Scalar and vector form factors of $D \to \pi \ell \nu$ and $D \to K \ell \nu$ decays with $N_f = 2+1+1$ Twisted fermions

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Overview

- Simulation details
- General strategy
- Results
- Calculation of CKM matrix elements V_{cd} and V_{cs}

Simulation details

- Twisted mass sea fermions at maximal twist
- Osterwalder-Seiler valence fermions
- Iwasaki gluonic action
- Twisted boundary conditions to simulate momenta

Simulation details

ensemble	β	V/a^4	$a\mu_{sea} = a\mu_\ell$	$a\mu_\sigma$	$a\mu_\delta$	N_{cfg}	$a\mu_s$	$a\mu_c$
$A30.32$	1.90	$32^3 \times 64$	0.0030	0.15	0.19	150	0.0180,	0.21256, 0.25000,
$A40.32$			0.0040			90	0.0220,	0.29404, 0.34583
$A50.32$			0.0050			150	0.0260	
$A40.24$	1.90	$24^3 \times 48$	0.0040	0.15	0.19	150		
$A60.24$			0.0060			150		
$A80.24$			0.0080			150		
$A100.24$			0.0100			150		
$B25.32$	1.95	$32^3 \times 64$	0.0025	0.135	0.170	150	0.0155,	0.18705, 0.22000,
$B35.32$			0.0035			150	0.0190,	0.25875, 0.30433
$B55.32$			0.0055			150	0.0225	
$B75.32$			0.0075			75		
$B85.24$	1.95	$24^3 \times 48$	0.0085	0.135	0.170	150		
$D15.48$	2.10	$48^3 \times 96$	0.0015	0.12	0.1385	60	0.0123,	0.14454, 0.17000,
$D20.48$			0.0020			90	0.0150,	0.19995, 0.23517
$D30.48$			0.0030			90	0.0177	

Pion masses as low as 210 MeV

ensemble	β	L(fm)	M_π(MeV)	$M_\pi L$
$A30.32$	1.90	2.84	245	3.53
$A40.32$			282	4.06
$A50.32$			314	4.53
$A40.24$	1.90	2.13	282	3.05
$A60.24$			344	3.71
$A80.24$			396	4.27
$A100.24$			443	4.78
$B25.32$	1.95	2.61	239	3.16
$B35.32$			281	3.72
$B55.32$			350	4.64
$B75.32$			408	5.41
$B85.24$	1.95	1.96	435	4.32
$D15.48$	2.10	2.97	211	3.19
$D20.48$			243	3.66
$D30.48$			296	4.46

Lattice spacing as low as 0.0619 fm

$$a|_{\beta=1.90,\ 1.95,\ 2.10} = \{0.0885(36),\ 0.0815(30),\ 0.0619(18)\}\text{fm}\ .$$

Several values of momenta for both mesons involved in the decay, ranging from 0 to 650 MeV → Several values of 4-momentum transfer

