Standard Model contributions to B and B_s meson semileptonic decays

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In collaboration with:

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HPQCD collaboration

Lattice 2014 at Columbia University, New York, USA

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Outline

- HPQCD's heavy-light meson semileptonic decay programs
- **$B \to D\, l\nu$ and $B_s \to D_s\, l\nu$ semileptonic decays**
  - Preliminary!
  - Dispersion relation
  - Chiral and continuum extrapolation
  - $R(D)$ and $R(D_s)$
  - $f_0(B_s \to D_s)/f_0(B \to D)$: important input for $Br(B_s \to \mu^+\mu^-)$
  - alternative $|V_{cb}|$ determination
- **$B_s \to K\, l\nu$ semileptonic decays**
  - First lattice calculation! C. Bouchard et al., arXiv:1406.2279
  - HPChPT z-expansion and error budget
  - Prediction of differential branching fractions
    - alternative $|V_{ub}|$ determination
  - Phenomenology
    - $R_{\mu\boldsymbol{\tau}}$, A^l_{FB}, $\bar{A}^l_{FB}$, and A^l_{pol}

Heavy-light semileptonic projects from HPQCD

- D → K lν, D → π lν, and B → K ll have been investigated recently.
  - PRD 82 (2010) 014506, PRD 84 (2011) 114505, PRD 88 (2013) 054509, PRL 111 (2013) 162002
- B → D lν, Bs → Ds lν, and Bs → K lν for the Standard Model contribution in tree level

$$< X|V^\mu|B_x >= f_+(q^2)(p^\mu_{B_x} + p^\mu_X - \frac{M^2_{B_x} - M^2_X}{q^2} q^\mu) + f_0(q^2)\frac{M^2_{B_x} - M^2_X}{q^2} q^\mu$$

$$q^2 = M^2_{B_x} + M^2_X - 2M_{B_x}E_X$$

$$< X|V^0|B_x >= \sqrt{2M_{B_x}} f_\parallel, \quad < X|V^k|B_x >= \sqrt{2M_{B_x}} p^k_X f_\perp$$

$$f_0(q^2) = \frac{\sqrt{2M_{B_x}}}{M^2_{B_x} - M^2_X}[(M_{B_x} - E_X)f_\parallel + (E^2_X - M^2_X)f_\perp]$$

$$f_+(q^2) = \frac{1}{\sqrt{2M_{B_x}}}[f_\parallel + (M_{B_x} - E_X)f_\perp]$$

Heavy-light semileptonic projects from HPQCD

- We used MILC N_f=2+1 asqtad gauge configurations

~ a (fm)	size	sea quarks	confs	tsrc
0.12 (C1)	24	0.005/0.05	2096 (1200)	2
0.12 (C2)	20	0.01/0.05	2256 (1200)	2
0.12 (C3)	20	0.02/0.05	1200 (600)	2
0.09 (F1)	28	0.0062/0.031	1896 (1200)	4
0.09 (F2)	28	0.0124/0.031	1200 (600)	4

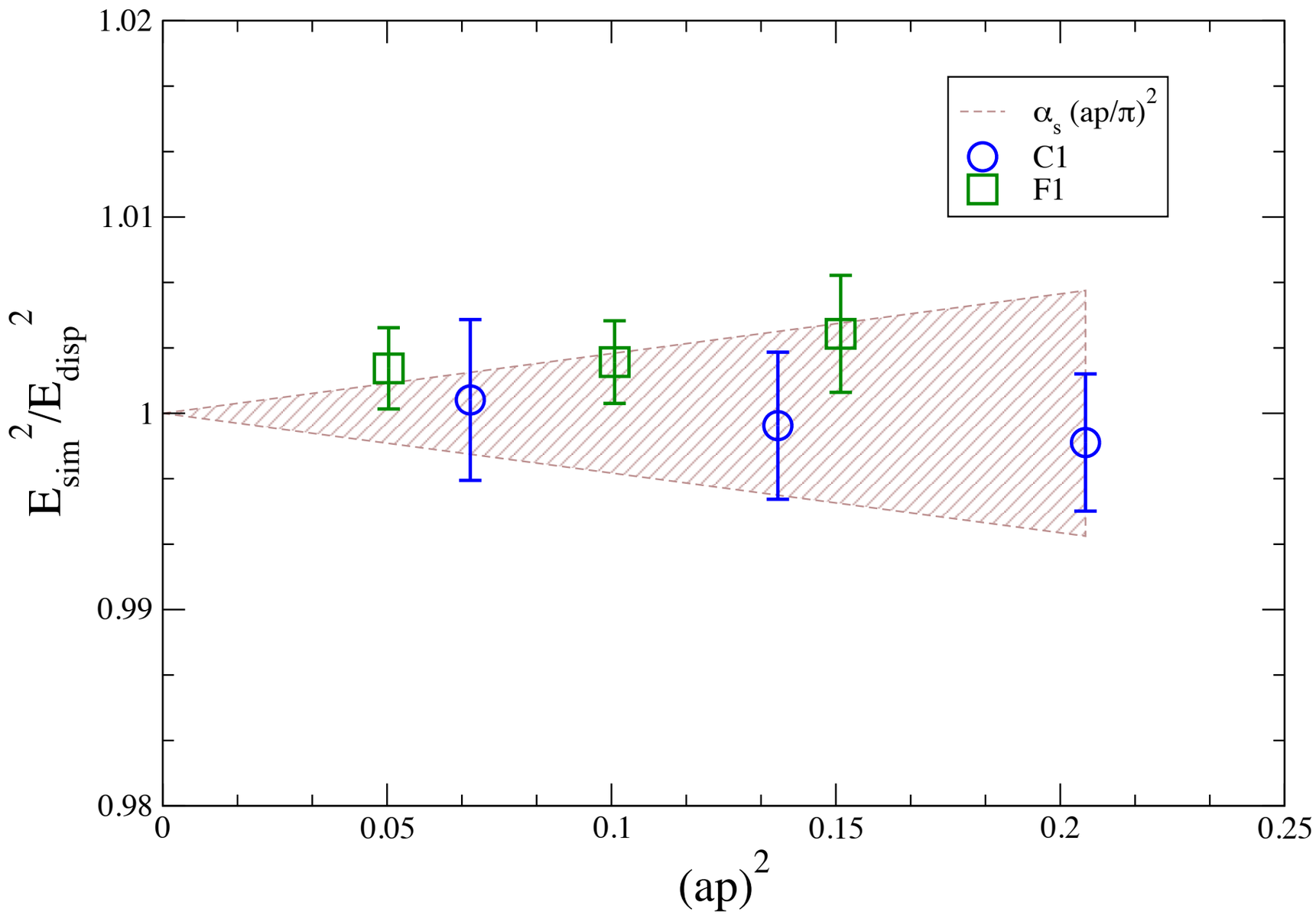
- We apply NRQCD heavy quark action for the bottom quark, and HISQ action for the light and charm quarks.
  - HISQ has leading discritization error at $O(\alpha_s(am_h)^2\ v^2/c^2)$ and $O((am_h)^4 v^2/c^2)$
  - The lattice vector current corrected through $O(\alpha_s, \Lambda_{QCD}/m_b, \alpha_s/(am_b))$ in one loop perturbative calculation.
  - U(1) random-wall source
  - New chaining and marginalizing technique for correlator fits (arXiv:1406.2279)

$B \to D$ and $B_s \to D_s$ semileptonic decays

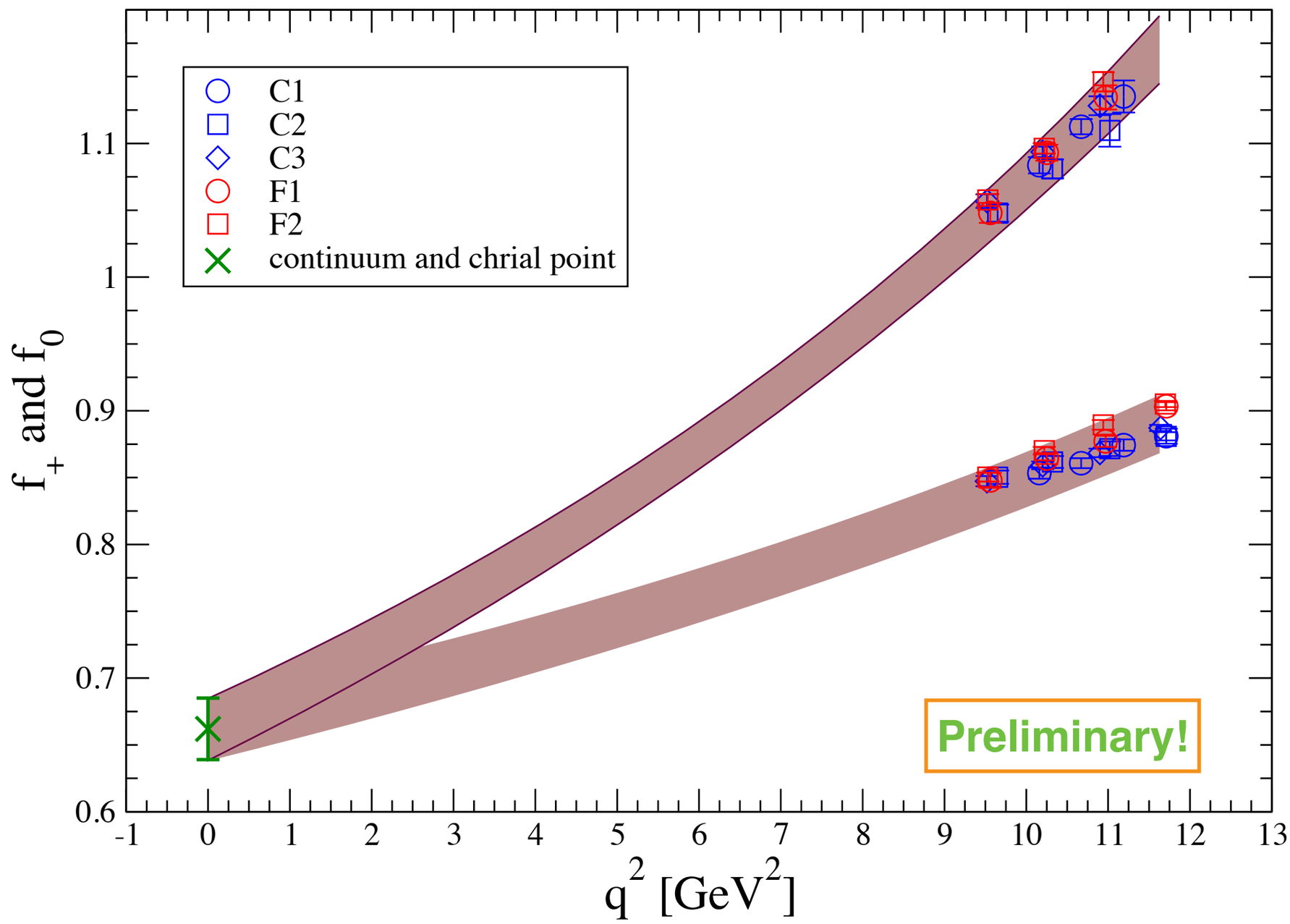
- Dispersion relation
- Chiral and continuum extrapolation
- R(D) and R(D_s)
- $f_0(B_s \to D_s)/f_0(B \to D)$: important input for $Br(B_s \to \mu^+\mu^-)$
- alternative $|V_{cb}|$ determination
- **Preliminary!**

Dispersion relation

- D mesons from HISQ light and charm quarks. Fully relativistic D meson.
- E_{sim}^2/E_{disp}^2 for D mesons on the coarse and fine ensembles



After correlator fits…



Modified z-expansion: Preliminary

- z-expansion with BCL parameterization

$$f_+(q^2) = \frac{1}{P}\sum_{k=0}^{K-1} a_k[z^k - (-1)^{k-K}\frac{k}{K}z^K], \quad P = 1 - \frac{q^2}{M_{B_c^*}}$$

- Modified z-expansion for continuum, chiral, and kinematic extrapolation

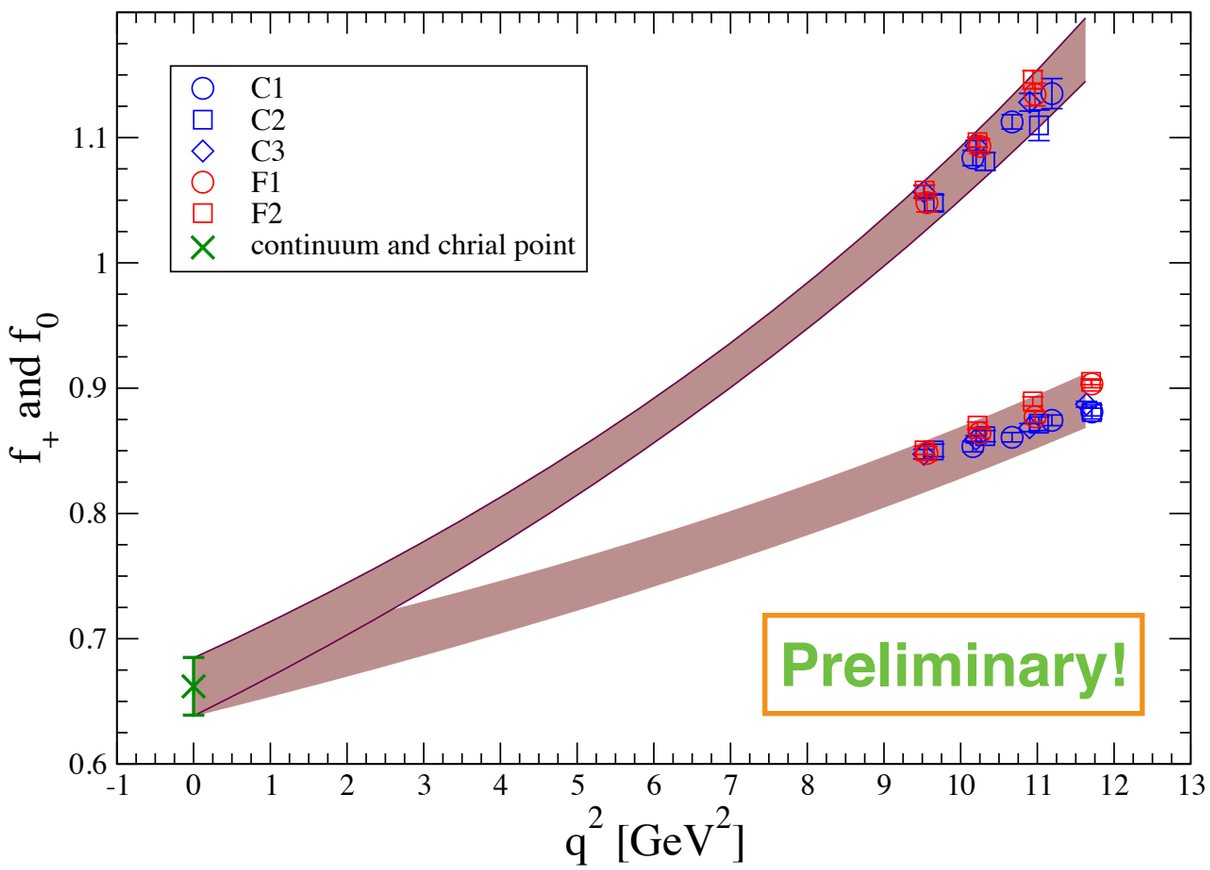
$$f_+(q^2) = \frac{1}{P}\sum_{k=0}^{K-1} a_k D_k[z^k - (-1)^{k-K}\frac{k}{K}z^K]$$

$$D_k = 1 + c_1 x_\pi + c_2(\frac{1}{2}\delta x_\pi + \delta x_K) + c_3 x_\pi log x_\pi + d_1(am_c)^2 + d_2(am_c)^4 + e_1(aE_D/\pi)^2 + e_2(aE_D/\pi)^4$$

