CHALLENGES IN SEMILEPTONIC B DECAYS

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The importance of $|V_{cb}|$

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

V_{cb} plays an important role in UT

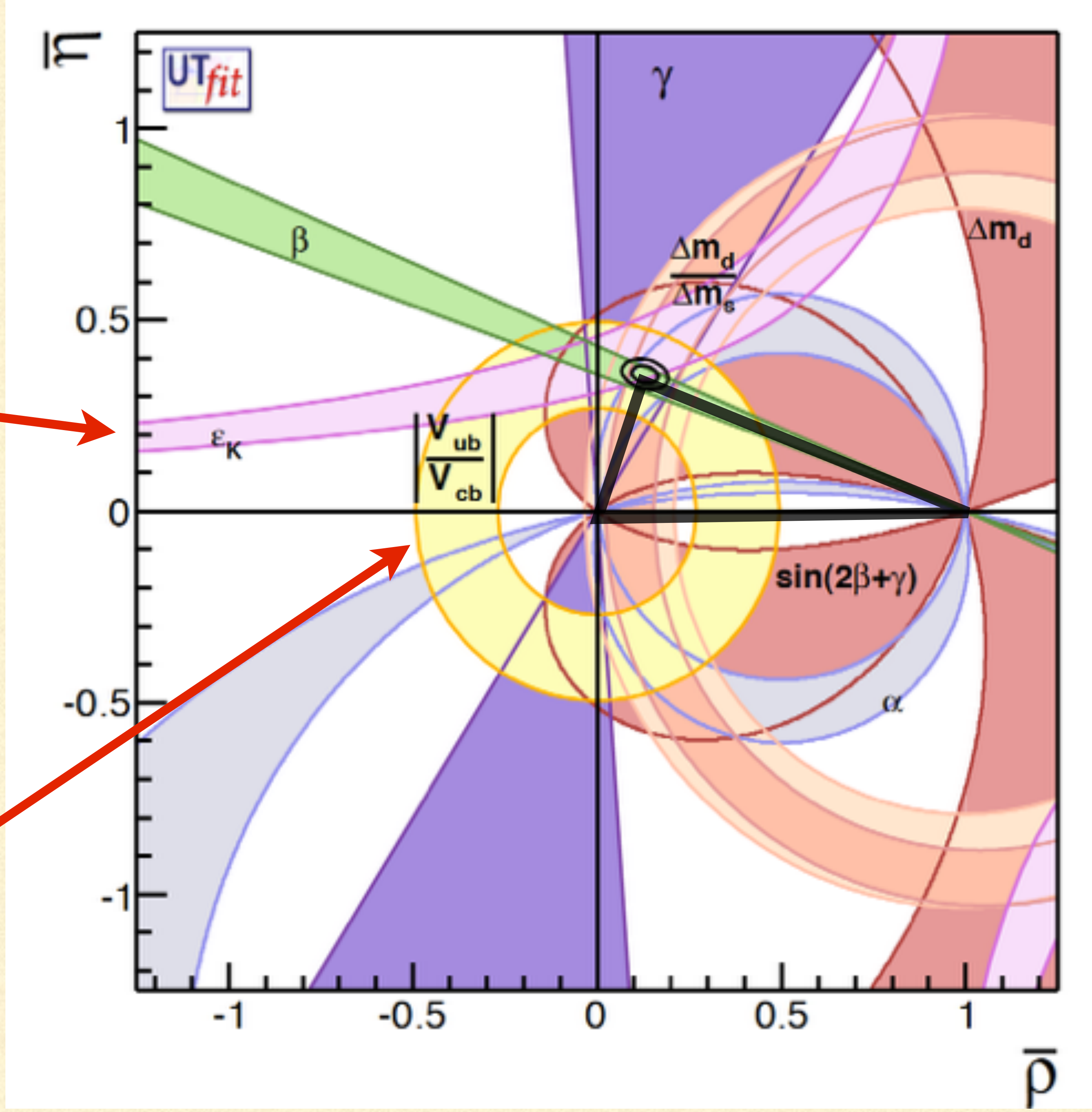
$$\varepsilon_K \approx x|V_{cb}|^4 + \ldots$$

and in the prediction of FCNC:

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

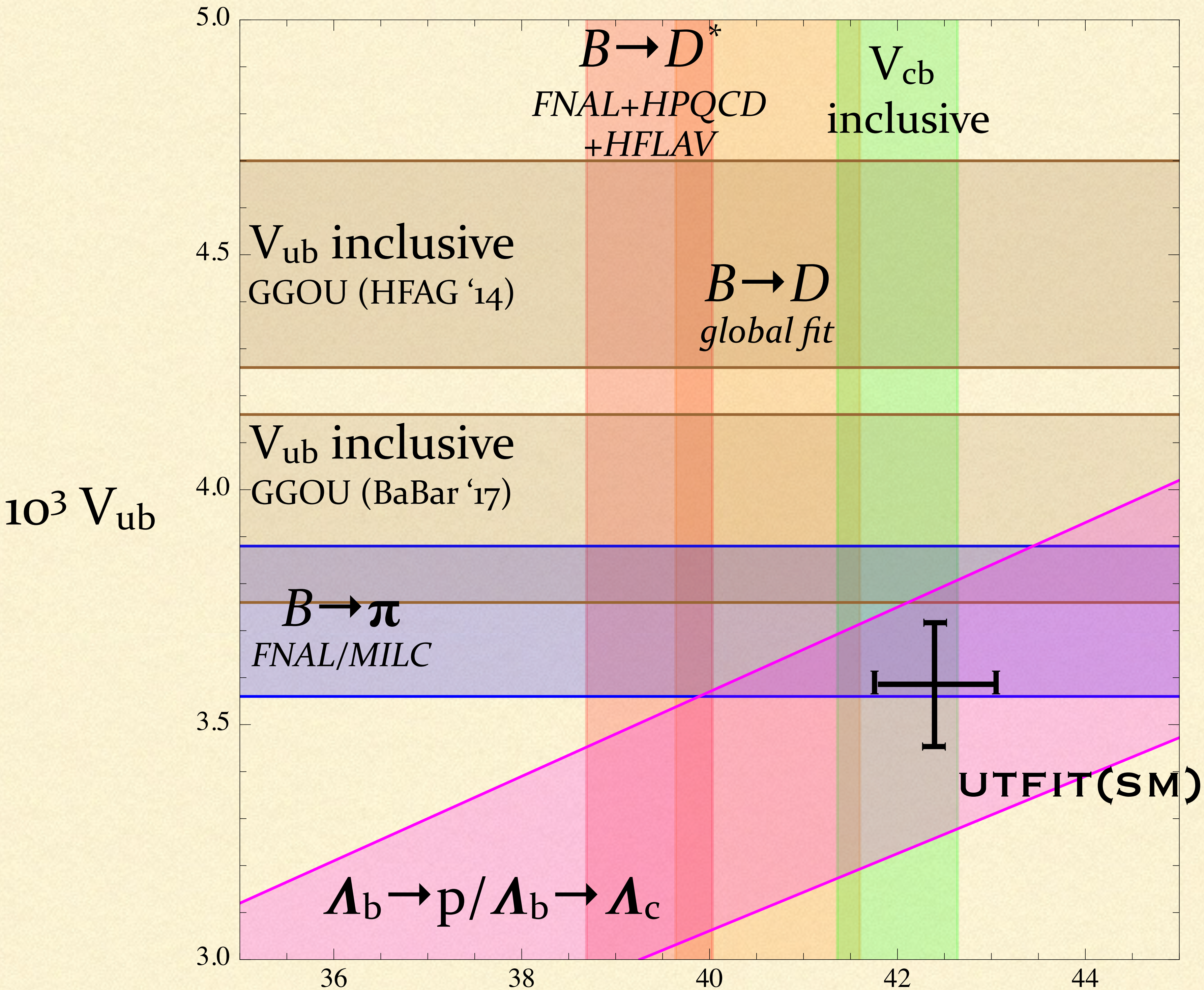
where it often dominates the theoretical uncertainty.

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



Since several years, exclusive decays prefer smaller $|V_{ub}|$ and $|V_{cb}|$

STATUS of V_{cb} and V_{ub}



New V_{ub} incl
by Babar
in agreement
with exclusive
PRD 95 (2017) 7, 072001

New HPQCD
$B\to D^*$ result
at zero recoil
arXiv:1711.11013

New Belle $B\to D^*$
result: with FNAL
V_{cb}=37.4(1.3) 10^{-3}
arXiv:1702.01521

UNLIKELY PLACE FOR NEW PHYSICS?

The difference in V_{cb} incl vs excl D^* with FNAL/MILC form factor is **large**: 3σ or about 8%. The perturbative corrections to inclusive V_{cb} total 5%…

Right Handed currents now excluded since

$$|V_{cb}|_{incl} \simeq |V_{cb}|\Big(1 + \frac{1}{2}|\delta|^2\Big)$$

$$|V_{cb}|_{B\to D^*} \simeq |V_{cb}|\Big(1 - \delta\Big)$$

$$|V_{cb}|_{B\to D} \simeq |V_{cb}|\Big(1 + \delta\Big)$$

Chen,Nam,Crivellin,Buras,Gemmler,
Isidori,Mannel,...

$$\delta = \epsilon_R \frac{\tilde{V}_{cb}}{V_{cb}} \approx 0.08$$

Most general SU(2) invariant dim 6 NP (without RH light neutrino) can explain results, but it is incompatible with $Z \to b\bar{b}$ data

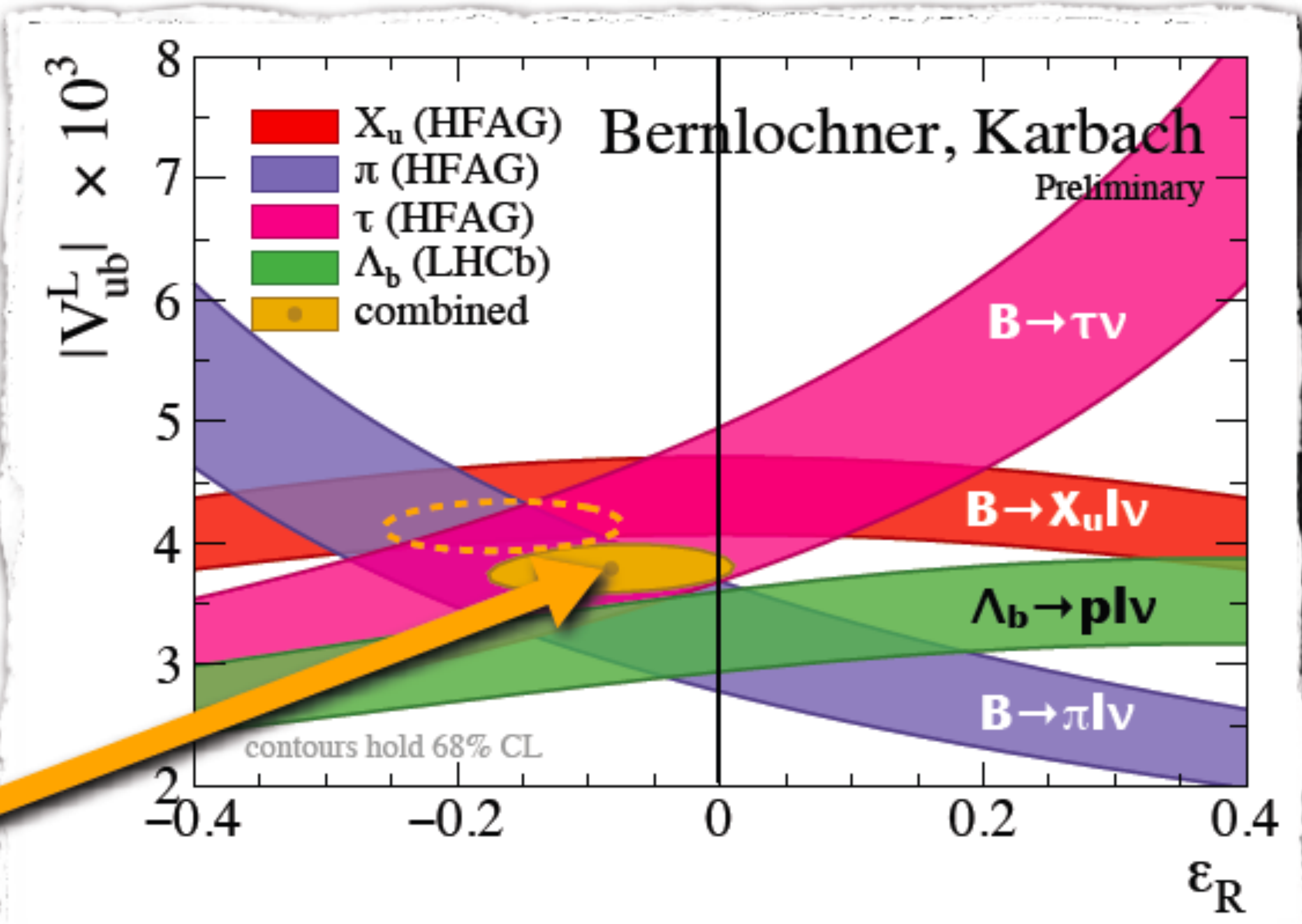
Crivellin, Pokorski 1407.1320

(though this may not apply to the tensor operator Colangelo, De Fazio)

