Reassessing the exclusive determination of V_{cb}

1703.06124 with D.Bigi and S. Schacht

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Importance of $|V_{xb}|$

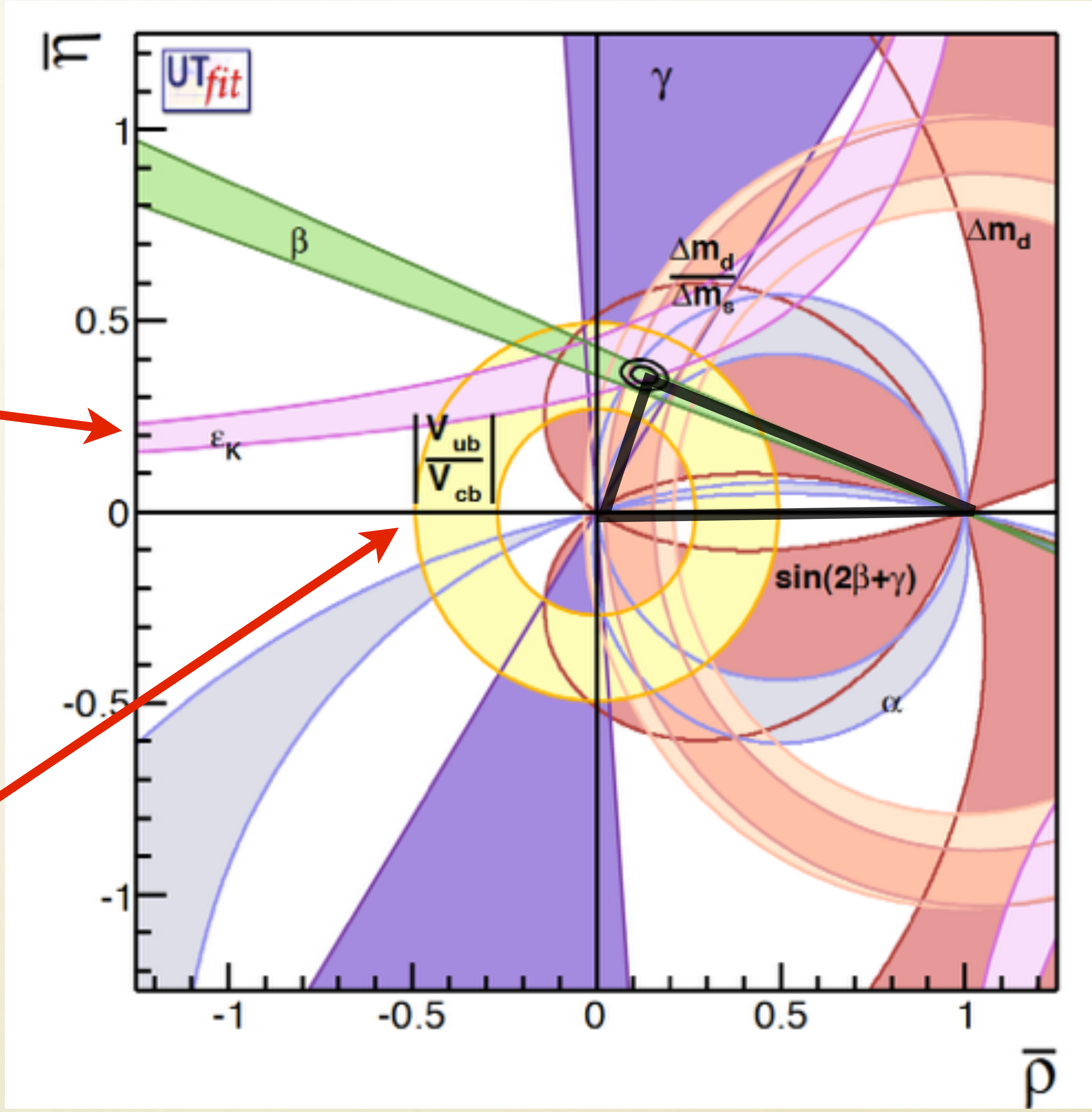
V_{cb} plays an important role in UT

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

and in the prediction of FCNC:

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

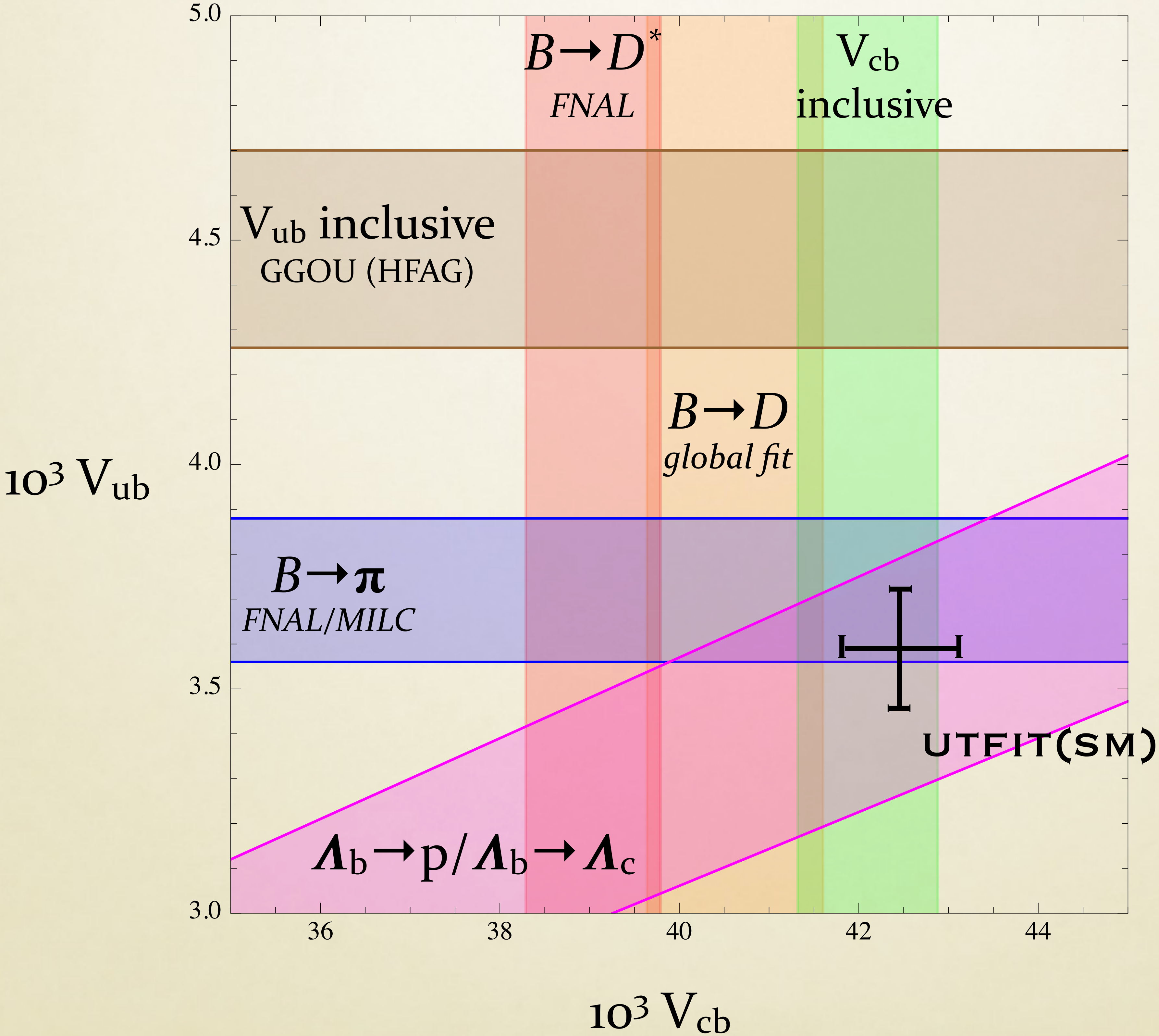
where it often dominates the theoretical uncertainty.
V_{ub}/V_{cb} constrains directly the UT



