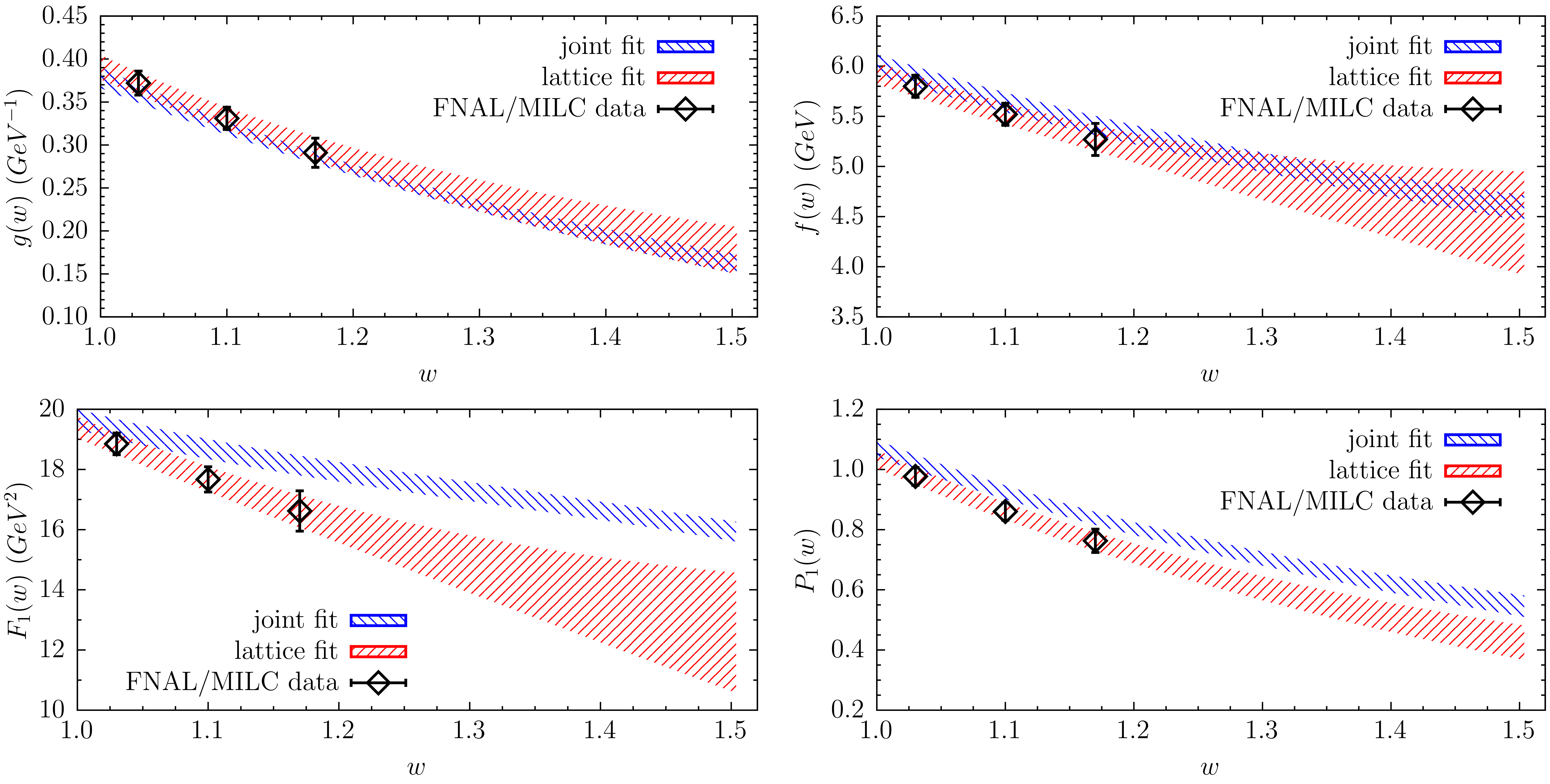
important news: LQCD form factors for $B \to D^* \ell \nu_\ell$ decays from **FNAL/MILC (arXiv:2105.14019)**

