SEMILEPTONIC B DECAYS, $|V_{xb}|$ and R(D,D*)

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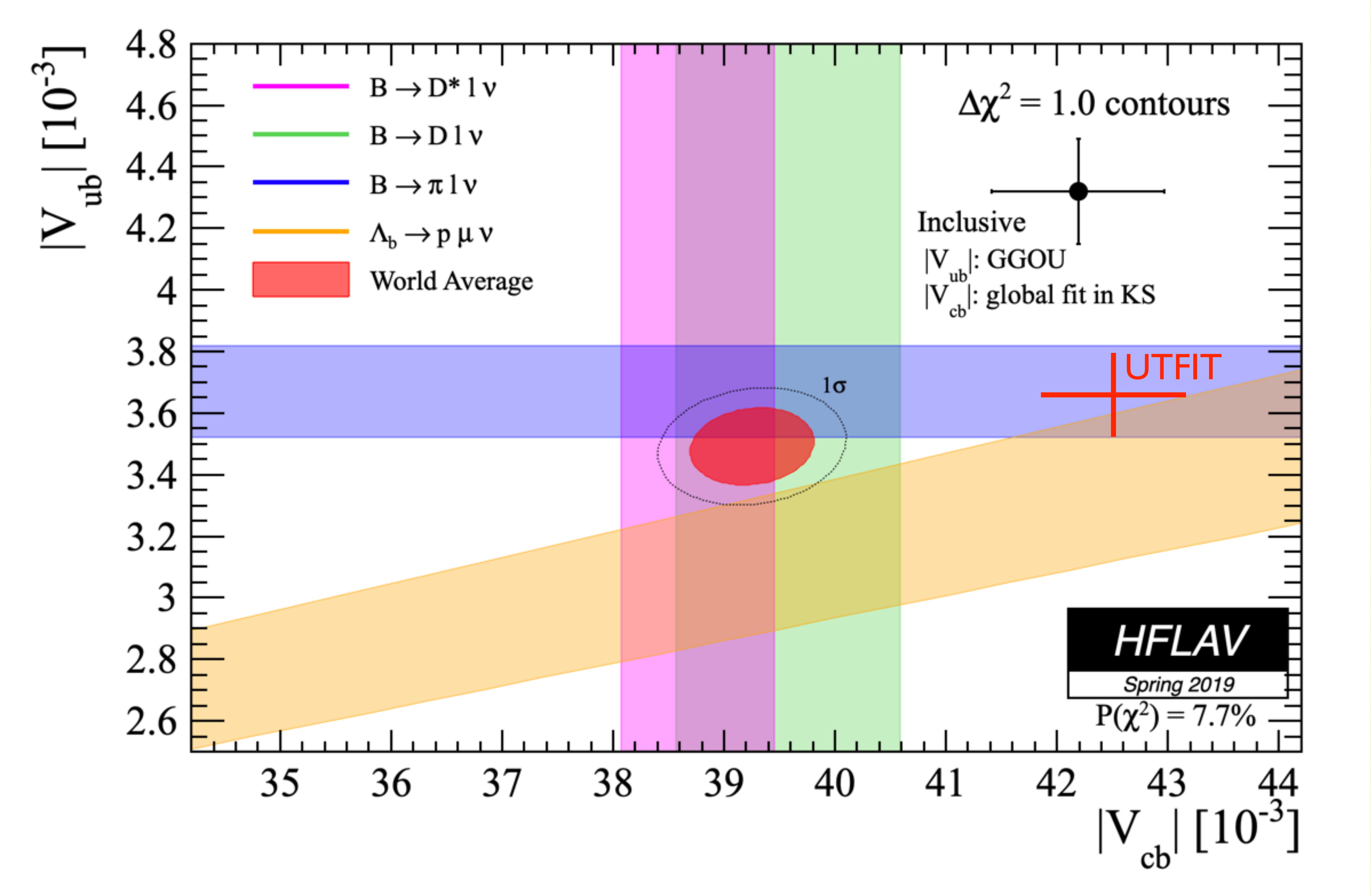
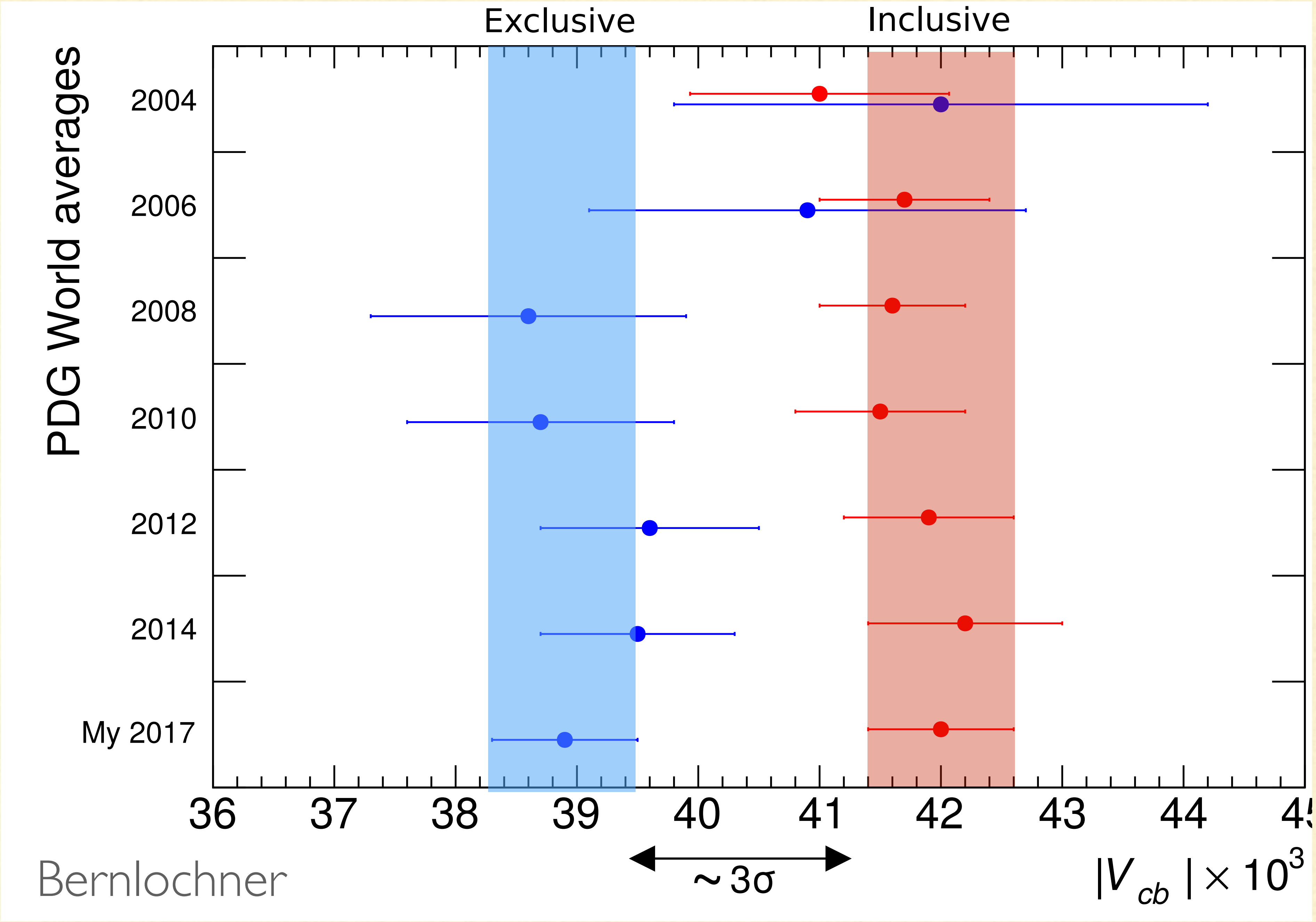
BEAUTY 2019

Ljubljana, 3 october 2019

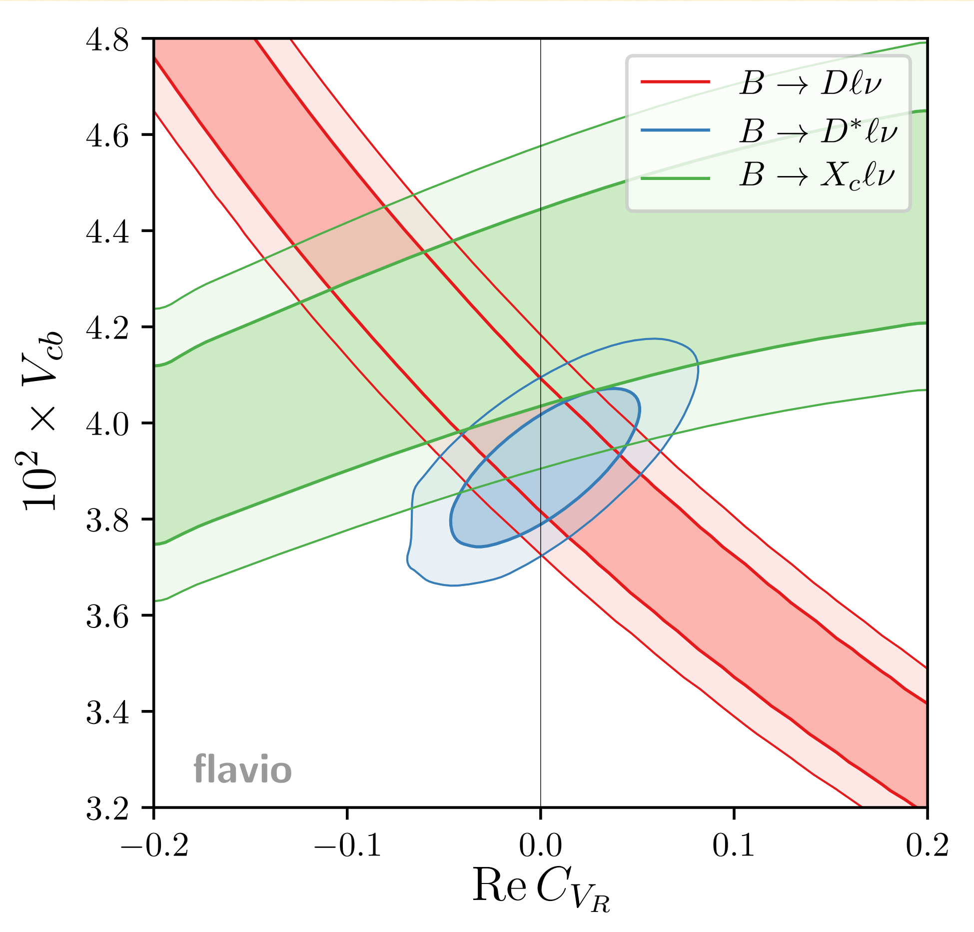


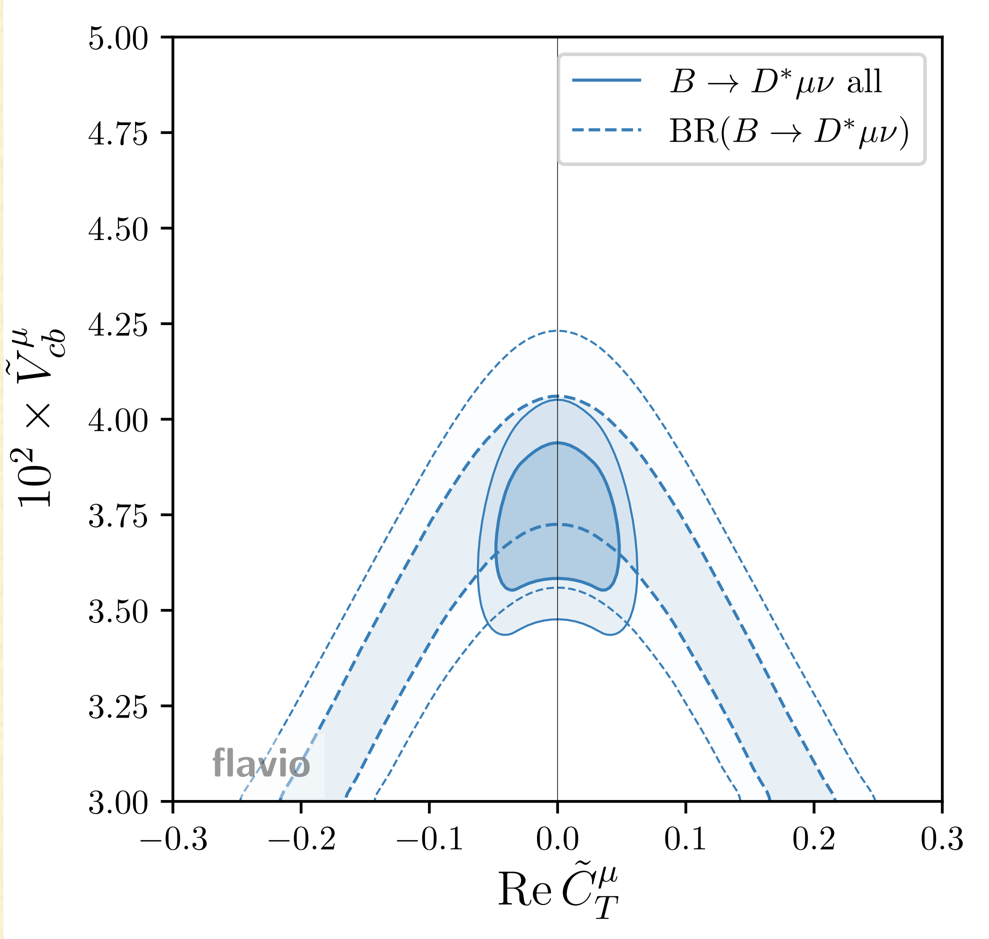
new analyses of B-factories data, new calculations of FFs by several lattice collaborations and for light-cone sum rules, rising to the challenges of a precision measurement

PDG AVERAGES



NEW PHYSICS?





Differential distributions constrain NP, SMEFT interpretation incompatible with LEP data. For a recent detailed analysis see Jung & Straub 1801.01112

the green band on the left is actually larger than it should

The importance of $|V_{xb}|$

The most important CKM unitarity test is the Unitarity Triangle (UT)

V_{cb} plays an important role in UT

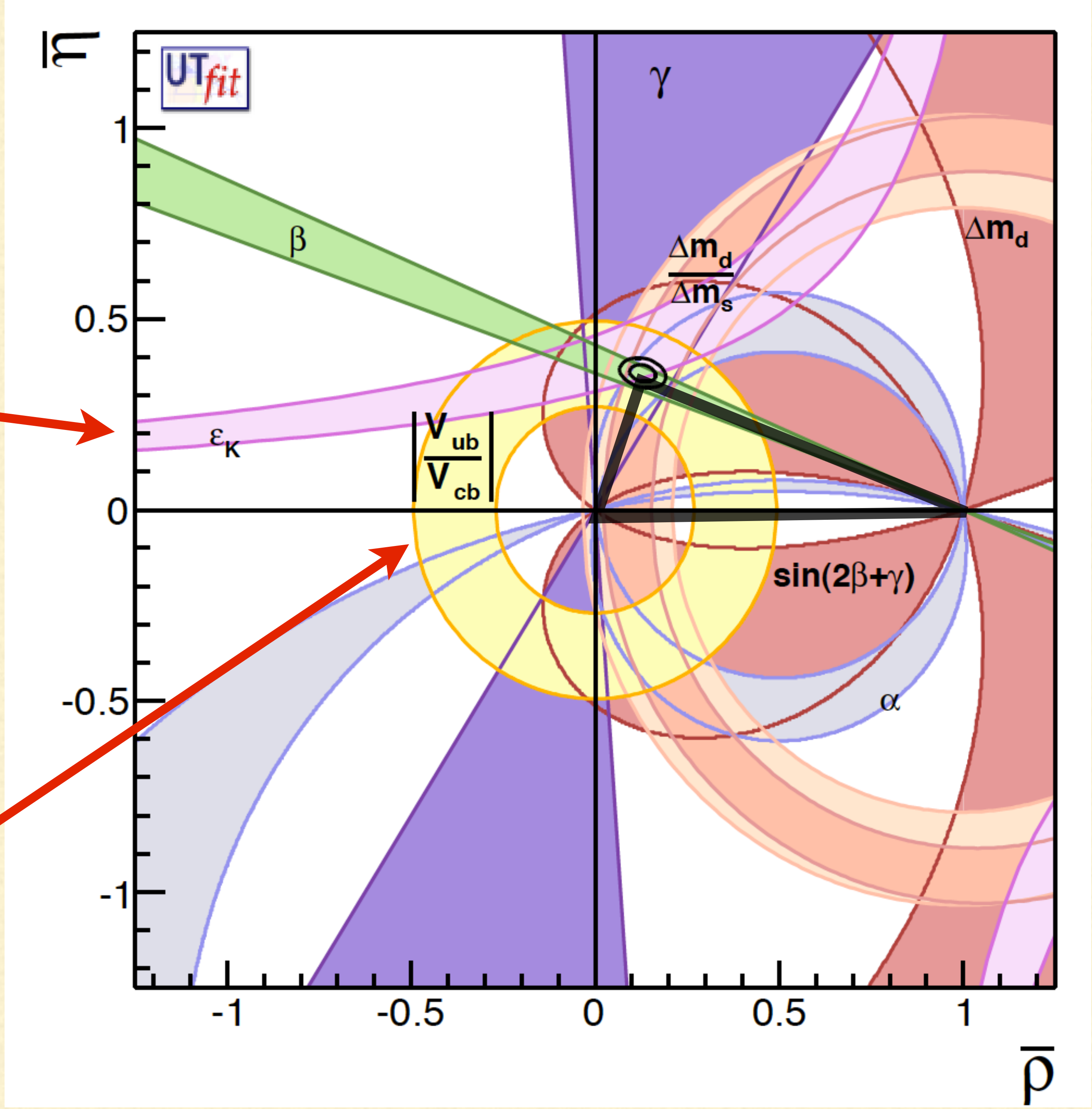
$$\varepsilon_K \approx x|V_{cb}|^4 + \ldots$$