General Strategy

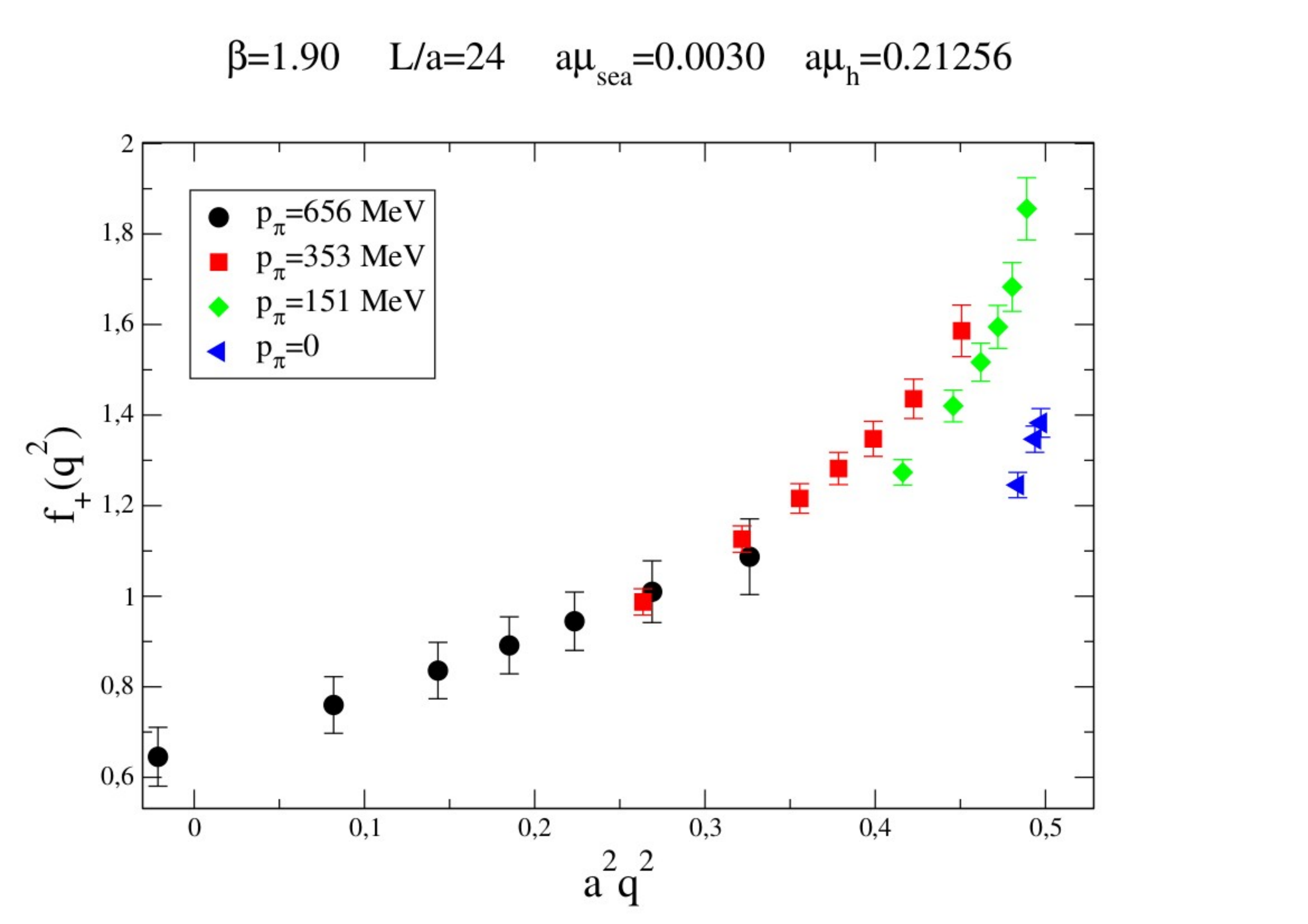
- Extract $\langle \pi | V_\mu | D \rangle$ and $\langle K | V_\mu | D \rangle$ from the corresponding smeared three-point correlation functions in order to calculate $f_0(q^2)$ and $f_+(q^2)$, where $q_\mu = (E_D - E_\pi, \vec{q})$

- Data selection

- Simultaneous fit of the form factors dependences on the light quark mass, lattice spacing and 4-momentum transfer

- extrapolation to the physical point

4-momentum transfer dependence



Lorentz invariance breaking effect

Can be induced by any hypercubic invariant discretization effect that breaks Lorentz invariance, like

