D and B Meson Semileptonic Decays from the Lattice

Lattice QCD Meets Experiment Workshop

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Fermilab

presented by :

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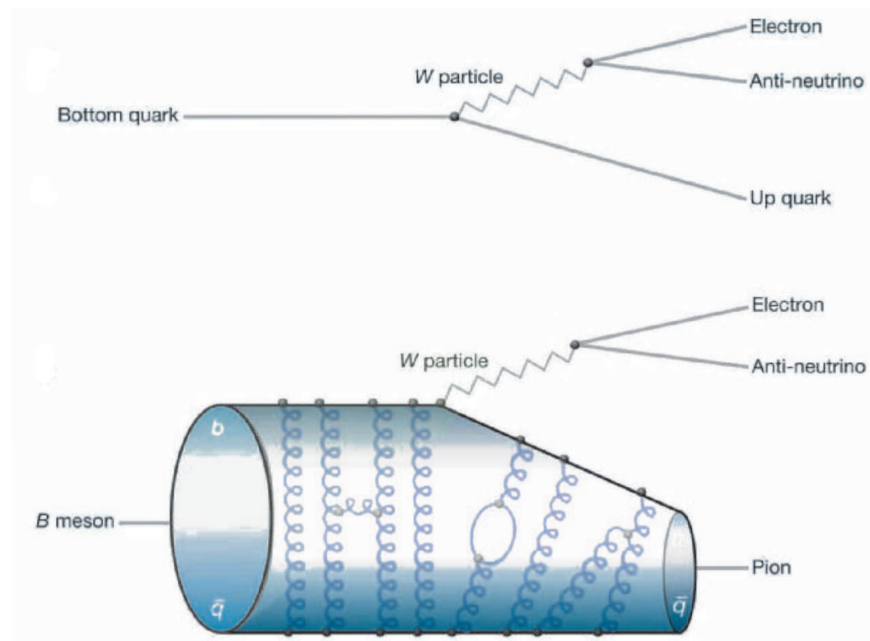
Meson **Semileptonic Decays** allow for direct determination of **CKM** matrix elements

$B \to D^*(D) l\nu \quad |V_{cb}|$
$B \to \pi l\nu \quad |V_{ub}|$
$D \to K l\nu \quad |V_{cs}|$
$D \to \pi l\nu \quad |V_{cd}|$
$D_s \to K^*(K) l\nu \quad |V_{cd}|$
$K \to \pi l\nu \quad |V_{us}|$



provided certain nonperturbative QCD inputs from theory (**form factors**) are available.

Where do we now stand ?

Summary for B mesons by Laiho-Lunghi-VandeWater (LLV)

$\boxed{|V_{ub}|_{excl} = (3.42 \pm 0.37) \times 10^{-3}}$ (11% errors)

(Fermilab/MILC + HPQCD , $B \to \pi$)

$\boxed{|V_{cb}|_{excl} = (38.6 \pm 1.2) \times 10^{-3}}$ (3% errors)

(Fermilab/MILC , $B \to D^*$ and $B \to D$)

CLEO-c publication arXiv:0906.2983 [hep-ex] using Fermilab/MILC 2004 form factors.

$\boxed{|V_{cs}| = 0.985 \pm 0.009 \pm 0.006 \pm 0.103}$ (1.1% + 10.4 %)

$\boxed{|V_{cd}| = 0.234 \pm 0.007 \pm 0.002 \pm 0.025}$ (3.1% + 10.7%)

pure lattice errors in red

For B decays, lattice errors are larger or about the same as experimental errors.

For D decays total error is now dominated by lattice uncertainties.

OUTLINE

- Brief Overview of Recent Published Results
- Current Work on D Semileptonic Decays
- Future Prospects. Lessons from D Decays for Future B Decay Studies
- Questions for Experimentalists
- Summary

