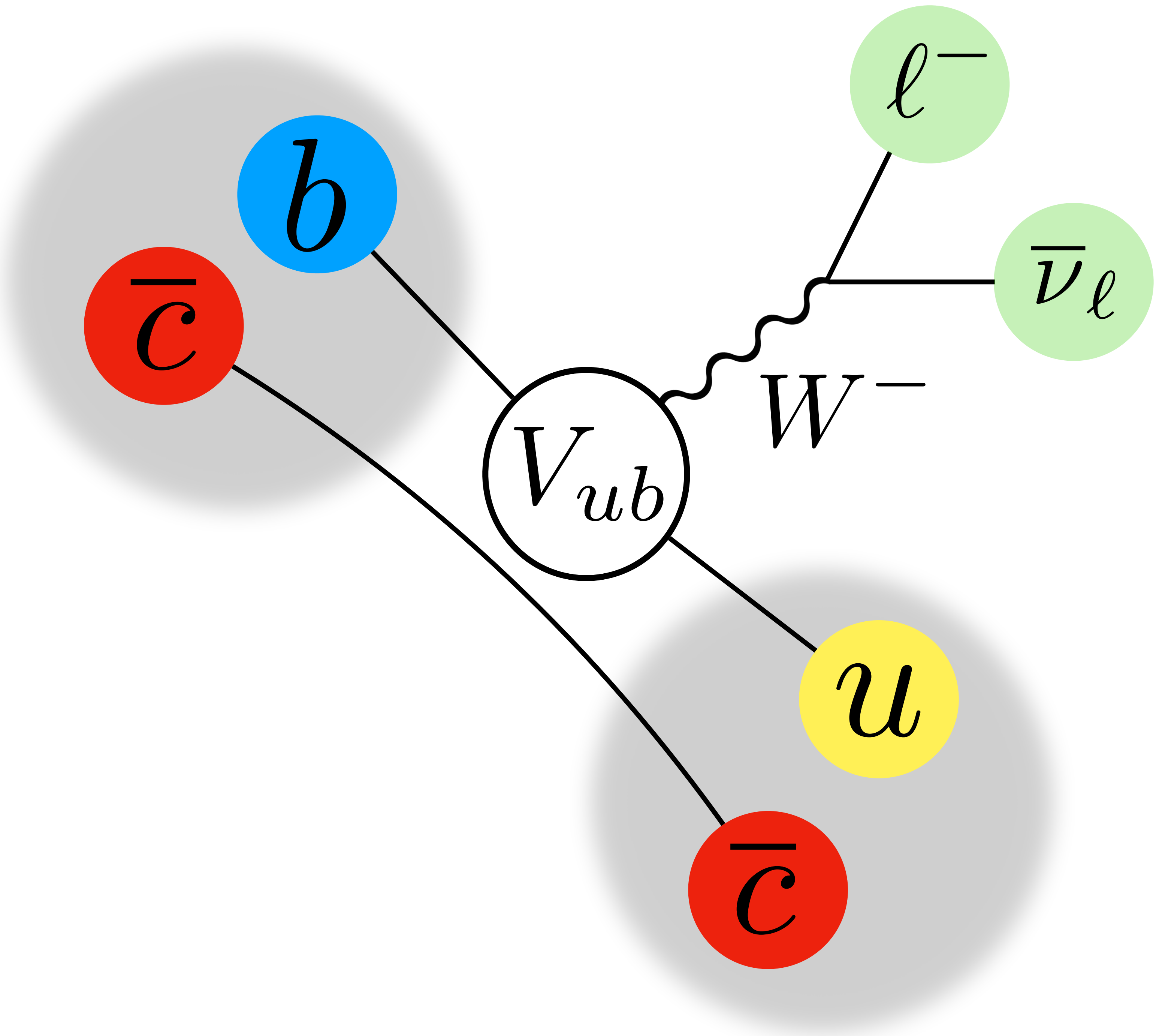
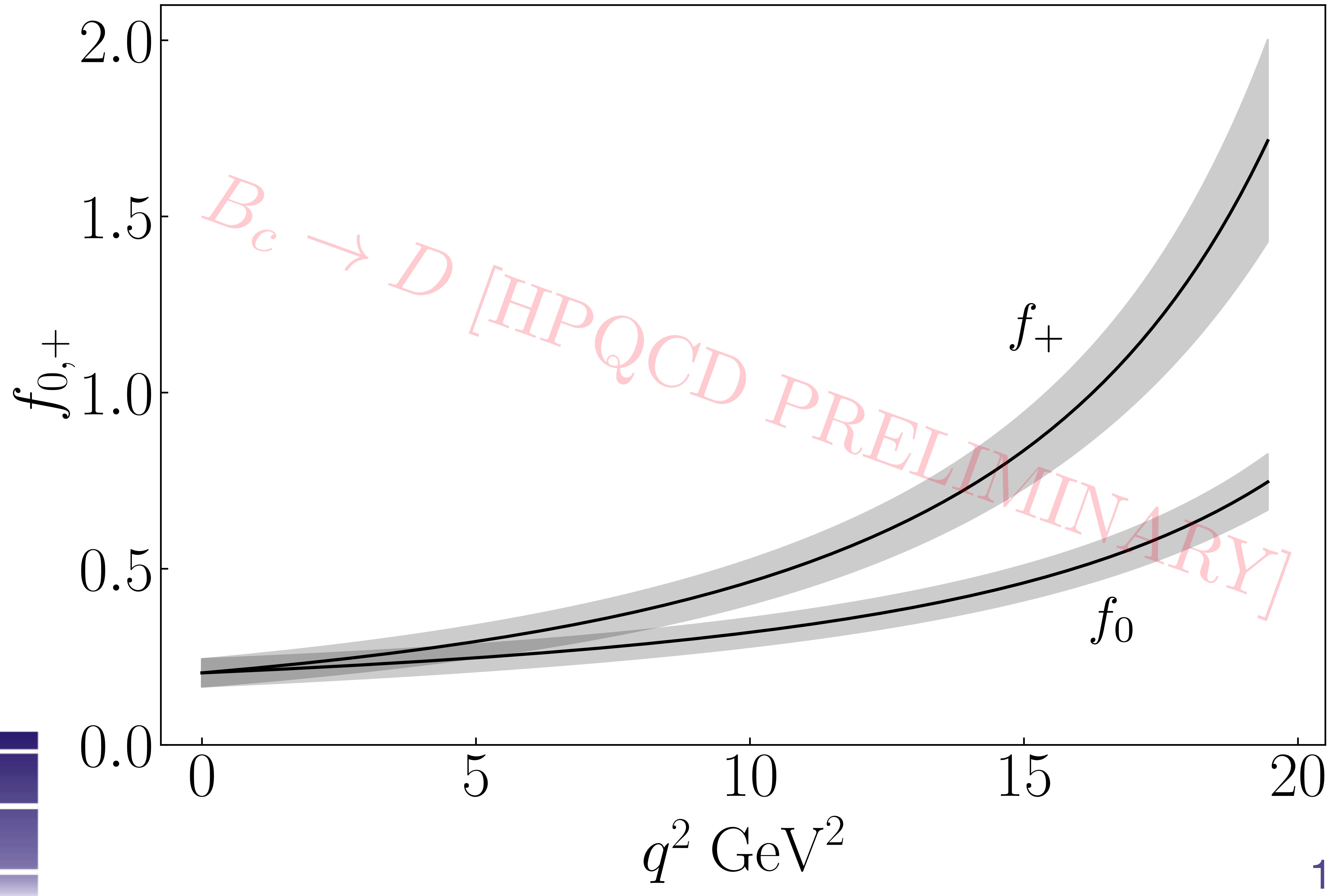
$B_c \to D$ form factors $f_{0,+}(q^2)$ from lattice QCD