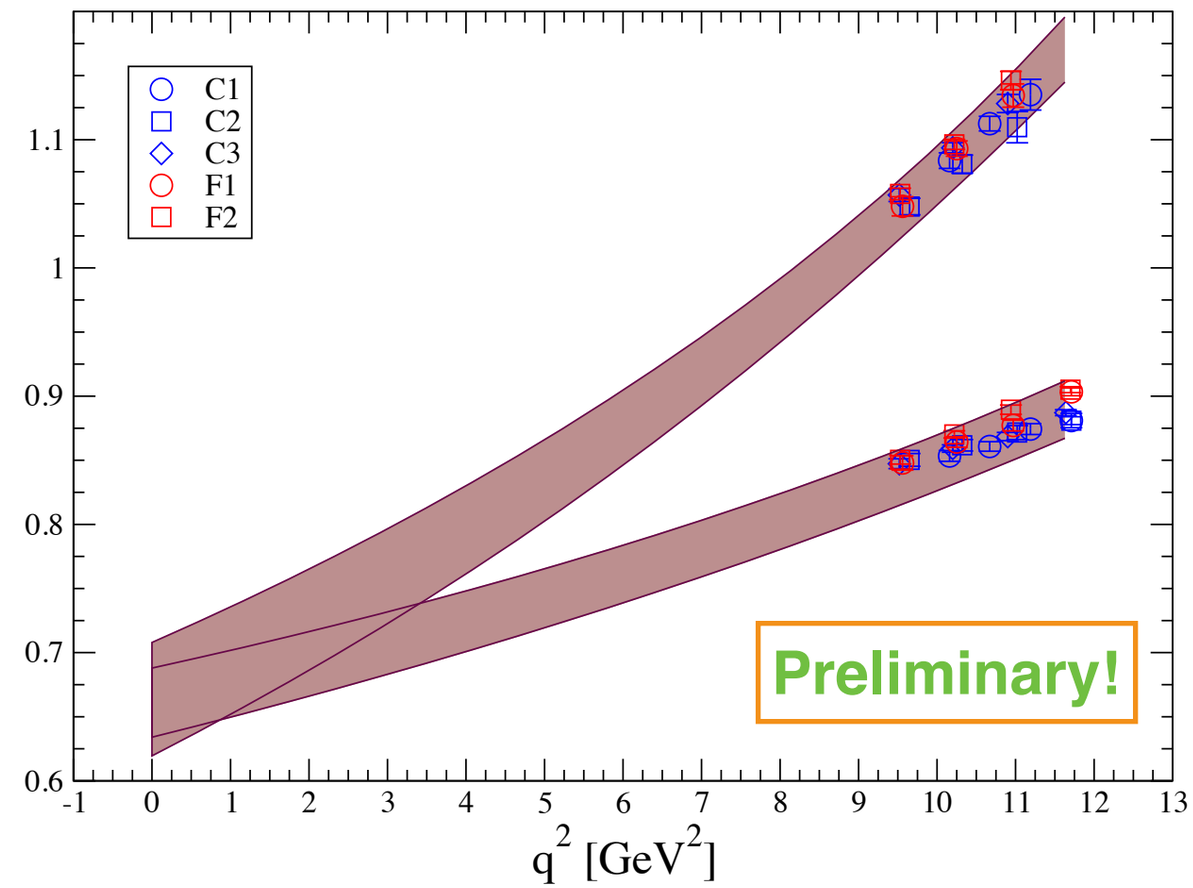
- Pole locations
  - f_+: B_c^* (1^-) = 6.33 GeV from a lattice calculation by HPQCD (PRL 104 (2010) 022001)
  - f_0: No measurement or lattice calculations for B_c (0^+).
    - We used 6.33 + exp(log(0.2 ±1.0)) GeV.

Modified z-expansion

- **B → D l ν**



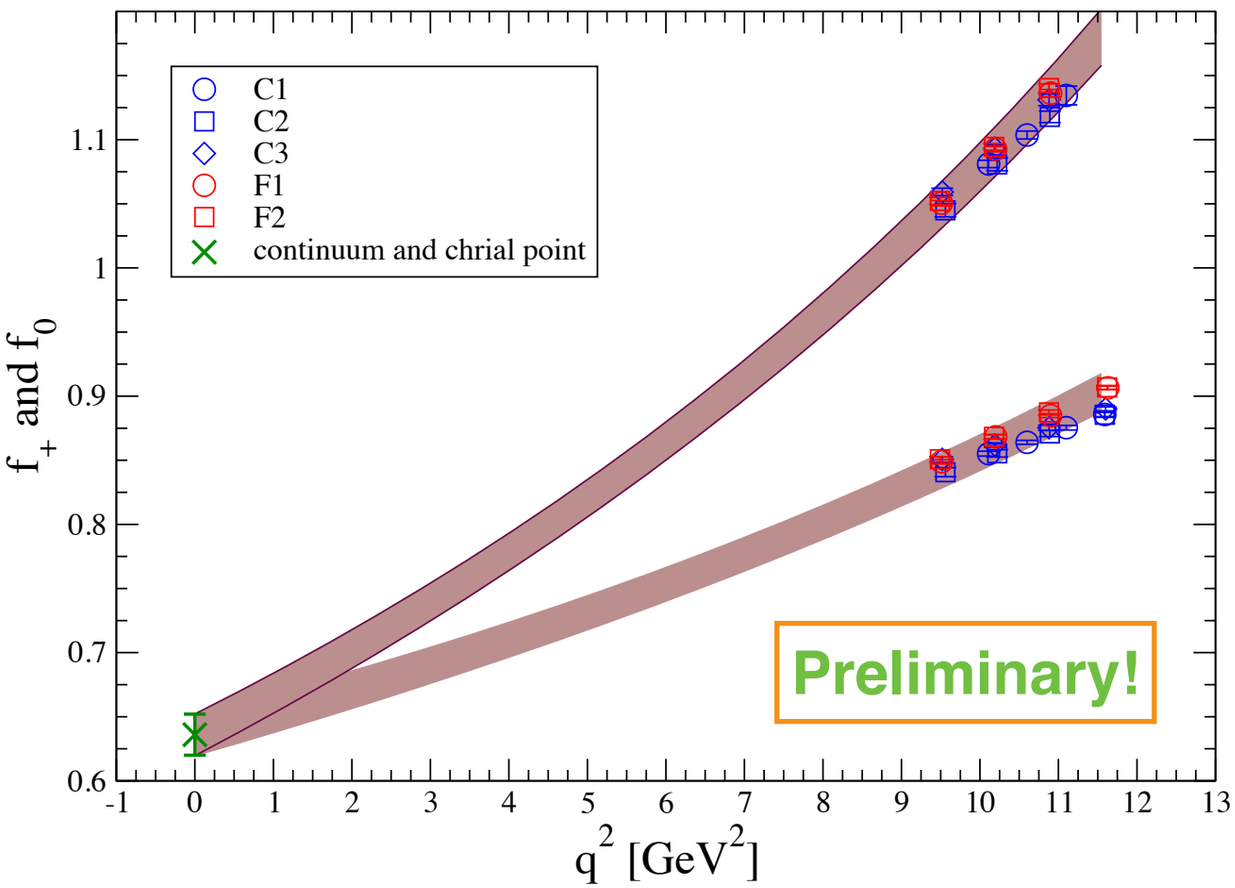
chi^2/dof = 0.76, Q = 0.85
With kinematic constraint: $f_+(0) = f_0(0)$



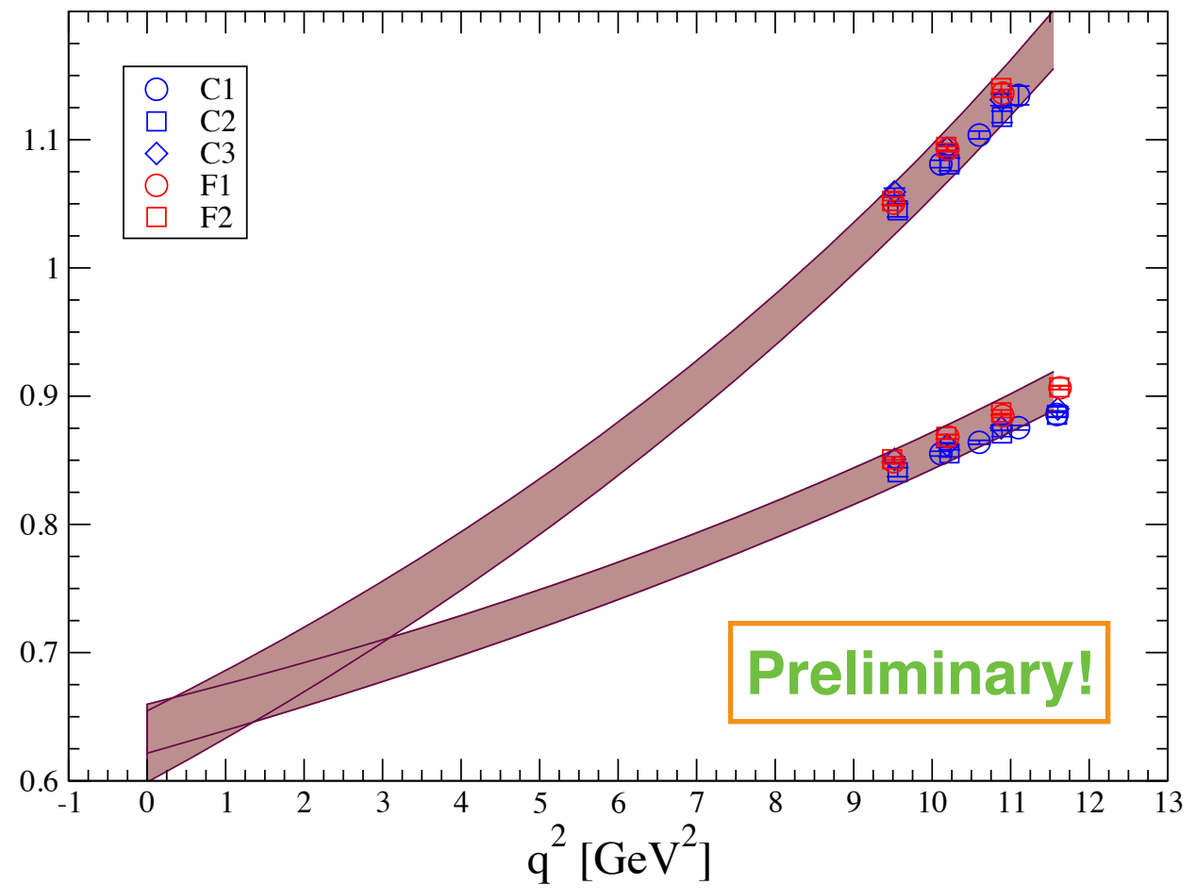
chi^2/dof = 0.78, Q = 0.82
Without kinematic constraint

Modified z-expansion

- **$B_s \to D_s$ l v**



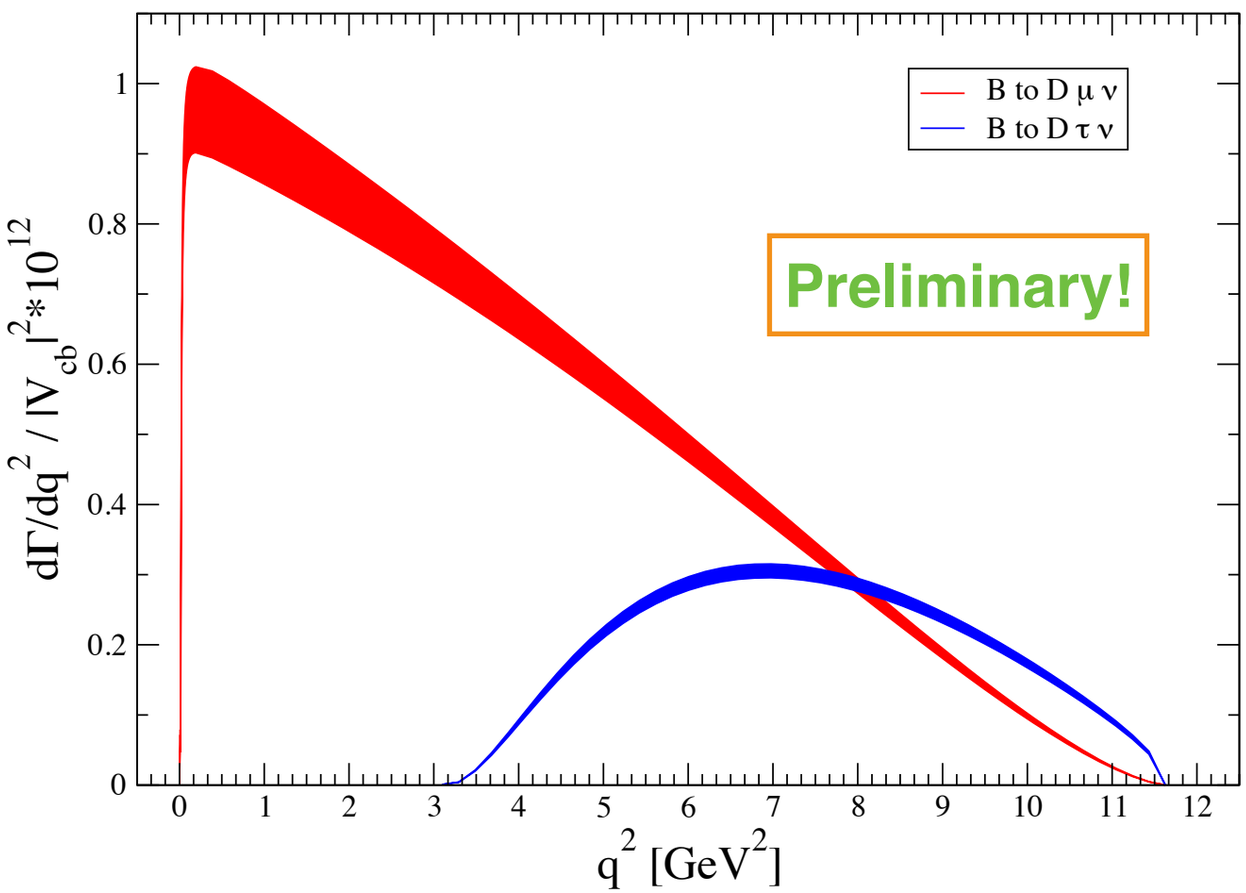
chi^2/dof = 0.78, Q = 0.83
With kinematic constraint