RH CURRENTS DON'T HELP V_{ub} EITHER

- Can ease $|V_{ub}|$ tension by allowing small right-handed contribution to Standard-Model weak current [Crivellin, PRD81 (2010) 031301]
- RH currents disfavored by Λ_b decays (taking $|V_{cb}|$ from $B\to D^*l\nu$ + HFAG to obtain $|V_{ub}|$)

p=0.03

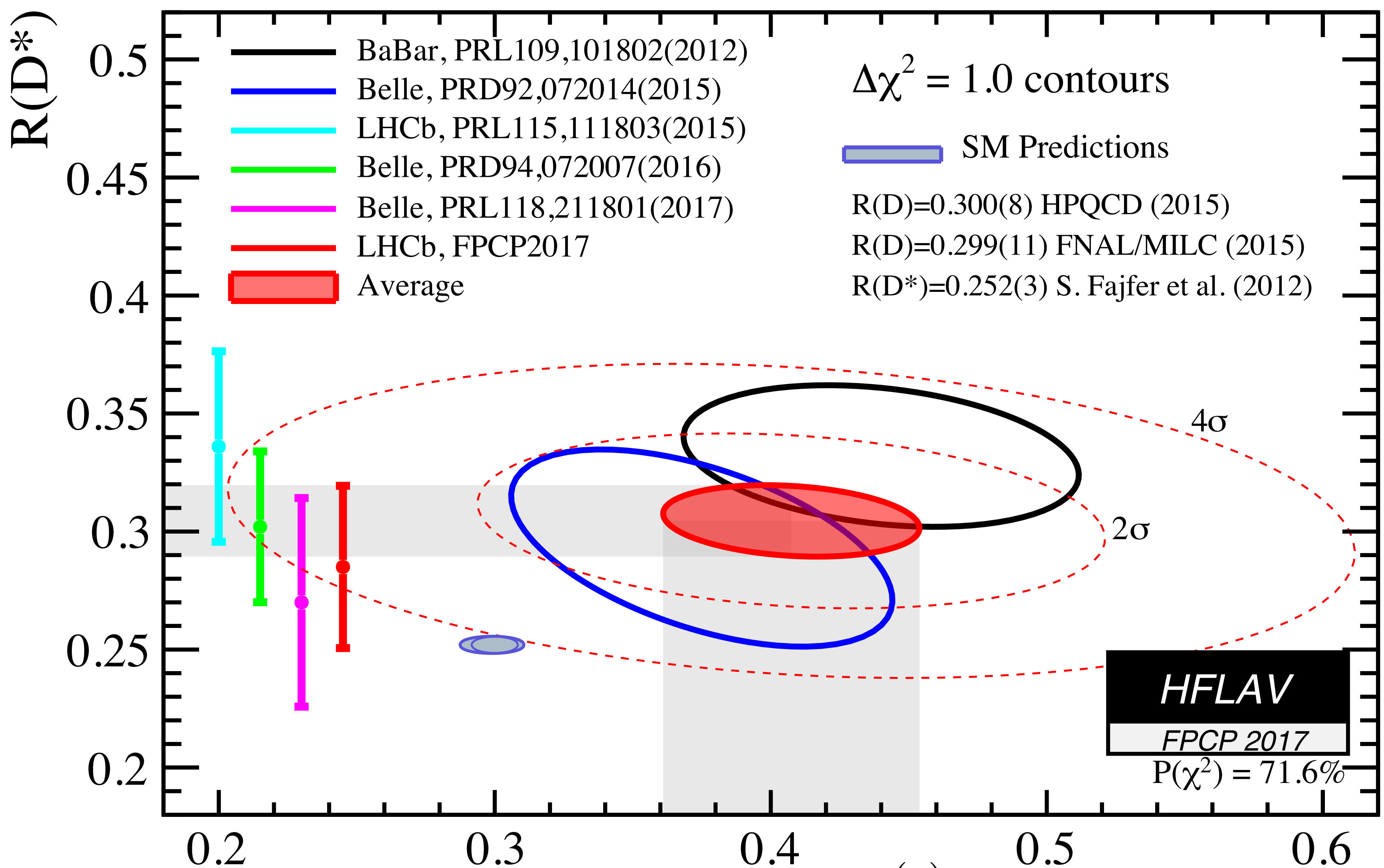


[based on Bernlochner *et al.*, PRD 90, 094003 (2014)]

R. van de Water

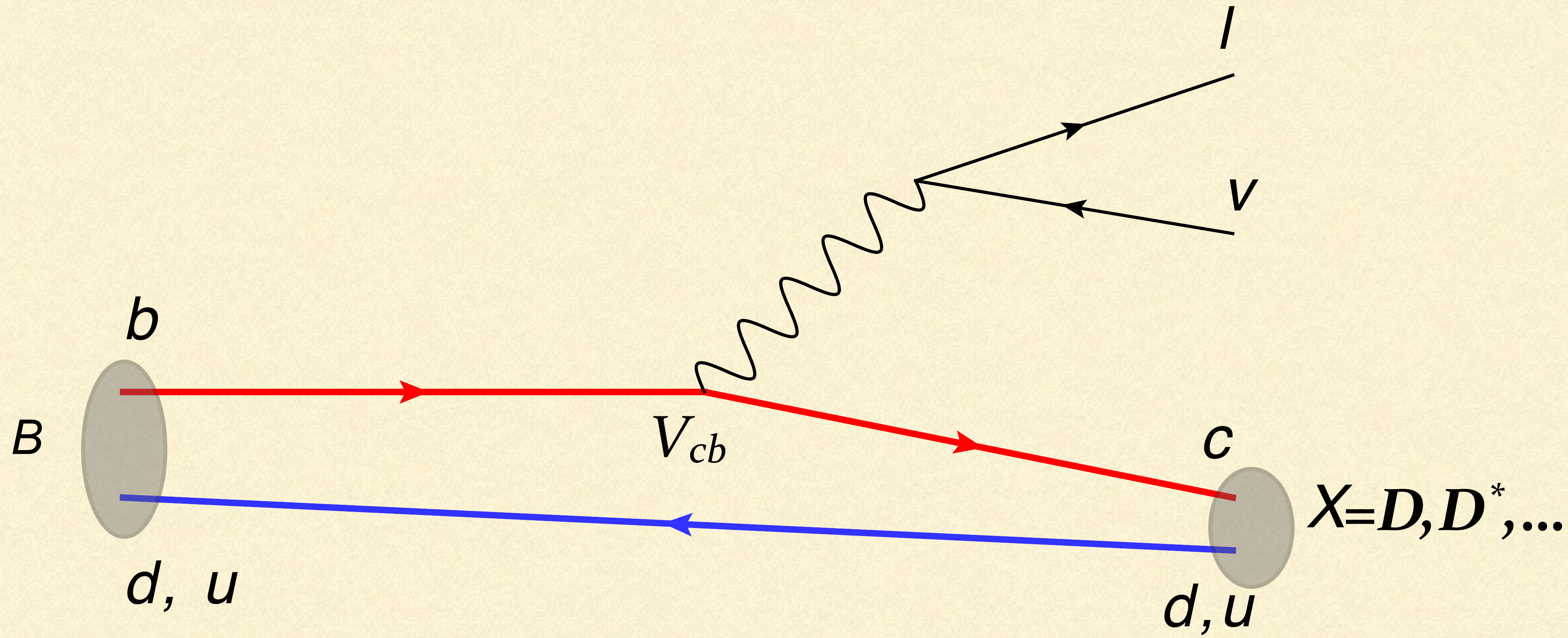
Also here SU(2)xU(1) invariant NP cannot explain discrepancies 1407.1320

LEPTON FLAVOUR UNIVERSALITY VIOLATION?



$$R(D^{(*)}) = \frac{\mathcal{B}(B \to D^{(*)}\tau\nu)}{\mathcal{B}(B \to D^{(*)}\mu\nu)}$$

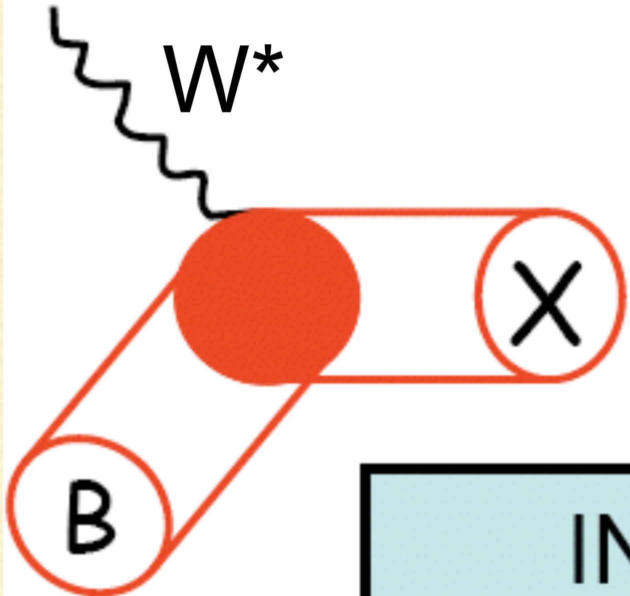
SEMILEPTONIC B DECAYS



Allow for the determination of V_{cb} , which drops out of $R(D,D^*)$.
There are 1(2) and 3(4) FFs for D and D^* for light (heavy) leptons, for instance

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

INCLUSIVE VS EXCLUSIVE *B* DECAYS



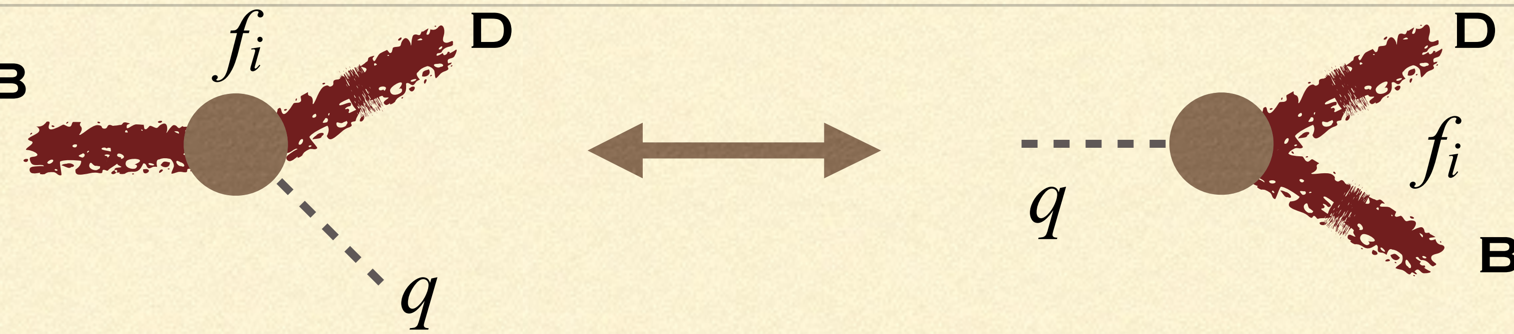
Simplicity: ew current probes B dynamics

INCLUSIVE	EXCLUSIVE
OPE: non-pert physics described by B matrix elemnts of local operators can be extracted by exp suppressed by $1/m_b^2$	Form factors: in general computed by non pert methods (lattice, sum rules,...) symmetry can provide normalization

Even when a lattice QCD calculation is available, it is generally limited to the high q^2 region: need parametrization

