Semileptonic D-decays with twisted mass QCD

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Summary

Introduction

- Semileptonic form factors, phenomenology and significance
- Our setup

Analysis

- Determination of matrix elements
- Form factor extraction
- Chiral and continuum extrapolation

Discussion of **PRELIMINARY** results

- Comparison of $f_+^{D\to K}$ with experimental results
- Comparison of $f_+^{D\to\pi}$ with exp. and Vector Meson Dominance
- Discussion of f_T/f_+

D meson semileptonic decays

$D \to \pi, K\ell\nu$ semileptonic decays

In D rest frame and for massless lepton $\left[q^2 = (p_\ell + p_\nu)^2\right]$

$$\frac{d\Gamma(D\to\pi(\vec{p})\ell\nu)}{dq^2} = \frac{G_F^2|V_{cd}|^2}{24\pi^3}|\vec{p}|^3\left|f_+^{D\to\pi}(q^2)\right|^2$$

$$\frac{d\Gamma(D\to K(\vec{p})\ell\nu)}{dq^2} = \frac{G_F^2|V_{cs}|^2}{24\pi^3}|\vec{p}|^3\left|f_+^{D\to K}(q^2)\right|^2$$

- Scalar form factor f_0 suppressed by lepton mass in Standard Model, sensitive to charged higgs in SM extension
- Tensorial form factor f_T appears in SM extension (leptoquark, new vector boson with tensorial couplings...)

Relevance of the three form factors

- Determining f_+ from measured $d\Gamma/dq^2$ provide V_{cd} and V_{cs}
- Bounds on SM extension from the knowledge of f_+, f_0 and f_T

Lattice determination of semileptonic form factors

Matrix elements in D rest frame

$$\langle K(p)|\, V_\mu \,|D\rangle = p_\mu f_+^{D\to K}\left(q^2\right) + q_\mu \frac{m_D^2 - m_K^2}{q^2}\left[f_0^{D\to K}\left(q^2\right) - f_+^{D\to K}\left(q^2\right)\right]$$

$$\langle K(p)|\, S \,|D\rangle = \frac{m_D^2 - m_K^2}{m_c - m_s} f_0^{D\to K}\left(q^2\right)$$

$$\langle K(p)|\, T_i\left(\mu\right) |D\rangle = \frac{2 m_D p_i}{m_K + m_D} f_T^{D\to K}\left(q^2\right)$$

and very similarly for the case of $D \to \pi$

Obtaining form factors from matrix elements

After determining matrix elements, form factors are extracted solving kinematical relations

Our setup

Lattice gauge configurations

Regularization: $N_f = 2$ twisted mass QCD

Continuum: 4 different lattice spacings ($a \in [0.054; 0.100]$ fm)

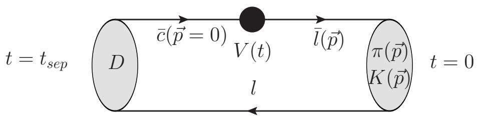
Chiral limit: $M_\pi \in [280; 500]$ MeV

Momentum: Using twisted boundary conditions

Renormalization: Non perturbative (RI-MOM)

QCD gauge field configurations produced by the ETM collaboration

Kinematical setup



Matrix element extraction: method

Basic ingredients

$$C_2^{\pi}(t) = \left\langle O_{\pi}^{\dagger}(t)\, O_{\pi}(0) \right\rangle, \quad O_{\pi} = \bar{\mathbf{l}}\gamma_5 \mathbf{l}, \quad \mathbf{l} = H_{sm} l$$

$$C_2^{D}(t) = \left\langle O_{D}^{\dagger}(t)\, O_{D}(0) \right\rangle, \quad O_{D} = \bar{\mathbf{c}}\gamma_5 \mathbf{l}, \quad \mathbf{c} = H_{sm} c$$

$$C_3^{D\pi}(t) = \left\langle O_{D}^{\dagger}(t_{sink})\, J_{\Gamma}(t) O_{\pi}^{\vec{p}}(0) \right\rangle, \quad J_{\Gamma} = \bar{c}\Gamma l, \quad O_{\pi}^{\vec{p}} = \bar{\mathbf{l}}\gamma_5 \mathbf{l} e^{i\vec{p}\vec{x}}$$