B $\to$ D and B $\to$ D* Decays

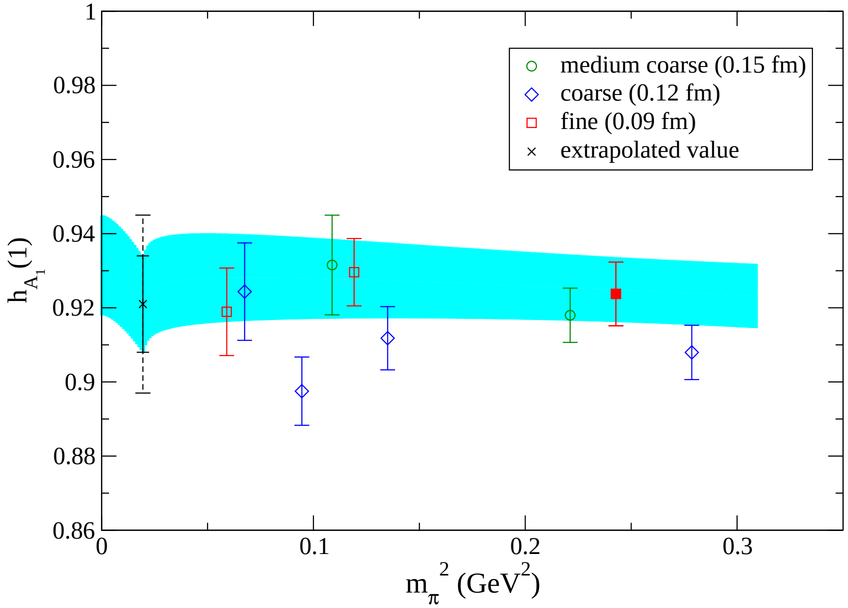
Masataka Okamoto et al. (Fermilab Lattice / MILC collaborations) 2004

Jack Laiho et al. (Fermilab Lattice / MILC collaborations) 2008

MILC AsqTad configurations ($N_f = 2 + 1$)
AsqTad (improv. stagg.) light quarks and Fermilab Heavy Clover b and c quarks.

In latest $B \to D^*$ paper, three lattices spacings and sophisticated chiral/continuum extrapolation of ratios.

Fermilab Lattice / MILC : $B \to D^*$



$$\boxed{\mathcal{F}(1) = 0.921(13)(20)}$$

Current Lattice error : 2.6 %

Goal for near future : 2.0 %

Chiral/Continuum Extrapolation

$\boxed{\text{B} \rightarrow \pi \text{ Decays}}$

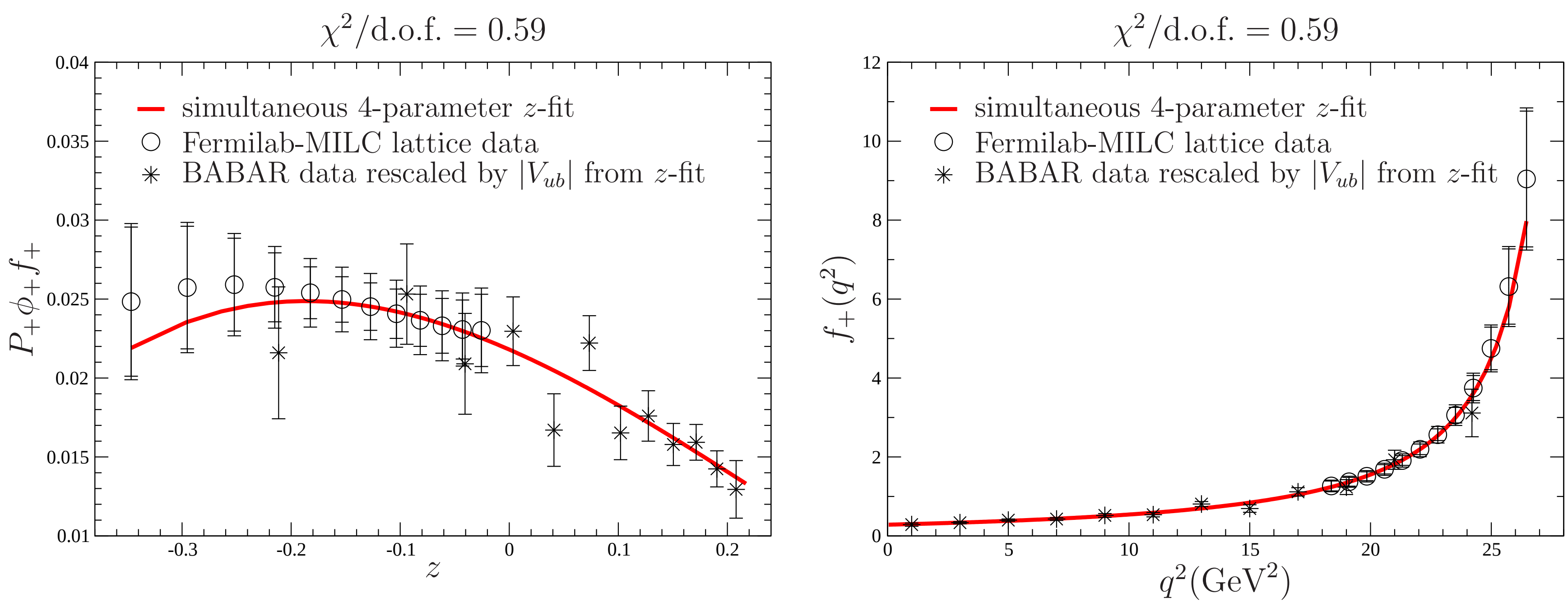
Emel Dalgic et al. (HPQCD collaboration) 2006