and in the prediction of FCNC:

$$\propto |V_{tb}V_{ts}|^2 \simeq |V_{cb}|^2\left[1 + O(\lambda^2)\right]$$

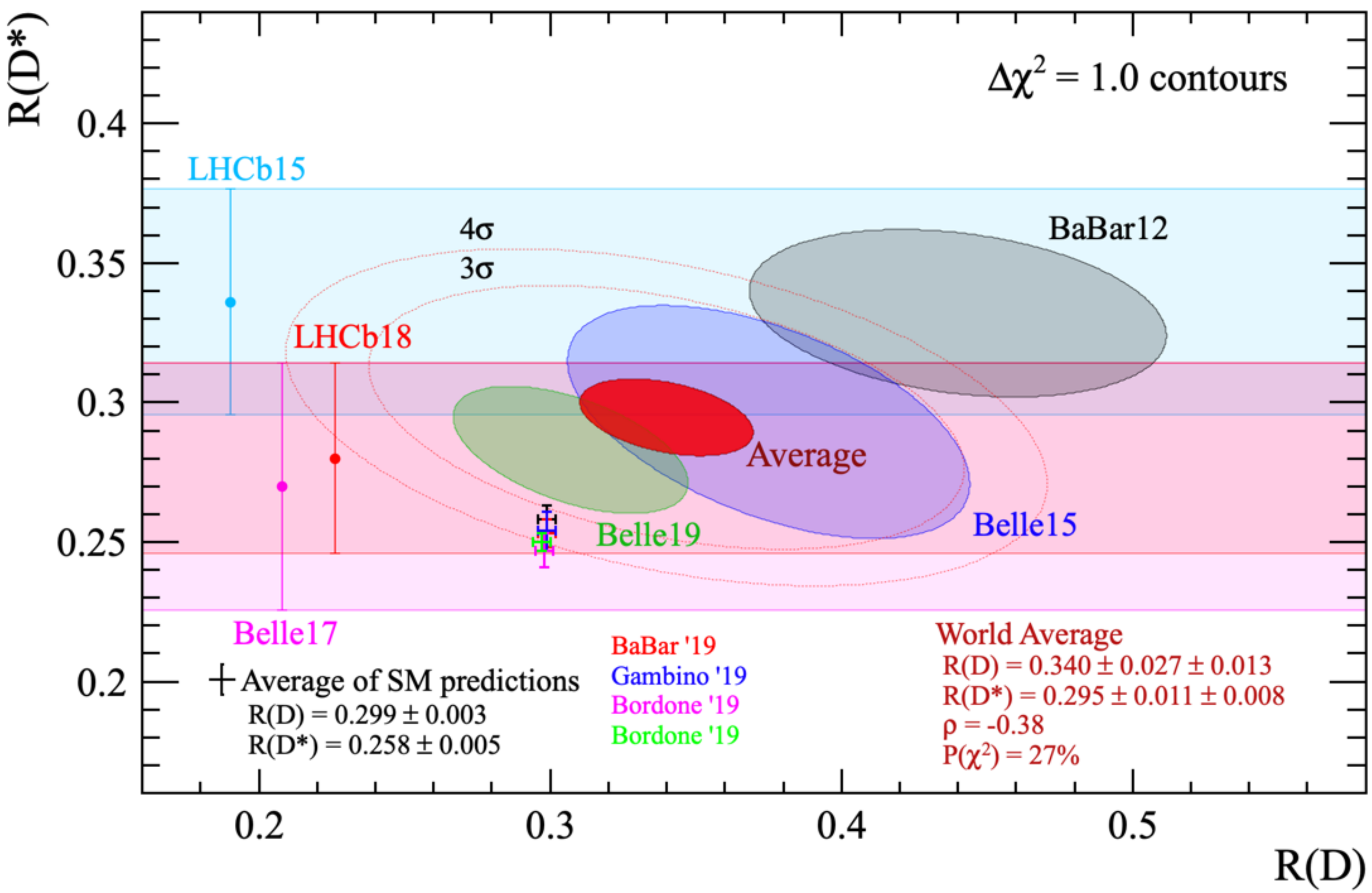
where it often dominates the theoretical uncertainty.

V_{ub}/V_{cb} constrains directly the UT



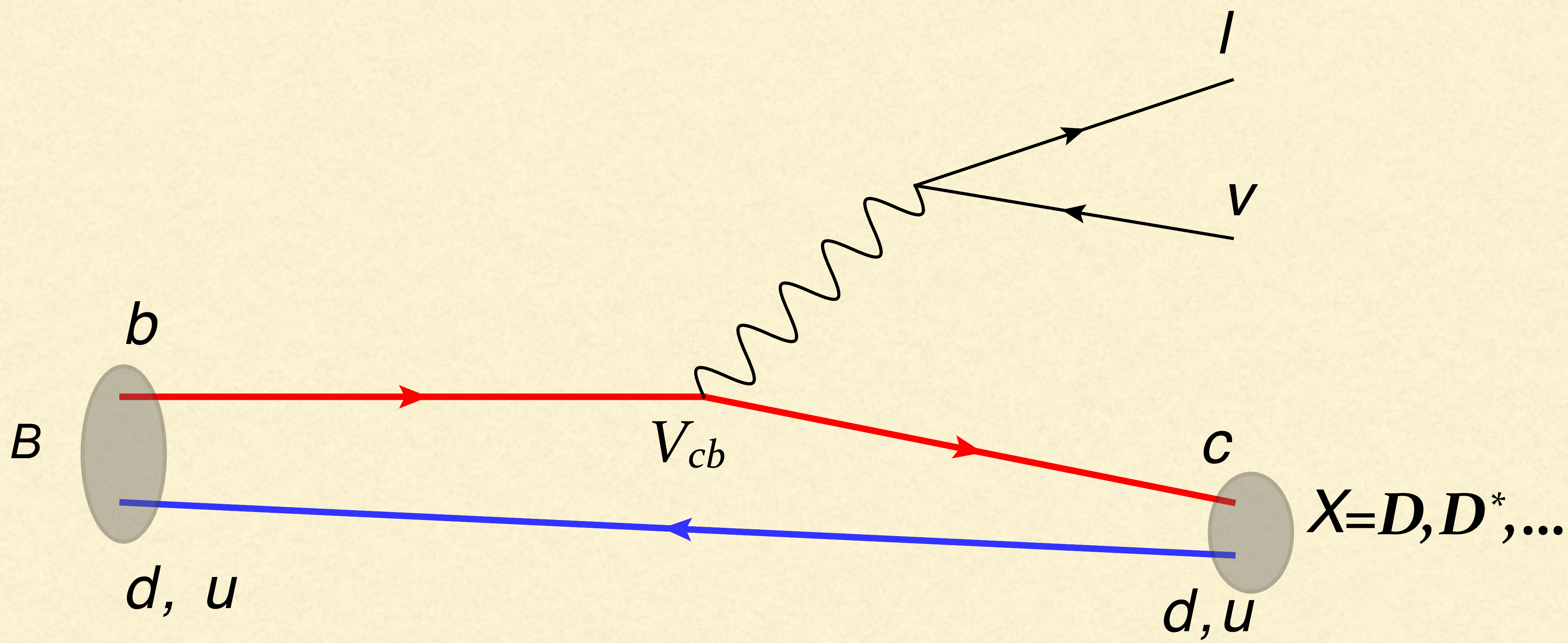
VIOLATION OF LFU WITH TAUS

$$R\left(D^{(*)}\right) = \frac{\mathcal{B}\left(B \to D^{(*)}\tau\nu_\tau\right)}{\mathcal{B}\left(B \to D^{(*)}\ell\nu_\ell\right)}$$



M. Rotondo

EXCLUSIVE DECAYS



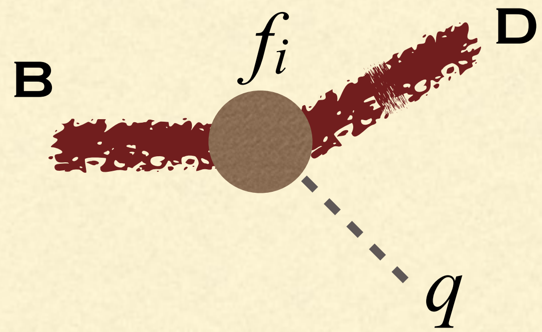
There are 1(2) and 3(4) FFs for D and D* for light (heavy) leptons, for instance

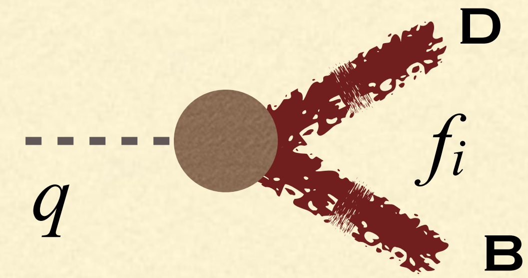
$$\langle D|\bar{c}\gamma^\mu b|B\rangle \propto f_{+,0}(q^2)$$

Information on FFs comes from LQCD (at high q^2), LCSR (at low q^2), exp…

MODEL INDEPENDENT FF PARAMETRIZATION

CROSSING + ANALITYCITY



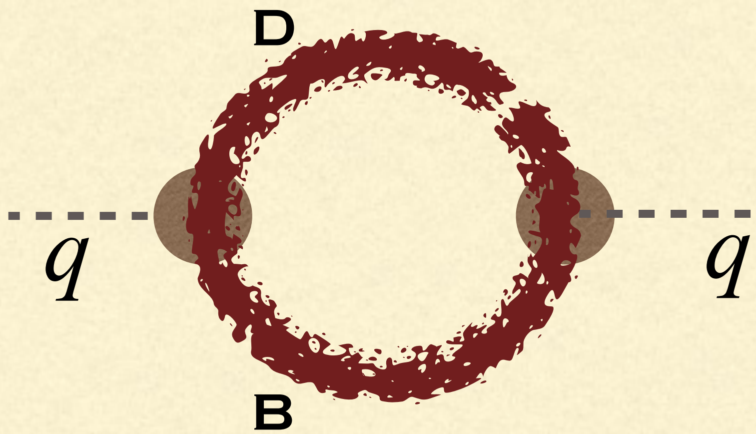


PHYSICAL SEMILEPTONIC REGION

$m_\ell^2 \le q^2 \le (m_B - m_D)^2$

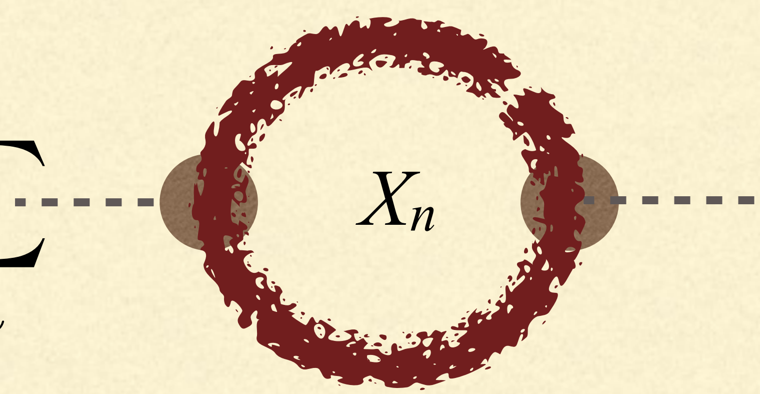
2-POINT CORRELATOR CUTS

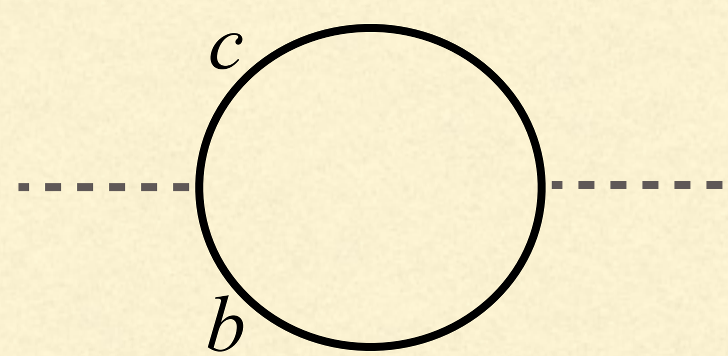
$q^2 \ge (m_B + m_D)^2$

Im 

$\propto |f_i(q^2)|^2 < \sum_n \mathrm{cuts}(X_n)$

POLES AT $q^2=m^2_{Bc}$ ETC

$\sum_n$ 

= 

+PERT CORR

(+CONDENSATES)

USING QUARK-HADRON DUALITY + DISPERSION RELATIONS

UNITARITY CONSTRAINTS

$$z = \frac{\sqrt{1+w} - \sqrt{2}}{\sqrt{1+w} + \sqrt{2}} \qquad w = \frac{m_B^2 + m_{D^*}^2 - q^2}{2 m_B m_{D^*}} \qquad 0 < z < 0.056$$

$$f_i(z) = \frac{\sqrt{\chi_i}}{P_i(z)\phi_i(z)} \sum_{n=0}^{\infty} a_n^i z^n$$

BGL Boyd Grinstein Lebed 1997

BLASCHKE FACTORS REMOVE POLES BELOW THRESHOLD

PHASE SPACE FACTORS

FAST CONVERGING EXPANSION

TRUNCATED AT ORDER N

$$\sum_{n=0}^{N} (a_n^i)^2 < 1$$

WEAK UNITARITY CONSTRAINTS

assuming saturation by single hadron channel

STRONG UNITARITY CONSTRAINTS

Information on other channels with same quantum numbers makes the bounds tighter. HQS implies that all $B^{(*)} \to D^{(*)}$ ff either vanish or are prop to the Isgur-Wise function: any ff F_j can be expressed as

$$F_j(z) = \left(\frac{F_j}{F_i}\right)_{\rm HQET} F_i(z)$$

which leads to (hyper)ellipsoids in the a_i space for S, P, V, A currents

Caprini Lellouch Neubert (CLN, 1998) exploit NLO HQET relations between form factors + QCD sum rules to **reduce parameters** for ffs "up to 2% uncertainty", ***never included in exp analysis***. The *practical version of CLN* is

$$h_{A1}(z) = h_{A1}(1)\left[1 - 8\rho^2 z + (53\rho^2 - 15)z^2 - (231\rho^2 - 91)z^3\right]$$

$$R_1(w) = R_1(1) - 0.12(w-1) + 0.05(w-1)^2,$$

$$R_2(w) = R_2(1) + 0.11(w-1) - 0.06(w-1)^2,$$

only 2+2 parameters! but uncertainty? bias?

HQS breaking in FF relations

HQET: $F_i(w) = \xi(w)\left[1 + c^i_{\alpha_s}\frac{\alpha_s}{\pi} + c^i_b\,\epsilon_b + c^i_c\,\epsilon_c + \ldots\right] \quad \epsilon_{b,c} = \overline{\Lambda}/2m_{b,c}$

$c_{b,c}$ can be computed using subleading IW functions from QCD sumrules

Neubert, Ligeti, Nir 1992-93, Bernlochner et al 1703.05330

RATIOS $\frac{F_j(w)}{V_1(w)} = A_j\left[1 + B_j\,w_1 + C_j\,w_1^2 + D_j\,w_1^3 + \ldots\right] \quad w_1 = w - 1$

Roughly $\epsilon_c \sim 0.25, \quad \epsilon_c^2 \sim 0.06$ but coefficients??

