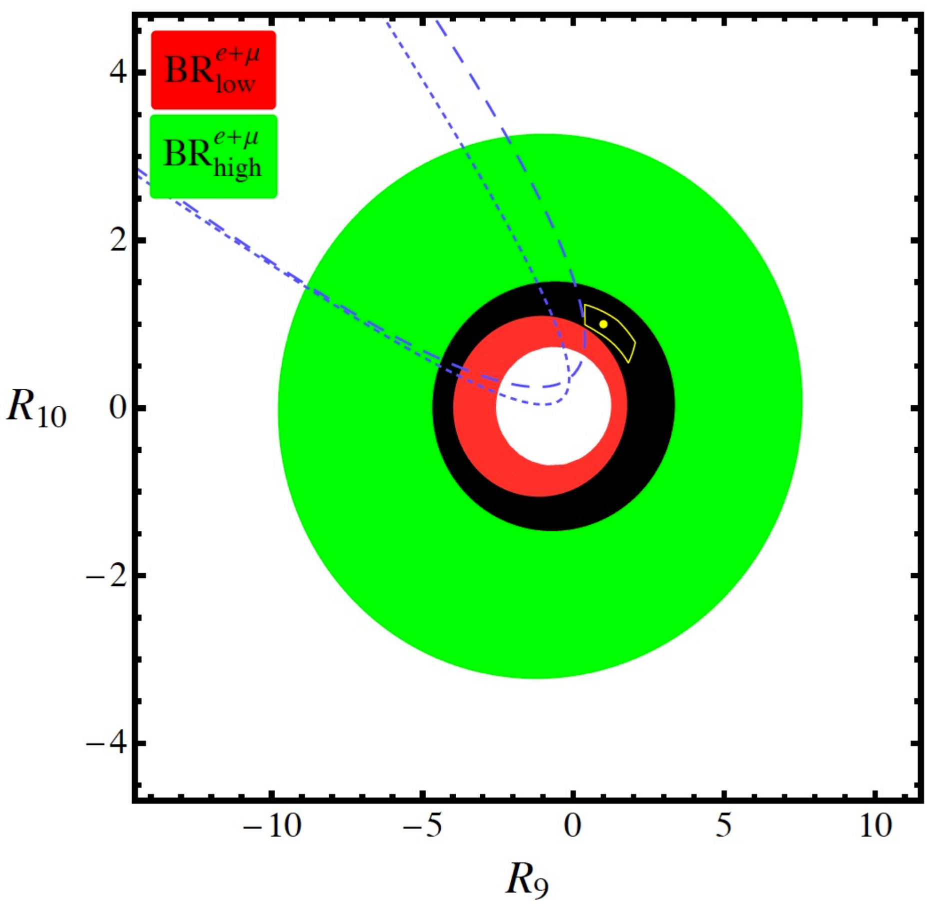
The 27th International Workshop on Weak Interactions and Neutrinos

★ B anomalies in exclusive B decays might be hints for new physics

[BaBar,1205.5442;1303.0571;Belle,1507.03233;1604.04042;1612.05014;LHCb,1406.6482;1705.05802;1512.04442;1506.08614; ATLAS,1805.04000;CMS,1710.02846;1904.02440…] see Golob's,Ricciardi's,Matias's,Rozanska's,Pardinas',Meaux's,Palestini's talks

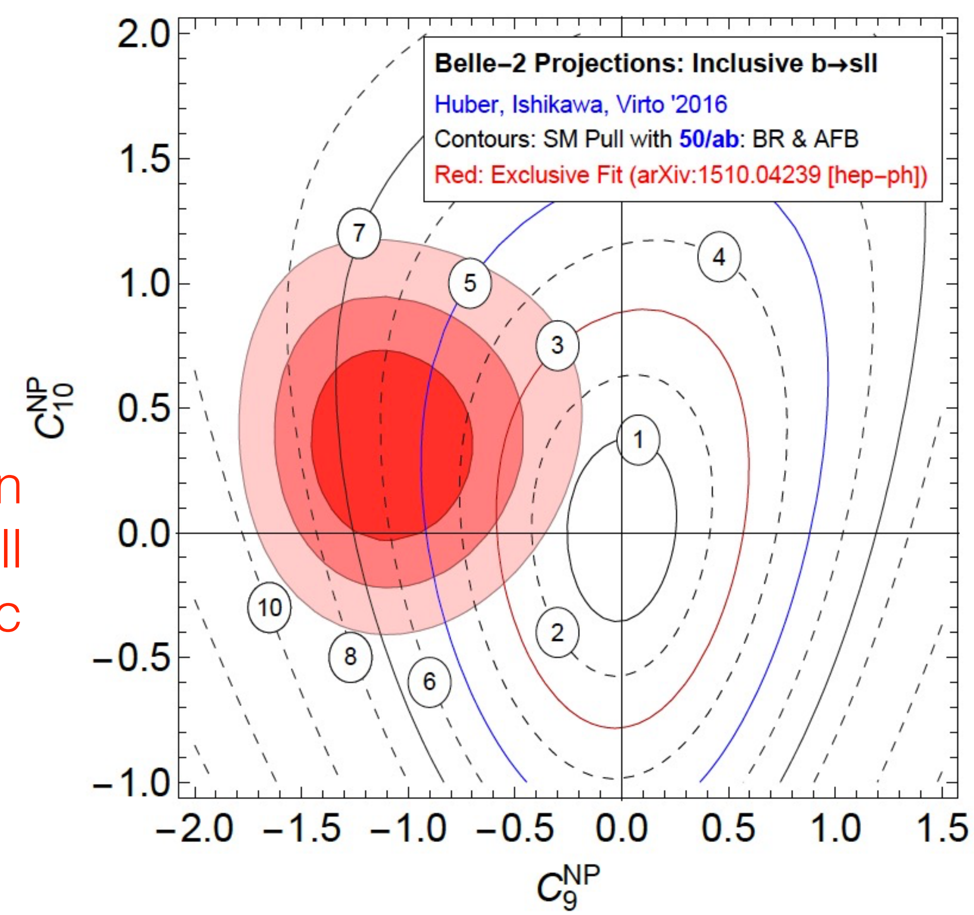
★ Precision measurements of inclusive $\bar{B} \to X_s \ell^+ \ell^-$ channel provide important complementary information

- ✳ Underlying hadronic uncertainties in inclusive mode are quite different and independent of those in exclusive transitions



(left) Constraints to Wilson coefficients from inclusive b-sll observables;

(right) Comparison between inclusive and exclusive b-sll constraints to Wilson coeffic -ients

