Exclusive Vub determination from QCD - solution to Vub puzzle?

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The B to π form factors from QCD and their impact on Vub
D.Leljak, BM (RBI, Zagreb), D. van Dyk (TUM), JHEP 07 (2021) 036, arXiv 2102.07233

HrZZ

Portorož 2021: Physics of the Flavourful Universe, Portorož 21-24.9.2021

V_{ub} STATUS

inclusive:

$$10^3 \times |V_{ub}|_{\mathrm{BLNP}} = 4.44\,^{+0.13}_{-0.14}|_{\mathrm{exp.}}\,^{+0.21}_{-0.22}|_{\mathrm{theory}} \simeq 4.44^{+0.25}_{-0.26}\,,$$

$$10^3 \times |V_{ub}|_{\mathrm{GGOU}} = 4.32\,\pm 0.12|_{\mathrm{exp.}}\,^{+0.12}_{-0.13}|_{\mathrm{theory}} \simeq 4.32^{+0.17}_{-0.18}$$

Bosch,Lange,Neubert,Paz, arXiv [ph]: 0504071
Gambino,Giordano,Ossola,Uratsev, arXiv [ph]: 0707.2493

exclusive:

$$10^3 \times |V_{ub}|^{\bar{B}\to\pi}_{\mathrm{LQCD+LCSR}} = 3.67 \pm 0.09|_{\mathrm{exp.}} \pm 0.12|_{\mathrm{theory}} \simeq 3.67 \pm 0.15$$

HFLAV , arXiv:1909.12524

exclusive vs inclusive Vub $\approx 2.7\sigma$

! new inclusive Vub measurement:

$$10^3 \times |V_{ub}| = 4.10 \pm 0.09 \pm 0.22 \pm 0.15 = 4.10 \pm 0.28$$

Belle , arXiv:2102.00020

IMPORTANT REMARKS ON V_{UB} EXTRACTION:

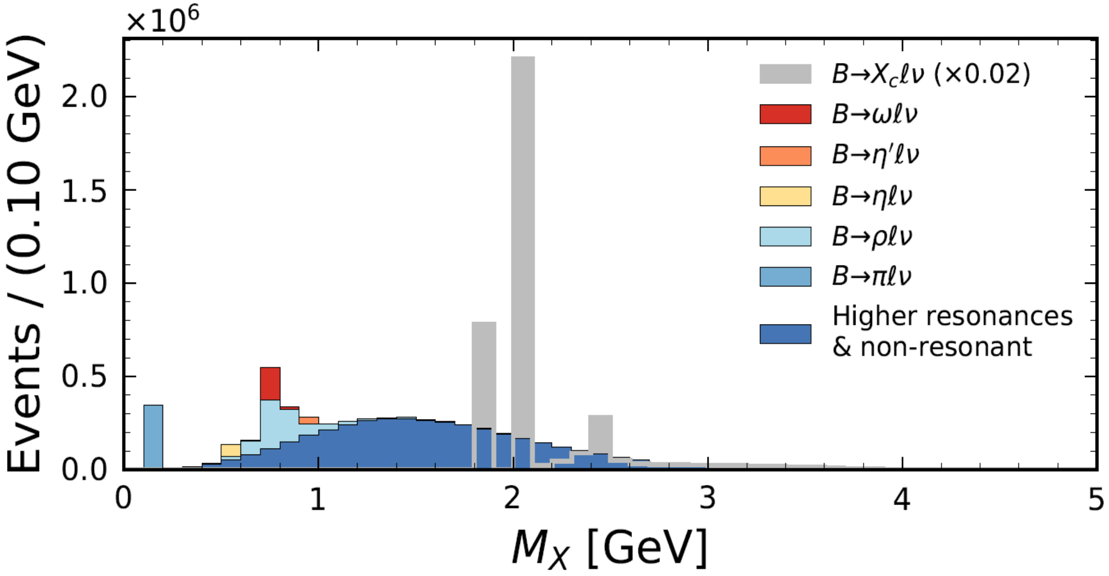
INCLUSIVE MEASURMENTS include

- theoretical prediction for non-perturbative shape functions in $B \to X_u \ell^+ \nu_\ell$
- in the low invariant mass region sum of the exclusive decays (B ‣ π,η,η‘,ω,ρ) – modeled by using LQCD and LCSR form factors
- huge background from $B \to X_c \ell^+ \nu_\ell$ if meaurement is extended to the B to Xc dominated phase space (like Belle2021)

$$|V_{ub}| = \sqrt{\frac{\Delta\mathcal{B}^{\text{exp}}(B \to X_u \ell^+ \nu_l)}{\tau_B\, \Delta\Gamma^{\text{th}}(B \to X_u \ell^+ \nu_l)}}$$

average of 4 different theoretical predictions

$\mathcal{B}$	Value B^+	Value B^0
$B \to X_u \ell^+ \nu_\ell$		
$B \to \pi \ell^+ \nu_\ell$	$(7.8 \pm 0.3) \times 10^{-5}$	$(1.5 \pm 0.06) \times 10^{-4}$
$B \to \eta \ell^+ \nu_\ell$	$(3.9 \pm 0.5) \times 10^{-5}$	-
$B \to \eta' \ell^+ \nu_\ell$	$(2.3 \pm 0.8) \times 10^{-5}$	-
$B \to \omega \ell^+ \nu_\ell$	$(1.2 \pm 0.1) \times 10^{-4}$	-
$B \to \rho \ell^+ \nu_\ell$	$(1.6 \pm 0.1) \times 10^{-4}$	$(2.9 \pm 0.2) \times 10^{-4}$
$B \to X_u \ell^+ \nu_\ell$	$(2.2 \pm 0.3) \times 10^{-3}$	$(2.0 \pm 0.3) \times 10^{-3}$