synthetic data points at 3 non-zero values of the recoil (w - 1)



joint fit:
BGL fit of LQCD points + Belle + BaBar exp. data

$|V_{cb}| \cdot 10^3 = 38.40 \pm 0.74$

$\simeq 1.9\,\%$

$R(D^*) = 0.2483 \pm 0.0013$

lattice fit:
quadratic BGL fit of LQCD points only

$R(D^*) = 0.265 \pm 0.013$

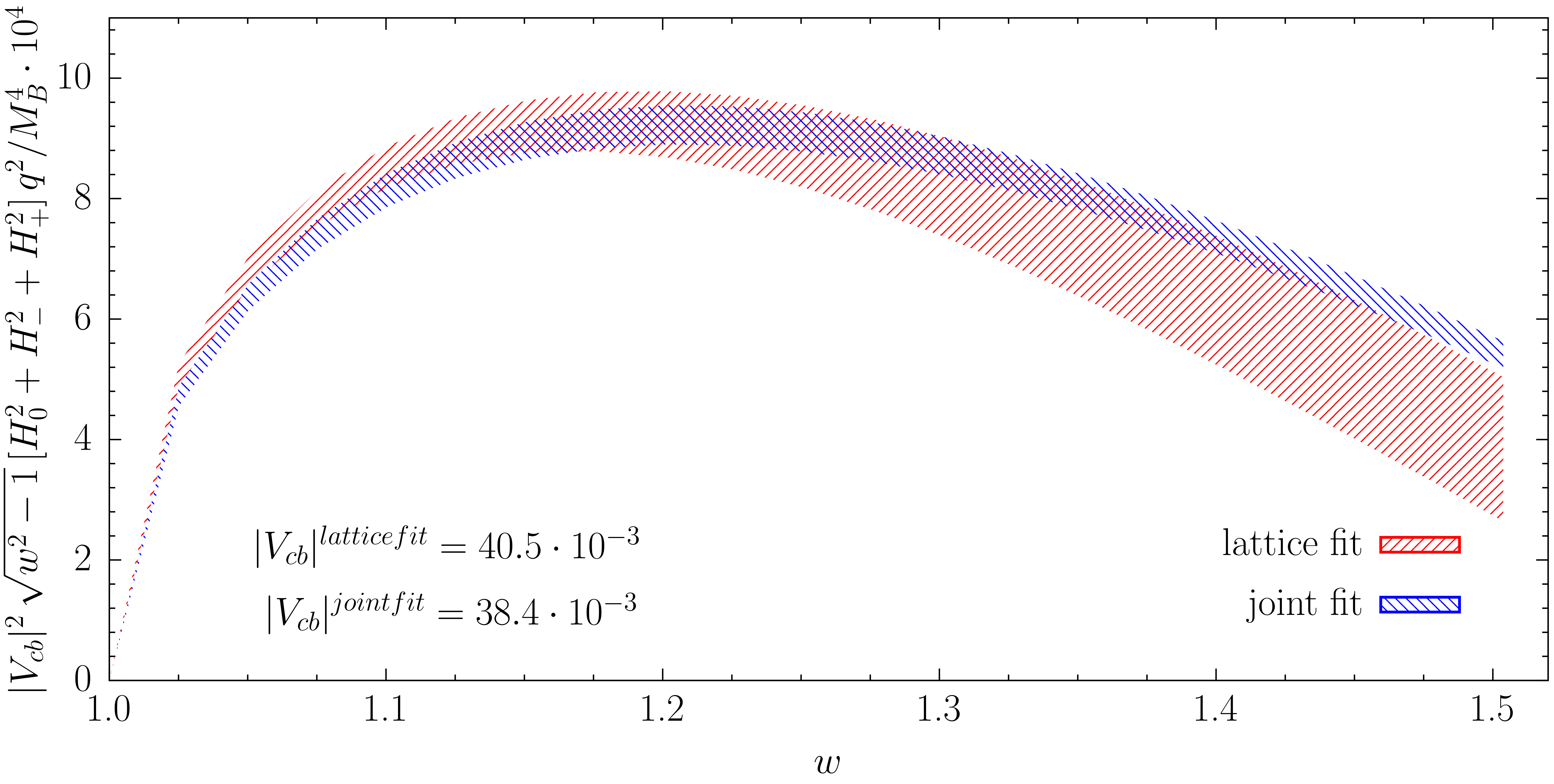
simultaneous fit of the lattice points and experimental data