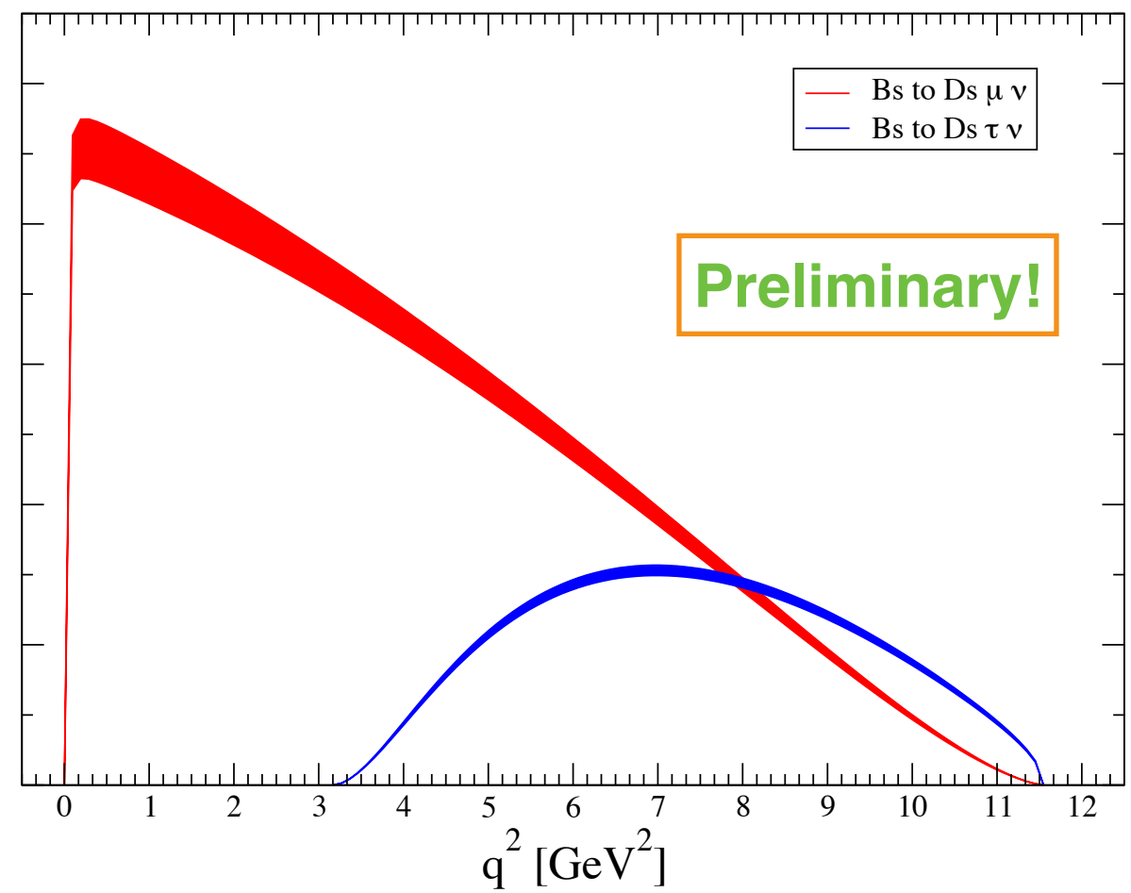
chi^2/dof = 0.79, Q = 0.8
Without kinematic constraint

R(D) and R(D_s): $R(D_x) = \frac{BR(B_x \to D_x \tau \nu)}{BR(B_x \to D_x \mu \nu)}$

- Potential New Physics signature: $B_x \to D_x \tau \nu$ and $B_x \to D_x \mu \nu$
  - The scalar form factor is more important for $B_x \to D_x \tau \nu$
- $B \to D$ and $B_s \to D_s$ show almost identical results.
  - Kinematic variable, q^2, is very close. $q^2 = m_B^2 + m_D^2 - 2m_B E_D$



B → D channels

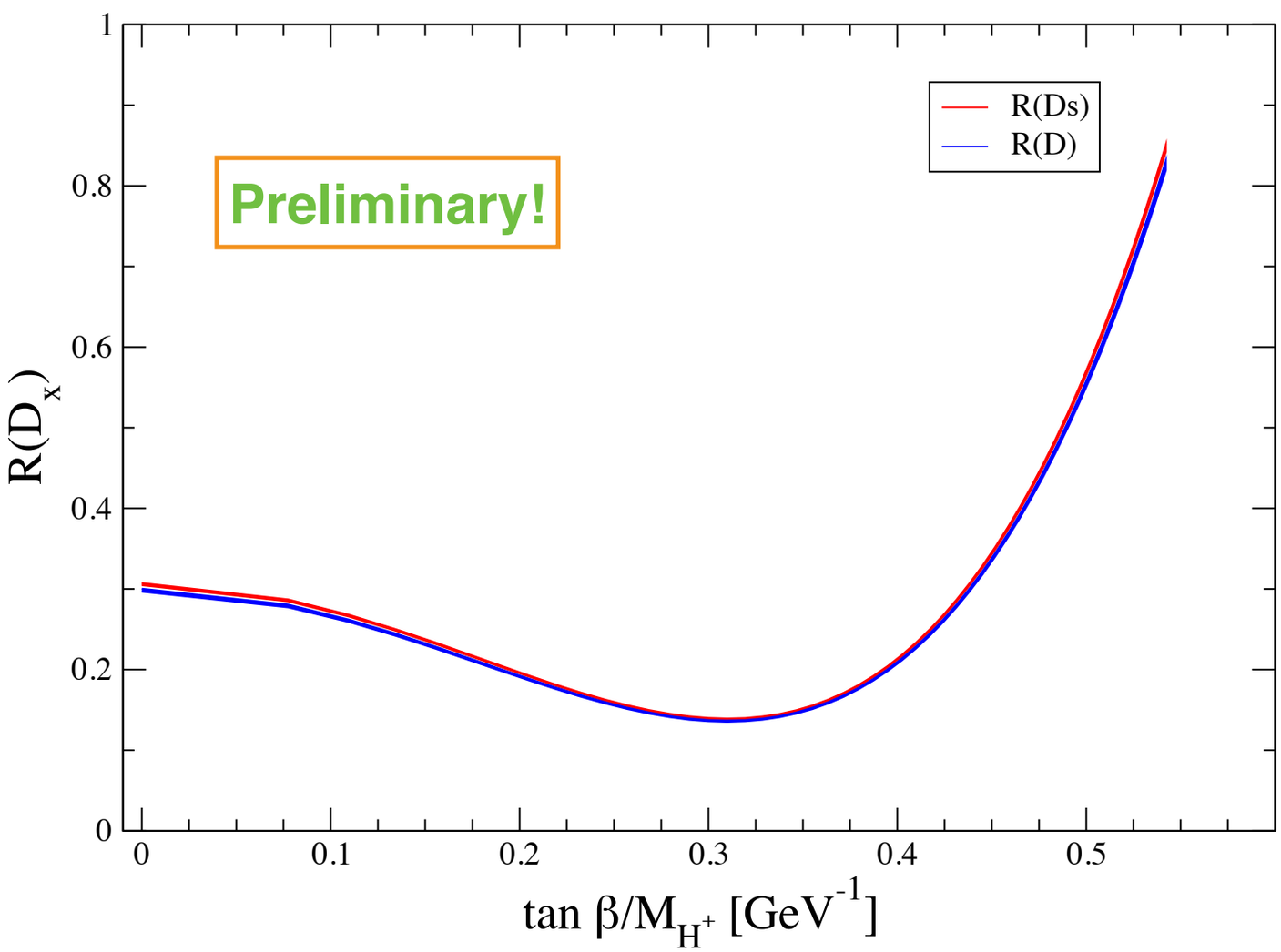


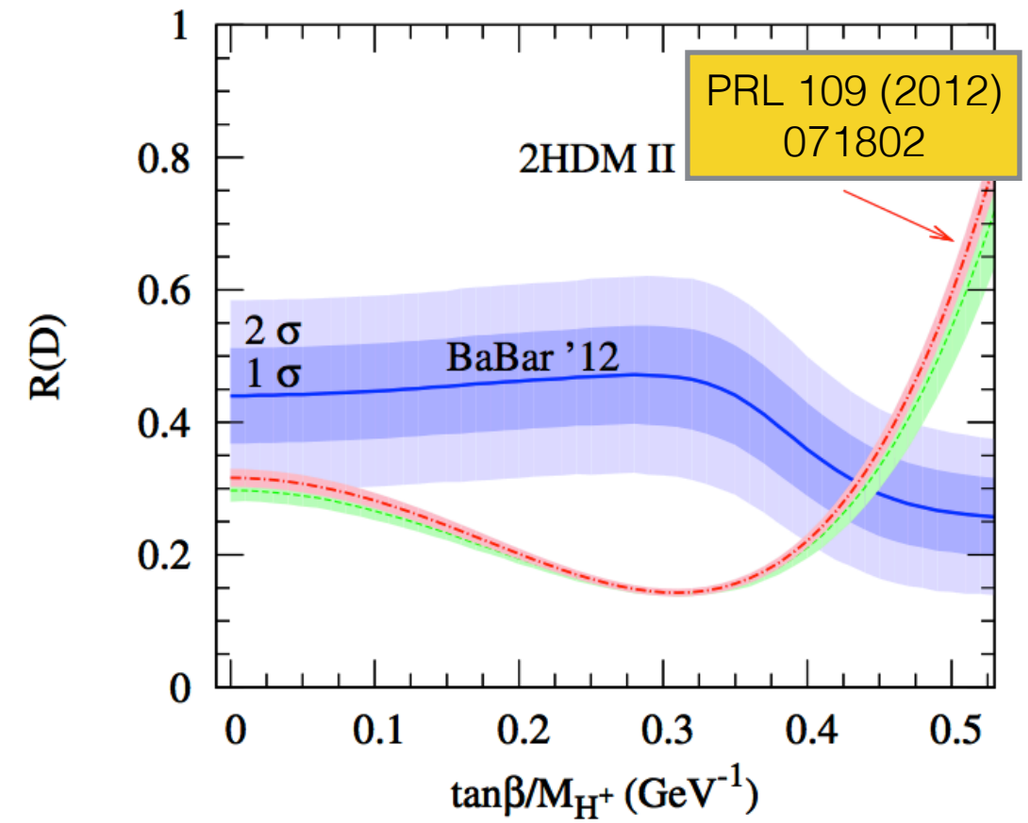
$B_s \to D_s$ channels

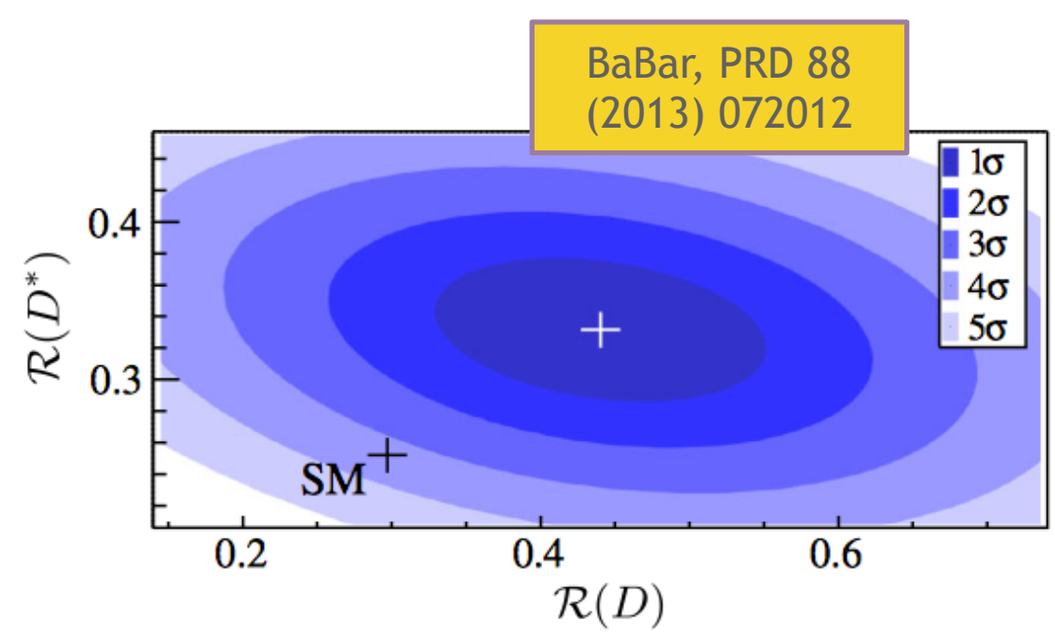
R(D) and R(D$_s$): 2HDM

- From 2HDM, the scalar coupling is given by

$$G_S \propto G_F V_{cb} m_l \frac{tan^2\beta}{M_{H^\pm}^2}$$







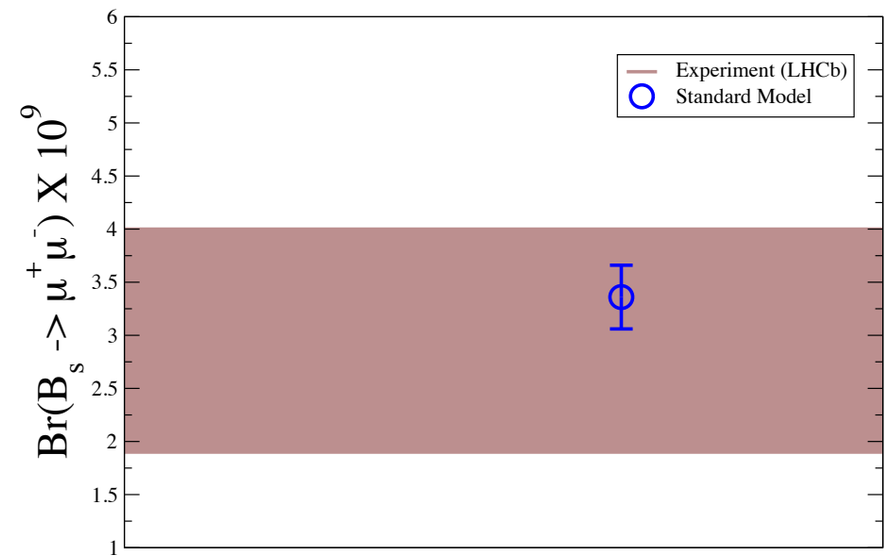
$f_0(B_s \to D_s; m_\pi^2)/f_0(B \to D; m_K^2)$: important input for $Br(B_s \to \mu^+\mu^-)$

- Probing New Physics from $B_s \to \mu^+ \mu^-$
  - Highly suppressed in SM

$$Br^{SM}(B_s \to \mu^+\mu^-) = (3.36 \pm 0.30) \times 10^{-9}$$

$$Br^{EXP}(B_s \to \mu^+\mu^-) = 2.9^{+1.1}_{-1.0} \times 10^{-9}$$

    - LHCb, PRL 111 (2013) 101805



- How to measure the branching ratio in experiments?

$$Br(B_s \to \mu^+\mu^-) = Br(B_s \to X)\frac{\epsilon_X}{\epsilon_{\mu\mu}}\frac{N_{\mu\mu}}{N_X}$$

$$\longrightarrow \quad Br(B_s \to \mu^+\mu^-) = Br(B_d \to X)\frac{f_d}{f_s}\frac{\epsilon_X}{\epsilon_{\mu\mu}}\frac{N_{\mu\mu}}{N_X}$$

- Now, $\frac{f_d}{f_s}$ is the dominant source of the systematic errors!