EXCLUSIVE MEASUREMENTS include

- $|V_{ub}|^2\,|f_+(q^2)|^2$
- theoretical predictions of B to π from factors – modeled by using LQCD and LCSR
- correlations among form factors
- complementary theoretical input: Lattice QCD ➡ FFs in the high q^2 region, LCSR ➡ FFs in the low q^2 regions

however, Vub extraction is the most precise in the mid q^2 region:

$$|V_{ub}| = \sqrt{\frac{\Delta\mathcal{B}^{\exp}(B\to\pi\ell\nu_l)}{\tau_B\,\Delta\xi^{\rm th}}}$$

$$\Delta\xi^{\rm th} = \int d\Gamma(B\to\pi l\nu_l)/|V_{ub}|^2$$

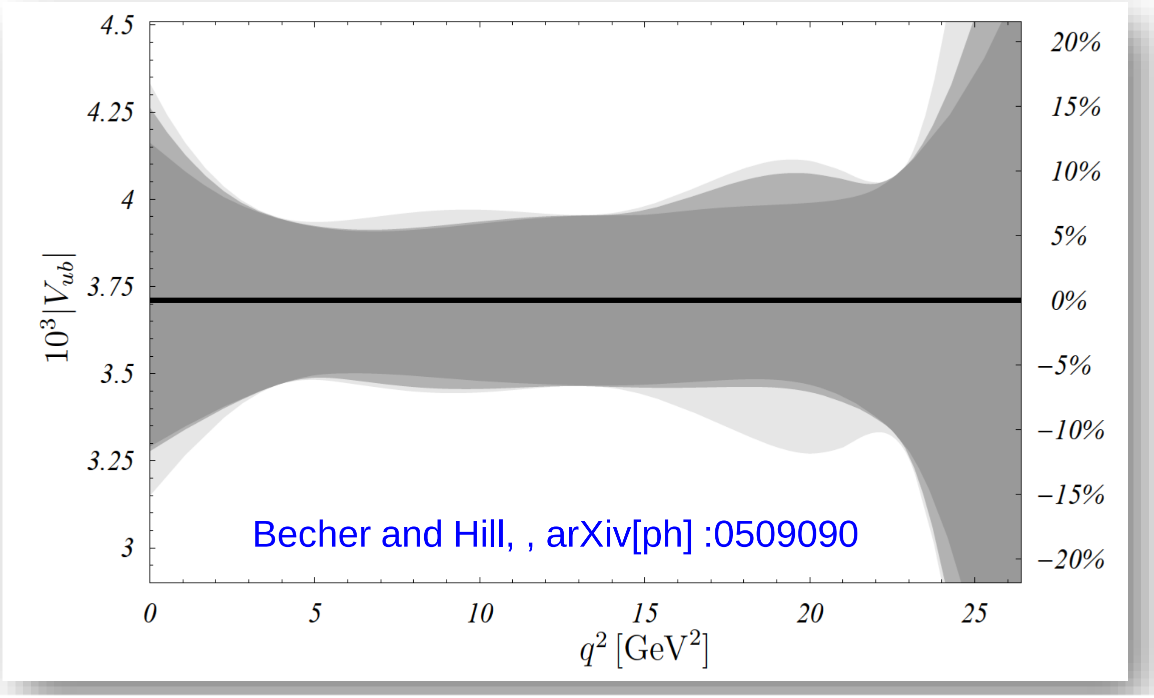


Figure 3: $\Delta\chi^2 = 1$ region for $|V_{ub}|$ for an infinitely precise form factor determination at a single q^2-value. The plot assumes that the form factor yields the central value $|V_{ub}| = 3.7\times10^{-3}$.

To significantly reduce error of Vub one would need to reduce FF errors at q^2 =0 to be less than 10%, while reduction if the error ar q^2_{max} has almost no impact ➡ **IMPORTANCE OF THE LCSR CALCULATIONS !**

FORM FACTORS FROM LIGHT-CONE SUM RULES (LCSR)

$$\frac{\mathrm{d}\Gamma}{\mathrm{d}q^2}\left(\bar{B}\to\pi\ell^-\bar{\nu}_\ell\right)=\frac{G_F^2|V_{ub}|^2}{24\pi^3 m_B^2 q^4}\left(q^2-m_\ell^2\right)^2|\vec{p}_\pi|\times$$

$$\left[\left(1+\frac{m_\ell^2}{2q^2}\right)m_B^2|\vec{p}_\pi|^2\left|f_+(q^2)\right|^2+\frac{3m_\ell^2}{8q^2}\left(m_B^2-m_\pi^2\right)^2\left|f_0(q^2)\right|^2\right]$$

$$\langle\pi(p_\pi)|\bar{u}\gamma^\mu b|B(p_B)\rangle=f_+(q^2)\left[(p_B+p_\pi)^\mu-\frac{m_B^2-m_\pi^2}{q^2}q^\mu\right]+f_0(q^2)\,\frac{m_B^2-m_\pi^2}{q^2}q^\mu\,,$$

$$\langle\pi(p_\pi)|\bar{u}\sigma_{\mu\nu}q^\nu b|B(p_B)\rangle=\frac{i\,f_T(q^2)}{m_B+m_\pi}\left[q^2(p_B+p_\pi)_\mu-\left(m_B^2-m_\pi^2\right)q_\mu\right]$$

$$F_\mu = i\int d^4x e^{iqx}\langle\pi(p)|T\{\bar{u}\gamma_\mu b(x), m_b\bar{b}i\gamma_5 d(0)\}|0\rangle$$

- $(p+q)^2 > 0 \rightarrow$ sum over hadronic states
- $(p+q)^2 < 0 \rightarrow$ light-cone OPE (expansion in terms light-cone pion DISTRIBUTION AMPLITUDES of increasing twist n

$$\phi_\pi^{(2)}(u,\mu) = 6u(1-u)\left\{1+\sum_{n=0}^{\infty} a_n^\pi(\mu) C_n^{3/2}(2u-1)\right\} \overset{\mu\to\infty}{=} 6u(1-u)$$

$$\frac{2m_B^2 f_B f_{B\pi}^+(q^2)}{m_B^2-(p+q)^2} + \text{higher states} = \frac{1}{\pi}\int_{m_b}^{\infty}\frac{ds}{s-(p+q)^2}\mathrm{Im}_s F(q^2,s)$$

$$= \frac{1}{\pi}\int_{m_b \to s_0^B}^{\infty}\frac{ds}{s-(p+q)^2}\sum_{n=twist}\int_0^1 du\,\mathrm{Im}_s T_H^{(n)}(u,q^2,s)\,\Phi_\pi^{(n)}(u)$$

$$\frac{ds}{s-(p+q)^2} \sim \frac{ds}{M^2}e^{-s/M^2}$$

- quark-hadron duality assumption:

$$\text{higher states} = \frac{1}{\pi}\int_{s_0^B}^{\infty}\frac{ds}{s-(p+q)^2}\sum_n\int_0^1 du\,\mathrm{Im}_s T_H^{(n)}(u,q^2,s)\Phi_\pi^{(n)}(u)$$

s_0^B = (duality) threshold parameter

- enhancement of the ground state and suppression of higher states: *Borel transform*

$$\frac{1}{(s-(p+q)^2)^n} \overset{s=(p+q)^2}{\Rightarrow} \frac{1}{\Gamma(n)}\frac{1}{(M^2)^n}e^{-s/M^2}$$

