INCLUSIVE SEMILEPTONIC B,D DECAYS

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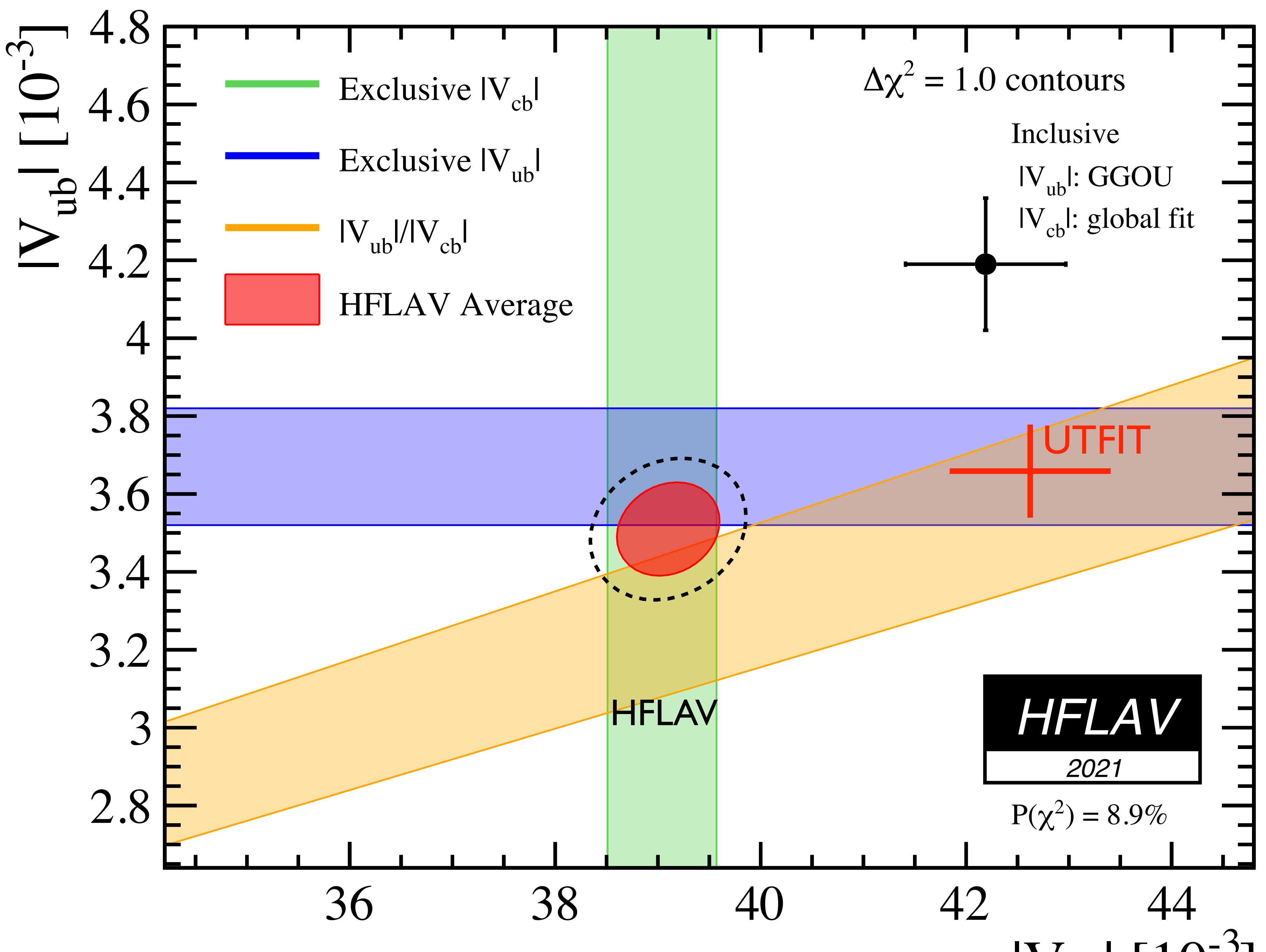
THE V_{cb} (and V_{ub}) PUZZLE

Since many years the inclusive and exclusive determinations of $|V_{cb}|$ and $|V_{ub}|$ diverge

Recent burst of activity: new exp analyses, new lattice and pert calculations.

This plot is outdated!



are these uncertainties realistic?

The importance of $|V_{cb}|$

An important CKM unitarity test is the Unitarity Triangle (UT) formed by

$$1+\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}+\frac{V_{td}V_{tb}^*}{V_{cd}V_{cb}^*}=0$$

V_{cb} plays an important role in UT

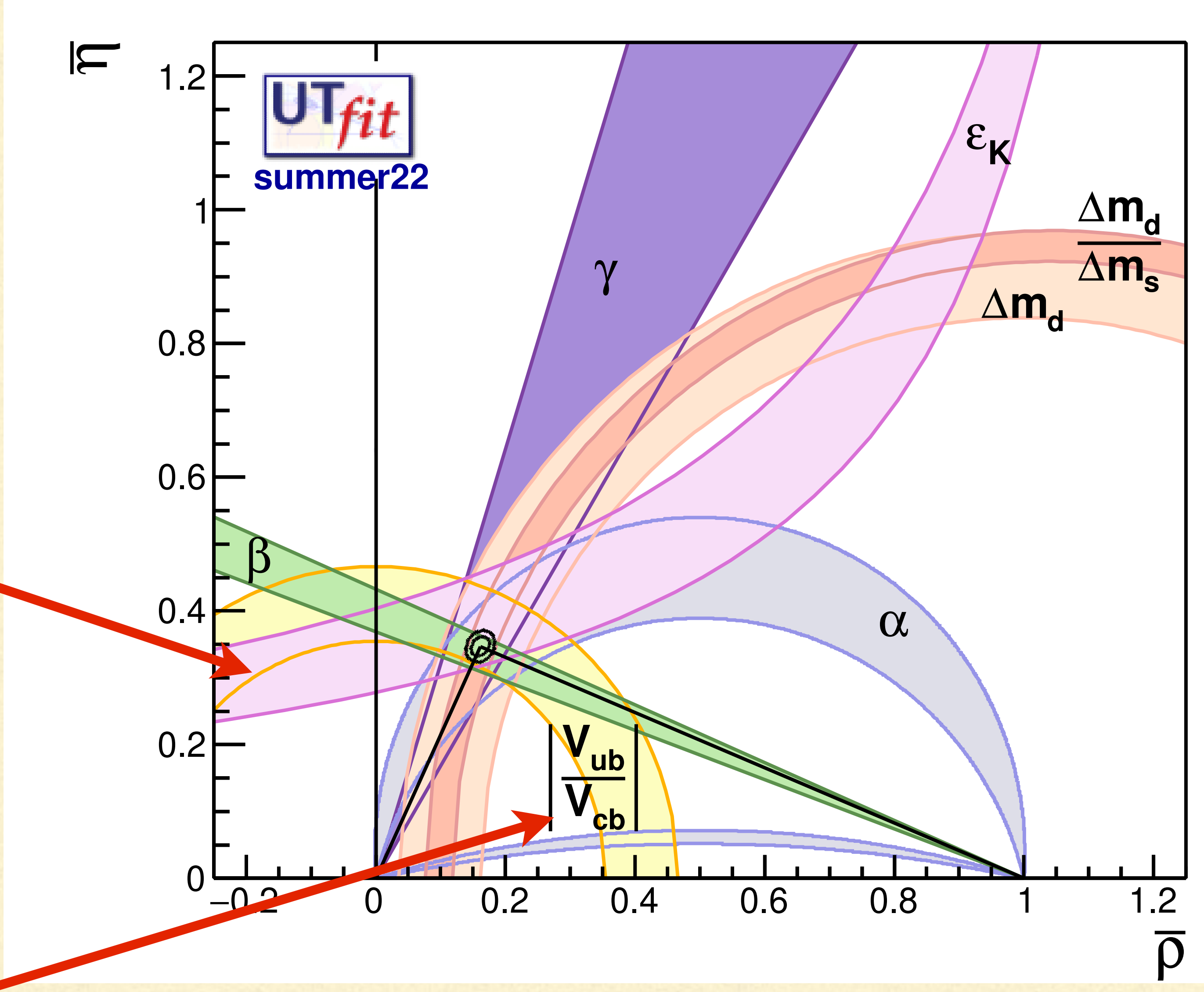
$$\varepsilon_K \approx x|V_{cb}|^4 + \ldots$$

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

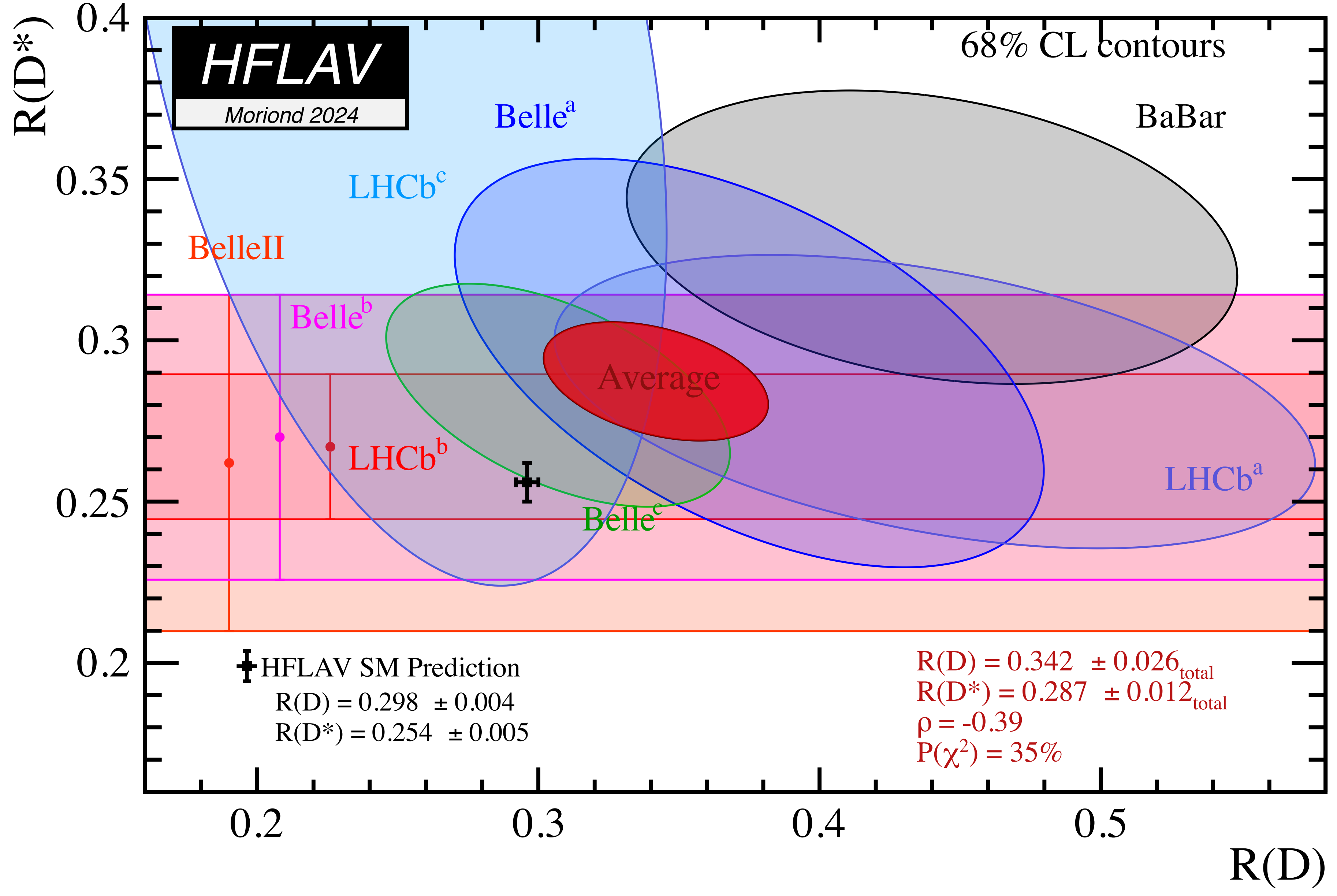


Our ability to determine precisely V_{cb} is crucial for indirect NP searches

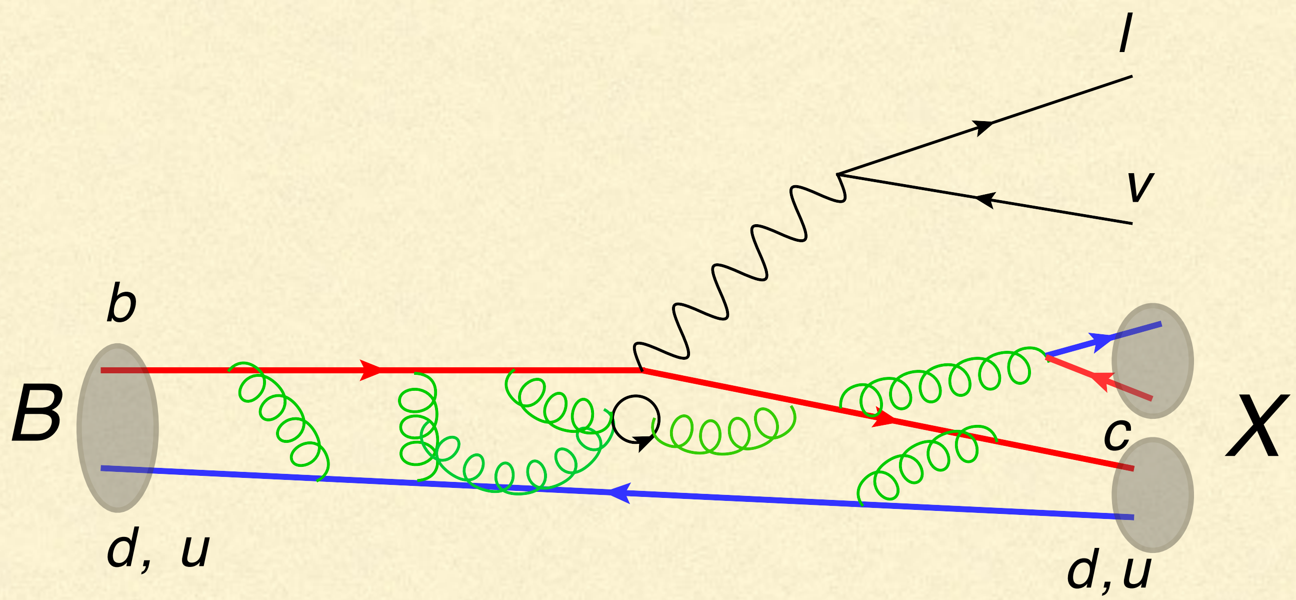
VIOLATION of LFU with TAUS

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

SM predictions based on same theory as V_{cb} extraction



INCLUSIVE DECAYS: BASICS



- ***Simple idea:*** inclusive decays do not depend on final state, long distance dynamics of the B meson factorizes. An OPE allows us 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*** $\alpha_s, \Lambda/m_b$

- Lowest order: decay of a free *b*, linear Λ/m_b absent. Depends on $m_{b,c}$, two parameters at $O(\Lambda^2/m_b^2)$, 2 more at $O(\Lambda^3/m_b^3)$ ... Many higher order effects have been computed.

INCLUSIVE SEMILEPTONIC B DECAYS

Inclusive observables are double series in Λ/m_b and α_s

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

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, inclusive V_{ub}...)