Laurence Cooper, University of Glasgow with HPQCD

Theory meets experiment on $|V_{ub}|$ and $|V_{cb}|$, 12th January 2021





The heavy-HISQ method

- All sea and valence quarks implemented with HISQ
- Non-perturbative renormalisation of vector current via PCVC
- Simulate at both physical and unphysical m_u, m_d
- Simulate at unphysically light b quarks, inform the limits $\to m_b$ and $\to M_{B_c}$
- Probe full range of q^2 for the form factors

See J. Harrison's talk next!

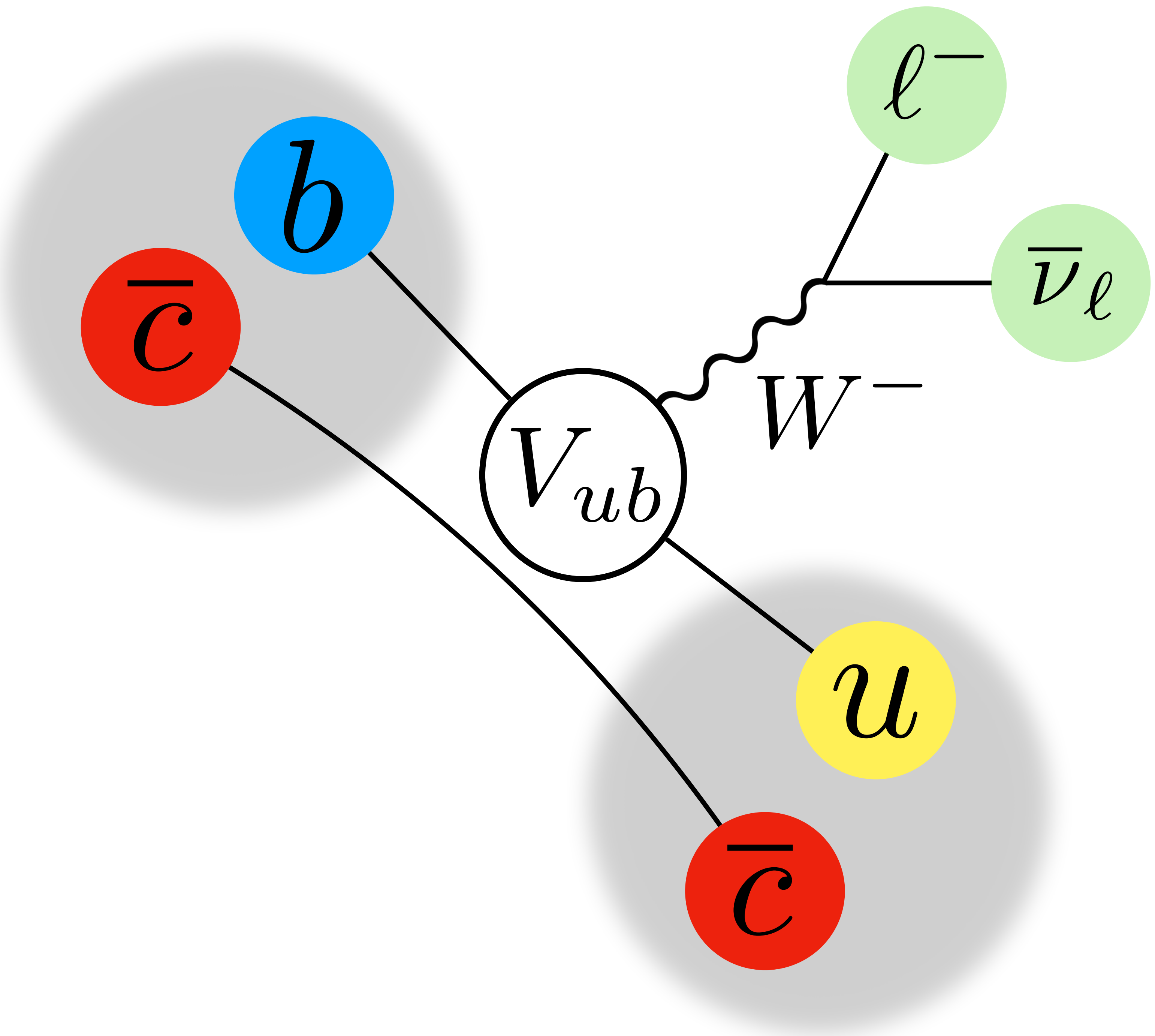
Other recent/ongoing heavy-HISQ work: $B_c \to J/\psi$, $B_s \to D_s^*$, $B_s \to \eta_s$, $B \to K$, $B_c \to B_{s(d)}$, $B_s \to D_s$ ...