FFs treated as pure theoretical quantities

the extracted FFs are hybrid quantities: their shape and uncertainties are affected by the experimental data

including their uncertainties

$$\frac{d\Gamma}{dw} \propto |V_{cb}|^2 \sqrt{w^2-1}\,\frac{q^2}{M_B^4}\left[H_0^2(w)+H_-^2(w)+H_+^2(w)\right] = |V_{cb}|^2\sqrt{w^2-1}\left\{\left(\frac{\mathcal{F}_1(w)}{M_B^2}\right)^2 + 2\frac{q^2}{M_B^2}\left[\left(\frac{f(w)}{M_B}\right)^2 + r^2(w^2-1)\,m_B^2\,g^2(w)\right]\right\} \qquad m_\ell = 0$$



extraction of $|V_{cb}|$ from $B \to D^* \ell \nu_\ell$ decays

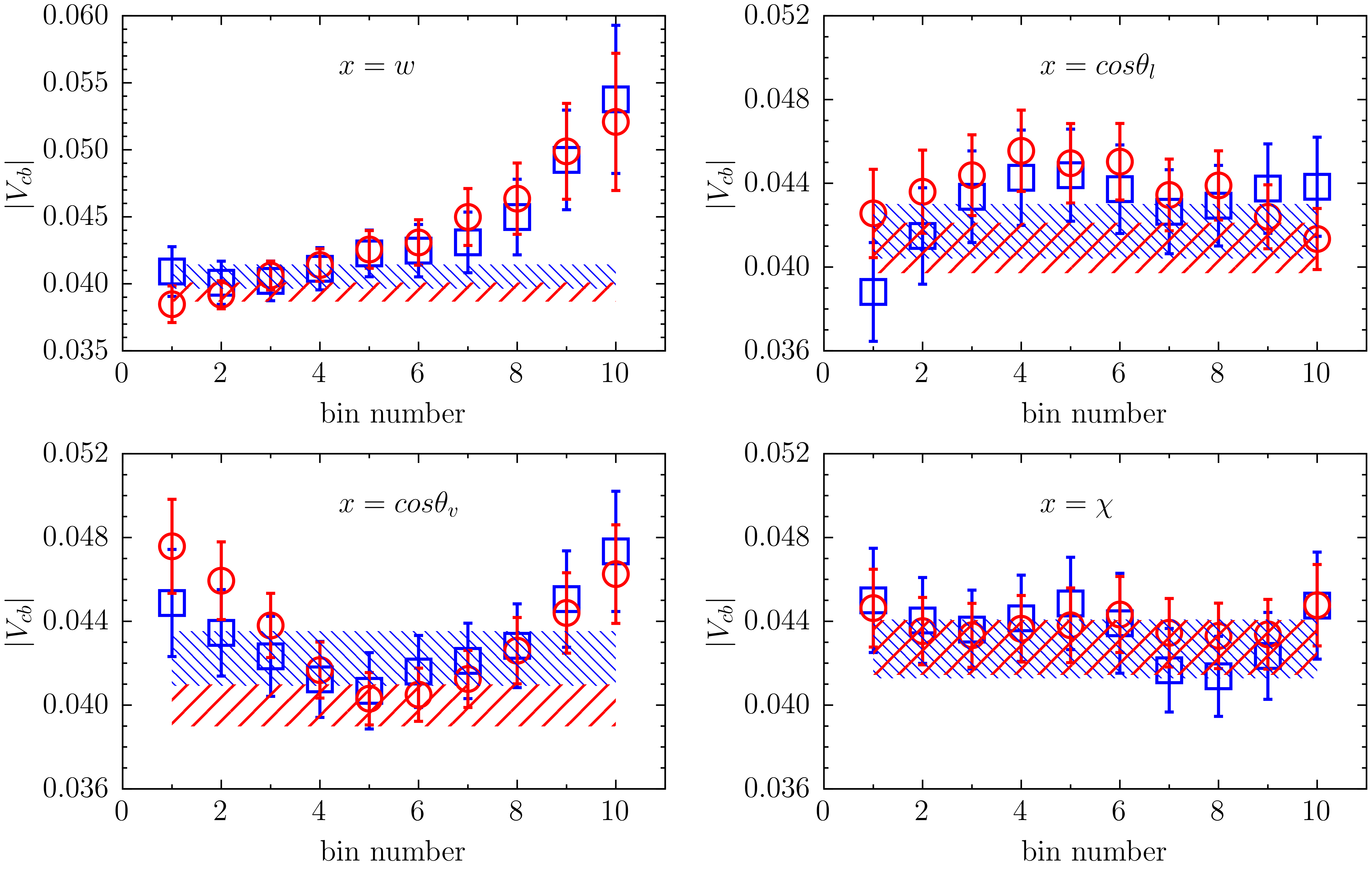
[arXiv:2109.15248]