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

V_{cb} and V_{ub} status

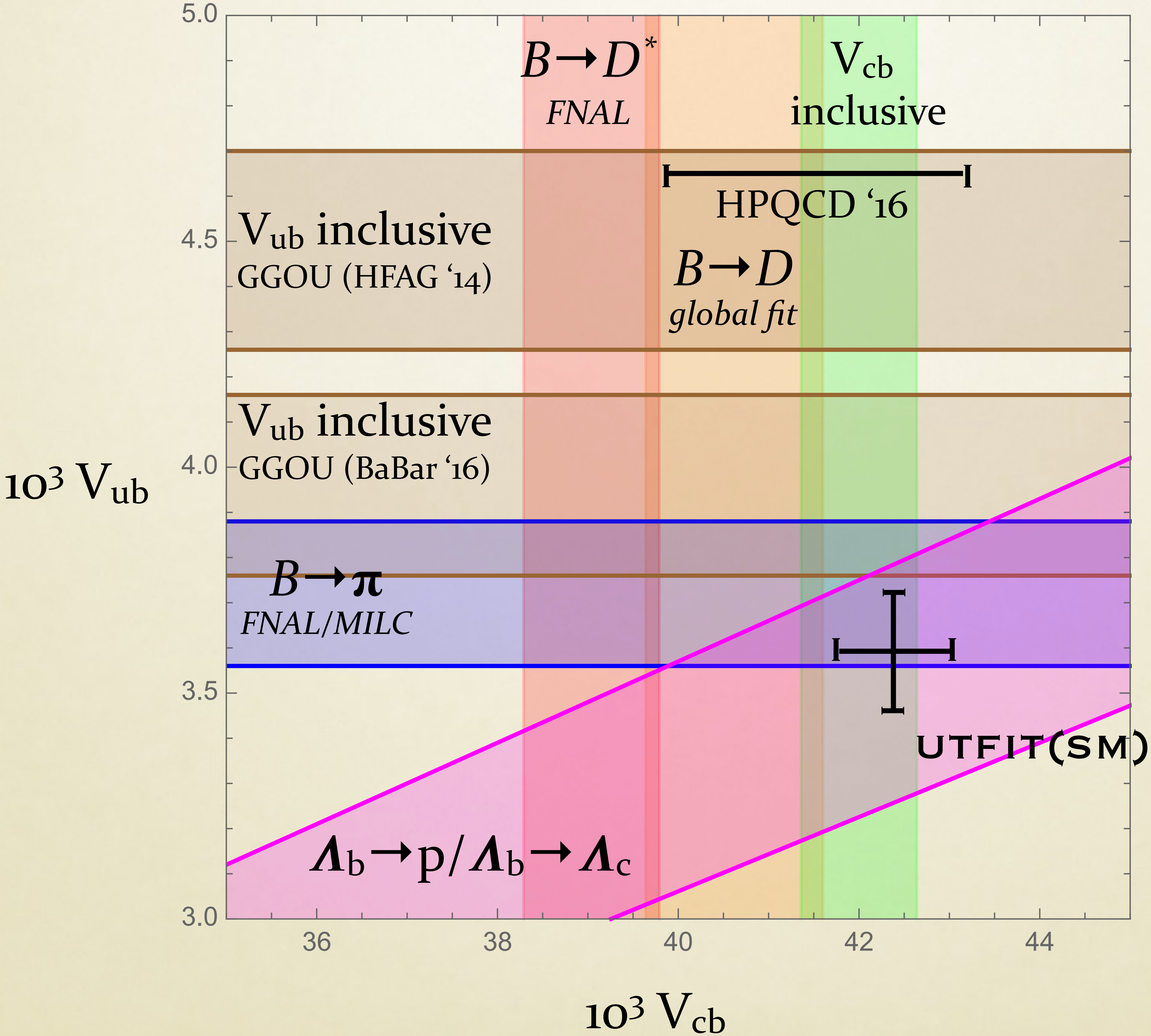
1σ ranges



reasonable consistency among exclusive channels

not all results at the same level

V_{cb} and V_{ub} updated status



CKM 2016:
NEW V_{ub} incl
by Babar
in agreement
with exclusive

NEW HPQCD
$B\to D^*$ result
V_{cb}=41.5(1.7) 10^{-3}

NEW Belle $B\to D^*$
with FNAL
V_{cb}=37.4(1.3) 10^{-3}

SEMITAUONIC ANOMALY

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

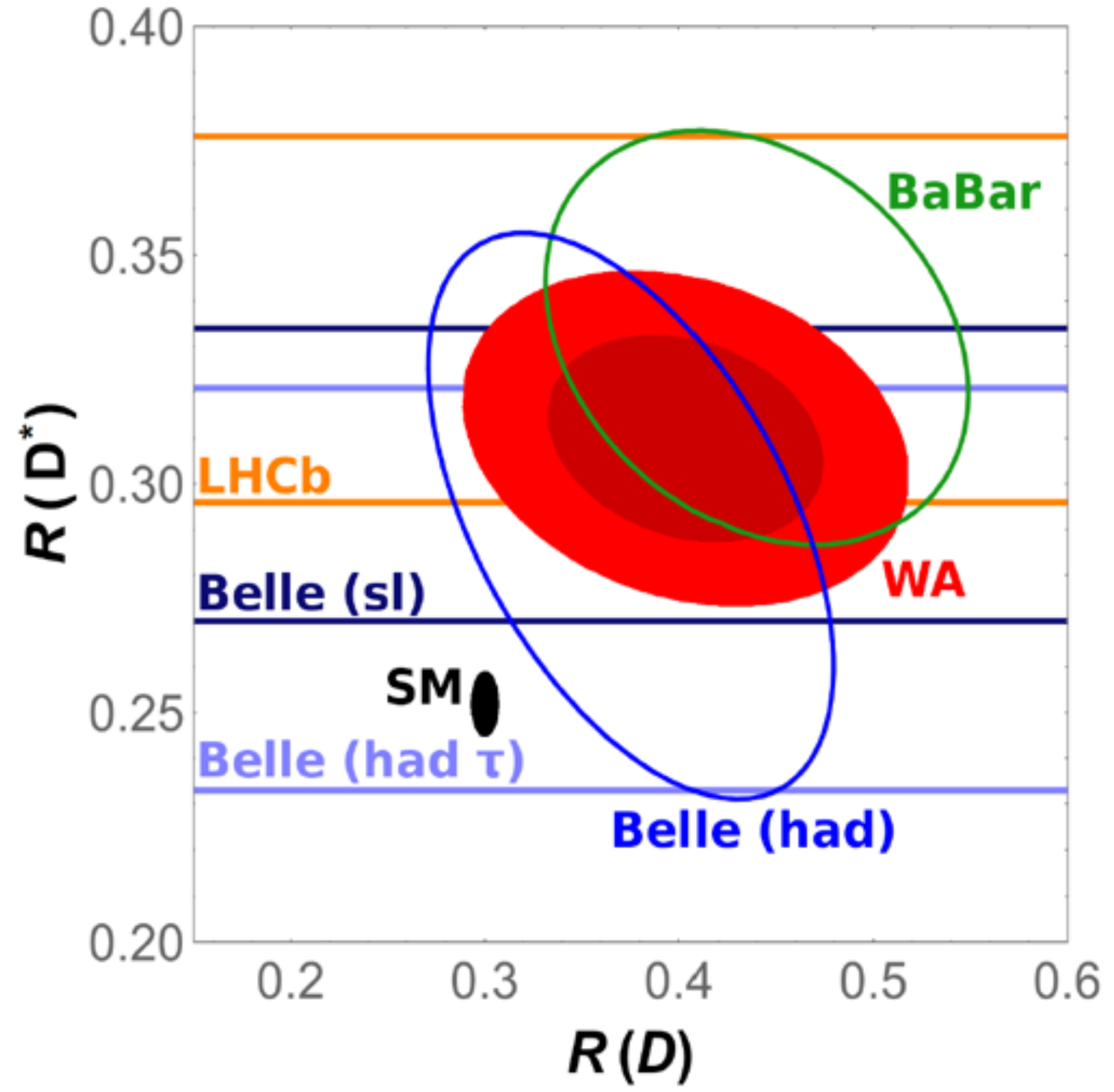
Combined discrepancy with SM 4.0σ

about 30% effect on tree-level process!

Lepton flavour universality violation: new scalars, leptoquarks, W'… possible connection with lepton flavour violation in $b \to sll$

Inconsistent with LEP inclusive measurement

SM predictions?