Mass and Z determination as usual...

$$C_2^{\pi,D}(t) \xrightarrow{t \gg 0} G_{\pi,D}^2 e^{-M_{\pi,D} t} / M_{\pi,D}$$

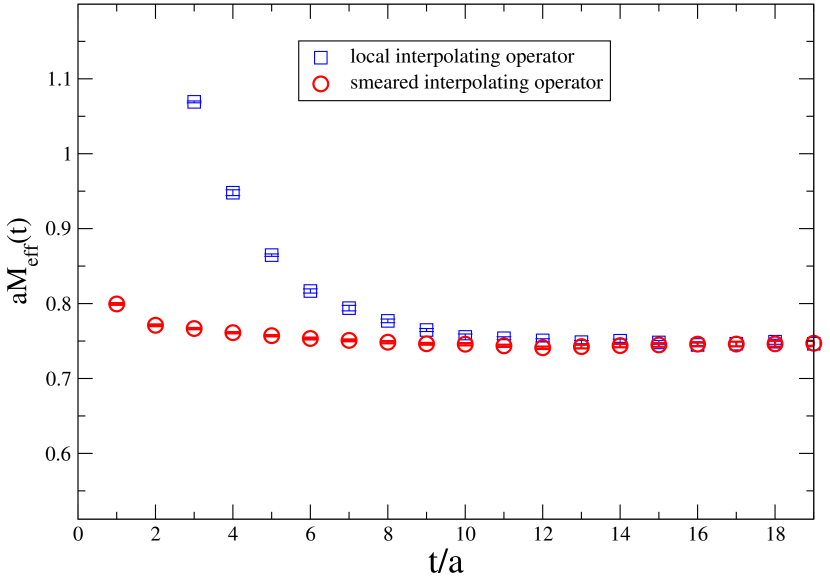
Analytic ratio to extract matrix element

$$R(t) = \frac{C_3^{D\pi}(t)}{d(t)}, \quad d(t) = \frac{G_{\pi} G_D}{4 E_{\pi} M_D} e^{-E_{\pi} t - M_D (T-t)}, \quad E_{\pi} = \sqrt{M_{\pi}^2 + \vec{p}^2}$$

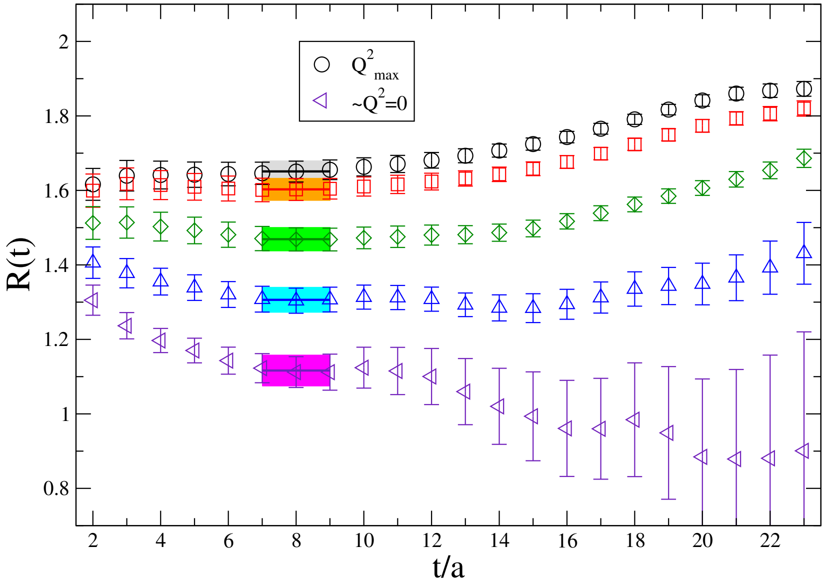
$$R(t) \xrightarrow{0 \ll t \ll t_{sep}} \langle \pi | J_{\Gamma} | D \rangle$$