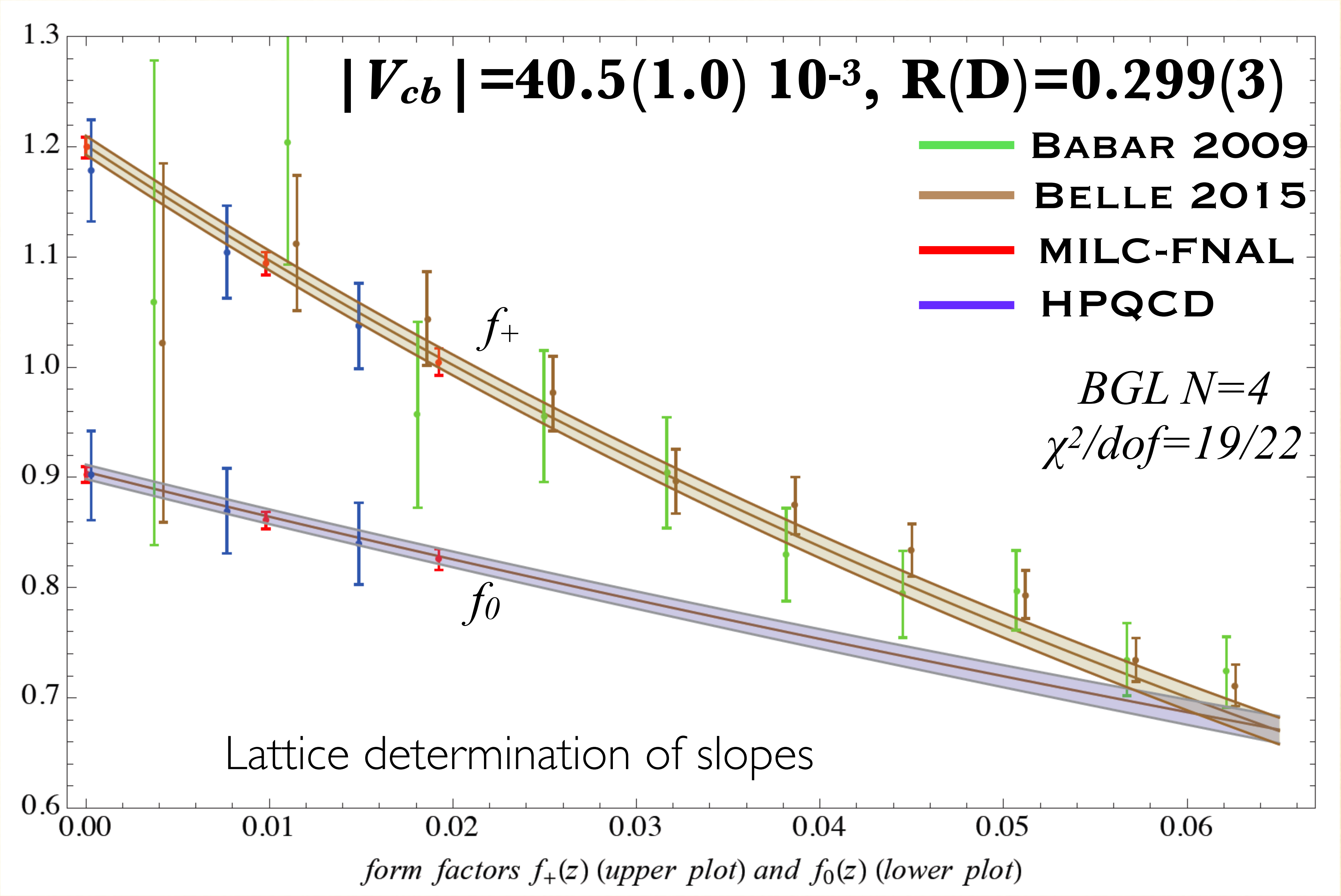
In a few cases we can compare these ratios with recent lattice results: there are 5-13% differences, always > NLO correction. For ex.:

$$\left.\frac{A_1(1)}{V_1(1)}\right|_{\mathrm{LQCD}} = 0.857(15), \qquad \left.\frac{A_1(1)}{V_1(1)}\right|_{\mathrm{HQET@NLO}} = 0.966(28)$$

Looking at NLO HQET corrections, NNLO can be sizeable, naturally O(10-20)%

LATTICE + EXP FIT for $B \to Dl\nu$

Bigi, PG 1606.08030



R(D) 2.4σ from exp

FLAG has very similar results

$|V_{cb}|$ from $B \to D^* l\nu$ *new HFLAV (2019)*

LQCD provided only light lepton FF at zero recoil, w=1, where rate vanishes. Experimental results must therefore be **extrapolated to zero-recoil**

Exp error only ~1.1%!!! $\mathcal{F}(1)\eta_{ew}|V_{cb}| = 35.27(38) \times 10^{-3}$

HFLAV extrapolate with CLN parametr. (no error), but χ^2/dof of=42.3/23!

Two unquenched lattice calculations

$\mathcal{F}(1) = 0.906(13)$
Bailey et al 1403.0635 (FNAL/MILC)

$\mathcal{F}(1) = 0.895(26)$
Harrison et al 1711.11013 (HPQCD)

Using their average 0.904(12): $|V_{cb}| = 38.76(69)\ 10^{-3}$

~ 3.4σ or ~ 8% from inclusive determination 42.00(65) 10^{-3}

PG,Healey,Turczyk 2016

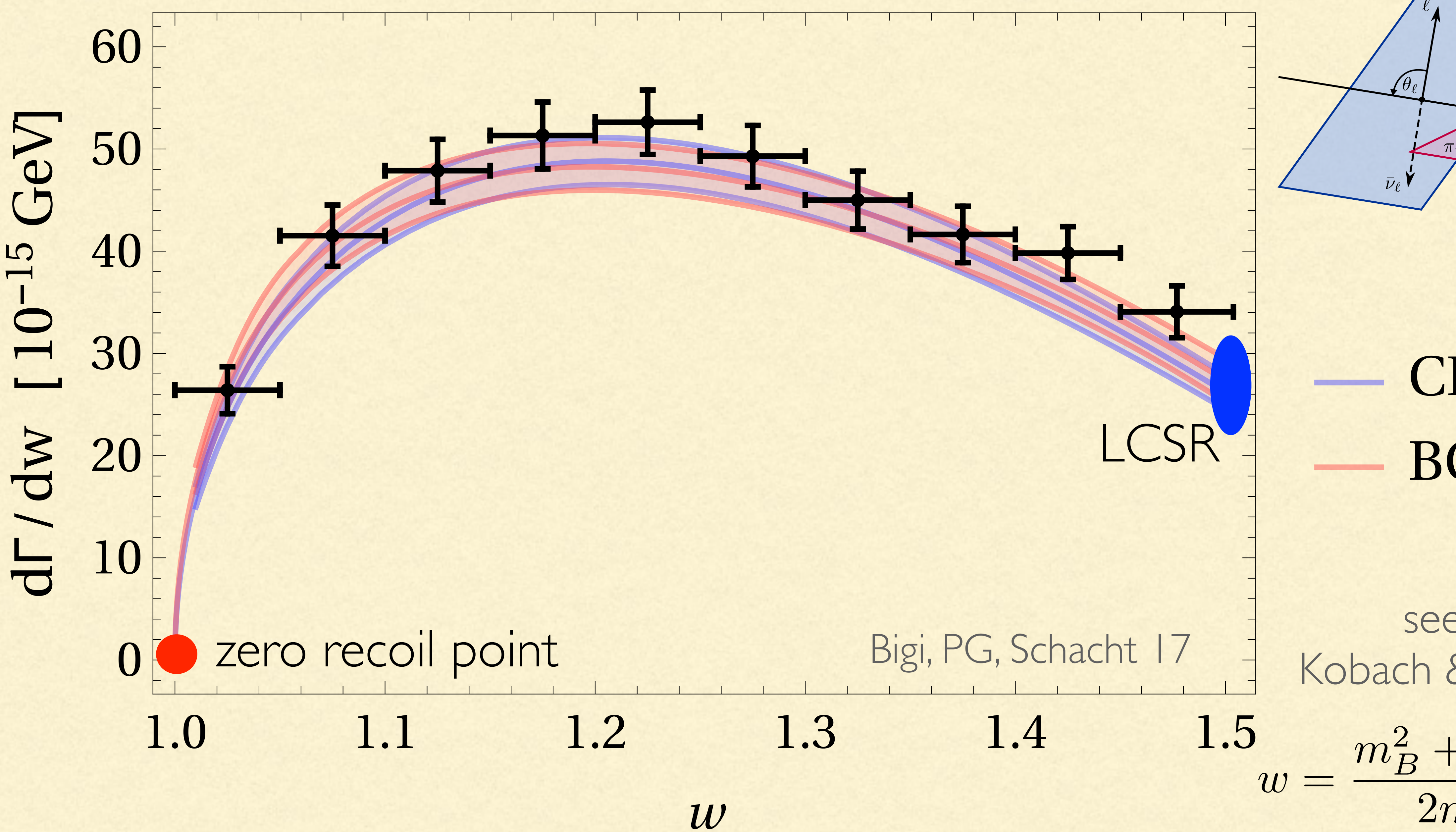
Heavy quark sum rules $F(1) < 0.925$ and estimate of inelastic contribution $F(1) \approx 0.86$

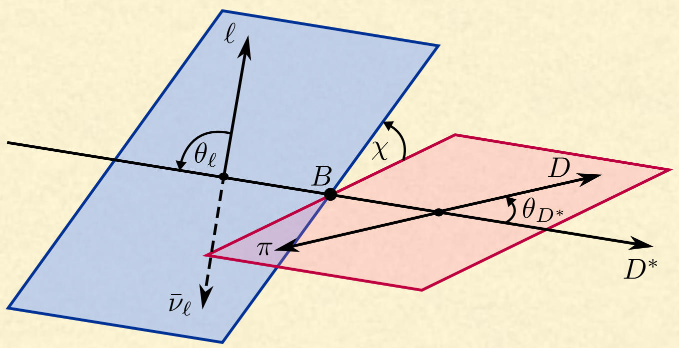
Mannel, Uraltsev, PG, 2012

2017 tagged Belle analysis (preliminary)

1702.01521

w and angular deconvoluted distributions (independent of parameterization).
All previous analyses are CLN based.





see also
Kobach & Grinstein

$$w = \frac{m_B^2 + m_{D^*}^2 - q^2}{2 m_B m_{D^*}}$$

Bands show two parametrizations both fitting data well, with 6% different V_{cb}

Updating Strong Unitarity Bounds

Fit to new Belle's data + total branching ratio (world average) in 1707.09509
with UPDATED strong unit. bounds (including uncertainties & LQCD inputs)

for reference CLN fit: $|V_{cb}|$=0.0392(12)

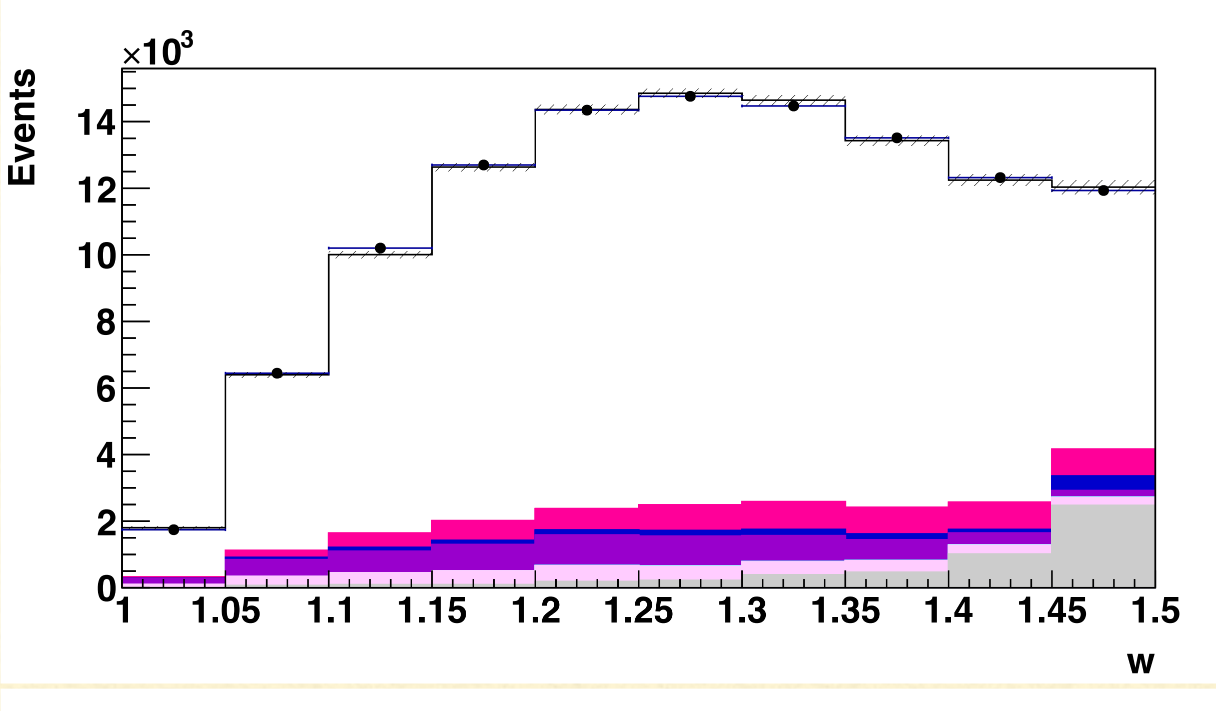
BGL Fit:	Data + lattice	Data + lattice + LCSR	Data + lattice	Data + lattice + LCSR
unitarity	weak	weak	strong	strong
χ^2/dof	28.2/33	32.0/36	29.6/33	33.1/36
$\lvert V_{cb} \rvert$	0.0424 (18)	0.0413 (14)	0.0415 (13)	$0.0406\,(^{+12}_{-13})$

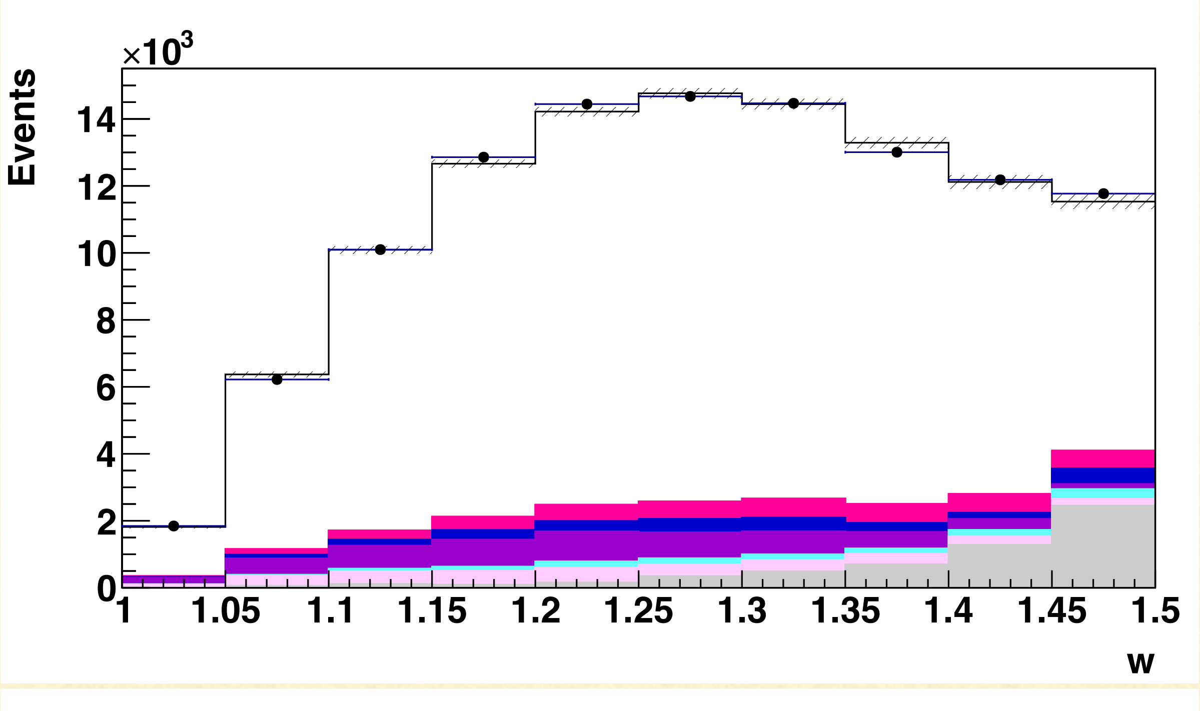
LCSR: Light Cone Sum Rule results from Faller, Khodjamirian, Klein, Mannel, 0809.0222

Using strong unitarity bounds brings BGL closer to CLN and reduce uncertainties but a 3.5-5% difference persists