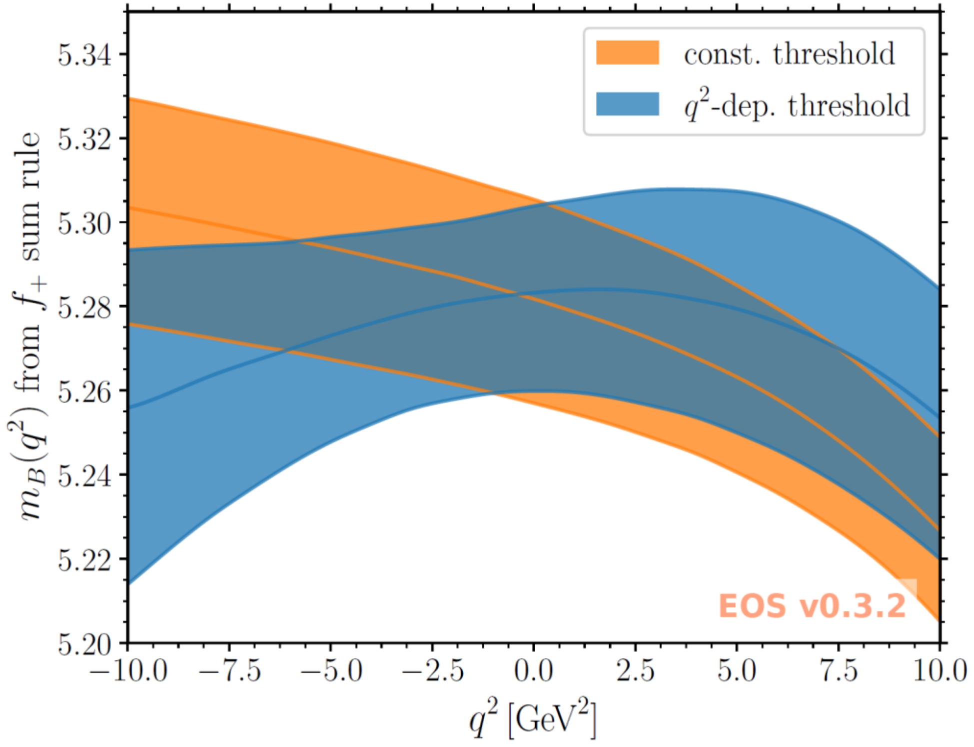
M^2 = Borel parameter

Important LCSR parameters:

$$[m_B^2(q^2;F)]_{\rm LCSR} = \frac{\int_0^{s_0} ds\, s\, {\rm Im}T_H^F(s,q^2)\, e^{-s/M^2}}{\int_0^{s_0} ds\, {\rm Im}T_H^F(s,q^2)\, e^{-s/M^2}}$$

$$s_0^F \quad \to \quad s_0^F(q^2) \equiv s_0^F + q^2\, s_0'^F$$

continuum threshold for each FF !



Borel parameter dependence is weak:

$$12\,{\rm GeV}^2 \le M^2 \le 20\,{\rm GeV}^2$$

PION DISTRIBUTION AMPLITUDE: $a_{2\pi}(1{\rm GeV}) = 0.157 \pm 0.027$ $\quad a_{4\pi}(1{\rm GeV}) = 0.06 \pm 0.10$

lattice - RQCD, arXiv: 1903.08038 LCSR - fit, arXiv: 1103.2655

RESULTS:

$f_0(0) = f_+(0)$

q^2	$-10\,{\rm GeV}^2$	$-5\,{\rm GeV}^2$	$0\,{\rm GeV}^2$	$+5\,{\rm GeV}^2$	$+10\,{\rm GeV}^2$
$f_+(q^2)$	0.170 ± 0.022	0.224 ± 0.022	0.297 ± 0.030	0.404 ± 0.044	0.574 ± 0.062
$f_0(q^2)$	0.211 ± 0.029	0.251 ± 0.024	—	0.356 ± 0.040	0.441 ± 0.052
$f_T(q^2)$	0.170 ± 0.021	0.222 ± 0.020	0.293 ± 0.028	0.396 ± 0.039	0.560 ± 0.053

EXTRAPOLATION TO HIGH Q^2

validity of LCSR $\quad q^2 < m_b^2 - 2m_b\bar{\Lambda} \sim 15\,\mathrm{GeV}^2$

BCL PARAMETRIZATION – SL phase space $0 \le q^2 \le t_- \equiv (m_B - m_\pi)^2$ is mapped onto the real z-axes:

$$z(q^2; t_+, t_0) = \frac{\sqrt{t_+ - q^2} - \sqrt{t_+ - t_0}}{\sqrt{t_+ - q^2} + \sqrt{t_+ - t_0}}$$

$$t_+ \equiv (m_B + m_\pi)^2$$

$$t_0 = t_{0,\mathrm{opt}} = (m_B + m_\pi)(\sqrt{m_B} - \sqrt{m_\pi})^2$$

Bourrely,Caprini,Lellouch,arXiv:0807.2722

$$f_+(q^2) = \frac{f_+(q^2=0)}{1 - q^2/m_{B^*}^2}\left[1 + \sum_{n=1}^{K-1} b_n^+ \left(\bar{z}_n - (-1)^{n-K}\frac{n}{K}\bar{z}_K\right)\right],$$

$$f_0(q^2) = f_+(q^2=0)\left[1 + \sum_{n=1}^{K-1} b_n^0 \bar{z}_n\right],$$

$$f_T(q^2) = \frac{f_T(q^2=0)}{1 - q^2/m_{B^*}^2}\left[1 + \sum_{n=1}^{K-1} b_n^T \left(\bar{z}_n - (-1)^{n-K}\frac{n}{K}\bar{z}_K\right)\right],$$