Challenges with $B_c \to D$

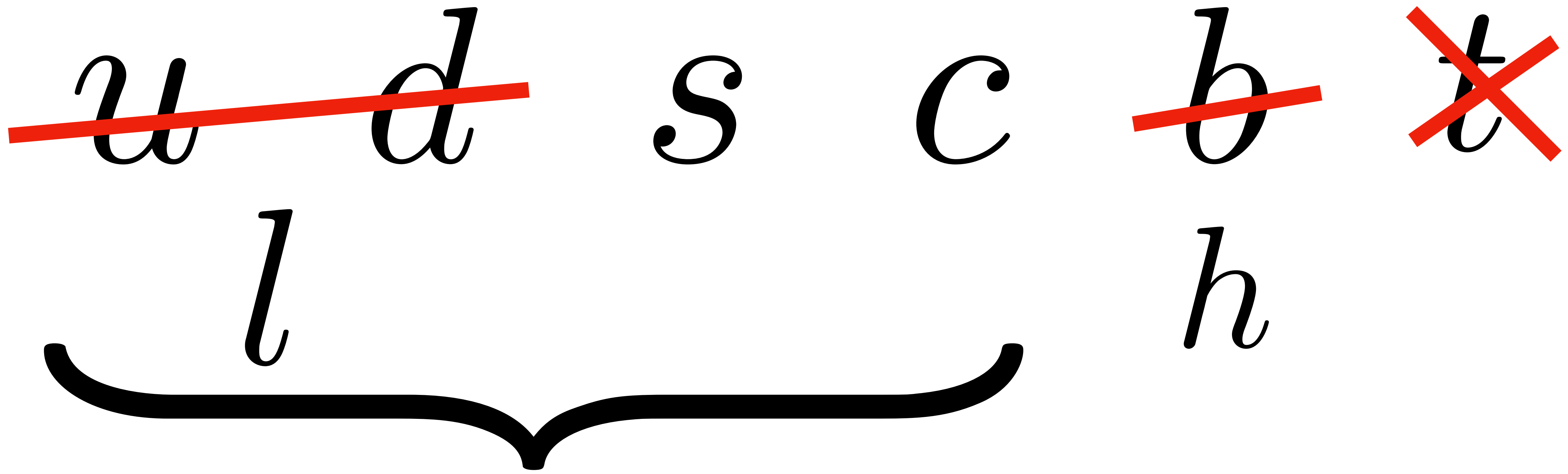
- Simultaneously access physical m_b (very large) and physical m_u, m_d (very small)

- Light daughter quark, expensive lattice propagators at many momenta

- $q^2_{\rm max} \approx 19\ {\rm GeV}^2$ - large (typical of heavy-to-light semileptonic decays), seek q^2 dependence of form factors all the way down to $q^2 = 0\ {\rm GeV}^2$



$$u \quad d \quad s \quad c \quad b \quad t$$



sea

(MILC HISQ 2+1+1)

$m_l \in \{m_s/27.4, m_s/5\}$

m_s, m_c physical

$m_c \longleftarrow m_h \longrightarrow m_b$

$\cancel{u}\ \cancel{d}\ \ s\ \ c\ \ \cancel{b}\ \ \times t$

$\underbrace{l \qquad\qquad}_{\text{sea}}\qquad h$

sea

(MILC HISQ 2+1+1)