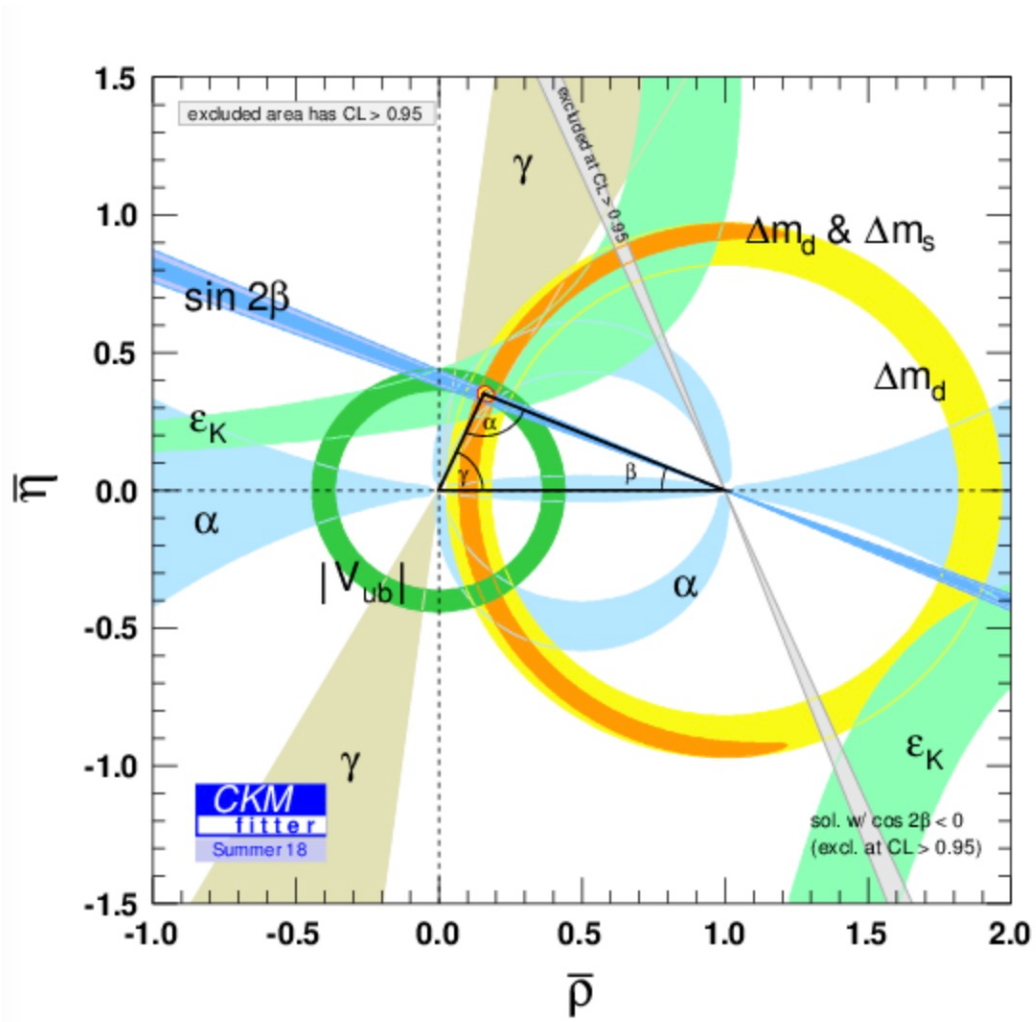


[Huber,Hurth,Lunghi,15']

["The Belle II Physics Book", by Huber, Ishikawa and Virto]

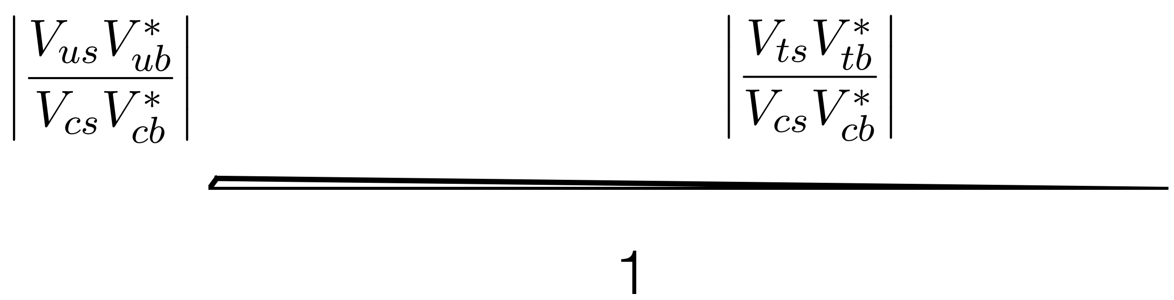
★ Inclusive $\bar{B} \to X_d \ell^+ \ell^-$ decay provides more observables

* possible <u>sizeable CP asymmetry</u>



CKM triangle for b-d transition

[CKM fitter,18']



CKM triangle for b-s transition

Lagrangian

$$\mathcal{L}_{\text{eff}} = \mathcal{L}_{\text{QCD}\times\text{QED}}(u,d,s,c,b,e,\mu,\tau) - \frac{4G_F}{\sqrt{2}} \sum_{q=u,c} V_{qd}^* V_{qb} (C_1^q P_1^q + C_2^q P_2^q) + \frac{4G_F}{\sqrt{2}} V_{td}^* V_{tb} \sum_{i=3}^{10} C_i(\mu) P_i$$

$$P_1^q = (\bar{d}_L \gamma_\mu T^a q_L)(\bar{q}_L \gamma^\mu T^a b_L),$$

$$P_2^q = (\bar{d}_L \gamma_\mu q_L)(\bar{q}_L \gamma^\mu b_L),$$

$$P_3 = (\bar{d}_L \gamma_\mu b_L) \textstyle\sum_q (\bar{q}\gamma^\mu q),$$

$$P_4 = (\bar{d}_L \gamma_\mu T^a b_L) \textstyle\sum_q (\bar{q}\gamma^\mu T^a q),$$

$$P_5 = (\bar{d}_L \gamma_{\mu_1}\gamma_{\mu_2}\gamma_{\mu_3} b_L) \textstyle\sum_q (\bar{q}\gamma^{\mu_1}\gamma^{\mu_2}\gamma^{\mu_3} q),$$

$$P_6 = (\bar{d}_L \gamma_{\mu_1}\gamma_{\mu_2}\gamma_{\mu_3} T^a b_L) \textstyle\sum_q (\bar{q}\gamma^{\mu_1}\gamma^{\mu_2}\gamma^{\mu_3} T^a q),$$

$$P_7 = \tfrac{e}{16\pi^2} m_b (\bar{d}_L \sigma^{\mu\nu} b_R) F_{\mu\nu},$$

$$P_8 = \tfrac{g}{16\pi^2} m_b (\bar{d}_L \sigma^{\mu\nu} T^a b_R) G^a_{\mu\nu},$$

$$P_9 = (\bar{d}_L \gamma_\mu b_L) \textstyle\sum_l (\bar{l}\gamma^\mu l),$$

$$P_{10} = (\bar{d}_L \gamma_\mu b_L) \textstyle\sum_l (\bar{l}\gamma^\mu \gamma_5 l).$$

[for b -> d]

★ Nonperturbative dynamics involved in hadronic matrix elements

$$\langle X_{d,s}|\mathcal{O}|\bar{B}\rangle$$ hadrons

★ How to solve this? OPE (operator product expansion).

[Falk,Luke,Savage,93']

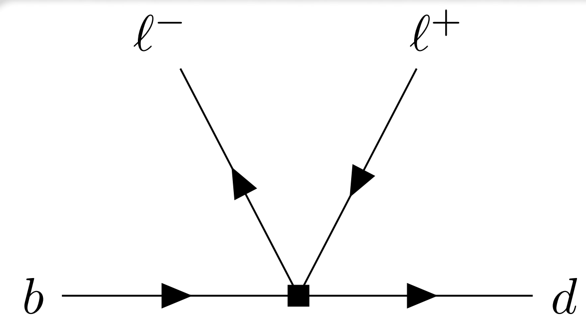
$$\sum_X \langle\bar{B}|\mathcal{O}^\dagger|X_{d,s}|\rangle\langle X_{d,s}|\mathcal{O}|\bar{B}\rangle$$

(optical theorem) $\propto \mathrm{Im}\langle\bar{B}|T\{\mathcal{O}^\dagger,\mathcal{O}\}|\bar{B}\rangle$

(OPE) $= \mathrm{Im}\langle\bar{B}|\mathcal{O}_0 + \frac{1}{m_b}\mathcal{O}_1 + \frac{1}{m_b^2}\mathcal{O}_2 + \cdots|\bar{B}\rangle$

1/mb power corrections, extracted from measurements

leading power: free quark interactions



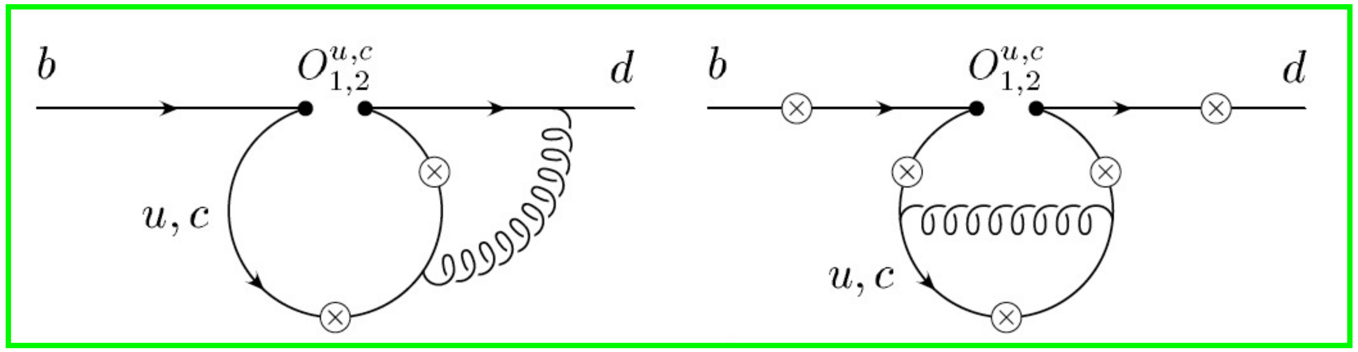
$+\alpha_{s,e}$ corrections

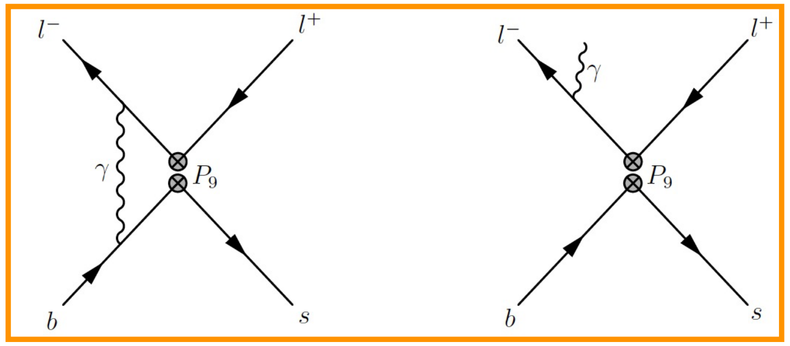
Previous studies

★ Nonperturbative power corrections, up to $1/m_b^2$ & $1/m_b^3$ (in specific kinetic regions) [Ali,Hiller,Handoko,Morozumi,97';Ligeti,Tackmann,07']