MODEL INDEPENDENT FF PARAMETRIZATION

CROSSING + ANALITYCITY

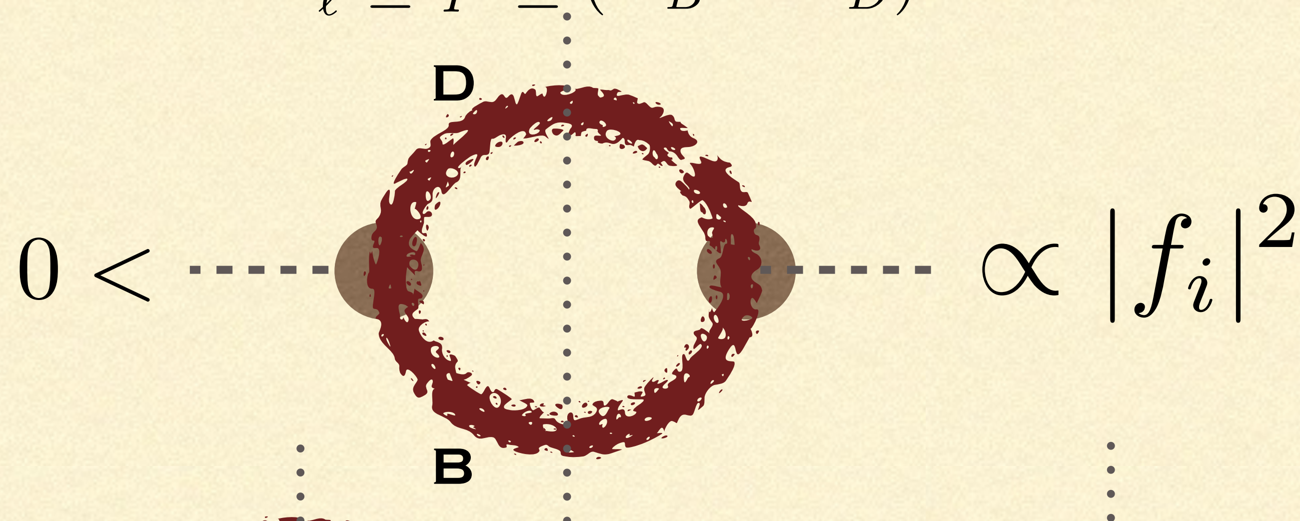


PHYSICAL SEMILEPTONIC REGION

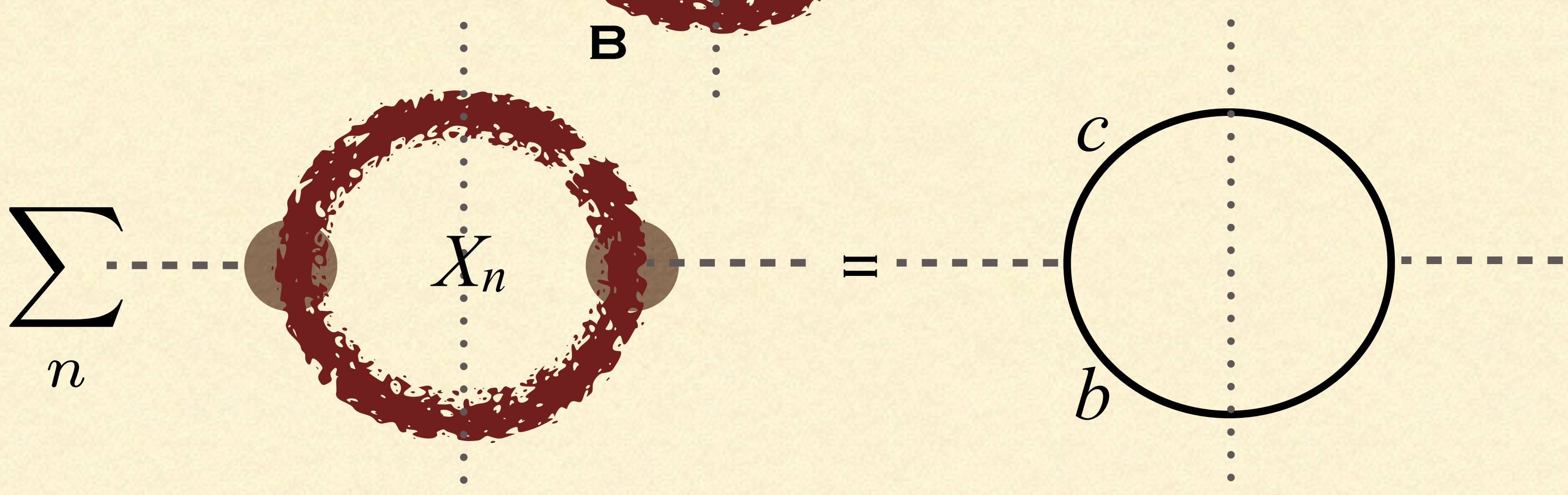
$m_\ell^2 \leq q^2 \leq (m_B - m_D)^2$

2-POINT CORRELATOR CUTS

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



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



+PERT CORR

(+CONDENSATES)

USING QUARK-HADRON DUALITY

UNITARITY CONSTRAINTS

$$\left(-g^{\mu\nu}+\frac{q^\mu q^\nu}{q^2}\right)\Pi^T(q^2)+\frac{q^\mu q^\nu}{q^2}\Pi^L(q^2)\equiv i\int d^4x\, e^{iqx}\langle 0|T J^\mu(x) J^{\dagger\nu}(0)|0\rangle$$

$$\chi^L(q^2)=\frac{\partial\Pi^L}{\partial q^2},\qquad \chi^T(q^2)=\frac{1}{2}\frac{\partial^2\Pi^T}{\partial(q^2)^2}$$

SATISFY UNSUBTRACTED DISP REL, PERT CALCULATION FOR $q^2=0$ Boyd, Grinstein, Lebed 1995

$$\chi^T_V(0)=[5.883+0.552_{\alpha_s}+0.050_{\alpha_s^2}]\ 10^{-4}\,\text{GeV}^{-2}=6.486(48)\ 10^{-4}\,\text{GeV}^{-2}$$

$$\chi^L_V(0)=[5.456+0.782_{\alpha_s}-0.034_{\alpha_s^2}]\ 10^{-3}=6.204(81)\ 10^{-3}$$ & analogous for axial etc

USING UP-TO-DATE QUARK MASSES AND 3LOOP CALCULATION Grigo et al 2012

$$\tilde\chi^T(0)=\chi^T(0)-\sum_{n=1,2}\frac{f_n^2(B_c^*)}{M_n^4(B_c^*)}$$

SUBTRACT BOUND STATE CONTRIBUTIONS

Type	Mass (GeV)	Decay constants (GeV)
1^-	6.329(3)	0.422(13)
1^-	6.920(20)	0.300(30)
1^-	7.020	
1^-	7.280	
0^+	6.716	
0^+	7.121	

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

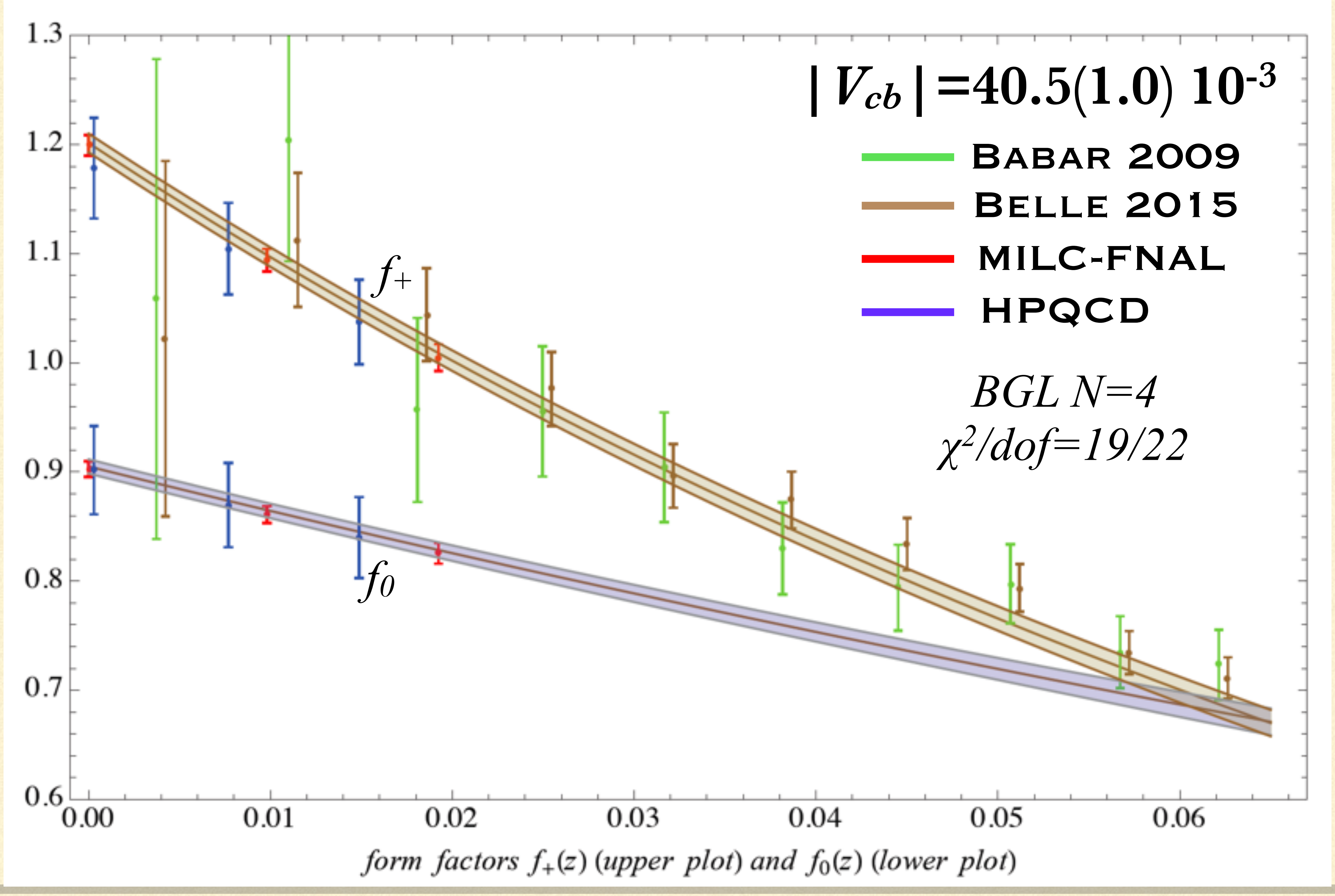
TRUNCATED AT ORDER N

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

WEAK UNITARITY CONSTRAINTS
assuming saturation
by single hadron channel

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

Bigi, PG 1606.08030



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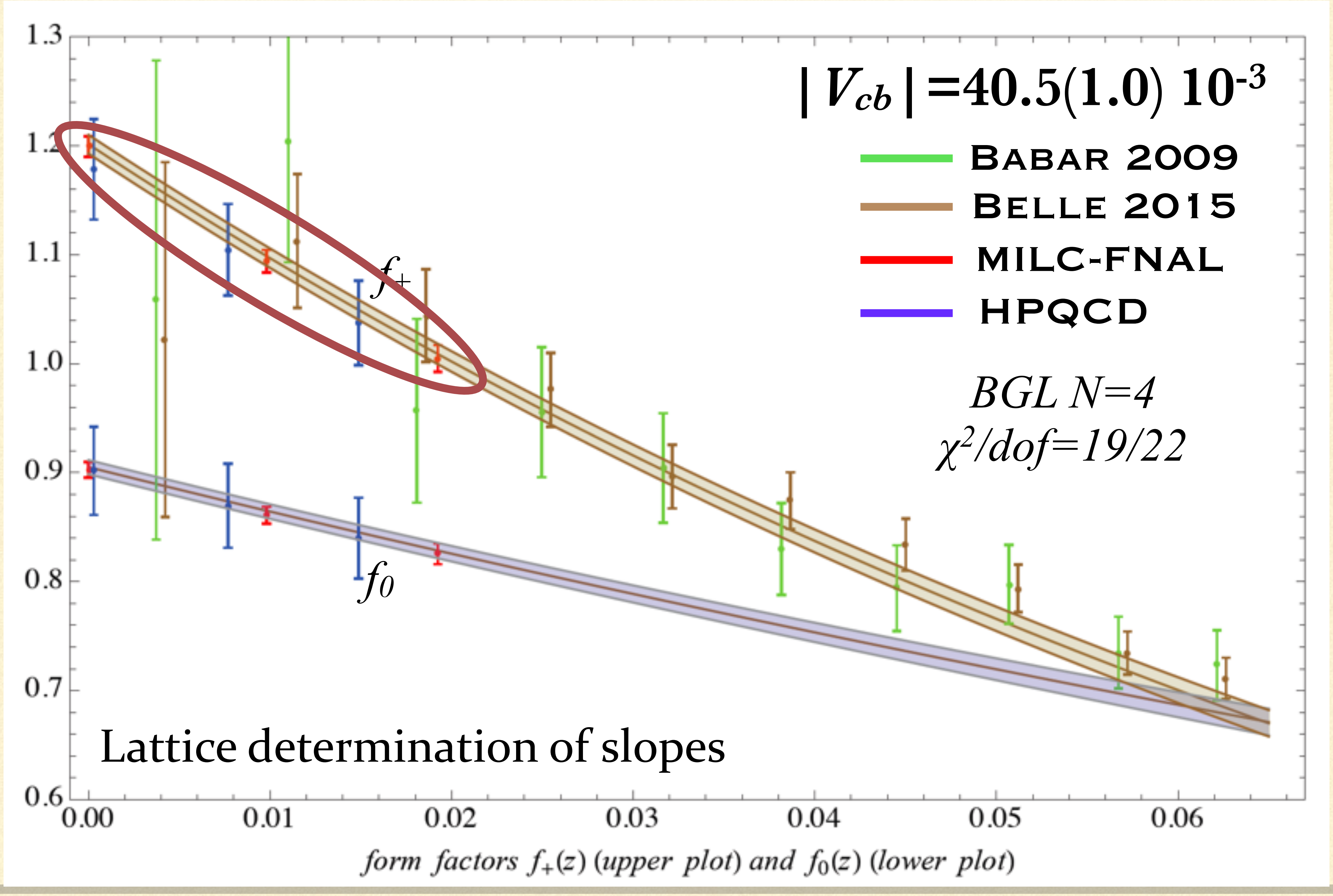


Ref.	$R(D)$	Deviation
Experiment [HFLAV update]	$0.407(39)(24)$	—
2016/17 theory results, using new lattice and exp. data:		
[Bigi Gambino 1606.08030]	$0.299(3)$	2.4σ
[Bernlochner Ligeti Papucci Robinson 1703.05330]	$0.299(3)$	2.4σ
[Jaiswal Nandi Patra 1707.09977]	$0.302(3)$	2.3σ
2012 theory results:		
[Fajfer Kamenik Nisandzic 1203.2654]	$0.296(16)$	2.3σ
[Celis Jung Li Pich 1210.8443]	$0.296\binom{8}{6}(15)$	2.3σ
[Tanaka Watanabe 1212.1878]	$0.305(12)$	2.2σ

LATTICE ONLY RESULTS

HPQCD 2015: 0.300(8), FNAL/MILC 2015: 0.299(11)

Strong Unitarity Bounds

Information on other channels makes the constraints 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

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

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 ff… up to < 2% uncertainty, never included in exp analysis.

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

nice: only 2 parameters! but theoretical uncertainty?