Celis et al., 1612.07757

EXCLUSIVE $B \to D^* \ell \nu$

<u>At zero recoil</u>, w=1, where rate vanishes, the ff is

$$\mathcal{F}(1) = \eta_A \left[1 + O\left(\frac{1}{m_c^2}\right) + \ldots \right]$$

Thanks to measurement of slopes and shape parameters, exp error only ~1.3% when extrapolation to zero recoil with CLN parameterization

The ff F(1) has been computed in Lattice QCD. <u>Only one</u> unquenched Lattice calculation is published:

F(1) =0.906(13) ➠ $|V_{cb}|$=38.71(75) 10^{-3}

Bailey et al 1403.0635 (FNAL/MILC) HFAG 2016

1.9% error

~ 3.3 (3.1) σ or ~ 8% from inclusive determination 0.04200(65)

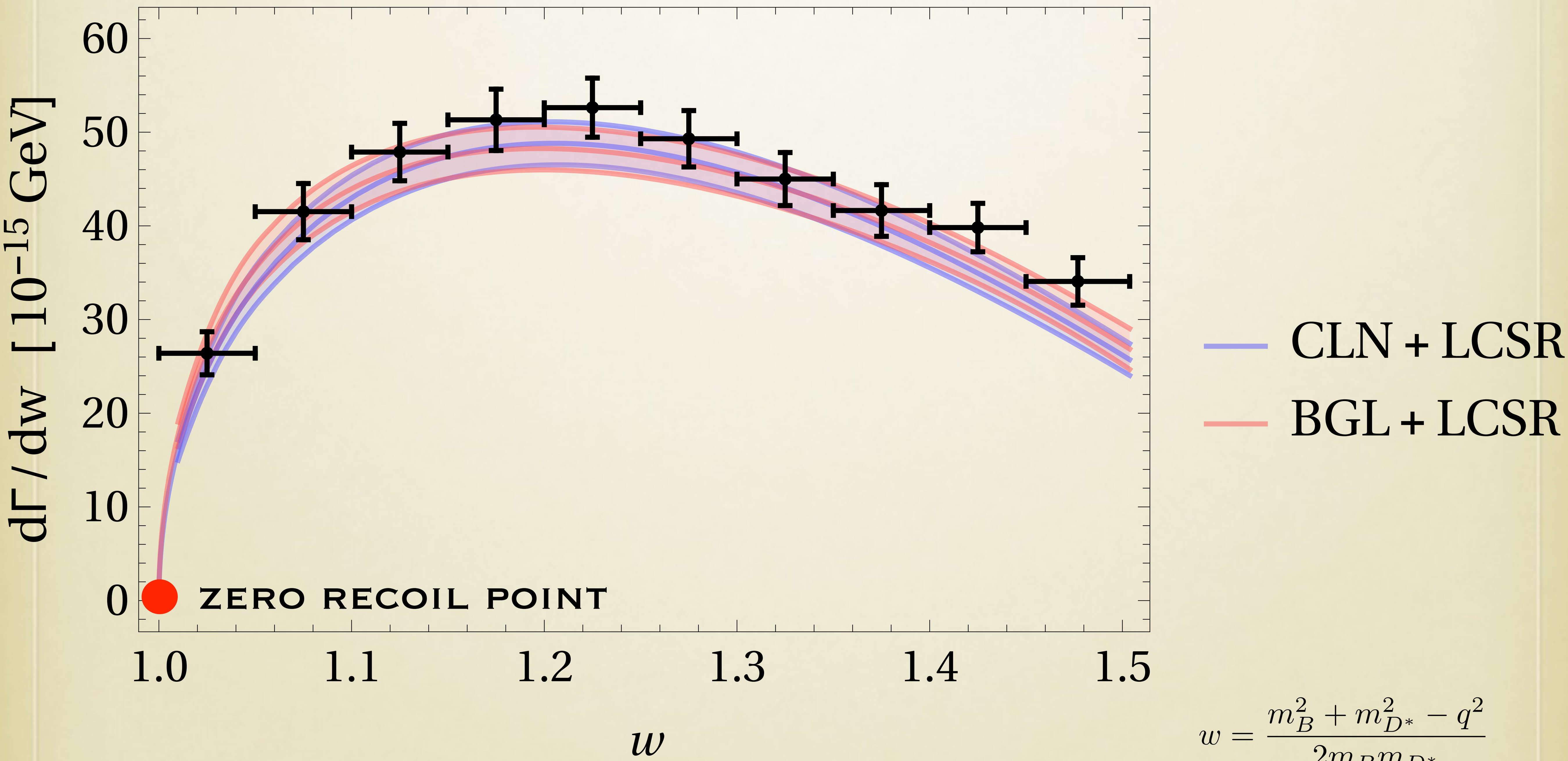
PG,Healey,Turczyk 2016

NEW HPQCD F(1)=0.862(35) preliminary, CKM 2016

NB Heavy Quark Sum Rules estimate F(1)=0.86(2) PG, Mannel, Uraltsev 2012

New preliminary Belle analysis 1702.01521

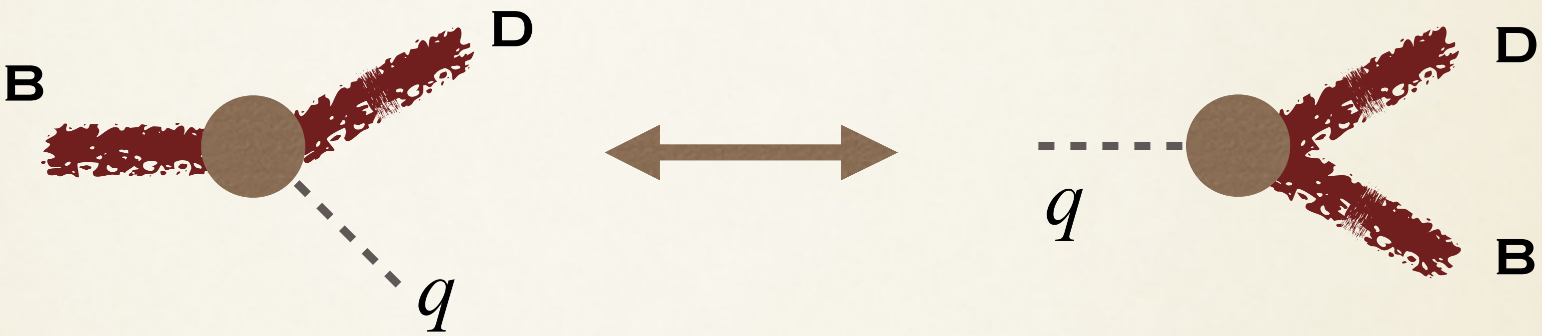
for the first time *w* and angular deconvoluted distributions independent of parameterization. All previous analyses are CLN based.