$f_0(B_s \to D_s; m_\pi^2)/f_0(B \to D; m_K^2)$: important input for $Br(B_s \to \mu^+\mu^-)$

- Combined result (LHCb-CONF-2013-011):

$$\frac{f_s}{f_d} = 0.259 \pm 0.015$$

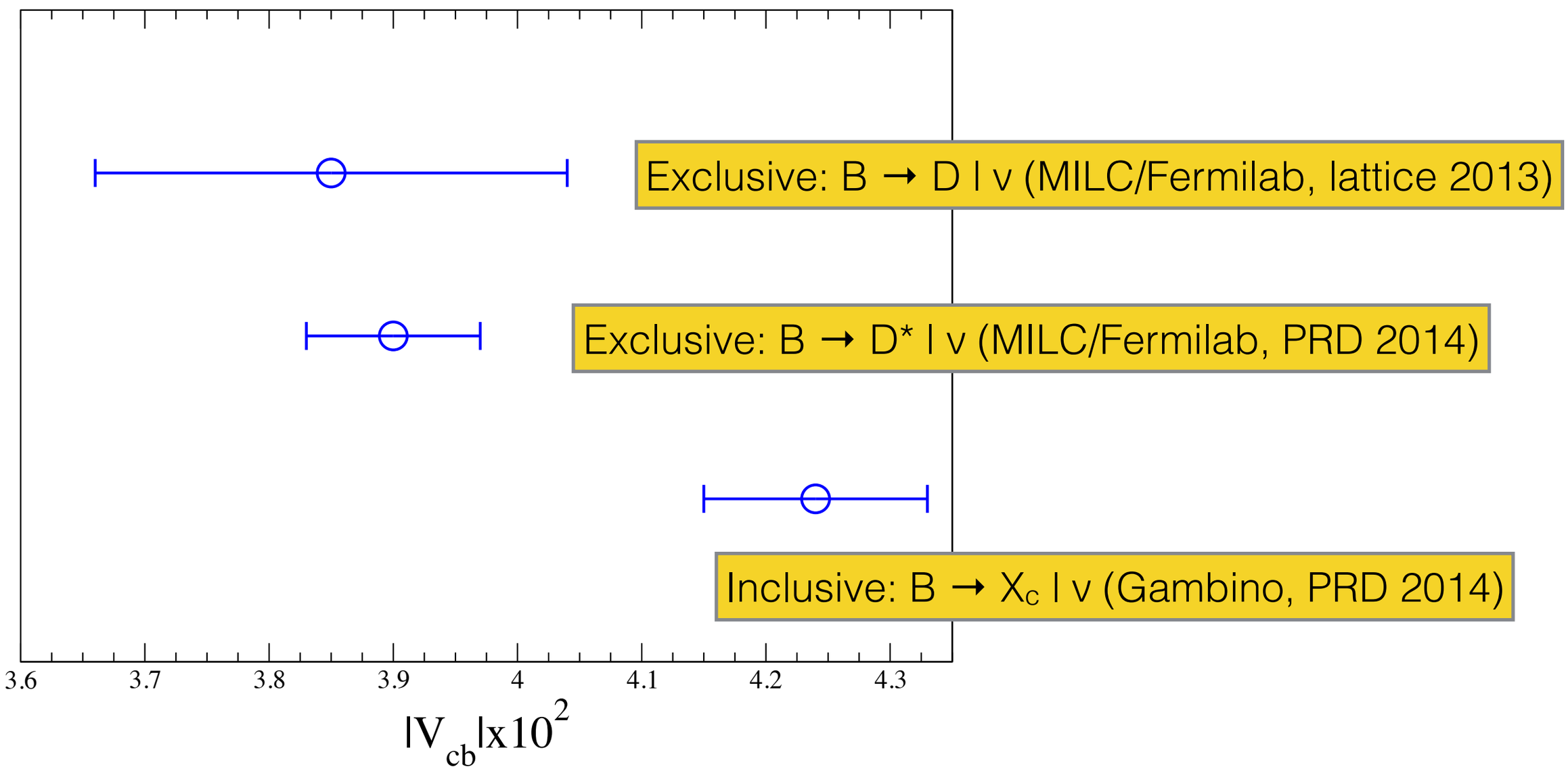
$$\to \left(\frac{f_s}{f_d}\right)_{semi} = 0.263 \pm 0.008(stat)^{+0.019}_{-0.016}(syst)$$

$$+ \left(\frac{f_s}{f_d}\right)_{hadr} = 0.242 \pm 0.004(stat) \pm 0.012(syst) \pm 0.021(theo)$$

- The theory errors are came from the ratio of the form factors, N_F.
- N_F = 1.092(93) from Fermilab/MILC, PRD 86 (2012) 039904
  - N_F = 1.24 ± 0.08 (Sum rule, Blasi et al PRD 49 (1994) 238)
- We are getting the result soon with at least 30% smaller errors!
  - Need to take into account the correlations
- More independent lattice calculations are needed!
- $\frac{f_d}{f_s}$ will be used for all other branching ratio experiments with B_s
  - Even for the CMS experiments

$|V_{cb}|$

- $B \to D$ and $B_s \to D_s$ can be used for alternative determinations of $|V_{cb}|$
  - But, the most accurate determination is from $B \to D^* l \nu$ at zero recoil, mostly due to the experiments.



$B_s \to K$ semileptonic decays

Lead by Chris Bouchard

arXiv: 1406.2279

- First lattice calculation!
- HPChPT z-expansion and error budget
- Prediction of differential branching fractions
  - alternative $|V_{ub}|$ determination
- Phenomenology
  - $R_{\mu\boldsymbol{\tau}}$, A^l_{FB}, $\bar{A}^l_{FB}$, and A^l_{pol}

HPChPT z-expansion

- HPChPT-motivated modified z-expansion

$$f_{\parallel,\perp}(E) = (1 + [\text{logs}])\ \mathcal{K}_{\parallel,\perp}(E)$$

$$f_+(q^2) = \frac{1}{P}\sum_{k=0}^{K-1} a_k[z^k - (-1)^{k-K}\frac{k}{K}z^K] \longrightarrow f_+(q^2) = \frac{1}{P}\sum_{k=0}^{K-1} a_k D_k[z^k - (-1)^{k-K}\frac{k}{K}z^K]$$

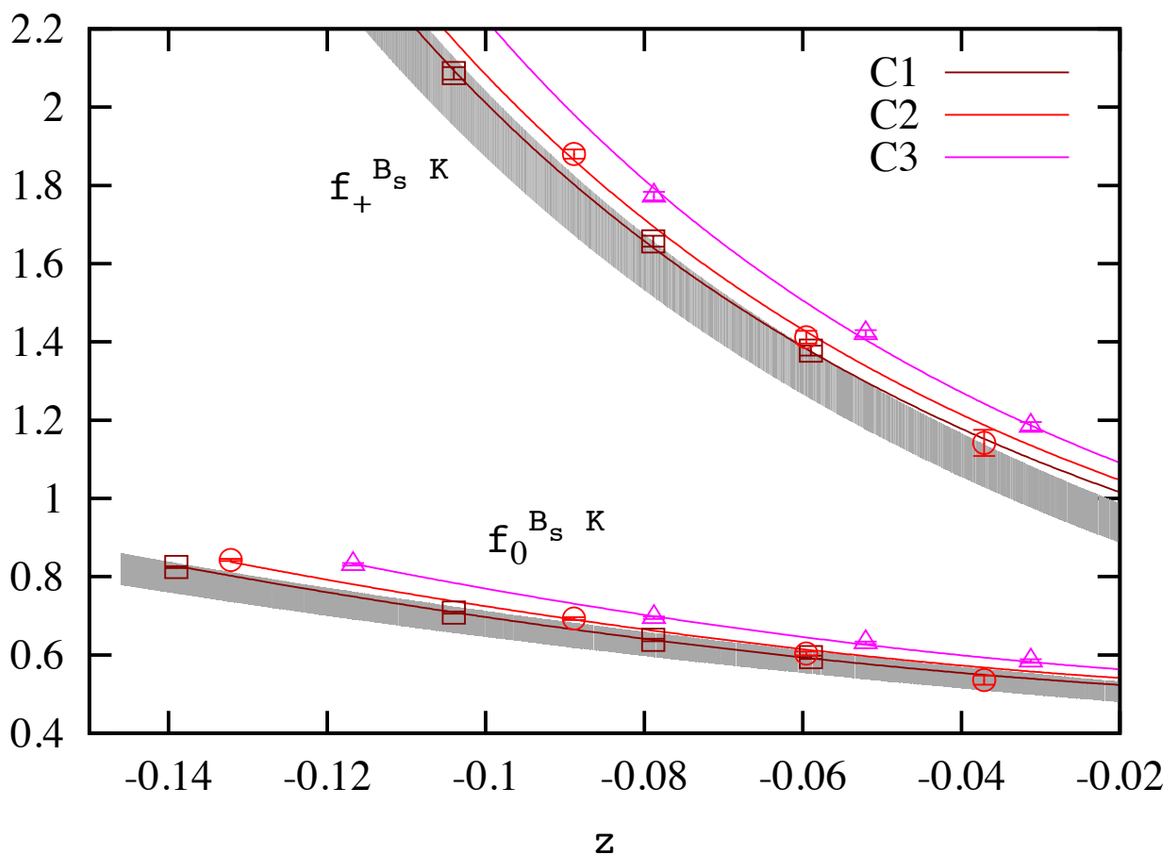
$$\longrightarrow f_+(q^2) = (1 + [logs])\frac{1}{P}\sum_{k=0}^{K-1} a_k D_k[z^k - (-1)^{k-K}\frac{k}{K}z^K]$$

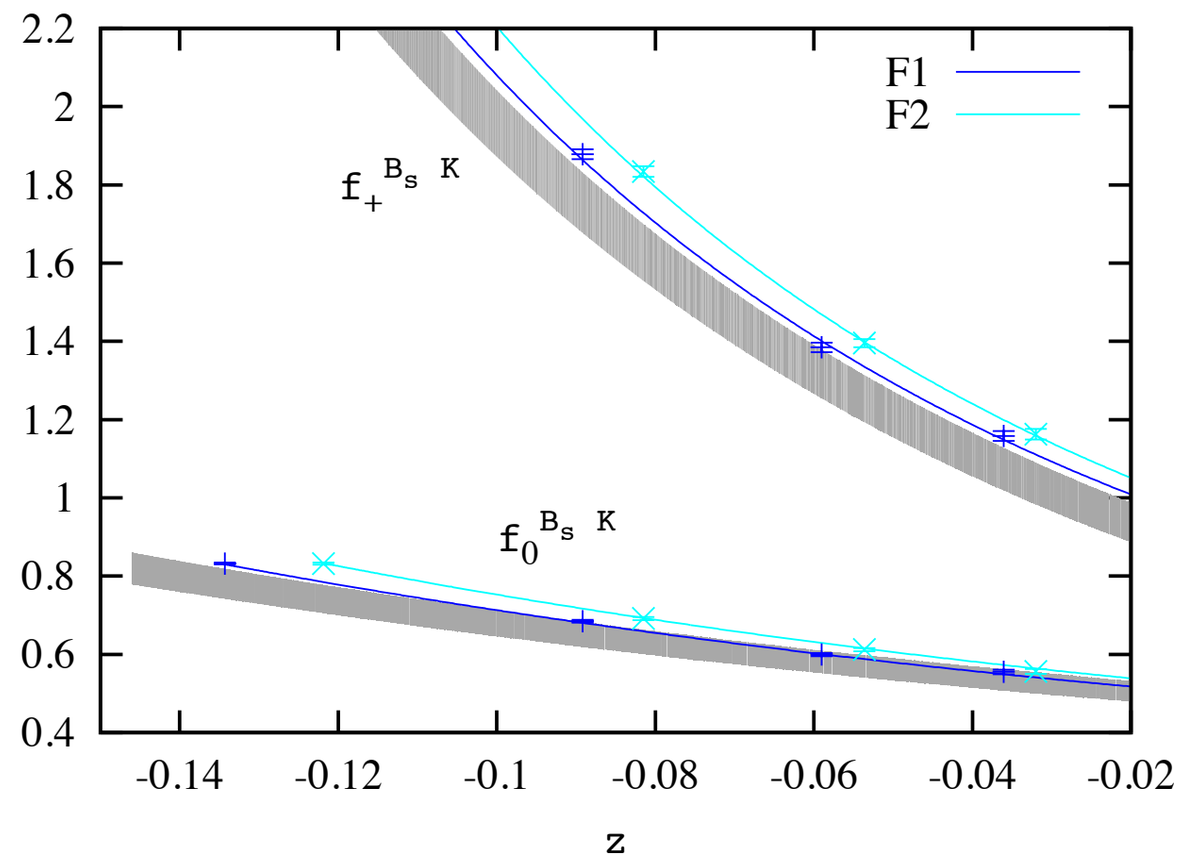
$$\begin{aligned}
D_k &= 1 + c_1^{(k)}x_\pi + c_2^{(k)}(\frac{1}{2}\delta x_\pi + \delta x_K) \\
&+ c_3^{(k)}\delta x_{\eta_s} + d_1^{(k)}(a/r_1)^2 + d_2^{(k)}(a/r_1)^4 \\
&+ e_1^{(k)}(aE_K)^2 + e_2^{(k)}(aE_K)^4, \\
[\text{logs}] &= -\frac{3}{8}x_\pi(\log x_\pi + \delta_{FV}) - \frac{1+6g^2}{4}x_K \log x_K \\
&- \frac{1+12g^2}{24}x_\eta \log x_\eta,
\end{aligned}$$