subthreshold pole

$$\bar{z}_n \equiv z^n - z_0^n,\ \ z_0 = z(0; t_+, t_0)$$

LCSR FIT AND RESULTS

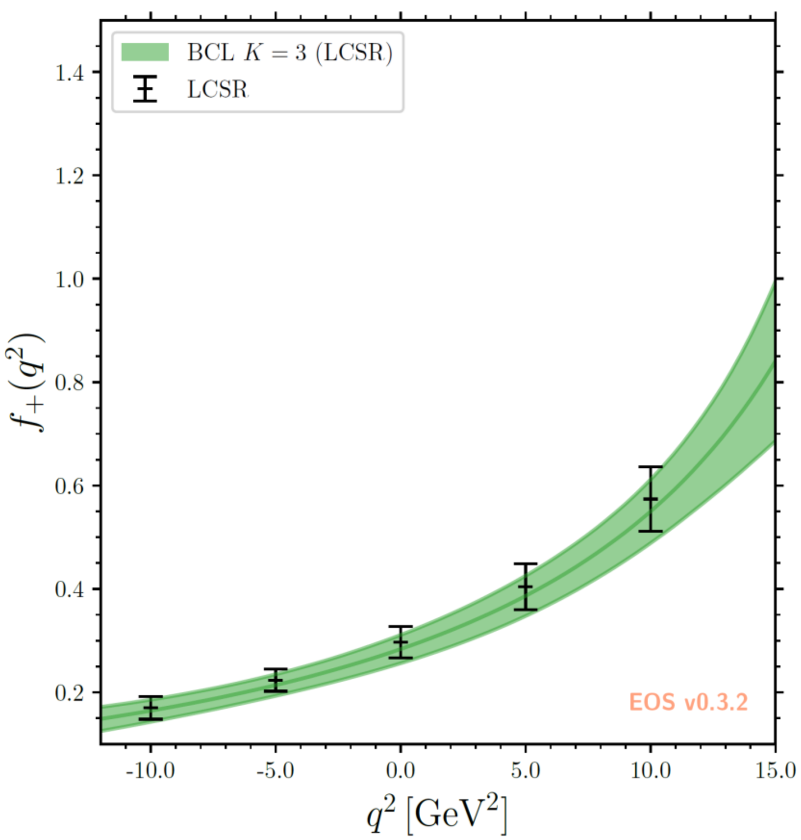
$$\chi^2_{\text{LCSR}} = \sum_{a,b=\{+,0,T\},i,j} \delta f_a^{\text{LCSR}}(q_i^2, \vec{b}_a) \left(C^{\text{LCSR}}\right)^{-1}_{abij} \delta f_b^{\text{LCSR}}(q_j^2, \vec{b}_b)$$

$$\delta f_a^{\text{LCSR}}(q_i^2, \vec{b}_a) = f_a^{\text{LCSR}}(q_i^2) - f_a(q_i^2, \vec{b}_a)$$

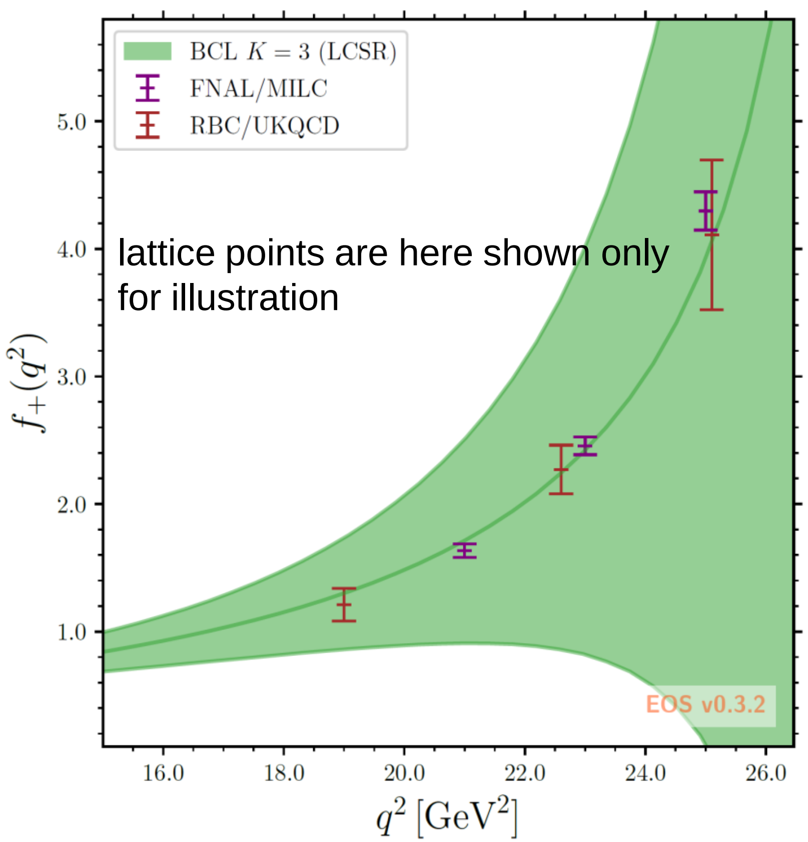
all form factors are fitted simultanously, with correlations among them included !

BCL parameters ($K = 3$)	
$f_+(0)$	$0.283^{+0.027}_{-0.027}$
b_1^+	$-1.0^{+4.3}_{-4.5}$
b_2^+	$-2.9^{+6.2}_{-5.8}$
b_1^0	$-6.8^{+6.3}_{-6.9}$
b_2^0	4^{+12}_{-12}
$f_T(0)$	$0.282^{+0.026}_{-0.026}$
b_1^T	$-0.7^{+4.3}_{-4.6}$
b_2^T	$-3.0^{+6.3}_{-5.9}$

low q^2 fit:



high q^2 fit:



INTERPOLATION BETWEEN LCSR AND LATTICE QCD RESULTS

LCSR: $q^2 < m_b^2 - 2m_b\bar{\Lambda} \sim 15\,\mathrm{GeV}^2$

LATTICE QCD: $19\,\mathrm{GeV}^2 \lesssim q^2 \lesssim 25\,\mathrm{GeV}^2$

FNAL/MILC coll: Nf = 2 + 1 gauge ensambles and staggered-quark action (staggering gets rid of some of degenerate fermions (doublers) in the fermion action by redistributing the fermionic degrees of freedom across different lattice sites)
RBC/UKQCD coll: Nf = 2 + 1 gauge ensambles and domain-wall fermions (by introducing an extra dimension the chirality of quarks is separted and controlle)
HPQCD – not considered (share the same ensambles with FNAL/MILC; no correlations between form factors)

