$|V_{ub}|$ and the potential impact of new physics in exclusive $b \to u\, l\, \nu$ decays

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- D.Leljak, BM (RBI, Zagreb), D. van Dyk (TUM): The B to π form factors from QCD and their impact on Vub, *JHEP 07 (2021) 036, arXiv 2102.07233*
- D.Leljak, BM (RBI, Zagreb), F. Novak (TUM), M. Reboud, D. van Dyk (Durham): Toward a complete description of $b \to u\, l\, \nu$ decays within the Weak Effective Theory, *JHEP 08 (2023) 063, arXiv 2302.05268*

CKM 2023: 12th International Workshop on the CKM Unitarity Triangle, Sep 18-22, 2023, Santiago de Compostela

V_{ub} FROM B → π STATUS 2021

inclusive:

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

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

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

exclusive:

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

HFLAV , arXiv:1909.12524

exclusive vs inclusive V_{ub} $\approx 2.7\sigma$

! 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

V_{ub} FROM b →u STATUS 2022/23

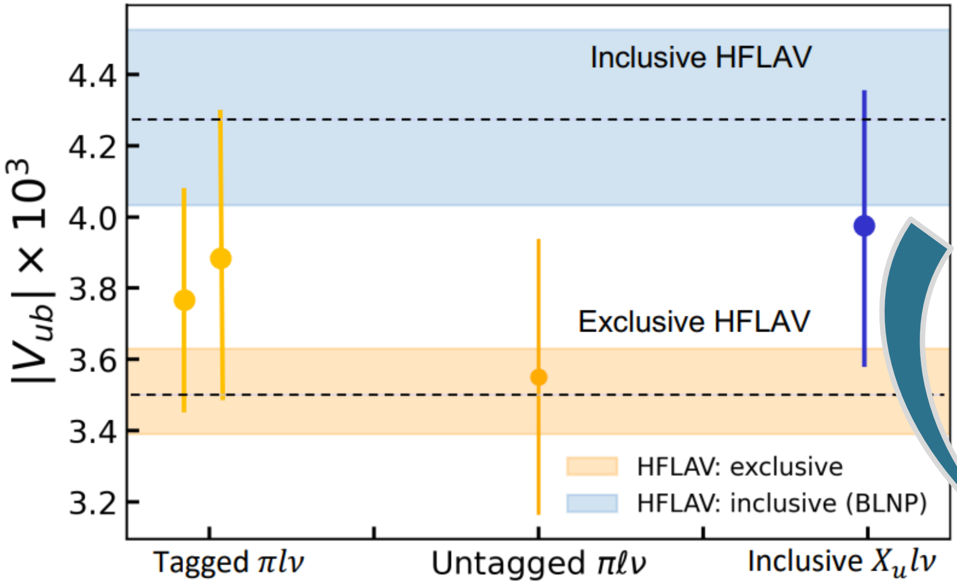
Current world HFLAV averages (2206.07501) :

$$|V_{ub}^{\text{exc}}| = (3.51 \pm 0.12) \cdot 10^{-3}$$

$$|V_{ub}^{\text{inc}}| = (4.19 \pm 0.16) \cdot 10^{-3}$$

$$\frac{|V_{ub}^{\text{exc}}|}{|V_{ub}^{\text{inc}}|} = 0.84 \pm 0.04$$

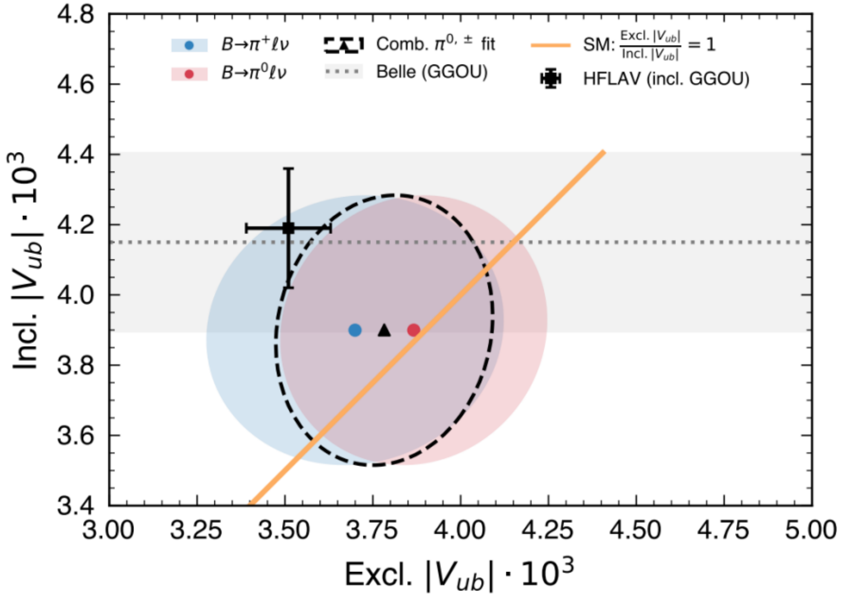
3.7 sigma!