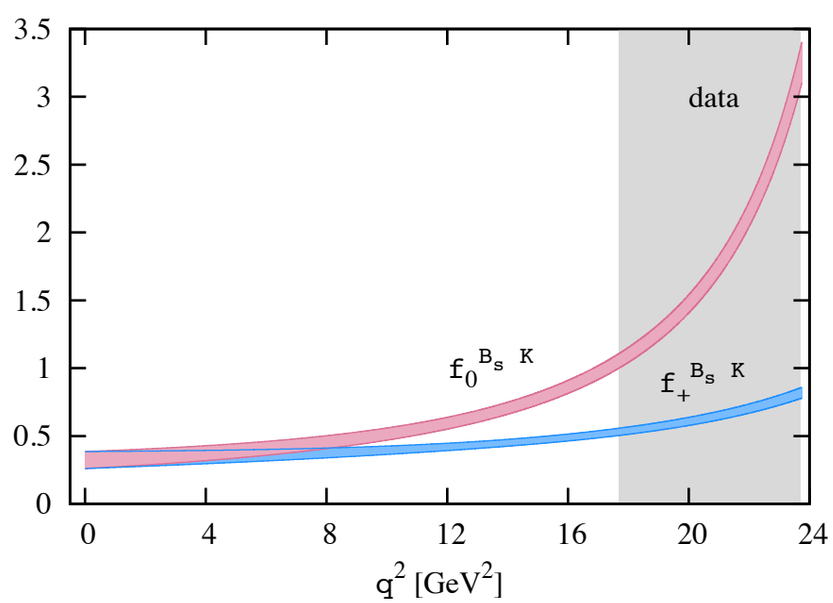
$$\begin{aligned}
d_1^{(k)} &\to d_1^{(k)}(1 + l_1^{(k)}x_\pi + l_2^{(k)}x_\pi^2)(1 + h_1^{(k)}\delta x_b + h_2^{(k)}\delta x_b^2) \\
d_2^{(k)} &\to d_2^{(k)}(1 + l_3^{(k)}x_\pi + l_4^{(k)}x_\pi^2)(1 + h_3^{(k)}\delta x_b + h_4^{(k)}\delta x_b^2)
\end{aligned}$$

HPChPT z-expansion

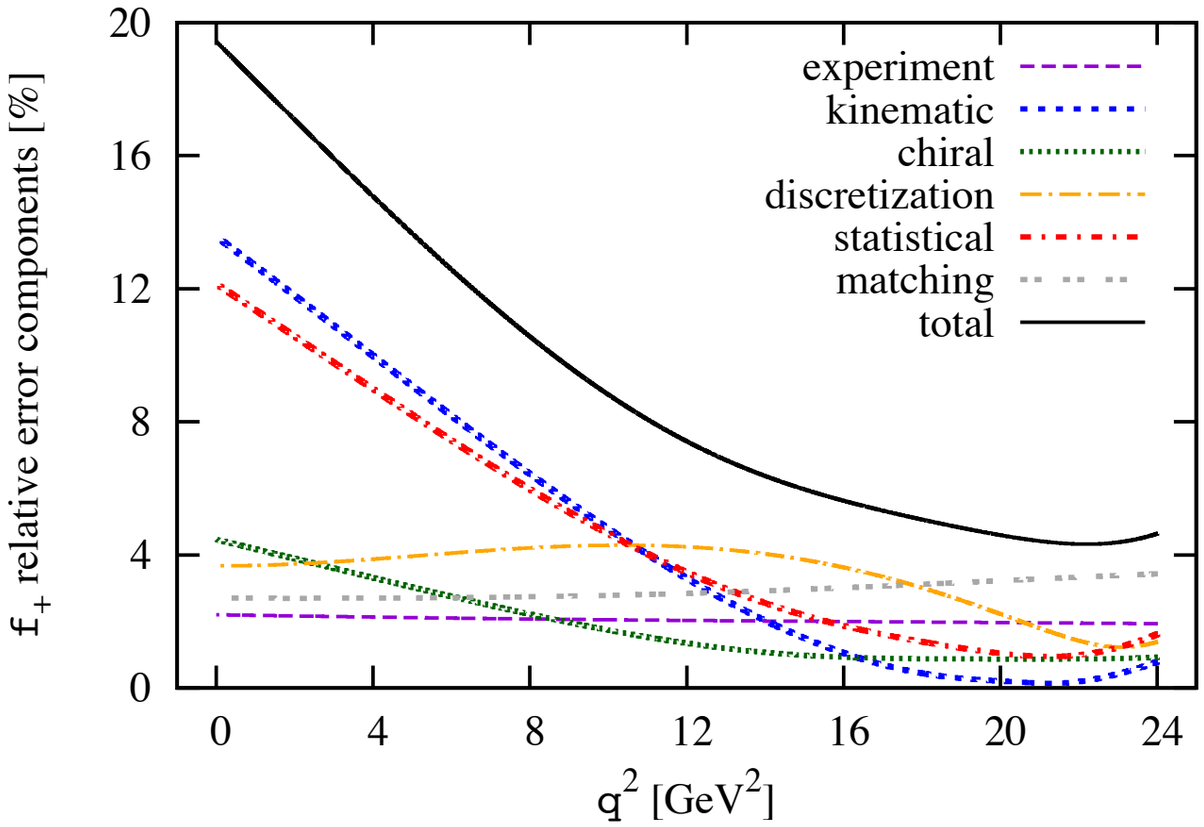
- Chiral and continuum extrapolation results

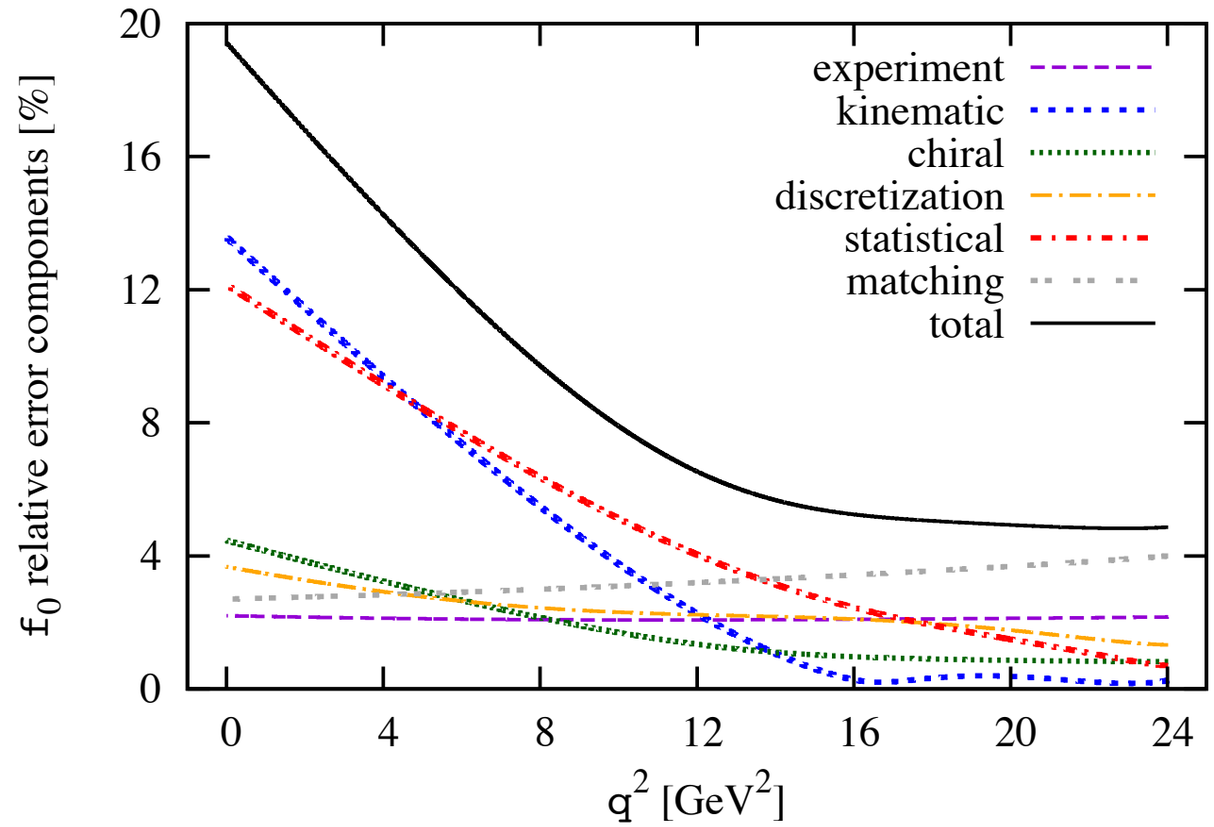






Form factors: error budget



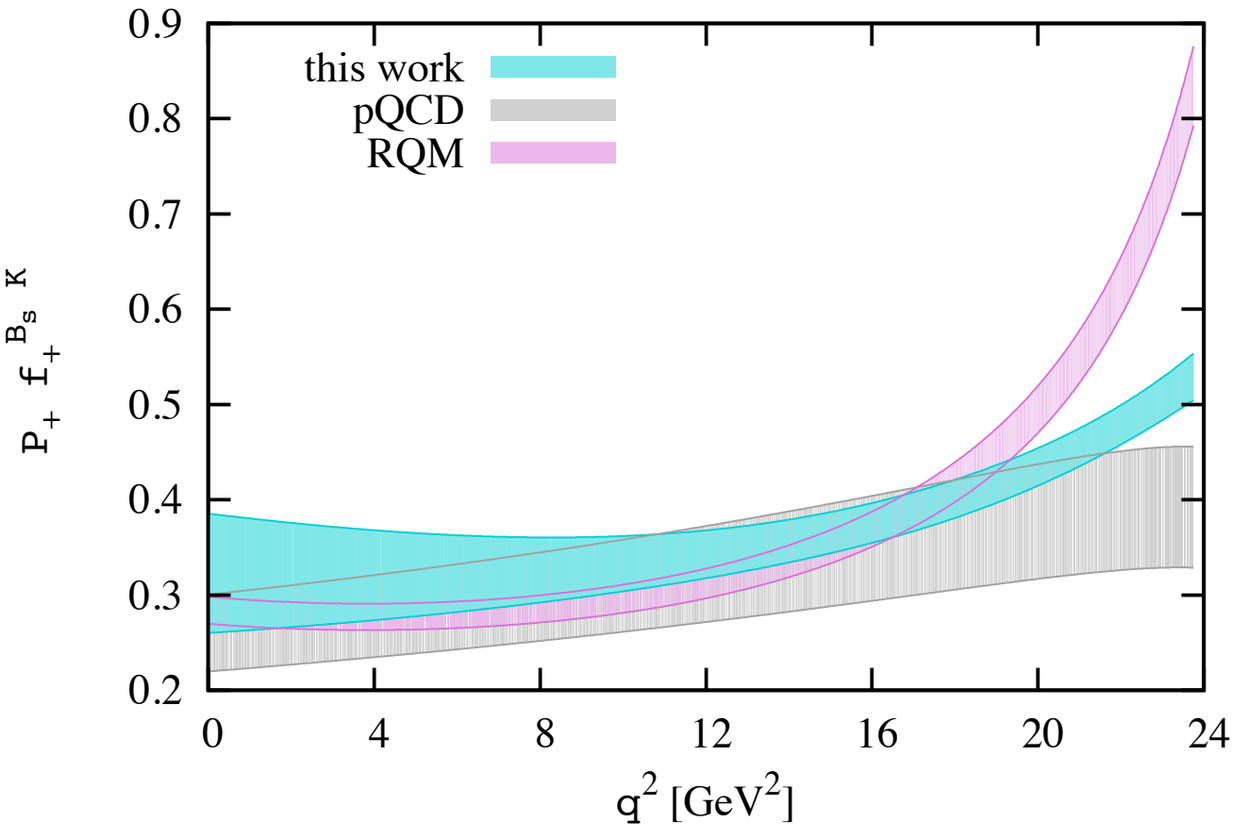


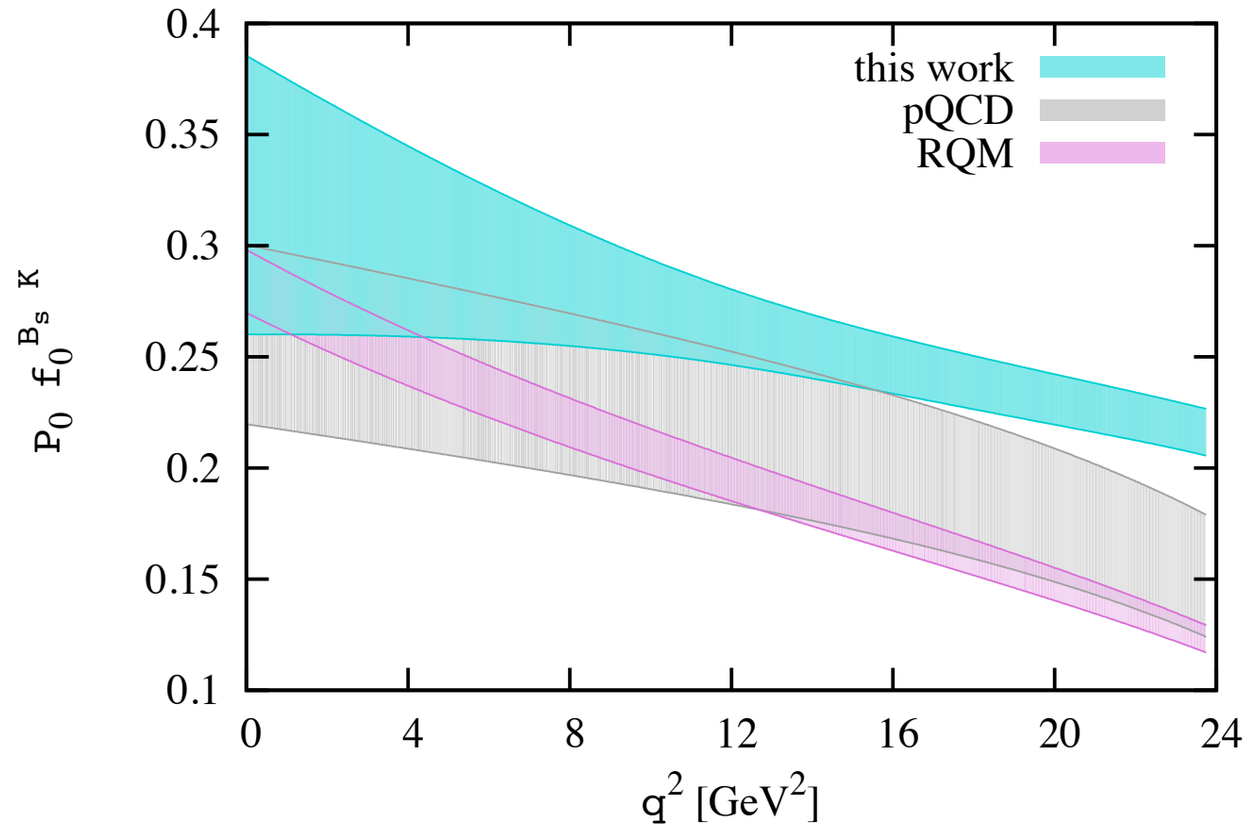
Bs → K, f_+

Bs → K, f_0

- f+(q2=0) = 0.323(63)
- Kinematic and statistical errors are the dominant errors at small q^2