Ruth Van de Water et al. (Fermilab Lattice / MILC collaborations) 2008

- improved chiral/continuum extrapolation
- z-expansion
- simultaneous fits to experimental and lattice data

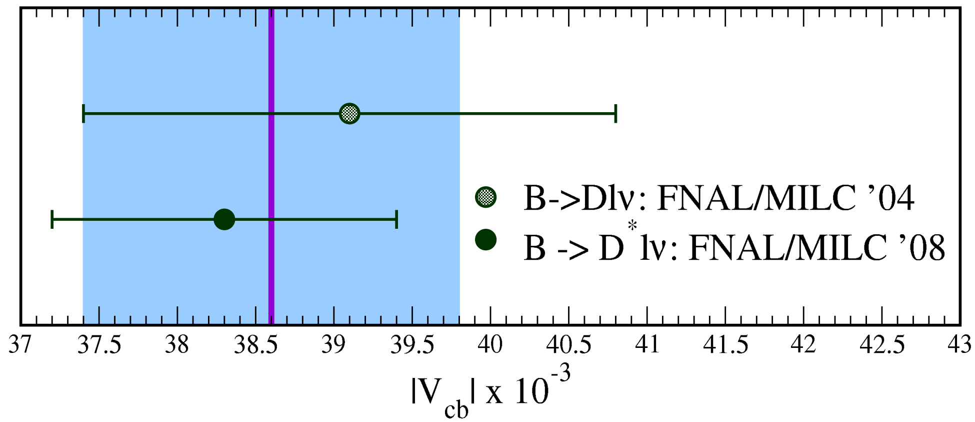
Simultaneous Fits to BABAR and Lattice Data

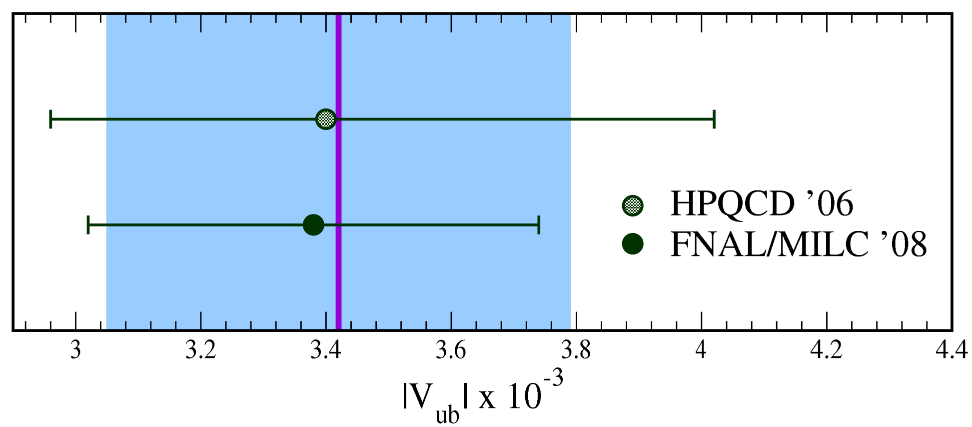
Fermilab Lattice & MILC 2008



Extraction of $|V_{ub}|$ in a model independent manner. Reduction of total error.