2018 UNTAGGED BELLE ANALYSIS

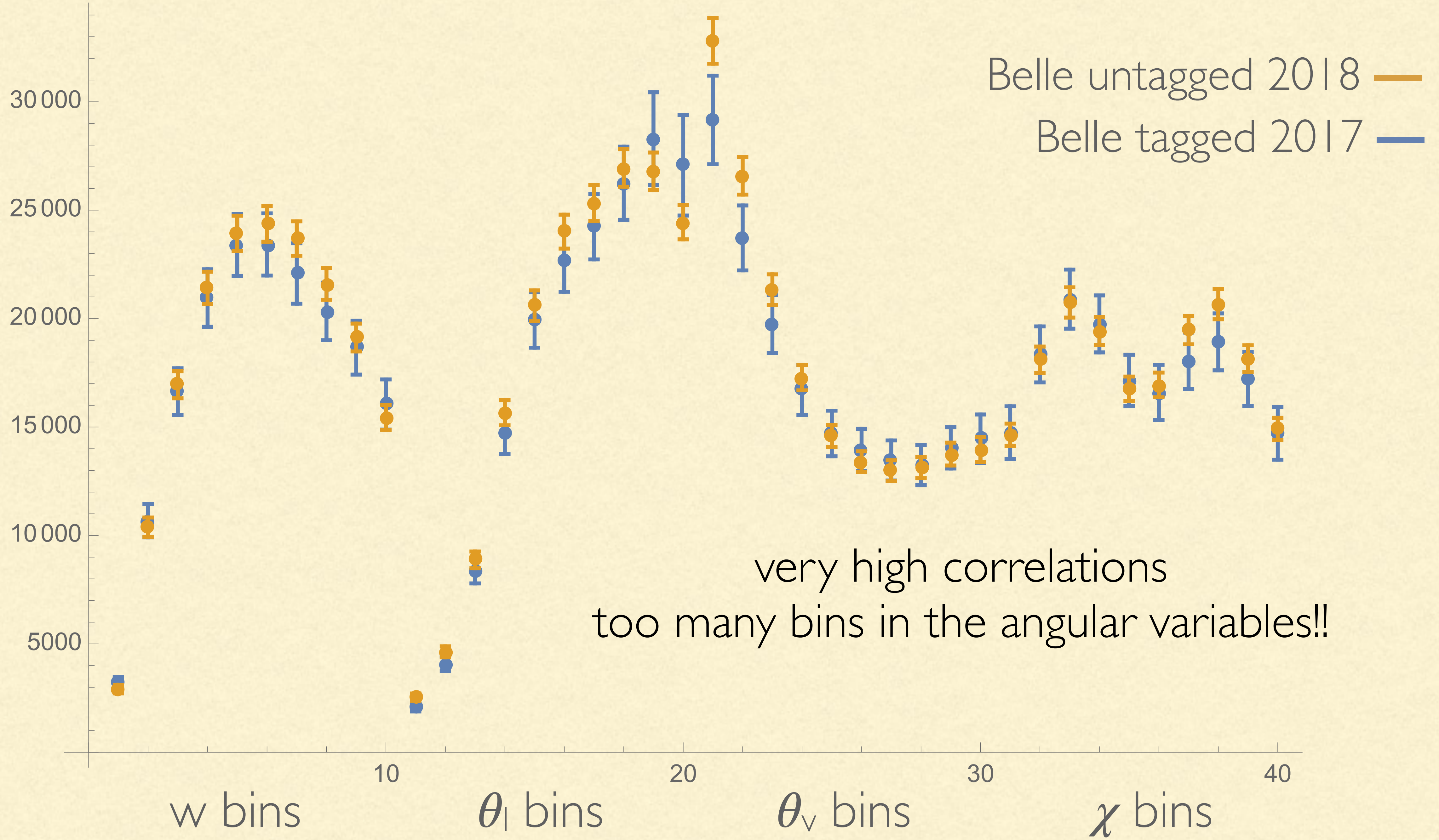
1809.03290v3





- Full Belle dataset, most precise study to date; provides data in a way that can be reanalysed with different assumptions.
- CLN and a somewhat simplified BGL analysis lead to very similar results, suggesting low **$|V_{cb}|$=38.4(0.9) 10^{-3}** .
- We used BGL$^{(222)}$ to fit the data, taking into account D'Agostini effect and got **$|V_{cb}|$=39.1(+1.5-1.3) 10^{-3}** 1905.08209

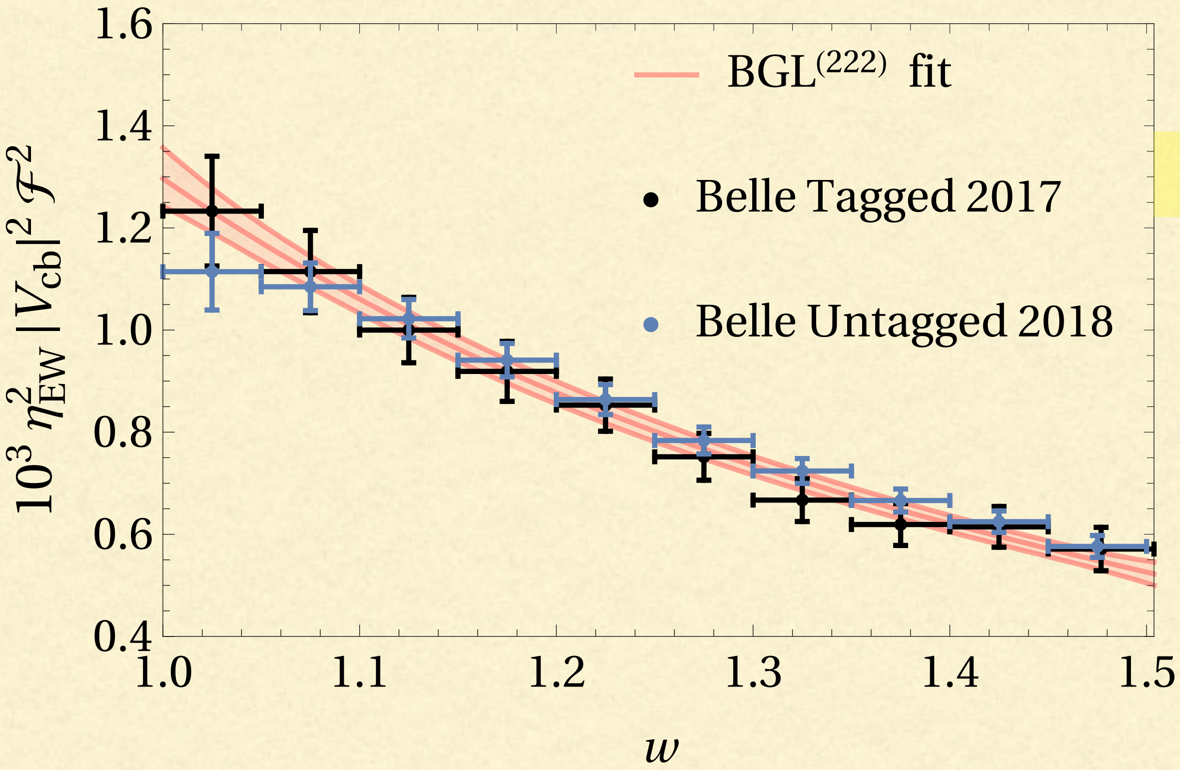
CONSISTENCY OF DATASETS (poor theorist approach)



very high correlations
too many bins in the angular variables!!

A GLOBAL FIT TO 2017 & 2018 DATA

Jung, Schacht, PG 1905.08209



BGL$^{(222)}$	Data + lattice (weak)	Data + lattice (strong)
χ^2/dof	80.1/72	80.1/72
$\lvert V_{cb}\rvert 10^3$	$39.6\,\left(^{+1.1}_{-1.0}\right)$	$39.6\,\left(^{+1.1}_{-1.0}\right)$
a_0^f	0.01221(16)	0.01221(16)
a_1^f	$0.006\,\left(^{+32}_{-45}\right)$	$0.006\,\left(^{+20}_{-32}\right)$
a_2^f	$-0.2\,\left(^{+12}_{-8}\right)$	$-0.2\,\left(^{+7}_{-3}\right)$
$a_1^{\mathcal{F}_1}$	$0.0042\,\left(^{+22}_{-22}\right)$	$0.0042\,\left(^{+19}_{-22}\right)$
$a_2^{\mathcal{F}_1}$	$-0.069\,\left(^{+41}_{-37}\right)$	$-0.068\,\left(^{+41}_{-30}\right)$
a_0^g	$0.024\,\left(^{+21}_{-9}\right)$	$0.024\,\left(^{+12}_{-4}\right)$
a_1^g	$0.05\,\left(^{+39}_{-72}\right)$	$0.05\,\left(^{+21}_{-41}\right)$
a_2^g	$1.0\,\left(^{+0}_{-20}\right)$	$0.9\,\left(^{+0}_{-18}\right)$

- No parametrization dependence (CLN and BGL give the same result)
- About 1 sigma higher than HFLAV, comparable uncertainty, p-value ~24% but not well-defined. 1.9σ from inclusive
- We truncate the BGL series when additional terms do not change the fit (no overfitting!). Fit stable. Strong constraints irrelevant.

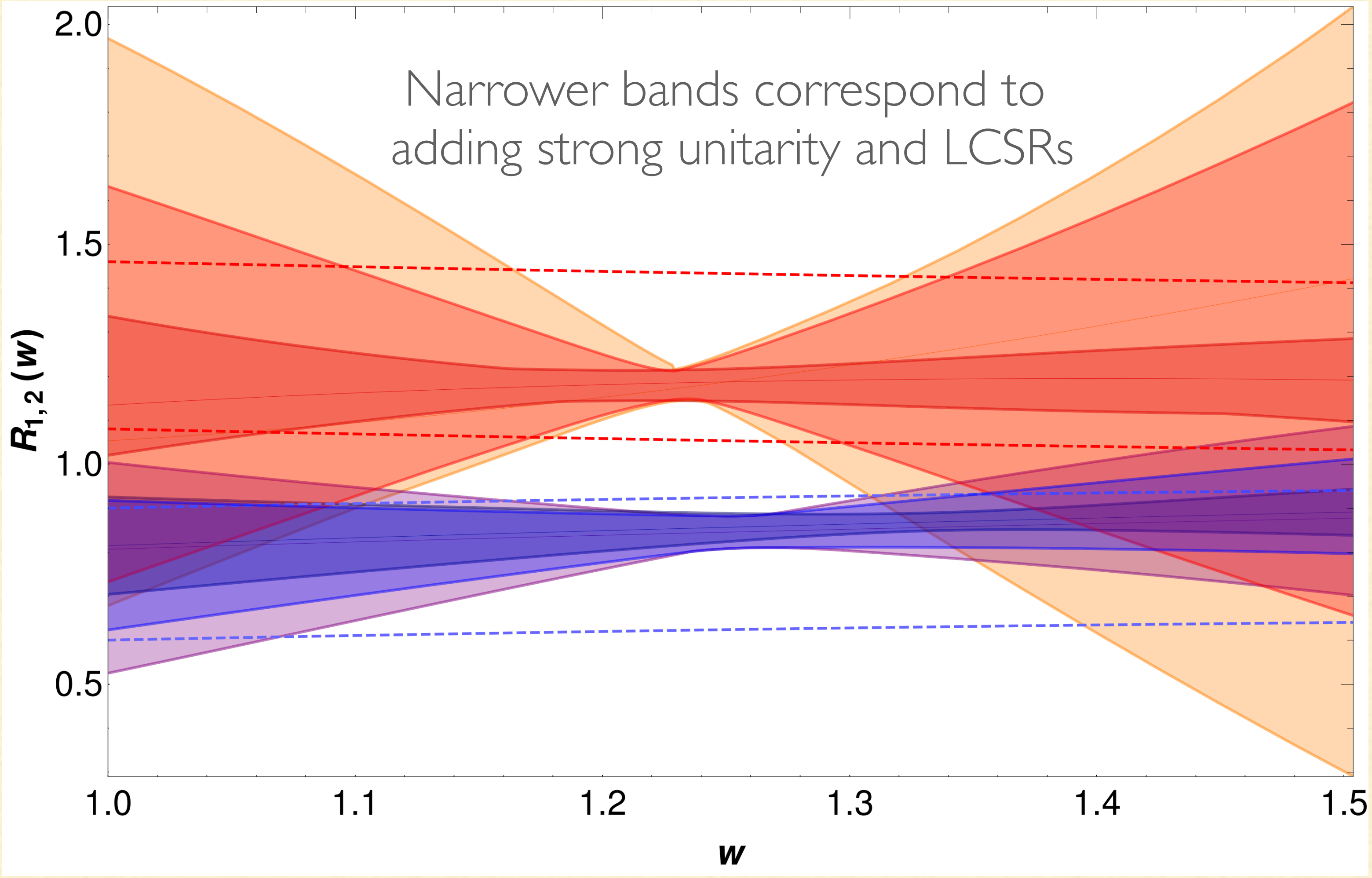
COMPARISON WITH HQS, DECAYS WITH TAU

1905.08209

$$R_1(w) = \frac{V_4(w)}{A_1(w)}$$

$$R_2(w) = \frac{w-r}{w-1}\left(1 - \frac{1-r}{w-r}\frac{A_5(w)}{A_1(w)}\right)$$

Comparison of $R_{1,2}$ from BGL fit to 2017+2018 data vs HQET+QCD sum rule predictions (with parametric + 15% th uncertainty) 2017 data only have problems…



- Decays with tau require pseudoscalar FF undetermined from fit, no lattice calculation yet.
- We use kinematic constraint at q^2=0 and HQET with conservative uncert.