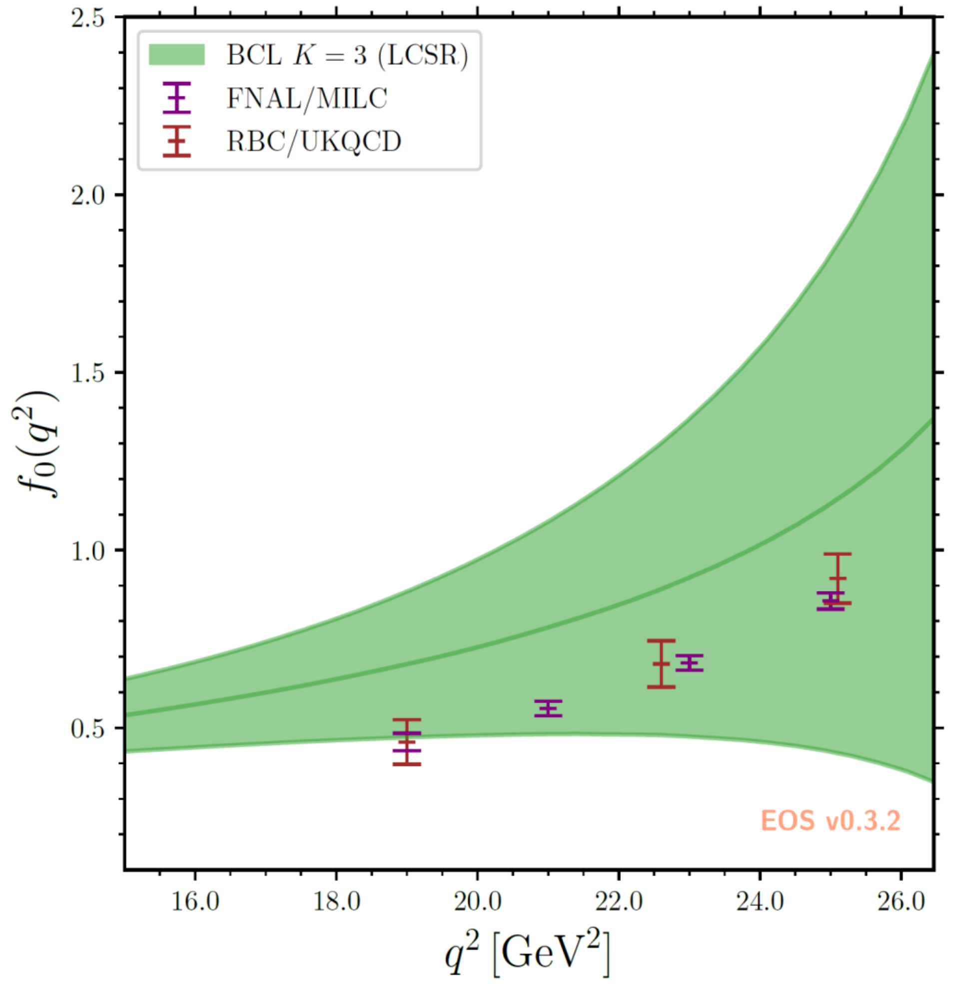
$$\chi^2_{\mathrm{theory}} = \chi^2_{\mathrm{LCSR}} + \chi^2_{\mathrm{LQCD}}$$

$$\chi^2_{\mathrm{LX}} = \sum_{a,b=\{+,0,T\},i,j} \delta f_a^{\mathrm{LX}}(q_i^2,\vec{b}_a)\,\left(C^{\mathrm{LX}}\right)^{-1}_{abij}\,\delta f_b^{\mathrm{LX}}(q_j^2,\vec{b}_b)$$

covariance matrix accounts for correlations between different FFs and different q^2 points

$$\delta f_a^{\mathrm{LX}}(q_i^2,\vec{b}_a) = f_a^{\mathrm{LX}}(q_i^2) - f_a(q_i^2,\vec{b}_a)$$

Problems with $f_0(q^2)$ at high q^2 –
incompatibilty with the lattice – very bad fit:



modification of the BCL parametrization
– introduction of the scalar pole above Bπ production threshold

$$f_0(q^2) = \frac{f_+(z_0)}{1 - q(z)^2/m_{B_0}^2}\left[1 + \sum_{n=1}^{K} b_n^0 \bar{z}_n\right]$$

models: $m_{B_0} \in [5.526, 5.756]\,\mathrm{GeV}$

scalar pole - modifies the shape parameters and allows for more flexibility of the fit:

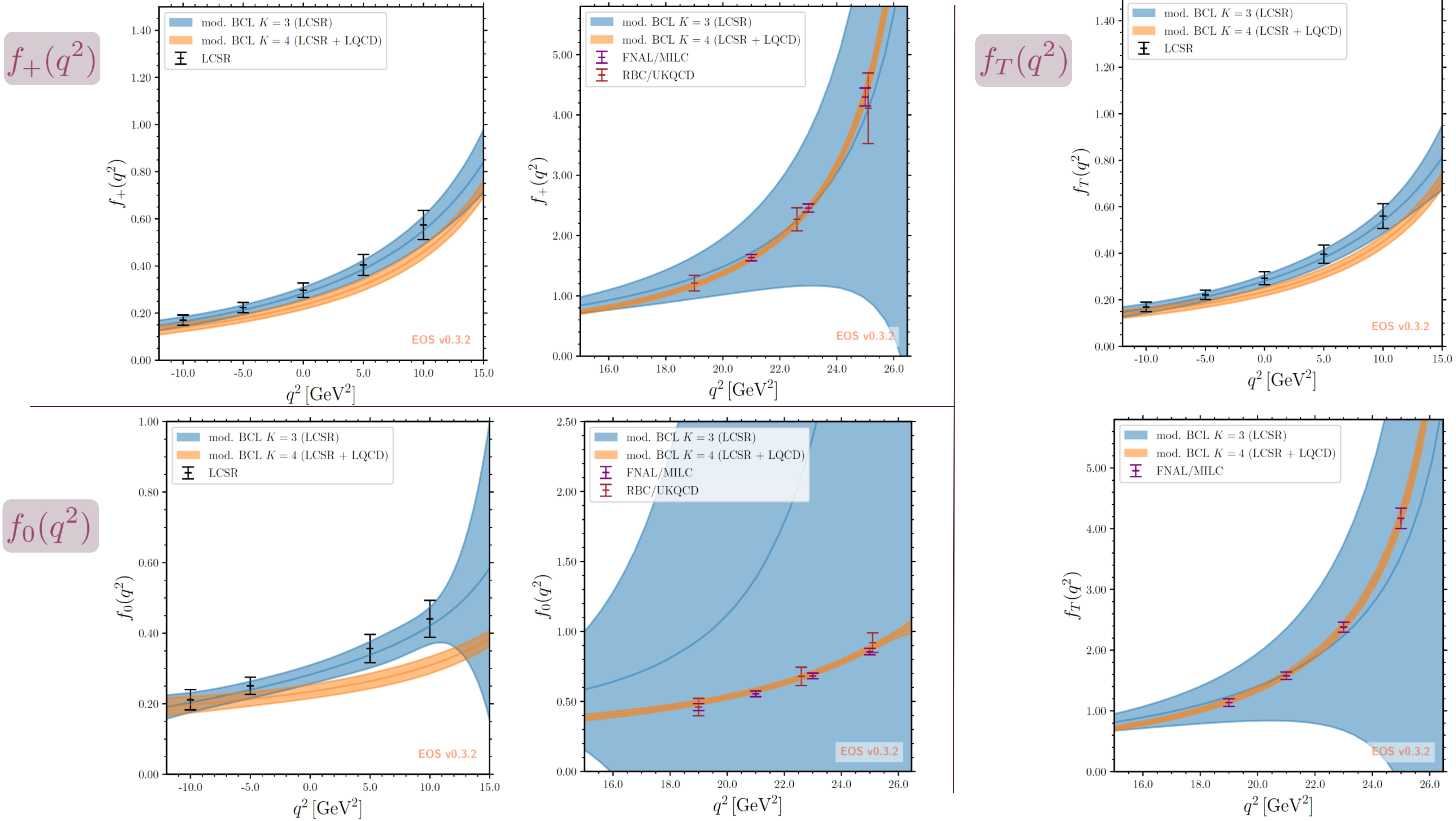
$$\frac{1}{1 - q(z)^2/m_{B_0}^2} \approx \frac{1}{1 - \frac{t_0}{m_{B_0}^2}} + 4\frac{m_{B_0}^2(t_0 - t_+)}{(m_{B_0}^2 - t_0)^2} z + \mathcal{O}\left(z^2\right)$$