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

UNITARITY CONSTRAINTS

CROSSING + ANALITYCITY



PHYSICAL SEMILEPTONIC REGION

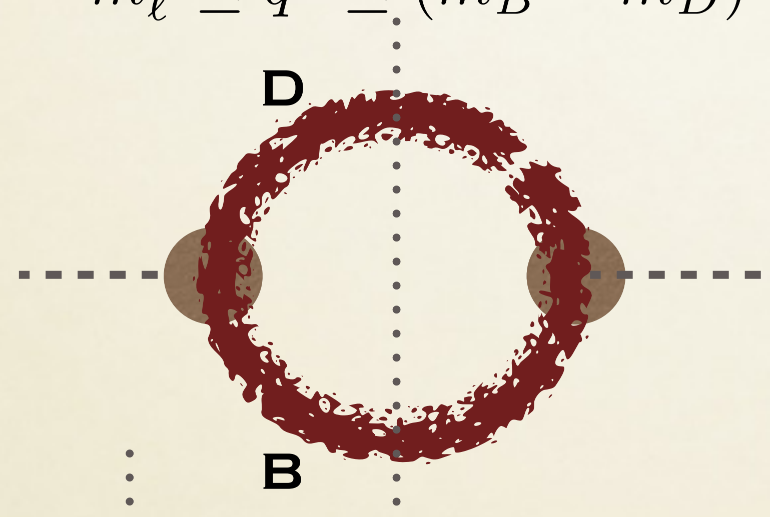
$m_\ell^2 \le q^2 \le (m_B - m_D)^2$

CUT FOR

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

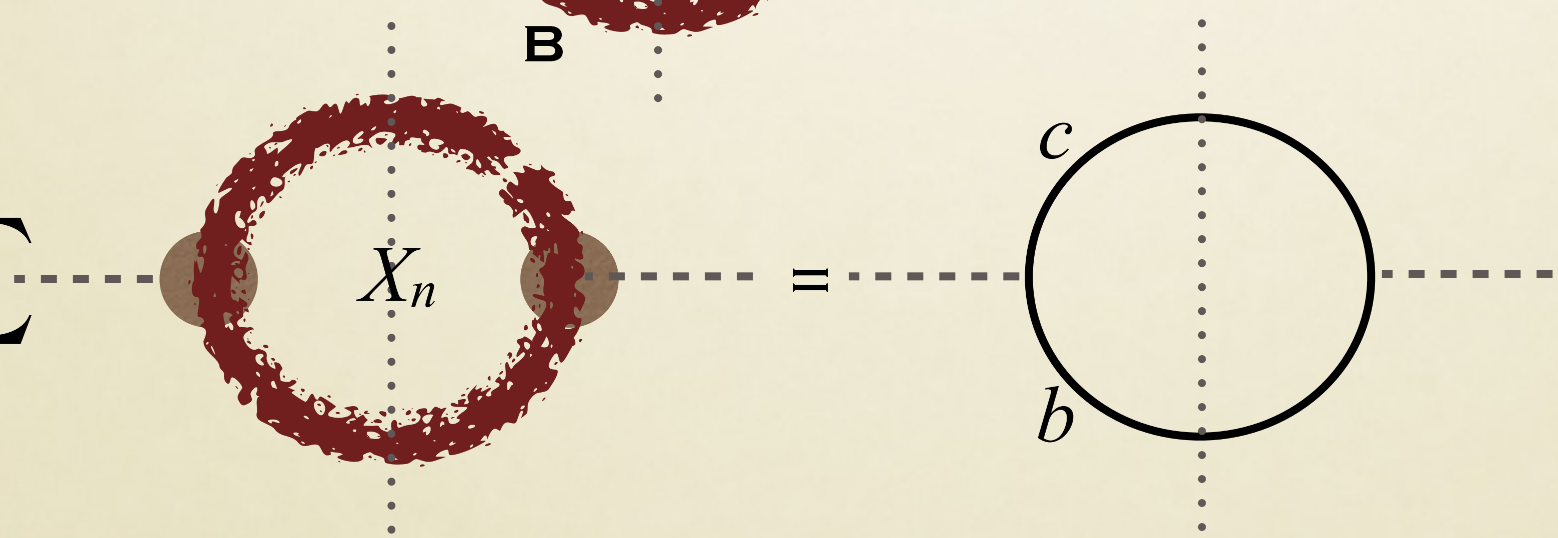
POLES AT $q^2 = m^2_{Bc}$ ETC

$0 <$



$\propto |f_{+,0}|^2$

$\sum_n$



+ PERT CORR

USING QUARK-HADRON DUALITY. DISPERSION RELATIONS→ GLOBAL QHD

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

$$\chi^T_V(0)=[5.883+0.552_{\alpha_s}+0.050_{\alpha_s^2}]\ 10^{-4}\,\mathrm{GeV}^{-2}=6.486(48)\ 10^{-4}\,\mathrm{GeV}^{-2}$$
$$\chi^L_V(0)=[5.456+0.782_{\alpha_s}-0.034_{\alpha_s^2}]\ 10^{-3}=6.204(81)\ 10^{-3}$$

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

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

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)

BLASCHKE FACTORS REMOVE POLES

PHASE SPACE FACTORS

TRUNCATED AT ORDER N

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

WEAK UNITARITY CONSTRAINTS

For massless leptons only 3 form factors f, g, F_1 contribute to $B \rightarrow D^* l\nu$

$$\sum_{i=0}^{\infty} (a_n^g)^2 < 1, \qquad \sum_{i=0}^{\infty} \left[(a_n^f)^2 + (a_n^{\mathcal{F}_1})^2 \right] < 1$$

vector current — axial vector current

STRONG UNITARITY CONSTRAINTS

Using information about the other channels the constraints become tighter
In the heavy quark limit all $B^{(*)}\to D^{(*)}$ form factors either vanish or are prop to the Isgur-Wise function

$$\sum_{i=1}^{H}\sum_{n=0}^{\infty} b_{in}^2 \leq 1$$

CAPRINI
LELLOUCH
NEUBERT
CLN
1998

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

$$R_1(w) = R_1(1) - 0.12 w_1 + 0.05 w_1^2$$

$$R_2(w) = R_2(1) + 0.11 w_1 - 0.06 w_1^2$$

$$w_1 = w - 1$$

CLN exploit NLO HQET relations between form factors to reduce to only 2 parameters…
up to less than 2% (never included in any exp analysis)
moreover $1/m^2$, α_s^2 and α_s/m corrections can be sizable For ex at zero recoil

$$\frac{F_{D^*}(z=0)}{f_+(z=0)} = 0.966 \neq 0.860(14)$$

NLO HQET LATTICE (FNAL)
11%

$$\frac{f_+(0)}{f_0(0)} = 0.775 \neq 0.753(3)$$

NLO HQET LATTICE (FNAL)
3%

CLN parameterization has intrinsic uncertainties that can no longer be neglected.
Recent update of HQET NLO relations by Bernlochner et al. 1703.05330

THE FITS

CLN

CLN Fit:	Data + lattice	Data + lattice + LCSR
χ^2/dof	34.3/36	34.8/39
$\lvert V_{cb}\rvert$	0.0382 (15)	0.0382 (14)
$\rho^2_{D^*}$	1.17 $\left(^{+15}_{-16}\right)$	1.16 (14)
$R_1(1)$	1.391 $\left(^{+92}_{-88}\right)$	1.372 (36)
$R_2(1)$	0.913 $\left(^{+73}_{-80}\right)$	0.916 $\left(^{+65}_{-70}\right)$
$h_{A_1}(1)$	0.906 (13)	0.906 (13)

reproduces Belle's deconvoluted results. Best CLN analysis V_{cb}=0.0374(13)