Summary Plots from Laiho-Lunghi-VandeWater





$\boxed{\text{D} \to \pi \text{ and D} \to \text{K Decays}}$

Masataka Okamoto et al. (Fermilab Lattice / MILC collaboration) 2005

Jon Bailey et al. (Fermilab Lattice / MILC collaboration) work in progress

Heechang Na et al. (HPQCD collaboration) work in progress

S.Simula et al. (ETM collaboration) work in progress

Actions for D Semileptonic Decay Studies

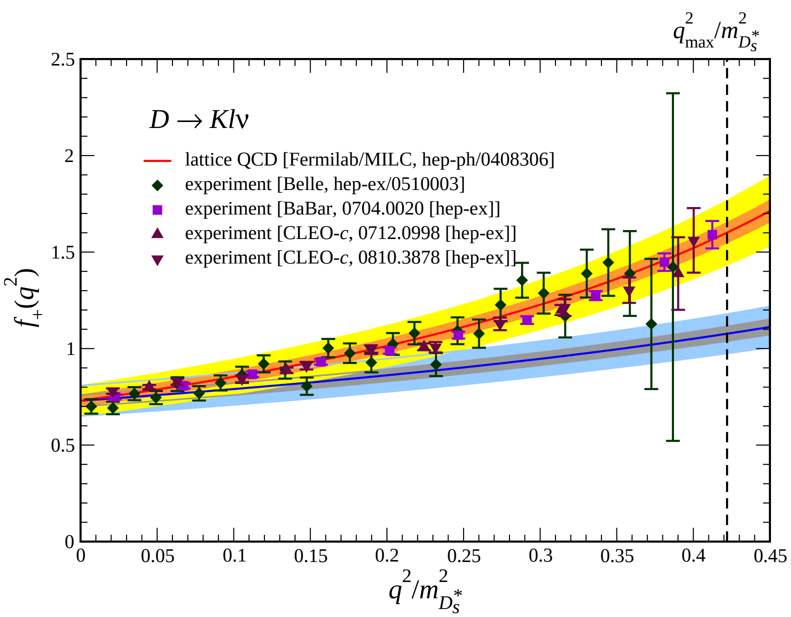
	Fermilab/MILC	HPQCD	ETM
glue	MILC (AsqTad) $N_f = 2+1$	MILC (AsqTad) $N_f = 2+1$	Twisted Mass $N_f = 2$
light valence	AsqTad	HISQ	Twisted Mass
charm	heavy clover	HISQ	Twisted Mass

(AsqTad : Improved Stagg., HISQ : Highly Imp. Stagg., Twisted Mass : Wilson type)

Several new projects being pursued using rather different lattice actions and approaches.
Success of these Charm Physics projects will hopefully also influence future B Physics calculations as well.

D Semileptonic Decays with Heavy Clover Charm and AsqTad Light Quarks

(Fermilab Lattice and MILC Collaboration)



2004 Lattice prediction for shape of $f_+(q^2)$

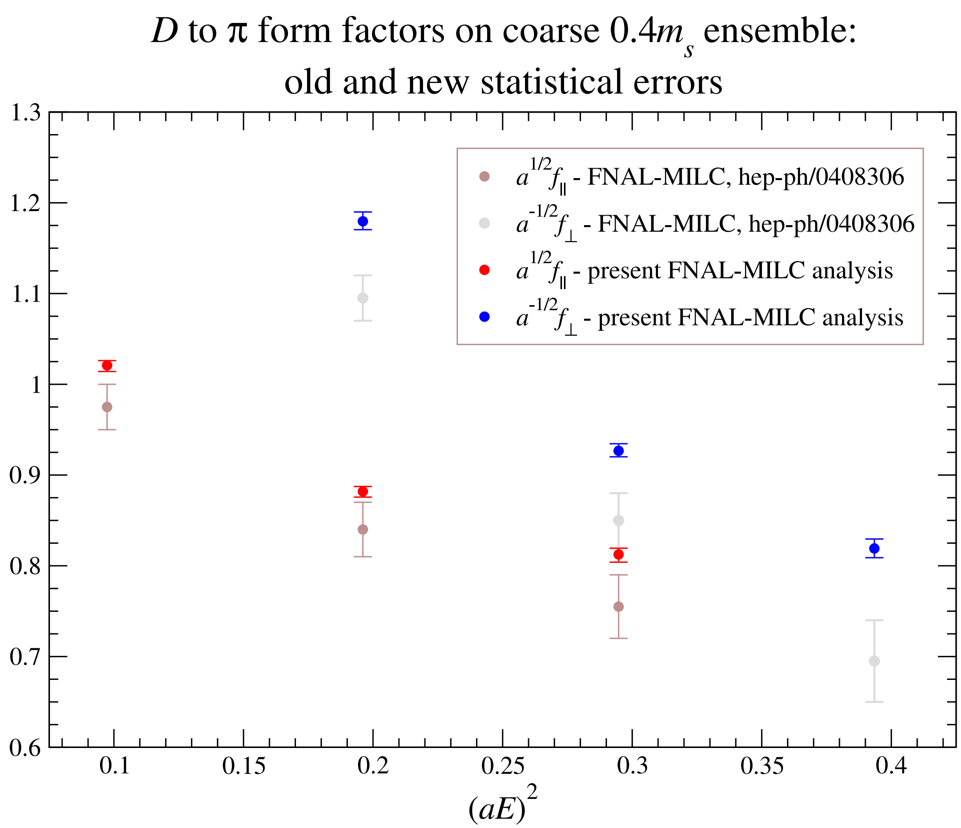
Experimental verification in subsequent years (Belle, BaBar, CLEO-c)

Next goal is to significantly reduce lattice errors $\sim 10\% \to \sim 4.5\%$

(P.Mackenzie: USQCD All Hands 2010)

High Statistics $D \to \pi$

(Jon Bailey, Fermilab/MILC)



Significant improvement in statistical errors achieved

D Semileptonic Decays with HISQ

Charm and Light Quarks

(HPQCD Collaboration)

The "Highly Improved Staggered Quark" or HISQ action provides the most highly improved lattice quark action on the market today. Furthermore HISQ can be used to simulate charm quarks on MILC configurations currently in use with lattice spacings ≤ 0.15fm. In the future one hopes to be able to work also with HISQ b quarks.