$m_l \in \{m_s/27.4, m_s/5\}$

m_s, m_c physical

$m_c \longleftarrow m_h \longrightarrow m_b$

fine
$a \approx 0.09$ fm

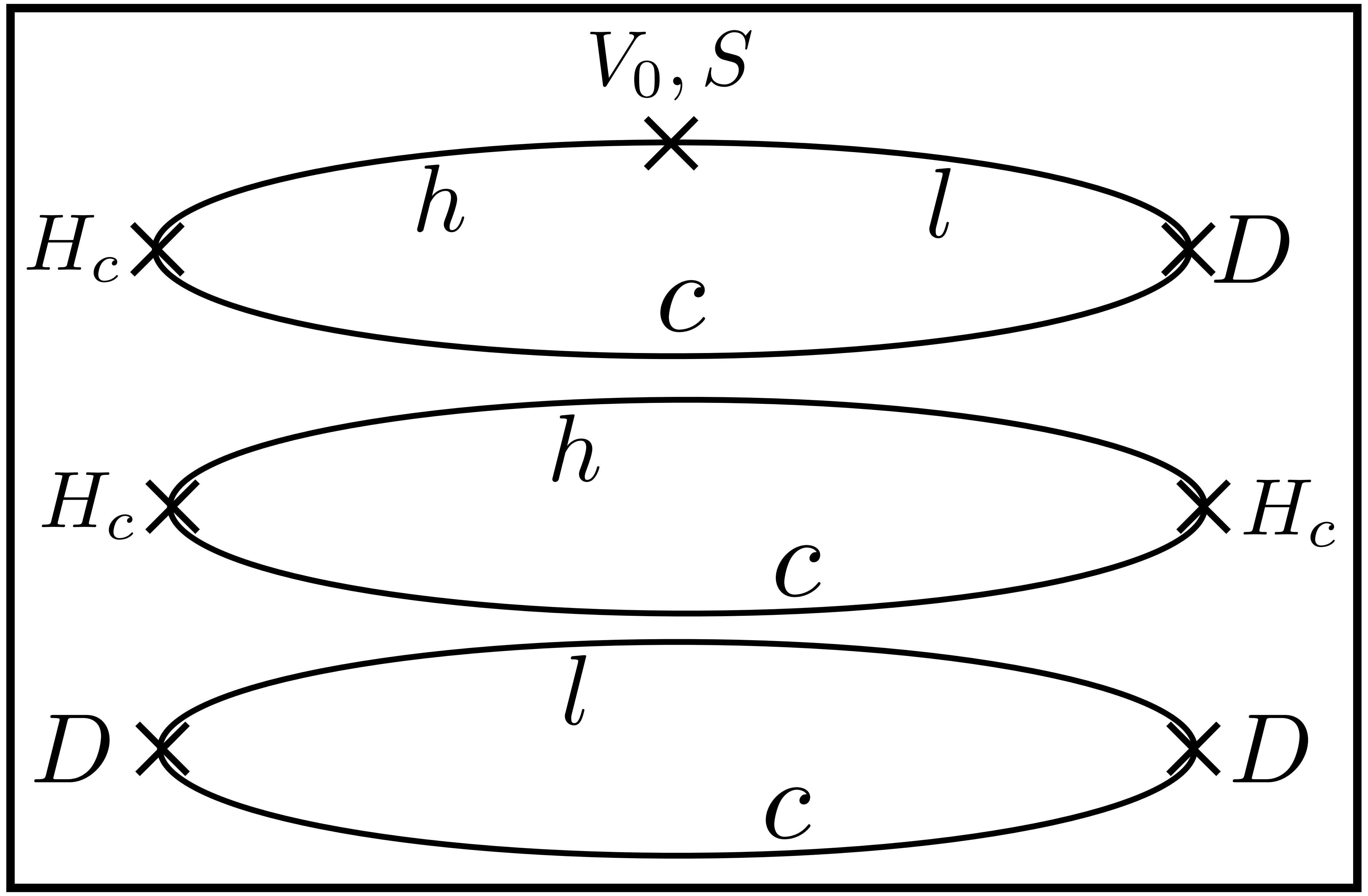
fine-physical
$a \approx 0.09$ fm

superfine
$a \approx 0.06$ fm

ultrafine
$a \approx 0.045$ fm

Coarser ⟷ Finer

M_{B_c}
$am_h = 0.8$
ultrafine
$a \approx 0.045$ fm
$am_h = 0.8$
superfine
$a \approx 0.06$ fm
fine
$a \approx 0.09$ fm
$am_h = 0.8$
fine-physical
$a \approx 0.09$ fm
M_{η_c}
M_{H_c} GeV
a^2 fm^2
0.000
0.002
0.004
0.006
0.008
3
4
5
6
am_h
0.80
0.65
0.50
0
1
$q^2/q^2_{\rm max}$

