



Precision predictions for ${\rm B}\to\rho\tau\nu$ and ${\rm B}\to\omega\tau\nu$ in the SM and beyond

EPS 2019 - Flavour Physics and CP Violation

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Form Factors



• Form factors encode the structure of matrix elements in terms of representations.



Form Factors - BCL Parametrization



The Bourrely-Caprini-Lellouch (BCL) parametrization is a model-independent ansatz for the form factors based on a fast converging series expansion of:

$$egin{aligned} & z(q^2,t_0) = rac{\sqrt{t_+ - q^2} - \sqrt{t_+ - t_0}}{\sqrt{t_+ - q^2} + \sqrt{t_+ - t_0}} \ & ext{with} \quad t_+ = (m_{ extsf{B}} + m_{ extsf{M}})^2 \ & t_0 = (m_{ extsf{B}} + m_{ extsf{M}})(\sqrt{m_{ extsf{B}}} - \sqrt{m_{ extsf{M}}}) \end{aligned}$$

2

The form factors are expanded as:

$$F_i(q^2) = P_i(q^2) \sum_k \alpha_k^i \left(z(q^2) - z(0) \right)^k$$

with $P_i(q^2) = (1 - q^2/m_R^2)^{-1}$ m_R : Mass of first resonance in spectrum



- In total exist 8 independent form factors: A_P , V, A_0 , A_1 , A_{12} , T_1 , T_2 , T_{23} .
- The pseudoscalar form factor can be removed under the equations of motion:

$$A_P = -2rac{m_M}{m_{
m b}+m_{
m u}}A_0\,.$$

- 4 form factors contribute to the SM process: *V*, *A*₀, *A*₁, *A*₁₂.
- 3 form factors can contribute to BSM processes: T_1 , T_2 , T_{23} .

Form Factors - B ightarrow V ℓu with V = ho,ω from Theory



- Theory predictions available from LCSR calculations:
 - JHEP 1608 (2016) 098
- Only valid up to $q^2 \approx 14 \, {\rm GeV}^2$.
- For $q^2 > 14 \, {\rm GeV}^2$ solely extrapolation available (no LQCD).



Differential Rate - Help from Experiment



- Fit form factor coefficients with theory and experimental input:
 - Phys.Rev. D88 (2013) no.3, 032005
 - Phys.Rev. D83 (2011) 032007
 - Phys.Rev. D87 (2013) no.3, 032004
- Use normalized spectra to take $V_{\rm ub}$ out of the equation.



Differential Rate - Fit Result







Differential rate corrections are extracted from experimental data.

Form Factor - Fit Result B $ightarrow ho \ell u$





Form factor corrections are extracted from experimental data.

Form Factor - Fit Result B $ightarrow \omega \ell u$





Form factor corrections are extracted from experimental data.



- Only small improvement in the individual uncertainties of the form factors.
- But the fit allows to constrain combinations of form factors.
- This improves the precision on certain observables, e.g. $R(\rho)$ and $R(\omega)$.



• Use fitted coefficients to predict R(V).

$$R(V) = \frac{\int_{m_{\tau}^{2}}^{q_{\max}^{2}} \frac{\mathrm{d}\Gamma(B \to V\tau\nu)}{\mathrm{d}q^{2}} \mathrm{d}q^{2}}{\int_{0}^{q_{\max}^{2}} \frac{\mathrm{d}\Gamma(B \to V\ell\nu)}{\mathrm{d}q^{2}} \mathrm{d}q^{2}} \frac{\mathrm{d}q^{2}}{\mathrm{d}q^{2}} \mathrm{d}q^{2}} \qquad \hat{R}(V) = \frac{\int_{m_{\tau}^{2}}^{q_{\max}^{2}} \frac{\mathrm{d}\Gamma(B \to V\ell\nu)}{\mathrm{d}q^{2}} \mathrm{d}q^{2}}{\int_{m_{\tau}^{2}}^{q_{\max}^{2}} \frac{\mathrm{d}\Gamma(B \to V\ell\nu)}{\mathrm{d}q^{2}} \mathrm{d}q^{2}} \mathrm{d}q^{2}}$$

$$\frac{R(V) \quad \text{LCSR} \quad \text{Fit} \quad \text{Improvement}}{R(\rho) \quad 0.532 \pm 0.011 \quad 0.535 \pm 0.008 \quad 25\%}{R(\omega) \quad 0.534 \pm 0.018 \quad 0.546 \pm 0.015 \quad 16\%}$$

$$\frac{\hat{R}(\rho) \quad 0.605 \pm 0.007 \quad 0.606 \pm 0.006 \quad 6\%}{\hat{R}(\omega) \quad 0.606 \pm 0.012 \quad 0.612 \pm 0.011 \quad 7\%}$$