★ Perturbative $\alpha_{s,e}$ corrections, including

- (N)NLO QCD corrections [Misiak et al,92',99';Greub et al,01',02',03',04';Seidel,04']
- log-enhanced NLO QED corrections [Huber et al,05',07']





★ Handling of long-distance subtleties (additional nonperturbative effects) [Kruger,Sehgal,96',96';Buchalla,Isidori,Rey,97';Benzke,Hurth,Turczyk,17']

Five-particle Contributions

Five-particle Contributions

[Huber, QQ, Vos, Eur.Phys.J.C78(2018)748]

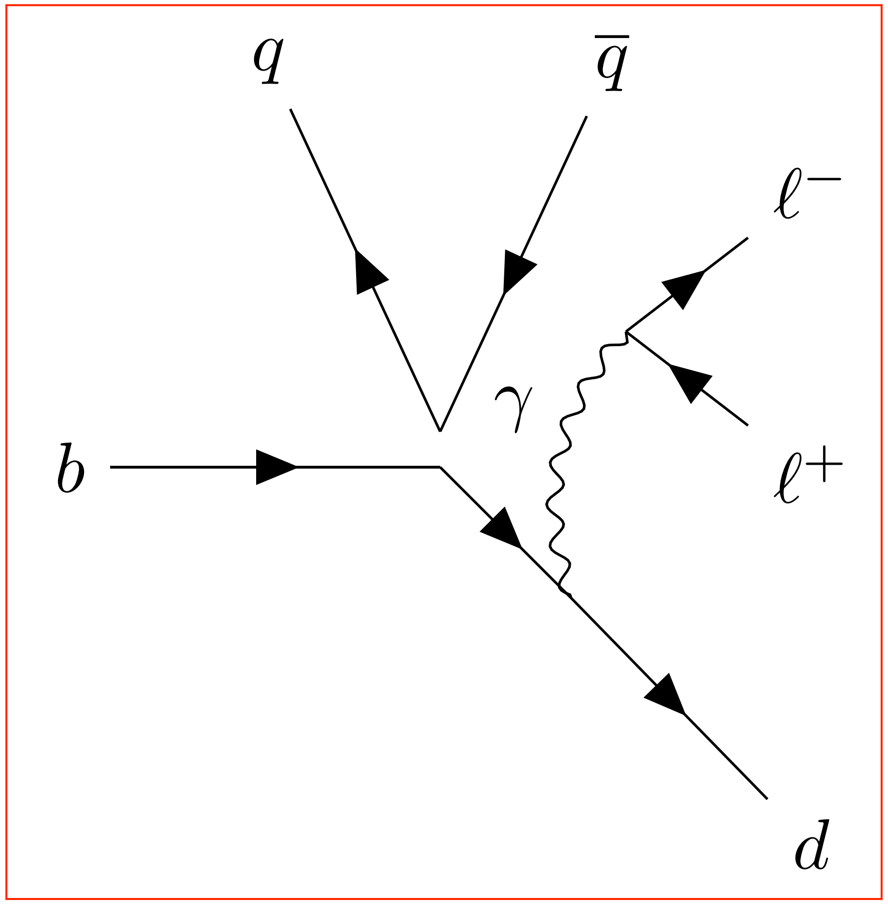
T. Huber, QQ, K. Vos, 1806.11521

★ Perturbative corrections include not only loop contributions but also multi-particle final-state contributions as $b \to d(s)\ell^+\ell^-\bar{q}q$

- $q = u$, d and s, but not c

★ Expand in couplings up to $\mathcal{O}(\tilde{\alpha}_s^3, \kappa^3)$

$$\left(\tilde{\alpha}_s \equiv \frac{\alpha_s}{4\pi}, \;\; \kappa \equiv \frac{\alpha_e}{\alpha_s}\right)$$



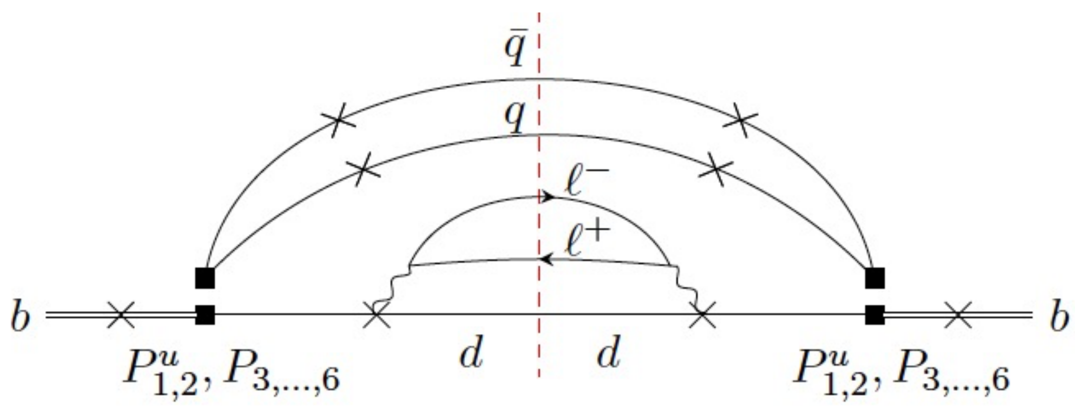
★ Contributions to observables

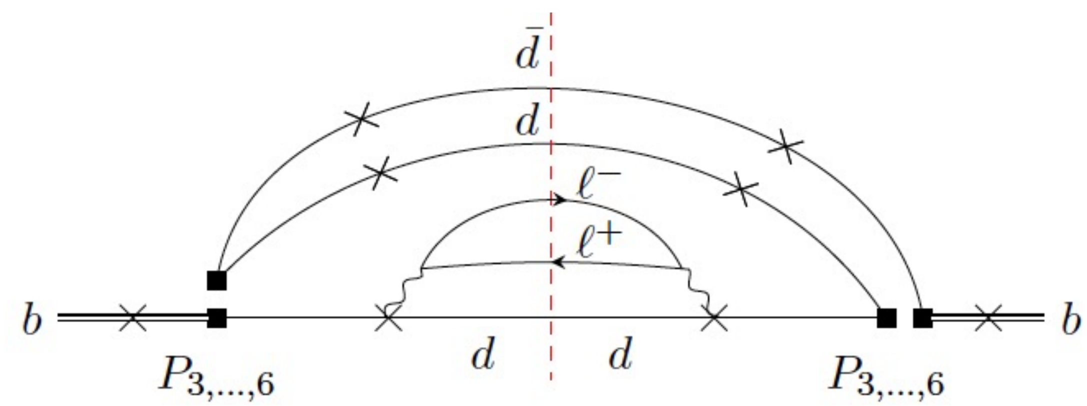
- branching ratio
- forward-backward asymmetry