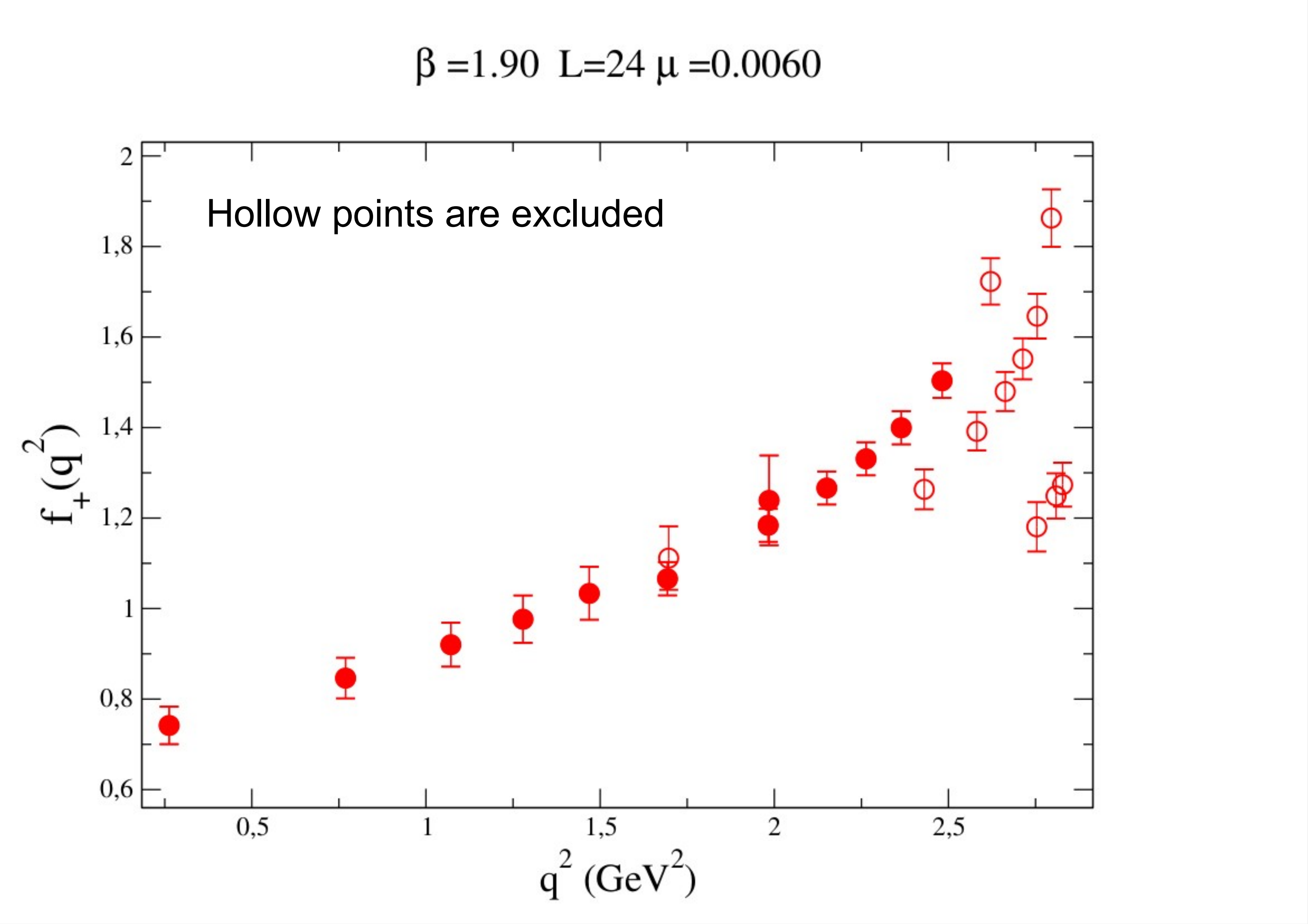
$$\frac{a^4 \tilde{q}_E^4}{a^2 q_E^2} \quad \text{or} \quad a^2 q_E^2$$

$$q_E^2 = \sum_{i=1}^{4} q_i^2 \qquad \tilde{q}_E^4 = \sum_{i=1}^{4} q_i^4$$

We noticed that the quantity $\frac{a^4 \tilde{q}_E^4}{a^2 q_E^2}$ can be very big