12/16

The complete basis of the four-Fermi operators mediating the b $ightarrow q\ell
u$ decay:

$$i2\sqrt{2}V_{\rm ub}G_{\rm F}\left[\bar{q}\chi_{j}^{i}\gamma^{\mu}P_{j}b\right]\left[\bar{\ell}\lambda_{l}^{k}\gamma_{\mu}P_{l}\nu\right]$$

- χ_l^i : NP coupling to quark current.
- λ_l^k : NP coupling to lepton current.
- j, l = L, R: Helicity of b quark or ν respectively.
- i, k = S, V, T: Type of current.
- NP couplings normalized to SM.
- Influence of new physics on $R(\rho)$ and $R(\omega)$ the same (both vector-like particles).













Summary & Outlook



- Form factors constrained from theory and experiment over whole q^2 range.
- Improved predictions of $\mathcal{O}(20\%)$ for $R(\rho)$ and $R(\omega)$
- Analysis of BSM physics influence on $R(\rho)$ and $R(\omega)$.
- No measurements of $R(\rho)$ and $R(\omega)$ yet.
- Results also available via HAMMER:
 - http://hammer.physics.lbl.gov/
 - HAMMER: a tool for new physics searches in semileptonic decays at Belle II and LHCb by Stephan Duell (12 Jul 2019, 11:45)
- Measurement of the full differential decay rate allows data driven extraction of form factors in the future.

Backup













 χ^2 -Profiles of B $ightarrow
ho \ell
u$ Fit





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Correlations of B $ightarrow ho \ell u$