BGL-2

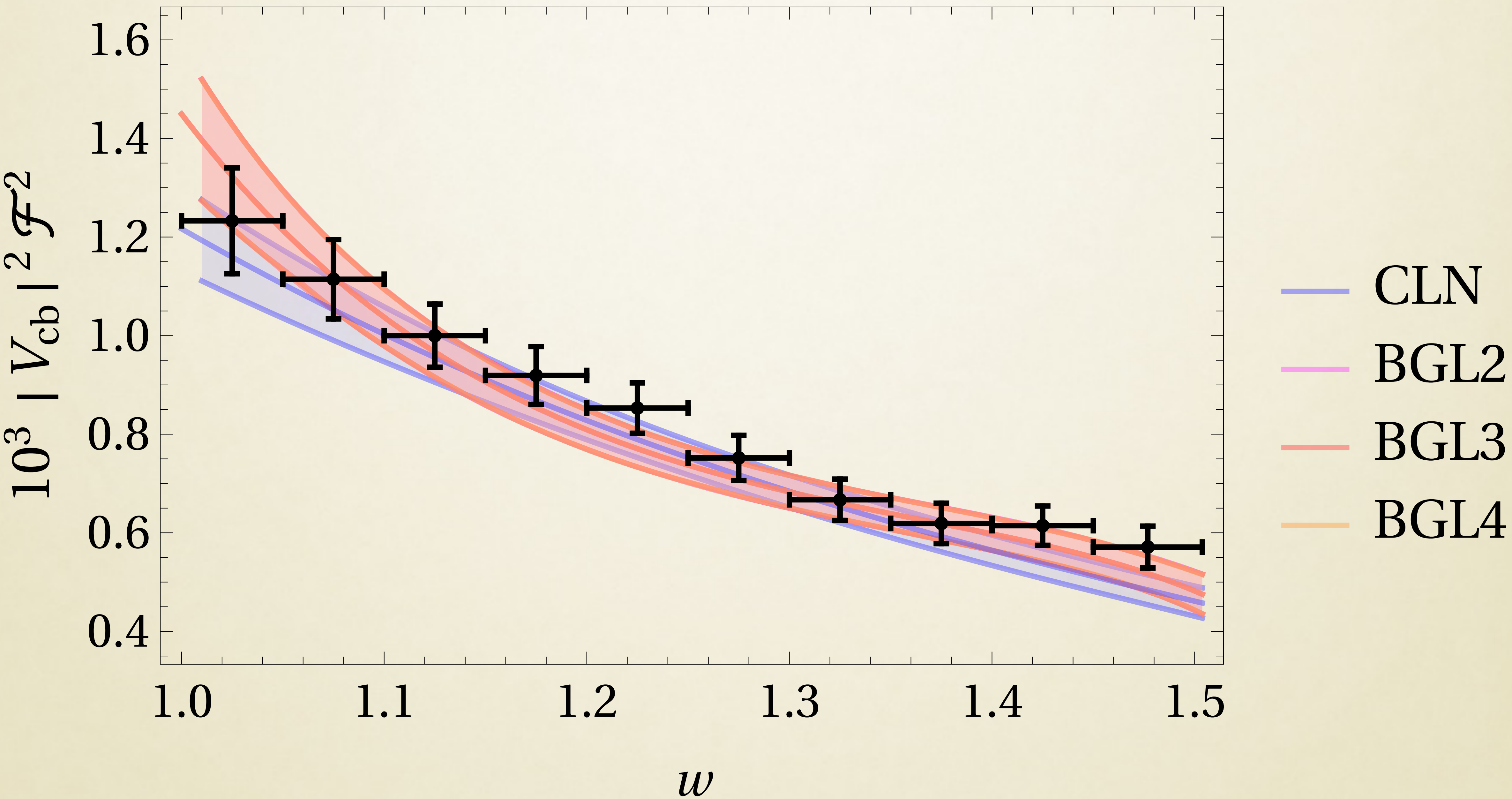
BGL Fit:	Data + lattice	Data + lattice + LCSR
χ^2/dof	27.9/32	31.4/35
$\lvert V_{cb}\rvert$	0.0417 $\left(^{+20}_{-21}\right)$	0.0404 $\left(^{+16}_{-17}\right)$
a_0^f	0.01223(18)	0.01224(18)
a_1^f	−0.054 $\left(^{+58}_{-43}\right)$	−0.052 $\left(^{+27}_{-15}\right)$
a_2^f	0.2 $\left(^{+7}_{-12}\right)$	1.0 $\left(^{+0}_{-5}\right)$
$a_1^{\mathcal{F}_1}$	−0.0100 $\left(^{+61}_{-56}\right)$	−0.0070 $\left(^{+54}_{-52}\right)$
$a_2^{\mathcal{F}_1}$	0.12 (10)	0.089 $\left(^{+96}_{-100}\right)$
a_0^g	0.012 $\left(^{+11}_{-8}\right)$	0.0289 $\left(^{+57}_{-37}\right)$
a_1^g	0.7 $\left(^{+3}_{-4}\right)$	0.08 $\left(^{+8}_{-22}\right)$
a_2^g	0.8 $\left(^{+2}_{-17}\right)$	−1.0 $\left(^{+20}_{-0}\right)$

see also Grinstein & Kobach, 1703.08170

9% and 6% (with LCSR) difference in V_{cb}

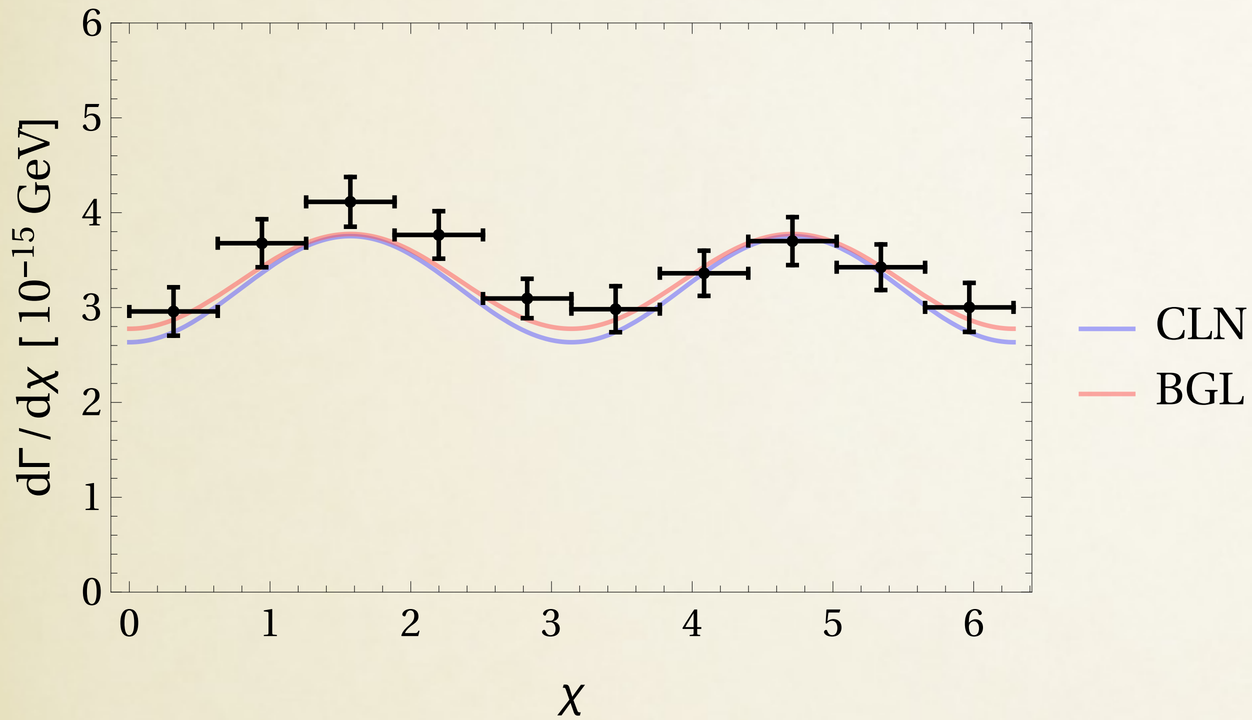
LCSR: Light Cone Sum Rule results from Faller et al, 0809.0222

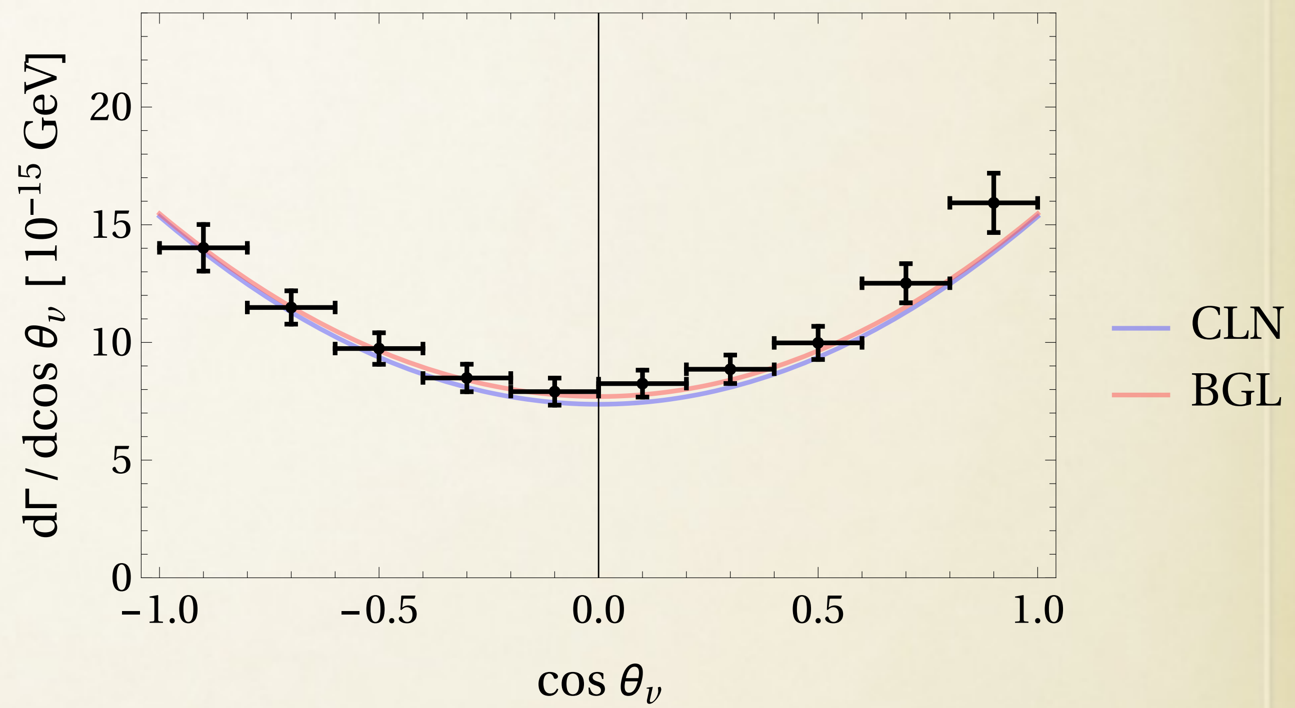
$$h_{A_1}(w_{max}) = 0.65(18),$$
$$R_1(w_{max}) = 1.32(4), \quad R_2(w_{max}) = 0.91(17)$$