*** we do not mix theoretical calculations with experimental data to describe the shape of the FFs ***

$$|V_{cb}|_i \equiv \sqrt{\frac{(d\Gamma/dx)_i^{exp}}{(d\Gamma/dx)_i^{th}}} \qquad i = 1, \ldots, N_{bins}$$

four different differential decay rates $d\Gamma/dx$ where $x = \{w, \cos\theta_v, \cos\theta_\ell, \chi\}$:

- 10 bins for each variable
- total of 80 data points



blue data: Belle 1702.01521

red data: Belle 1809.03290

bands are (correlated) weighted averages

$$|V_{cb}| = \frac{\sum_{i,j=1}^{10} (\mathbf{C}^{-1})_{ij} |V_{cb}|_j}{\sum_{i,j=1}^{10} (\mathbf{C}^{-1})_{ij}} ,$$

$$\sigma^2_{|V_{cb}|} = \frac{1}{\sum_{i,j=1}^{10} (\mathbf{C}^{-1})_{ij}} ,$$

	experiment	$\vert V_{cb}\vert(x = w)$	$\vert V_{cb}\vert(x = \cos\theta_l)$	$\vert V_{cb}\vert(x = \cos\theta_v)$	$\vert V_{cb}\vert(x = \chi)$
Belle 1702.01521	Ref. [11]	0.0398 (9)	0.0422 (13)	0.0421 (13)	0.0426 (14)
Belle 1809.03290	Ref. [12]	0.0395 (7)	0.0405 (11)	0.0402 (10)	0.0430 (13)

averaging procedure

$$\mu_x = \frac{1}{N}\sum_{k=1}^{N} x_k \ ,$$

$$\sigma_x^2 = \frac{1}{N}\sum_{k=1}^{N}\sigma_k^2 + \frac{1}{N}\sum_{k=1}^{N}(x_k - \mu_x)^2,$$

$$\rightarrow \quad |V_{cb}|_{excl.} \cdot 10^3 = 41.3 \pm 1.7$$

$|V_{cb}|_{incl.} \cdot 10^3 = 42.16 \pm 0.50$ (Bordone et al: arXiv:2107.00604)

exclusive/inclusive tension reduced to less than 1σ

the use of exp. data to describe the shape of the FFs leads to smaller errors, but it produces a bias on the extracted value of $|V_{cb}|$ $\Leftarrow$

$|V_{cb}|_{excl.} \cdot 10^3 = 39.6^{+1.1}_{-1.0}$ Gambino et al., arXiv:1905.08209

$|V_{cb}|_{excl.} \cdot 10^3 = 39.56^{+1.04}_{-1.06}$ Jaiswal et al., arXiv:2002.05726

$|V_{cb}|_{excl.} \cdot 10^3 = 38.86 \pm 0.88$ FLAG '21, arXiv:2111.09849