We applied a cut $$\frac{1}{a^2} \frac{a^4 \tilde{q}_E^4}{a^2 q_E^2} < 2.5 \mathrm{GeV}^2$$

Example of data selection



Global fit

Fit ansatz (for both the decays studied)

$$f_+(q^2) = \frac{f_+(0)}{(1 - q^2/M_V^2)}(1 + Aq^2)(1 + Bm_l + Ca^2)$$

$$f_0(q^2) = \frac{f_+(0)}{(1 - q^2/M_S^2)}(1 + Bq^2)(1 + Bm_l + Ca^2)$$

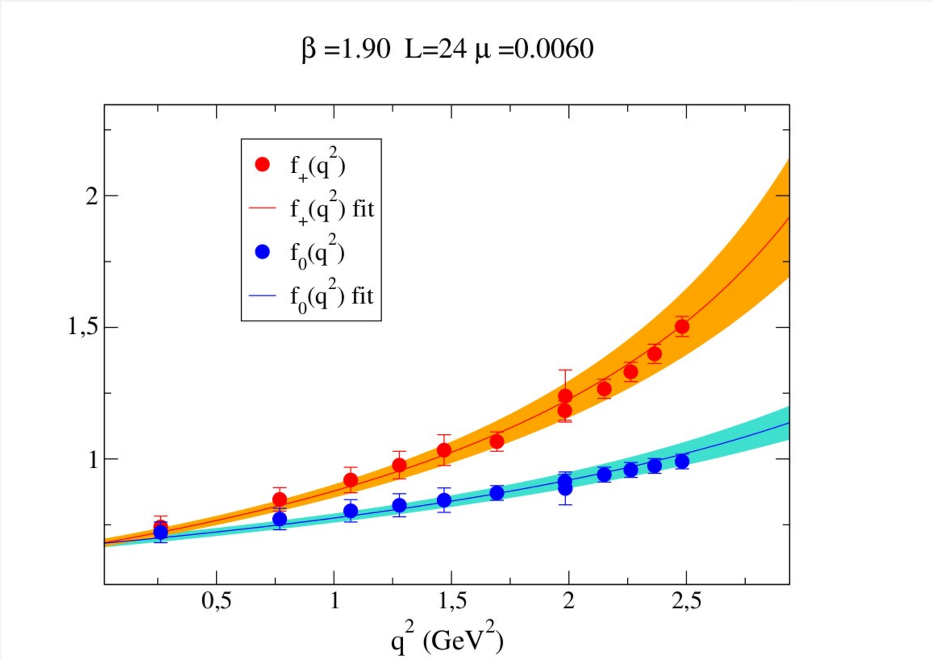
$$M_V = M_{PS} + \Delta_{PS,V}$$

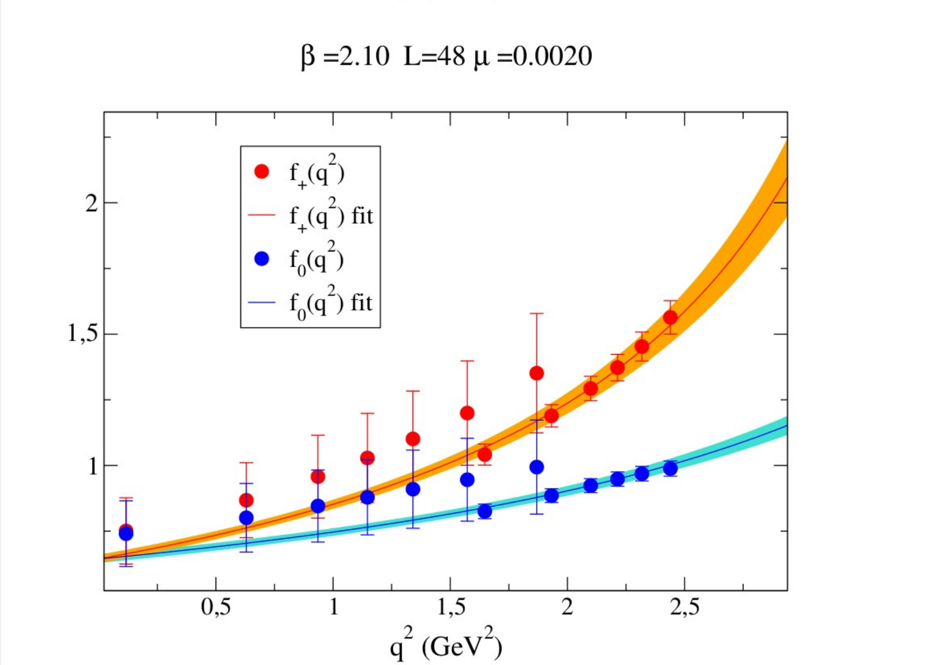
$$M_S = M_{PS} + \Delta_{PS,S}$$

M_{PS} is calculated on the lattice

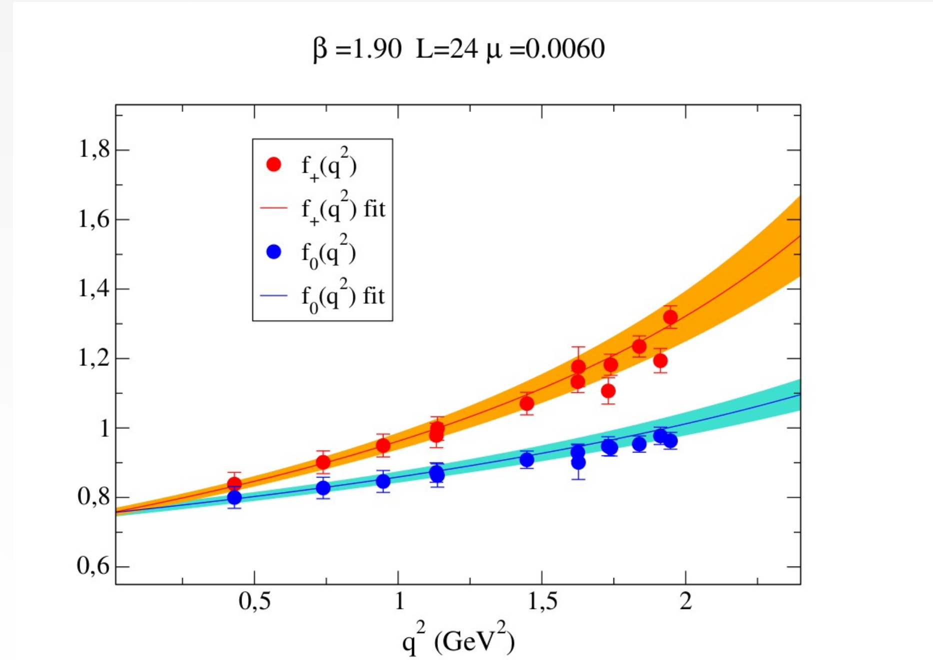
$\Delta_{PS,V}$ and $\Delta_{PS,S}$ are taken from the PDG