Some important features for D physics
— many advantages of using same action for charm and light quarks
— operator matching is either unnecessary (decay constants, $f_0(q^2)$) or can be done nonperturbatively
— m_c can be tuned accurately
— numerically fast, high statistics possible
— small discretization errors

Traditional Approach based on Vector Current

$$\langle P|V^\mu|D\rangle = f_+(q^2)\left[p_D^\mu + p_P^\mu - \frac{m_D^2 - m_P^2}{q^2}q^\mu\right] + f_0(q^2)\frac{m_D^2 - m_P^2}{q^2}q^\mu$$

"P" $=\pi$ or K.

In continuum QCD the vector and scalar currents obey

$$q^\mu\langle V_\mu^{cont.}\rangle = (m_c - m_q)\langle S^{cont.}\rangle$$

which can be used for "fully nonperturbative matching" of the lattice vector current entering the simulations. In the D restframe,

$$(m_D - E_P)\langle V_0^{latt.}\rangle Z_t + \vec{p}\cdot\langle\vec{V}^{latt.}\rangle Z_s = (m_c - m_q)\langle S^{latt.}\rangle$$

Note: the combination $(m_c - m_q)\langle S\rangle$ is R.G. invariant and does not require a Z-factor. This is one advantage of using same HISQ action for both charm and light quarks.

$f_+(q^2 = 0)$ from the Scalar Current

Experimentalists have provided precise measurements of $\boxed{f_+(0)\,|V_{cq}|}$ 1.1% accuracy for $D \to K$ and 3.1% for $D \to \pi$.

HPQCD's first priority is to obtain precision results for $f_+(0)$ and we will do so by exploiting the kinematic relation
$f_+(0) = f_0(0)$ and the relation $\langle S \rangle = \frac{m_D^2 - m_P^2}{m_c - m_q}\, f_0(q^2)$

$$\boxed{f_0(q^2) = \frac{(m_c - m_q)\langle S \rangle}{m_D^2 - m_P^2}}$$

No Z-factors required for this calculation.

Progress to date :

— this is very new project (initiated in 2009).

— studied test case $D_s \to \eta_s$

— verified consistency between using $\langle V_\mu \rangle$ and $\langle S \rangle$ for $f_0(q^2)$.

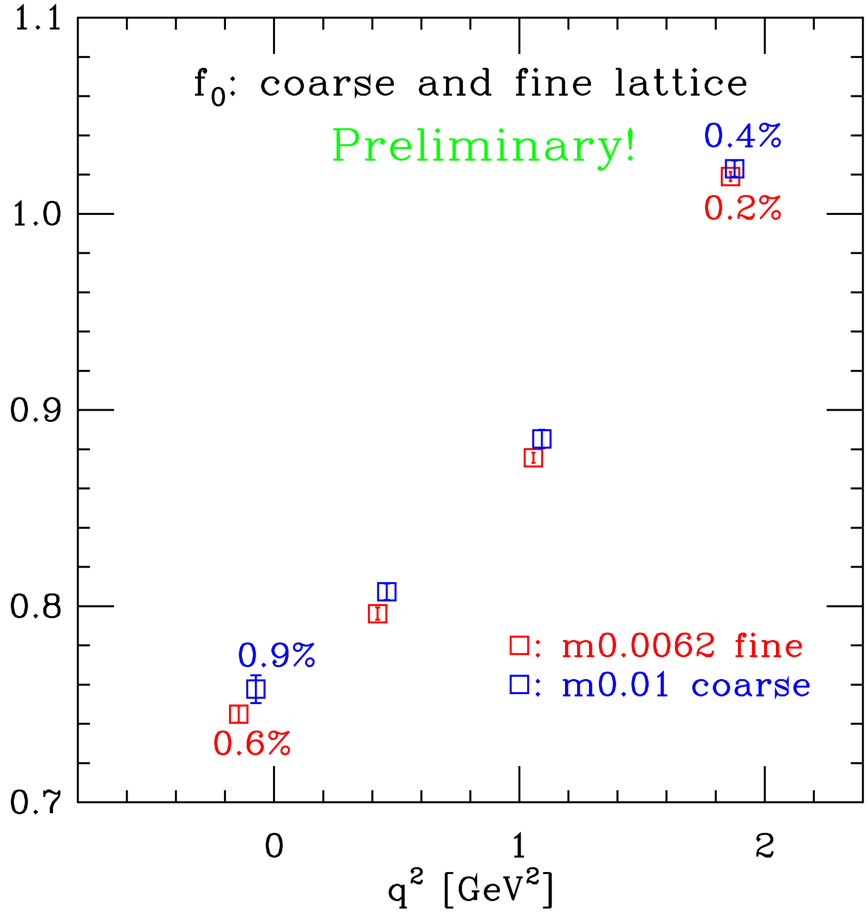
— many improvements to reduce statistical errors (random wall sources, multiple T fits ...)