Needed renormalization constants Z_V, Z_T^{μ} computed in RI-MOM scheme

Correlator smearing: D meson effective mass



Matrix element extraction: example of $\langle \pi | V_0 | D \rangle$



Chiral and continuum extrapolation

Method 1 (M1): extrapolation at fixed momentum transfer

- fix a value for the momentum transfer q^2
- consider form factor for various lattice spacings a and pion masses M_π
- take combined chiral and continuum limit

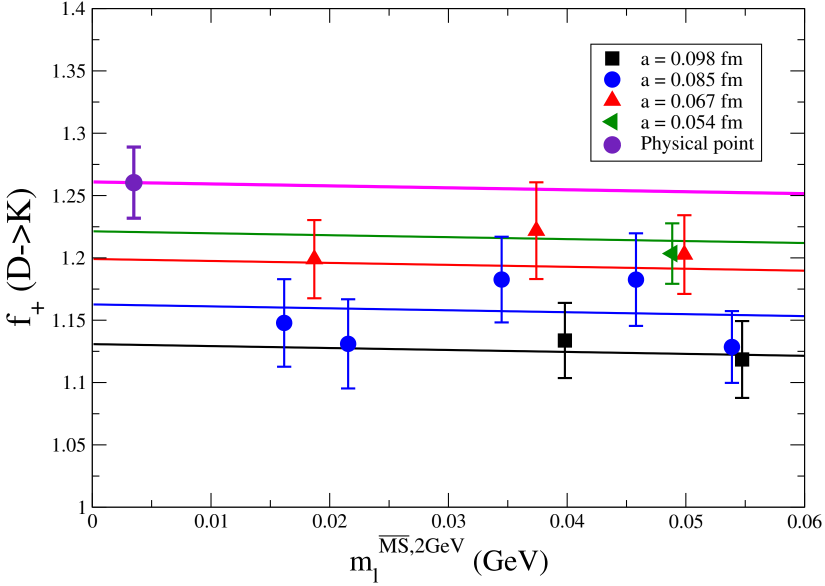
Method 2 (M2): extrapolation of z parameterization coefficients

- remove dominant pole from form factor: $\psi\left(q^2\right) \equiv f\left(q^2\right) \cdot \left(1 - \frac{q^2}{M_V^2}\right)$
- consider ψ as function of $z = \frac{\sqrt{t_+^2 - q^2} - \sqrt{t_+}}{\sqrt{t_+^2 - q^2} + \sqrt{t_+}}, \quad t_+ = M_D + M_K$
- for fixed a and M_π, fit $\psi\left(z\right)$ as a n-degree polynomial in z:

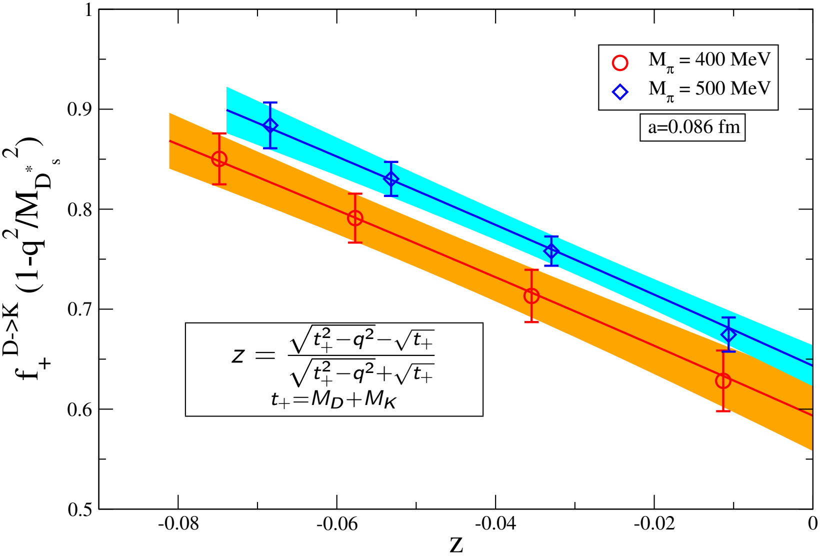
$$\psi\left(z\right) = c_0 + c_1 z + \ldots c_n z^n$$