★ Almost all results are analytical

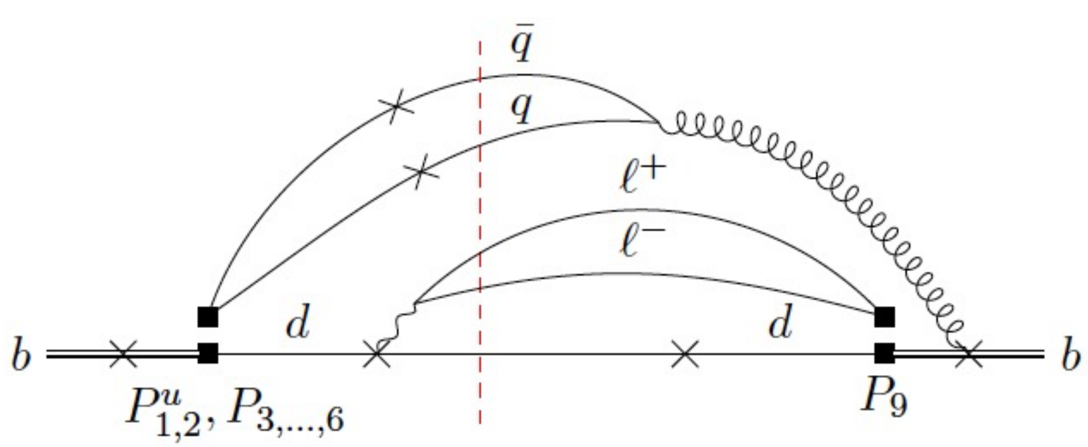
★ Include tree-level interferences of

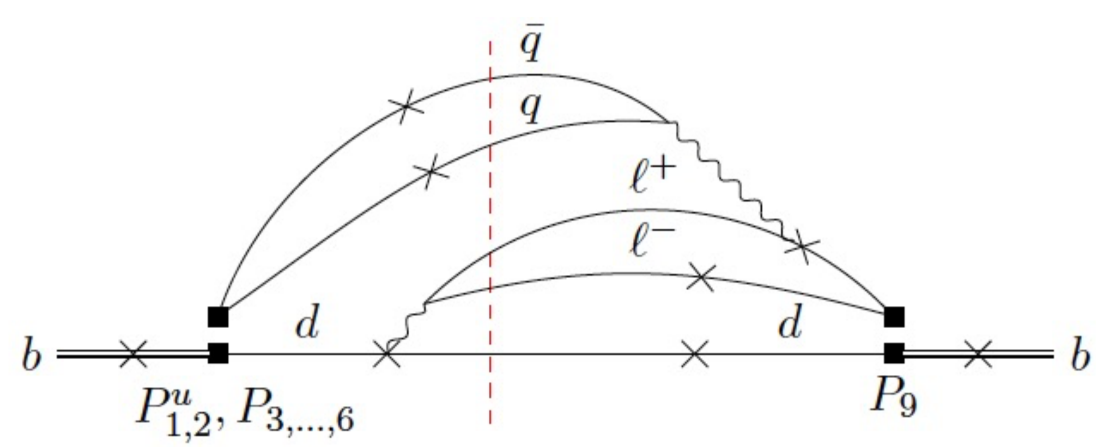
- $(P^u_{1,2}, P_{3,\ldots,6})$ with $(P^u_{1,2}, P_{3,\ldots,6})$





- $(P^u_{1,2}, P_{3,\ldots,6})$ with $(P_{7,\ldots,10})$





Five-particle contributions

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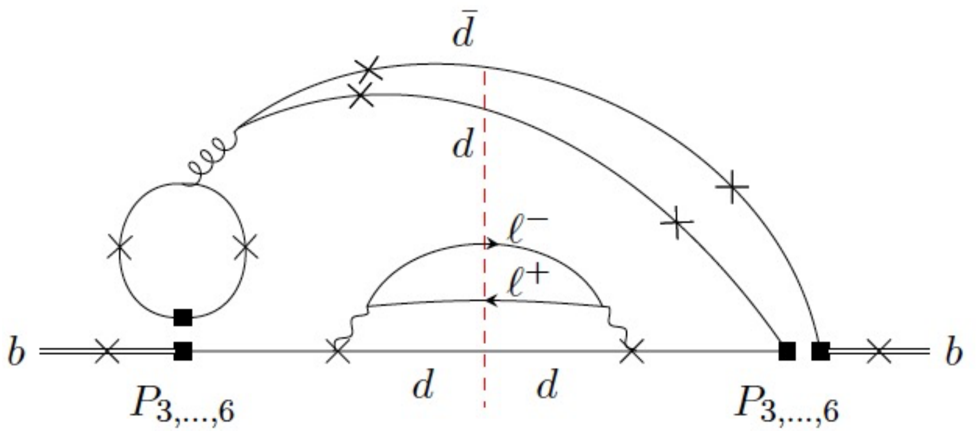
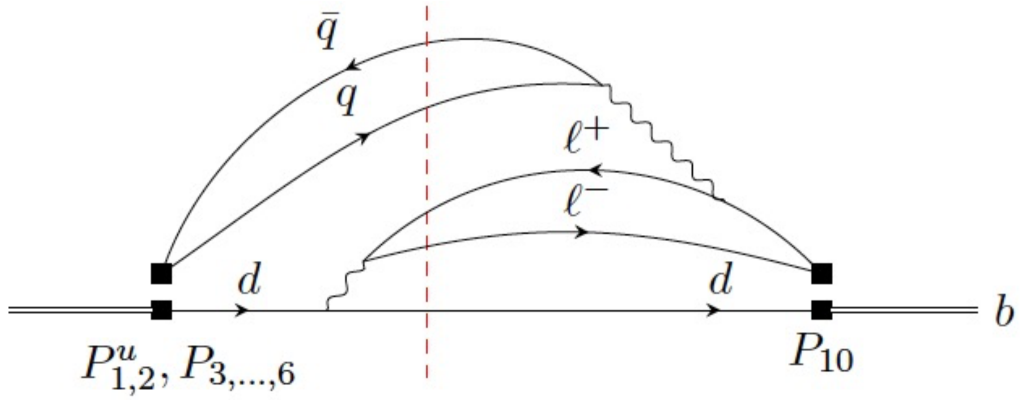
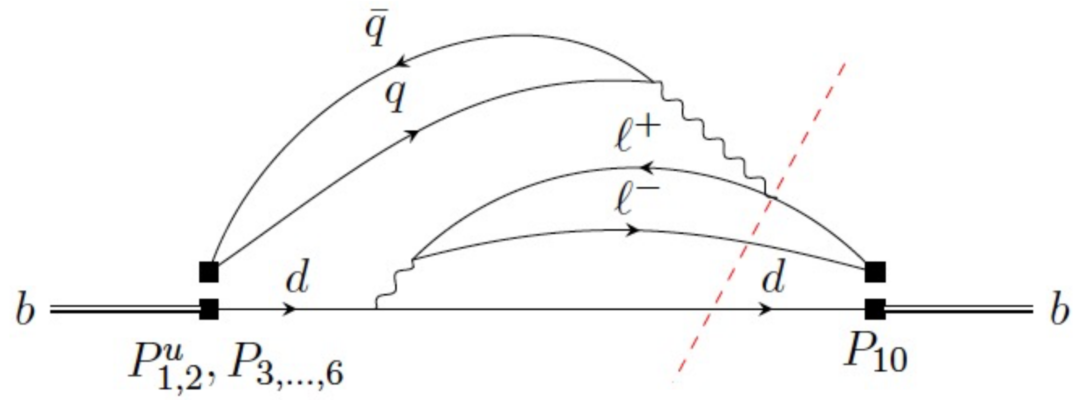
★ Discard

- one-loop interferences of $(P^u_{1,2}, P_{3,\ldots,6})$ with $(P^u_{1,2}, P_{3,\ldots,6})$



- and interferences that require fewer-particle cuts involving loops for renormalisation





Five-particle contributions

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★ Adopt two different phase-space parametrizations [Kumar,69';Heinrich,06']

$$\frac{d\Phi_5}{ds}\,|\mathcal{M}|^2 = \frac{\pi^2 m_b^6}{16(2\pi)^{11}} \int_s^1 ds_1 \int_s^{s_1} ds_2 \int_{s_2/s_1}^{1-s_1+s_2} du_1 \int_{u_2^-}^{u_2^+} du_2 \int_{u_3^-}^{u_3^+} du_3 \int_{t_2^-}^{t_2^+} dt_2 \int_{t_3^-}^{t_3^+} dt_3$$
$$\times \frac{(s_2-s)}{s_2\,(u_2^+-u_2^-)\,(u_3^+-u_3^-)\,\sqrt{(t_2^+-t_2)(t_2-t_2^-)}\,\sqrt{(t_3^+-t_3)(t_3-t_3^-)}} \left(\frac{1}{2}|\mathcal{M}|^2\Big|_{s_{34}\to s_{34}^+} + \frac{1}{2}|\mathcal{M}|^2\Big|_{s_{34}\to s_{34}^-}\right)$$

$$\int d\Phi_5\,|\mathcal{M}|^2 = \frac{m_b^6}{4^8\pi^9}\int_0^1 dt_2\ldots dt_4 dt_6 \ldots dt_{10}\,\frac{t_2\,t_6\,t_7^2\,(1-t_6)(1-t_7)\,\delta(t_2\,t_4\,t_6\,t_7-s_{14})}{\sqrt{t_8}\,\sqrt{1-t_8}\,\sqrt{t_{10}}\,\sqrt{1-t_{10}}}\left(|\mathcal{M}|^2\Big|_{t_5=0} + |\mathcal{M}|^2\Big|_{t_5=1}\right)$$