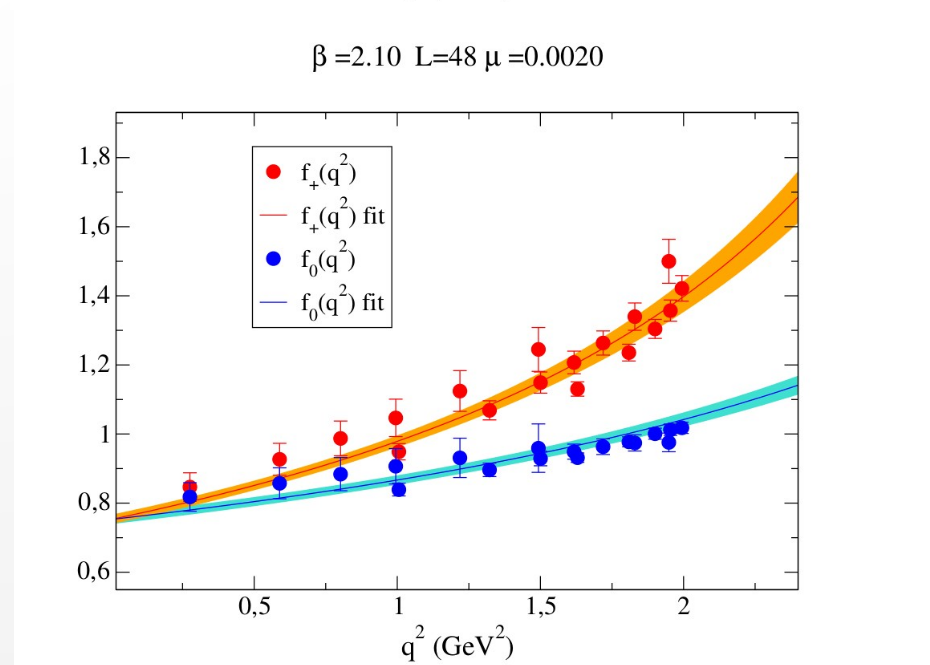
$D \to \pi$


β =1.90 L=24 μ =0.0060
f+(q2)
f+(q2) fit
f0(q2)
f0(q2) fit
q2 (GeV2)