Form factors: comparisons to non-lattice calculations



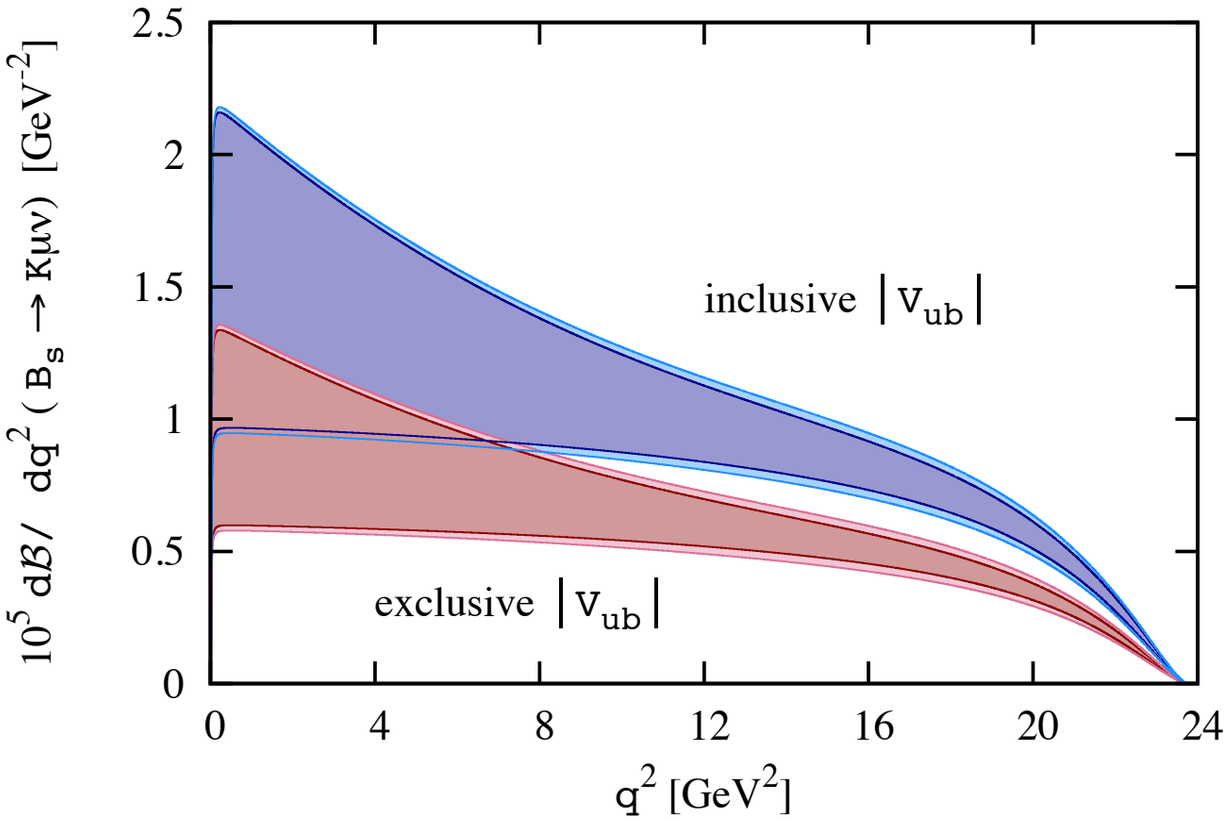


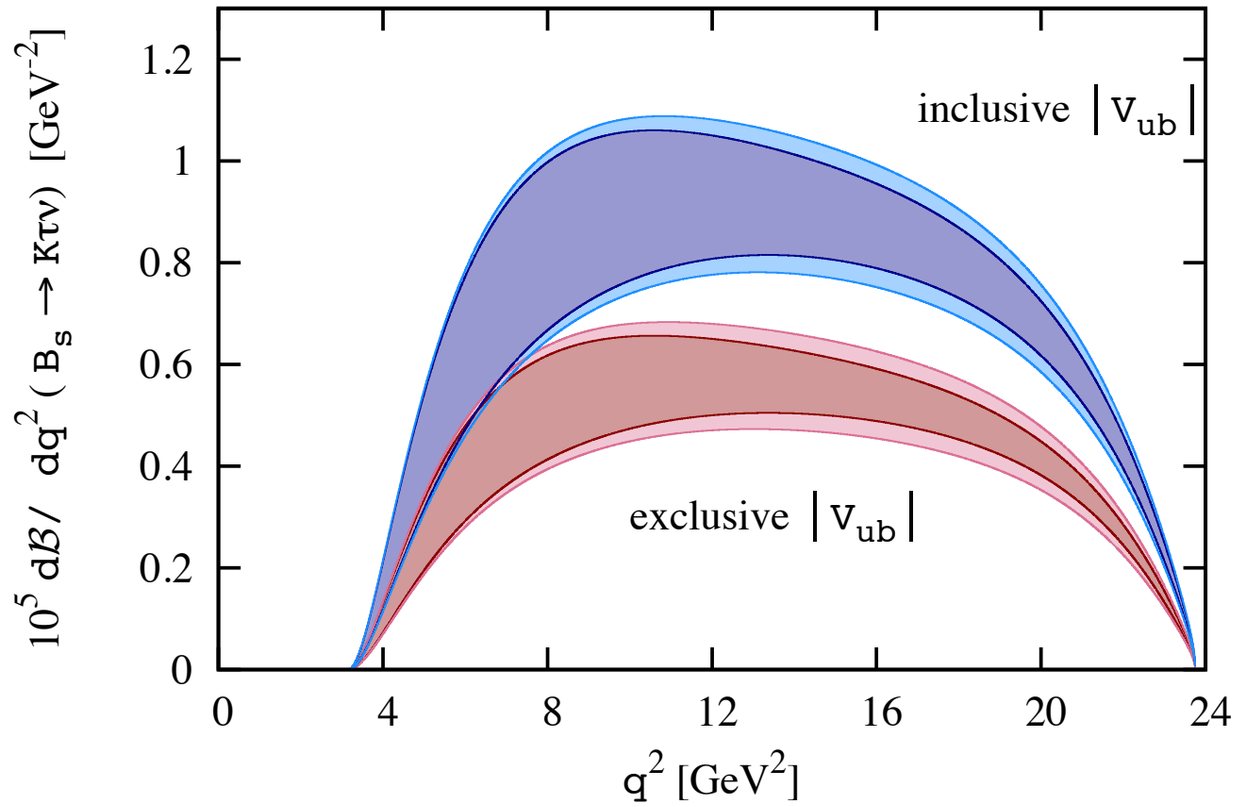
Bs → K, f_+

Bs → K, f_0

- pQCD: perturbative QCD
- ROM : Relativistic Quark Model
- much better clarification at large q^2

Branching fractions: Predictions!

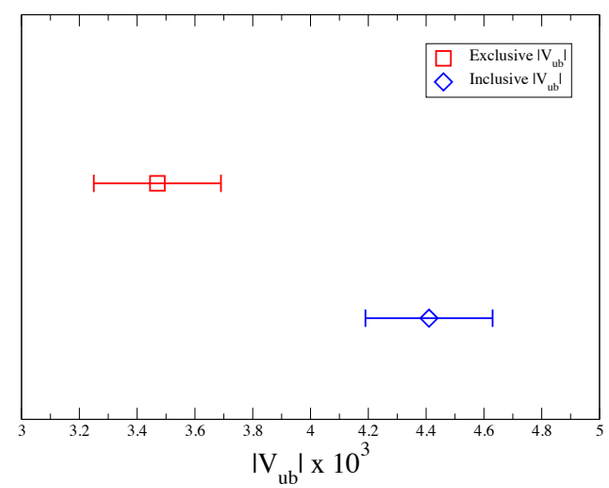




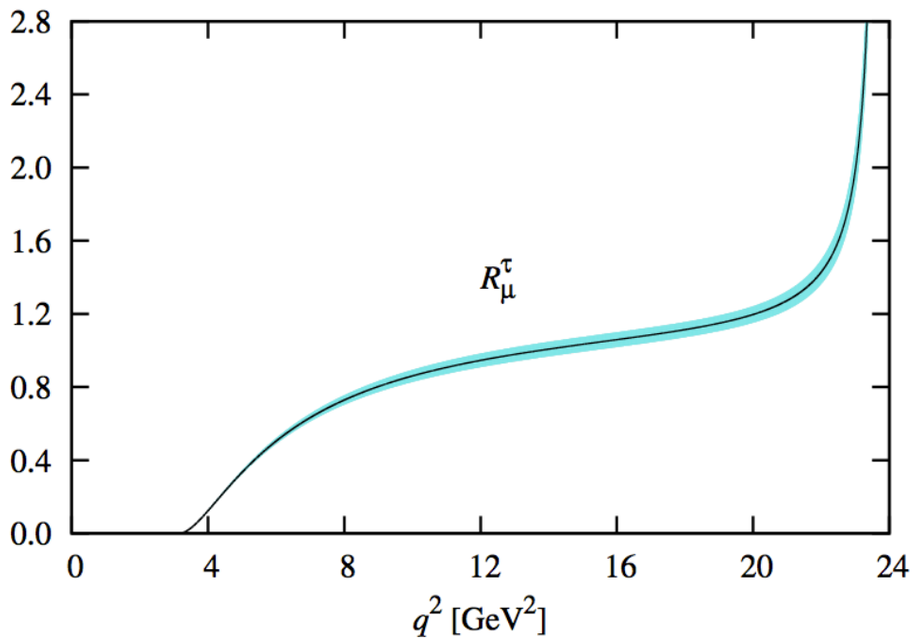
Bs → K μ ν

Bs → K **τ** ν

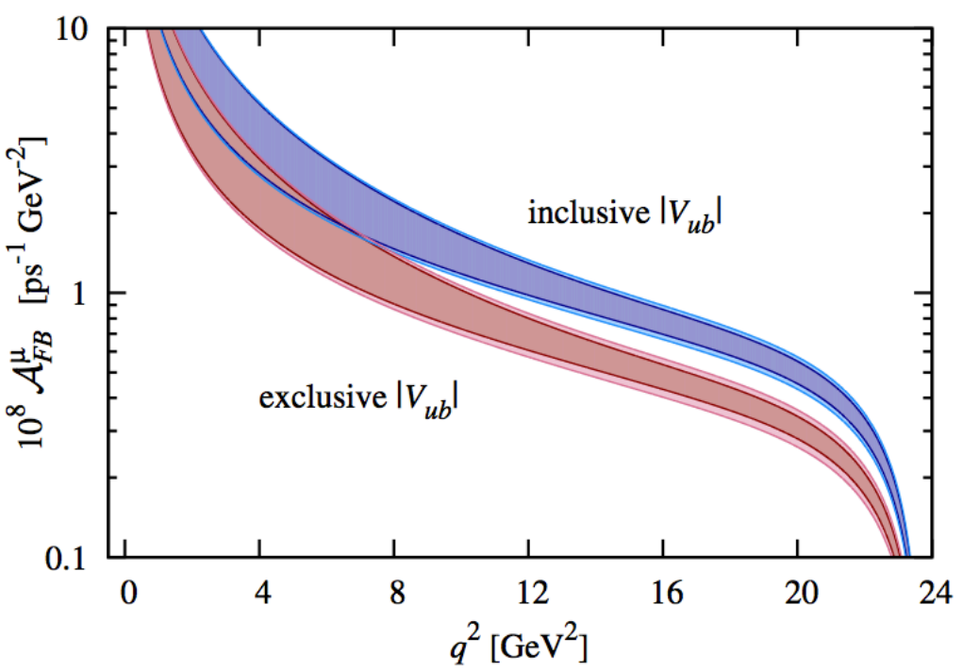
- Assuming inclusive or exclusive $|V_{ub}|$
- Potential ~ 3 σ discrepancy at large q^2
- Waiting for LHCb and BelleII