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

3LOOP CALCULATIONS

Fael, Schoenwald, Steinhauser, 2011.11655, 2011.13654, 2205.03410

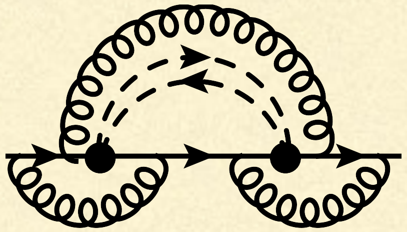
3loop and 2loop charm mass effects in relation between kinetic and $\overline{\mathrm{MS}}$ b mass

$$m_b^{kin}(1\mathrm{GeV}) = \left[4163 + 259_{\alpha_s} + 78_{\alpha_s^2} + 26_{\alpha_s^3}\right]\mathrm{MeV} = (4526 \pm 15)\,\mathrm{MeV}$$

Using FLAG $\overline{m}_b(\overline{m}_b) = 4.198(12)\mathrm{GeV}$ one gets $m_b^{kin}(1\mathrm{GeV}) = 4.565(19)\,\mathrm{GeV}$

3loop correction to ***total semileptonic width***

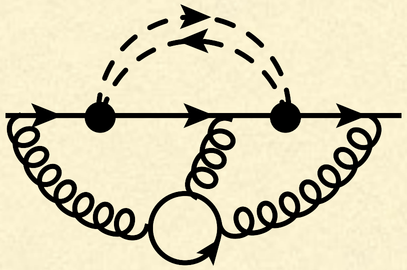
$$\Gamma_{sl} = \Gamma_0 f(\rho)\left[0.9255 - 0.1162_{\alpha_s} - 0.0350_{\alpha_s^2} - 0.0097_{\alpha_s^3}\right]$$



(d)

in the kin scheme with $\mu = 1\mathrm{GeV}$ and $\overline{m}_c(3\mathrm{GeV}) = 0.987\,\mathrm{GeV}$, $\mu_{\alpha_s} = m_b^{kin}$

$$\Gamma_{sl} = \Gamma_0 f(\rho)\left[0.9255 - 0.1140_{\alpha_s} - 0.0011_{\alpha_s^2} + 0.0103_{\alpha_s^3}\right]$$



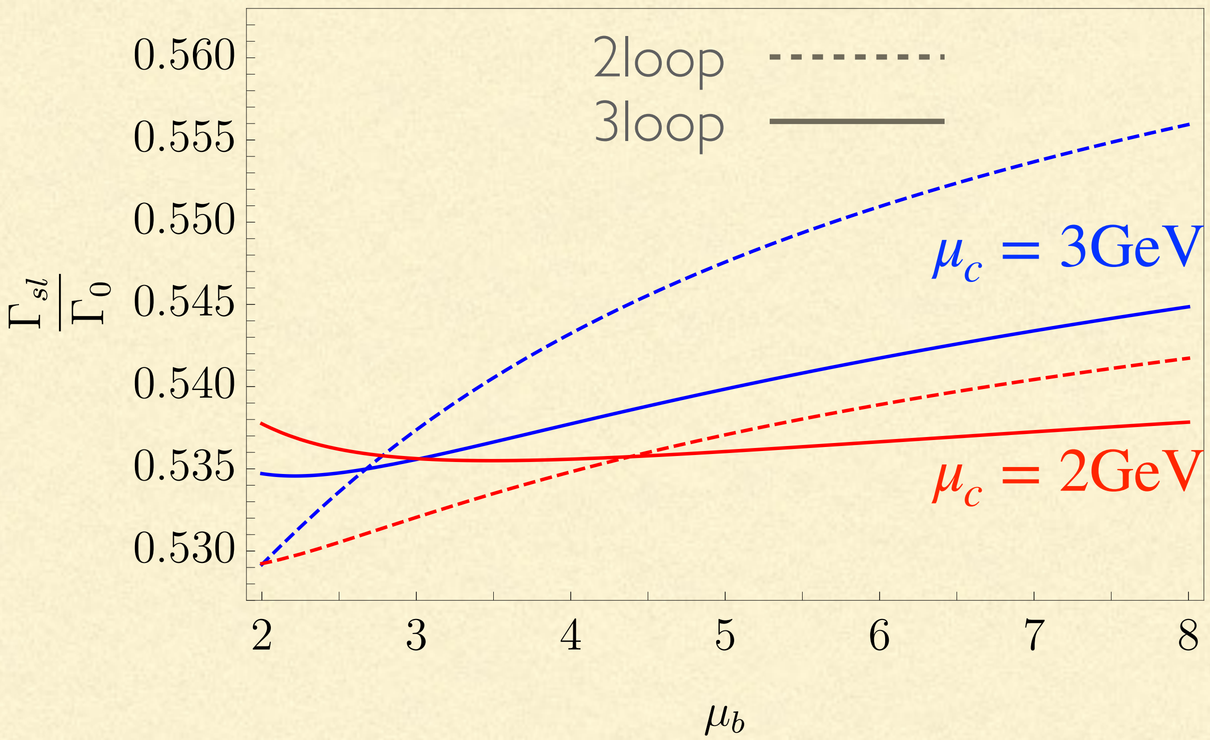
(f)

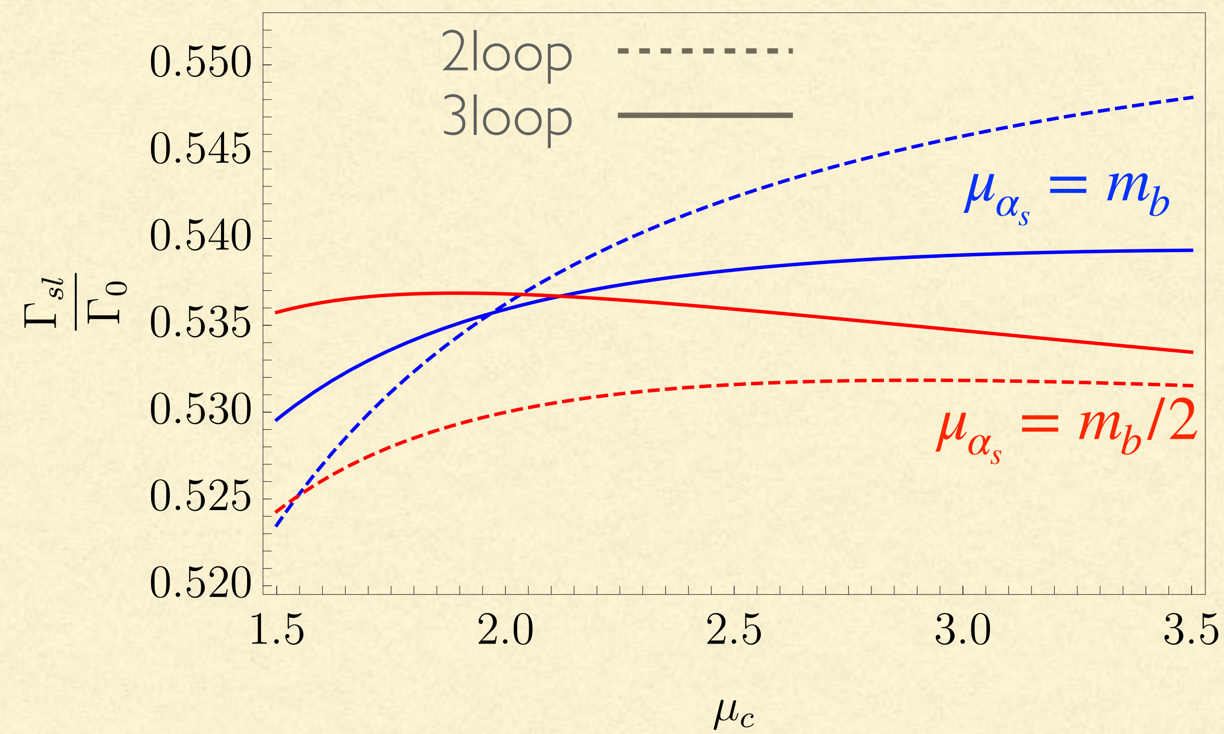
in the kin scheme with $\mu = 1\mathrm{GeV}$ and $\overline{m}_c(2\mathrm{GeV}) = 1.091\,\mathrm{GeV}$, $\mu_{\alpha_s} = m_b^{kin}/2$

3loop correction tends to lower Γ_{sl} and therefore pushes $|V_{cb}|$ slightly up (~0.5%)

RESIDUAL UNCERTAINTY on Γ_{sl}

Bordone, Capdevila, PG, 2107.00604





Similar reduction in μ_{kin} dependence. Purely perturbative uncertainty $\pm 0.7\,\%$ (max spread), central values at $\mu_c = 2\mathrm{GeV}$, $\mu_{\alpha_s} = m_b/2$.

$O(\alpha_s/m_b^2, \alpha_s/m_b^3)$ effects in the width are known. Additional uncertainty from higher power corrections, soft charm effects of $O(\alpha_s/m_b^3 m_c)$, duality violation.

Conservatively: 1.2% overall theory uncertainty in Γ_{sl} (a ~50% reduction)

Interplay with fit to semileptonic moments, known only to $O(\alpha_s^2, \alpha_s\Lambda^2/m_b^2)$

HIGHER ORDER CORRECTIONS TO MOMENTS

- complete $O(\alpha_s)$ corrections to triple differential
  Aquila, Ridolfi, PG, Trott, Czarnecki, Jezabek, Kuhn, …

- complete $O(\alpha_s^2)$ corrections to leptonic, hadronic (*partly numerical*), q^2 moments at arbitrary cuts
  Biswas, Melnikov, Czarnecki, Pak, PG, Fael, Herren

- $O(\alpha_s^3)$ corrections to leptonic, hadronic, q^2 moments *without cuts*
  Fael, Schoenwald, Steinhauser

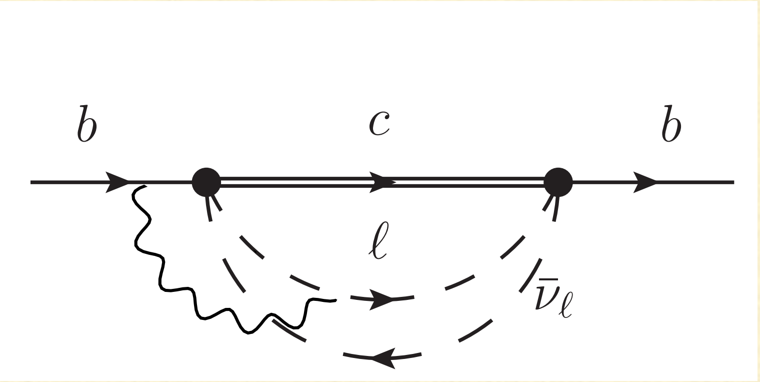
- complete $O(\alpha_s \Lambda^2/m_b^2)$ corrections to triple differential, $O(\alpha_s \Lambda^3/m_b^3)$ to width and q^2 moments
  Alberti, Healey, Nandi, PG, Becher, Lunghi, Mannel, Moreno, Pivovarov

- power corrections of $O(\Lambda^2/m_b^2)$ and $O(\Lambda^3/m_b^3)$ to triple differential, $O(\Lambda^4/m_b^4)$ and $O(\Lambda^5/m^5)$ for moments
  Manohar, Wise, Blok, Koyrakh, Shifman, Vainshtein, Grimm, Kapustin, Mannel, Turzcyk, Uraltsev, Milutin, Vos

QED CORRECTIONS

Bigi, Bordone, Haisch, Piccione PG
2309.02849

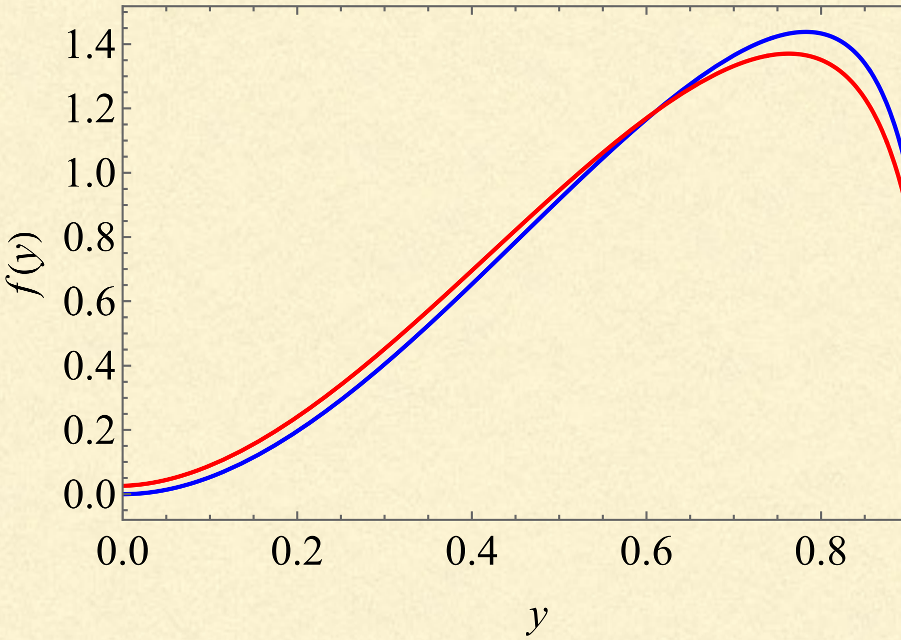
In the presence of photons, ***OPE valid only for total width*** and moments that do not resolve charged lepton or hadron properties ($E_\ell, q^2, E_X \ldots$). Expect mass singularities and $O(\alpha\Lambda/m_b)$ corrections.



Leading logs $\alpha \ln m_e/m_b$ can be easily computed for simple observables using structure function approach, for ex the lepton energy spectrum

$$\left(\frac{d\Gamma}{dy}\right)^{(1)} = \frac{\alpha}{2\pi} \ln\frac{m_b^2}{m_\ell^2} \int_y^1 \frac{dx}{x} P_{\ell\ell}^{(0)}\left(\frac{y}{x}\right) \left(\frac{d\Gamma}{dx}\right)^{(0)}$$

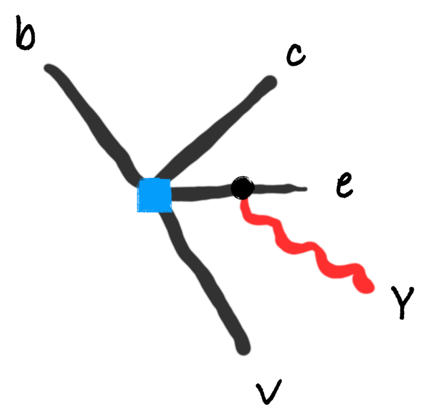
$$P_{\ell\ell}^{(0)}(z) = \left[\frac{1+z^2}{1-z}\right]_+$$



Electron energy spectrum

QED Leading contributions

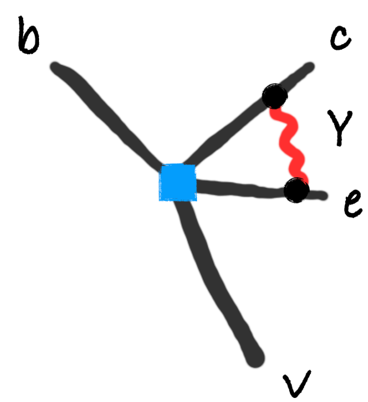
1. **Collinear logs**: captured by splitting functions



also at subleading power!

$$\sim \frac{\alpha_e}{\pi} \log \frac{m_b^2}{m_e^2}$$

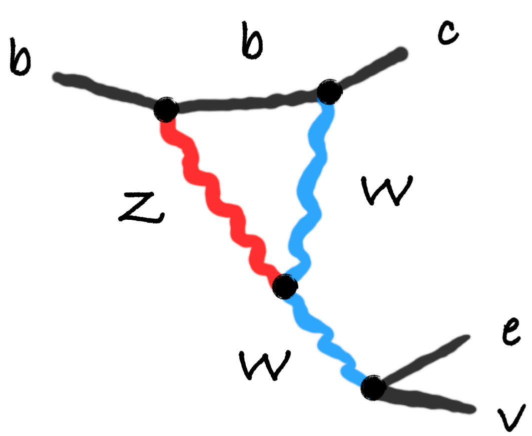
2. **Threshold effects** or Coulomb terms



$$\sim \frac{4\pi\alpha_e}{9}$$

discontinuity at threshold

3. **Wilson Coefficient**



$$\sim \frac{\alpha_e}{\pi} \left[\ln \frac{M_Z^2}{\mu^2} - \frac{11}{6} \right]$$

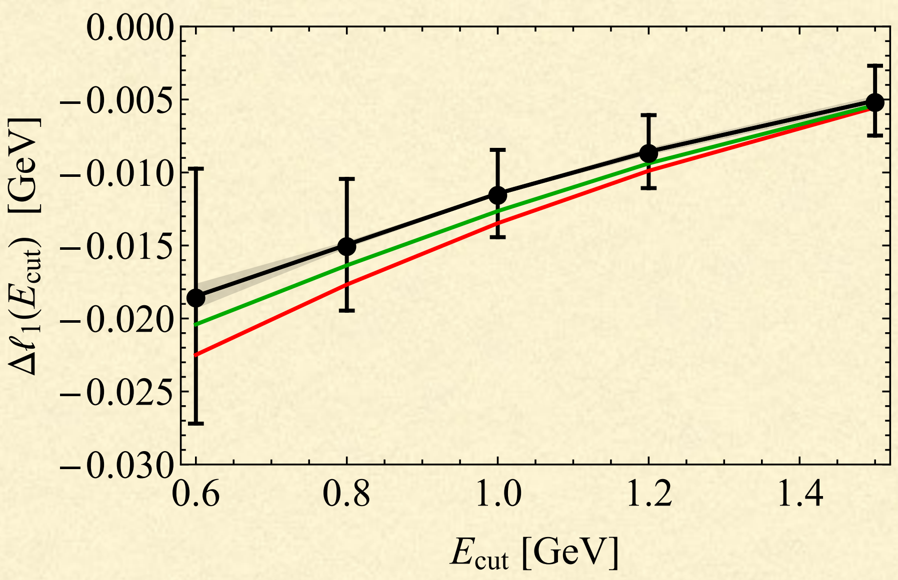
M. Bordone

COMPLETE $O(\alpha)$ EFFECTS IN LEPTONIC SPECTRUM

Typical measurements are completely inclusive, $B \to X_c \ell \nu(\gamma)$, but QED radiation is ***subtracted*** by experiments using ***PHOTOS*** (soft-collinear photon radiation to MC final states).

Small but non-negligible differences with *PHOTOS* in BaBar leptonic moments hep-ex/0403030

$E_{\rm cut}$	$\delta {\rm BR}^{\rm BaBar}_{\rm incl}$	$\delta {\rm BR}^{\rm LL}_{\rm incl}$	$\delta {\rm BR}^{\rm NLL}_{\rm incl}$	$\delta {\rm BR}^{\alpha}_{\rm incl}$	$\delta {\rm BR}^{1/m_b^2}_{\rm incl}$	$\delta {\rm BR}_{\rm incl}$	σ
0.6	-1.26%	-1.92%	-1.95%	-0.54%	-0.50%	-0.45%	$+0.34$
0.8	-1.87%	-2.88%	-2.91%	-1.36%	-1.29%	-1.22%	$+0.30$
1.0	-2.66%	-4.03%	-4.04%	-2.38%	-2.26%	-2.15%	$+0.25$
1.2	-3.56%	-5.43%	-5.41%	-3.65%	-3.43%	-3.27%	$+0.14$
1.5	-5.22%	-8.41%	-8.26%	-6.37%	-5.73%	-5.39%	-0.09



The black curve corresponds to the correction obtained by BaBar using PHOTOS, while the red (green) curve corresponds to our QED prediction including the LL terms (all QED corrections). The grey band represents the systematic uncertainty on the PHOTOS bremsstrahlungs corrections that BaBar quotes, while the black error bars correspond to the total uncertainties of the QED corrected BaBar results.