- take combined chiral and continuum limit of the coefficients c_i
- reconstruct the physical $f(q^2)$ from c_i coefficients

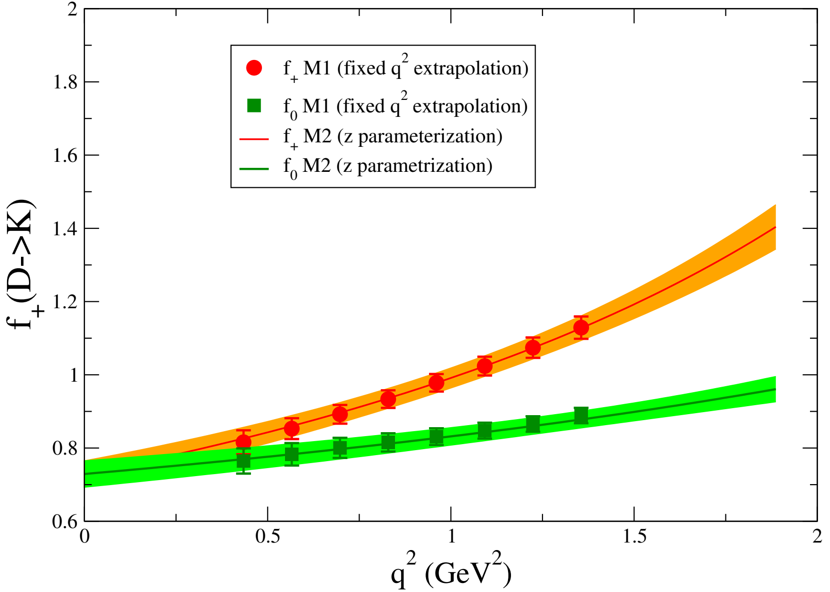
M1: extrapolation at fixed q^2 (ex: $\sim 1.35\,\mathrm{GeV}^2$)