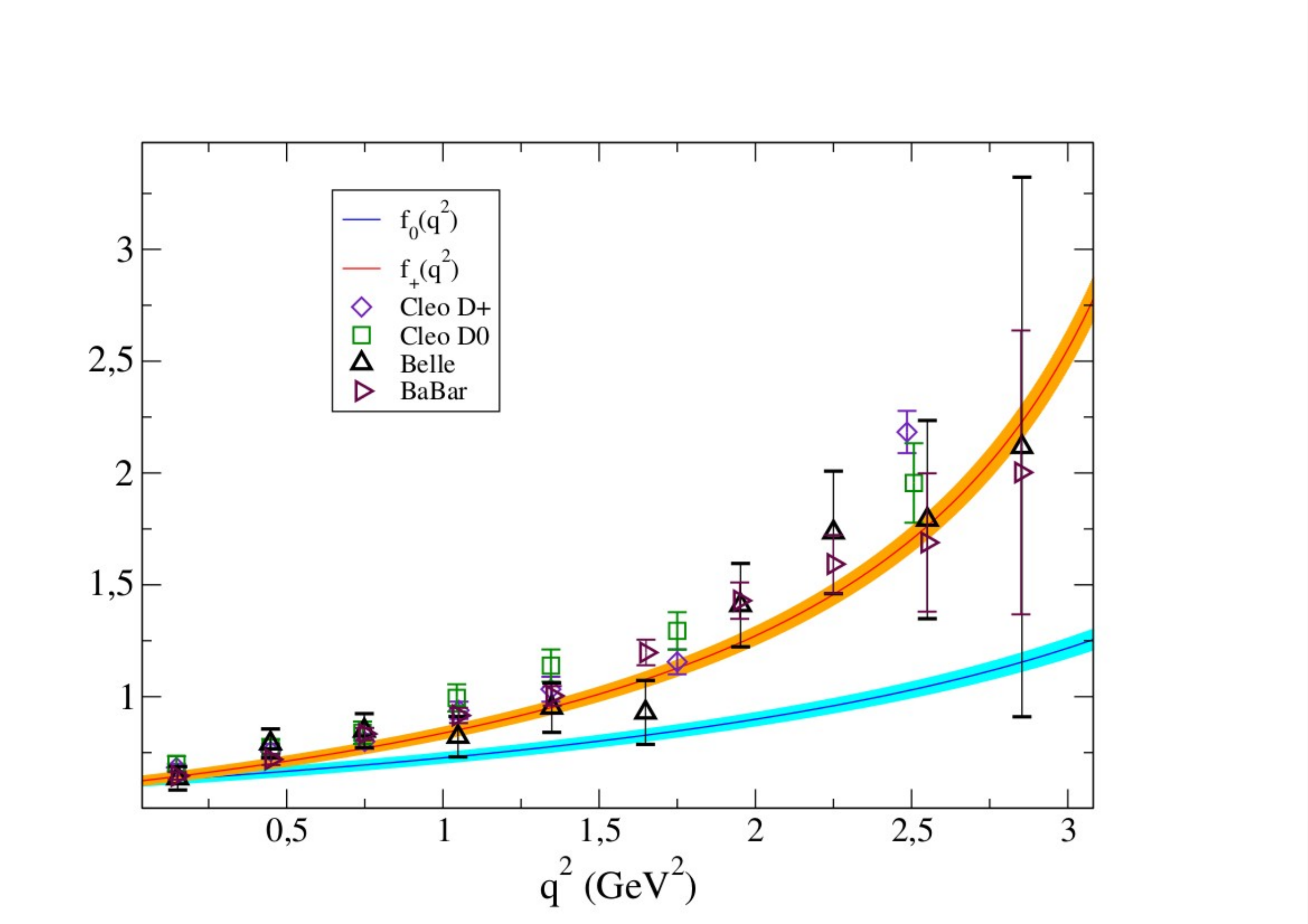

β =2.10 L=48 μ =0.0020
f+(q2)
f+(q2) fit
f0(q2)
f0(q2) fit
q2 (GeV2)

$D \to K$


β =1.90 L=24 μ =0.0060
f+(q2)
f+(q2) fit
f0(q2)
f0(q2) fit
q2 (GeV2)


β =2.10 L=48 μ =0.0020
f+(q2)
f+(q2) fit
f0(q2)
f0(q2) fit
q2 (GeV2)