input

form factor	# of points	q^2 values (in GeV^2)	type	source
f_+	5	$-10.0, -5.0, 0.0, 5.0, 10.0$	LCSR	this work
	3	21.0, 23.0, 25.0	LQCD	FNAL/MILC [33]
	3	19.0, 22.6, 25.1	LQCD	RBC/UKQCD [35]
f_0	4	$-10.0, -5.0, 5.0, 10.0$	LCSR	this work
	4	19.0, 21.0, 23.0, 25.0	LQCD	FNAL/MILC [33]
	3	19.0, 22.6, 25.1	LQCD	RBC/UKQCD [35]
f_T	5	$-10.0, -5.0, 0.0, 5.0, 10.0$	LCSR	this work
	4	19.0, 21.0, 23.0, 25.0	LQCD	FNAL/MILC [34]

RESULTS

param. \ scenario	LCSR+LQCD		LCSR
	$K=3$	$K=4$	$K=3$
$f_+(0)$	$0.237^{+0.017}_{-0.017}$	$0.235^{+0.019}_{-0.019}$	$0.283^{+0.027}_{-0.027}$
b_1^+	$-2.38^{+0.33}_{-0.38}$	$-2.45^{+0.49}_{-0.54}$	$-1.0^{+3.5}_{-3.6}$
b_2^+	$-0.82^{+0.76}_{-0.81}$	$-0.2^{+1.1}_{-1.2}$	$-2.8^{+4.9}_{-4.7}$
b_3^+	—	$-0.9^{+4.2}_{-4.0}$	—
b_1^0	$0.48^{+0.07}_{-0.07}$	$0.40^{+0.18}_{-0.20}$	-5^{+52}_{-51}
b_2^0	$0.14^{+0.39}_{-0.44}$	$0.1^{+1.1}_{-1.2}$	22^{+200}_{-200}
b_3^0	$2.79^{+0.71}_{-0.77}$	$3.7^{+1.6}_{-1.6}$	-32^{+240}_{-240}
b_4^0	—	1^{+14}_{-13}	—
$f_T(0)$	$0.240^{+0.016}_{-0.016}$	$0.235^{+0.017}_{-0.017}$	$0.281^{+0.025}_{-0.025}$
b_1^T	$-2.05^{+0.32}_{-0.36}$	$-2.45^{+0.45}_{-0.50}$	$-0.6^{+4.2}_{-4.4}$
b_2^T	$-1.45^{+0.63}_{-0.66}$	$-1.08^{+0.68}_{-0.71}$	$-3.2^{+5.9}_{-5.8}$
b_3^T	—	$2.6^{+2.1}_{-2.0}$	—
p value	$\sim 52\%$	$\sim 54\%$	$\sim 100\%$
χ^2/d.o.f	$\sim 21.01/22$	$\sim 17.75/19$	$\sim 0.0278/5$