$|V_{cb}|$ from $B \to D^* l\nu$ (usual way)

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

Exp error only ~1.3%: $\mathcal{F}(1)\eta_{ew}|V_{cb}| = 35.61(45) \times 10^{-3}$
(extrapolation with CLN parameterization)

Two unquenched lattice calculations

$\mathcal{F}(1) = 0.906(13)$ **$\mathcal{F}(1) = 0.895(26)$**

Bailey et al 1403.0635 (FNAL/MILC) Harrison et al 1711.11013 (HPQCD)

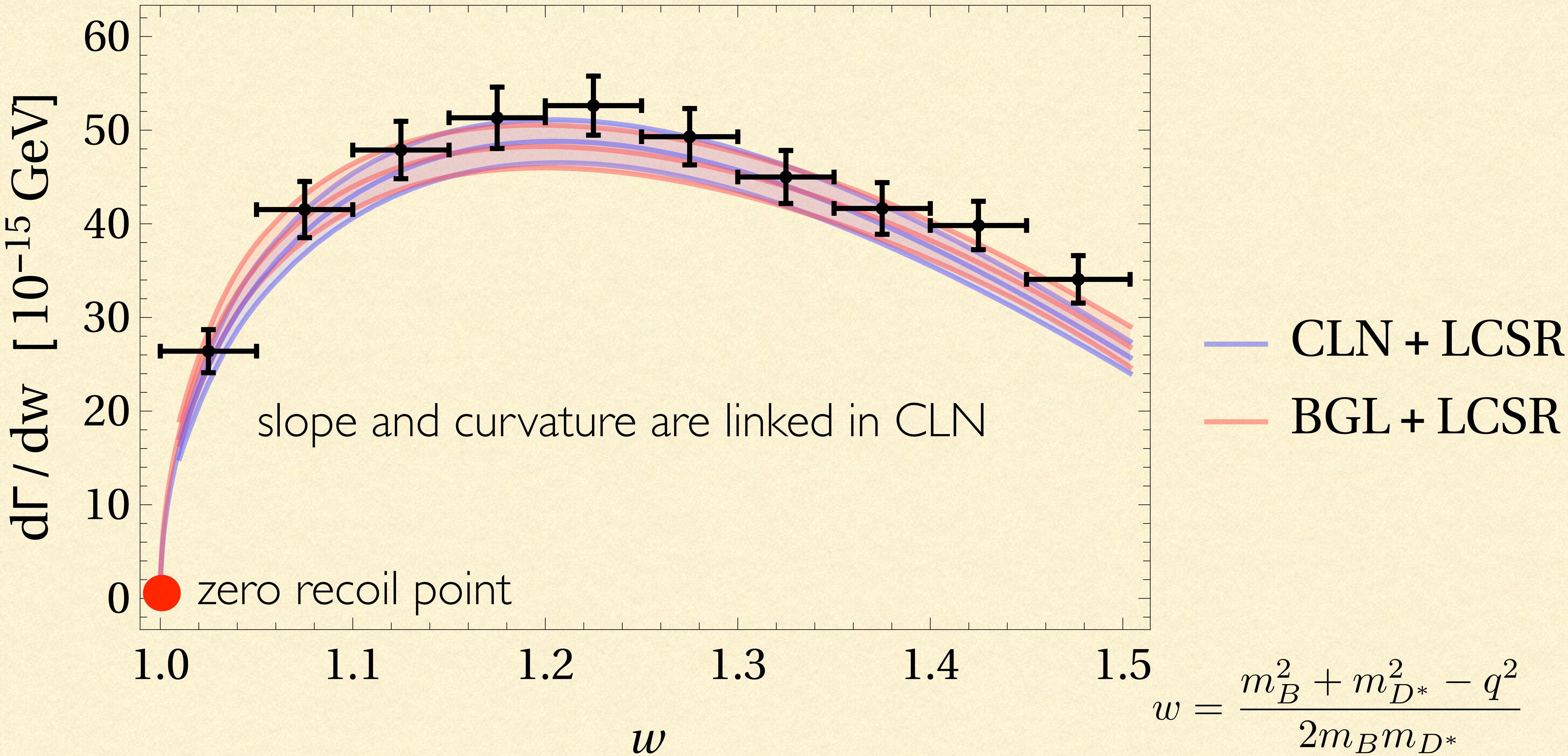
Using their average 0.904(12): $|V_{cb}| = 39.13(75)\ 10^{-3}$

~ 2.9σ or ~ 7% from inclusive determination 42.00(65) 10^{-3}

PG, Healey, Turczyk 2016

2017 preliminary Belle analysis **1702.01521**

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



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

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

HQS breaking in FF relations

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

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

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

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

Roughly $\quad \epsilon_c \sim 0.25, \quad \epsilon_c^2 \sim 0.06 \quad$ 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.:

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

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

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)	$0.0406\,(^{+12}_{-13})$

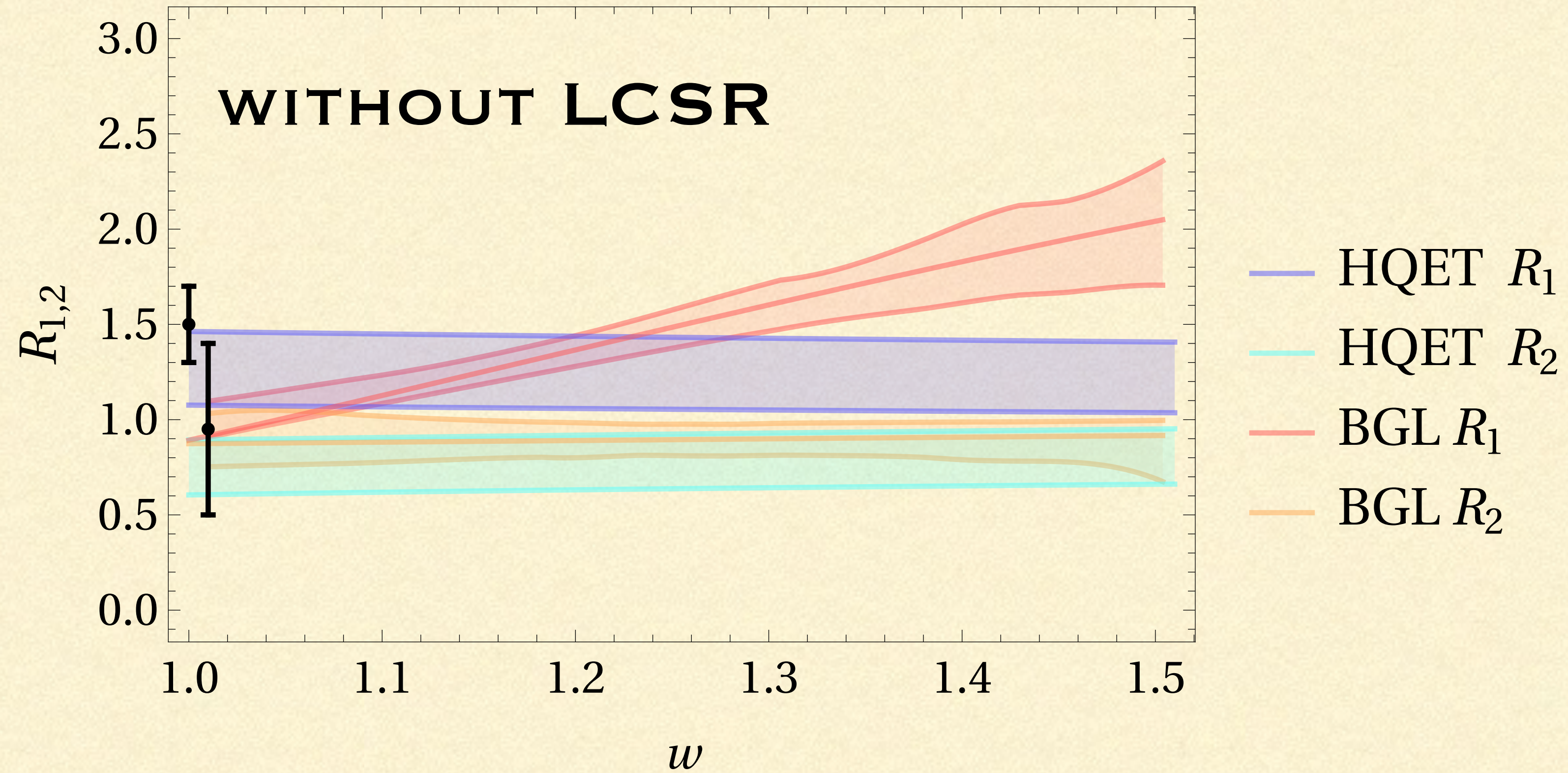
LCSR: Light Cone Sum Rule results from Faller et al, 0809.0222

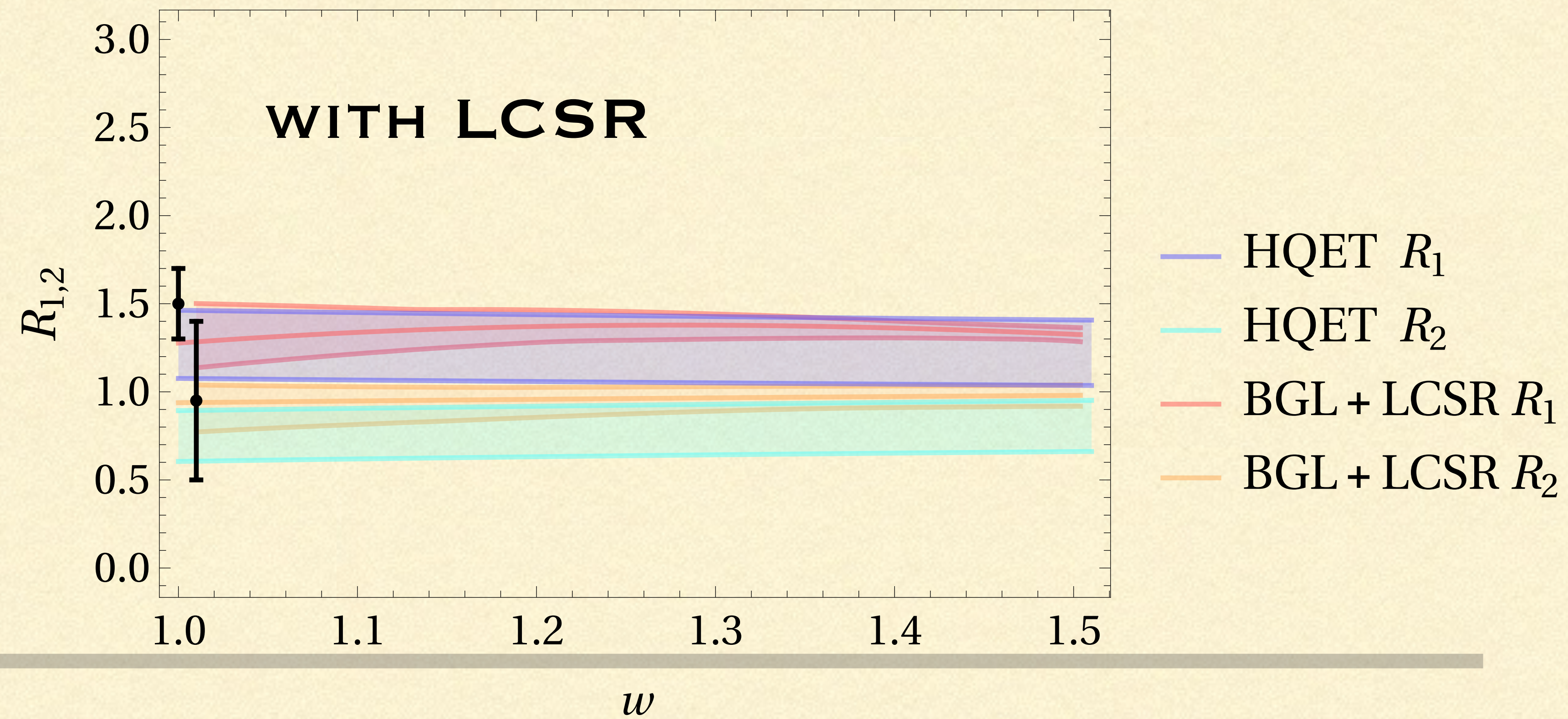
Using strong unitarity bounds brings BGL closer to CLN and reduce uncertainties but 3.5-5% difference persists

CONSISTENCY WITH HQET

Comparison of $R_{1,2}$ from BGL fit vs HQET+QCD sum rule predictions (with parametric + 15% th uncertainty)

black points from preliminary FNAL-MILC calculation according to Bernlochner et al 1708.07134 (before continuum and chiral extrapolations…)





CALCULATION of $R(D^*)$

$$\frac{d\Gamma_\tau}{dw} = \frac{d\Gamma_{\tau,1}}{dw} + \frac{d\Gamma_{\tau,2}}{dw}$$

$$\begin{cases} \dfrac{d\Gamma_{\tau,1}}{dw} = \left(1 - \dfrac{m_\tau^2}{q^2}\right)^2 \left(1 + \dfrac{m_\tau^2}{2q^2}\right) \dfrac{d\Gamma}{dw}, \\ \dfrac{d\Gamma_{\tau,2}}{dw} = k\dfrac{m_\tau^2 (m_\tau^2 - q^2)^2 r^3 (1+r)^2 (w^2-1)^{\frac{3}{2}} P_1(w)^2}{(q^2)^3} \end{cases}$$

±30%!!

$$R(D^*) = R_{\tau,1}(D^*) + R_{\tau,2}(D^*)$$

$$R_{\tau,1}(D^*) = \frac{\int_1^{w_{\tau,\max}} dw\, d\Gamma_{\tau,1}/dw}{\int_1^{w_{\max}} dw\, d\Gamma/dw}$$

$$R_{\tau,2}(D^*) = \frac{\int_1^{w_{\tau,\max}} dw\, d\Gamma_{\tau,2}/dw}{\int_1^{w_{\max}} dw\, d\Gamma/dw}$$