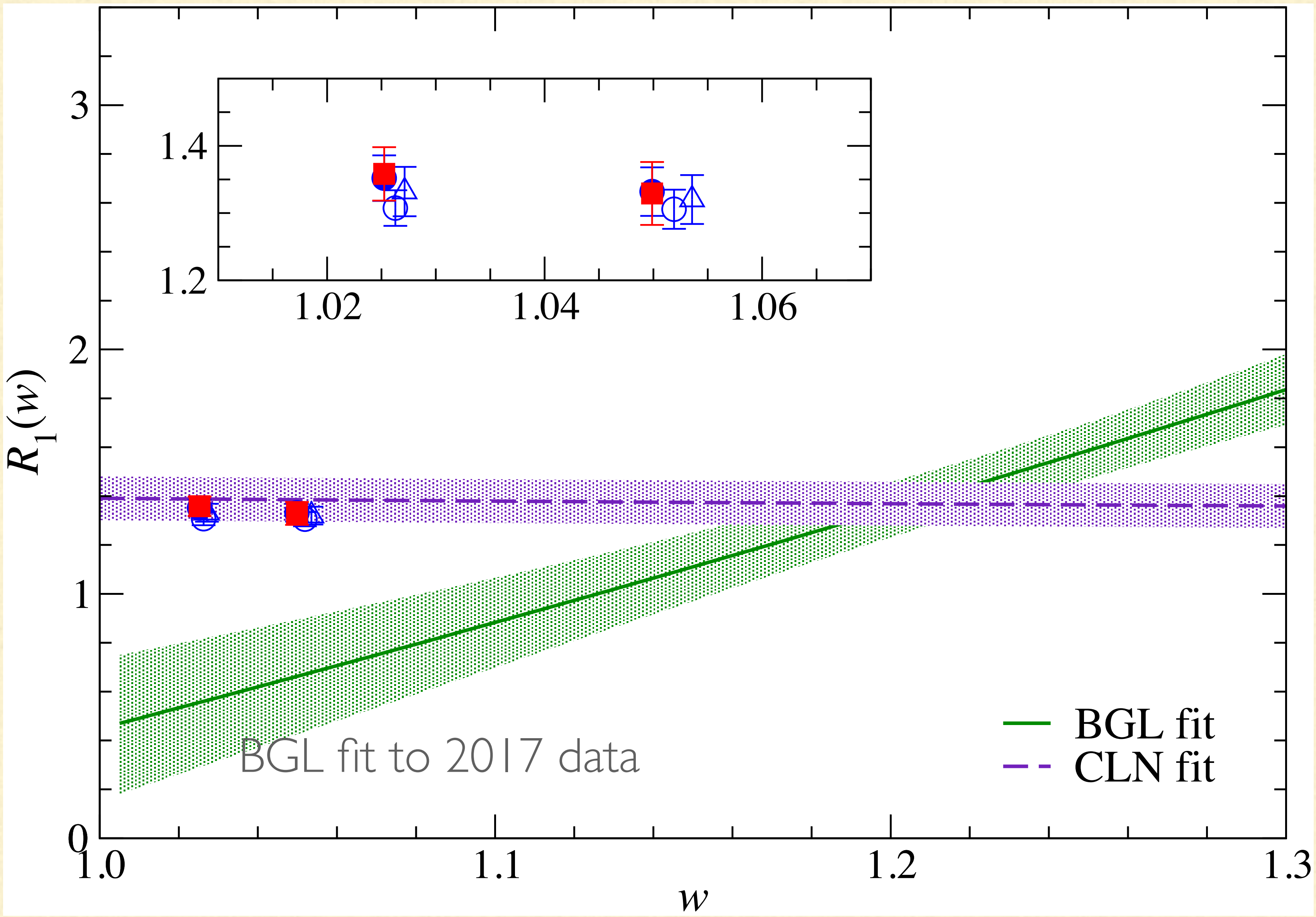
$$R(D^*) = 0.254^{+0.007}_{-0.006}\,,$$

$$P_\tau = -0.476^{+0.037}_{-0.034}\,,$$

$$F_L^{D^*} = 0.476^{+0.015}_{-0.014}\,,$$

PRELIMINARY JLQCD RESULTS

1811.00794

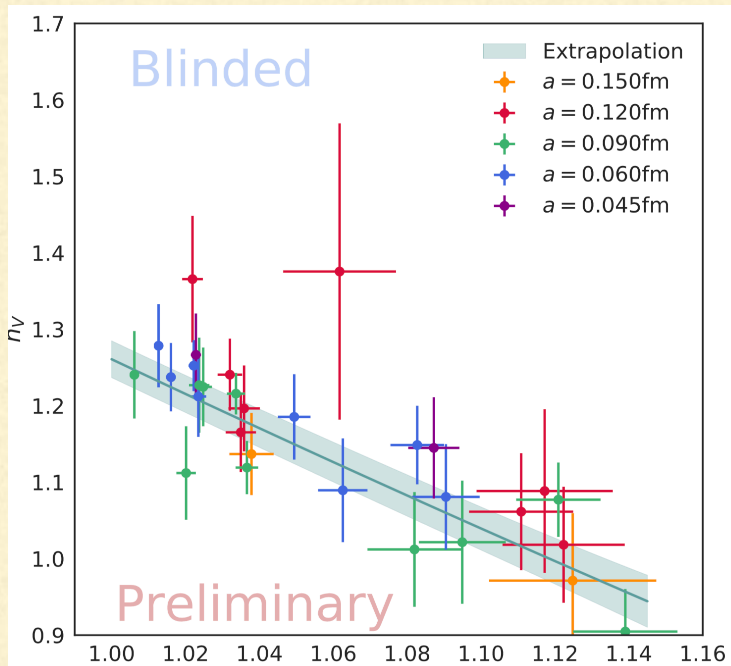


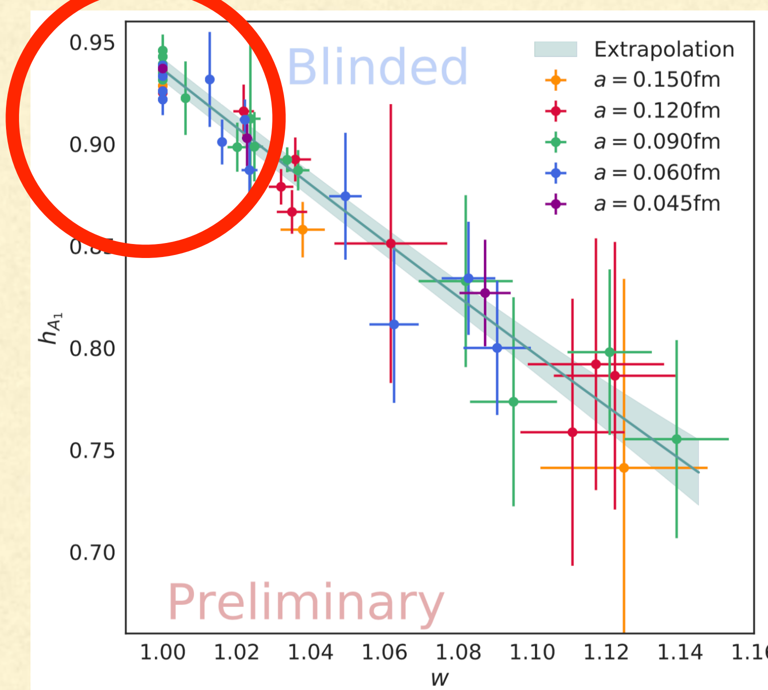
see Kaneko's talk tomorrow

BLINDED FNAL-MILC RESULTS

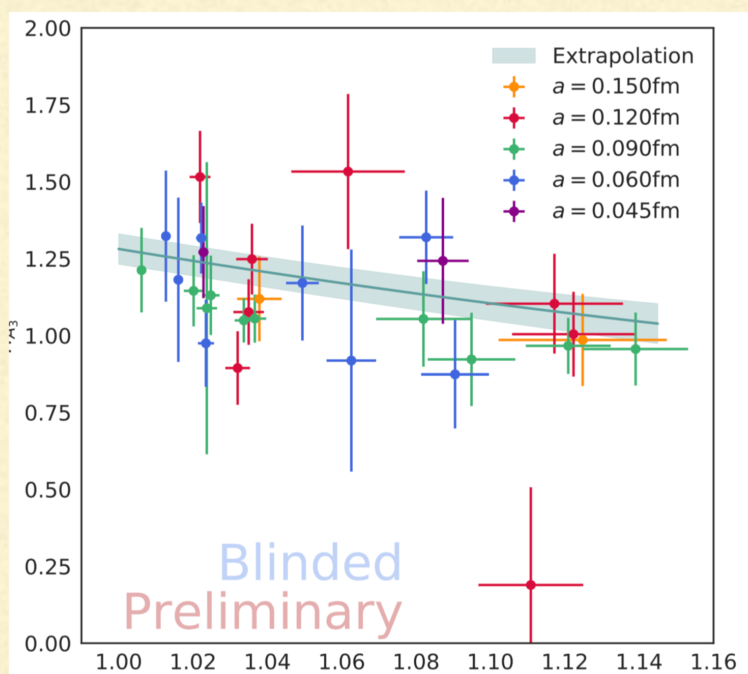
1901.00216

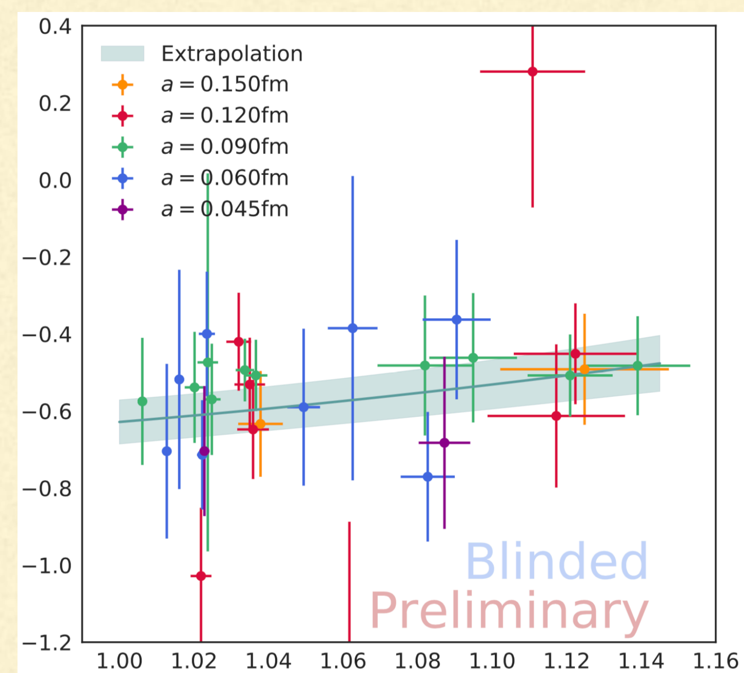
Unquenched calculation of all B→D* form factors at small recoil
Discretization errors are still missing



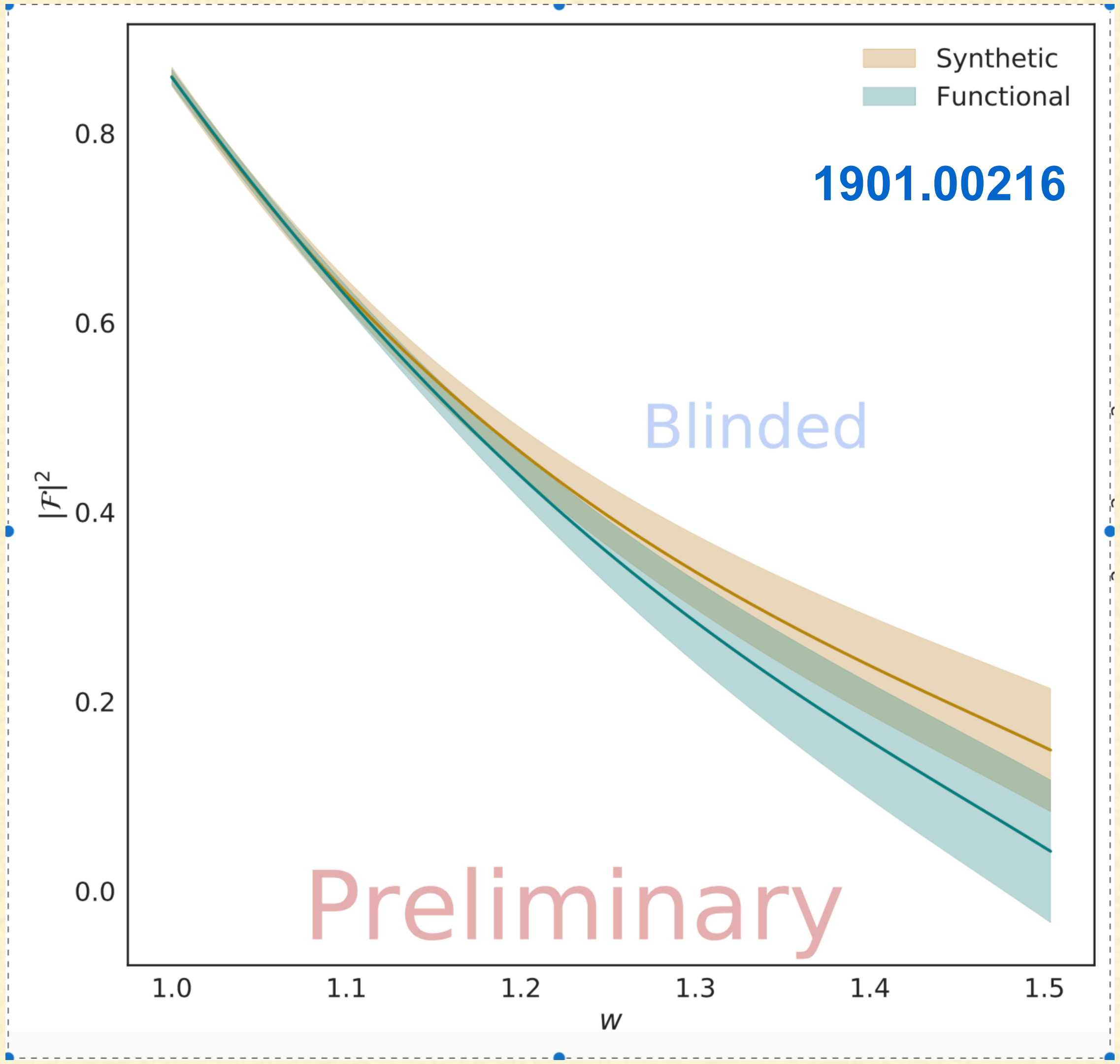


Blinding is introduced as a global normalisation factor close to 1, which multiplies all form factors in the same way.





THE IMPORTANCE OF THE SLOPE



Blinding affects only marginally the slope of the ff F, which is the key to V_{cb}.

Plot suggests large slope, dF/dw~-1.4.

Assuming -1.40(7) we see that the fit can still accomodate a high V_{cb}

Here we use **new improved LCSR** results by Gubernari, Kokulu, van Dyk, 1811.00983 that lead to a minor change wrt 0809.0222

Constraints	$10^3\, V_{cb}$	χ^2
slope	40.8(0.8)	84.5/73
slope+LCSR	40.8(0.8)	88.0/76

EXPLOITING LCSRS

Bordone, Jung, Van Dyk 1908.

Theory determination of $b \to c$ Form Factors

SM: BGL fit to data + FF normalization $\to |V_{cb}|$

NP: can affect the q^2-dependence, introduces additional FFs

➥ To determine general NP, FF shapes needed from theory

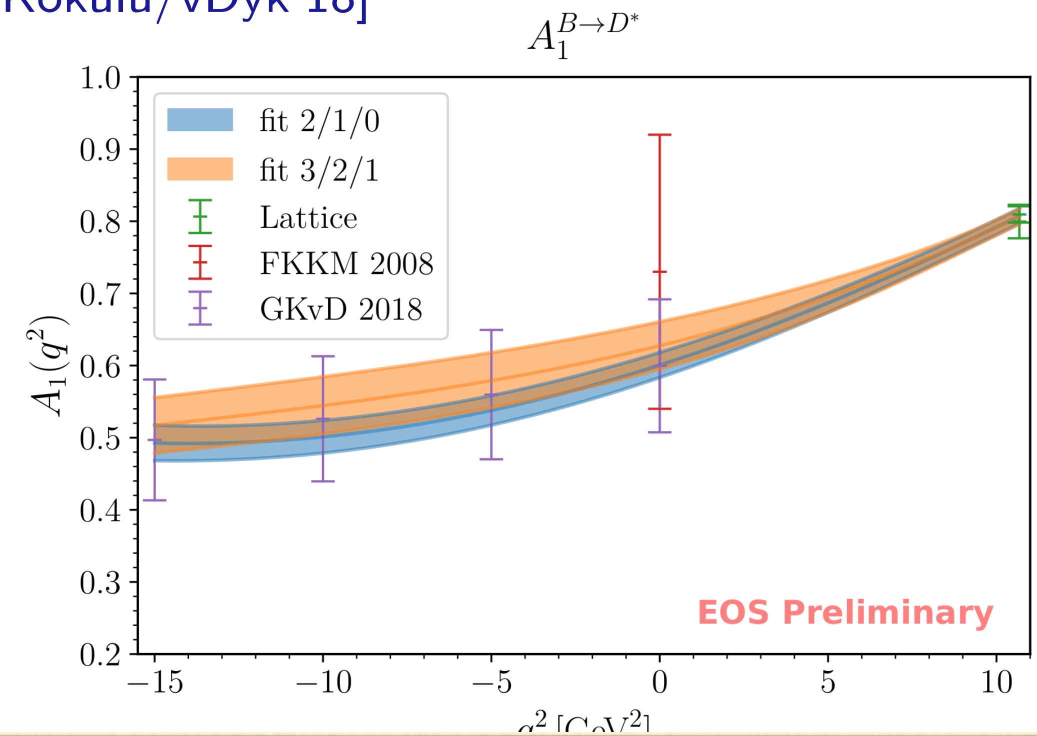
In [MJ/Straub'18,Bordone/MJ/vDyk'19] , we use all available theory input:

- Unitarity bounds (using results from [BGL,Bigi/Gambino(/Schacht)'16'17])
- LQCD for $f_{+,0}(q^2)$ $(B \to D)$, $h_{A_1}(q^2_{\max})$ $(B \to D^*)$ [HPQCD'15,'17,Fermilab/MILC'14,'15]
- LCSR for all FFs [Gubernari/Kokulu/vDyk'18]
- Consistent HQET expansion [Bernlocher+] to $\mathcal{O}(\alpha_s, 1/m_b, 1/m_c^2)$
  ➥ improved description

Including both $B \to D, D^*$ they get
V_{cb}=40.3(0.8)10^{-3}

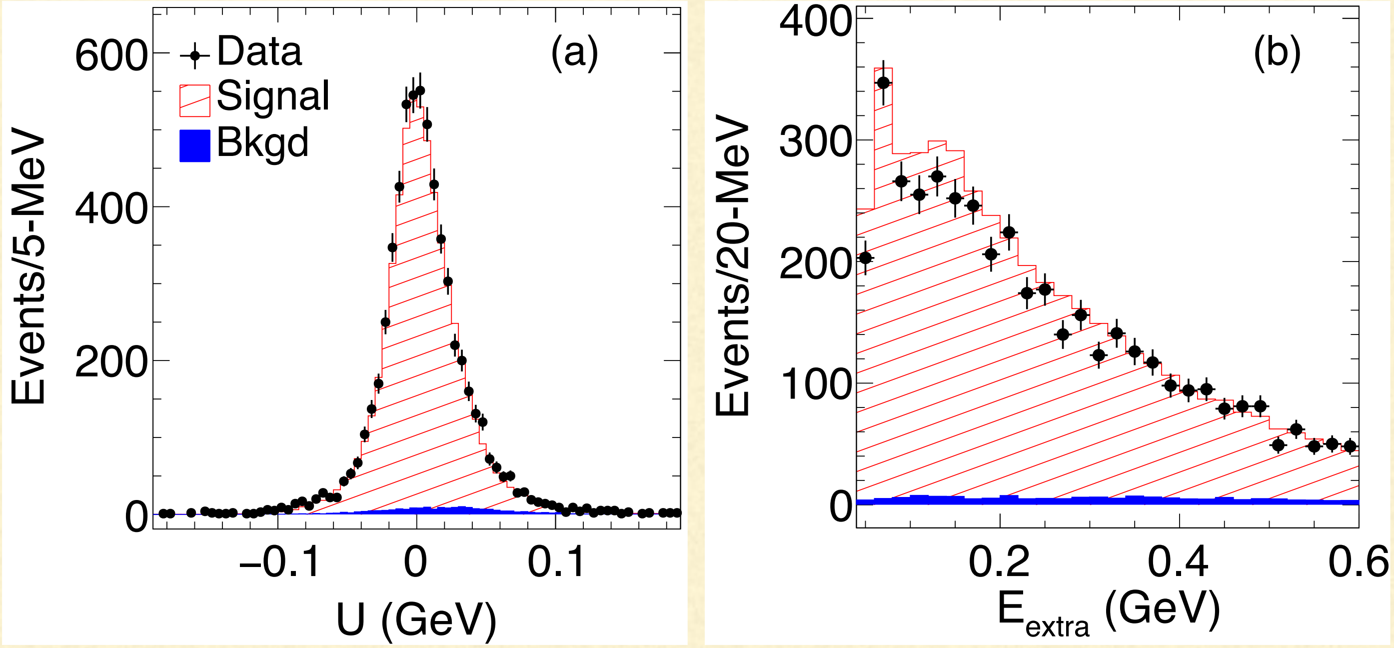
Theory only

FFs under control;
$R(D^*) = 0.247(6)$
[Bordone/MJ/vDyk'19]