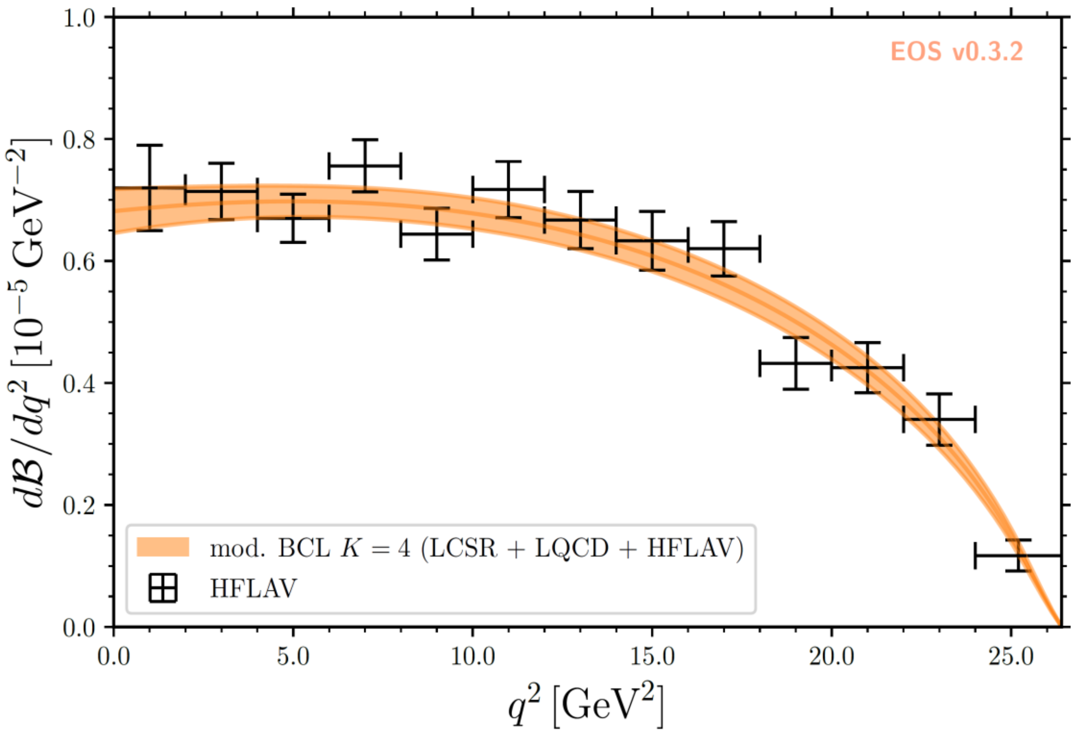


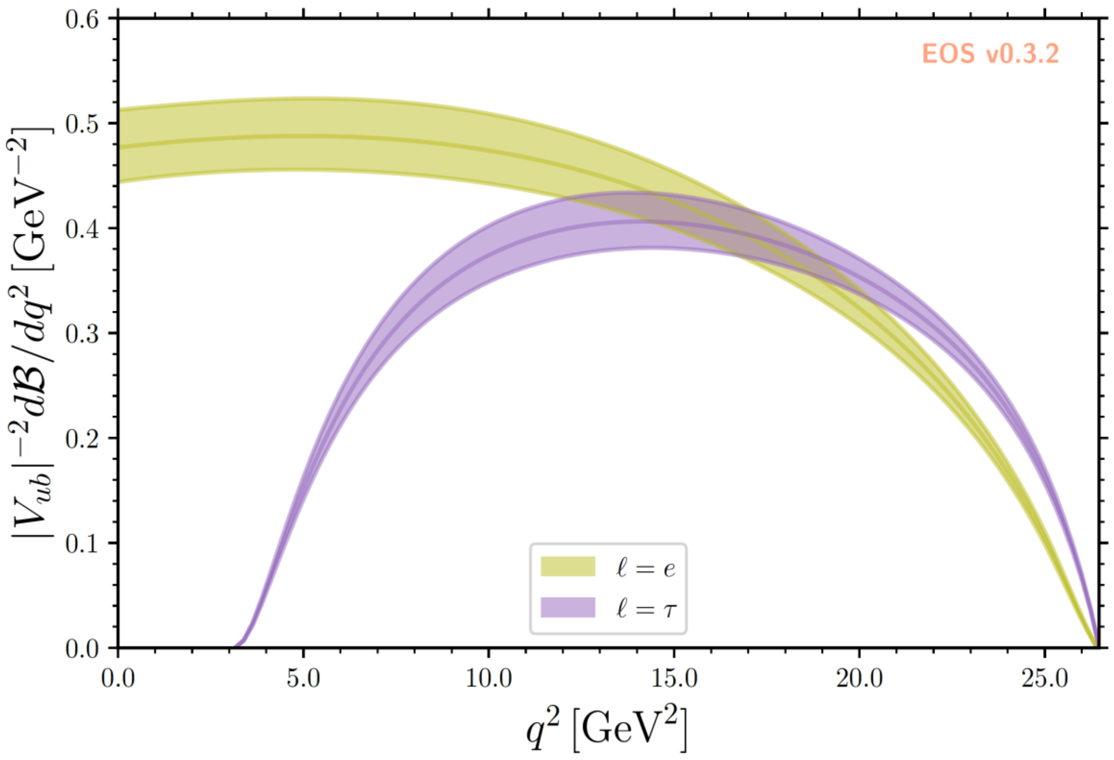
$f_+(q^2)$
mod. BCL $K = 3$ (LCSR)
mod. BCL $K = 4$ (LCSR + LQCD)
LCSR
FNAL/MILC
RBC/UKQCD
EOS v0.3.2
$f_T(q^2)$
$f_0(q^2)$
q^2 [GeV^2]

LCSR + LQCD FORM FACTORS RESULTS vs OTHERS

Source	$f_+(0) = f_0(0)$	$f_T(0)$
Lattice QCD		
Fermilab/MILC [33, 34]	0.2 ± 0.2	0.2 ± 0.2
RBC/UKQCD [35]	0.24 ± 0.08	—
combination w/ Pade approx. [51]	$0.265 \pm 0.010 \pm 0.002$	—
Light-cone sum rules		
Duplancic et al. [16]	$0.26^{+0.04}_{-0.03}$	0.255 ± 0.035
Imsong et al. [21]	0.31 ± 0.02	—
Bharucha [17]	$0.261^{+0.020}_{-0.023}$	—
Khodjamirian/Rusov [30]	0.301 ± 0.023	0.273 ± 0.021
Gubernari et al. (B LCDA) [22]	0.21 ± 0.07	0.19 ± 0.06
this work	0.283 ± 0.027	0.282 ± 0.026
Light-cone sum rules + Lattice QCD combination		
this work	0.235 ± 0.019	0.235 ± 0.017

BRANCHING RATIOS





Our predictions:

$$\mathcal{B}(\bar{B} \to \pi \mu^- \bar{\nu}_\mu) = \left(9.6^{+1.0}_{-1.0}\right) \times |V_{ub}|^2$$

$$\mathcal{B}(\bar{B} \to \pi \tau^- \bar{\nu}_\tau) = \left(6.7^{+0.6}_{-0.5}\right) \times |V_{ub}|^2$$

PRECISE PREDICTIONS FOR THE SM OBSERVABLES:

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$$R_\pi = \frac{\Gamma(\bar{B} \to \pi\tau^-\bar{\nu}_\tau)}{\Gamma(\bar{B} \to \pi\ell^-\bar{\nu}_\ell)} = \frac{\int_{m_\tau^2}^{q^2_{\max}} d\Gamma(\bar{B} \to \pi\tau^-\bar{\nu}_\tau)/dq^2}{\int_{m_\ell^2}^{q^2_{\max}} d\Gamma(\bar{B} \to \pi\ell^-\bar{\nu}_\ell)/dq^2}, \qquad (\ell = e, \mu).$$

$$R_\pi\Big|_{\mathrm{LCSR+LQCD}} = 0.699^{+0.022}_{-0.020}$$

$$R_\pi\Big|_{\mathrm{Belle}} = 1.05 \pm 0.51\Big|_{\text{upper limit}}$$

Belle , arXiv:1509.06521

$$R_\pi(f_+)\Big|_{\mathrm{LCSR+LQCD}} = 0.476^{+0.014}_{-0.013} \qquad R_\pi(f_0)\Big|_{\mathrm{LCSR+LQCD}} = 0.224^{+0.014}_{-0.013}$$