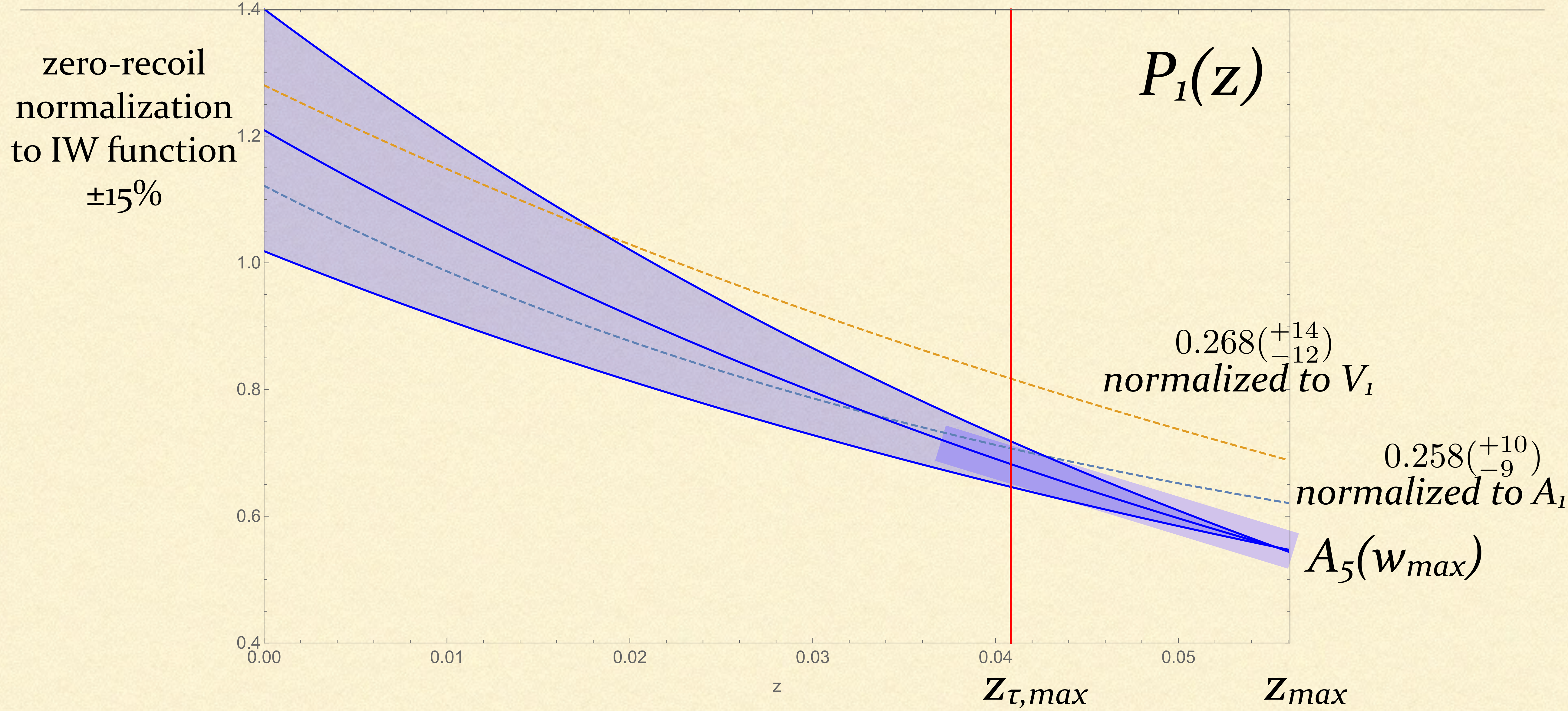
$$w_{\max} \approx 1.56, \qquad w_{\tau,\max} \approx 1.35$$

P_1 is a new FF, for which no lattice calculation is yet available, but its contribution is only ~10%

$$R_{\tau,1} \sim 90\% R_\tau \quad R_{\tau,2} \sim 10\% R_\tau$$

Again, normalize P_1 to one of the FF with proper uncertainties

$$P_1 = (P_1/V_1)_{\rm HQET} V_1^{exp} \qquad P_1 = (P_1/A_1)_{\rm HQET} A_1^{exp} \qquad P_1 = \xi(w)(1+\ldots)_{\rm HQET}$$



Important endpoint constraint

$$P_1(w_{max}) = A_5(w_{max}) = 0.545 \pm 0.025$$

$$R(D^*) = 0.260(5)(6) = 0.260(8)$$

2.6σ from exp

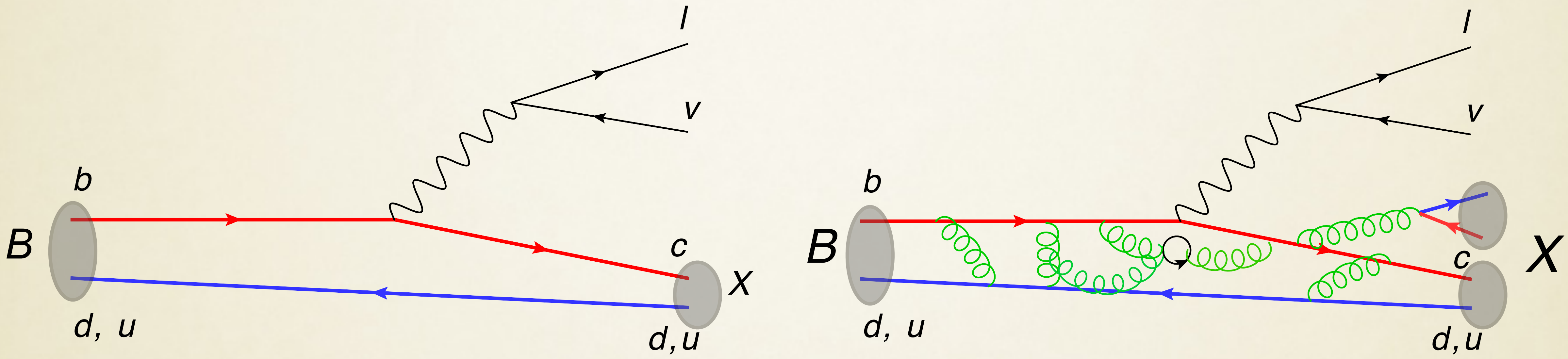
Consistent with previous estimates but with larger uncertainty

Ref.	$R(D^*)$	Deviation
Experiment [HFLAV update]	0.304(13)(7)	—
2017 theory results, using new lattice and exp. data:		
[Bernlochner Ligeti Papucci Robinson 1703.05330]	0.257(3)	3.1σ
Our result [Bigi Gambino Schacht 1707.09509]	0.260(8)	2.6σ
[Jaiswal Nandi Patra 1707.09977]	0.257(5)	3.0σ
2012 theory results:		
[Fajfer Kamenik Nisandzic 1203.2654]	0.252(3)	3.5σ
[Celis Jung Li Pich 1210.8443]	0.252(2)(3)	3.4σ
[Tanaka Watanabe 1212.1878]	0.252(4)	3.4σ

SUMMARY

- **Is the V_{cb} puzzle resolved?** No, but a few pieces fit together. The uncertainty of $B\to D^* l\nu$ was **underestimated** and the result was likely biased: old data should be reanalysed.
- We revisited main ideas behind CLN, using LQCD & exp results and conservative theory uncertainties, and obtained new strong unitarity bounds. We do *not* give a simplified parametrization. Our results provide a **framework for future exp analyses**. ***Lattice will soon settle the matter*** with calculations at non-zero recoil.
- For $R(D^*)$ we know little about P_1 and we have to rely on HQET + QCD sum rules. Hence a larger uncertainty, but the **anomaly persists.** The upcoming LQCD determination of P_1 at zero recoil could cut the uncertainty by ~2.
- Lessons for Belle-II: avoid CLN, document your results in model-indep way to facilitate reanalyses, update backgrounds…

Inclusive decays: basics



- ***Simple idea:*** inclusive decays do not depend on final state, long distance dynamics of the B meson factorizes. An OPE allows to express it in terms of B meson matrix elements of local operators

- The Wilson coefficients are perturbative, matrix elements of local ops parameterize non-pert physics: ***double series in α_s, Λ/m_b***

- Lowest order: decay of a free *b*, linear Λ/m_b absent. Depends on $m_{b,c}$, 2 parameters at $O(1/m_b^2)$, 2 more at $O(1/m_b^3)$...

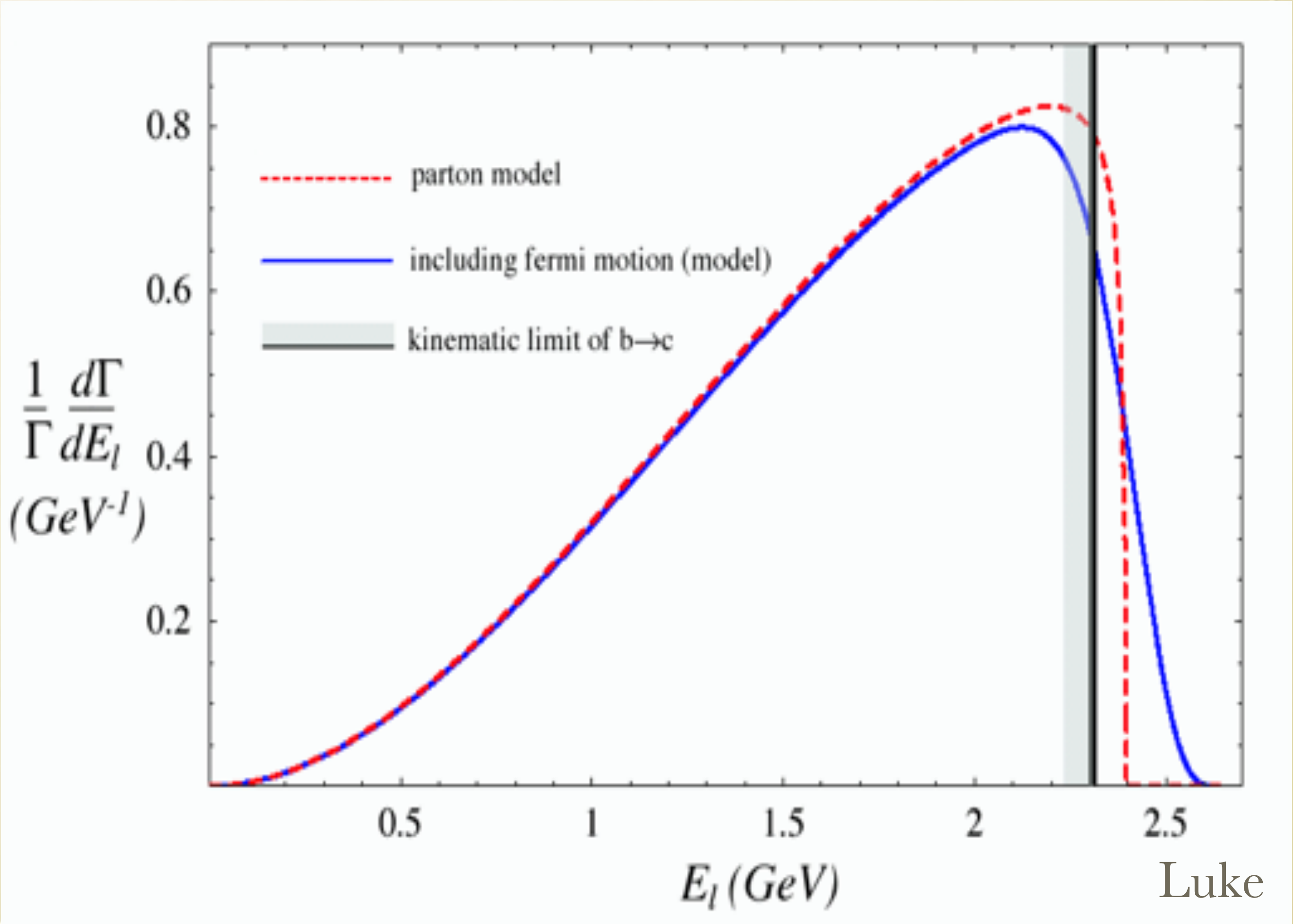
CUTS IN $B \to X_u l v$

Experiments often use kinematic cuts to avoid the b→clv background:

$$m_X < M_D \qquad E_\ell > (M_B^2 - M_D^2)/2M_B \qquad q^2 > (M_B - M_D)^2 \ldots$$

The cuts destroy convergence of the OPE that works so well in b→c. OPE expected to work only away from pert singularities

Rate becomes sensitive to *local* b-quark wave function properties like Fermi motion. Dominant non-pert contributions can be resummed into a ***SHAPE FUNCTION*** *$f(k_+)$*. Equivalently the SF is seen to emerge from soft gluon resummation



How to access the SF?

$$\frac{d^3\Gamma}{dp_+ dp_- dE_\ell} = \frac{G_F^2 |V_{ub}|^2}{192\pi^3} \int dk C(E_\ell, p_+, p_-, k) F(k) + O\left(\frac{\Lambda}{m_b}\right)$$

Subleading SFs

OPE constraints
e.g. at $q^2=0$

$$\int_{-\infty}^{\bar{\Lambda}} k^2 F(k)\, dk = \frac{\mu_\pi^2}{3} + O(\frac{\Lambda^3}{m_b})$$ etc.