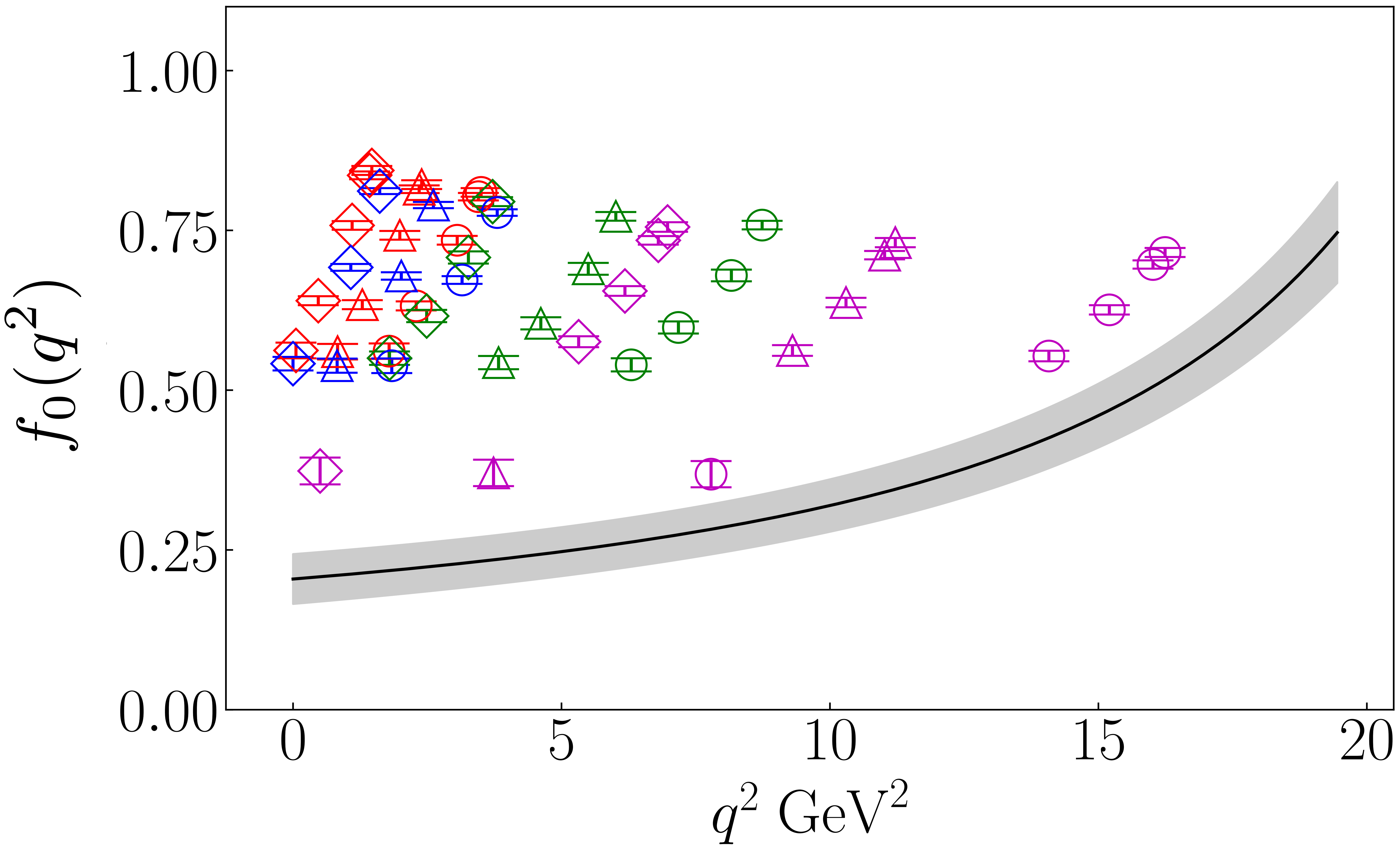


$$Z_V \langle D | V_0 | H_c \rangle$$

$$\langle D | S | H_c \rangle$$

$$f_{0,+}^{\text{latt}}\left(q^2\right)$$

$$f_0\left(q^2\right) = P\left(q^2\right)^{-1} \sum_{n,r,j,k=0}^{N=3} A_{rijk}^{(n)}(-z)^n \mathcal{N}_{\text{mis}}^{(n)} \Delta_{H_l}^{(r)} \left(\frac{am_h}{\pi}\right)^{2j} \left(\frac{am_c}{\pi}\right)^{2k}$$