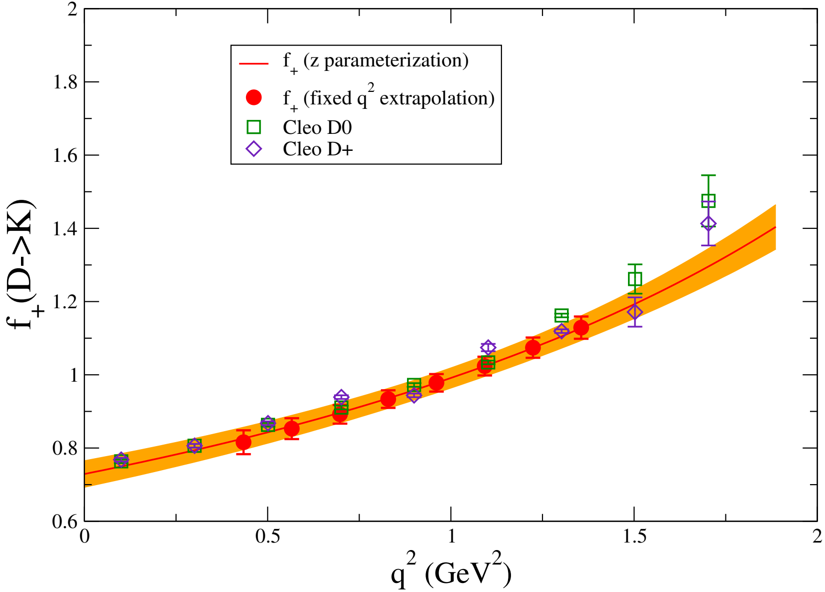
M2: Z parametrization



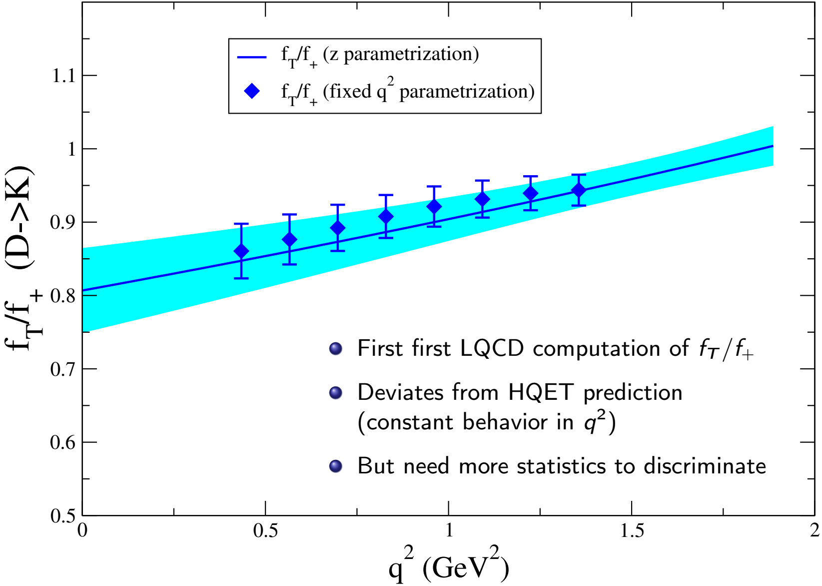
$D \to K$ vector and scalar form factors



Comparison with experimental data



$D \to K$ tensorial over vectorial form factors ratio



- First first LQCD computation of f_T/f_+
- Deviates from HQET prediction (constant behavior in q^2)
- But need more statistics to discriminate

Comparison of $f_+^{D\to\pi}$ with Vector Meson Dominance model

Vector meson dominance model

$$f_+^{VMD}(q^2) = \frac{\mathrm{Res}_{D^*} f_+(q^2)}{m_{D^*}^2 - q^2}, \quad \text{with} \quad \mathrm{Res}_{D^*} f_+(q^2) = \frac{1}{2} m_{D^*} f_{D^*} g_{D^* D\pi}$$

Correction to the model: other poles comings from heavier resonances

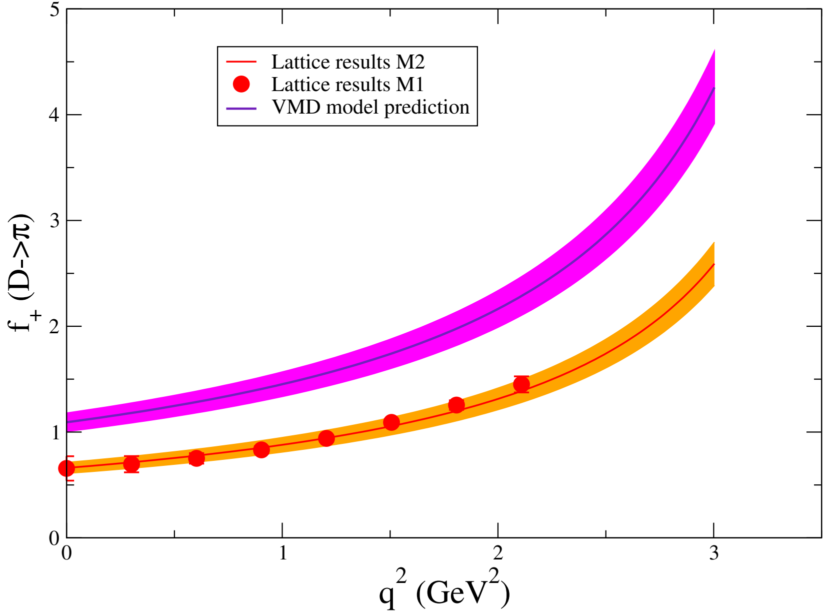
Ingredient of the model

According to our previous studies on the same lattice ensembles:

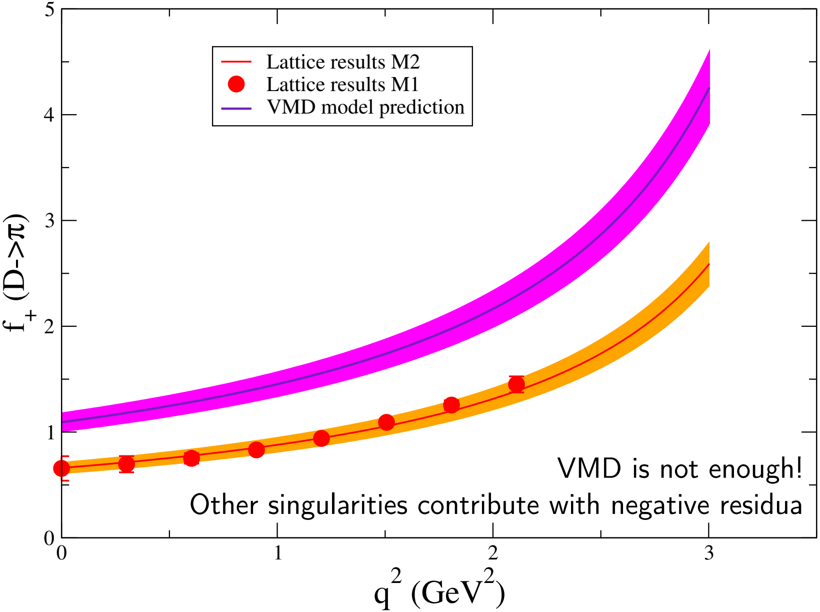
- $f_{D^*} = 278(16)\text{MeV}$ [JHEP 1202 (2012) 042, arXiv:1201.4039]
- $g_{D^* D\pi} = 15.8(8)$ [Phys.Lett. B721 (2013) 94, arXiv:1210.5410]

We can make a self-contained comparison of the model

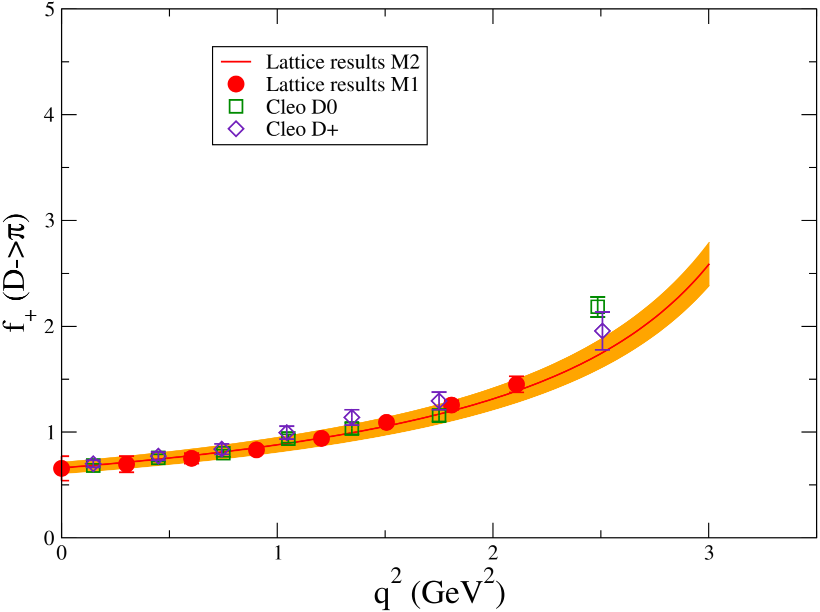
Comparison of $f_+^{D\to\pi}$ with Vector Meson Dominance model



Comparison of $f_+^{D\to\pi}$ with Vector Meson Dominance model



Comparison of $f_+^{D\to\pi}$ with experimental data



Conclusions and perspectives

Comparison of form factor

- Good agreement between $f_+^{D\to K}$, $f_+^{D\to\pi}$ calculation with experiments
- VMD model predicts higher than experimental form factor
- f_T/f_+ deviates from HQET prediction