★ Staying differential in $q^2 \equiv (p_{\ell^+} + p_{\ell^-})^2$ allows to perform the calculation in D = 4 dimensions. Seven integrations are required.

$$f_1(\hat{s}) = \frac{\pi}{6} - \arctan(x)$$

$$f_7(\hat{s}) = 2i f_1(\hat{s})\left[\mathrm{Li}_2\left(\frac{1-ix}{1+ix}\right) - c.c.\right] - \left[\mathrm{Li}_3\left(\frac{1-ix}{1+ix}\right) + c.c.\right] + \frac{2\zeta(3)}{3}\,, \qquad x = \sqrt{\frac{\hat{s}}{4-\hat{s}}}$$

Five-particle contributions

T. Huber, QQ, K. Vos, 1806.11521

★ Differential branching ratio and forward-backward asymmetry

$$\frac{d\mathcal{B}(b\to d\ell^+\ell^- q\bar{q})}{d\hat{s}} = \mathcal{B}(\bar{B}\to X_c e\bar{\nu})_{\rm exp}\left|\frac{V_{td}^* V_{tb}}{V_{cb}}\right|^2 \frac{4}{C\Phi_u}\left(\sum_{i,j=1}^{10} \mathcal{R}^{ij}_{\rm CKM} C_i^* C_j \mathcal{F}_{ij}(\hat{s})\right)$$

$$\frac{dA_{\rm FB}}{d\hat{s}} = \mathcal{B}(\bar{B}\to X_c e\bar{\nu})_{\rm exp}\left|\frac{V_{td}^* V_{tb}}{V_{cb}}\right|^2 \frac{4}{C\Phi_u}\sum_{i=1}^{6}\left(-\mathcal{R}^{i10}_{\rm CKM} C_i^* C_{10}\mathcal{A}_i(\hat{s}) + c.c.\right)$$

★ $\mathcal{O}(1\%)$ correction in the case of $\bar{B}\to X_d\ell^+\ell^-$

$q^2 \equiv (p_{\ell+} + p_{\ell-})^2$

	[1, 3.5] GeV^2	[3.5, 6] GeV^2	[1, 6] GeV^2
$\mathcal{B}(b\to d\ell^+\ell^- q\bar{q})$ $(\times 10^{-10})$	9.22	0.30	9.52
$A_{\rm FB}(b\to d\ell^+\ell^- q\bar{q})$ $(\times 10^{-12})$	1.48	0.49	1.97

★ $\mathcal{O}(0.01\%)$ correction in the case of $\bar{B}\to X_s\ell^+\ell^-$ (CKM suppression)

	[1, 3.5] GeV^2	[3.5, 6] GeV^2	[1, 6] GeV^2
$\mathcal{B}(b\to s\ell^+\ell^- q\bar{q})$ $(\times 10^{-10})$	2.18	0.05	2.23
$A_{\rm FB}(b\to s\ell^+\ell^- q\bar{q})$ $(\times 10^{-11})$	1.57	0.52	2.10

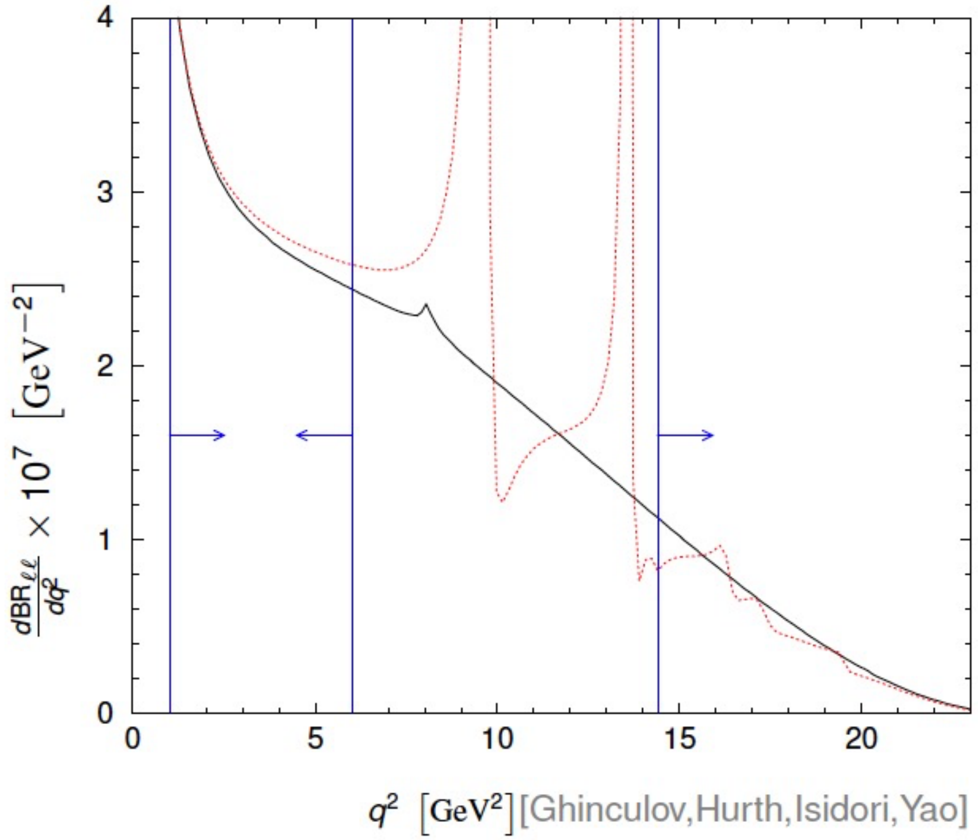
Long-distance Effects

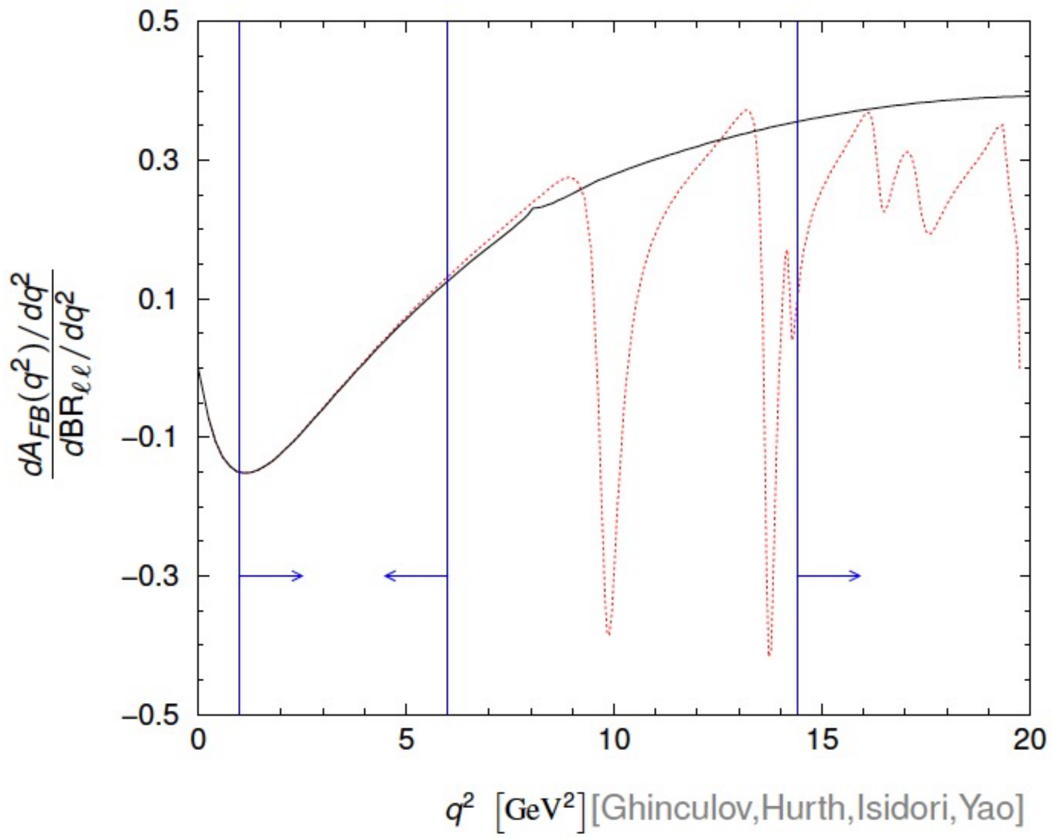
Long-distance Effects

[T. Huber, T. Hurth, J. Jenkins, E. Lunghi, QQ, K. Vos, in preparation]

★ In the $q^2 \equiv (p_{\ell^+} + p_{\ell^-})^2$ spectrum of $\bar{B} \to X_s \ell^+ \ell^-$, $c\bar{c}$ resonances show up as large peaks