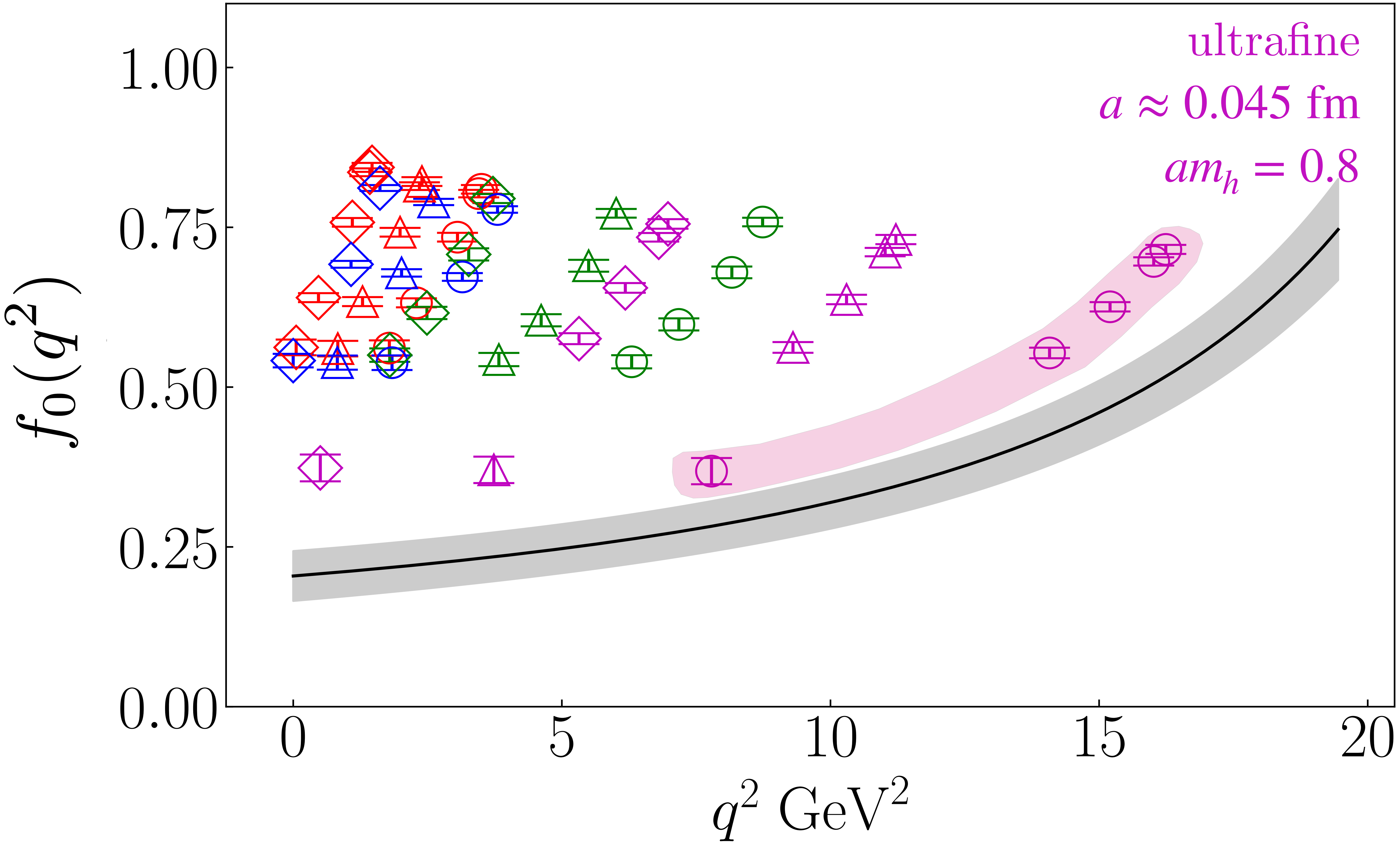


$$z\left(q^2\right) = \frac{\sqrt{t_+ - q^2} - \sqrt{t_+ - t_0}}{\sqrt{t_+ - q^2} + \sqrt{t_+ - t_0}}$$

$$\Delta_{H_l}^{(r)} = \left(\frac{\Lambda}{M_{H_l}}\right)^r$$

$$P(q^2) = 1 - \frac{q^2}{M_{\text{res}}^2}$$

$$f_0\left(q^2\right) = P\left(q^2\right)^{-1} \sum_{n,r,j,k=0}^{N=3} A^{(n)}_{rijk} (-z)^n \mathcal{N}^{(n)}_{\text{mis}} \Delta^{(r)}_{H_l} \left(\frac{am_h}{\pi}\right)^{2j} \left(\frac{am_c}{\pi}\right)^{2k}$$



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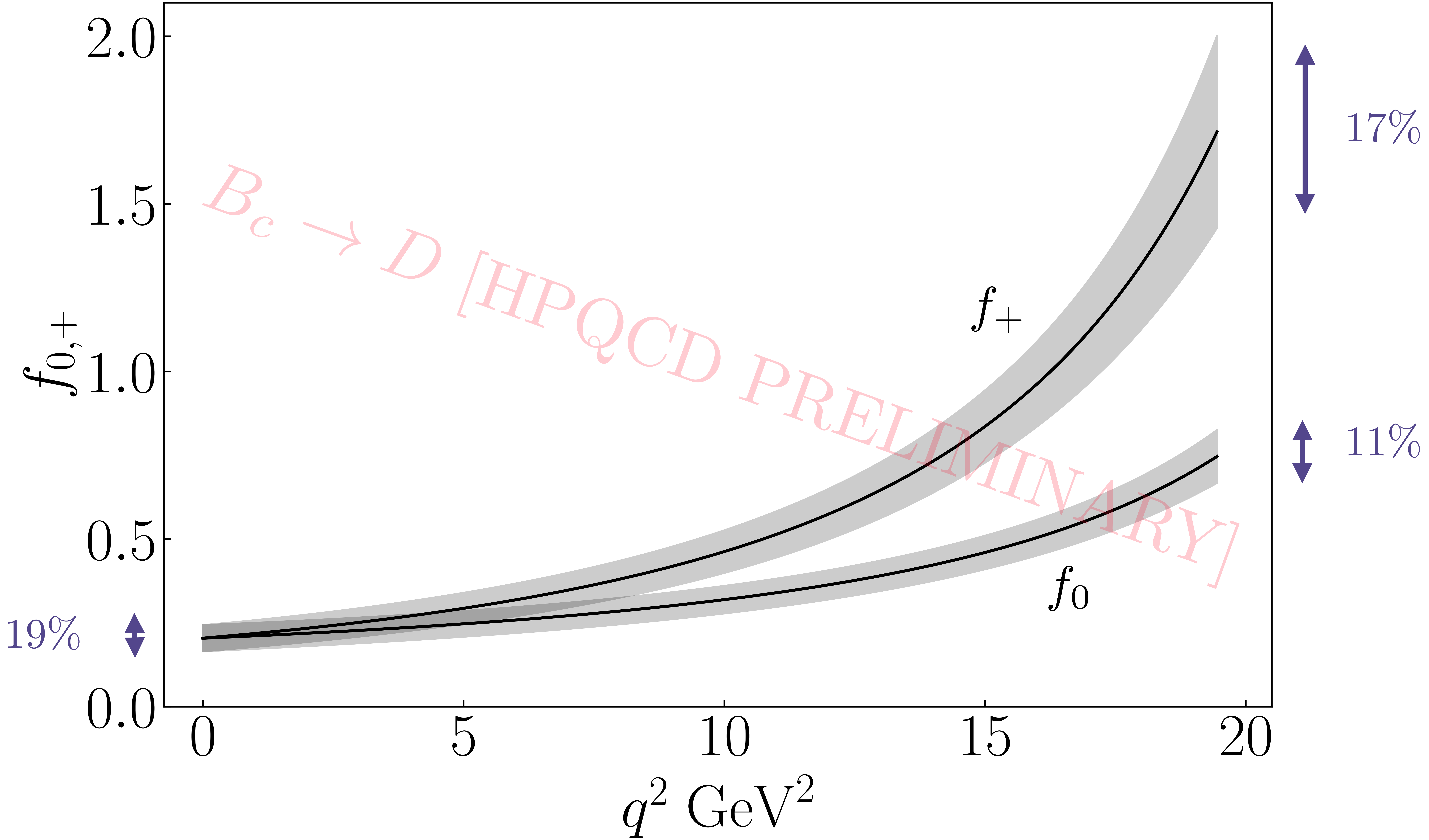