Th. only	source	RBC/UKQCD (2015)	Bečirević et al. (2020)	this work
	R_π	0.69±0.19	0.78±0.10	0.699±0.022
Th. + Exp.	source	Bernlochner (2015)	Bečirević et al. (2020)	this work
	R_π	0.641±0.016	0.66±0.02	0.688±0.014

Th + Exp prefers somewhat lower values

FORWARD-BACKWARD ASYMMETRY

$$A_{\mathrm{FB}}^{\ell} = \frac{1}{\Gamma(\bar{B} \to \pi \ell^- \bar{\nu}_\ell)} \int_{m_\ell^2}^{q^2_{\mathrm{max}}} dq^2 \left[\int_{-1}^{0} - \int_{0}^{-1} \right] d\cos\theta_\ell \frac{d\Gamma^2(\bar{B} \to \pi \ell^- \bar{\nu}_\ell)}{dq^2 d\cos\theta_\ell}$$

$$A_{\mathrm{FB}}^{\mu} = -0.0048 \pm 0.0003$$

$$A_{\mathrm{FB}}^{\tau} = -0.259 \pm 0.004$$

FLAT TERM

$$F_H^{\ell} = 1 + \frac{2}{3} \frac{1}{\Gamma(\bar{B} \to \pi \ell^- \bar{\nu}_\ell)} \frac{d^2}{d(\cos\theta)^2} \left[\frac{d\Gamma(\bar{B} \to \pi \ell^- \bar{\nu}_\ell)}{d\cos\theta} \right] = 1 + \frac{2}{3} C_F^{\ell}$$

$$F_H^{\mu} = 0.0024 \pm 0.0001; \qquad F_H^{\tau} = 0.134 \pm 0.003$$

TAU POLARIZATION

$$P^{\tau} = \frac{\Gamma(\bar{B} \to \pi \tau_{\uparrow}^- \bar{\nu}_\tau) - \Gamma(\bar{B} \to \pi \tau_{\downarrow}^- \bar{\nu}_\tau)}{\Gamma(\bar{B} \to \pi \tau^- \bar{\nu}_\tau)}$$

$$P^{\tau} = -0.21 \pm 0.02$$

V_{ub} DETERMINATION FROM EXTRACTED FORM FACTORS

$$\chi^2 = \chi^2_{\bar{B}\to\pi\ell^-\bar{\nu}_\ell} + \chi^2_{\mathrm{LCSR}} + \chi^2_{\mathrm{LQCD}}$$

$$\chi^2_{\bar{B}\to\pi\ell^-\bar{\nu}_\ell} = \sum_{i,j} \delta\mathcal{B}_i (C^{\mathrm{EXP}})^{-1}_{ij} \delta\mathcal{B}_j$$

$$\delta\mathcal{B}_i = \mathcal{B}_i^{\mathrm{exp}} - \frac{\tau_B}{C_v} \int_{\Delta q_i^2} \frac{G_F^2}{24\pi^3} |V_{ub}|^2 \left| f_+(q^2, \vec{b}) \right|^2 |\vec{p}_\pi|^3 \mathrm{d}q^2$$

exp from HFLAV , arXiv:1909.12524

- q^2 binned average of BaBar (2010,2012) and Belle (2010,2013) data

param. \ method	LCSR+LQCD $K=3$	LCSR+LQCD $K=4$	LCSR only $K=3$
$10^{-3} \times \lvert V_{ub}\rvert$	$3.80^{+0.14}_{-0.14}$	$3.77^{+0.15}_{-0.15}$	$3.28^{+0.33}_{-0.28}$
$f_+(0)$	$0.248^{+0.009}_{-0.009}$	$0.246^{+0.009}_{-0.009}$	$0.284^{+0.025}_{-0.025}$
b_1^+	$-2.13^{+0.19}_{-0.19}$	$-2.10^{+0.22}_{-0.21}$	$-1.91^{+0.31}_{-0.30}$
b_2^+	$-0.82^{+0.54}_{-0.55}$	$0.23^{+0.87}_{-0.87}$	$-1.42^{+0.85}_{-0.89}$
b_3^+	—	$-3.0^{+2.8}_{-2.8}$	—
χ^2/d.o.f	$\sim 32.33/34$	$\sim 29.30/31$	$\sim 10.72/17$
p value	$\sim 55\%$	$\sim 55\%$	$\sim 87\%$

$$|V_{ub}|^{\bar{B}\to\pi}_{\mathrm{LCSR+LQCD}} = (3.77 \pm 0.15) \cdot 10^{-3}$$

V_{ub} EXTRACTED FROM LCSR + LQCD FORM FACTORS AND HFLAV DATA

Source	$10^{-3} \times \lvert V_{ub} \rvert$ EXCLUSIVE
LQCD	
Fermilab/MILC [33, 34]	3.72 ± 0.16
RBC/UKQCD [35]	3.61 ± 0.32
combination w/ Pade approx. [51]	$3.53 \pm 0.08_{\text{stat}} \pm 0.06_{\text{syst}}$
HFLAV [8]	$3.70 \pm 0.10_{\text{stat}} \pm 0.12_{\text{syst}}$
LCSR	
Duplancic et al. [16]	$3.5 \pm 0.4 \pm 0.2 \pm 0.1$
Imsong et al. [21]	$3.32^{+0.26}_{-0.22}$
this work	$3.28^{+0.33}_{-0.28}$
LCSR + LQCD	
HFLAV [8]	$3.67 \pm 0.09_{\text{stat}} \pm 0.12_{\text{syst}}$
this work	3.77 ± 0.15

CONCLUSIONS

- we revisit LCSR prediction for the full set of $B \to \pi$ form factors by simultaneously fitting them, including correlations and focus on systematic uncertainties by using Bayesian fit and extrapolation in the full q^2 region

- we carry out combined fit with precise QCD lattice results and provide the most up-to-date theoretical (LCSR + LQCD) form factors in $B \to \pi$ decays

- using HFLAV average of experimental $B \to \pi$ measurements with correlations we perform the fit and extract $|V_{ub}|_{excl}$

- with obtained result we probe lepton-flavour universality, forward-backward asymmetry, flat parameter and polarization of the tau lepton in the SM the extracted **exclusive |Vub|**

$$|V_{ub}|^{\bar{B}\to\pi}_{\mathrm{LCSR+LQCD}} = (3.77 \pm 0.15) \cdot 10^{-3}$$

differs from the most recent Belle result on **inclusive |Vub|** determination

$$|V_{ub}|^{B\to X_u}_{\mathrm{Belle2021}} = (4.10 \pm 0.28) \cdot 10^{-3}$$

by just 1σ !

THANK YOU