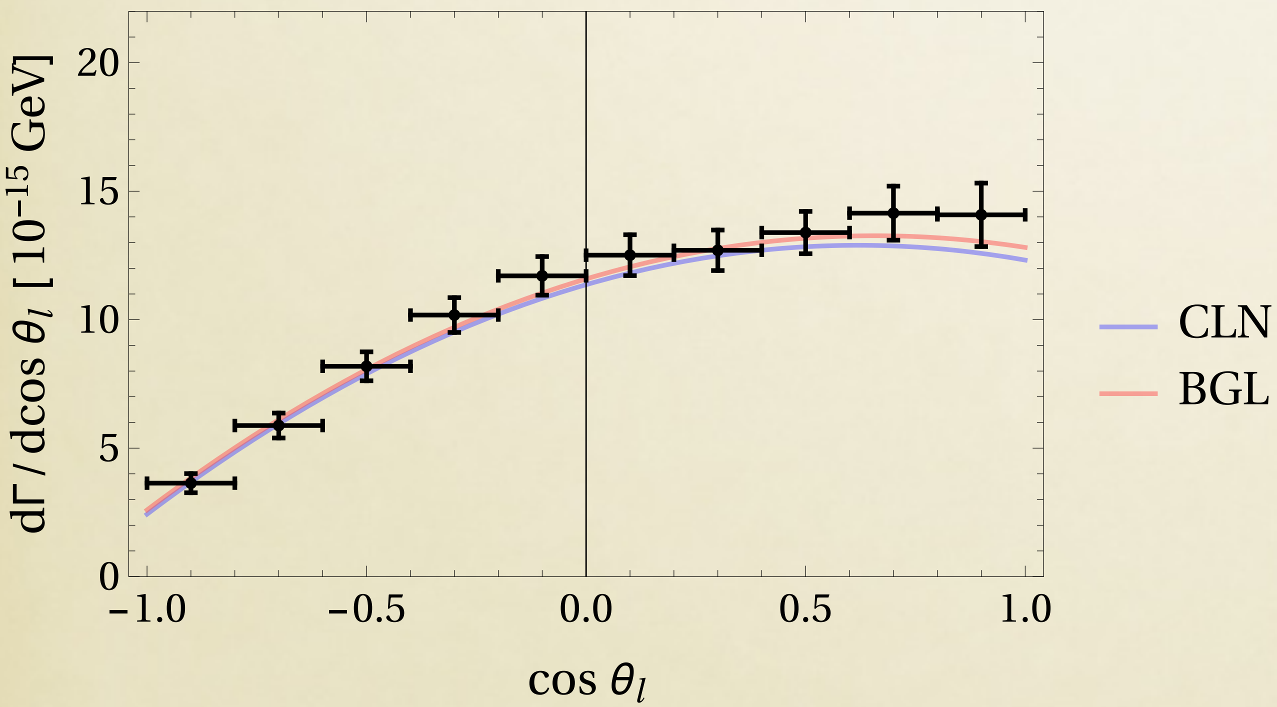


1.6
1.4
1.2
1.0
0.8
0.6
0.4
$10^3 \, |V_{cb}|^2 \mathcal{F}^2$
1.0
1.1
1.2
1.3
1.4
1.5
w
CLN
BGL2
BGL3
BGL4