— results for $D \to K$ on 5 MILC ensembles at two lattice spacings

— work in progress on chiral/continuum extrapolation

Preliminary Results for $f_0(q^2)$ for $D \to K, l\nu$

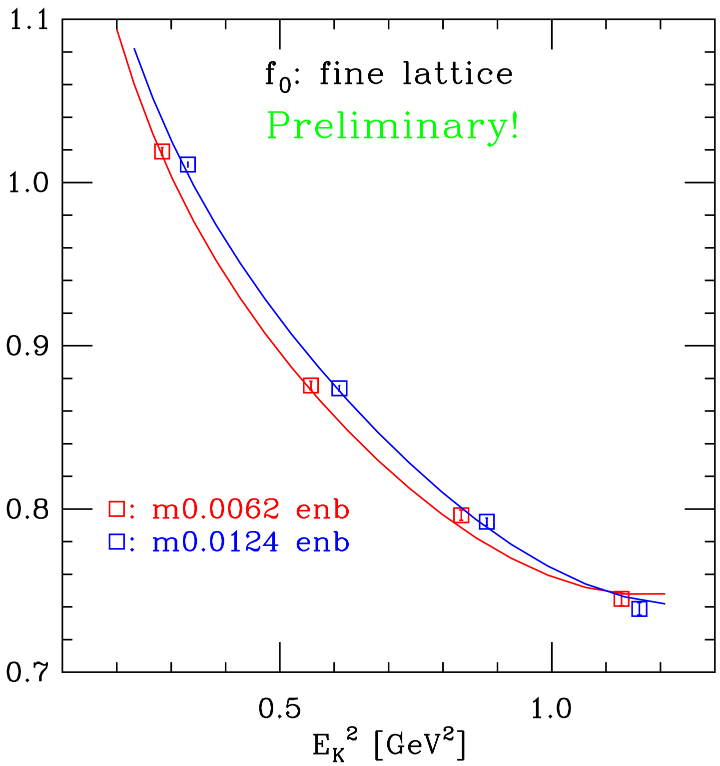
(Heechang Na, HPQCD)

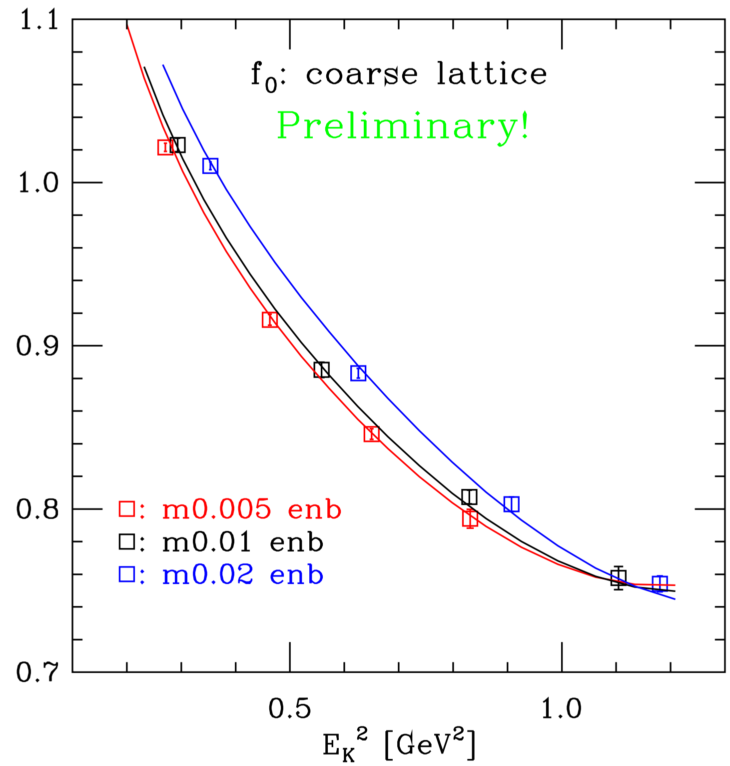


Sub-percent statistical errors even close to $q^2 = 0$ (large Kaon momentum)