- The $\bar{B} \to X_s \psi \to X_s \ell^+ \ell^-$ BR exceeds the short-distance BR by 2 orders

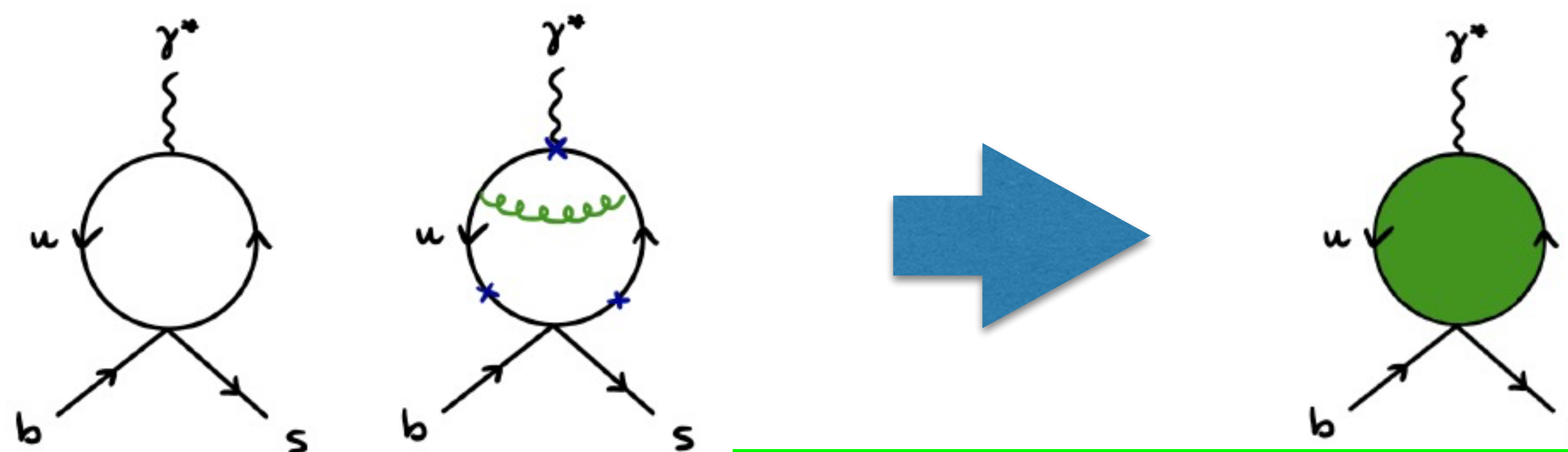




★ In $\bar{B} \to X_d \ell^+ \ell^-$ also light-quark resonances are relevant

★ Despite of cuts on q^2, we need to capture the tail effects of the resonances following the idea of Kruger and Sehgal [Kruger,Sehgal,96']

- Replace the perturbative amplitudes (factorizable) by data extracted ones



$$(q^\mu q^\nu - q^2 g^{\mu\nu}) h_q^{\rm KS}(q^2) = \frac{16\pi^2}{9Q_q}\, i \int d^4x\, e^{iqx} \langle 0|T J_q^\mu(0) J_{\rm em}^\nu(x)|0\rangle$$

- Very similar currents contribute to $R_{\rm had}(s) \equiv \dfrac{\sigma_{\rm had}(s)}{4\pi\alpha^2/3s} = 12\pi\, {\rm Im}[\Pi_\gamma(s)]$ (and hadronic tau decays)

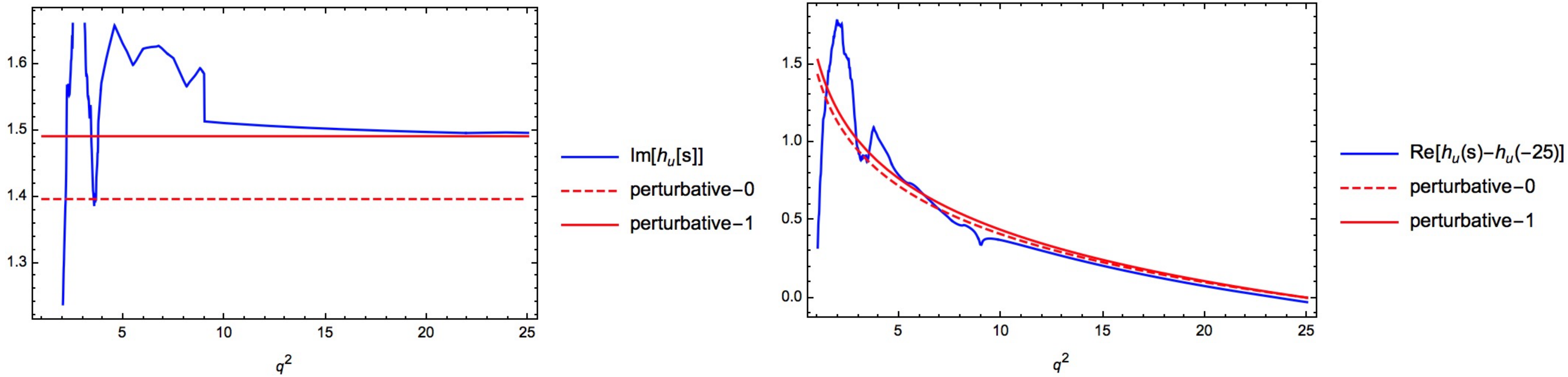
$$(q^\mu q^\nu - q^2 g^{\mu\nu}) \Pi_\gamma(q^2) = i \int d^4x\, e^{iqx} \langle 0|T J_{\rm em}^\mu(0) J_{\rm em}^\nu(x)|0\rangle$$

- Data tells us the imaginary part, and the real part is obtained by the dispersion relation $${\rm Re}[h_q^{\rm KS}(s)] = {\rm Re}[h_q^{\rm KS}(s_0)] + \frac{s-s_0}{\pi}\int_0^\infty dt\, \frac{{\rm Im}[h_q^{\rm KS}(t+i\epsilon)]}{(t-s_0)(t-s-i\epsilon)}.$$

★ Use latest data (including ee collision and tau decays) from BESIII, BaBar, ALEPH in the resonance regions [see Keshavarzi,Nomura,Teubner,18']

★ In the replacement of the perturbative function we take into account all factorizable pieces up to two loops. Separation of factorizable two-loop perturbative function are provided by St. de Boer. [de Boer,17']

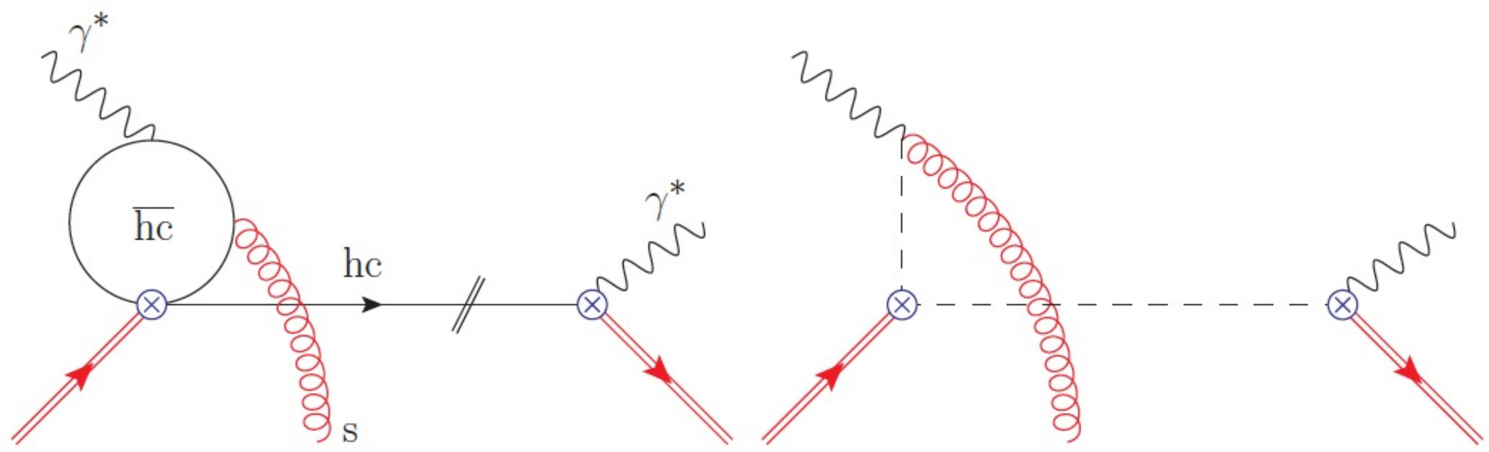
★ Choose as subtraction point $s_0 = -(5\mathrm{GeV})^2$