Predictions *based* on resummed pQCD Dress Gluon Exponentiation, ADFR	OPE constraints + parameterization without/with resummation GGOU, BLNP

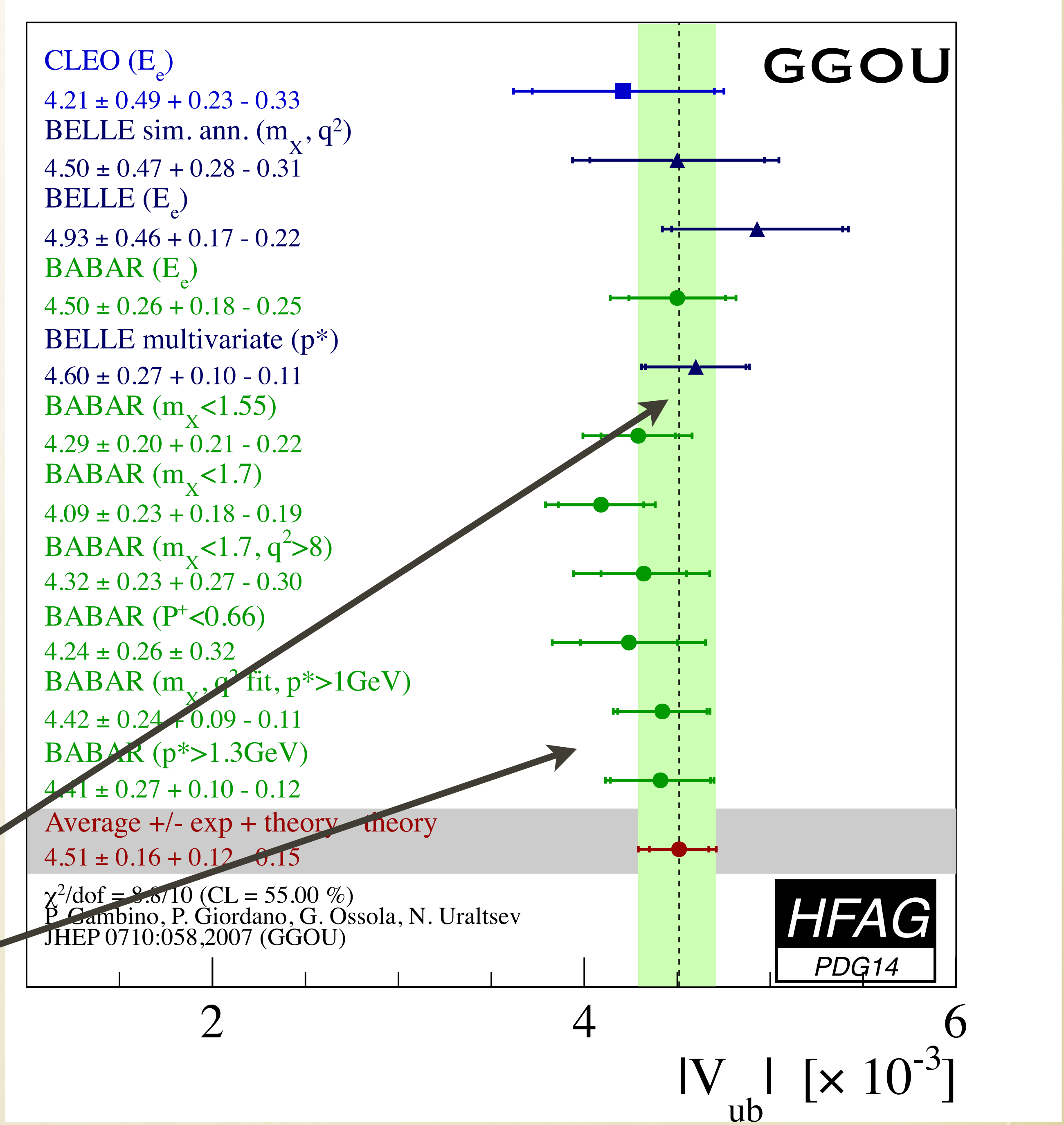
Fit semileptonic (and radiative) data
SIMBA, NNVub

$|V_{ub}|$ DETERMINATIONS

Inclusive: 5% total error

HFAG 2014	Average lV
DGE	4.52(16)(16)
BLNP	4.45(16)(22)
GGOU	4.51(16)(15)

UT fit (without direct V_{ub}):
V_{ub}=3.66(12) 10^{-3}



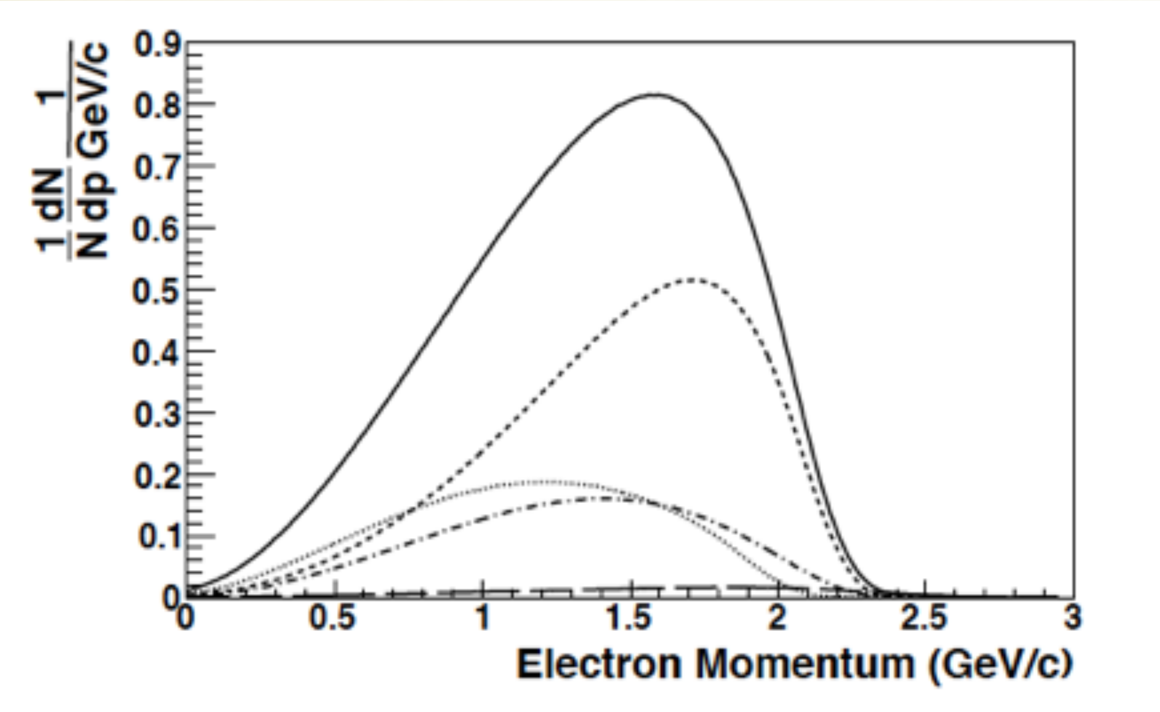
Recent experimental results
are theoretically cleanest (2%)
but based on background modelling.
Signal simulation also relies on theoretical models…

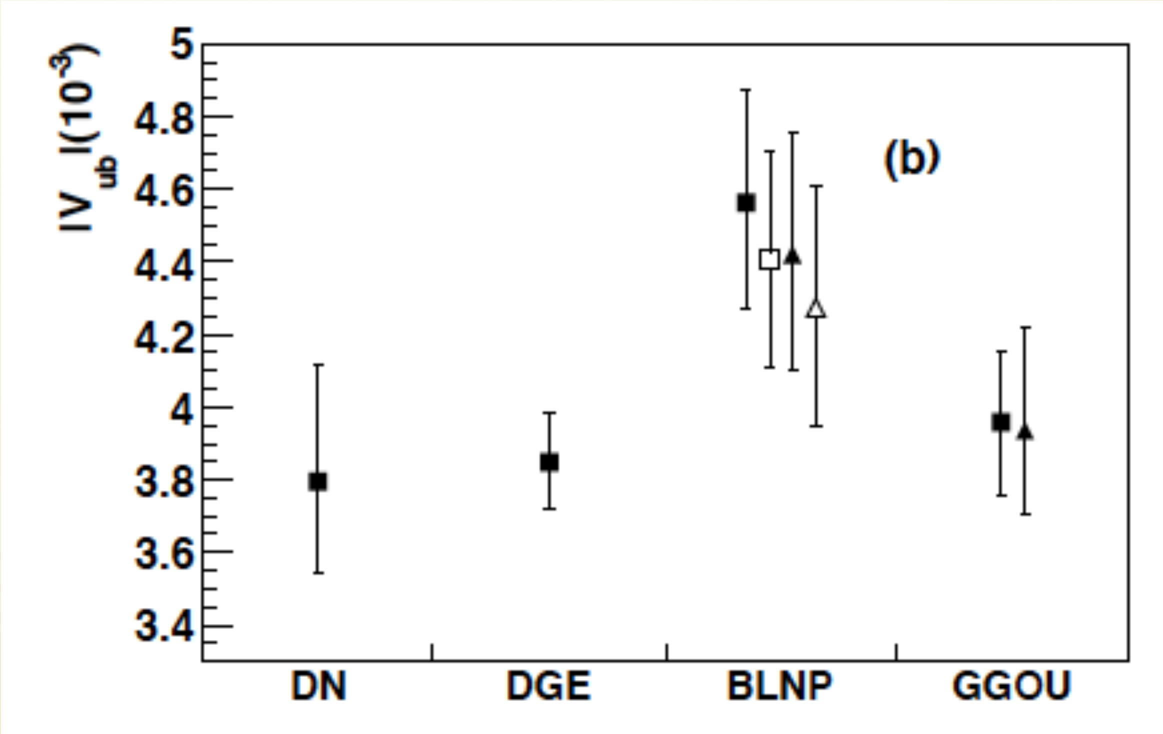
NEW Babar endpoint analysis

1611.05624

High sensitivity of the BR on the shape of the signal in the endpoint region. Single most precise measurement to date, not yet in HFAG

$$\text{GGOU: } |V_{ub}| = (3.96 \pm 0.10_{exp} \pm 0.17_{th}) \times 10^{-3}$$





What happens if same is done in other BaBar analyses? What's going on with BLNP?

NB Belle multivariate analysis uses GGOU+DN for the inclusive part

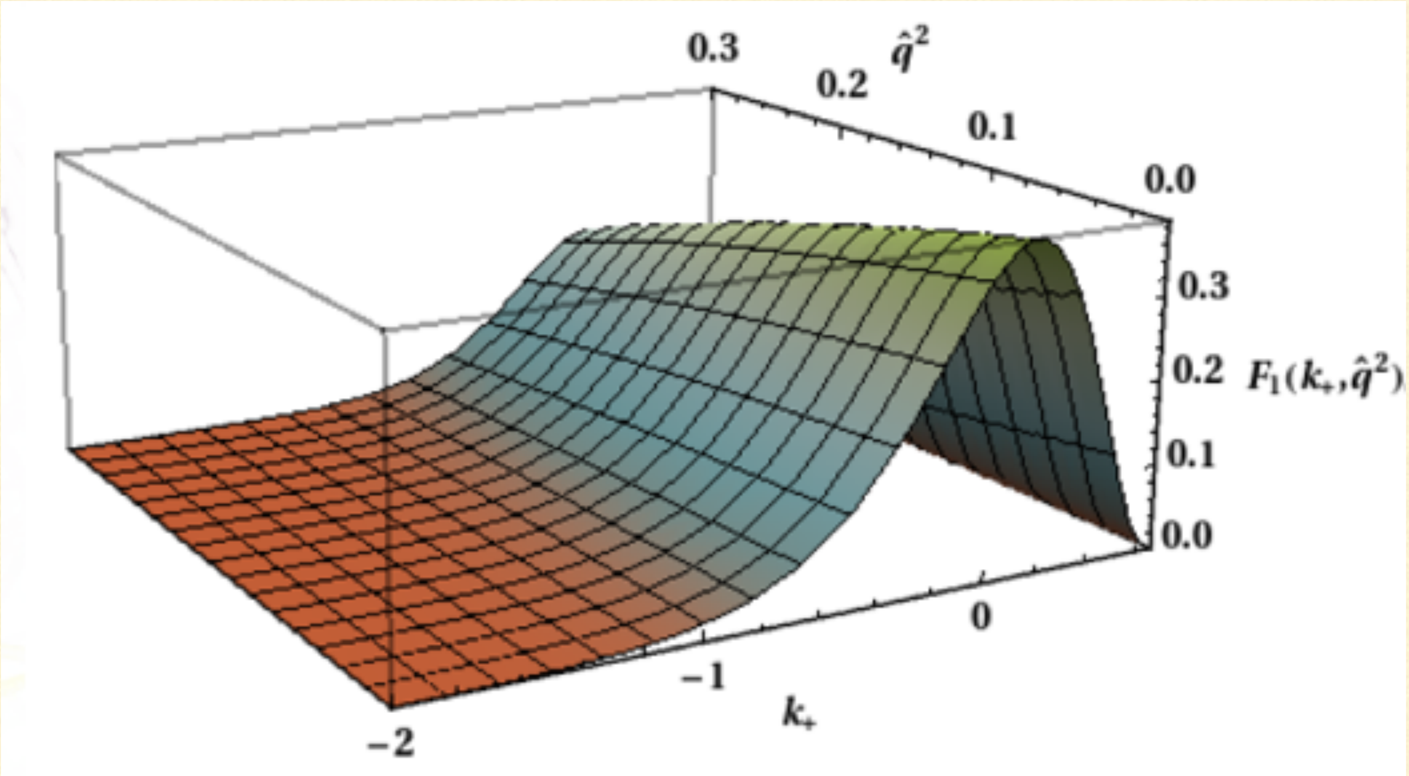
SHAPE FUNCTIONS IN GGOU

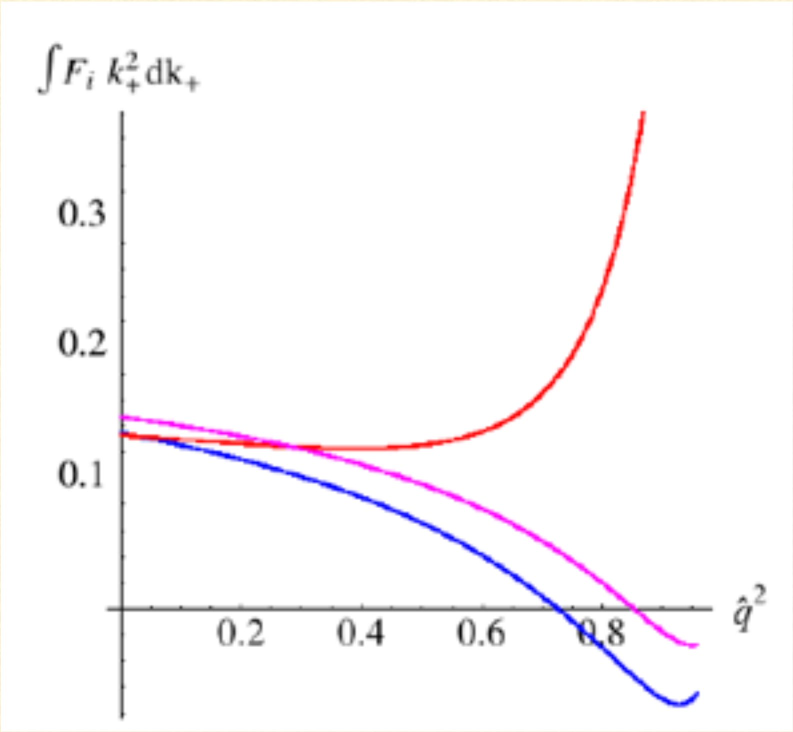
$$W_i(q_0, q^2) \sim \int dk_+ \; F_i(k_+, q^2, \mu) W_i^{pert}\left[q_0 - \frac{k_+}{2}\left(1 - \frac{q^2}{m_b M_B}\right), q^2, \mu\right]$$