$B_c \to D$ [HPQCD PRELIMINARY]
$f_{0,+}$
q^2 GeV^2
f_+
f_0
17%
11%
19%
2.0
1.5
1.0
0.5
0.0
0
5
10
15
20

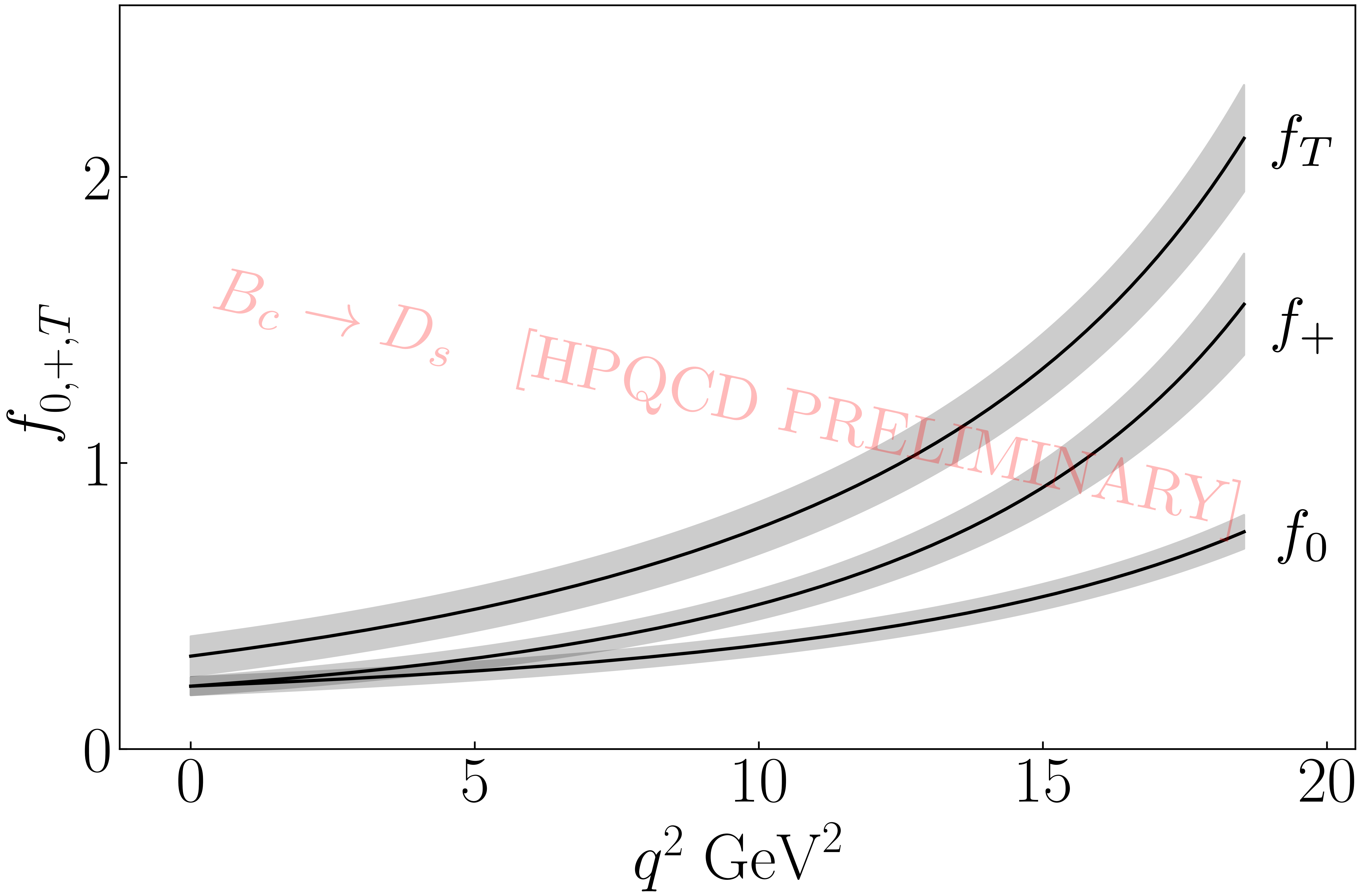
Prospects: improving errors

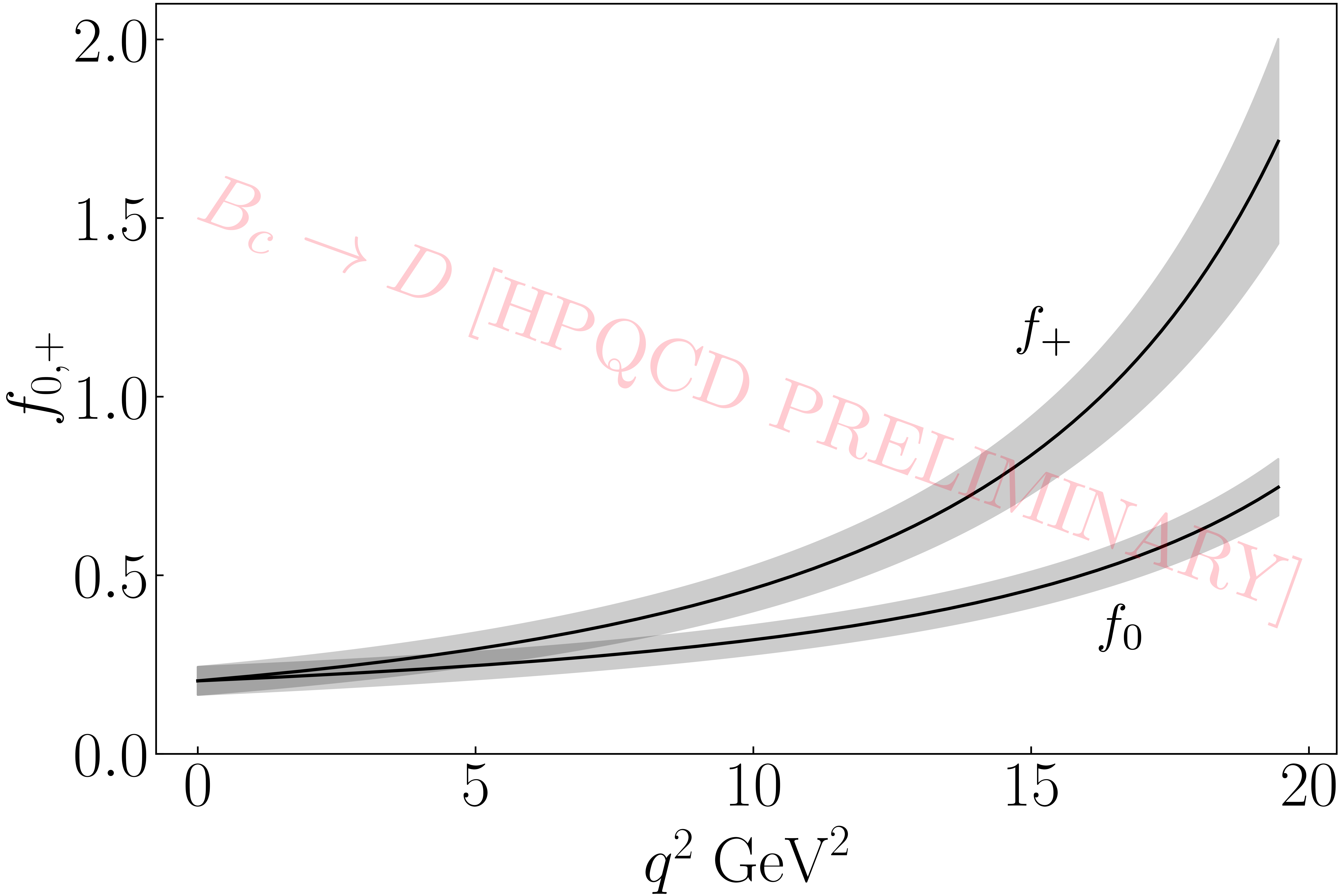
- Statistics can be increased
- Improve f_+ error at zero-recoil by including the *spatial* vector current
- Most error coming from reaching the physical b mass
    - More values of am_h on existing lattices...
    - ... and/or simulate at $am_h = am_b$ on the exafine lattice
        - $a \approx 0.033$ fm
        - $am_b \approx 0.625$

(exafine run in progress for $B_c \to D_s$)

Prospects: f_T for heavy-to-light decays

- $B_c \to D$ in tandem with a calculation of $f_{0,+,T}$ for $B_c \to D_s$ (via (rare) $b \to s$)





2.0
1.5
1.0
0.5
0.0
$f_{0,+}$
$B_c \to D$ [HPQCD PRELIMINARY]
f_+
f_0
0
5
10
15
20
q^2 GeV^2