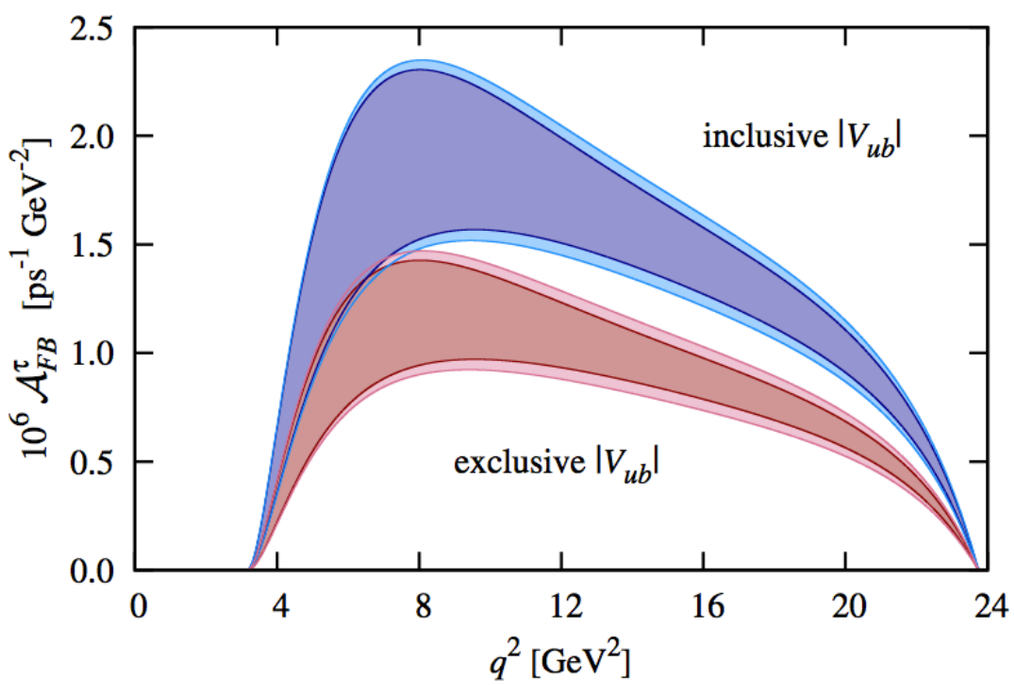


Other phenomenological quantities

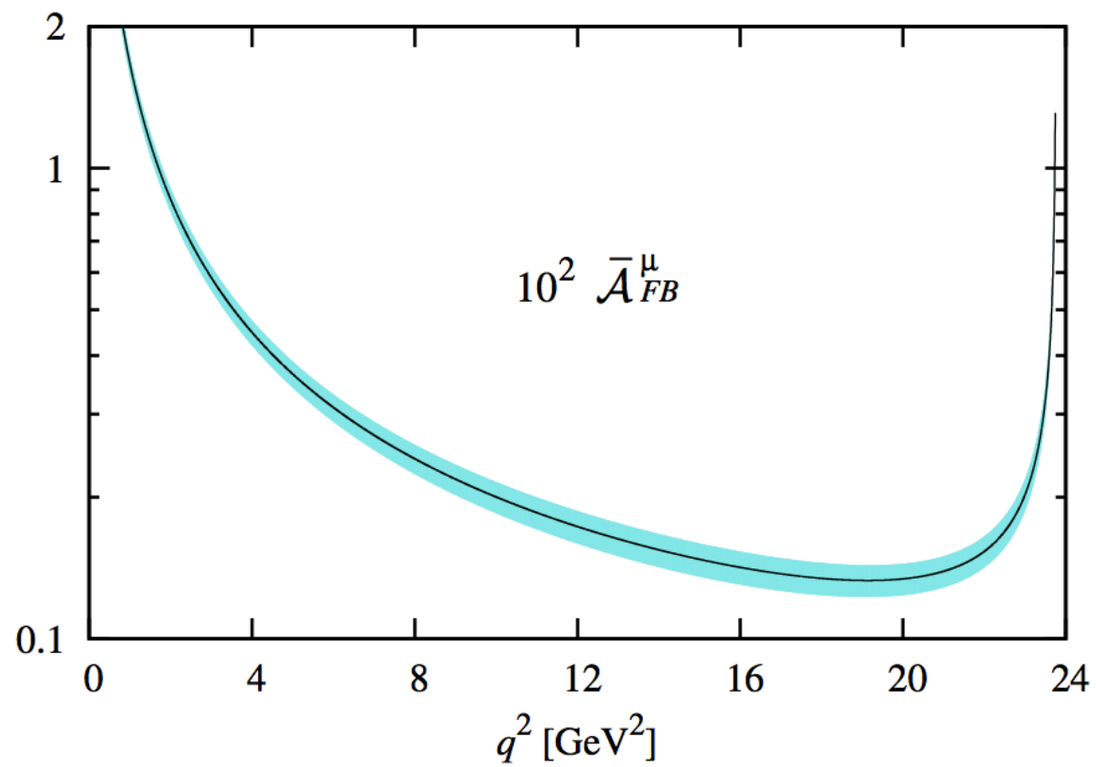


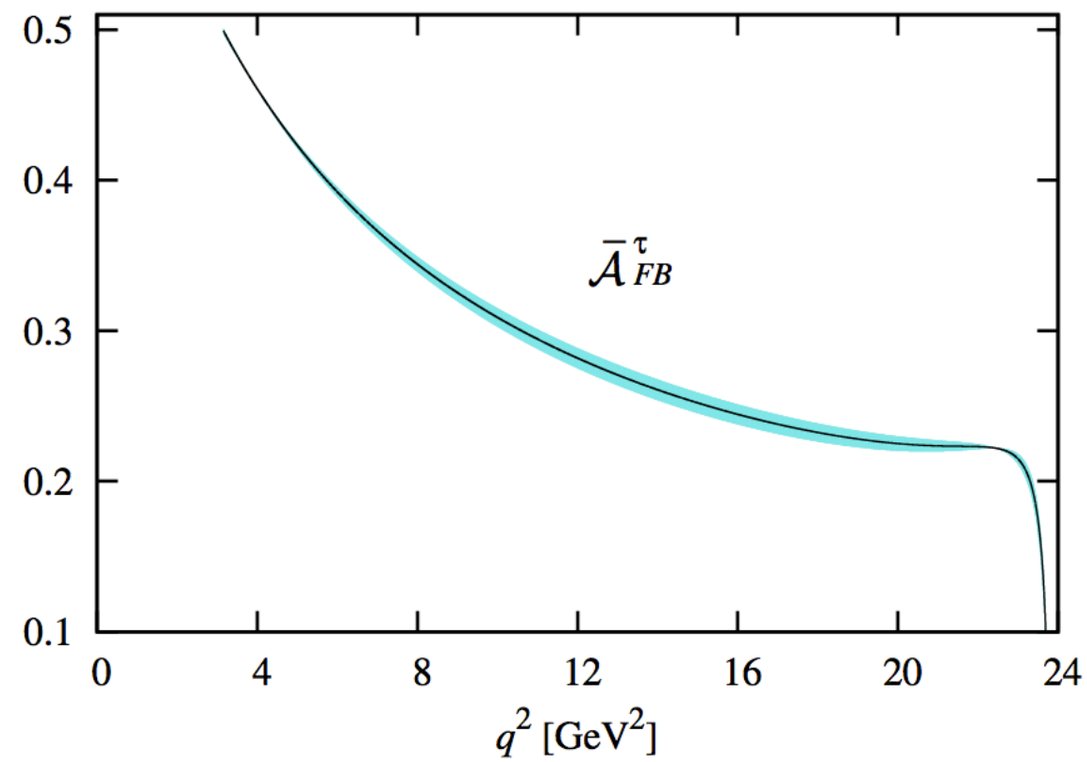
- $R_\mu\tau$ = Differential branching fraction ratio
- A_{FB} = Forward and backward asymmetry

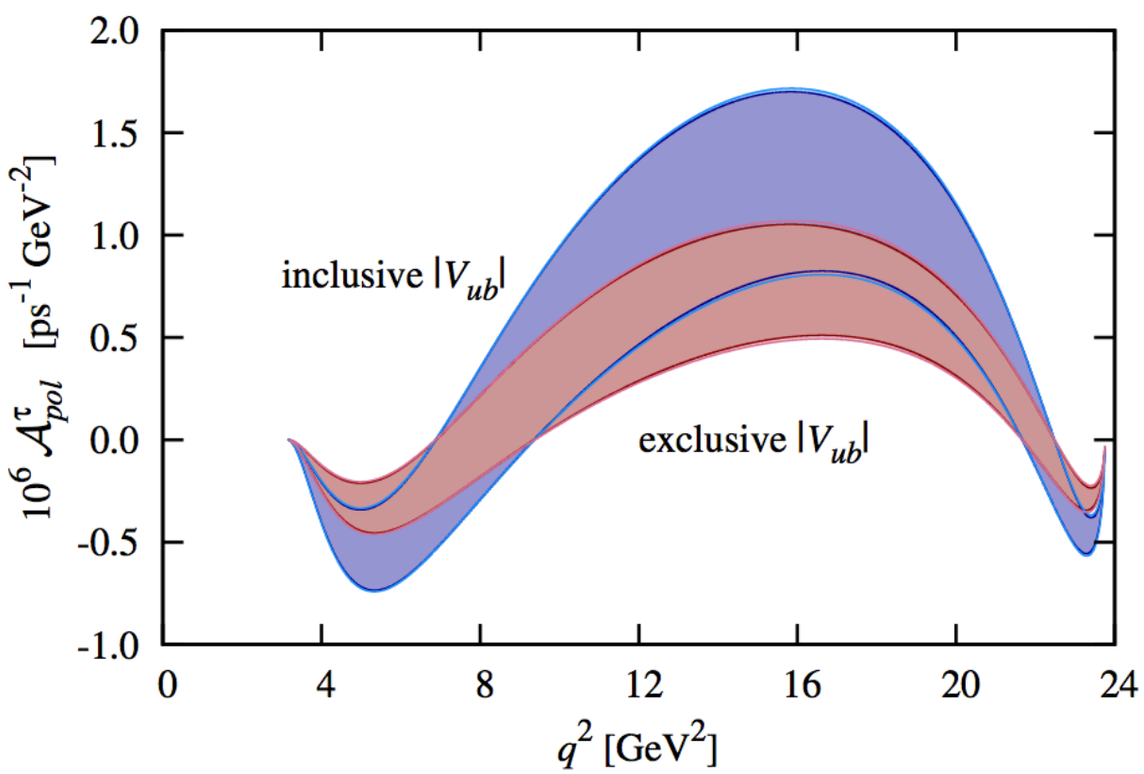




Other phenomenological quantities

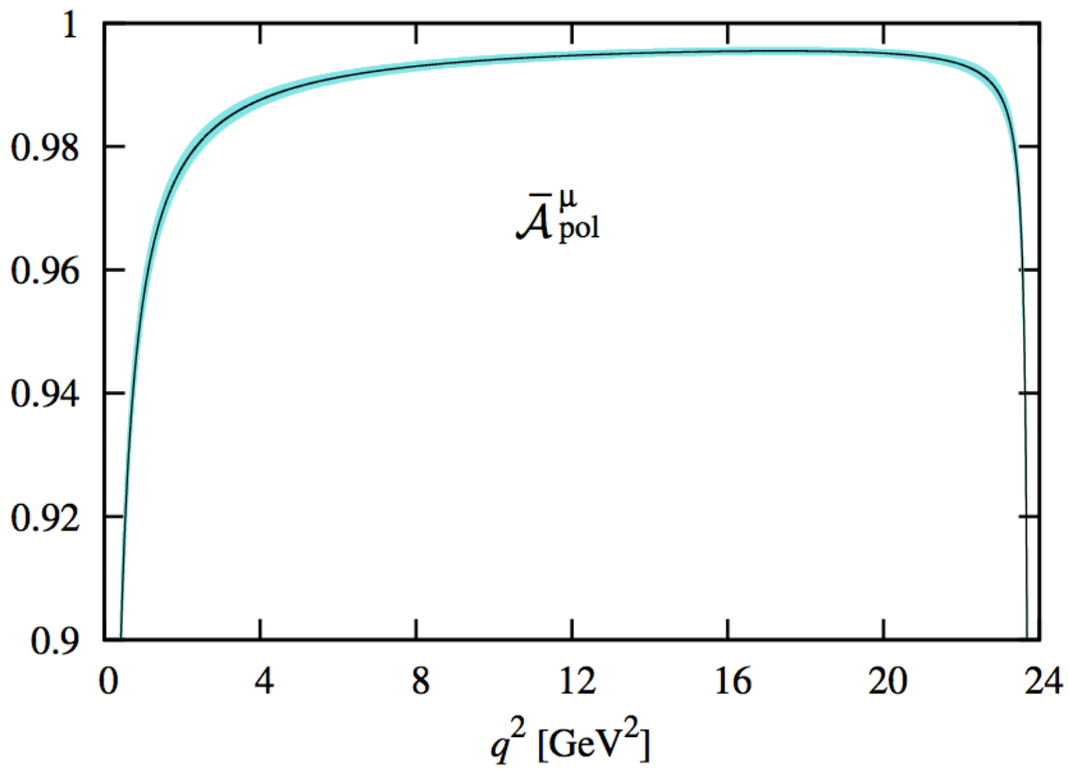


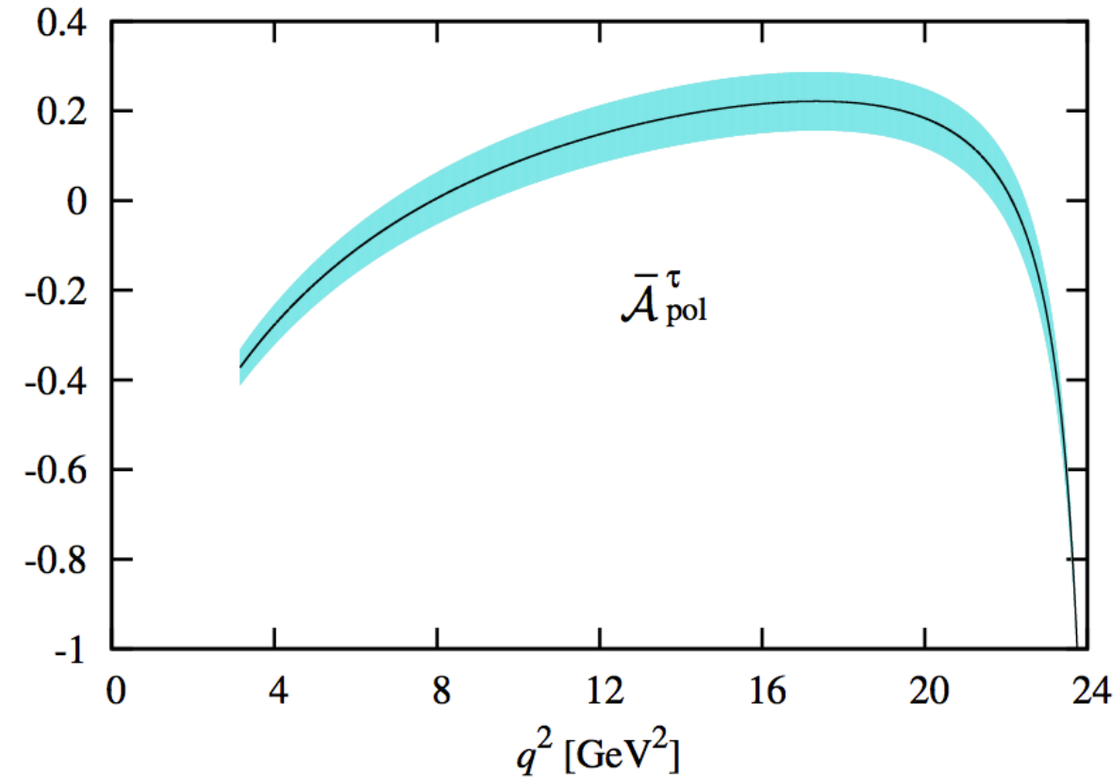




- $\bar{A}_{FB}$ = Normalized F-B asymmetry
- $A_{pol}\tau$ = τ polarization distribution