Angular dependence



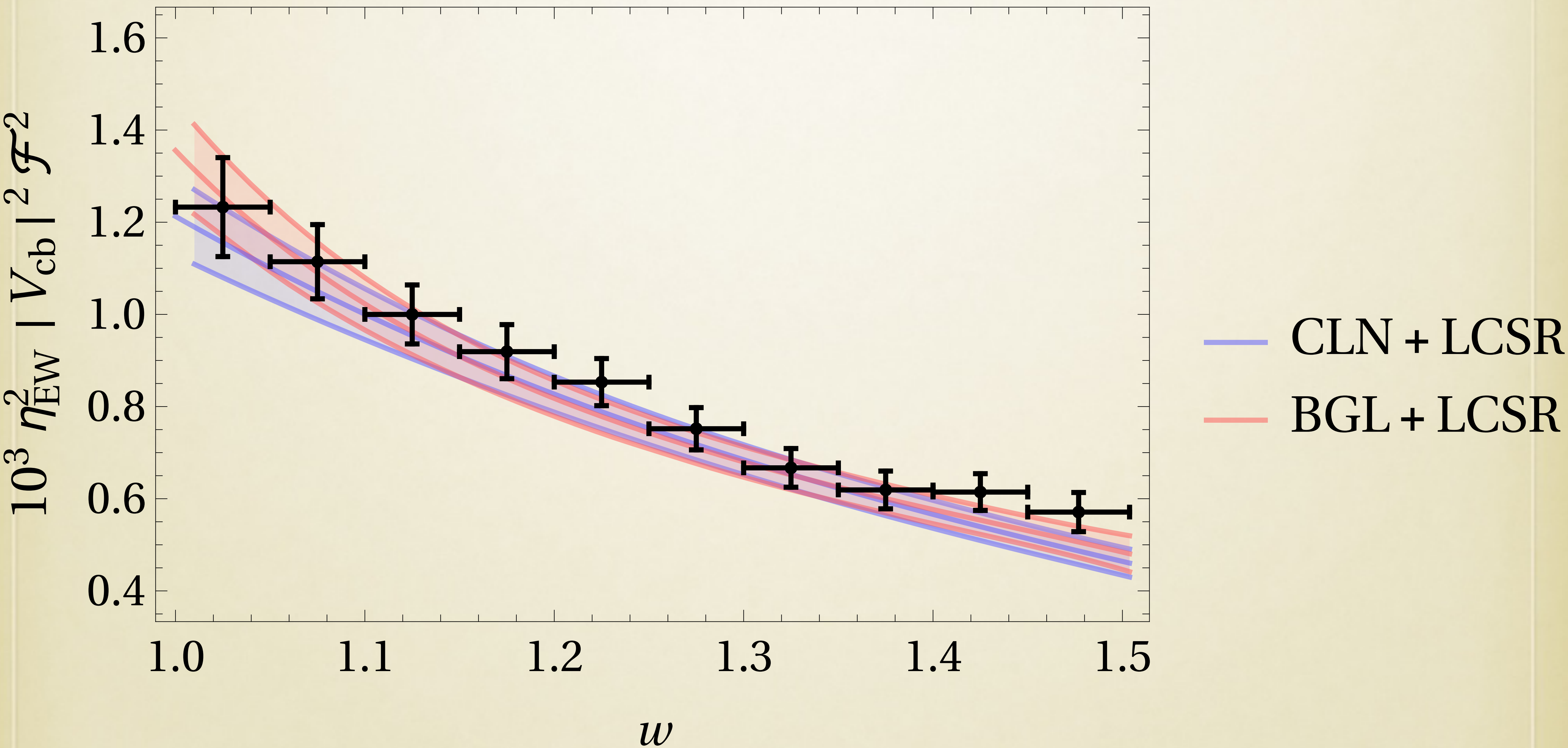




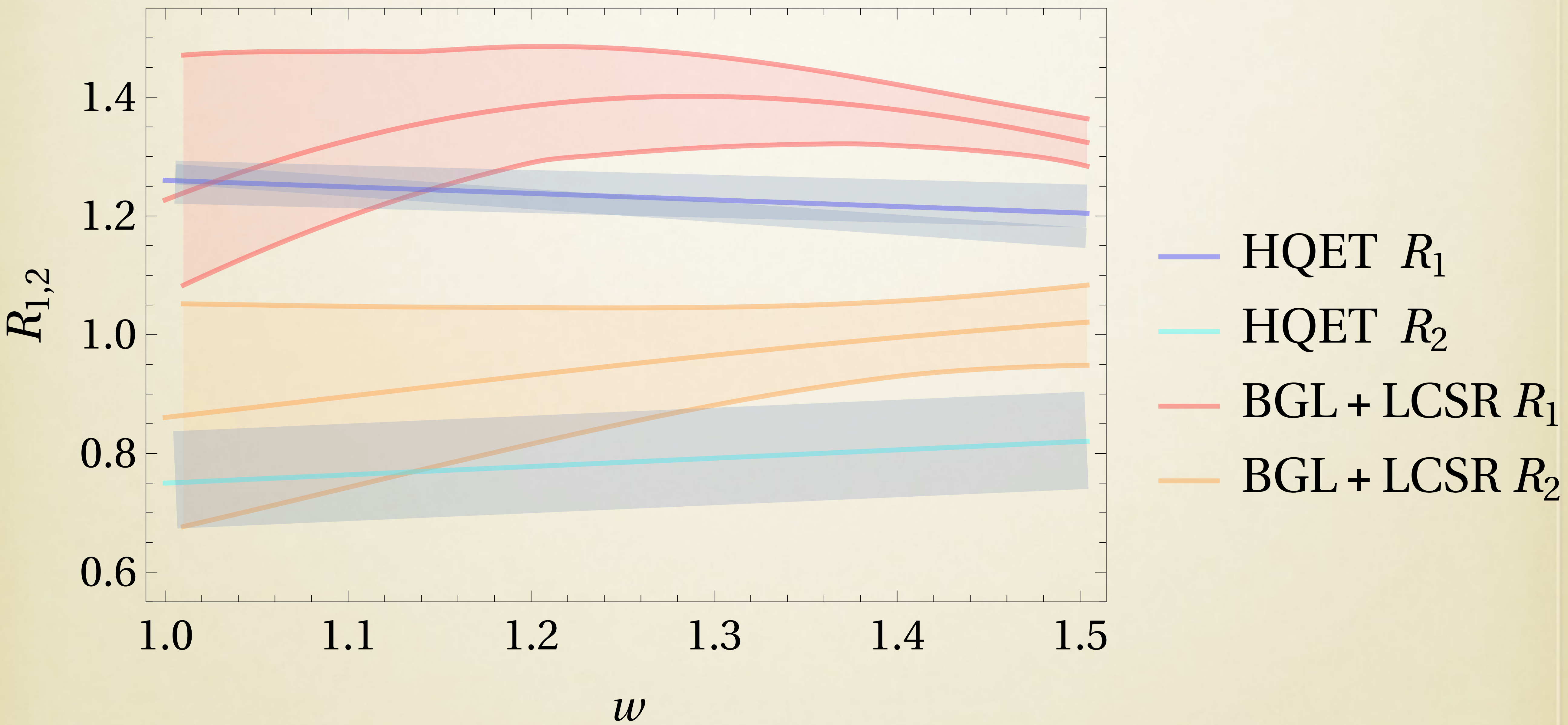
Angular bins are very little sensitive to the low recoil region. Effectively, they dilute the information of the first bins in the w spectrum

CLN fit *without* angular variables gives $|V_{cb}|$=0.0409(16)

WITH LCSR CONSTRAINTS

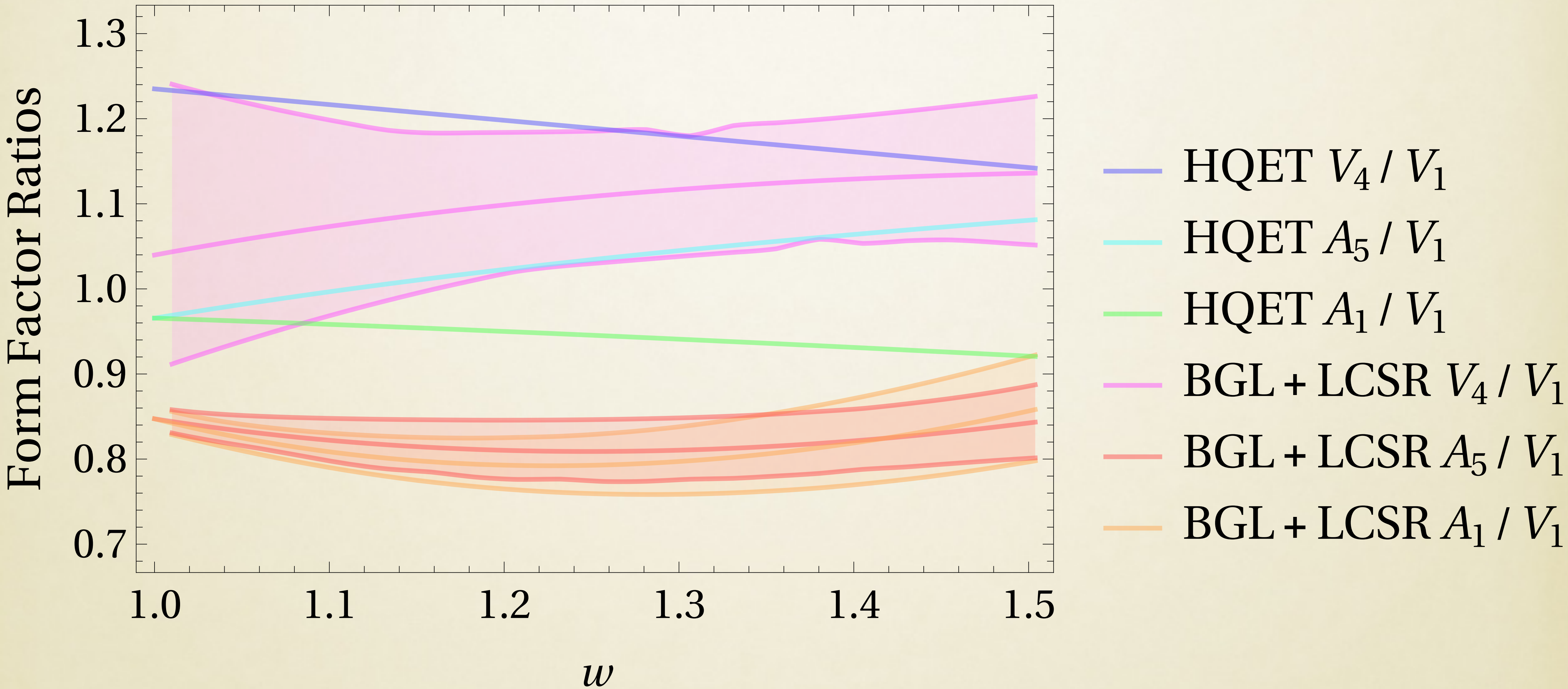


Comparing with HQET



HQET NLO predictions from Bernlochner et al.
Uncertainties ONLY due to QCD sum rules

Comparing with HQET



HQET NLO predictions from Bernlochner et al (uncertainties not shown)