Belle Collaboration, arXiv:2303.17309

"First simultaneous determination of Vub (inc) and Vub (exc)",

$B \to \pi\ell\nu$ only:



$$|V_{ub}^{\text{excl}}|/|V_{ub}^{\text{incl}}| = 0.97 \pm 0.12_{\text{tot}}$$

excellent agreement !

$$|V_{ub}^{\text{excl}}| = (3.78 \pm 0.23_{\text{stat}} \pm 0.16_{\text{syst}} \pm 0.14_{\text{theo}})\times 10^{-3}$$
$$|V_{ub}^{\text{incl}}| = (3.90 \pm 0.20_{\text{stat}} \pm 0.32_{\text{syst}} \pm 0.09_{\text{theo}})\times 10^{-3}$$

IMPORTANT REMARKS ON V_{ub} EXTRACTION:

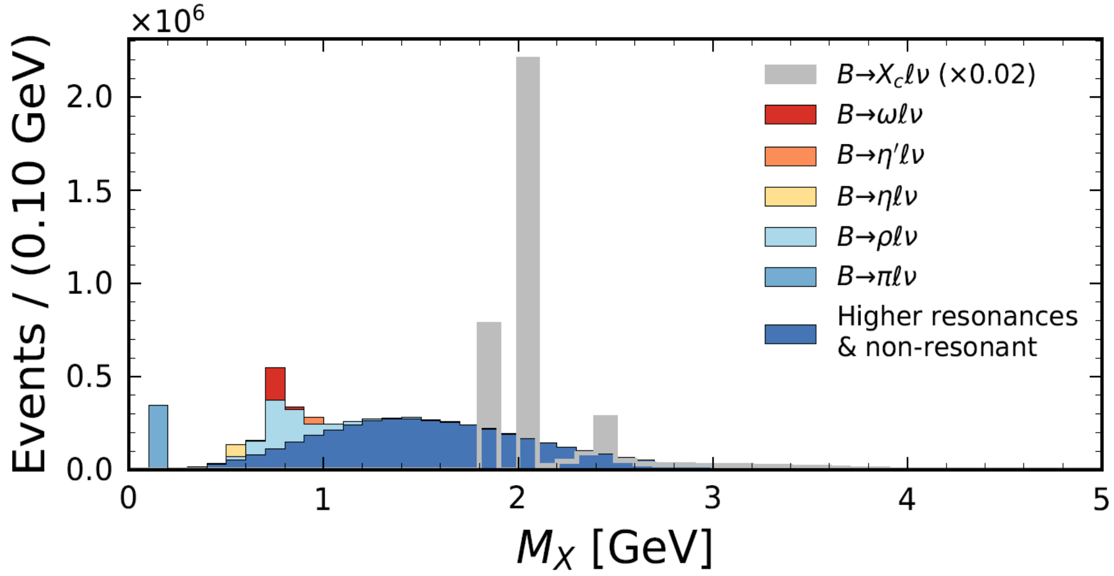
INCLUSIVE MEASURMENTS include :

- theoretical prediction for non-perturbative shape functions (non-local OPE region) of $B \to X_u \ell^+ \nu_\ell$
- 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)

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

average of 4 different theoretical predictions (models: BLNP, GGOU, ADGF, DGE)

$\mathcal{B}$	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:

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

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

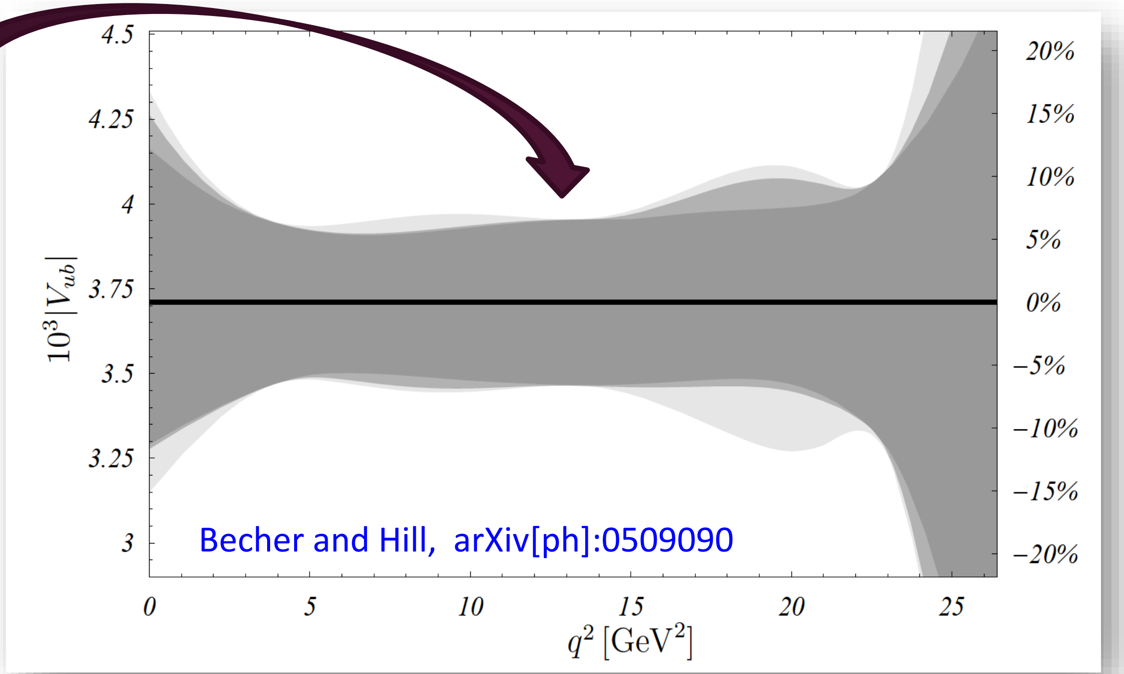


Figure 3: $\Delta\chi^2 = 1$ region for $|V_{ub}|$ for an infinitely precise form factor determination at a single q^2-value. The plot assumes that the form factor yields the central value $|V_{ub}| = 3.7 \times 10^{-3}$.