Other phenomenological quantities





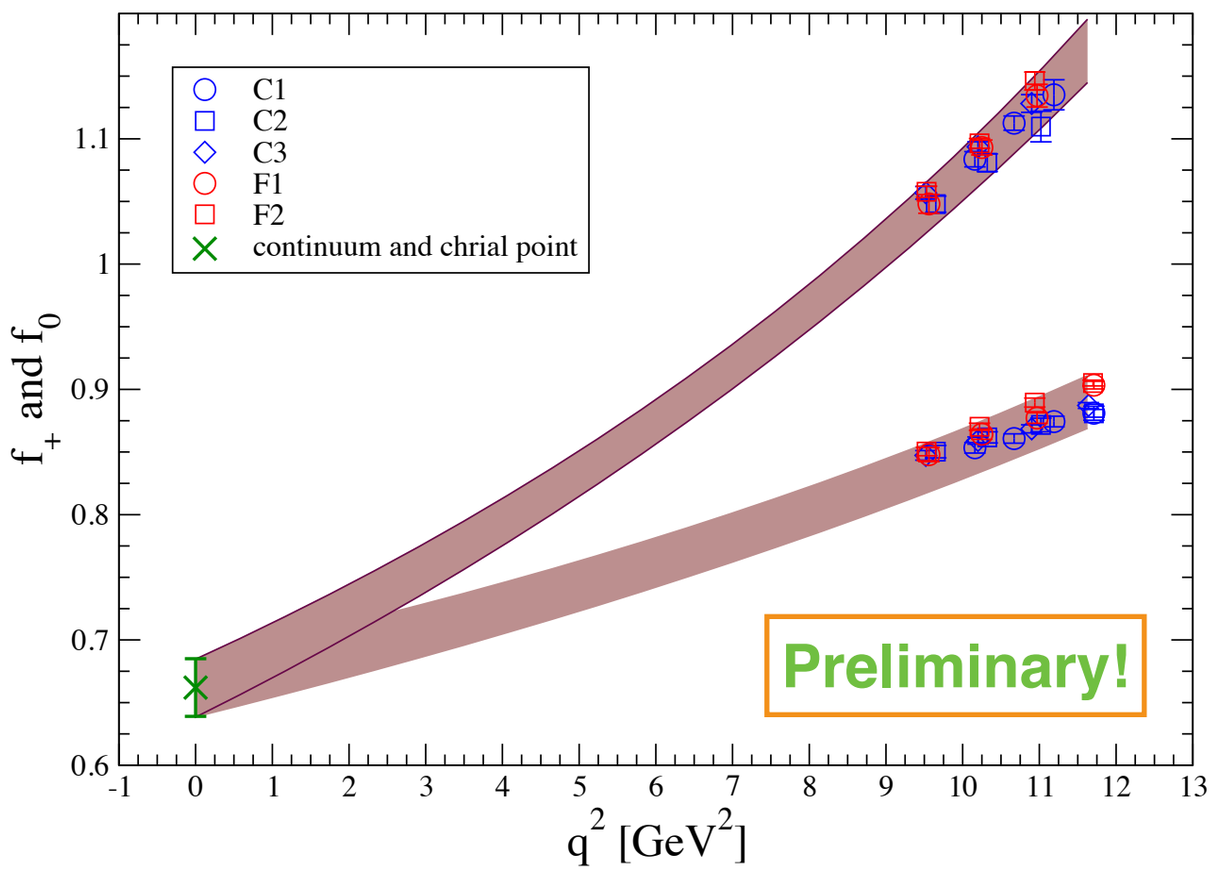
- $\bar{A}_{pol}\mu$= Normalized μ polarization distribution
- $\bar{A}_{pol}\tau$ = Normalized τ polarization distribution

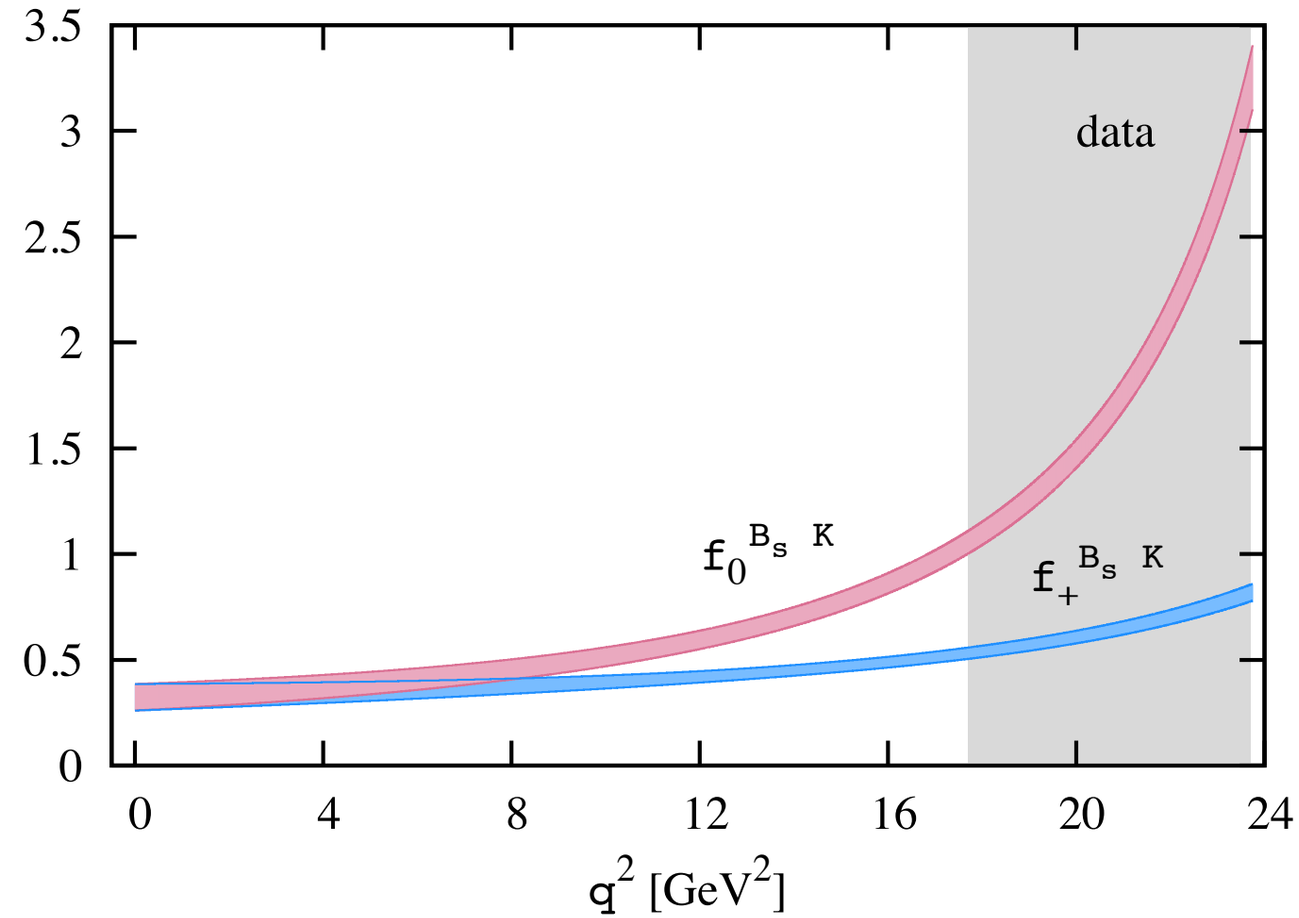
Summary and future plan

- Our semileptonic programs have been very successful.
- We presented preliminary results on $B \to Dlv$ and $B_s \to D_s lv$, and complete analysis results on $B_s \to Klv$
- $B \to Dlv$ and $B_s \to D_s lv$
  - HPChPT z-expansion
  - Correlations between $B \to D$ and $B_s \to D_s$ form factors
    - Ratio of the form factors $\to Br(B_s \to \mu^+\mu^-)$
- $B_s \to Klv$
  - Finished project: C. Bouchard et al., arXiv:1406.2279
  - Waiting experiment results from LHCb and BelleII
  - Precise non-perturbative renormalization for $B \to \pi lv$ with $B_s \to \eta_s lv$ with HISQ b quark

Backup

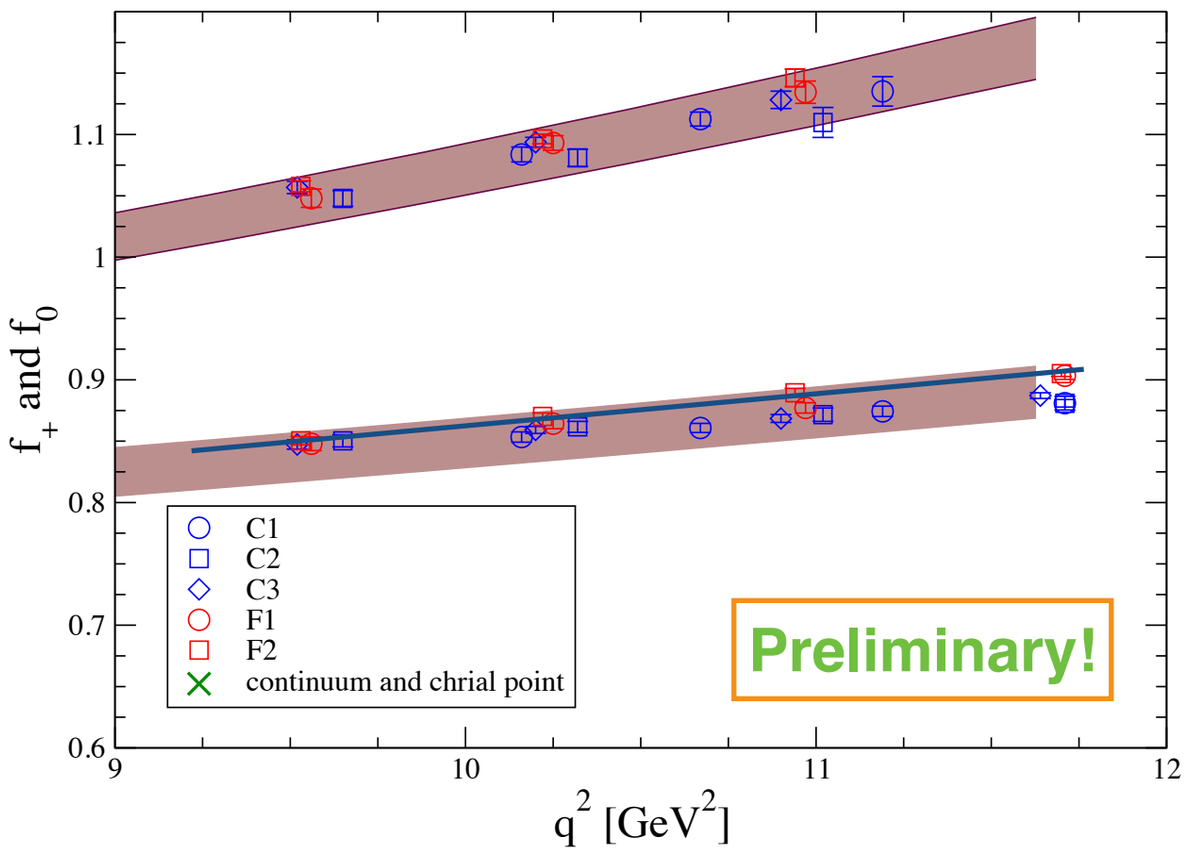
Pole for f_0

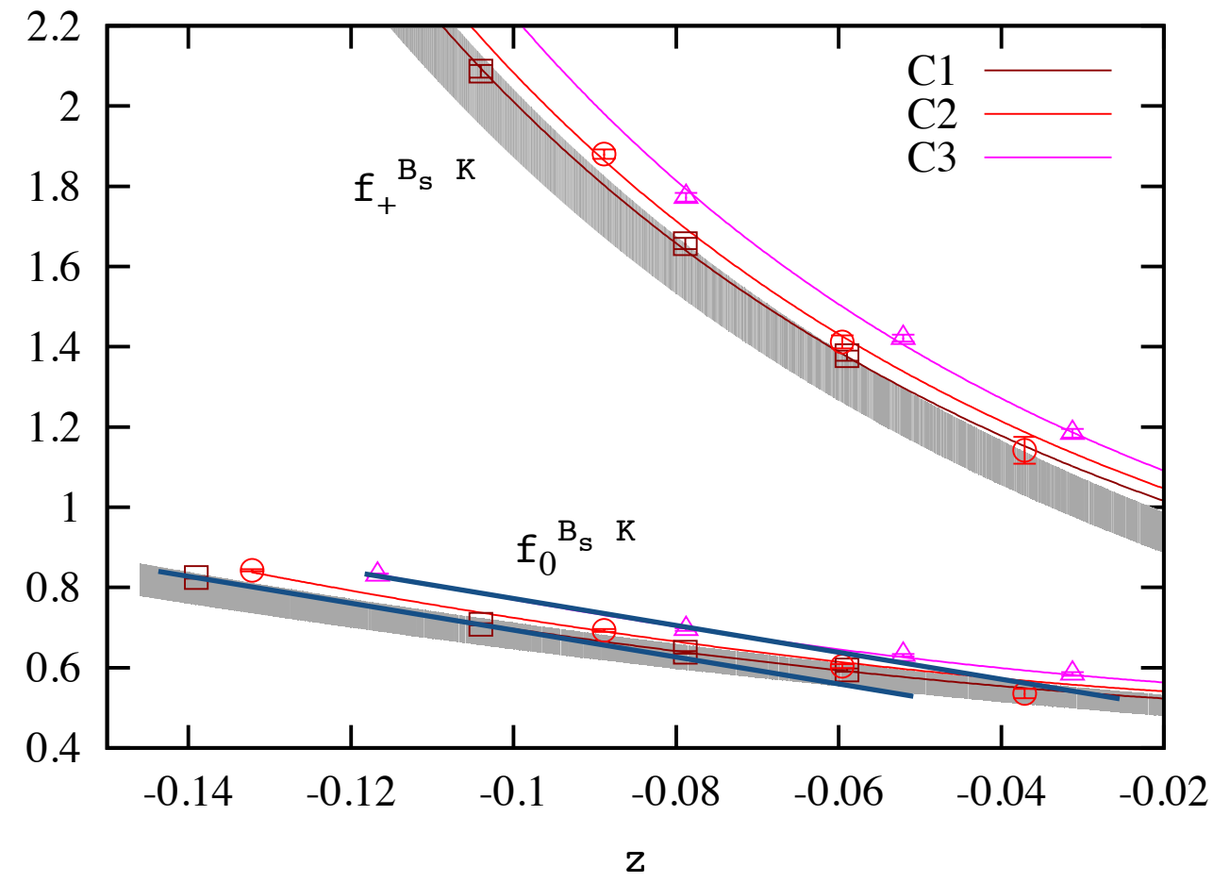




- $B_c^*(1-)$: 6.33 GeV → pole location: 40 GeV^2
- $B^*(1-)$: 5.325 GeV → pole location: 28.4 GeV^2

Pole for f_0





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