Bottom line: BGL fit compatible with HQET within uncertainties

FUTURE SCENARIO

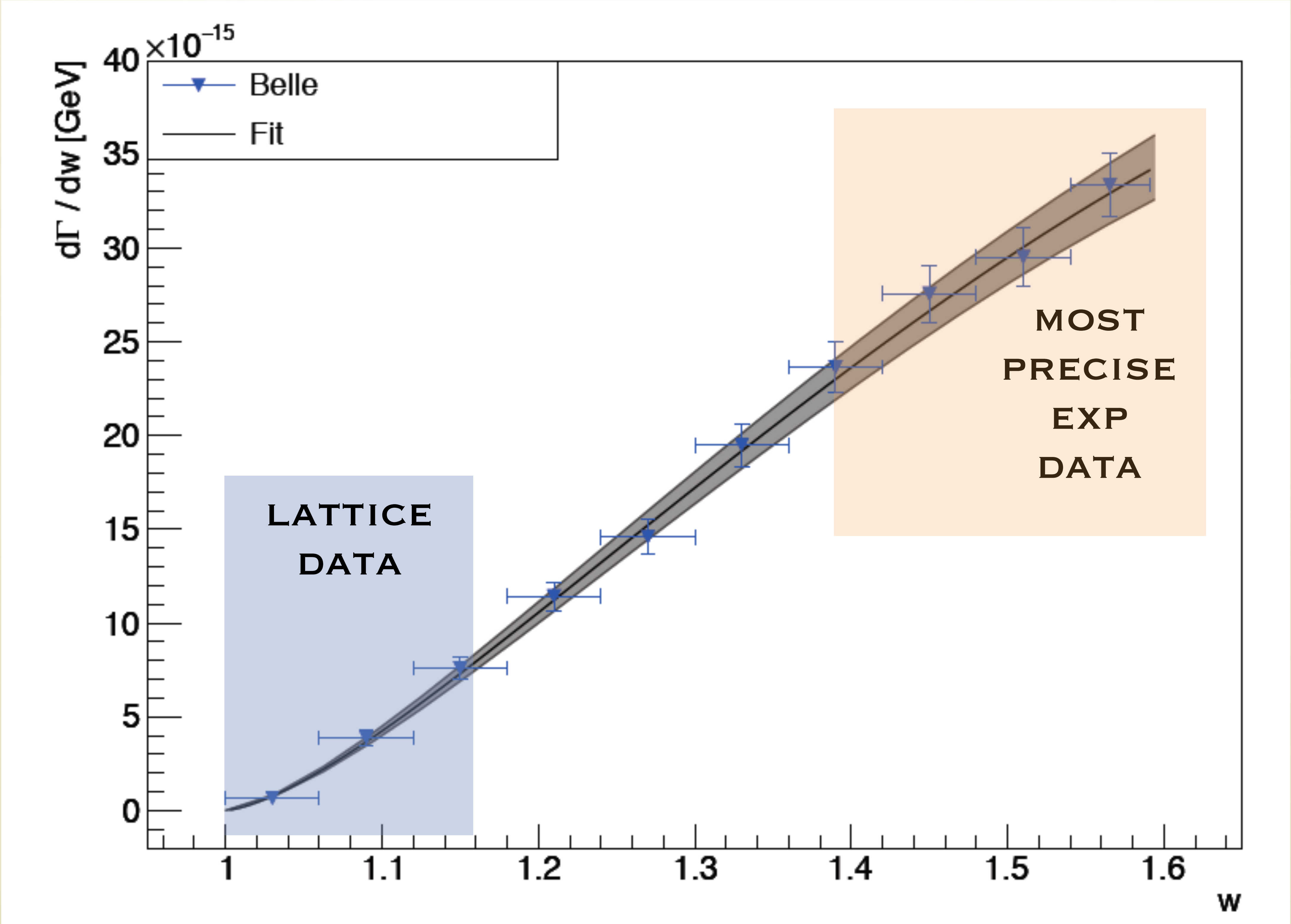
Future lattice fits	χ^2/dof	$\lvert V_{cb}\rvert$
CLN	56.4/37	0.0407 (12)
CLN+LCSR	59.3/40	0.0406 (12)
BGL	28.2/33	0.0409 (15)
BGL+LCSR	31.4/36	0.0404 (13)

assuming Lattice QCD will provide an estimate of the slope with 5% accuracy

$$\frac{\partial \mathcal{F}}{\partial w}\Big|_{w=1} = -1.44 \pm 0.07$$

BELLE SPECTRUM 1510.03657

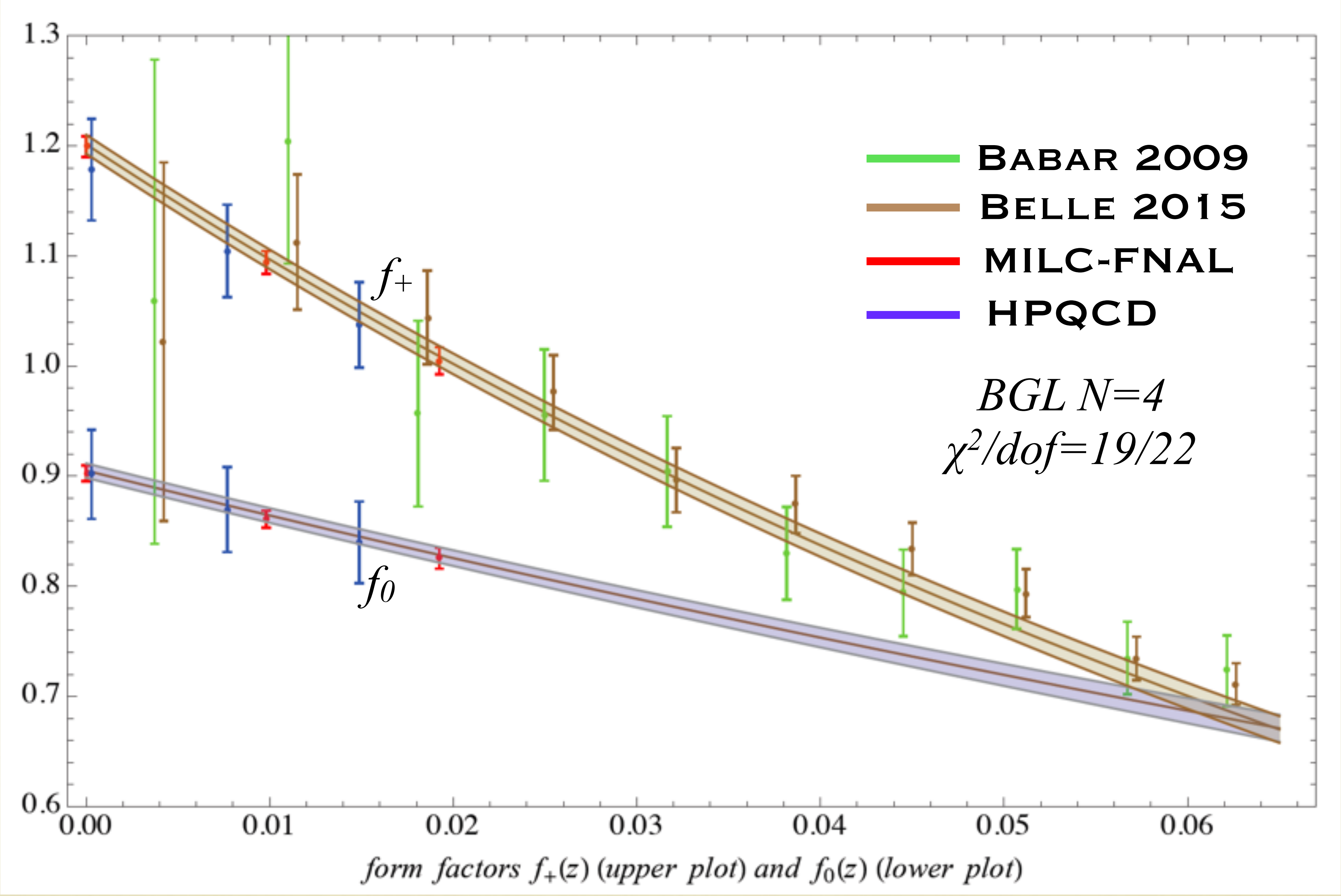
provided in a parametrization independent way



Global fit to $B \to Dl\nu$

D.Bigi, PG

arXiv:1606.08030



RESULTS

exp data	lattice data	N,par	$10^3 \times \|V_{cb}\|$	χ^2/dof	$R(D)$
all	all	2,BGL	40.62(98)	22.1/26	0.302(3)
all	all	3,BGL	40.47(97)	18.2/24	0.299(3)
all	all	4,BGL	**40.49(97)**	19.0/22	**0.299(3)**
Belle	all	3,BGL	40.92(1.12)	11.6/14	0.300(3)
BaBar	all	3,BGL	40.11(1.55)	12.6/14	0.301(4)
all	FNAL	3,BGL	40.17(1.05)	10.4/18	0.293(4)
all	HPQCD	3,BGL	$40.51^{+1.82}_{-1.71}$	10.1/18	0.299(7)
all	all	CLN	40.85(95)	77.1/29	0.305(3)
all	f_+ only	CLN	40.33(99)	20.0/23	0.305(3)
all	all	2,BCL	40.49(98)	18.2/26	0.299(3)
all	all	3,BCL	40.48(96)	18.2/24	0.299(3)
all	all	4,BCL	40.48(97)	17.9/22	0.299(3)

Summary

- Fitting the latest Belle $B \to D^* l\nu$ data with BGL and CLN leads to quite different values of V_{cb}. While this may be related to this specific set of data, it certainly calls for a reanalysis of previous Babar and Belle data with a **more flexible parameterization**.

- HQET input is still useful, but it carries **non-negligible uncertainty** which can no longer be neglected.

- Future lattice determinations of the **zero recoil slope** of the form factors will improve significantly the situation, but it will be impossible to combine them with the present HFAG averages based on CLN. This is already the case for the $B \to D$ channel.

- We did not resolve the V_{cb} puzzle, just pointed out a neglected systematics