First Attempt at a Chiral/Continuum Extrapolation

(Heechang Na, HPQCD)



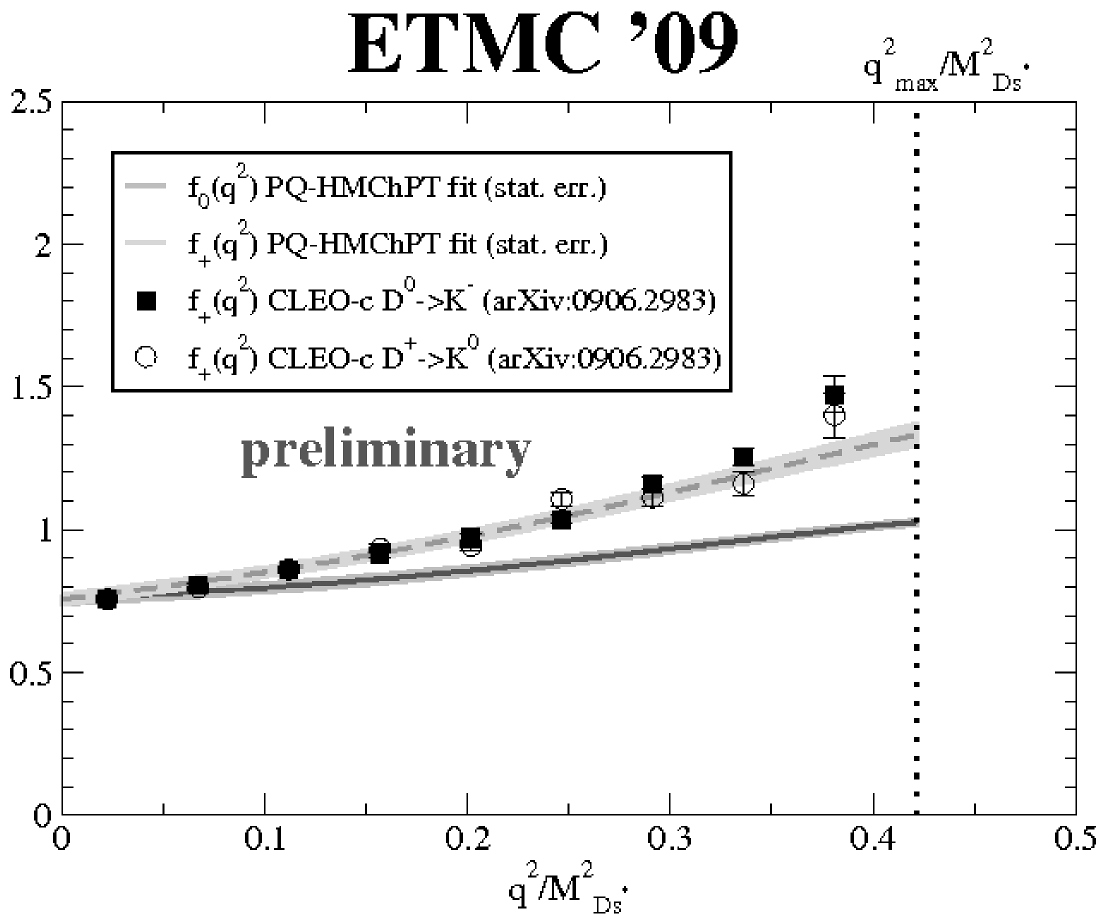


Simultaneous fit to all coarse and fine data points using partially quenched ChPT.

We find a chiral/continuum extrapolated curve close to the most chiral fine lattice curve.