Asymptotic behaviours of perturbative and nonperturbative functions

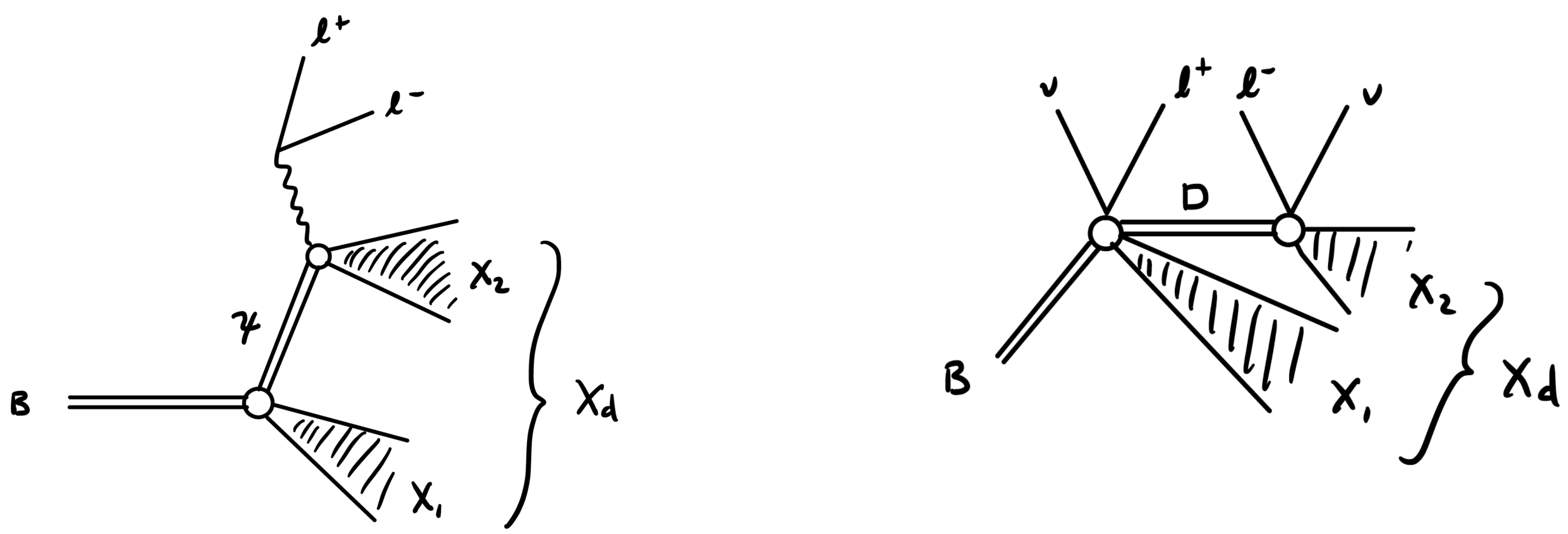
★ Resolved photon effects cause additional uncertainty of ~5%

[See Voloshin,96';Buchalla,Isidori,Rey,97';Benzke,Hurth,Turczyk,17']



★ Cascade decays not covered by either local OPE or KS

[see Buchalla,Isidori,Rey,97'; Beneke,Buchalla,Neubert,Sachrajda,09']



- Q: More investigation from theory or cuts from experiments?

Power Corrections

Power Corrections

[T. Huber, T. Hurth, J. Jenkins, E. Lunghi, QQ, K. Vos, in preparation]

★ Computing power-corrections requires HQET matrix elements of dimension-five and -six operators

$$\lambda_1 \equiv \langle B|\bar{h}_v (iD)^2 h_v|B\rangle$$
$$\lambda_2 \equiv \langle B|\bar{h}_v g\sigma_{\mu\nu} G^{\mu\nu} h_v|B\rangle$$

$$\frac{1}{3}\rho_1(g_{\alpha\beta} - v_\alpha v_\beta)v_\mu \equiv \frac{1}{2m_B}\langle B|\bar{h}_v iD_\alpha iD_\mu iD_\beta h_v|B\rangle$$
$$\frac{1}{2}\rho_2\ i\epsilon_{\nu\alpha\beta\delta} v^\nu v_\mu \equiv \frac{1}{2m_B}\langle B|\bar{h}_v iD_\alpha iD_\mu iD_\beta \gamma_\delta\gamma_5 h_v|B\rangle$$

$$f_q^{0,\pm} \equiv \frac{1}{2m_B}\langle B^{0,\pm}|Q_2^q - Q_1^q|B^{0,\pm}\rangle$$

- λ_i, ρ_i were extracted from moments of inclusive $B \to X_c \ell\nu$ spectrum [Gambino,Healey,Turczyk,16']
- We extract the weak-annihilation matrix elements $f_q^{\pm,0}$ from data of semileptonic D meson decays following [Gambino,Kamenik,10']

★ Flavor symmetries assumed for weak-annihilation matrix elements

$$f_V \equiv f_u^{\pm} \overset{SU(2)}{=} f_d^0$$

$$f_{NV} \equiv f_u^0 \overset{SU(2)}{=} f_d^{\pm} \overset{SU(3)}{=} f_s^0 \overset{SU(2)}{=} f_s^{\pm}$$

V/NV stands for valence and non-valence terms
with respect to external B meson states

- (Largely) uncorrelated combinations are f_{NV} and $f_V - f_{NV}$
- Introduce SU(2,3) breaking effects according to [Ligeti,Tackmann,07']

$f_{NV} = (-0.02 \pm 0.16)\ \mathrm{GeV}^3$	$\lambda_2^{\mathrm{eff}} = \lambda_2 - \frac{\rho_2}{m_b} = 0.130(21)\ \mathrm{GeV}^2$
$f_V - f_{NV} = (-0.041 \pm 0.052)\ \mathrm{GeV}^3$	$\lambda_1 = -0.267(90)\ \mathrm{GeV}^2$
$[\delta f]_{SU(3)} = (0 \pm 0.04)\ \mathrm{GeV}^3$	$\rho_1 = 0.038(70)\ \mathrm{GeV}^3$
$[\delta f]_{SU(2)} = (0 \pm 0.004)\ \mathrm{GeV}^3$	$(f_V + f_{NV})/2 = (-0.04 \pm 0.17)\ \mathrm{GeV}^3$

Q: Can lattice QCD compute these matrix elements in analogy to the ones in B lifetime?

Phenomenology

[Huber, Hurth, Jenkins, Lunghi, QQ, Vos, in preparation]

$q^2 \equiv (p_{\ell^+} + p_{\ell^-})^2$

★ We consider the observables in two kinetic regions $q^2 \in [1, 6]\mathrm{GeV}^2$ and $q^2 > 14.4\mathrm{GeV}^2$, to reduce the charm resonance effects, including

- The branching ratios in the low- and high-q^2 regions
- The forward-backward asymmetries in the low-q^2 region
- The CP asymmetries in both regions
- The ratio between $\bar{B} \to X_d \ell^+ \ell^-$ and $B^0 \to X_u \ell \nu$ with the same kinematic cut in the high-q^2 region to reduce power-correction uncertainties [Ligeti,Tackmann,07']

$$\mathcal{R}(s_0) = \int_{\hat{s}_0}^{1} \mathrm{d}\hat{s}\, \frac{\mathrm{d}\Gamma(\bar{B} \to X_d \ell^+ \ell^-)}{\mathrm{d}\hat{s}} \Big/ \int_{\hat{s}_0}^{1} \mathrm{d}\hat{s}\, \frac{\mathrm{d}\Gamma(B^0 \to X_u \ell \nu)}{\mathrm{d}\hat{s}}$$

Preliminary

★ Branching ratios and the R-ratio of $\bar{B} \to X_d \ell^+ \ell^-$

$$\mathcal{B}[1,6]_{ee} = (7.81 \pm 0.37_{\rm scale} \pm 0.08_{m_t} \pm 0.17_{C,m_c} \pm 0.08_{m_b}$$

$$0.04_{\alpha_s} \pm 0.15_{\rm CKM} \pm 0.12_{\rm BR_{sl}} \pm 0.05_{\lambda_2}) \times 10^{-8} = (7.81 \pm 0.47) \times 10^{-8} \,.$$

$$\mathcal{B}[1,6]_{\mu\mu} = (7.59 \pm 0.35_{\rm scale} \pm 0.08_{m_t} \pm 0.17_{C,m_c} \pm 0.09_{m_b}$$

$$\pm 0.04_{\alpha_s} \pm 0.14_{\rm CKM} \pm 0.11_{\rm BR_{sl}} \pm 0.05_{\lambda_2}) \times 10^{-8} = (7.59 \pm 0.45) \times 10^{-8} \,.$$