~0.2% reduction in V_{cb}

A GLOBAL FIT

Finauri, PG 2310.20324

$m_b^{\rm kin}$	$\overline{m}_c(2\,{\rm GeV})$	μ_π^2	$\mu_G^2(m_b)$	$\rho_D^3(m_b)$	ρ_{LS}^3	${\rm BR}_{c\ell\nu}$	$10^3\lvert V_{cb}\rvert$
4.573	1.090	0.454	0.288	0.176	−0.113	10.63	41.97
0.012	0.010	0.043	0.049	0.019	0.090	0.15	0.48

Includes all leptonic, hadronic, and q^2 moments measured by BaBar, Belle, Belle II, Cleo, CDF, Delphi

Up to $O(\alpha_s^2)$, $O(\alpha_s/m_b^2)$, $O(1/m_b^3)$ for M_X, E_ℓ moments, up to $O(\alpha_s^2\beta_0)$, $O(\alpha_s/m_b^3)$ for q^2moments (complete $O(\alpha_s^2)$ calculation by Fael and Herren 2403.03976 to be implemented)

Subtracts QED effects beyond those computed by PHOTOS (only BaBar BR and lept moments) $\delta V_{cb} \sim -0.2\,\%$

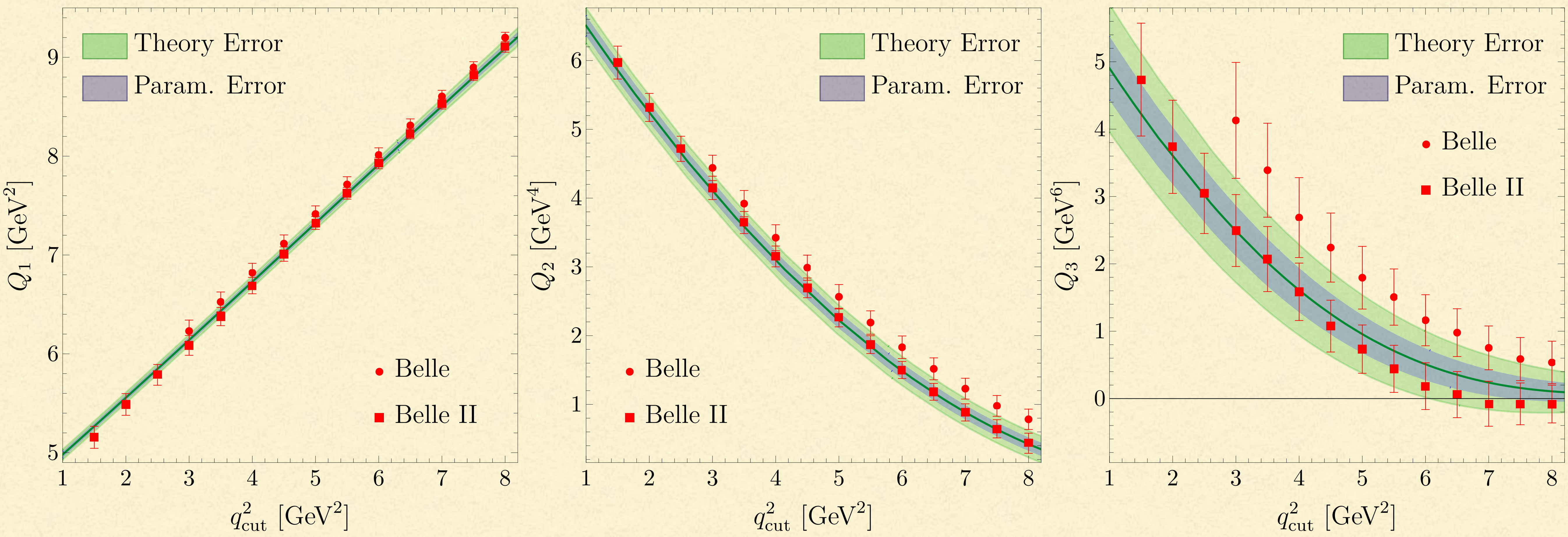
Employs $\overline{m}_b(\overline{m}_b) = 4.203(11)\mathrm{GeV}$ and $\overline{m}_c(3\mathrm{GeV}) = 0.989(10)\mathrm{GeV}$ (FLAG)
$\chi^2_{min}/dof = 0.55$

$$|V_{cb}| = (41.97 \pm 0.27_{exp} \pm 0.31_{th} \pm 0.25_\Gamma) \times 10^{-3} = (41.97 \pm 0.48) \times 10^{-3}$$

consistent with analysis of q^2 moments by Bernlochner et al, 2205.10274

MINOR TENSIONS IN HIGHER q^2 MOMENTS

Finauri, PG 2310.20324



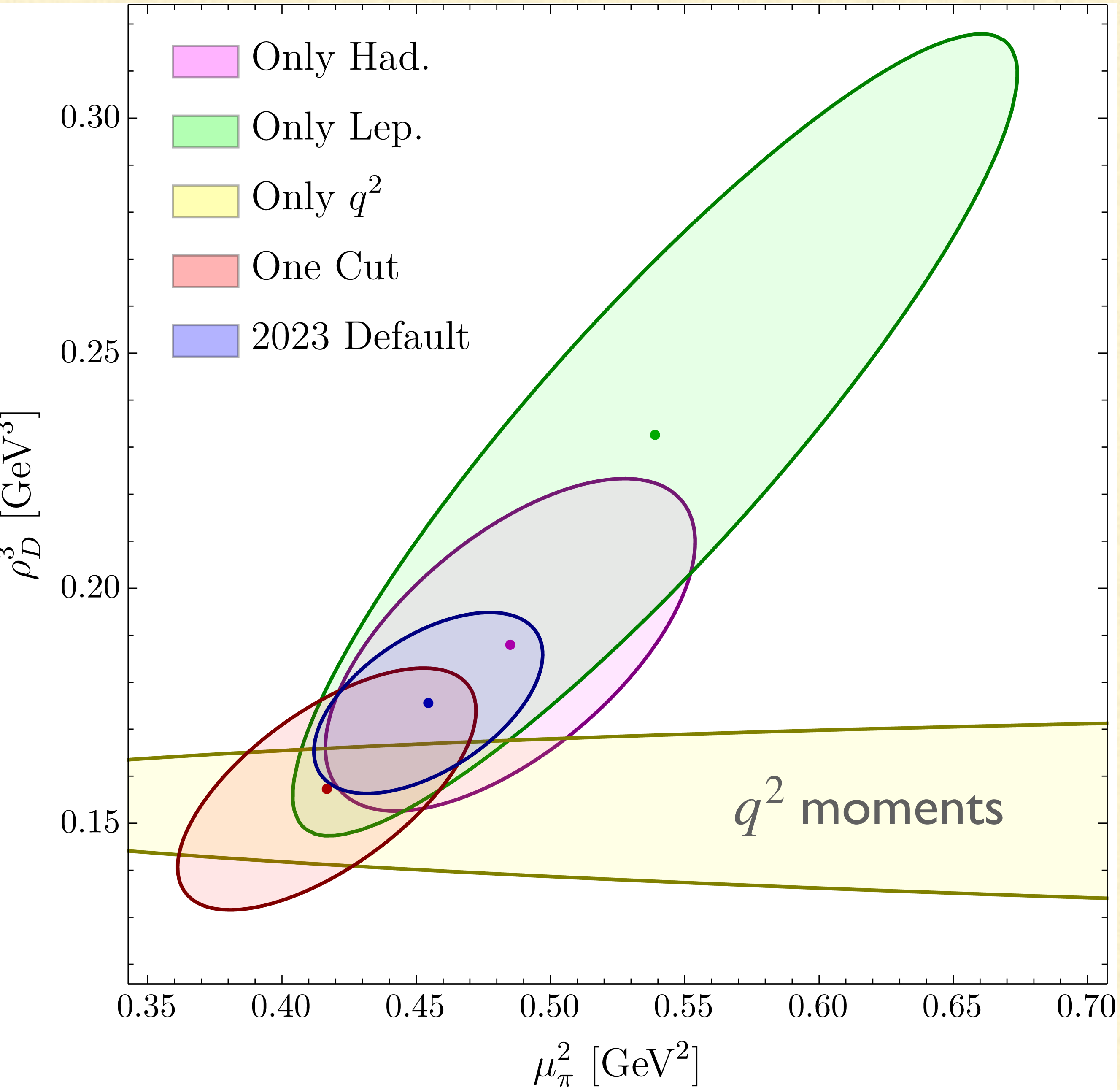
$$Q_1 = \langle q^2 \rangle, \qquad Q_2 = \langle (q^2 - \langle q^2 \rangle)^2 \rangle, \qquad Q_3 = \langle (q^2 - \langle q^2 \rangle)^3 \rangle$$

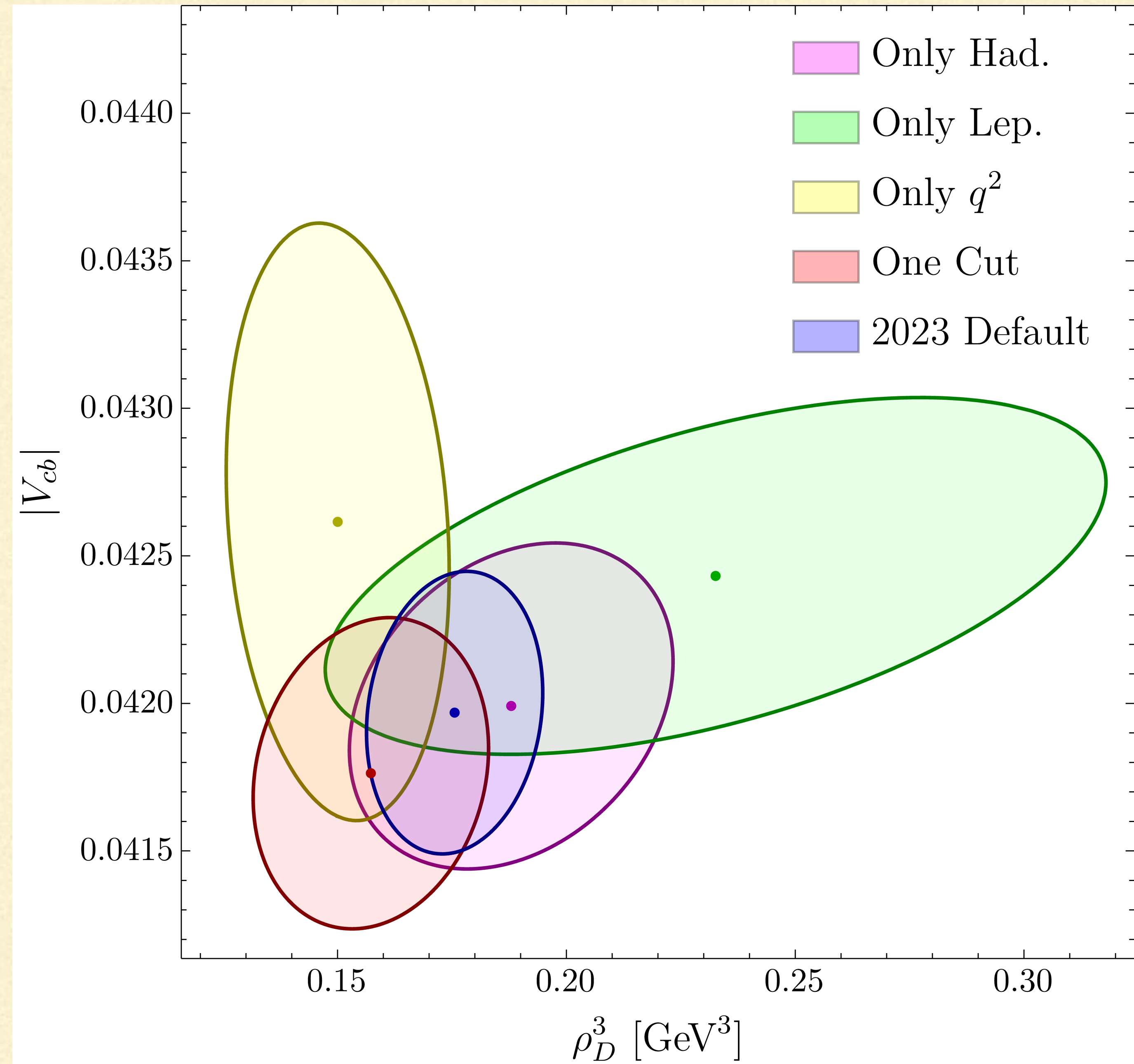
Highly correlated data and theoretical predictions: we include only 5 Belle II and 4 Belle points for each moment and employ an ansatz for theory correlations

Schwanda, PG 1307.4551

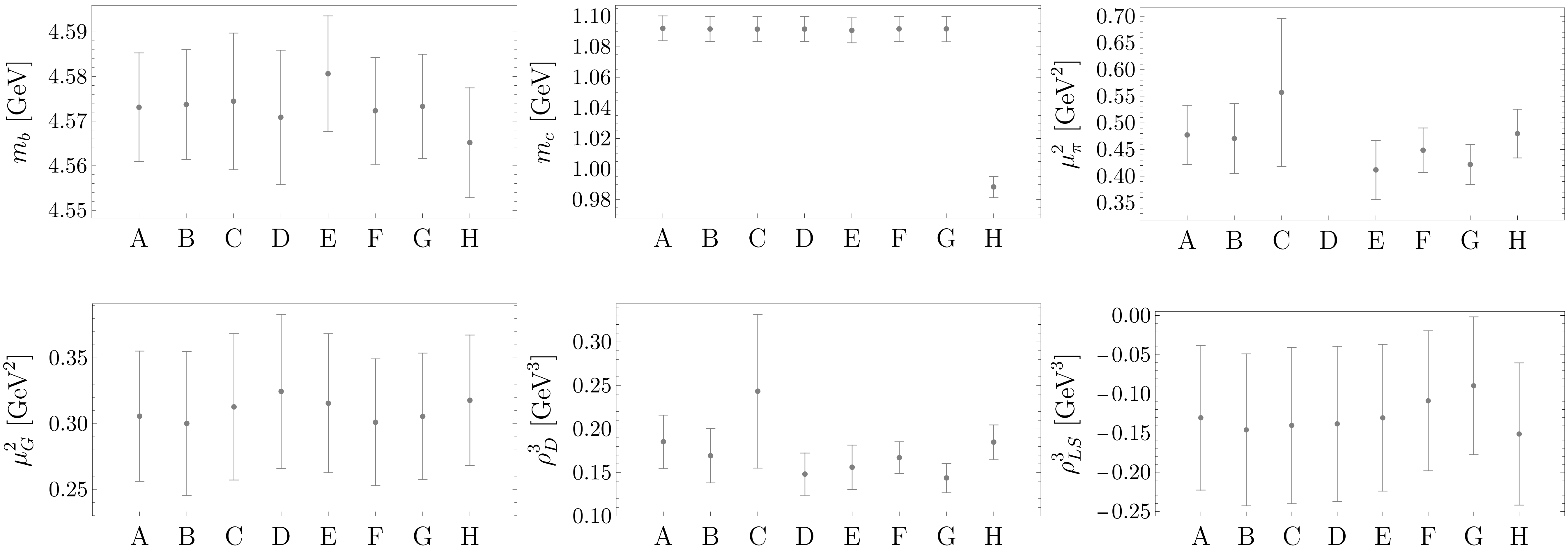
comparison of different datasets

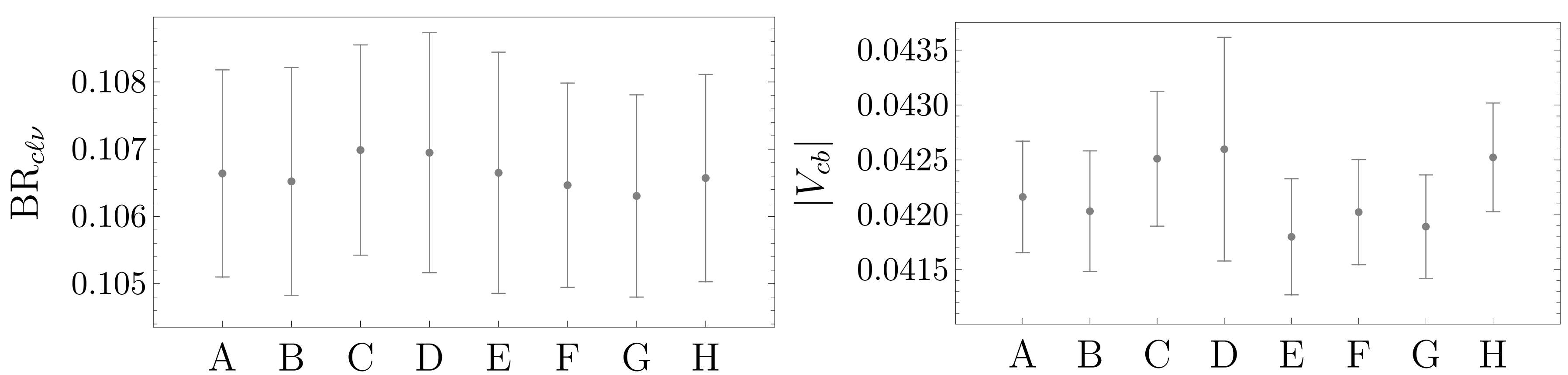
Finauri, PG 2310.20324





Theory correlations are no longer an issue





A: 2021 Default

B: Only Hadronic

C: Only Leptonic

D: Only q^2

E: One Cut

F: All Data

G: $\mu_s = m_b$

H: $\mu_c = 3$ GeV

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.