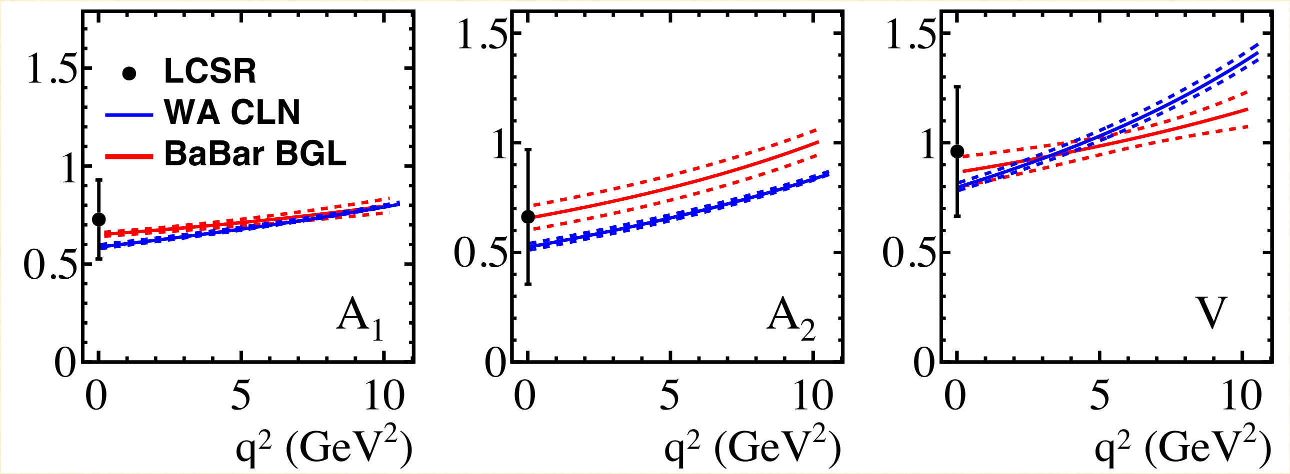
BABAR REANALYSIS 1903.10002

Reanalysis of tagged B^0 and B^+ data, unbinned 4 dimensional fit with BGL only
About 6000 events
No data provided yet



BGL form factors
compared with CLN HFLAV

V_{cb}=0.03836(90)



See next talk

INCLUSIVE SEMILEPTONIC B DECAYS

Inclusive observables are double series in Λ/m_b and α_s

$$
\begin{aligned}
M_i = & M_i^{(0)} + \frac{\alpha_s}{\pi} M_i^{(1)} + \left(\frac{\alpha_s}{\pi}\right)^2 M_i^{(2)} + \left(M_i^{(\pi,0)} + \frac{\alpha_s}{\pi} M_i^{(\pi,1)}\right) \frac{\mu_\pi^2}{m_b^2} \\
& + \left(M_i^{(G,0)} + \frac{\alpha_s}{\pi} M_i^{(G,1)}\right) \frac{\mu_G^2}{m_b^2} + M_i^{(D,0)} \frac{\rho_D^3}{m_b^3} + M_i^{(LS,0)} \frac{\rho_{LS}^3}{m_b^3} + \ldots
\end{aligned}
$$

Global shape parameters (first moments of the distributions, with various lower cuts on E_l) tell us about m_b, m_c and the B structure, total rate about $|V_{cb}|$

OPE parameters describe universal properties of the B meson and of the quarks: they are useful in many applications (rare decays, V_{ub},...)

Reliability of the method depends on our control of higher order effects. Quark-hadron duality violation would manifest as inconsistency in the fit.

kinetic scheme fit includes all corrections $O(\alpha_s^2, \alpha_s/m_b^2, 1/m_b^3)$, m_c constraint from sum rules/lattice

FIT RESULTS

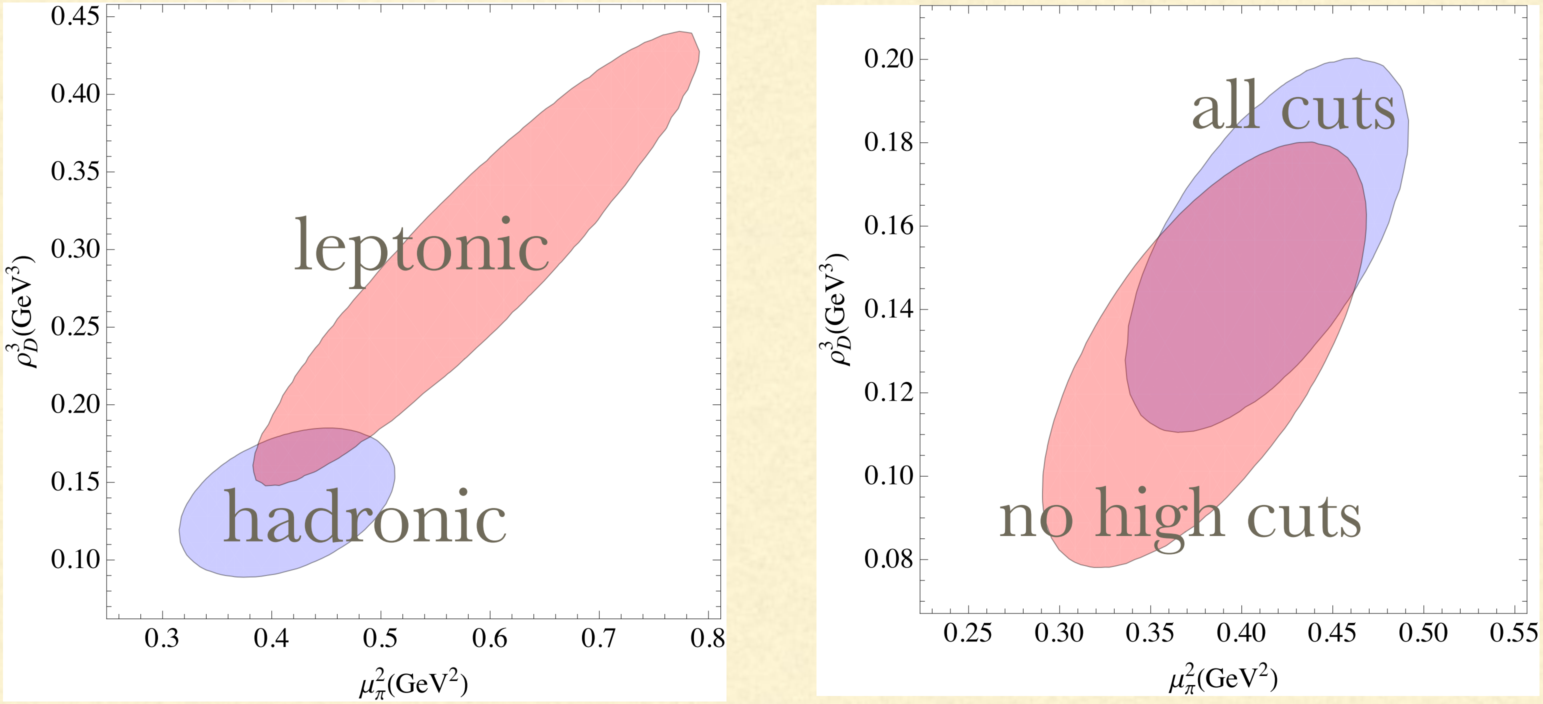
m_b^{kin}	$\overline{m}_c(3\,\mathrm{GeV})$	μ_π^2	ρ_D^3	μ_G^2	ρ_{LS}^3	$\mathrm{BR}_{c\ell\nu}$	$10^3\lvert V_{cb}\rvert$
4.553	0.987	0.465	0.170	0.332	-0.150	10.65	42.21
0.020	0.013	0.068	0.038	0.062	0.096	0.16	0.78

Alberti, Healey, Nandi, PG, 1411.6560

WITHOUT MASS CONSTRAINTS

$$m_b^{kin}(1\mathrm{GeV}) - 0.85\,\overline{m}_c(3\mathrm{GeV}) = 3.714 \pm 0.018\,\mathrm{GeV}$$

- results depend little on assumption for correlations and choice of inputs, 1.8% determination of V_{cb}
- 20-30% determination of the OPE parameters
- b mass determination in agreement with recent lattice and sum rules results



HIGHER POWER CORRECTIONS

Proliferation of non-pert parameters starting $1/m^4$: 9 at dim 7, 18 at dim 8

In principle relevant: HQE contains $O(1/m_b^n 1/m_c^k)$

Mannel,Turczyk,Uraltsev 1009.4622

Lowest Lying State Saturation Approx (LLSA) truncating

$$\langle B|O_1 O_2|B\rangle = \sum_n \langle B|O_1|n\rangle\langle n|O_2|B\rangle$$

see also Heinonen,Mannel 1407.4384

and relating higher dimensional to lower dimensional matrix elements, e.g.

$$\rho_D^3 = \epsilon\,\mu_\pi^2 \qquad \rho_{LS}^3 = -\epsilon\,\mu_G^2 \qquad \epsilon \sim 0.4\text{GeV}$$

excitation energy to P-wave states. LLSA might set the scale of effect, but large corrections to LLSA have been found in some cases 1206.2296

We use LLSA as loose constraint or priors (60% gaussian uncertainty, dimensional estimate for vanishing matrix elements) in a fit including higher powers. The rest of the fit is unchanged, with slightly smaller theoretical errors

$$\boxed{|V_{cb}| = 42.00(64) \times 10^{-3}}$$

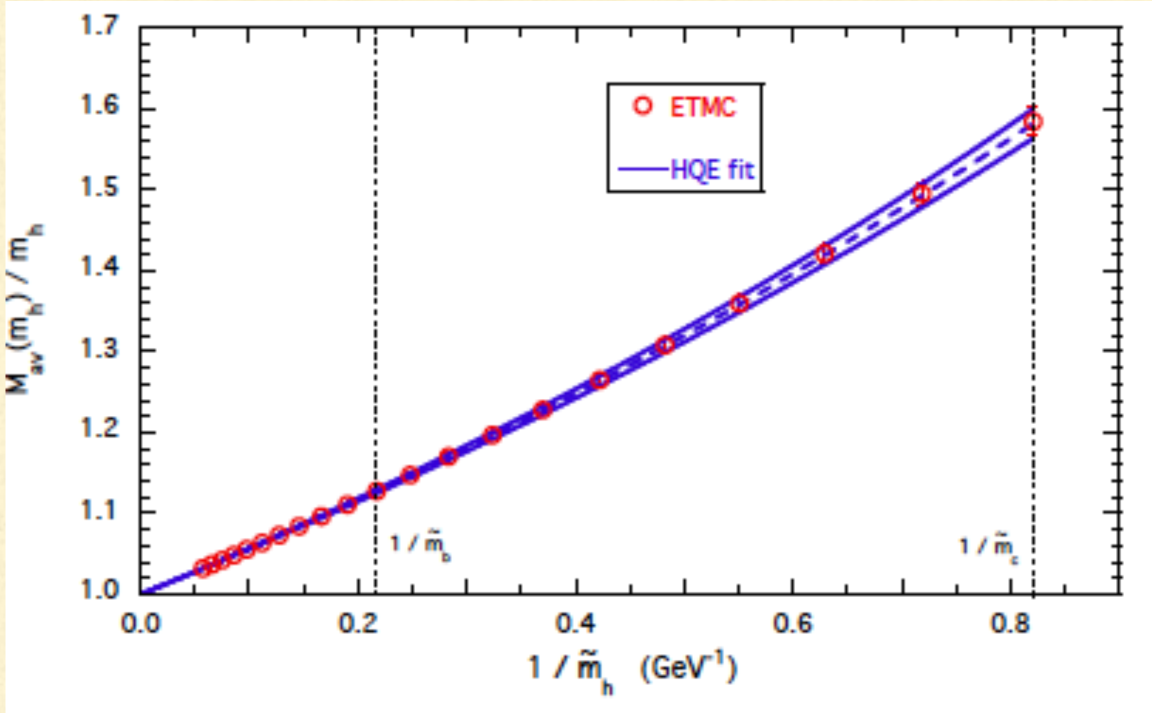
PROSPECTS for INCLUSIVE V_{cb}

- Theoretical uncertainties already dominant
- $O(\alpha_s/m_b^3)$ calculation completed for width (Mannel, Pivovarov) in progress for the moments (Nandi, PG)
- $O(1/m_Q^{4,5})$ effects need further investigation but small effect on V_{cb}
- $O(\alpha_s^3)$ corrections to total width feasible, needed for 1% uncertainty?
- Electroweak (QED) corrections require attention
- New observables in view of Belle-II: FB asymmetry proposed by S.Turczyk could be measured already by Babar and Belle now, q^2 moments…
- **Lattice QCD** information on local matrix elements is the next frontier (e.g. heavy meson masses and Hashimoto's proposal)