★ Branching ratios and the R-ratio of $\bar{B} \to X_d \ell^+ \ell^-$

$$\mathcal{B}[>14.4]_{ee} = (0.98 \pm 0.12_{\text{scale}} \pm 0.01_{m_t} \pm 0.01_{C,m_c} \pm 0.08_{m_b} \pm 0.02_{\text{CKM}} \pm 0.02_{\text{BR}_{\text{sl}}} \pm 0.06_{\lambda_2} \pm 0.25_{\rho_1} \pm 0.25_{f_{u,d}}) \times 10^{-8} = (0.98 \pm 0.38) \times 10^{-8} \,,$$

$$\mathcal{B}[>14.4]_{\mu\mu} = (1.12 \pm 0.12_{\text{scale}} \pm 0.01_{m_t} \pm 0.02_{C,m_c} \pm 0.09_{m_b} \pm 0.02_{\text{CKM}} \pm 0.02_{\text{BR}_{\text{sl}}} \pm 0.05_{\lambda_2} \pm 0.25_{\rho_1} \pm 0.25_{f_{u,d}}) \times 10^{-8} = (1.12 \pm 0.38) \times 10^{-8} \,.$$

$$\mathcal{R}(14.4)_{ee} = (0.96 \pm 0.02_{\text{scale}} \pm 0.01_{m_t} \pm 0.01_{C,m_c} \pm 0.002_{m_b} \pm 0.01_{\alpha_s} \pm 0.05_{\text{CKM}} \pm 0.004_{\lambda_2} \pm 0.06_{\rho_1} \pm 0.05_{f_{u,d}}) \times 10^{-4} = (0.96 \pm 0.09) \times 10^{-4} \,,$$

$$\mathcal{R}(14.4)_{\mu\mu} = (1.11 \pm 0.01_{\text{scale}} \pm 0.01_{m_t} \pm 0.01_{C,m_c} \pm 0.002_{m_b} \pm 0.01_{\alpha_s} \pm 0.05_{\text{CKM}} \pm 0.002_{\lambda_2} \pm 0.04_{\rho_1} \pm 0.02_{f_{u,d}}) \times 10^{-4} = (1.11 \pm 0.07) \times 10^{-4} \,.$$

★ Forward-backward asymmetries of $\bar{B} \to X_d \ell^+ \ell^-$

$$\mathcal{A}_{\rm FB}[1,3.5]_{ee} =(-7.10 \pm 0.67_{\rm scale} \pm 0.01_{m_t} \pm 0.11_{C,m_c} \pm 0.22_{m_b} \pm 0.19_{\alpha_s} \pm 0.02_{\rm CKM} \pm 0.04_{\lambda_2})\%$$
$$= (-7.11 \pm 0.74)\% \, ,$$

$$\mathcal{A}_{\rm FB}[3.5,6]_{ee} =(8.60 \pm 0.74_{\rm scale} \pm 0.01_{m_t} \pm 0.13_{C,m_c} \pm 0.37_{m_b} \pm 0.18_{\alpha_s} \pm 0.02_{\rm CKM} \pm 0.11_{\lambda_2})\%$$
$$= (8.60 \pm 0.87)\% \, ,$$

$$\mathcal{A}_{\rm FB}[1,6]_{ee} =(-0.12 \pm 0.77_{\rm scale} \pm 0.004_{m_t} \pm 0.13_{C,m_c} \pm 0.29_{m_b} \pm 0.20_{\alpha_s} \pm 0.02_{\rm CKM} \pm 0.02_{\lambda_2})\%$$
$$= (-0.12 \pm 0.86)\% \, .$$

$$\mathcal{A}_{\rm FB}[1,3.5]_{\mu\mu} =(-7.97 \pm 0.69_{\rm scale} \pm 0.01_{m_t} \pm 0.11_{C,m_c} \pm 0.22_{m_b} \pm 0.20_{\alpha_s} \pm 0.02_{\rm CKM} \pm 0.05_{\lambda_2})\%$$
$$= (-7.97 \pm 0.76)\% \, ,$$

$$\mathcal{A}_{\rm FB}[3.5,6]_{\mu\mu} =(8.16 \pm 0.82_{\rm scale} \pm 0.01_{m_t} \pm 0.13_{C,m_c} \pm 0.39_{m_b} \pm 0.19_{\alpha_s} \pm 0.02_{\rm CKM} \pm 0.11_{\lambda_2})\%$$
$$= (8.16 \pm 0.94)\% \, ,$$

$$\mathcal{A}_{\rm FB}[1,6]_{\mu\mu} =(-0.70 \pm 0.82_{\rm scale} \pm 0.004_{m_t} \pm 0.13_{C,m_c} \pm 0.30_{m_b} \pm 0.21_{\alpha_s} \pm 0.02_{\rm CKM} \pm 0.02_{\lambda_2})\%$$
$$= (-0.70 \pm 0.91)\% \, .$$

Preliminary

★ The "zeros" of $\bar{B} \to X_d \ell^+ \ell^-$

(q^2 where AFB is zero)

$$(q_0^2)_{ee} = 3.28 \pm 0.11_{\text{scale}} \pm 0.001_{m_t} \pm 0.02_{C,m_c} \pm 0.05_{m_b}$$
$$\pm 0.03_{\alpha_s} \pm 0.004_{\text{CKM}} \pm 0.002_{\lambda_1} \pm 0.001_{\lambda_2} = (3.28 \pm 0.13)\ \text{GeV}^2$$

$$(q_0^2)_{\mu\mu} = 3.39 \pm 0.12_{\text{scale}} \pm 0.001_{m_t} \pm 0.02_{C,m_c} \pm 0.05_{m_b}$$
$$\pm 0.03_{\alpha_s} \pm 0.004_{\text{CKM}} \pm 0.002_{\lambda_1} \pm 0.002_{\lambda_2} = (3.39 \pm 0.13)\ \text{GeV}^2$$

★ CP asymmetries of $\bar{B} \to X_d \ell^+ \ell^-$: order 1%

$$\mathcal{A}_{\rm CP}[1,6]_{ee} = (-1.45 \pm 0.75_{\rm scale} \pm 0.015_{m_t} \pm 0.019_{C,m_c} \pm 0.05_{m_b} \pm 0.15_{\alpha_s} \pm 0.03_{\rm CKM} \pm 0.002_{\lambda_2}) \times 10^{-2} = (-1.45 \pm 0.77) \times 10^{-2} \, .$$

$$\mathcal{A}_{\rm CP}[1,6]_{\mu\mu} = (-1.32 \pm 0.71_{\rm scale} \pm 0.014_{m_t} \pm 0.015_{C,m_c} \pm 0.05_{m_b} \pm 0.15_{\alpha_s} \pm 0.03_{\rm CKM} \pm 0.002_{\lambda_2}) \times 10^{-2} = (-1.32 \pm 0.72) \times 10^{-2} \, .$$

$$\mathcal{A}_{\rm CP}[> 14.4]_{ee} = (-1.68 \pm 0.14_{\rm scale} \pm 0.01_{m_t} \pm 0.12_{C,m_c} \pm 0.12_{m_b} \pm 0.05_{\alpha_s} \pm 0.05_{\rm CKM} \pm 0.28_{\lambda_2} \pm 0.34_{\rho_1} \pm 0.55_{f_{u,d}}) \times 10^{-2} = (-1.68 \pm 0.74) \times 10^{-2} \, .$$

$$\mathcal{A}_{\rm CP}[> 14.4]_{\mu\mu} = (-1.64 \pm 0.21_{\rm scale} \pm 0.01_{m_t} \pm 0.09_{C,m_c} \pm 0.11_{m_b} \pm 0.04_{\alpha_s} \pm 0.05_{\rm CKM} \pm 0.24_{\lambda_2} \pm 0.30_{\rho_1} \pm 0.45_{f_{u,d}}) \times 10^{-2} = (-1.64 \pm 0.64) \times 10^{-2} \, .$$

Summary and Outlook

Summary and Outlook

★ We update the SM theory predictions in inclusive $\bar{B} \to X_d \ell^+ \ell^-$ decay and $\bar{B} \to X_s \ell^+ \ell^-$ is on the way

★ Further investigate the resolved photon effects and the Cascade decay effects…

★ Study effects of lepton-flavour universality violation, e.g. in the observable

$$R_{X_s} = \frac{\mathcal{B}(\bar{B} \to X_s \, \mu^+ \mu^-)}{\mathcal{B}(\bar{B} \to X_s \, e^+ e^-)}$$

Thank you very much!