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

ϵ 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.

still without q^2 moments!

$$\boxed{|V_{cb}| = 42.00(53)\times 10^{-3}}$$

Bordone, Capdevila, PG, 2107.00604

Update of 1606.06174

The advantage of q^2 moments

Mannel, KKV, JHEP 1806 (2018) 115; Fael, Mannel, KKV, JHEP 02 (2019) 177

- Standard lepton energy and hadronic mass moments are not RPI quantities
- New q^2 moments are RPI!

Reparametrization invariant quantities:

- Setting up the HQE: momentum of b quark: $p_b = m_b v + k$, expand in $k \sim iD$
- Choice of v not unique: Reparametrization invariance (RPI)

$$v_\mu \to v_\mu + \delta v_\mu$$

$$\delta_{RP}\ v_\mu = \delta v_\mu \quad \text{and} \quad \delta_{RP}\ iD_\mu = -m_b \delta v_\mu$$

  - links different orders in $1/m_b \to$ reduction of parameters
  - up to $1/m_b^4$: 8 parameters (previous 13)

- q^2 moments enable (?) a full extraction up to $1/m_b^4$

Bernlochner, Welsch, Fael, Olschewsky, Persson, van Tonder, KKV [2205.10274]

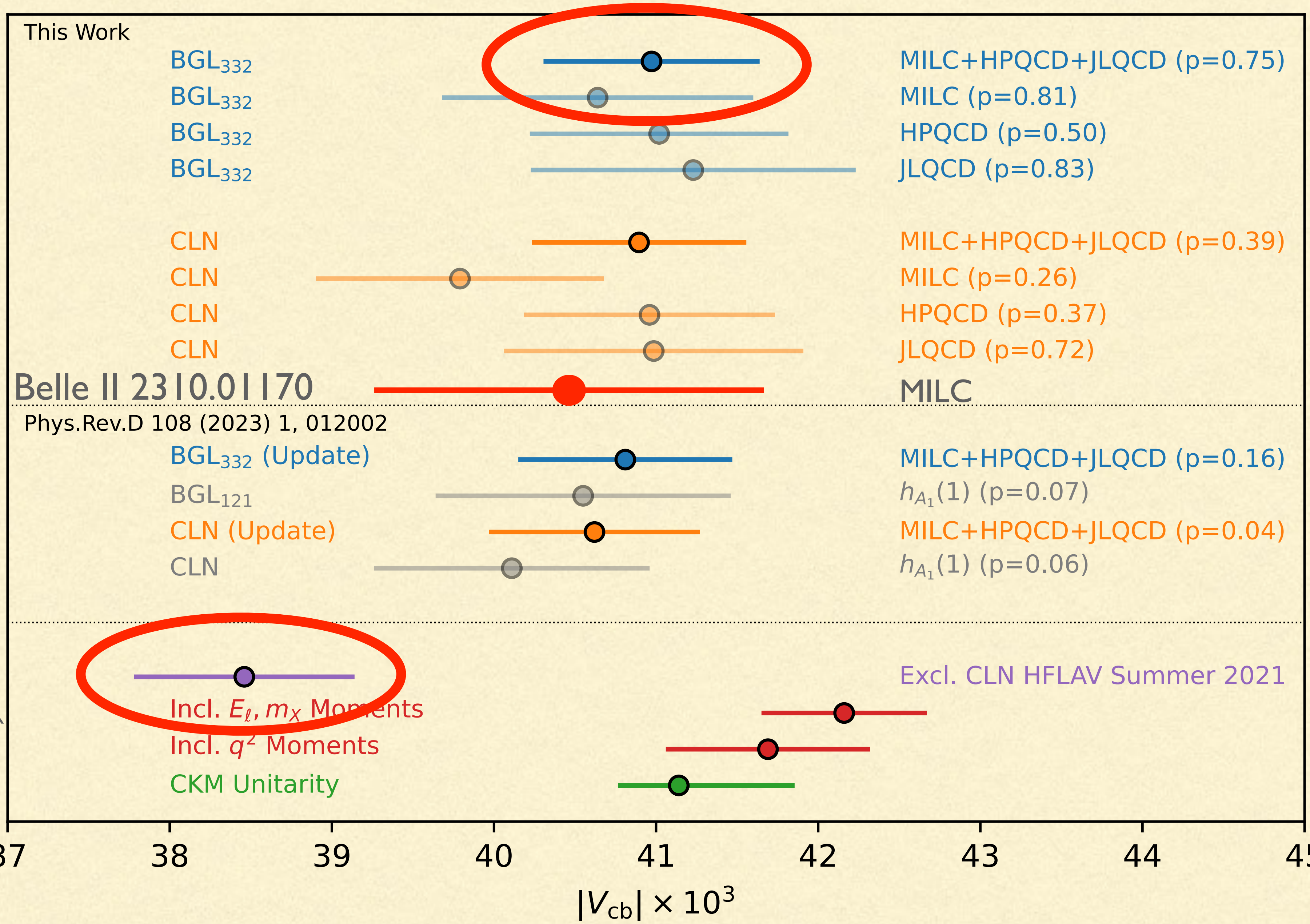
$$|V_{cb}|^{q^2}_{\text{incl}} = (41.69 \pm 0.63) \times 10^{-3}$$

Important consistency check

for next week…

New from Belle [2310.20286]

$$|V_{cb}| = 41.0(7) \times 10^{-3}$$



normalisation from HFLAV total rate!

SEE ALSO
1903.10002, LHCB
2001.03225 BABAR

Do we understand why they differ so much?
Should we average them?

PROSPECTS

- ***Experiment***: more precise measurement of moments and BR at Belle II, new observables (A_{FB}, quantities computable on the lattice with optimal uncertainty), correlations between different kinds of moments, improved QED treatment

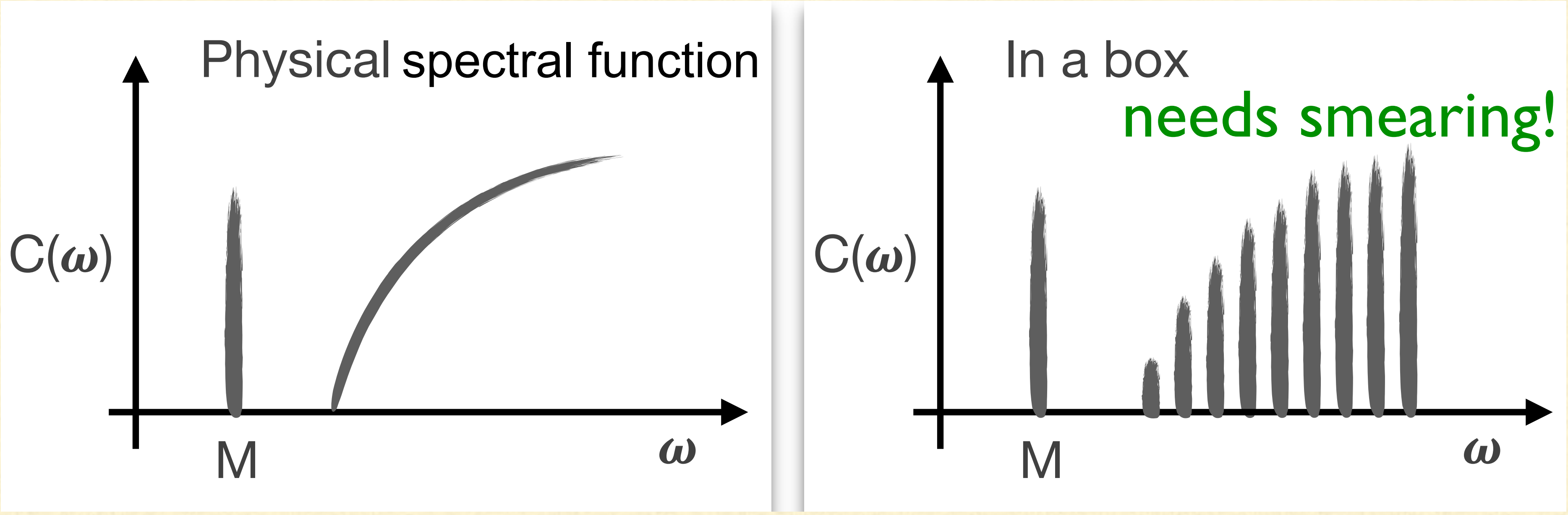
- ***Theory***: analytic calculation of $O(\alpha_s^2)$ corrections to moments, inclusion of complete $O(\alpha_s^2)$ in q^2-moments, $O(\alpha_s \rho_D^3/m_b^3)$ to lept and hadr moments, QED effects in q^2-moments…

- ***Interplay with lattice calculations*** (this afternoon discussion): in the mid term look for complementarity with exp data, and new directions in parameters space (lattice as virtual lab: new observables, V, A, S, P currents,…)

INCLUSIVE DECAYS ON THE LATTICE

- Inclusive processes *impractical* to treat directly on the lattice. Vacuum current correlators computed in euclidean space-time are related to $e^+e^- \to$ hadrons or τ decay via analyticity. In our case the correlators have to be computed in the B meson, but analytic continuation more complicated: two cuts, decay occurs only on a portion of the physical cut.

- While the lattice calculation of the spectral density of hadronic correlators is an ***ill-posed problem***, the spectral density is accessible *after smearing,* as provided by phase-space integration Hansen, Meyer, Robaina, Hansen, Lupo, Tantalo, Bailas, Hashimoto, Ishikawa



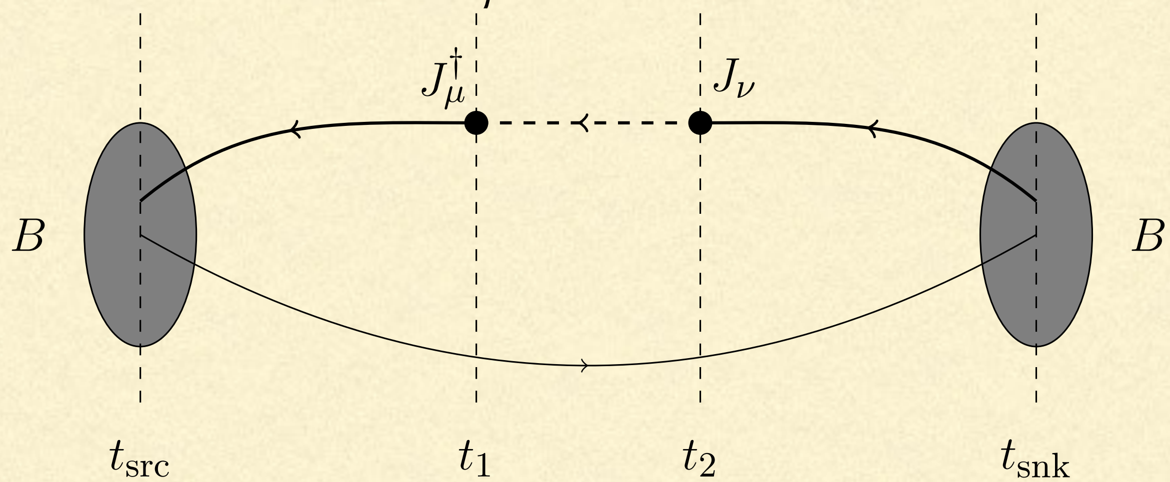
W. Jay @Snowmass workshop

A PRACTICAL APPROACH

Hashimoto, PG 2005.13730

4-point functions on the lattice are related to the hadronic tensor in euclidean

$$\sim \langle B | J^\dagger_\mu(\mathbf{x}, t) J_\nu(\mathbf{0},0) | B \rangle$$

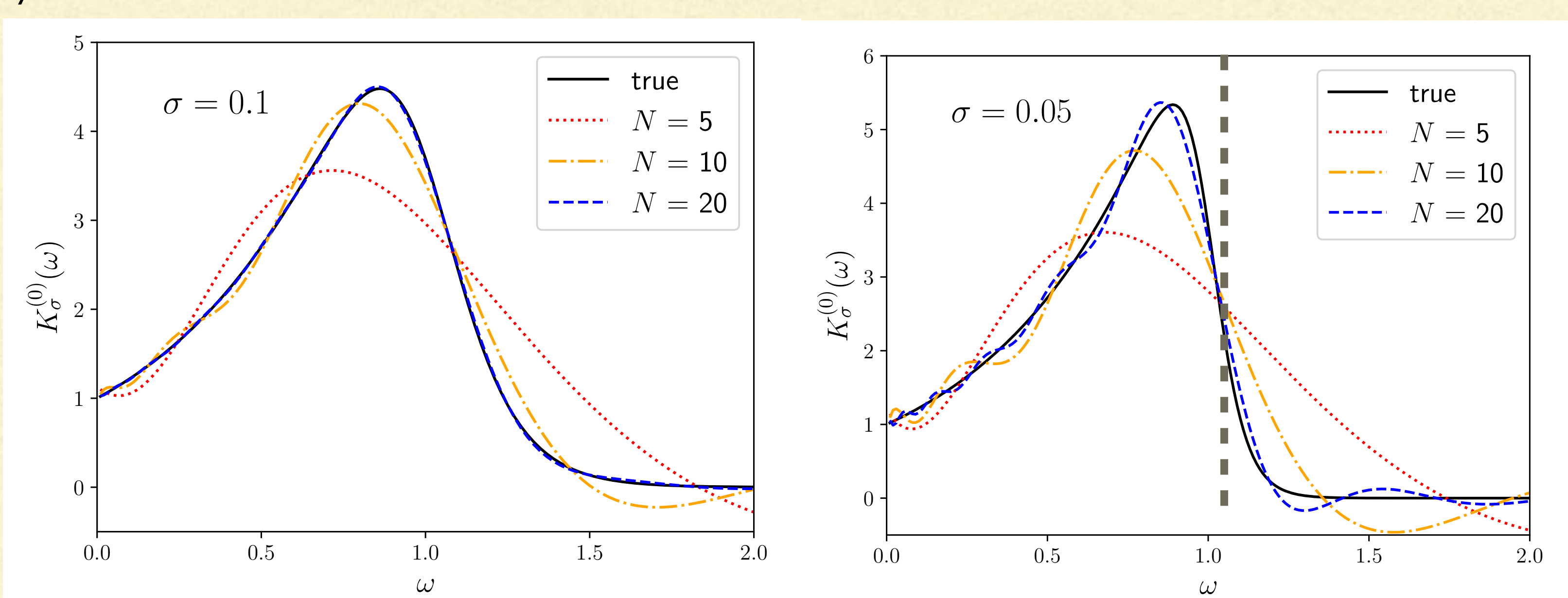


$$d\Gamma \sim L^{\mu\nu} W_{\mu\nu}, \quad W_{\mu\nu} \sim \sum_X \langle B | J^\dagger_\mu | X \rangle \langle X | J_\nu | B \rangle$$

$$\int d^3x \frac{e^{i\mathbf{q}\cdot\mathbf{x}}}{2M_B} \langle B | J^\dagger_\mu(\mathbf{x}, t) J_\nu(\mathbf{0},0) | B \rangle \sim \int_0^\infty d\omega W_{\mu\nu} e^{-t\omega}$$

smearing kernel $f(\omega) = \sum_n a_n e^{-na\omega}$

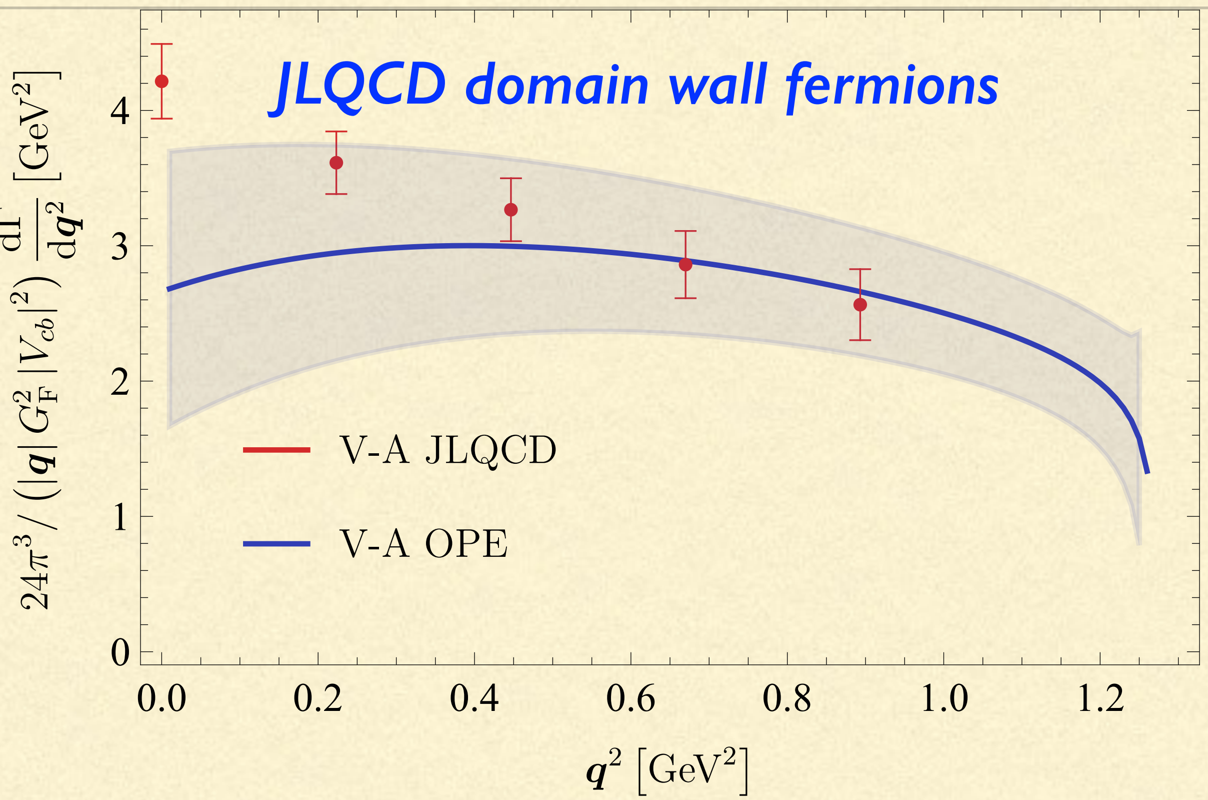
The necessary smearing is provided by phase space integration over the hadronic energy, which is cut by a θ function: sigmoid $1/(1+e^{x/\sigma})$ can be used to replace kinematic $\theta(x)$. Larger number of polynomials needed for small σ ***The kernel must be reconstructed by taking $\sigma \to 0$***