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

FORM FACTORS FROM LIGHT-CONE SUM RULES (LCSR)

$$\frac{d\Gamma}{dq^2}(\bar{B} \to \pi \ell^- \bar{\nu}_\ell) = \frac{G_F^2 |V_{ub}|^2}{24\pi^3 m_B^2 q^4} \left(q^2 - m_\ell^2\right)^2 |\vec{p}_\pi| \times \left[\left(1 + \frac{m_\ell^2}{2q^2}\right) m_B^2 |\vec{p}_\pi|^2 \left|f_+(q^2)\right|^2 + \frac{3m_\ell^2}{8q^2}\left(m_B^2 - m_\pi^2\right)^2 \left|f_0(q^2)\right|^2\right]$$

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

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

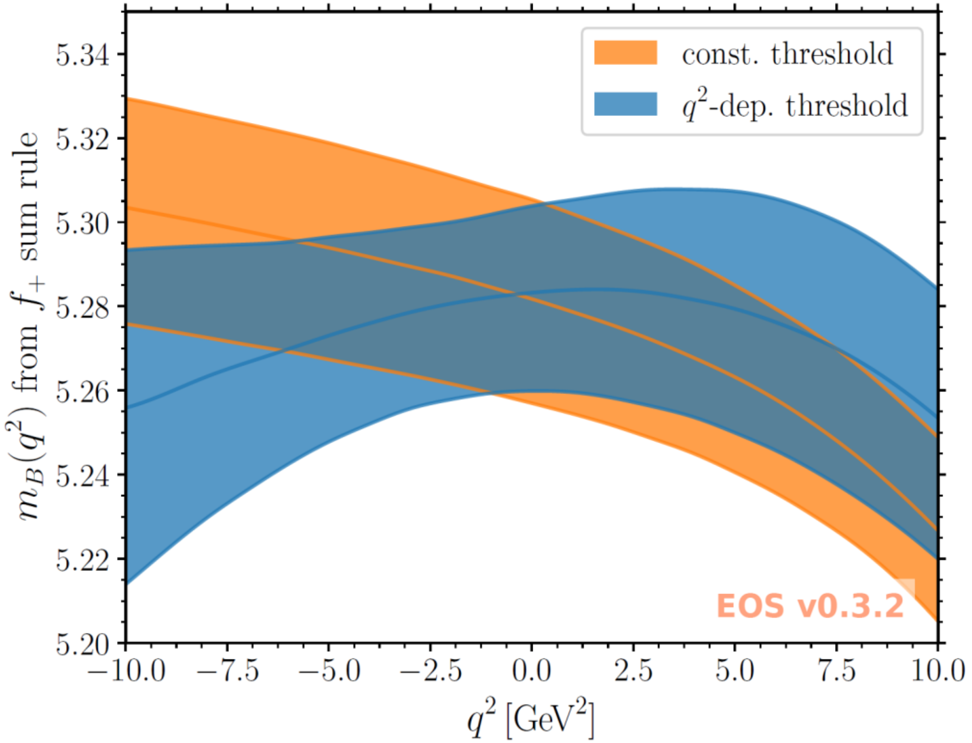
f_T is important in rare $B \to (P, V)\,\ell^+\ell^-$ decays

Important LCSR parameters, s_0^F and M^2 :

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

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

continuum threshold for each FF !



Borel parameter dependence is weak:

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

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 $\quad$ 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:

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

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

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

BCL, 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

Leljak, BM, van Dyk, *2102.07233*

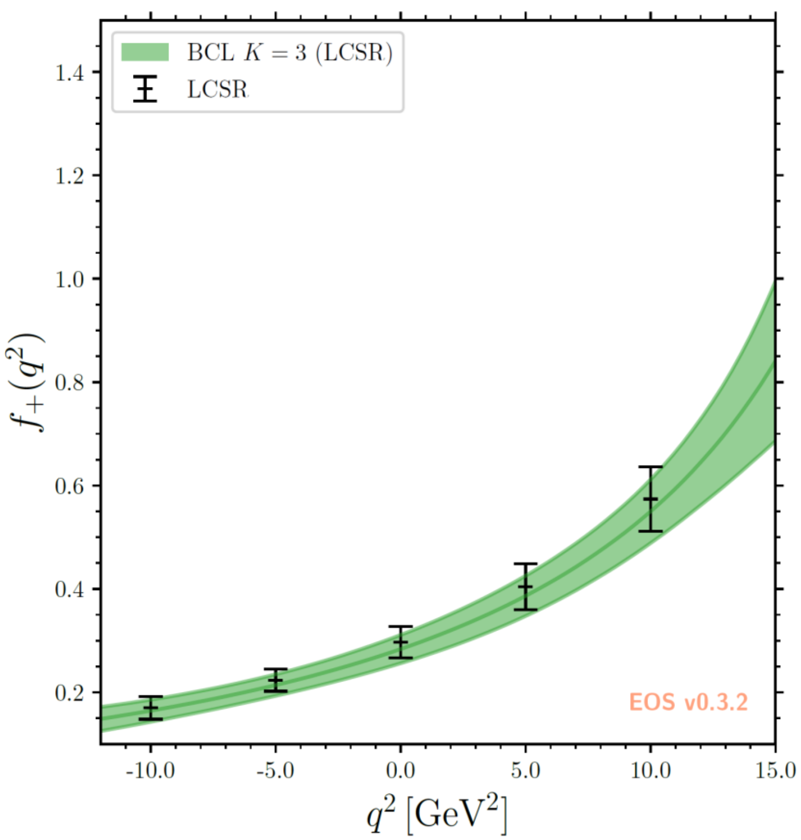
$$\chi^2_{\rm LCSR} = \sum_{a,b=\{+,0,T\},i,j} \delta f_a^{\rm LCSR}(q_i^2,\vec{b}_a) \left(C^{\rm LCSR}\right)^{-1}_{abij} \delta f_b^{\rm LCSR}(q_j^2,\vec{b}_b)$$