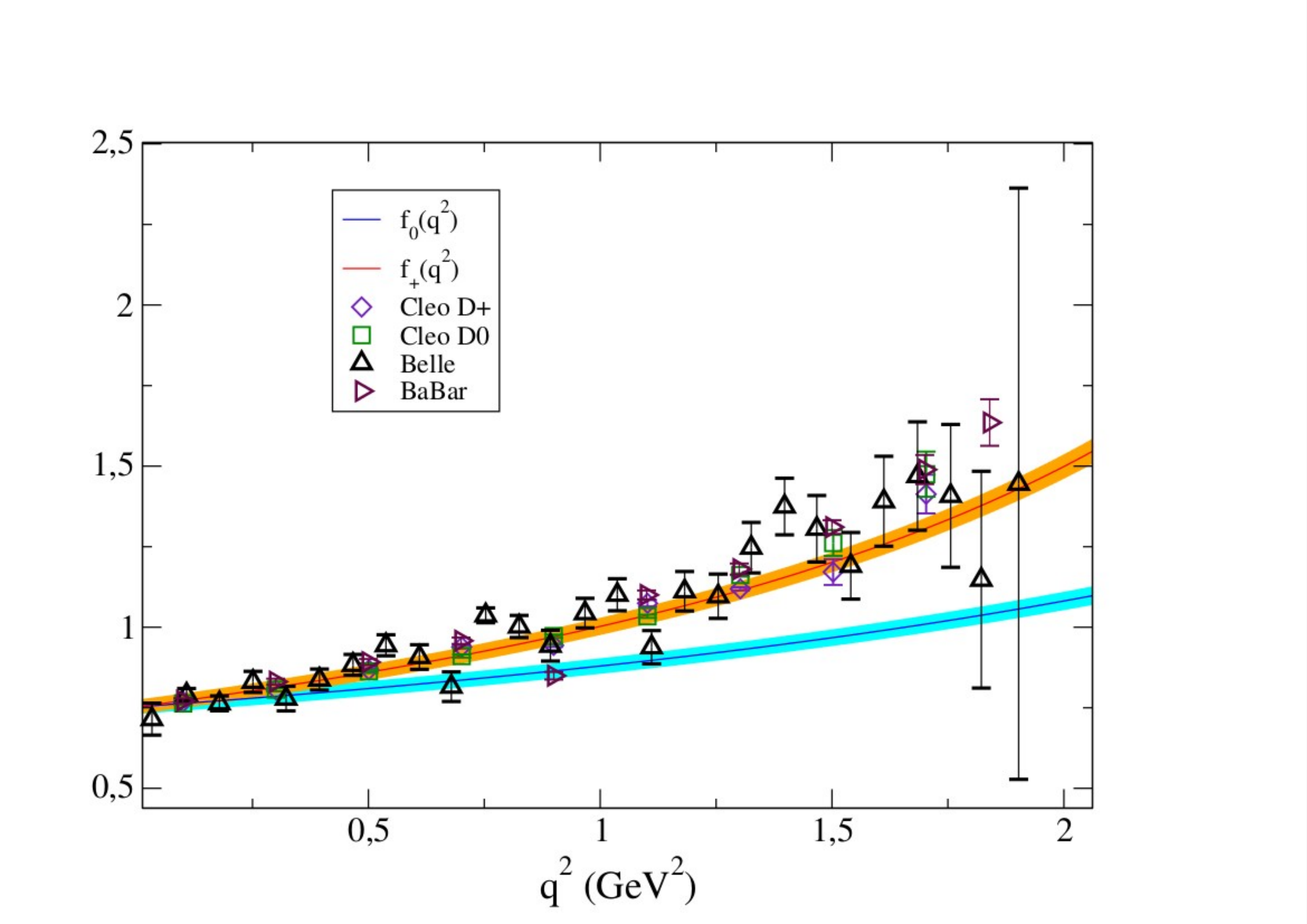
Global fit result for $D \to \pi$



$$f_+(0) = 0.610(23)$$

The uncertainty is only statistical!

Global fit result for $D \to K$



$f_+(0) = 0.747(22)$

The uncertainty is only statistical!

$D \to \pi$ $D \to K$

From the experimental value of

$f_+(0)|V_{cd}|$ $f_+(0)|V_{cs}|$

We obtain

$|V_{cd}| = 0.2336(93)$ $|V_{cs}| = 0.975(29)$

$$|V_{cd}|^2 + |V_{cs}|^2 + \cancel{|V_{cb}|^2} = 1.004(31)$$

We previously found the CKM matrix elements from the decay constants*
and obtained

$|V_{cd}| = 0.2221(67)$ $|V_{cs}| = 1.014(27)$

$$|V_{cd}|^2 + |V_{cs}|^2 + \cancel{|V_{cb}|^2} = 1.08(5)$$

*N. Carrasco *et al* **Phys. Rev. D 91, 054507 (2015)**

Comparison with other results

	$f_+(0)^{D\to\pi}$	V_{cd}	$f_+(0)^{D\to K}$	V_{cs}
This work	0.610(23)	$0.2336(88)_{latt}(31)_{exp}$	0.747(22)	$0.975(29)_{latt}(7)_{exp}$
ETMC 2015 decay constants*		0.2221(67)		1.014(27)
FLAG $N_f = 2+1$	0.666(29)	$0.2192(95)_{latt}(45)_{exp}$	0.747(19)	$0.9746(248)_{latt}(67)_{exp}$

*N. Carrasco *et al* **Phys. Rev. D 91, 054507 (2015)**

Still much to do...

- Further investigation of the Lorentz invariance breaking effect
- Inclusion of three point scalar correlation functions to obtain f_0 with better precision
- Estimate of systematic effects, i.e. further studies of the chiral and continuum extrapolations as well as q^2 dependence of the form factors (e.g. **hard-pion ChPT** and **z-expansion**)

Thank you for the attention!