3 SFs, one for each form factor

No subleading SFs, but

SF depend on q^2 through moments





In the past each SF parametrized by simple 2-parameter functional forms

THE NNVub PROJECT

K.Healey, C. Mondino, PG, 1604.07598

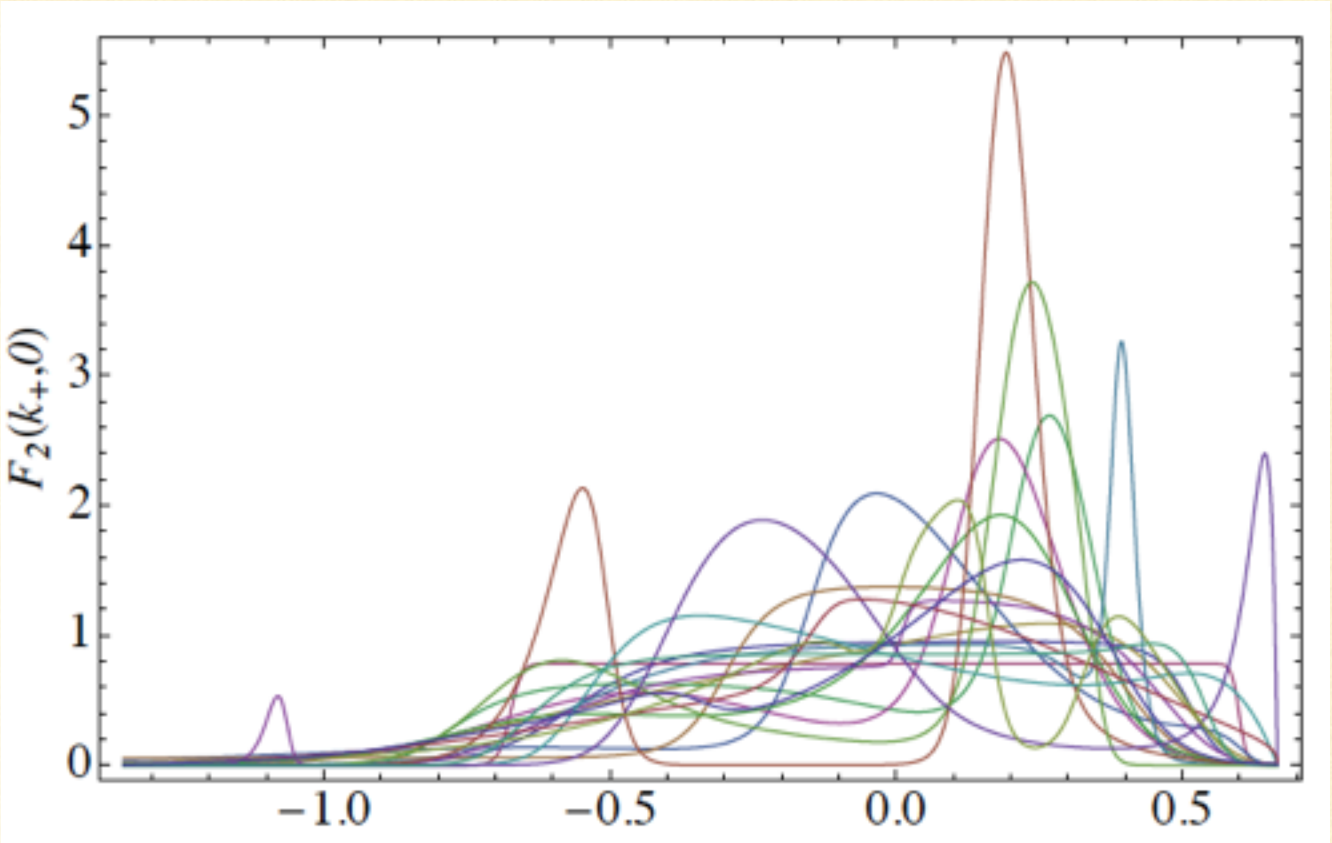
- Use Artificial Neural Networks to parametrise SFs without bias and extract V_{ub} from theoretical constraints and data, together with HQE parameters in a model independent way (without assumptions on functional form). Similar to NNPDF. Applies to $b \to u l \nu$, $b \to s \gamma$, $b \to s l^+ l^-$

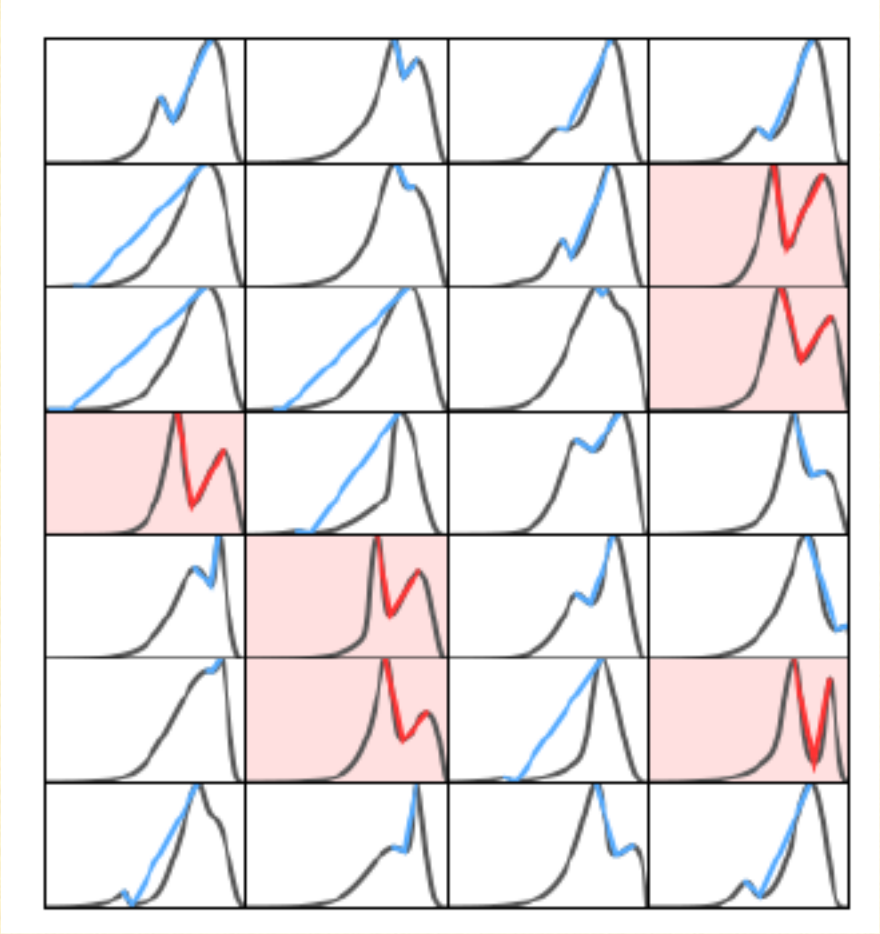
- Belle-II will measure some kinematic distributions, thus constraining directly the shape functions. NNVub will provide a flexible tool to analyse data.

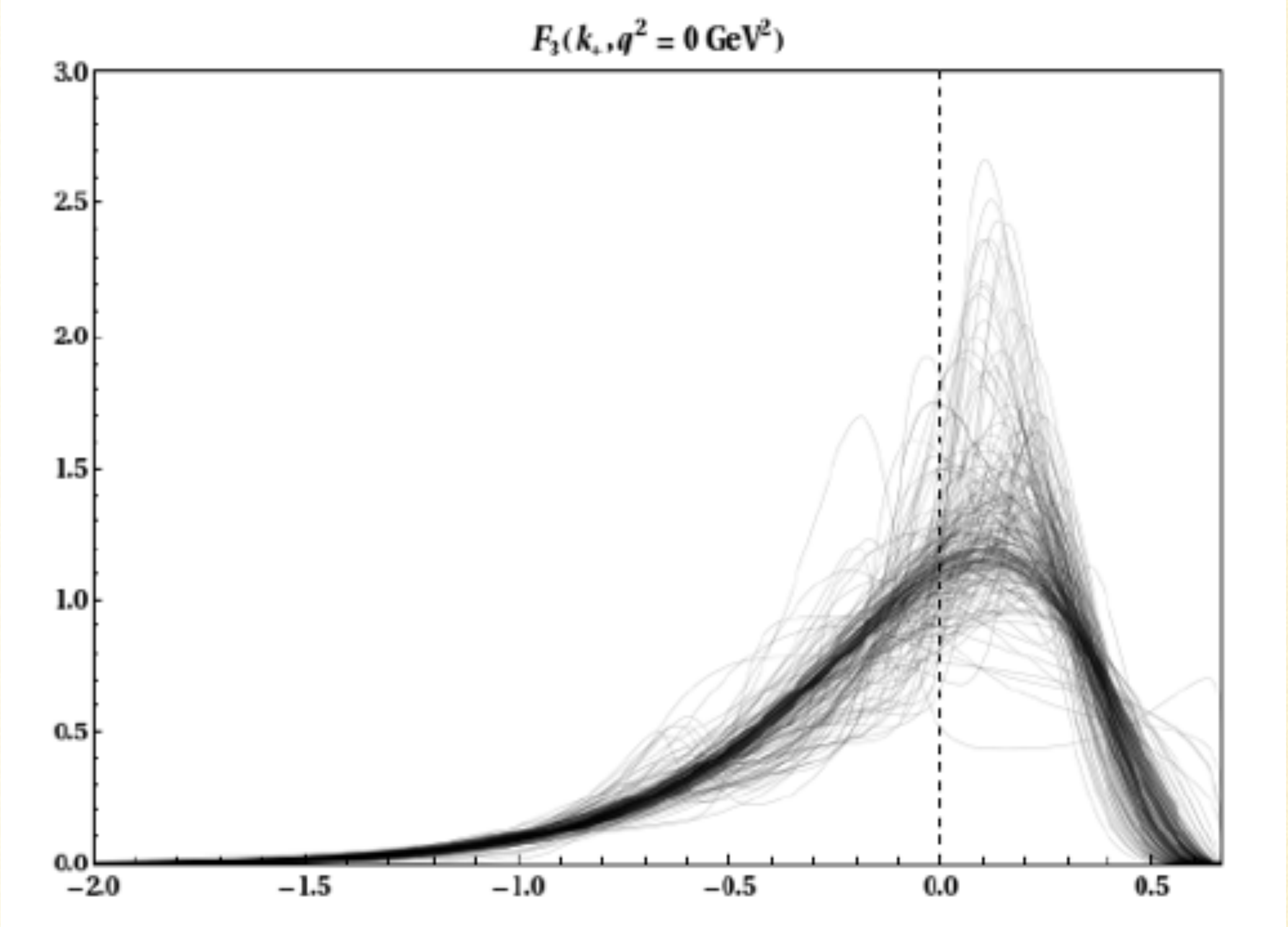
- NN provide unbiased parameterization of a continuous function: in the limit of infinite nodes they are universal approximators, highly non-linear functions
- Weights are trained to reproduce desired response: random weights undergo random modifications, retaining only those that improve response (e.g. better χ^2): genetic algorithm → replicas
- Used in pattern recognition, computationally intensive, data-driven

Selection of NN replicas trained on the **first three moments only.** They are not sufficient. But we know photon spectrum in bsgamma: single peak dominance, not too steep