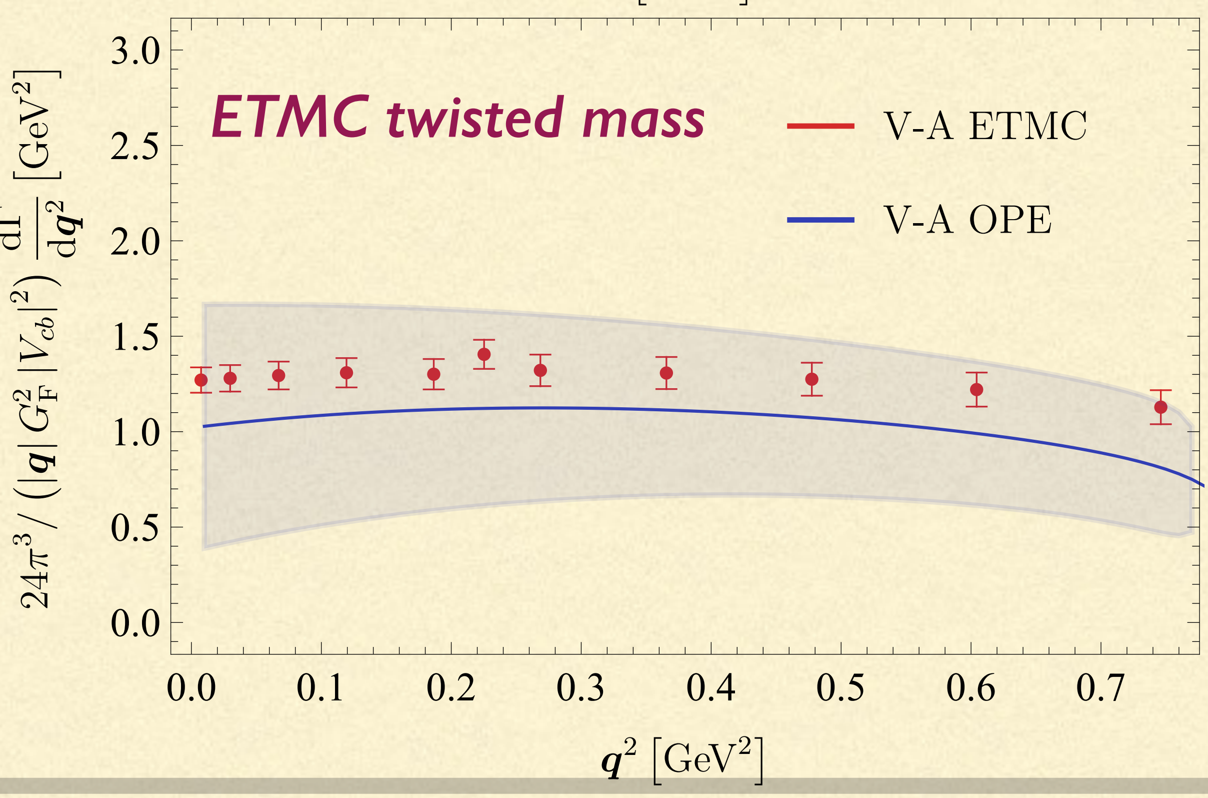


Two methods based on Chebyshev polynomials and Backus-Gilbert. Important:

$$\lim_{\sigma\to 0} \lim_{V\to\infty} \lim_{a\to 0} X_\sigma$$

LATTICE VS OPE





m_b^{kin} (JLQCD)	2.70 ± 0.04
$\overline{m}_c(2\text{ GeV})$ (JLQCD)	1.10 ± 0.02
m_b^{kin} (ETMC)	2.39 ± 0.08
$\overline{m}_c(2\text{ GeV})$ (ETMC)	1.19 ± 0.04
μ_π^2	0.57 ± 0.15
ρ_D^3	0.22 ± 0.06
$\mu_G^2(m_b)$	0.37 ± 0.10
ρ_{LS}^3	-0.13 ± 0.10
$\alpha_s^{(4)}(2\text{ GeV})$	0.301 ± 0.006

OPE inputs from fits to exp data (physical m_b), HQE of meson masses on lattice

1704.06105, J.Phys.Conf.Ser. 1137 (2019) 1, 012005

We include $O(1/m_b^3)$ and $O(\alpha_s)$ terms

Hard scale $\sqrt{m_c^2+\mathbf{q}^2} \sim 1-1.5\,\text{GeV}$

We do not expect OPE to work at high $|\mathbf{q}|$

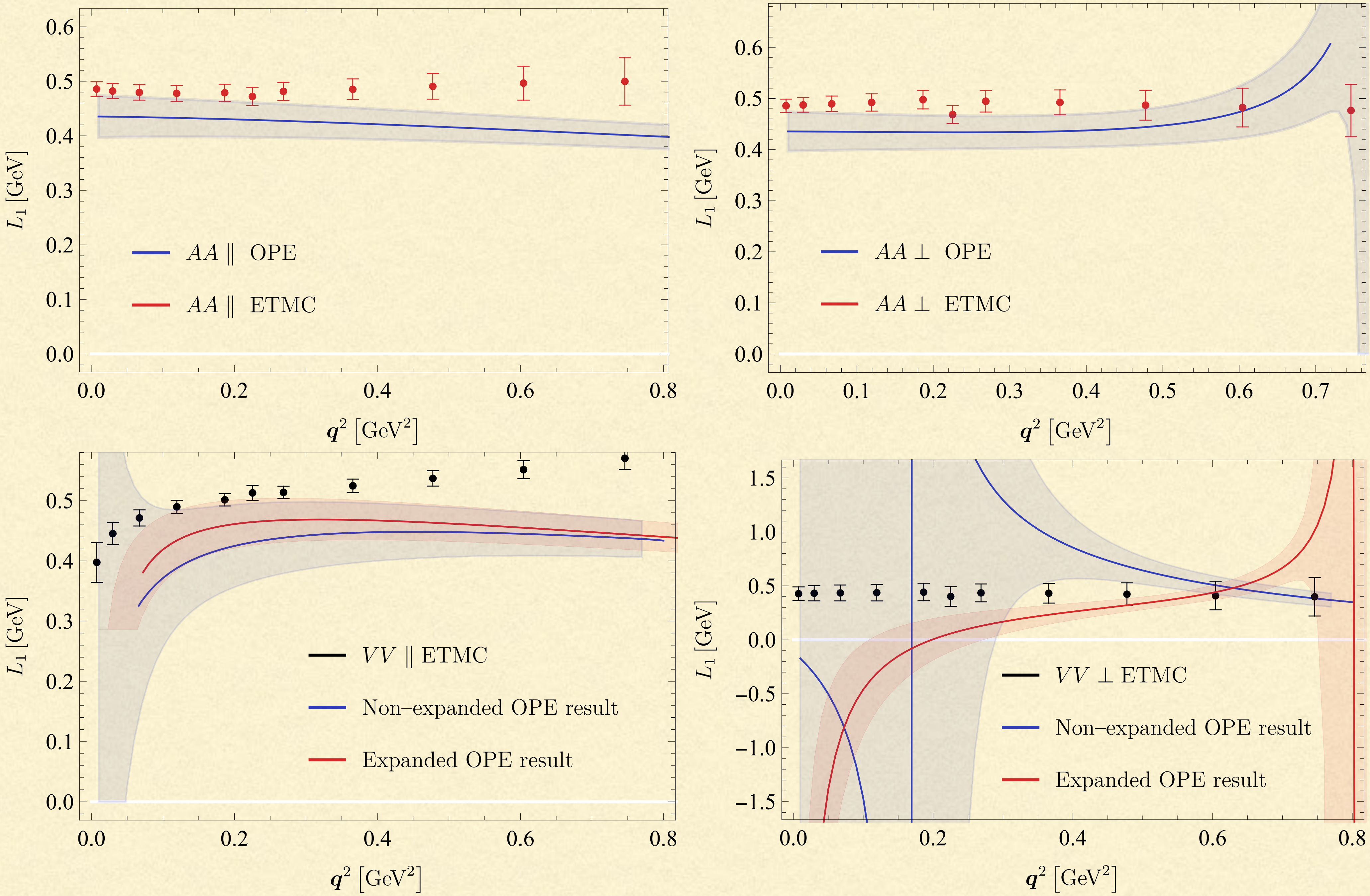
Twisted boundary conditions allow for any value of $\vec{q}^2$

Smaller statistical uncertainties

MOMENTS

PG, Hashimoto, Maechler, Panero, Sanfilippo, Simula, Smecca, Tantalo, 2203.11762

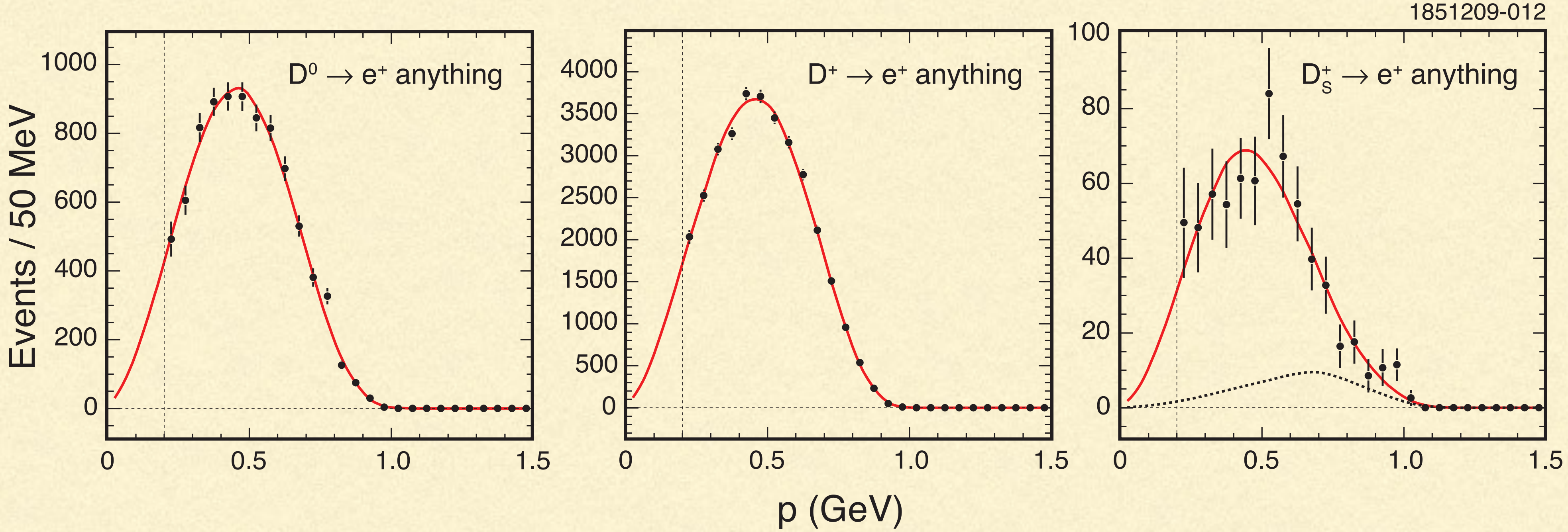
$$L_1 = \langle E_\ell(\mathbf{q}^2)\rangle$$



smaller errors, cleaner comparison with OPE, individual channels AA, VV, parallel and perpendicular polarization, could help extracting OPE parameters

$D_{(s)}$ INCLUSIVE SEMILEPTONIC DECAYS

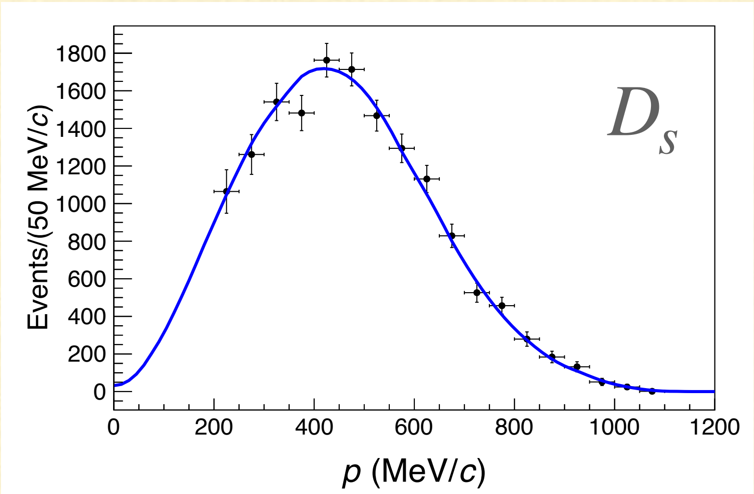
Cleo-c
0912.4232



$D_{(s)}$ decay offer the opportunity to **validate the method on experimental data.**

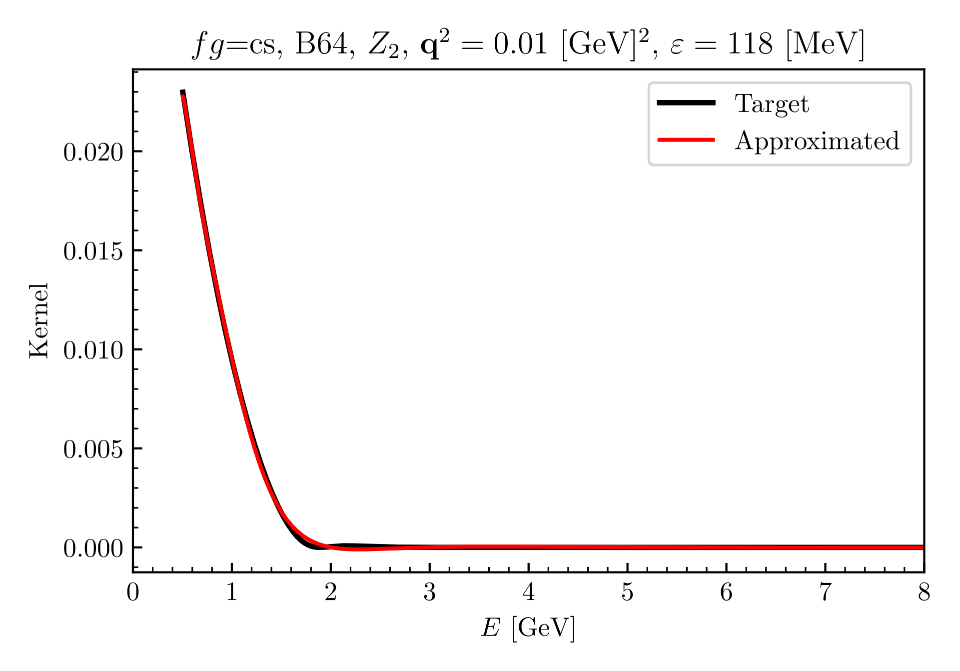
Easiest to extrapolate the exp spectrum then compute total width (0.5% uncertainty) mean $\langle E_e \rangle$ (0.5%) and variance (1%) for D^+, with D_s a bit less precise