MESON MASSES FROM ETMC

Melis, Simula, PG 1704.06105

$$M_{H_Q} = m_Q + \bar{\Lambda} + \frac{\mu_\pi^2 - a_H \mu_G^2}{2m_Q} + \dots$$

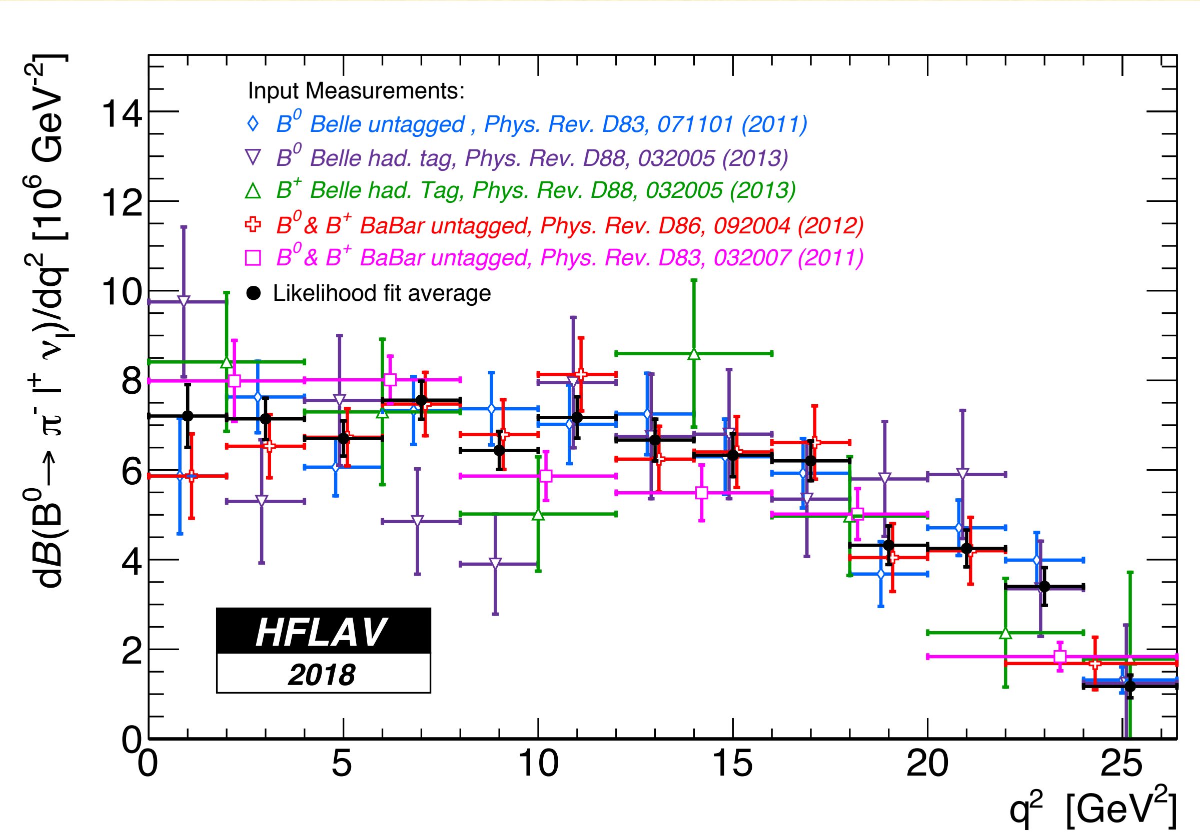


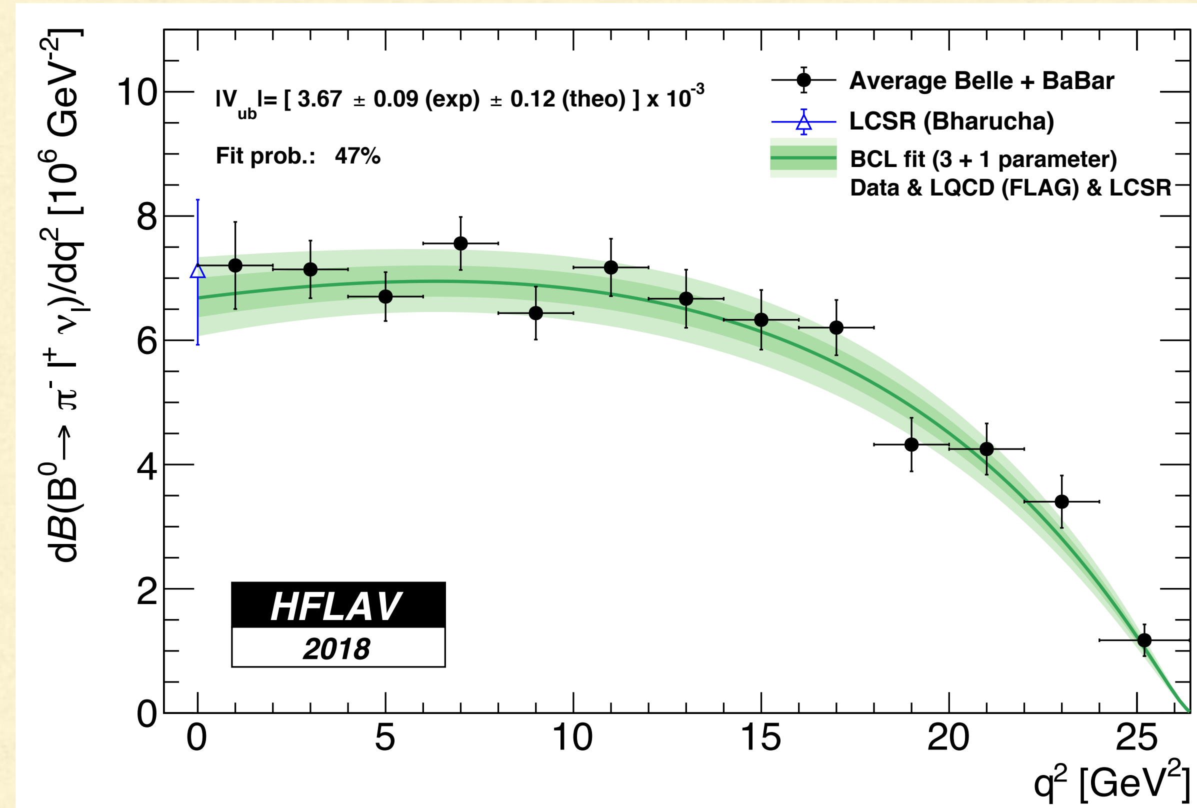
- on the lattice one can compute mesons for arbitrary quark masses

  see also Kronfeld & Simone hep-ph/0006345, 1802.04248

- We used both pseudoscalar and vector mesons
- Direct 2+1+1 simulation, a=0.62-0.89 fm, m_π=210-450 MeV, heavy masses from m_c to $3m_c$, ETM ratio method with extrapolation to static point.
- Kinetic scheme with cutoff at 1GeV, good sensitivity up to $1/m^3$ corrections
- Results consistent with s.l. fits

EXCLUSIVE V_{ub} $B \to \pi \ell \nu$





$$|V_{ub}| = (3.70 \pm 0.10\,(\mathrm{exp}) \pm 0.12\,(\mathrm{theo})) \times 10^{-3} \;\; (\mathrm{data} + \mathrm{LQCD}),$$
$$|V_{ub}| = (3.67 \pm 0.09\,(\mathrm{exp}) \pm 0.12\,(\mathrm{theo})) \times 10^{-3} \;\; (\mathrm{data} + \mathrm{LQCD} + \mathrm{LCSR}),$$

- Theory good: two LQCD and LCSR agree well
- bad chi2/dof, situation would improve (and V_{ub} would increase) by considering discrepant results with care

INCLUSIVE V_{ub}

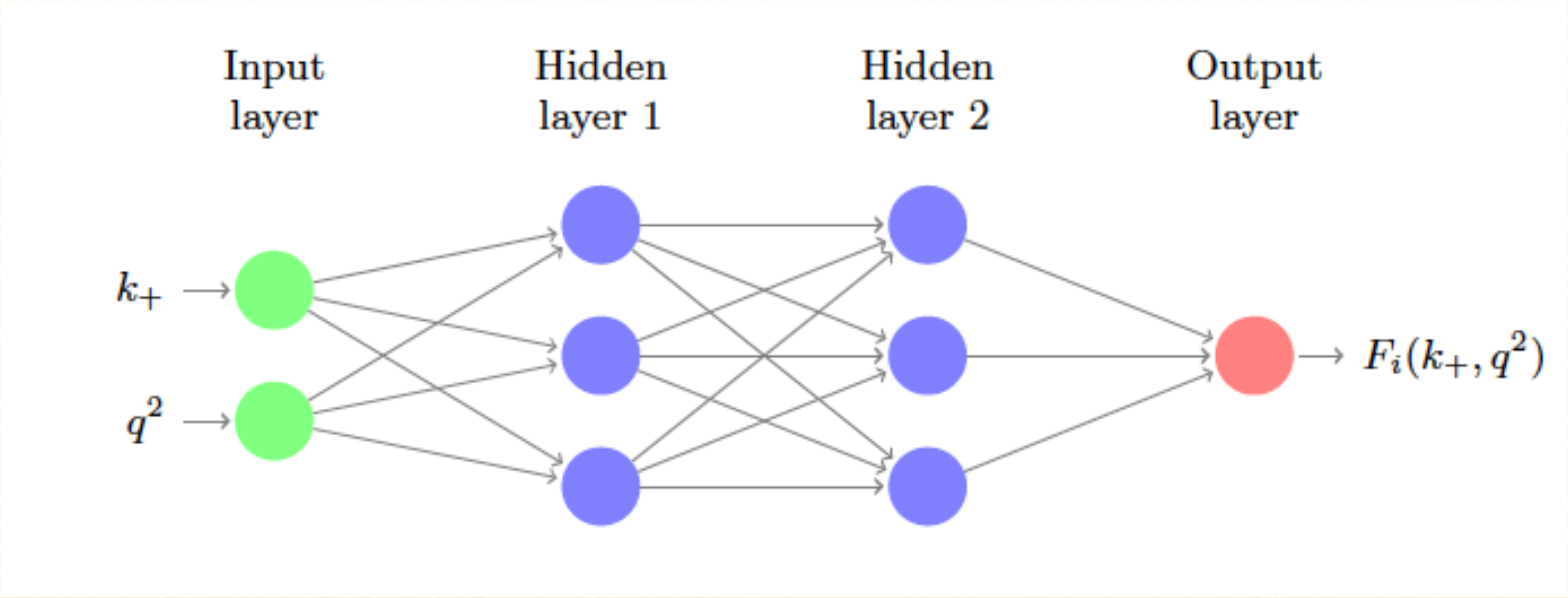
HFLAV 1909.12524

	BLNP	DGE	GGOU	ADFR	BLL
Input parameters					
scheme	SF	$\overline{MS}$	kinetic	$\overline{MS}$	$1S$
Ref.	[572, 573]	Ref. [574]	see Sec. 6.2.2	Ref. [575]	Ref. [556]
m_b (GeV)	4.582 ± 0.026	4.188 ± 0.043	4.554 ± 0.018	4.188 ± 0.043	4.704 ± 0.029
μ_π^2 (GeV^2)	$0.145\ ^{+0.091}_{-0.097}$	-	0.414 ± 0.078	-	-
Ref.	$\|V_{ub}\|$ values $[10^{-3}]$				
CLEO E_e [564]	$4.22 \pm 0.49^{+0.29}_{-0.34}$	$3.86 \pm 0.45^{+0.25}_{-0.27}$	$4.23 \pm 0.49^{+0.22}_{-0.31}$	$3.42 \pm 0.40^{+0.17}_{-0.17}$	-
Belle M_X, q^2 [566]	$4.51 \pm 0.47^{+0.27}_{-0.29}$	$4.43 \pm 0.47^{+0.19}_{-0.21}$	$4.52 \pm 0.48^{+0.25}_{-0.28}$	$3.93 \pm 0.41^{+0.18}_{-0.17}$	$4.68 \pm 0.49^{+0.30}_{-0.30}$
Belle E_e [565]	$4.93 \pm 0.46^{+0.26}_{-0.29}$	$4.82 \pm 0.45^{+0.23}_{-0.23}$	$4.95 \pm 0.46^{+0.16}_{-0.21}$	$4.48 \pm 0.42^{+0.20}_{-0.20}$	-
BABAR E_e [560]	$4.41 \pm 0.12^{+0.27}_{-0.27}$	$3.85 \pm 0.11^{+0.08}_{-0.07}$	$3.96 \pm 0.10^{+0.17}_{-0.17}$	-	-
BABAR E_e, s_h^{max} [563]	$4.71 \pm 0.32^{+0.33}_{-0.38}$	$4.35 \pm 0.29^{+0.28}_{-0.30}$	-	$3.81 \pm 0.19^{+0.19}_{-0.18}$	
Belle p_ℓ^*, (M_X, q^2) fit [554]	$4.50 \pm 0.27^{+0.20}_{-0.22}$	$4.62 \pm 0.28^{+0.13}_{-0.13}$	$4.62 \pm 0.28^{+0.09}_{-0.10}$	$4.50 \pm 0.30^{+0.20}_{-0.20}$	-
BABAR M_X [555]	$4.24 \pm 0.19^{+0.25}_{-0.25}$	$4.47 \pm 0.20^{+0.19}_{-0.24}$	$4.30 \pm 0.20^{+0.20}_{-0.21}$	$3.83 \pm 0.18^{+0.20}_{-0.19}$	-
BABAR M_X [555]	$4.03 \pm 0.22^{+0.22}_{-0.22}$	$4.22 \pm 0.23^{+0.21}_{-0.27}$	$4.10 \pm 0.23^{+0.16}_{-0.17}$	$3.75 \pm 0.21^{+0.18}_{-0.18}$	-
BABAR M_X, q^2 [555]	$4.32 \pm 0.23^{+0.26}_{-0.28}$	$4.24 \pm 0.22^{+0.18}_{-0.21}$	$4.33 \pm 0.23^{+0.24}_{-0.27}$	$3.75 \pm 0.20^{+0.17}_{-0.17}$	$4.50 \pm 0.24^{+0.29}_{-0.29}$
BABAR P_+ [555]	$4.09 \pm 0.25^{+0.25}_{-0.25}$	$4.17 \pm 0.25^{+0.28}_{-0.37}$	$4.25 \pm 0.26^{+0.26}_{-0.27}$	$3.57 \pm 0.22^{+0.19}_{-0.18}$	-
BABAR p_ℓ^*, (M_X, q^2) fit [555]	$4.33 \pm 0.24^{+0.19}_{-0.21}$	$4.45 \pm 0.24^{+0.12}_{-0.13}$	$4.44 \pm 0.24^{+0.09}_{-0.10}$	$4.33 \pm 0.24^{+0.19}_{-0.19}$	-
BABAR p_ℓ^* [555]	$4.34 \pm 0.27^{+0.20}_{-0.21}$	$4.43 \pm 0.27^{+0.13}_{-0.13}$	$4.43 \pm 0.27^{+0.09}_{-0.11}$	$4.28 \pm 0.27^{+0.19}_{-0.19}$	-
Belle M_X, q^2 [567]	-	-	-	-	$5.01 \pm 0.39^{+0.32}_{-0.32}$
Average	$4.44^{+0.13+0.21}_{-0.14-0.22}$	$3.99 \pm 0.10^{+0.09}_{-0.10}$	$4.32 \pm 0.12^{+0.12}_{-0.13}$	$3.99 \pm 0.13^{+0.18}_{-0.12}$	$4.62 \pm 0.20^{+0.29}_{-0.29}$

Importance of the model used to simulate the signal

THE NNVUB PROJECT

K.Healey, C. Mondino, PG, 1604.07598

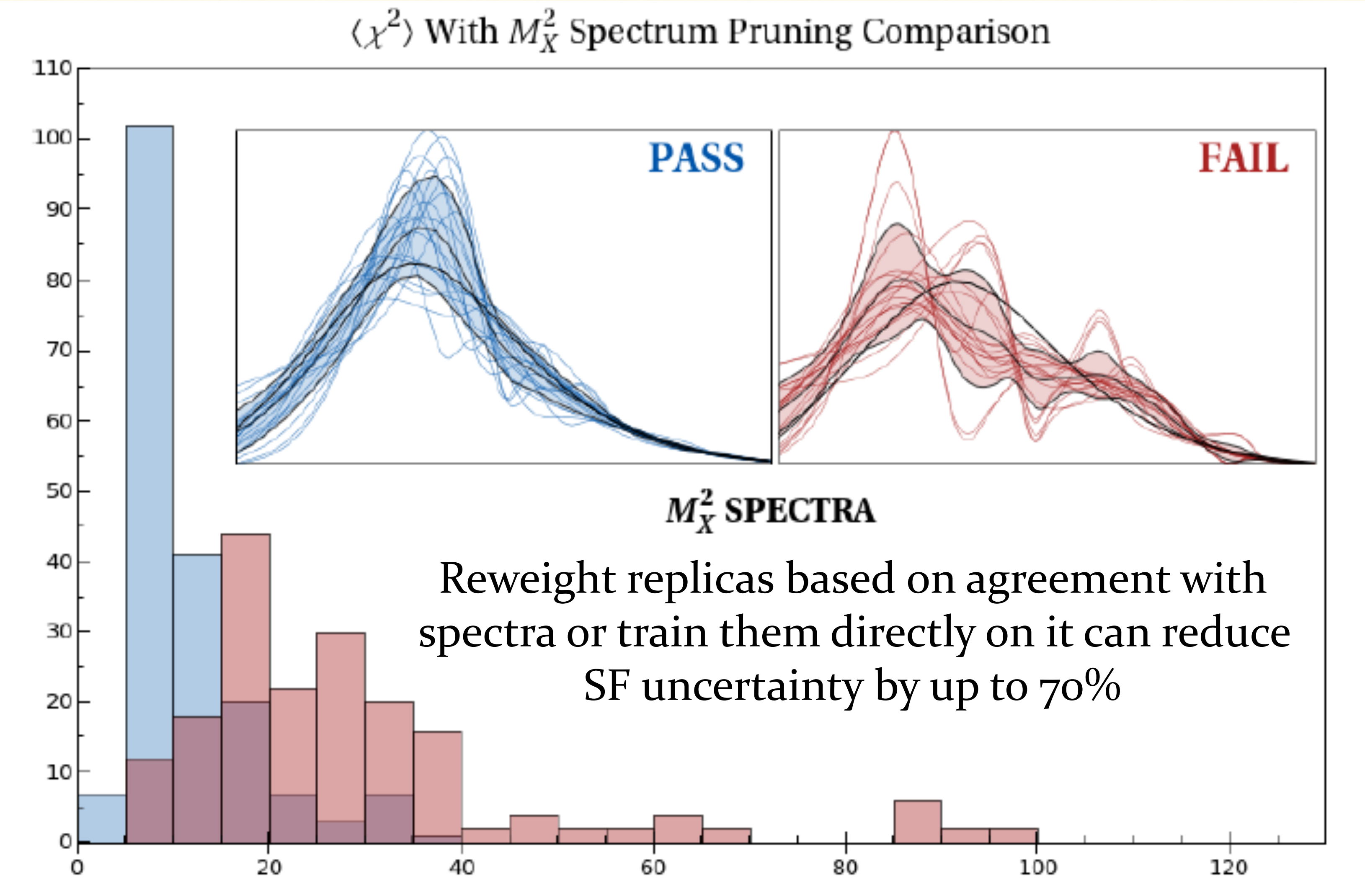


- Use **Artificial Neural Networks** to parameterize shape functions without bias and extract V_{ub} from theoretical constraints and data, together with HQE parameters in a model independent way (without assumptions on functional form). Similar to NNPDF. Applies to $b \to u l \nu$, $b \to s \gamma$, $b \to s l^+ l^-$

- Belle-II will be able to measure some kinematic distributions, thus constraining directly the shape functions. NNVub will provide a flexible tool to analyse data.