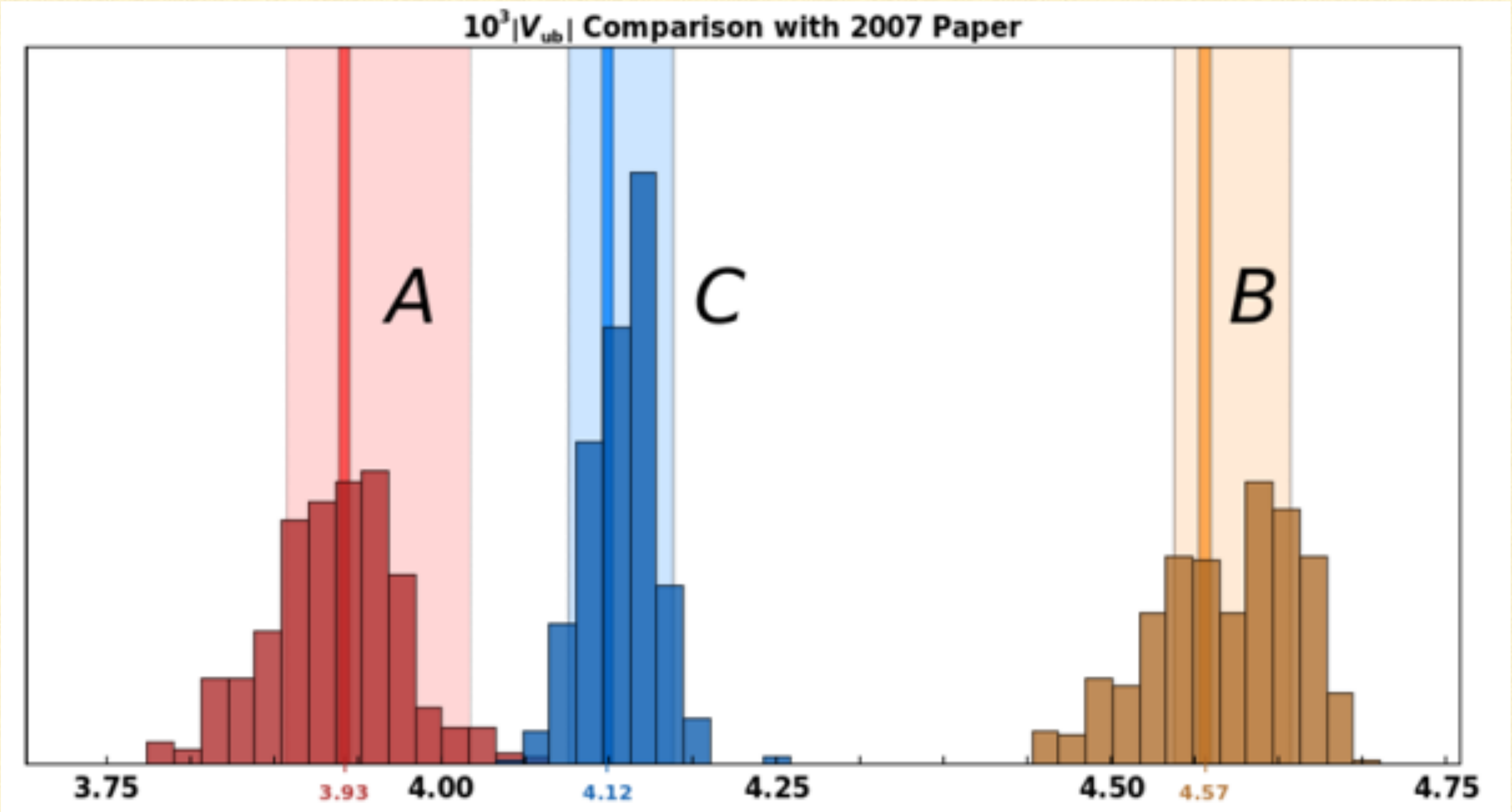
Beware: sampling can be biased by implementation, e.g. random initialization, or selection based on training speed







Comparison with 2007 paper, same inputs

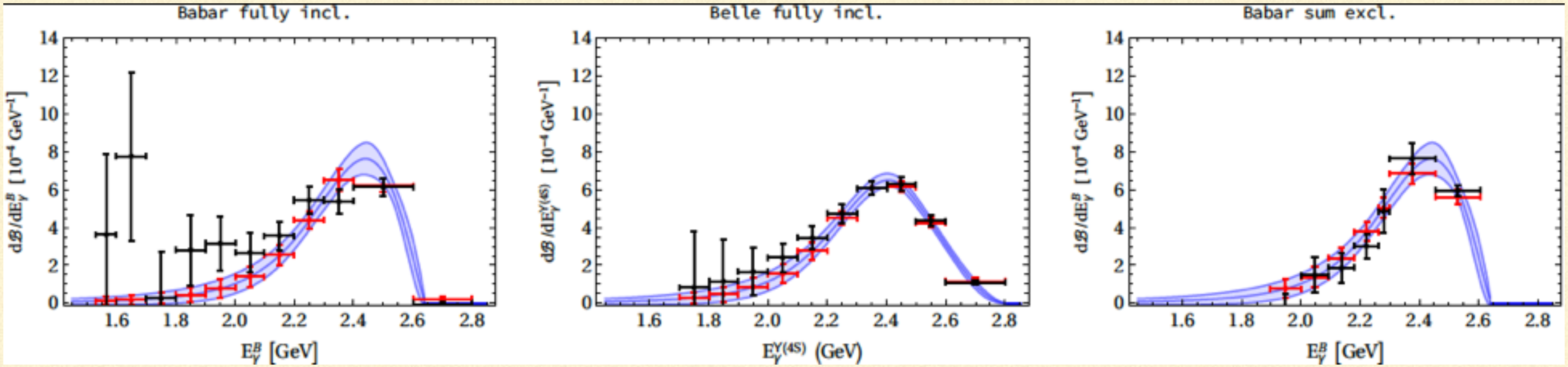


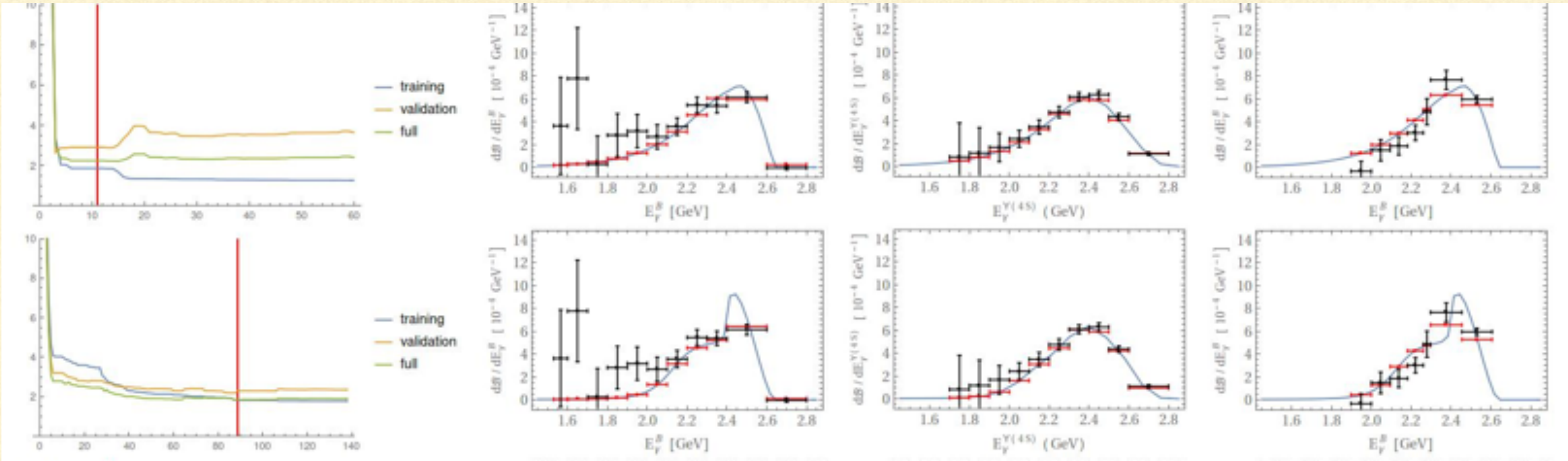
Experimental cuts (in GeV or GeV^2)	NNVub $\lvert V_{ub}\rvert \times 10^3$	GGOU(HFAG 2014) $\lvert V_{ub}\rvert \times 10^3$[15]
$M_X < 1.55, E_\ell > 1.0$ Babar [44]	$4.30(20)(^{26}_{27})$	$4.29(20)(^{21}_{22})$
$M_X < 1.7, E_\ell > 1.0$ Babar [44]	$4.05(23)(^{19}_{20})$	$4.09(23)(^{18}_{19})$
$M_X \leq 1.7, q^2 > 8, E_\ell > 1.0$ Babar[44]	$4.23(23)(^{26}_{28})$	$4.32(23)(^{27}_{30})$
$E_\ell > 2.0$ Babar [41]	$4.47(26)(^{22}_{27})$	$4.50(26)(^{18}_{25})$
$E_\ell > 1.0$ Belle [45]	$4.58(27)(^{10}_{11})$	$4.60(27)(^{10}_{11})$

Inputs for constraints from sl fit by Alberti et al, 2014 with full uncertainties and correlations

The $b \to s\gamma$ spectrum

E. Lunghi, M.Misiak, S.Schacht, PG
in progress

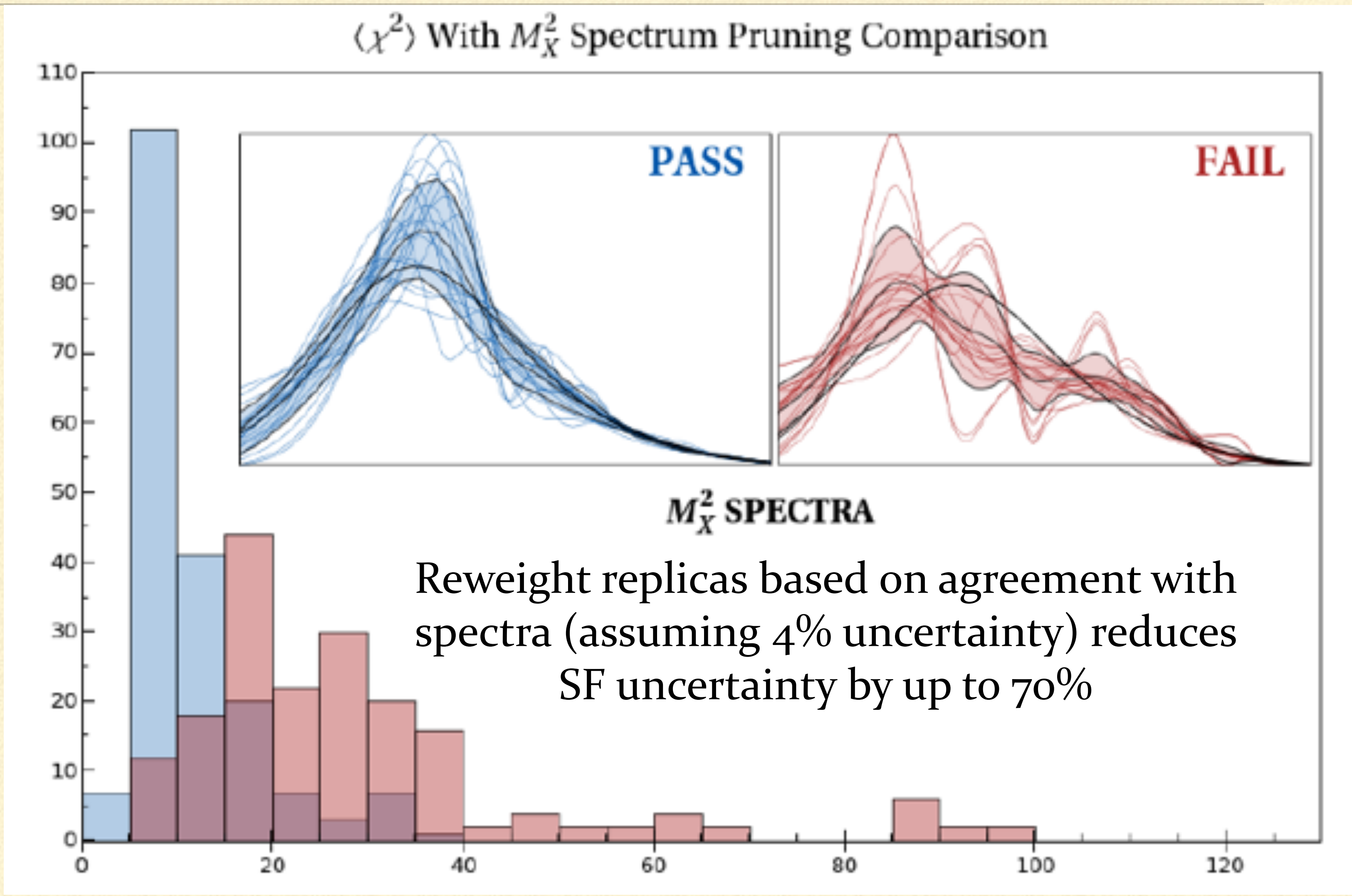




Up-to-date theoretical description of spectrum to get i) leading SF at $q^2=0$ for V_{ub}, ii) HQE elements to compare with s.l. fit iii) reliable extrapolation to low cuts.

PROSPECTS

- Learning @ Belle-II from kinematic distributions, e.g. M_X spectrum
- OPE parameters checked/ improved in b→ulν (moments): global NN+OPE fit
- 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



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

BACKUP

Role of HQET relations in V_{cb} extraction
(prelim Belle data only)

- "practical" CLN : $|V_{cb}| = 38.2(1.5) \times 10^{-3}$ [1,5,6,7,8]
- CLN+QCD sumrule errors+B→D $|V_{cb}| = 38.5(1.1) \times 10^{-3}$ [2]
- same + lattice at non-zero recoil $|V_{cb}| = 39.3(1.0) \times 10^{-3}$ [2]
- BGL+HQET+B→D with nuisance $|V_{cb}| = 40.9(0.9) \times 10^{-3}$ [3]
- BGL+strong unitarity $|V_{cb}| \sim 40.8(1.5) \times 10^{-3}$ [4]
- BGL+weak unitarity $|V_{cb}| = 41.7(2.0) \times 10^{-3}$ [5,6,7,8]

HQET

V_{cb}

[1] Belle coll. 1702.01521
[2] Bernlochner et al. 1703.05330
[3] Jaiswal, Nandi, Patra, 1707.09977
[4] Bigi, Gambino, Schacht 1707.09509
[5] Bigi, Gambino, Schacht 1703.06124
[6] Harrison et al. 1711.11013 (HPQCD)
[7] Bernlochner et al 1708.07134
[8] Grinstein, Kobach, 1703.08170