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

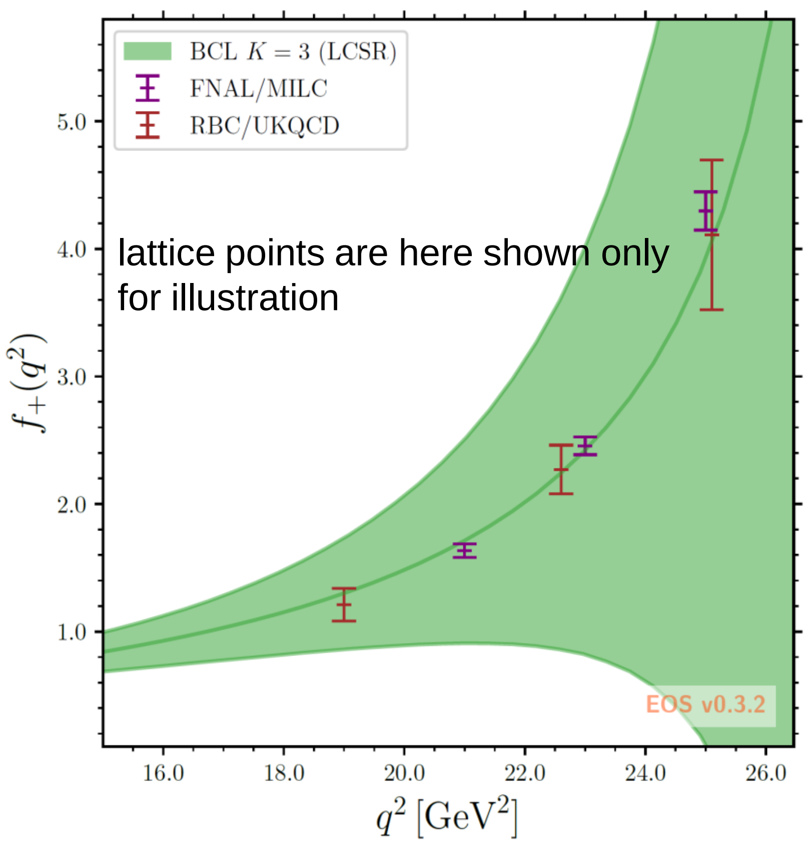
all form factors are fitted simultaneously, with correlations among them included !

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 controlled)
HPQCD – not considered (share the same ensambles with FNAL/MILC; no correlations between form factors)

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

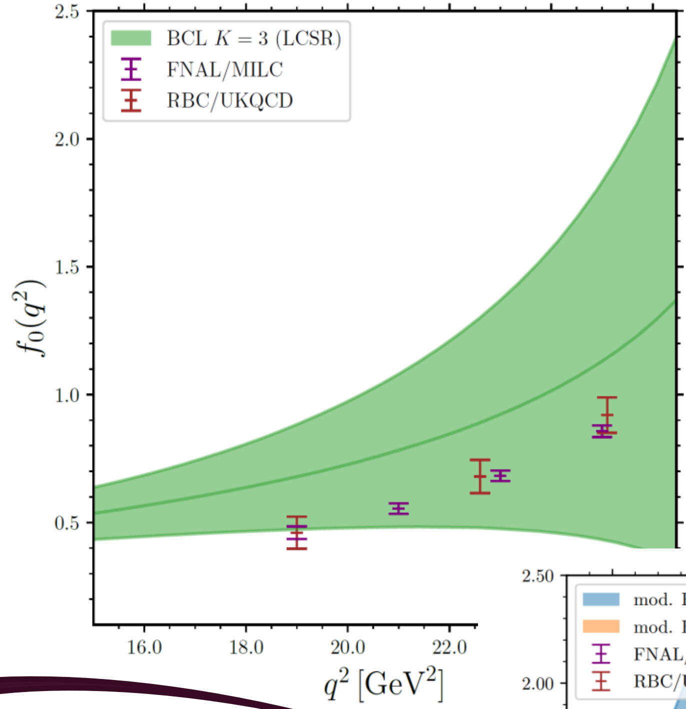
$$\chi^2_{\mathrm{LX}} = \sum_{a,b=\{+,0,T\},i,j} \delta f_a^{\mathrm{LX}}(q_i^2, \vec{b}_a) \left(C^{\mathrm{LX}}\right)^{-1}_{abij} \delta f_b^{\mathrm{LX}}(q_j^2, \vec{b}_b)$$

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:

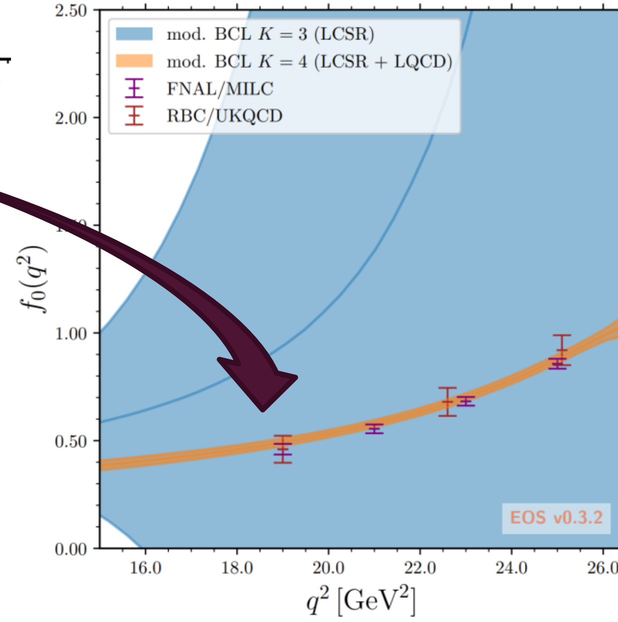


modification of the BCL parametrization for $f_0(q^2)$

– 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:

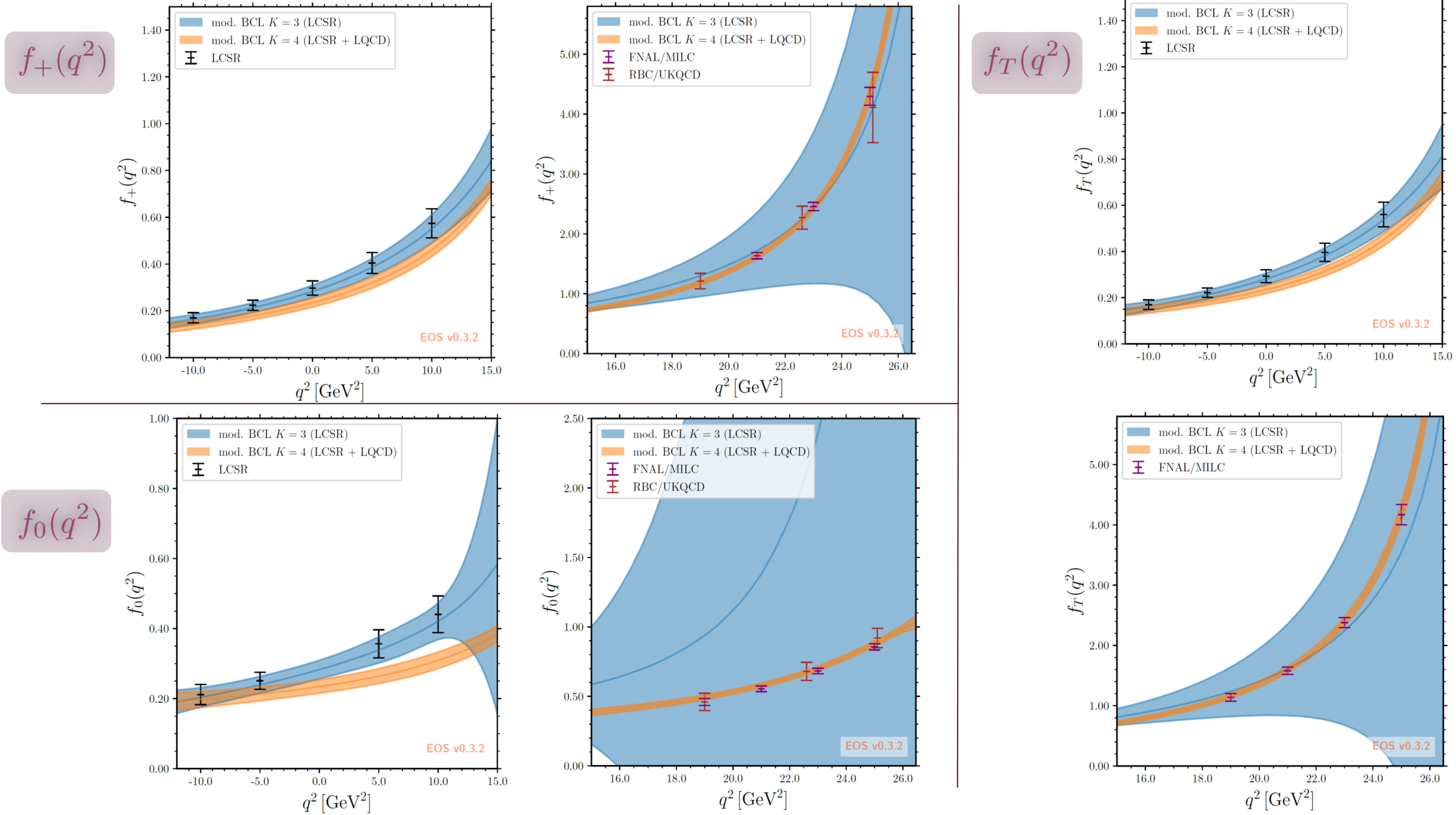
$$\frac{1}{1 - q(z)^2/m_{B_0}^2} \approx \frac{1}{1 - \frac{t_0}{m_{B_0}^2}} + 4\frac{m_{B_0}^2(t_0 - t_+)}{(m_{B_0}^2 - t_0)^2} z + \mathcal{O}\left(z^2\right)$$