PRELIMINARY results

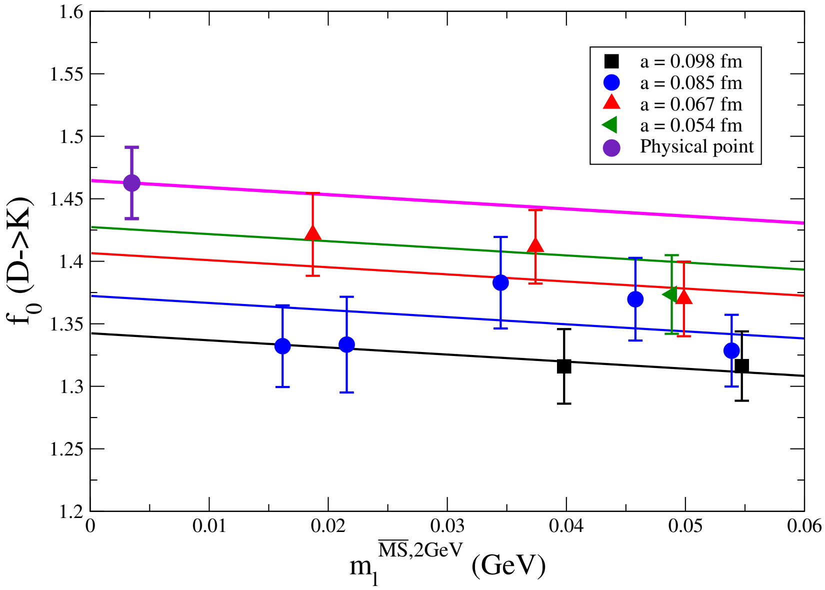
$f_+^{D\to\pi}(0) = 0.66(6)$
$f_+^{D\to K}(0) = 0.71(5)$

$f_T^{D\to\pi}(0)/f_+^{D\to\pi}(0) = 0.81(8)$
$f_T^{D\to K}(0)/f_+^{D\to K}(0) = 0.73(8)$

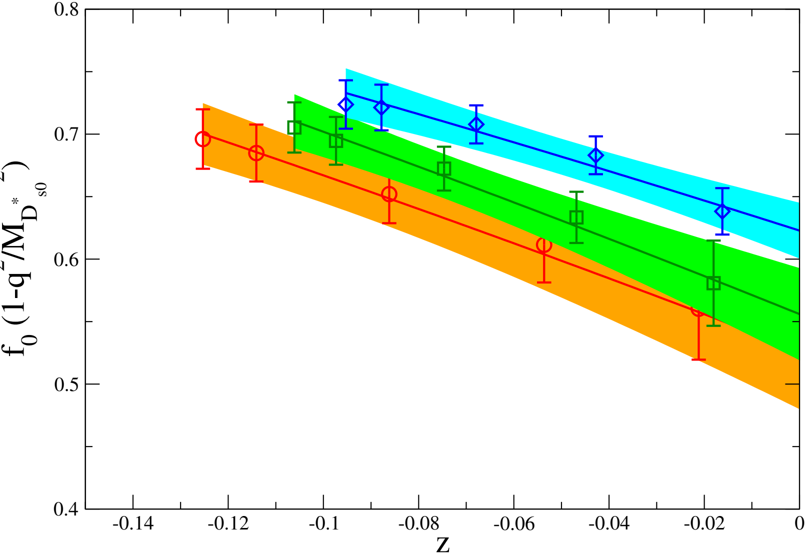
Future development

- Increase the statistic
- Apply ratio method to extrapolate to b quark

Secret Backup Slides



a = 0.098 fm
a = 0.085 fm
a = 0.067 fm
a = 0.054 fm
Physical point
f_0 (D->K)
$m_l^{\overline{MS},2GeV}$ (GeV)
1.2
1.25
1.3
1.35
1.4
1.45
1.5
1.55
1.6
0
0.01
0.02
0.03
0.04
0.05
0.06



$f_0\,(1-q^2/M_{D^*_{s0}}^2)$
0.8
0.7
0.6
0.5
0.4
-0.14
-0.12
-0.1
-0.08
-0.06
-0.04
-0.02
0
z