PROSPECTS @ BELLE-II

- Learning @ Belle-II from kinematic distributions, e.g. M_X spectrum
- OPE parameters checked/improved in $b \to u l \nu$ (moments): global NN+OPE fit
- alternative approach SIMBA
  Bernlochner, Tackmann, Ligeti, Stewart
- include all relevant information with correlations
- check signal dependence at endpoint
- full phase space implementation of α_s^2 and α_s/m_b^2 corrections
- model/exclude high q^2 tail



Reweight replicas based on agreement with spectra or train them directly on it can reduce SF uncertainty by up to 70%

At Belle-II we can hope to bring inclusive V_{ub} at almost the same level as V_{cb}

CONCLUSIONS

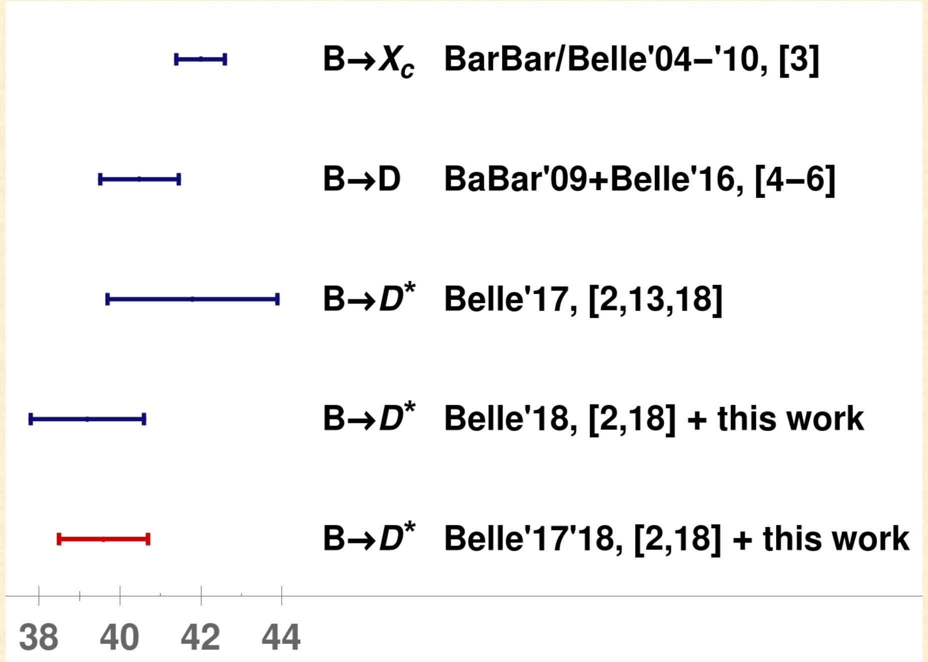
- Revisiting the exclusive b→c decays has been useful: uncertainties were underestimated. Several lattice coll. are computing all necessary FFs, in parallel with Belle-II improved measurements (also for the inclusive moments).

- Inclusive/Exclusive tensions remain, but weaker. Hopefully, they will disappear.

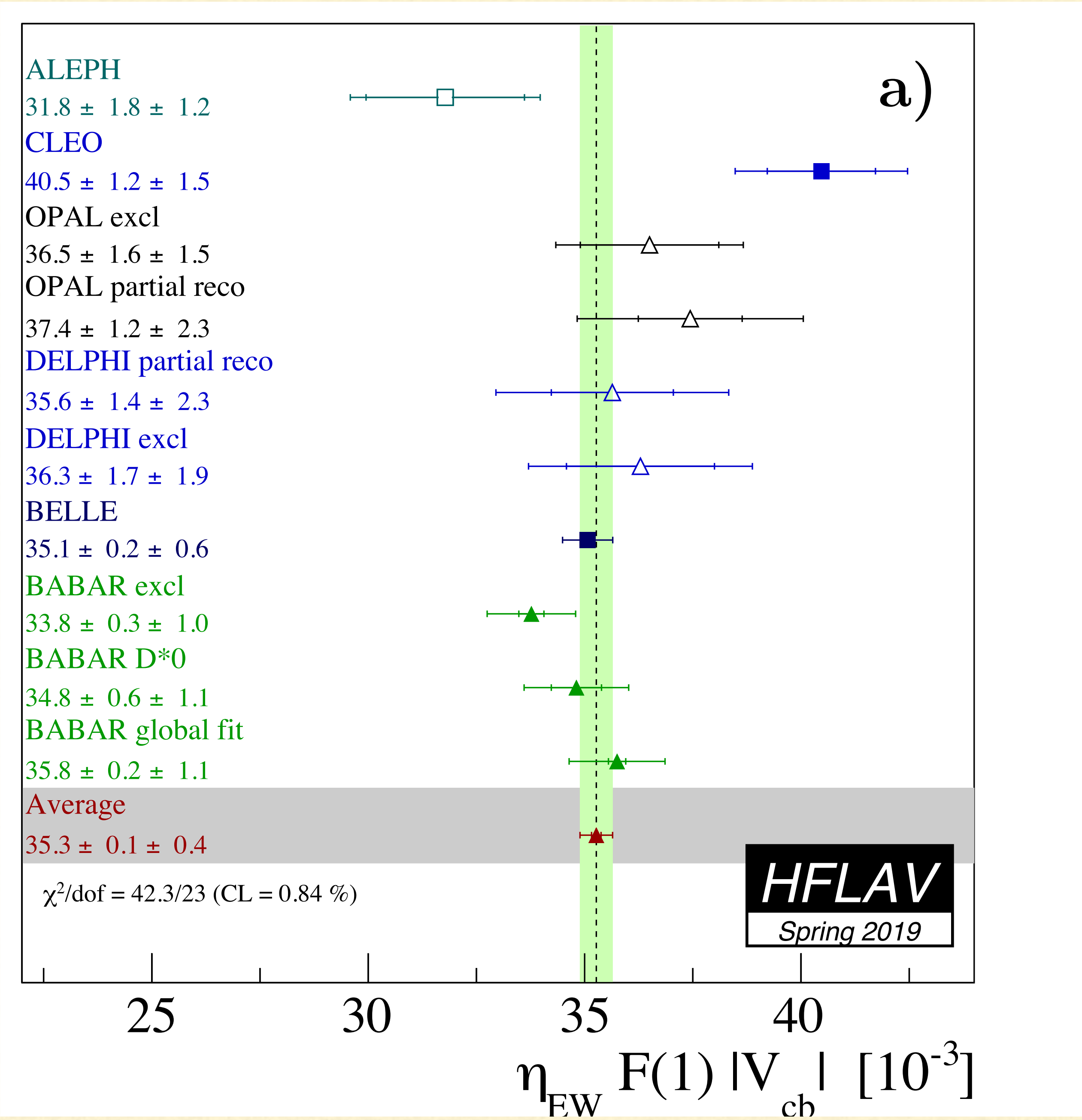
- Experiments should **provide deconvoluted spectra** or alternative but equivalent information. Theoretical prejudice is transient by definition and should never be hardwired into precision measurements.

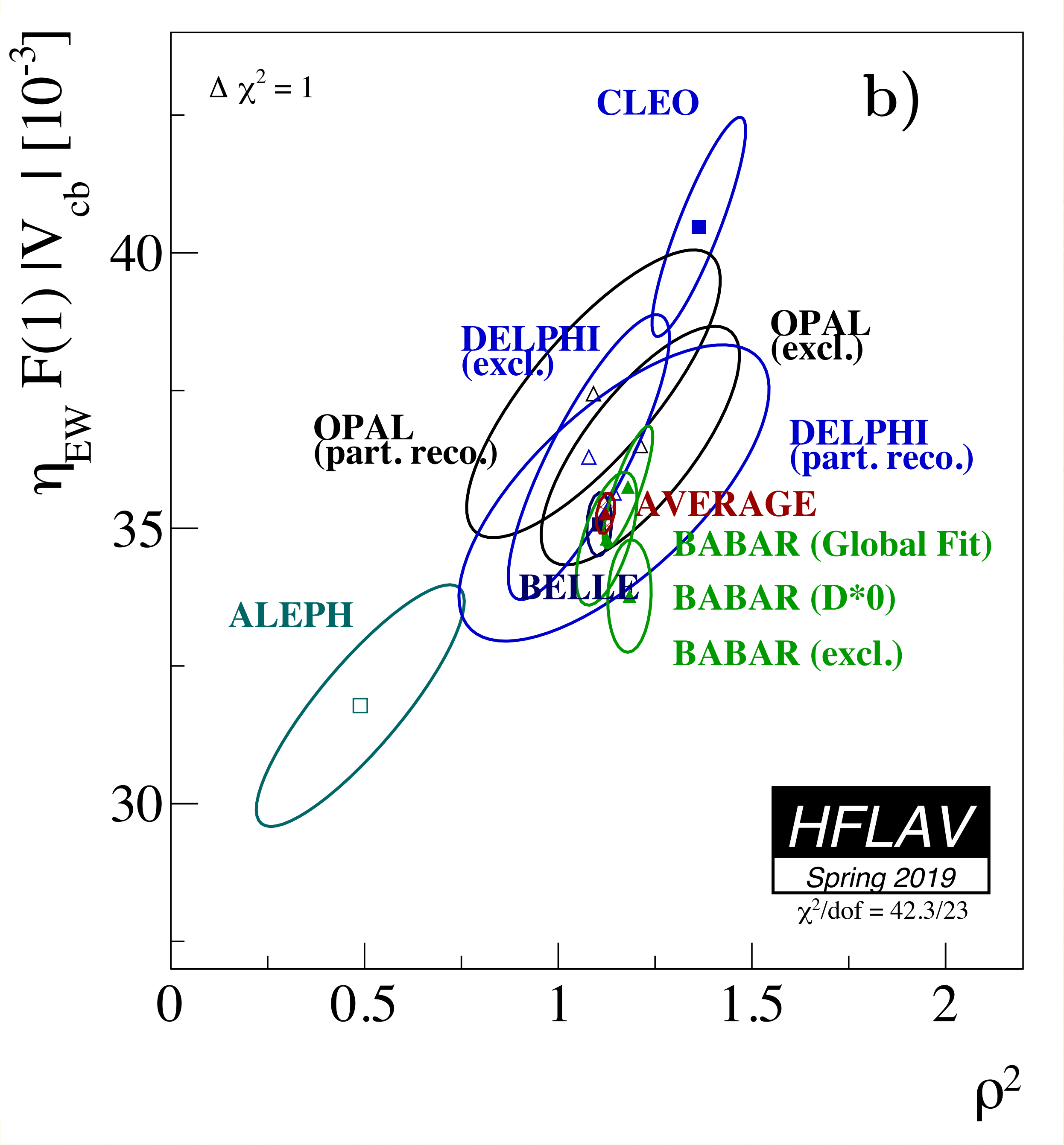
- Lattice calculations may have an impact on inclusive analyses: unexplored land.

- Something is moving also for V_{ub} and more will come by the enhanced possibilities at Belle-II

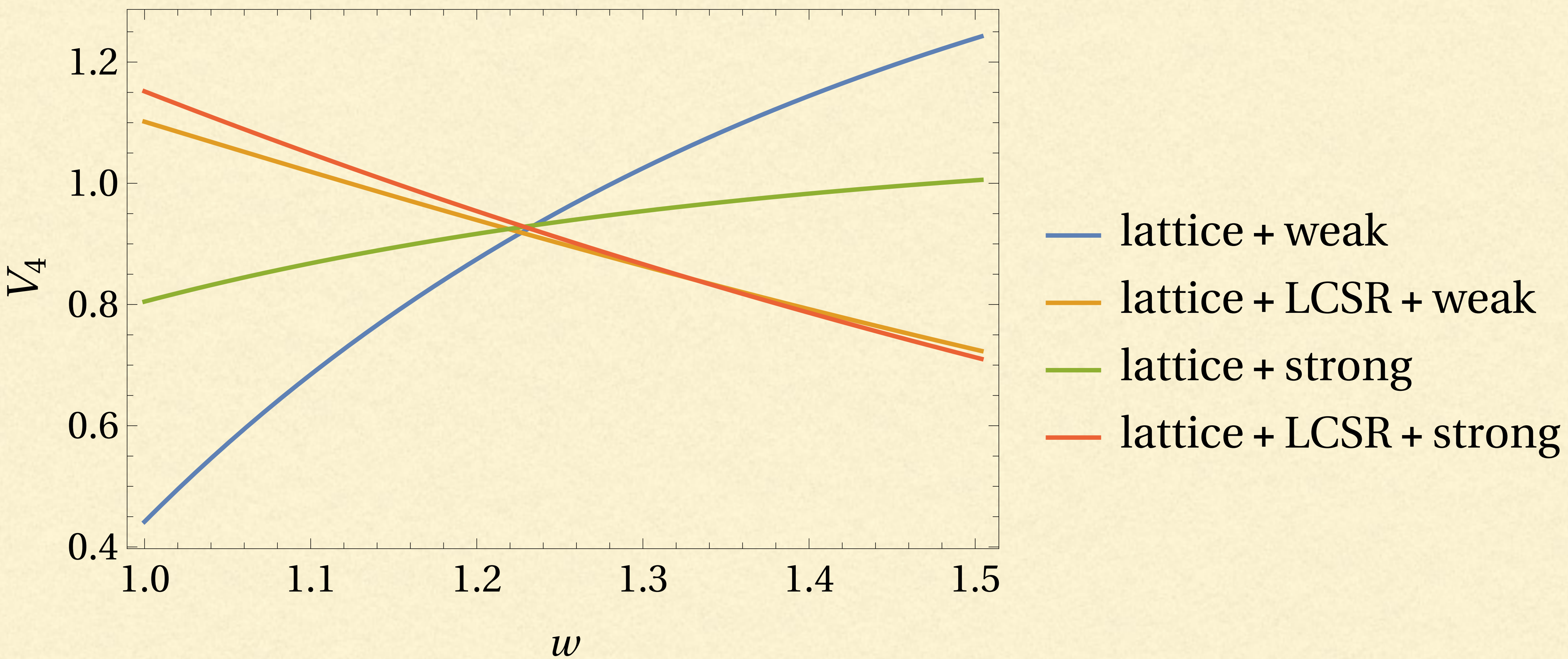


BACKUP


ALEPH
31.8 ± 1.8 ± 1.2
CLEO
40.5 ± 1.2 ± 1.5
OPAL excl
36.5 ± 1.6 ± 1.5
OPAL partial reco
37.4 ± 1.2 ± 2.3
DELPHI partial reco
35.6 ± 1.4 ± 2.3
DELPHI excl
36.3 ± 1.7 ± 1.9
BELLE
35.1 ± 0.2 ± 0.6
BABAR excl
33.8 ± 0.3 ± 1.0
BABAR D*0
34.8 ± 0.6 ± 1.1
BABAR global fit
35.8 ± 0.2 ± 1.1
Average
35.3 ± 0.1 ± 0.4
a)
χ²/dof = 42.3/23 (CL = 0.84 %)
HFLAV
Spring 2019
25
30
35
40
η_EW F(1) |V_cb| [10^-3]


Δ χ² = 1
b)
CLEO
DELPHI (excl.)
OPAL (excl.)
OPAL (part. reco.)
DELPHI (part. reco.)
AVERAGE
BABAR (Global Fit)
BELLE
BABAR (D*0)
ALEPH
BABAR (excl.)
HFLAV
Spring 2019
χ²/dof = 42.3/23
η_EW F(1) |V_cb| [10^-3]
40
35
30
0
0.5
1
1.5
2
ρ²

SOMETIMES UNITARITY IS NOT ENOUGH…



The BGL fit with 2017 data tends to prefer **unphysical solutions** for V_4 with a positive w-slope. Imposing LCSR at w_{max} cures the problem, but one could equally well ask for a negative slope at w=1 or use HQET ratios with appropriate uncertainty. They all tend to lower V_{cb} slightly.

The size of NLO corrections varies strongly. Some ff are protected by Luke's theorem (no 1/m corrections at zero recoil), others are linked by kinematic relations at max recoil to those protected

NNLO corrections can be sizeable and are naturally O(10-20)%

$$\frac{F_j(w)}{V_1(w)} = A_j \left[1 + B_j\, w_1 + C_j\, w_1^2 + D_j\, w_1^3 + \dots\right]$$

F_j	A_j	B_j	C_j	D_j
S_1	1.0208	−0.0436	0.0201	−0.0105
S_2	1.0208	−0.0749	−0.0846	0.0418
S_3	1.0208	0.0710	−0.1903	0.0947
P_1	1.2089	−0.2164	0.0026	−0.0007
P_2	0.8938	−0.0949	0.0034	−0.0009
P_3	1.0544	−0.2490	0.0030	−0.0008
V_1	1	0	0	0
V_2	1.0894	−0.2251	0.0000	0.0000
V_3	1.1777	−0.2651	0.0000	0.0000
V_4	1.2351	−0.1492	−0.0012	0.0003
V_5	1.0399	−0.0440	−0.0014	0.0004
V_6	1.5808	−0.1835	−0.0009	0.0003
V_7	1.3856	−0.1821	−0.0011	0.0003
A_1	0.9656	−0.0704	−0.0580	0.0276
A_2	0.9656	−0.0280	−0.0074	0.0023
A_3	0.9656	−0.0629	−0.0969	0.0470
A_4	0.9656	−0.0009	−0.1475	0.0723
A_5	0.9656	0.3488	−0.2944	0.1456
A_6	0.9656	−0.2548	0.0978	−0.0504
A_7	0.9656	−0.0528	−0.0942	0.0455

SENSITIVITY TO HIGHER POWER CORRECTIONS

Moderate changes to the leading HQE m.e.