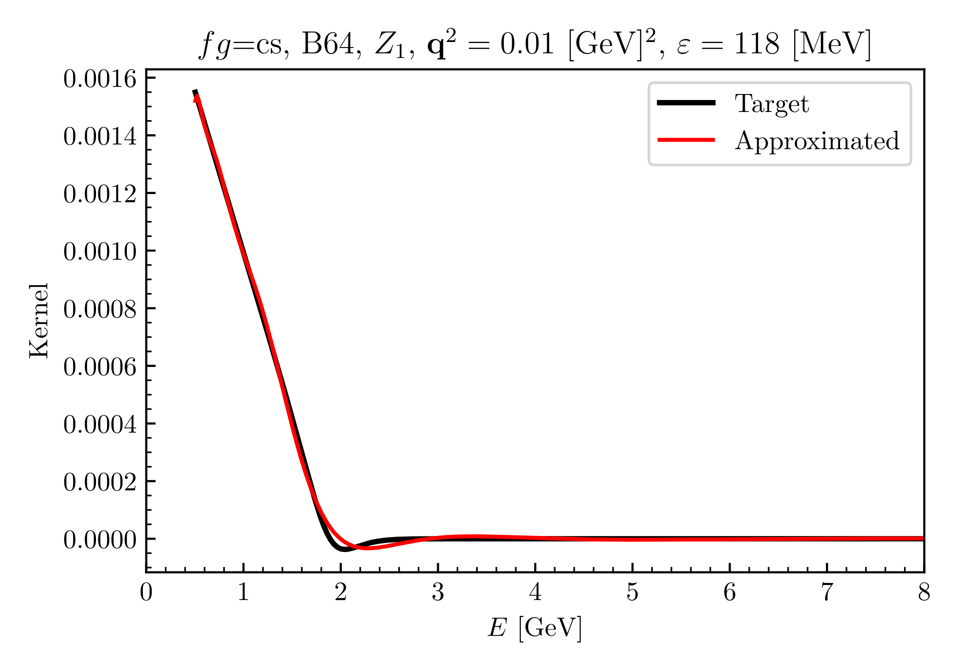
slow convergence (?) of HQE in charm decays