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 $K=3$	LCSR+LQCD $K=4$	LCSR $K=3$
$f_+(0)$	$0.237^{+0.017}_{-0.017}$	$0.235^{+0.019}_{-0.019}$	$0.283^{+0.027}_{-0.027}$
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
$f_T(q^2)$
$f_0(q^2)$
q^2 [GeV^2]
EOS v0.3.2

LCSR + LQCD FORM FACTORS RESULTS vs OTHERS

Leljak, BM, van Dyk, *2102.07233*

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

V_{ub} DETERMINATION FROM EXTRACTED FORM FACTORS

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

$$\chi^2_{\bar{B}\to\pi\ell^-\bar{\nu}_\ell} = \sum_{i,j} \delta\mathcal{B}_i (C^{\mathrm{EXP}})^{-1}_{ij} \delta\mathcal{B}_j \qquad \delta\mathcal{B}_i = \mathcal{B}_i^{\mathrm{exp}} - \frac{\tau_B}{C_v}\int_{\Delta q_i^2} \frac{G_F^2}{24\pi^3}|V_{ub}|^2 \left|f_+(q^2,\vec{b})\right|^2 |\vec{p}_\pi|^3 dq^2$$

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	$\sim 55\%$	$\sim 55\%$	$\sim 87\%$

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

Leljak, BM, van Dyk, *2102.07233*

INCLUSION OF $B \to \rho, \omega$ DECAYS AND TEST OF THE SM

Leljak, BM , Novak, Reboud, van Dyk , *2302.05268*

$|V_{ub}|$ from $B \to \rho, \omega$ is constantly below other exclusive (and inclusive) extractions !

We perform the statistical fit of b to u decays in EOS program [EOS Authors collaboration 2111.15428] :

$$B^0 \to \pi^+ \ell^- \bar{\nu}$$

exp: HFLAV average (Babar & Belle)
th: FF from LCSR + lattice, BCL q^2 param of FF [Leljak, BM, van Dyk, 2102.07233]

$$B^- \to \rho \ell^- \bar{\nu}$$
$$B^- \to \omega \ell^- \bar{\nu}$$

exp: average from Bernlochner, Prim, Robinson, 2104.05739 (Babar & Belle)
th: FF from LCSR [Bharucha, Strub, Zwicky (BSZ) 2015], BSZ q^2 param. of FF

(similar analysis in EOS for $B_s \to K \ell \nu$ only, Bolognoni, van Dyk, Vos, 2308.04347)

WET setup

$$\mathcal{H}^{ub\ell\nu} = -\frac{4G_F}{\sqrt{2}}\tilde{V}_{ub}\sum_i C_i^\ell \mathcal{O}_i^\ell + \ldots + \text{h.c.}$$

$$\mathcal{O}_{V,L} = [\bar{u}\gamma^\mu P_L b]\,[\bar{\ell}\gamma_\mu P_L \nu]\,, \quad \mathcal{O}_{V,R} = [\bar{u}\gamma^\mu P_R b]\,[\bar{\ell}\gamma_\mu P_L \nu]\,,$$

$$\mathcal{O}_{S,L} = [\bar{u}P_L b]\,[\bar{\ell}P_L \nu]\,, \quad \mathcal{O}_{S,R} = [\bar{u}P_R b]\,[\bar{\ell}P_L \nu]\,,$$

$$\mathcal{O}_T = [\bar{u}\sigma^{\mu\nu} b]\,[\bar{\ell}\sigma_{\mu\nu}P_L \nu]\,.$$

- **SM - null hypothesis** $\tilde{V}_{ub}\,\mathcal{C}_{V,L}^\ell = 3.67 \times 10^{-3}$ $\quad C_{V,L}^\ell = 1 + O(\alpha_e)$ $\quad \mathcal{C}_i^\ell(i \neq (V,L)) = 0$

- **CKM** $\tilde{V}_{ub}\,\mathcal{C}_{V,L}^\ell \in [3.0, 4.5] \times 10^{-3}$ $\quad \mathcal{C}_i^\ell(i \neq (V,L)) = 0$