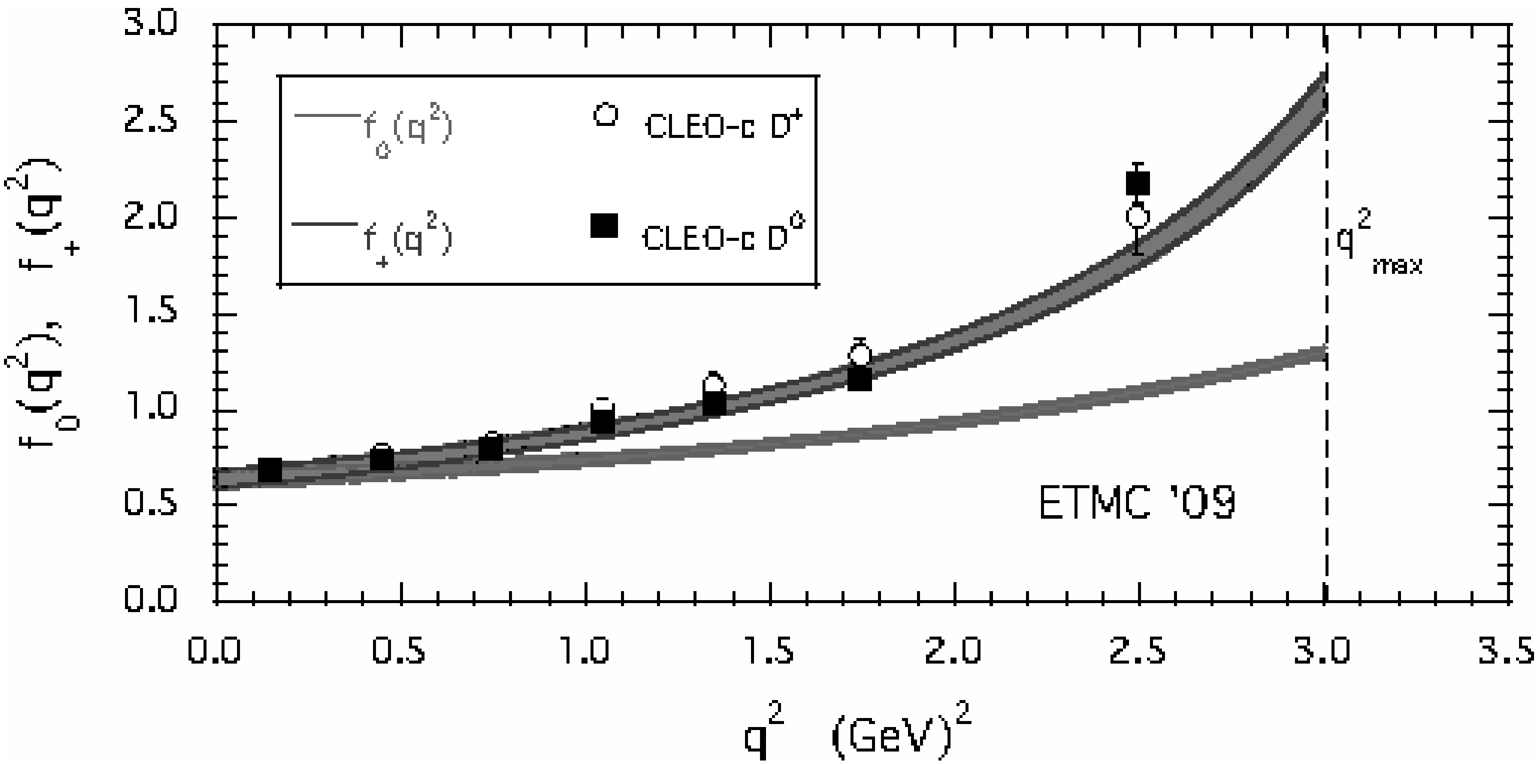
D Semileptonic Decays with Twisted Mass Quarks

$N_f = 2$



$D \to K$

$D \to \pi$ FF from ETMC and Comparison with CLEO-c arXiv:0906.2983 [hep-ex]



After chiral extrapolation at single 0.088fm lattice spacing
$f_+^{D\pi}(0) = 0.64 \pm 0.05$, $f_+^{DK}(0) = 0.76 \pm 0.02$
(statistical errors only)

Calculations at two further lattice spacings underway.

Future Prospects

- Can look forward to many new and significantly improved results on $D \to K$ and $D \to \pi$ semileptonic decays in the near future.

- Work also underway to steadily improve B semileptonic decay results.
  — higher statistics
  — smaller lattice spacings
  — better fitting procedures, etc.

- Lessons from D semileptonic studies should impact B studies as well
  — random wall sources
  — simultaneous fits to several T-values
  — better tuning of quark masses, etc.

- **Work on Rare B decays (**$B \to K^*\gamma$**,** $B \to K^{(*)}ll$**) also being pursued.**

Questions to Experimentalists

- **What are prospects for improvements in $B \to D^{(*)}$ or $B \to \pi$?**

- **What are prospects for $D \to K$ or $D \to \pi$?**

- **How about $D_s \to K^{(*)}$?**

- **Is the ratio $f_+(q^2)/f_{B(D)}$ a useful quantity to look at ?**

- **Future prospects in Rare B decays ?**