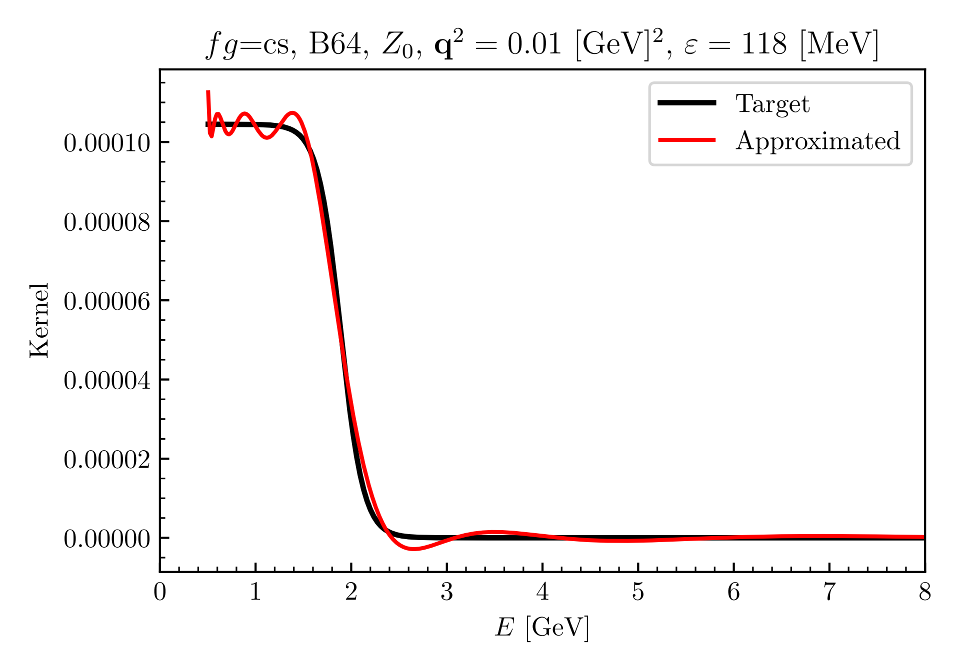


BES III
2104.07311

KERNEL RECONSTRUCTION



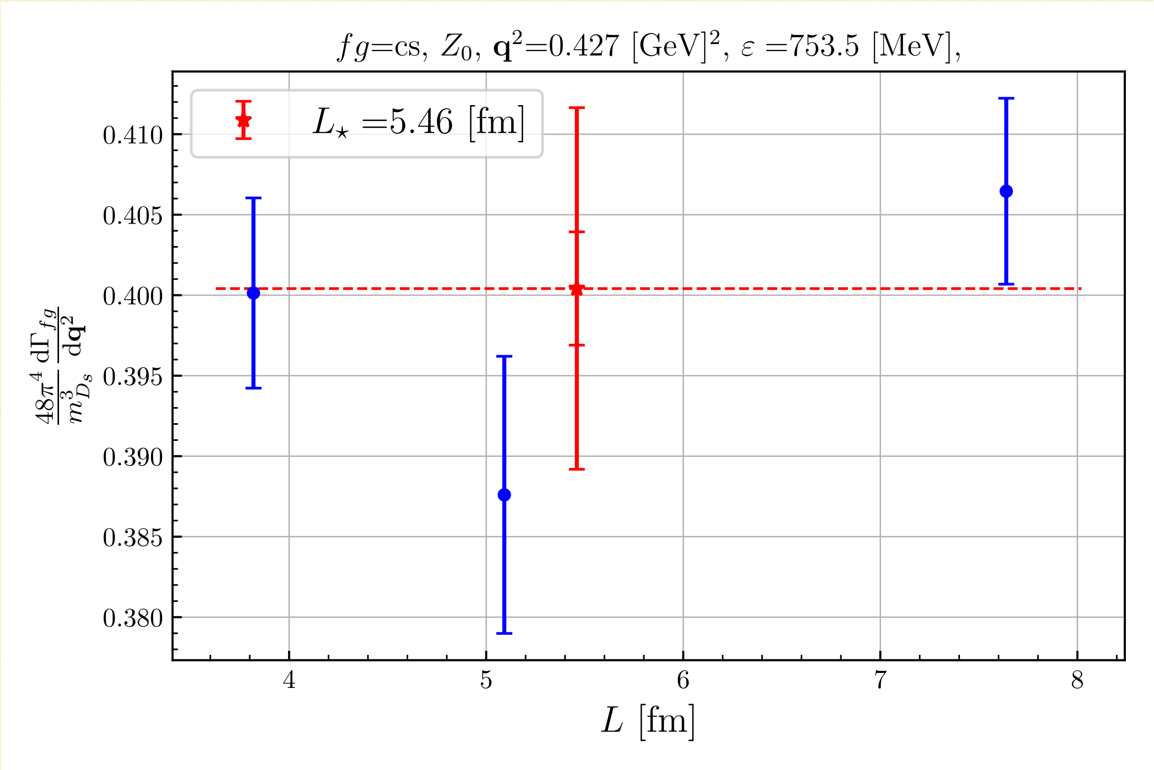


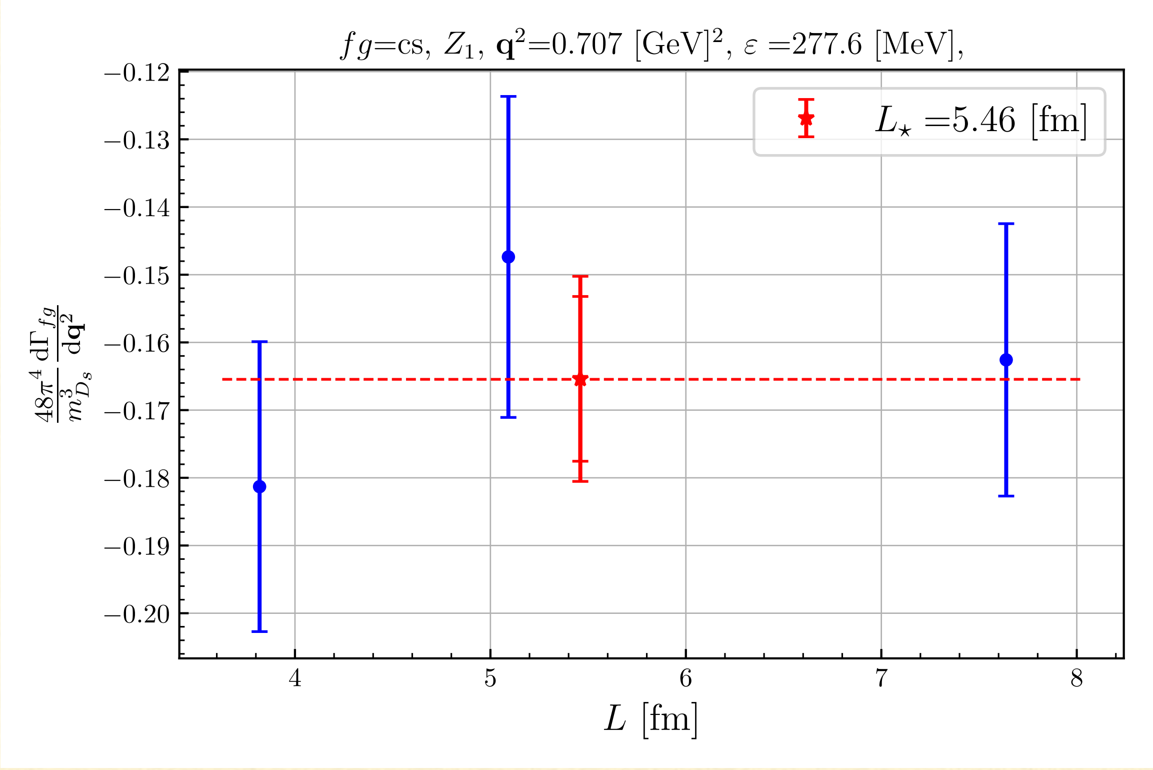


preliminary by ETMC

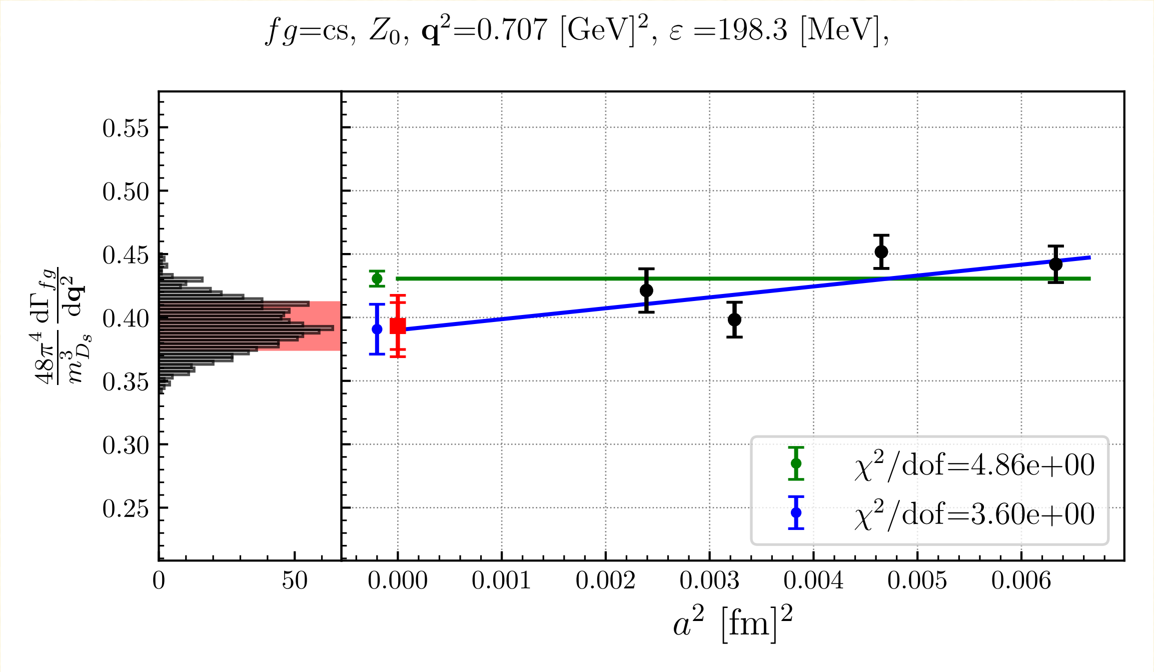
Backus-Gilbert

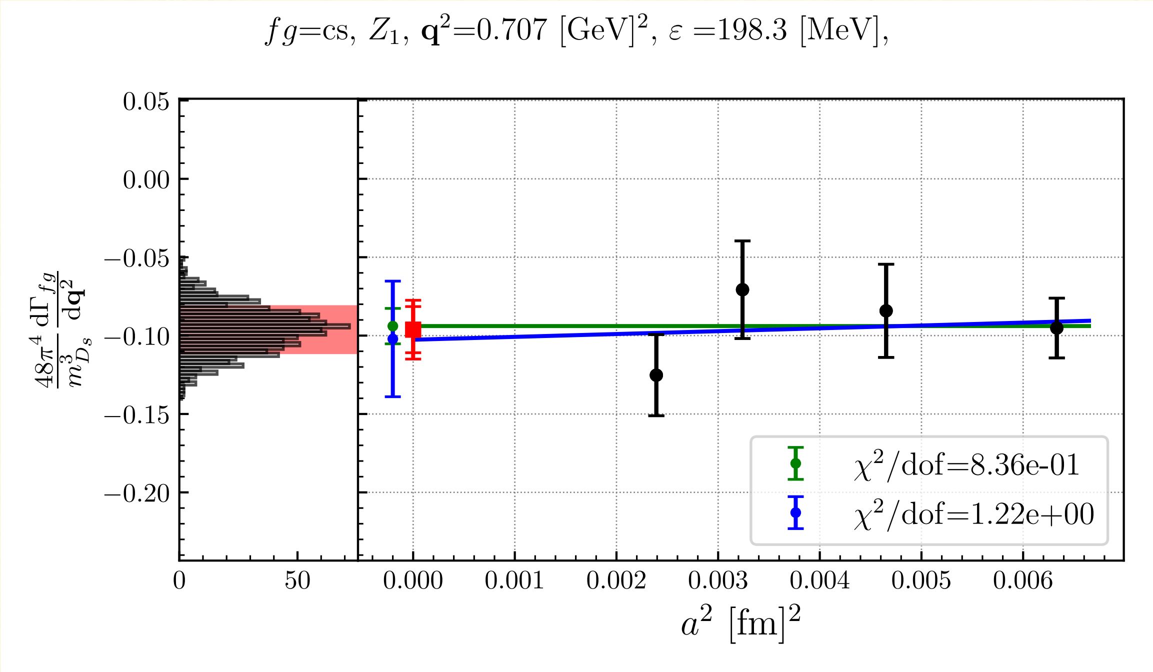
CONTINUUM AND INFINITE VOLUME LIMITS





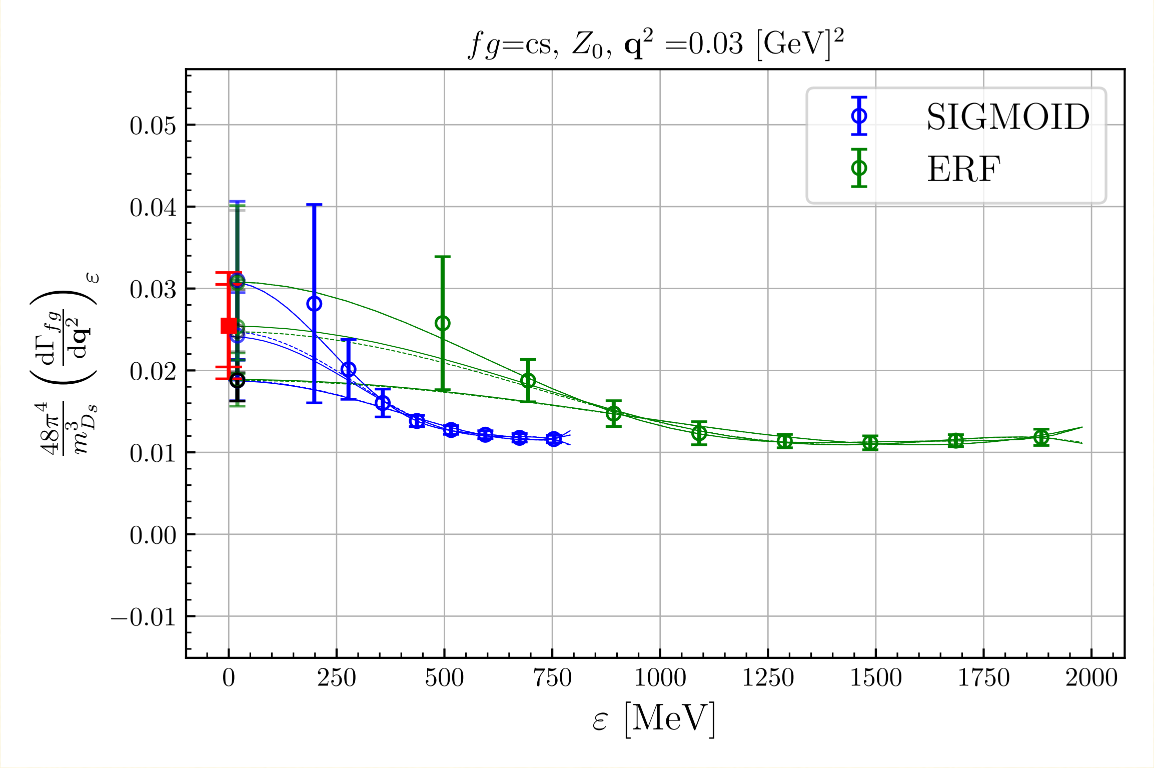
preliminary by ETMC

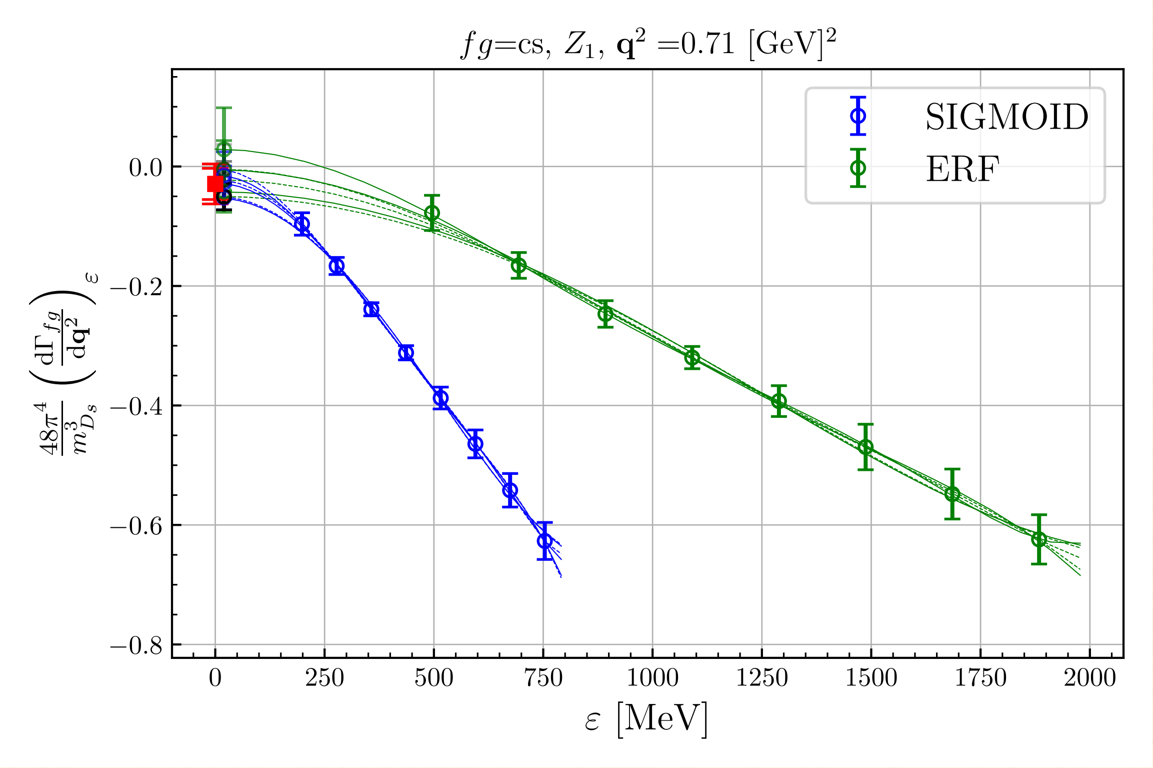




$\sigma \to 0$ EXTRAPOLATION

preliminary by ETMC



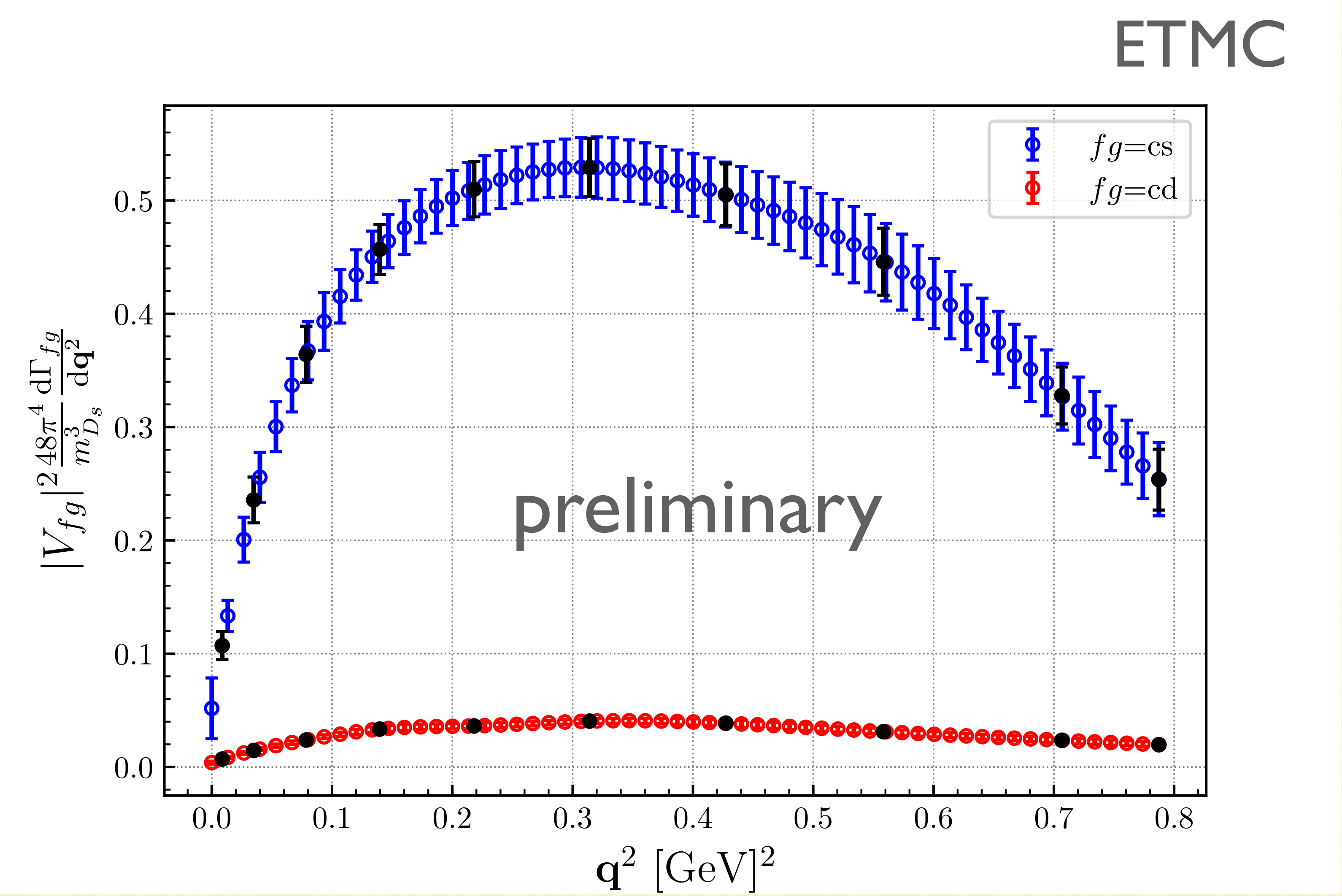


NB we expect a quadratic dependence on $\boldsymbol{\sigma}$

D_s INCLUSIVE SEMILEPTONIC DECAYS

Connected diagrams only

Weak Annihilation (disconnected diagrams) in progress



~3.5% uncertainty on total s.l. width

$$\mathcal{B}\left(D_s^+ \to X e^+ \nu_e\right) = (6.30 \pm 0.13\,(\text{stat.}) \pm 0.10\,(\text{syst.}))\,\%.$$ BES-III

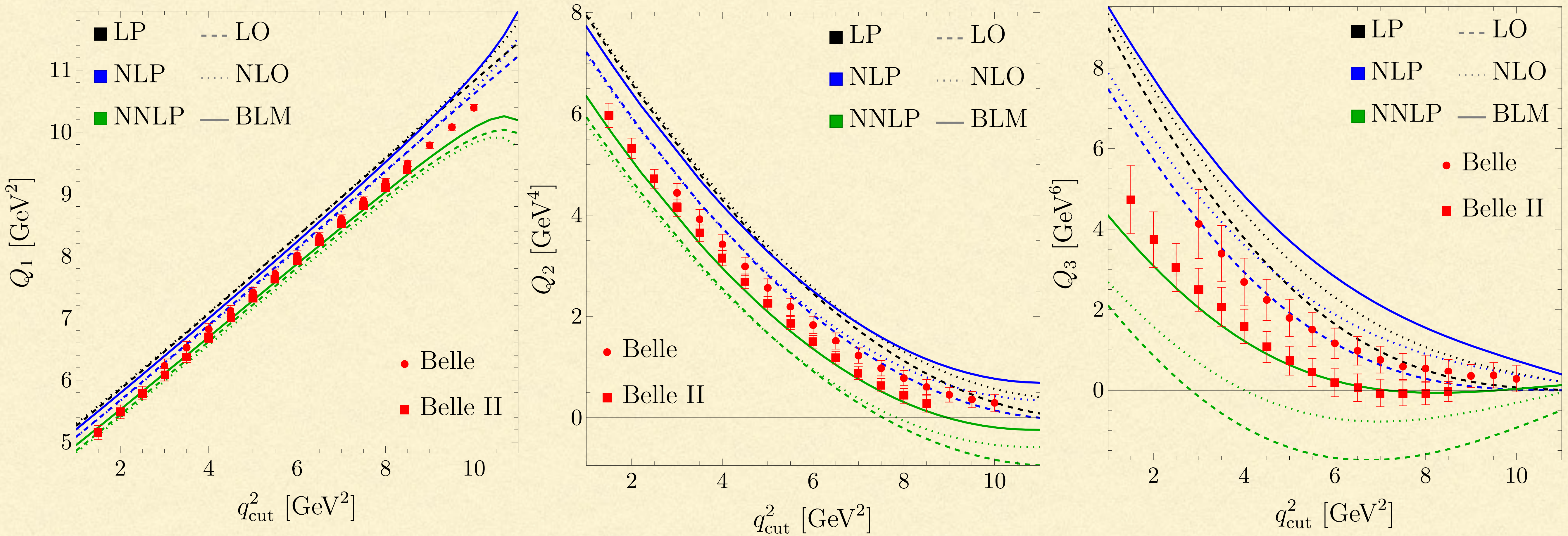
Moments of the E_e distribution coming soon…

SUMMARY AND OUTLOOK

- *Inclusive $b \to c$ appears OK: q^2 moments consistent with leptonic and hadronic ones, perturbation theory generally OK; higher powers look small. But I doubt one can go below 1% on V_{cb}*
- *Calculations of inclusive semileptonic meson decays on the lattice have started. Precision to be seen, but you can count they will soon contribute.*
- *Preliminary ETMC results for D_s inclusive semileptonic decays encouraging: they provide a validation of the method on experimental data. Next: move to b physics, including $b \to u$*

$O(\alpha_s^2\beta_0)$ CORRECTIONS TO q^2 MOMENTS

Finauri, PG 2310.20324

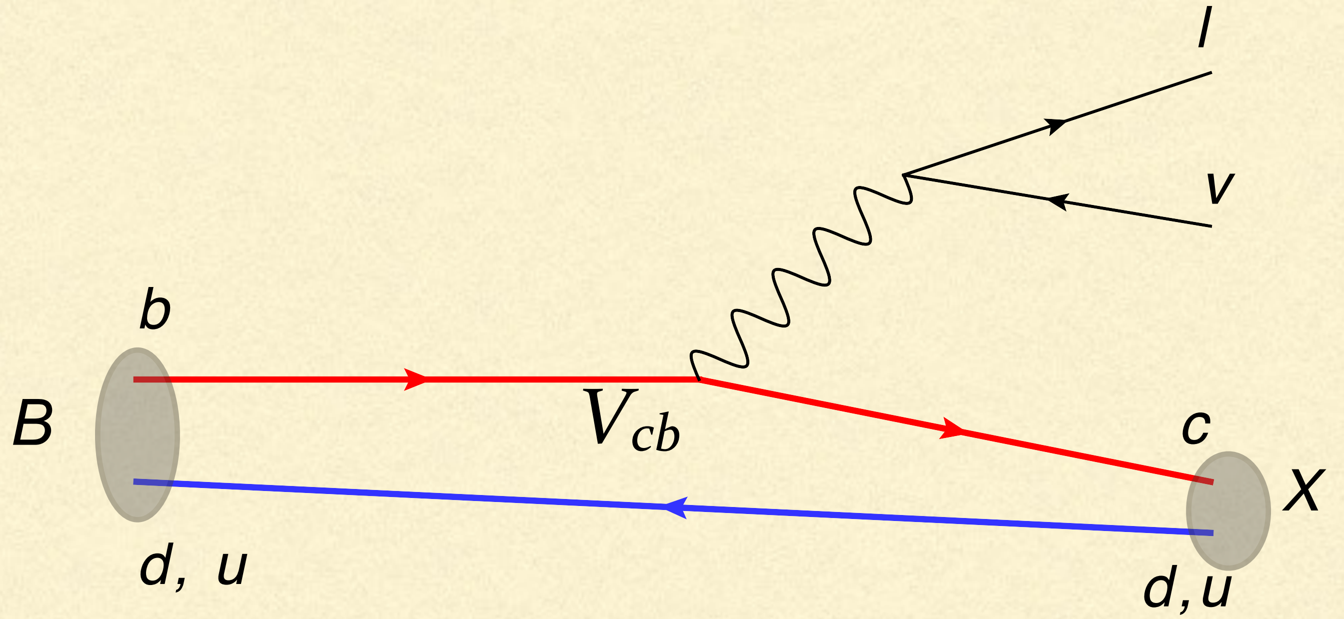


sizeable for 2nd and 3rd moments

Belle and Belle II moments differ by $\sim 2\sigma$

New $O(\alpha_s^2)$ calculation Fael and Herren 2403.03976

EXCLUSIVE DECAYS



$= D, D^*, \ldots$

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

$$\langle D(k)|\,\bar{c}\gamma^\mu b\,|\bar{B}(p)\rangle = \left[(p+k)^\mu - \frac{M_B^2 - M_D^2}{q^2}q^\mu\right] f_+^{B\to D}(q^2) + \frac{M_B^2 - M_D^2}{q^2}q^\mu f_0^{B\to D}(q^2)$$

Information on FFs from LQCD (at high q^2), LCSR (at low q^2), HQE, exp, extrapolation, unitarity constraints, …

A ***model independent parametrization*** is very useful. In particular BGL (Boyd, Grinstein, Lebed)

INCLUSIVE $|V_{ub}|$

Important Belle measurement 2102.00020

In my opinion, the cleanest measurement is the most inclusive one with $M_X < 1.7\text{GeV}, E_\ell > 1\text{GeV}$:

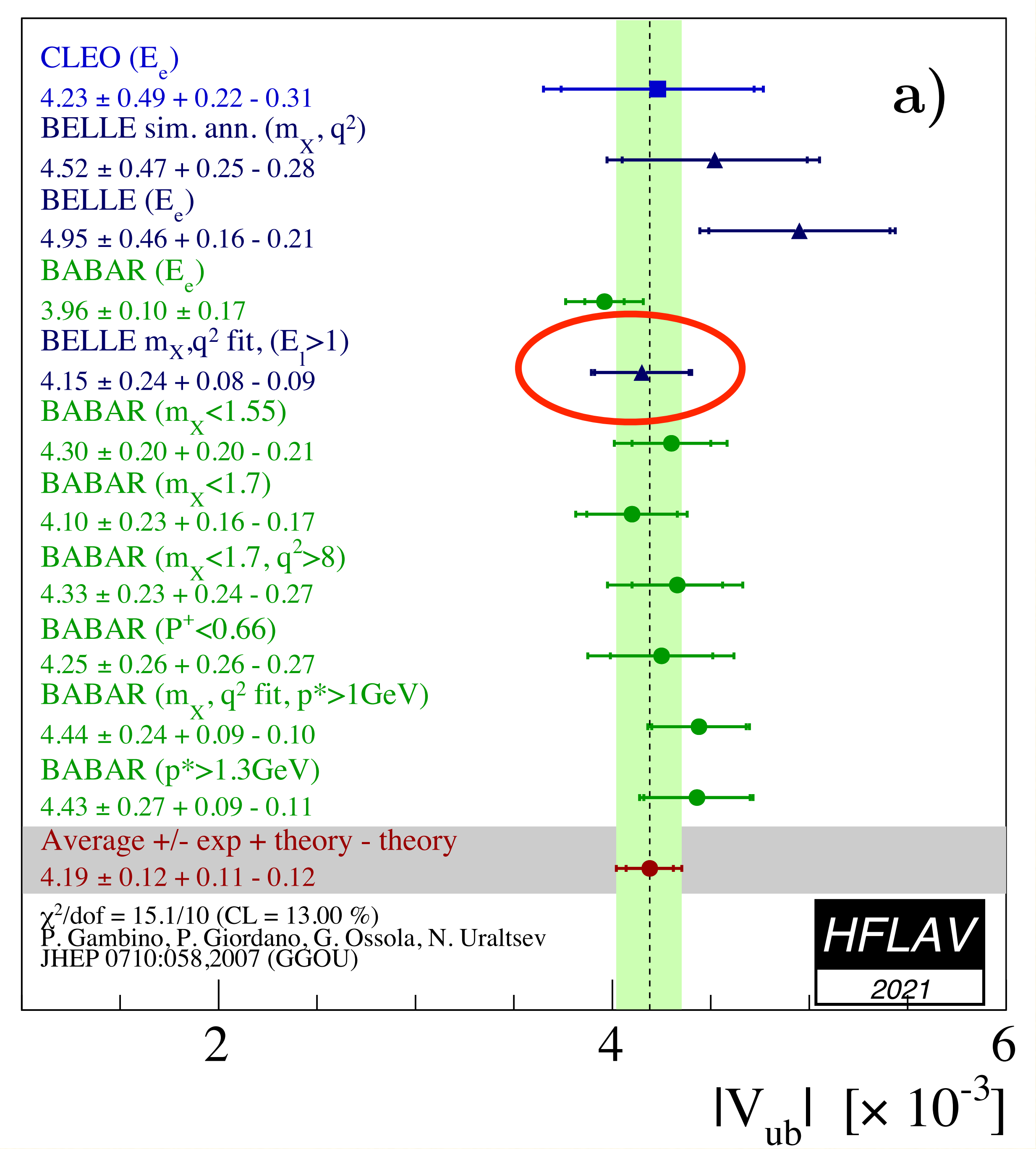
$$|V_{ub}| = (3.97 \pm 0.08 \pm 0.16 \pm 0.16)\, 10^{-3}$$