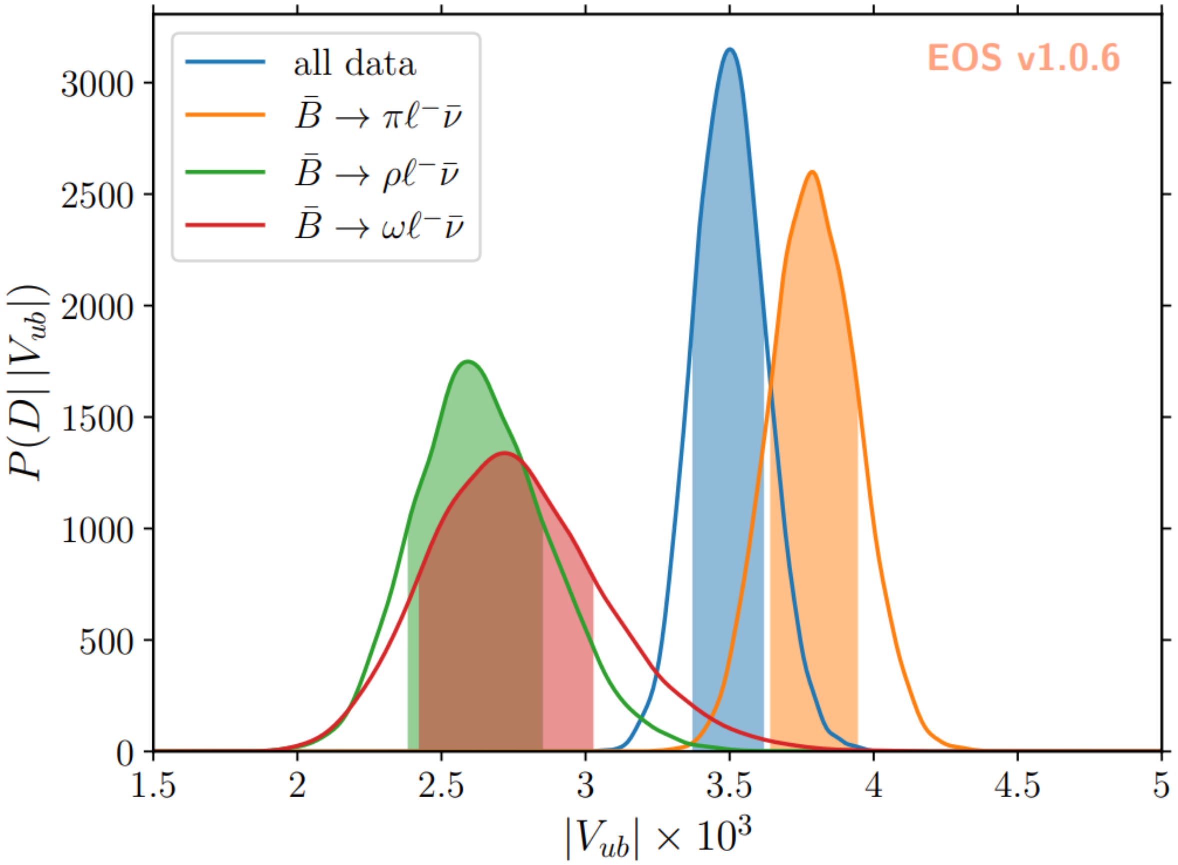
- **WET** $\tilde{V}_{ub} = 3.67 \times 10^{-3}$

$$0 \leq \mathcal{C}_{V,L}^\ell \leq 1\,, \quad 0 \leq \mathcal{C}_{V,R}^\ell \leq 1.1\,,$$

$$0 \leq \mathcal{C}_{S,L}^\ell \leq 0.7\,, \quad -0.7 \leq \mathcal{C}_{S,R}^\ell \leq 0.3\,, \quad -0.25 \leq \mathcal{C}_T^\ell \leq 0.25$$

values are fixed by the upper bound on BR(B →π l ν) < 5 σ of HFLAV avarage

CKM FIT RESULTS:



Goodness of fit

Data set	χ^2	d.o.f.	p value [%]	$\lvert V_{ub}\rvert \times 10^3$
$\bar{B} \to \pi \ell \nu$	27.83	31	62.98	$3.79^{+0.15}_{-0.15}$
$\bar{B} \to \rho \ell \nu$	4.05	10	94.49	$2.92^{+0.28}_{-0.25}$
$\bar{B} \to \omega \ell \nu$	4.20	4	37.90	$3.00^{+0.38}_{-0.32}$
all data	43.75	47	60.78	$3.59^{+0.13}_{-0.12}$

Predictions:

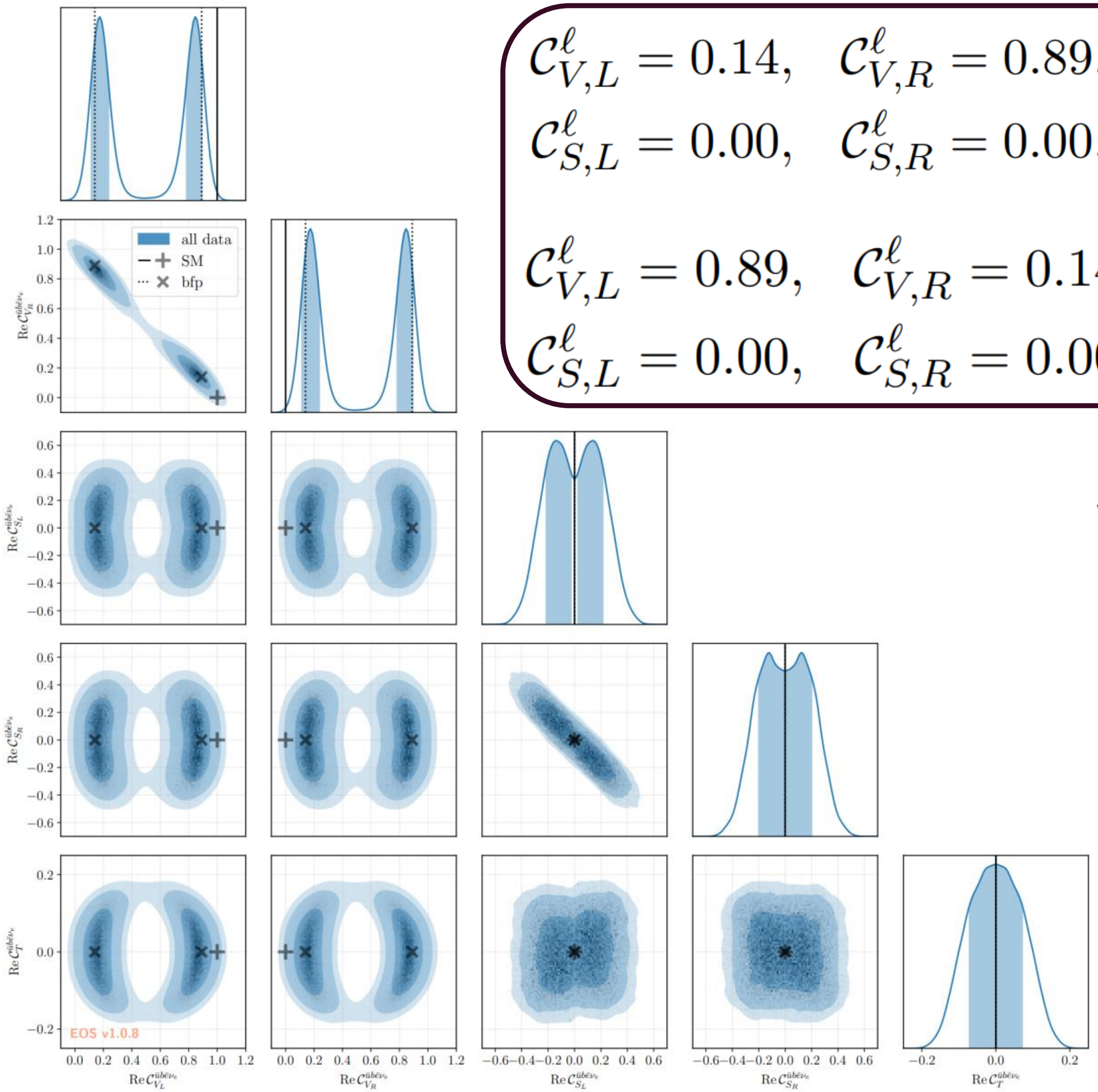
$$\mathcal{B}(\bar{B}^- \to \tau^- \bar{\nu}) = \left(8.28^{+0.61}_{-0.57}\big|_{|V_{ub}|} \pm 0.13\big|_{f_B}\right) \times 10^{-5},$$

$$\mathcal{B}(\bar{B}^- \to \mu^- \bar{\nu}) = \left(3.72^{+0.27}_{-0.25}\big|_{|V_{ub}|} \pm 0.06\big|_{f_B}\right) \times 10^{-7},$$

$$\mathcal{B}(\bar{B}^- \to e^- \bar{\nu}) = \left(8.71^{+0.64}_{-0.60}\big|_{|V_{ub}|} \pm 0.14\big|_{f_B}\right) \times 10^{-12}.$$

$$\mathcal{B}(\bar{B}^- \to \mu^- \bar{\nu})\big|_{\text{Belle '19}} = (5.3 \pm 2.2) \times 10^{-7}$$

WET FIT RESULTS:



$$\mathcal{C}^{\ell}_{V,L} = 0.14, \quad \mathcal{C}^{\ell}_{V,R} = 0.89,$$
$$\mathcal{C}^{\ell}_{S,L} = 0.00, \quad \mathcal{C}^{\ell}_{S,R} = 0.00, \quad \mathcal{C}^{\ell}_{T} = 0.00,$$

$$\mathcal{C}^{\ell}_{V,L} = 0.89, \quad \mathcal{C}^{\ell}_{V,R} = 0.14,$$
$$\mathcal{C}^{\ell}_{S,L} = 0.00, \quad \mathcal{C}^{\ell}_{S,R} = 0.00, \quad \mathcal{C}^{\ell}_{T} = 0.00.$$

WET (only ν_L) describes preferably the data:

$$\frac{P(\text{all data}\,|\,\text{WET})}{P(\text{all data}\,|\,\text{SM})} = 55\,, \qquad \frac{P(\text{all data}\,|\,\text{WET})}{P(\text{all data}\,|\,\text{CKM})} = 60$$

$$Z \equiv P(D\,|\,M) = \int d\vec{x}\, P(D\,|\,\vec{x}, M)\, P_0(\vec{x}\,|\,M)$$

WET - BSM is favoured model!

CONCLUSIONS

- we revisit **LCSR prediction for the full set of B → π 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 → π decays**

- we **add B → ρ, ω** decays and usings average of experimental measurements of **B → (π , ρ, ω) l ν** with correlations we perform fits and **extract |Vub|$_{excl}$**

$$|V_{ub}|^{B\to\pi,\rho,\omega} = (3.59^{+0.13}_{-0.12}) \times 10^{-3}$$

compatible with the global CKMfitter fit:

$$|V_{ub}|^{\text{CKMfitter}} = (3.67^{+0.09}_{-0.07}) \times 10^{-3}$$

- with perform **WET (with only left-handed neutrinos) fit** of all $B \to (\pi, \rho, \omega) l \nu$ data, and conclude that the **BSM is preferred over SM interpretation**
  /more input is needed, in particular from theory side on $\mathbf{B \to (\rho, \omega) l \nu}$ decays/

- we provide Gaussian Mixture Model of marginalized WET Wilson coefficients
  - to provide computationally efficient way of using the WET parameter space without having to re-run a complicated, computationally expensive statistical analysis
  in ancillary material of 2302. 05268 paper/

THANK YOU