	$B \rightarrow \rho (\rightarrow 2\pi) / \nu$ Prefit															$B \rightarrow \rho (\rightarrow 2\pi)/\nu$ Postfit																											
$\alpha_1^{A_0}$	100	-21	-4	19	20	42	88	84	-10	26	9	-11	28	6	20	24	34	88	71		100	$\alpha_1^{A_0}$	100	-14	7	13	19	29	86	81	-3	21	17	-4	24	13	14	26	24	86	73		100
$\alpha_2^{A_0}$	-21	100	8 (8	26	-14	-30	-24	3	1	59	-12	1	57	6	43	-9	-1	37-		1	$\alpha_{2}^{A_{c}}$	-14	100	2	15	28	-6	-23	-19	-1	7	57	-16	7	55	12	44	-3	8	40	1	
$\alpha_{0}^{\hat{A}_{1}}$	-4	8	100	46	43	15	-12	-22	90	46	-23	88	46	-27	45	37	15	8	6-	.	75	$\alpha^{\hat{A}_1}$	7	2	100	56	46	30	2	-15	90	54	-30	88	55	-33	55	38	24	20	9	-	75
$\alpha_1^{A_1}$	-19	8	46	100	86	-5	16	1	42	95	-29	39	95	-32	99	76	-1	28	18		-	$\alpha_1^{A_1}$	-13	15	56	100	87	-14	6	-5	49	95	-23	45	94	-27	98	79	-7	23	18	-	
$\alpha_2^{\hat{A}_1}$	-20	26	43	86	100	-9	12	9	36	86	1	30	86	-4	85	94	-3	27	32-		50	$\alpha_2^{\hat{A}_1}$	19	28	46	87	100	-12	11	8	37	88	2	31	88	-3	87	94	-5	27	32-	1	50
$\alpha_0^{\tilde{A_{12}}}$	42	-14	15	-5	-9	100	56	38	16	-7	-1	15	-7	1	-5	-13	72	43	17-			$\alpha_0^{\tilde{A_{12}}}$	-29	-6	30	-14	-12	100	42	25	29	-16	6	28	-16	8	-14	-14	69	31	12		
$\alpha_1^{\tilde{A}_{12}}$	-88	-30	-12	16	12	56	100	89	-15	24	-13	-11	26	-14	18	8	35	83	56		1.05	$\alpha_1^{A_{12}}$	86	-23	2	6	11	42	100	89	-5	18	-4	-2	20	-8	8	11	23	80	60	-	25
$\alpha_{2}^{\tilde{A}_{12}}$	-84	-24	-22	1	9	38	89	100	-28	12	-0	-24	15	-4	4	9	17	65	58	1	25	$\alpha_2^{\tilde{A}_{12}}$	81	-19	-15	-5	8	25	89	100	-23	8	4	-19	10	0	-2	10	6	59	57	-	25
$\bar{\alpha}_0^{\nu}$	-10	3	90	42	36	16	-15	-28	100	48	-32	90	43	-30	43	31	16	3	-3-		:	$\bar{\alpha}_0^{\nu}$	3	-1	90	49	37	29	-5	-23	100	54	-37	90	49	-34	50	31	23	12	0	1	
α_1^{v}	-26	1	46	95	86	-7	24	12	48	100	0 -37	42	97	-39	97	77	•6	32	22-		0	α_1^{v}	21	7	54	95	88	-16	18	8	54	100	-33	48	97	-35	96	80	12	28	22	-	0
α_2^{ν}	- 9	59	-23	-29	1	-1	-13	-0	-32	-37	7 100	.42	-35	96	-33	22	10	16	50		-	α_2^{ν}	17	57	-30	-23	2	6	-4	4	-37	-33	100	-47	-31	96	-28	22	16	25	53	-	
$\alpha_1^{T_1}$	-11	-12	88	39	30	15	-11	-24	90	42	-42	10	46	-48	44	23	14	-1	-12		-25	$\alpha_1^{T_1}$	4	-16	88	45	31	28	-2	-19	90	48	-47	100	51	-52	50	23	20	7	-10	1	-25
$\alpha_2^{T_1}$	-28	1	46	95	86	-7	26	15	43	97	-35	46	100	-42	98	79	-5	34	24			$\alpha_2^{T_1}$	-24	7	55	94	88	-16	20	10	49	97	-31	51	100	-38	98	82	10	30	24	1	
$\alpha_0^{T_2}$	-6	57	-27	-32	-4	1	-14	-4	-30	-39	9 96	-48	-42	100	-38	15	12	13	46			$\alpha_0^{T_2}$	13	55	-33	-27	-3	8	-8	0	-34	-35	96	-52	-38	100	-34	15	17	21	48	•	50
$\alpha_1^{T_2}$	-20	6	45	99	85	-5	18	4	43	97	-33	44	98	-38	100	77	-2	28	17-		-50	$\alpha_1^{T_2}$	14	12	55	98	87	-14	8	-2	50	96	-28	50	98	-34	100	81	-8	22	17-	1	-50
$\alpha_2^{T_2}$	-24	43	37	76	94	-13	8	9	31	77	22	23	79	15	77	100	-4	33	49		:	$\alpha_2^{T_2}$	-26	44	38	79	94	-14	11	10	31	80	22	23	82	15	81	L00	-4	36	49	1	
$\alpha_0^{1_{23}}$	-34	-9	15	-1	-3	72	35	17	16	-6	10	14	-5	12	-2	-4	100	39	14		-75	$\alpha_{0}^{T_{23}}$	-24	-3	24	-7	-5	69	23	6	23	-12	16	20	-10	17	-8	-4	100	31	10-	-	-75
$\alpha_{1}^{T_{23}}$	-88	-1	8	28	27	43	83	65	3	32	16	-1	34	13	28	33	39	100	83-		1	$\alpha_{1}^{T_{23}}$	-86	8	20	23	27	31	80	59	12	28	25	7	30	21	22	36	31 1	100	86-	1	
$\alpha_{2}^{T_{23}}$	71	37	6	18	32	17	56	58	-3	22	50	-12	24	46	17	49	14	83	100		1-100	$\alpha_{2}^{T_{23}}$	73	40	9	18	32	12	60	57	0	22	53	-10	24	48	17	49 	10	86	109	-	-100
	$\alpha_1^{A_0}$	a ^A o	a ^Å i	ahi	a ^A 1	$\alpha_0^{A_{12}}$	$\alpha_1^{A_{12}}$	α ⁴¹²	م ^ر	a',	a ²	α_{1}^{+}	άţ	a ¹ ₂	$\alpha_{1_{2}}^{\dagger_{2}}$	$\alpha_{1}^{\frac{1}{2}}$	α ¹ 23	$\alpha_{1}^{T_{23}}$	$\alpha_2^{T_{23}}$				$\alpha_1^{A_0}$	α ^Å	a ^A	a ^A 1	a ^{A1}	$\alpha_0^{A_{12}}$	$\alpha_1^{A_{12}}$	$\alpha_2^{A_{12}}$	20<	a'	2 ²²	α_1^{-1}	$\alpha_{2^{+}}^{2^{+}}$	$\alpha_{0,2}^{-2}$	$\alpha_{1,2}^{2}$	α_{2}^{2}	a ¹²	α_1^{12}	$\alpha_2^{1_{23}}$		

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24/16



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