Framework	$\lvert V_{ub}\rvert[10^{-3}]$
BLNP	$4.28 \pm 0.13^{+0.20}_{-0.21}$
DGE	$3.93 \pm 0.10^{+0.09}_{-0.10}$
GGOU	$4.19 \pm 0.12^{+0.11}_{-0.12}$
ADFR	$3.92 \pm 0.1^{+0.18}_{-0.12}$
BLL (m_X/q^2 only)	$4.62 \pm 0.20 \pm 0.29$

Not all approaches at the same level
Some discrepancy hidden in the average

Recent calculation of the $O(\alpha_s/m_b^2)$ effects in $B \to X_u \ell \nu$, Capdevila, Nandi, PG

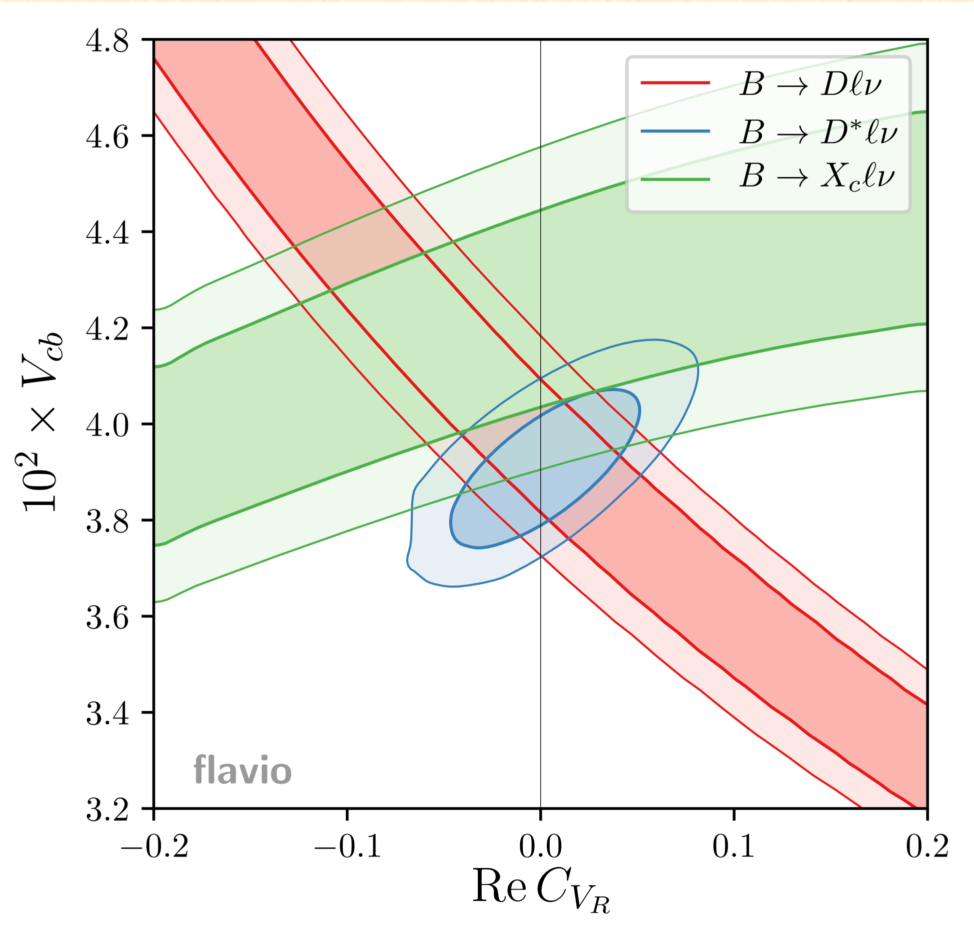
recent $\boxed{\left|V_{ub}^{\text{excl.}}\right| / \left|V_{ub}^{\text{incl.}}\right| = 0.97 \pm 0.12}$ 2303.17309

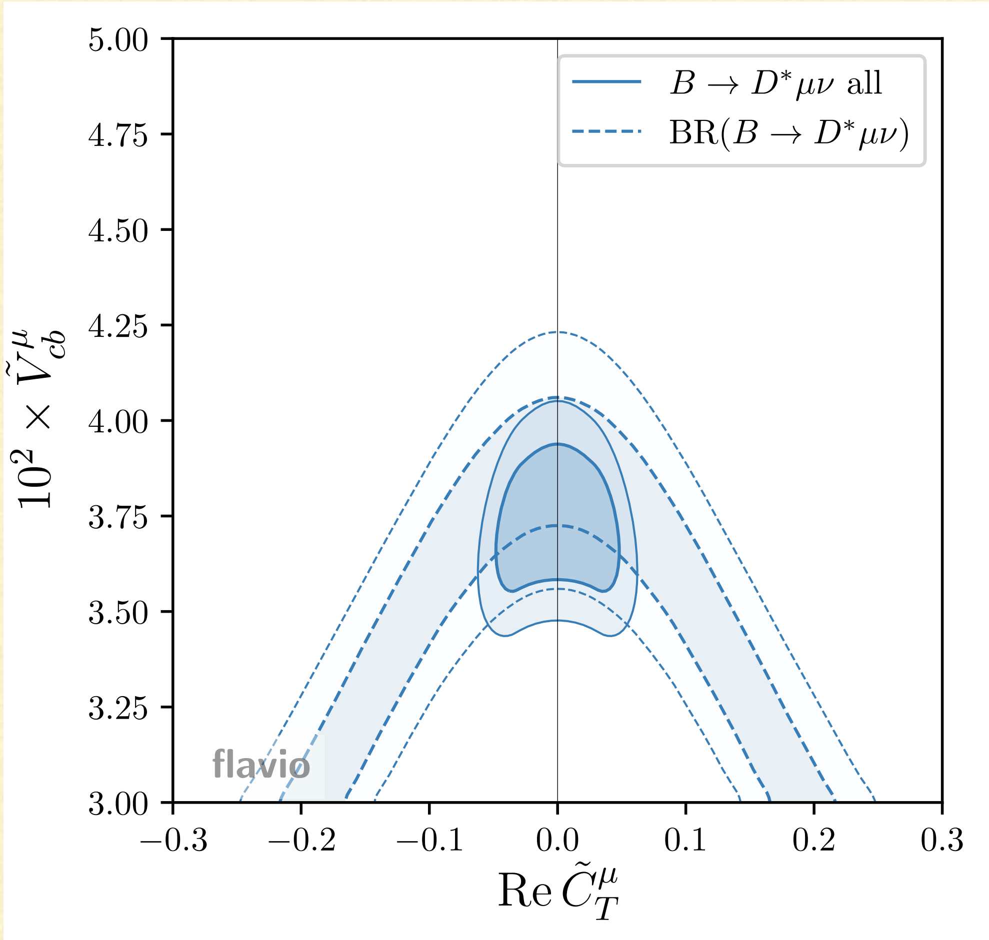


Look forward to validating approaches on Belle II data (SIMBA, NNVUB)!

NEW PHYSICS FOR THE V_{cb} PUZZLE?

Jung & Straub, 1801.01112

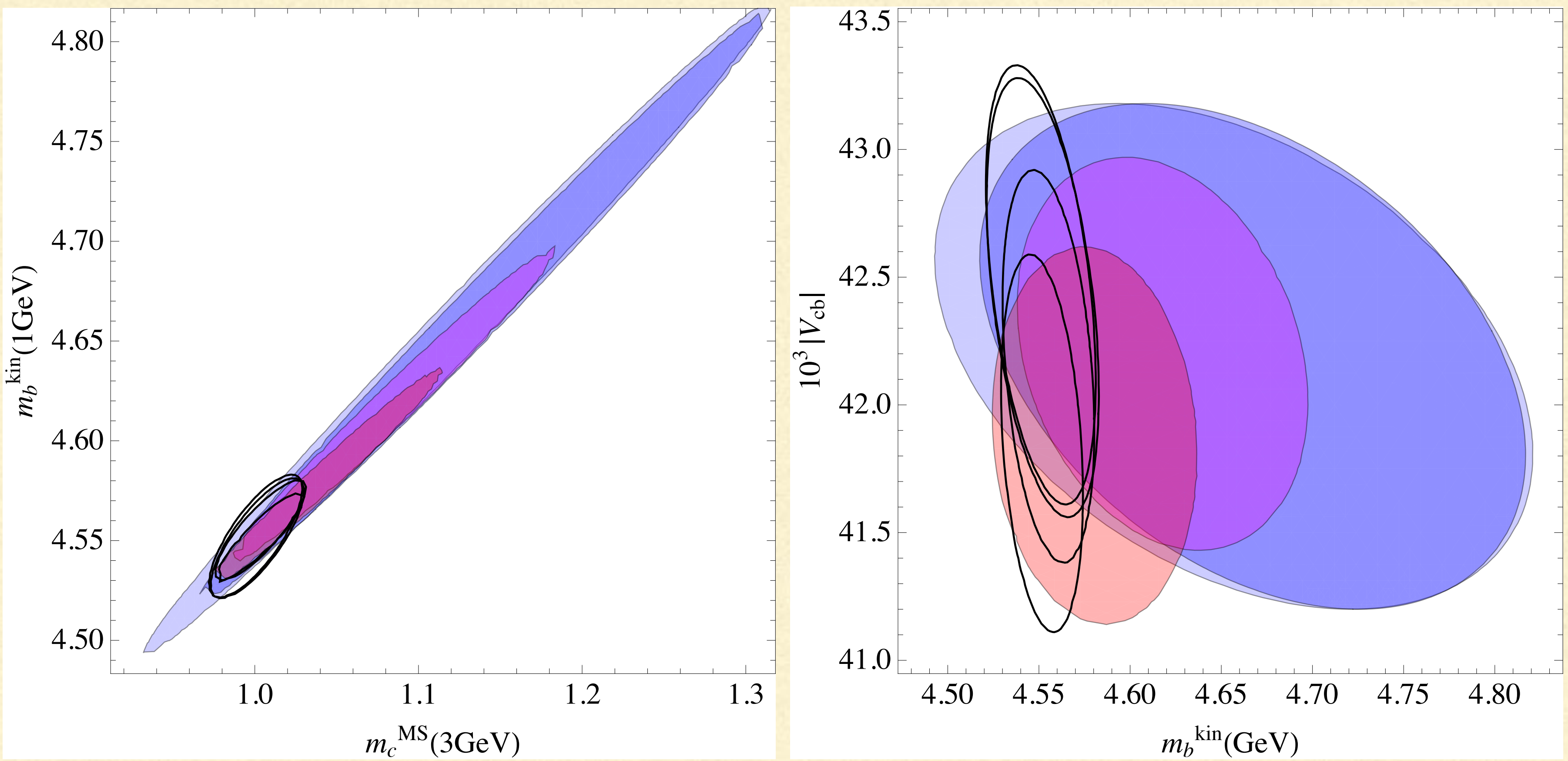




Differential distributions constrain NP strongly, SMEFT interpretation incompatible with LEP data: Crivellin, Pokorski, Jung, Straub…

HEAVY QUARK MASSES AND THEORETICAL CORRELATIONS

C. Schwanda, PG 2013



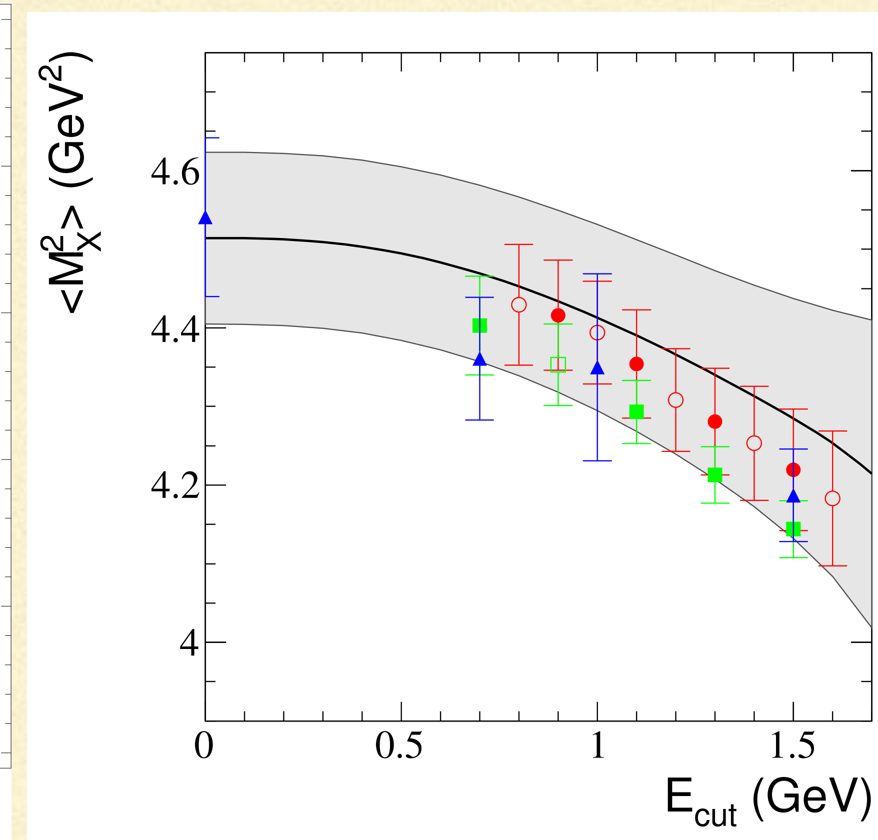


Fig. 3. Two-dimensional projections of the fits performed with different assumptions for the theoretical correlations. The orange, magenta, blue, light blue 1-sigma regions correspond to the four scenarios considered in [58]. The black contours show the same regions when the m_c constraint of Ref. [59] is employed.

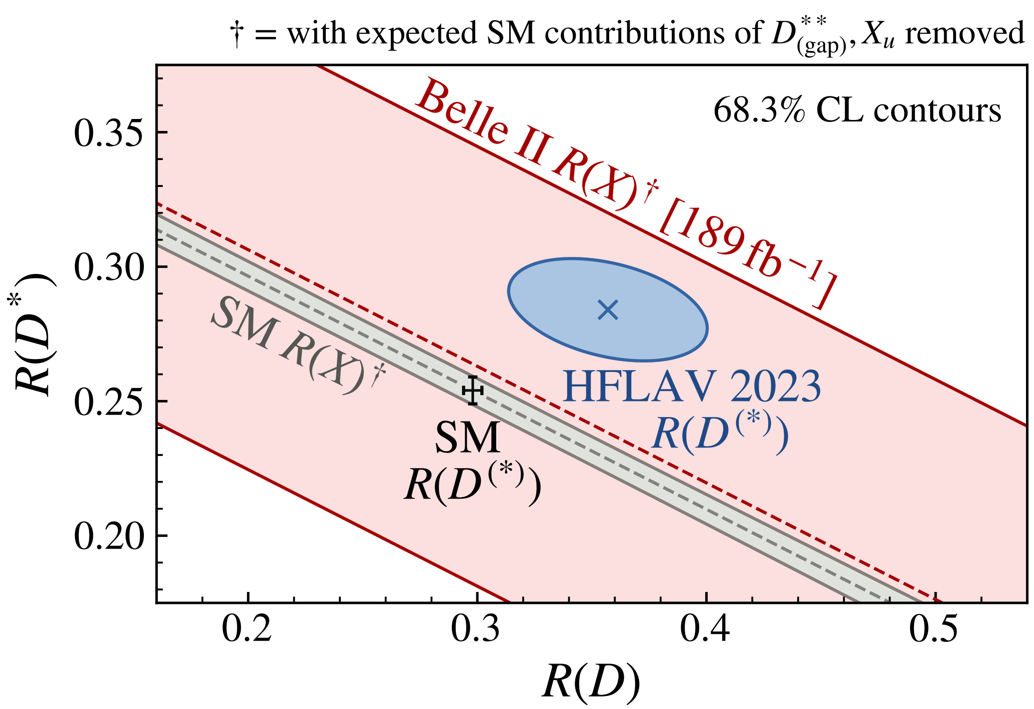
Tests of Lepton Flavor Universality

KKV, Rahimi [2207.03432]; Ligeti, Tackmann [1406.7013];Bernlocner, Sevilla, Robinson, Wormser [2101.08326]

$$R_{e/\mu}(X) \equiv \frac{\Gamma(B \to X_c e \bar{\nu}_e)}{\Gamma(B \to X_c \mu \bar{\nu}_\mu)}$$

- Belle II result: $R_{e/\mu}(X) = 1.033 \pm 0.022$ PRL131 [2023] [2301.08266]
- In agreement with new SM predictions: 1.006 ± 0.001 at 1.2σ
- New! Belle II result: $R_{\tau/\ell}(X) = 0.228 \pm 0.016 \pm 0.036$ @EPS 2311.07248
- In agreement with SM prediction:

$$R_{\tau/\ell}(X) = 0.221 \pm 0.004$$



Belle 2311.07248