Precision Measurements of Charm Semileptonic Form Factors

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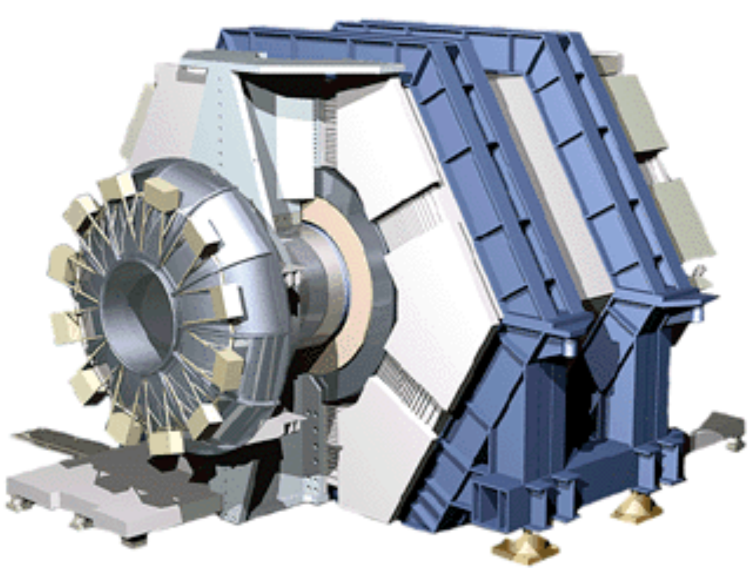

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Introduction

I will concentrate on results obtained at e^+e^- colliders via the process $e^+e^- \to c\bar{c} \to$ fragmentation (D/D_s...)

I will start with D decays into pseudoscalar mesons $D \to \pi/K l \nu$

easier to treat experimentally and theoretically

Then, I will move on to D_s decays into vector mesons in the final state $D_s \to KKe\nu$

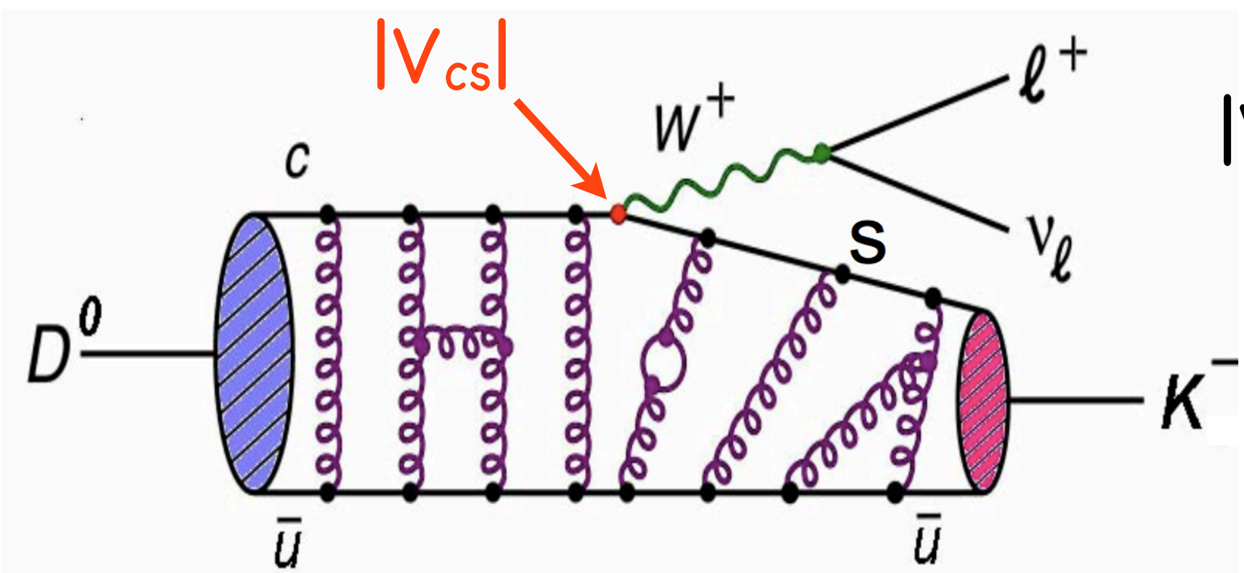
Finally, something about future prospects: larger datasets, $D \to K\pi l\nu$,...

Introduction

The extraction of CKM parameters from exclusive decay modes requires precise information about the normalization and shapes of various form factors

(eg the extraction of $|V_{ub}|$ from exclusive B SL decays)

Semileptonic D decays are an excellent laboratory where to test LQCD with great precision



$|V_{cs}|$ and $|V_{cd}|$ well constrained thanks to unitarity $\Rightarrow$ measure $f_+(q^2)$

$q^2 = (P_D - P_P)^2$

p = momentum of daughter P meson

$$\frac{d\Gamma(D \to Pe\nu_e)}{dq^2} = \frac{G_F^2 |V_{cq}|^2}{24\pi^3} p^3 |f_+(q^2)|^2$$

$f_+(q^2)$ measures the probability that a given hadronic final state will be produced

Form Factor Parameterizations

Most general FF parameterization (Becher and Hill) for decays into pseudoscalar mesons that satisfies dispersion relations and QCD constraints:

$$f_+(q^2) = \frac{1}{P(q^2)\phi(q^2, t_0)} \sum_{k=0}^{\infty} a_k(t_0)[z(q^2, t_0)]^k$$

accounts for D_s^* pole

ensures a_k's good behaviour

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

$$t_\pm \equiv (M_D \pm m_{K,\pi})^2$$

first two terms sufficient to describe data
measure a_0, $r_1 = a_1/a_0$ and $r_2 = a_2/a_0$

Model dependent parameterization: modified pole...

$$f_+(q^2) = \frac{f_+(0)}{(1 - \frac{q^2}{m^2_{\rm pole}})(1 - \alpha \frac{q^2}{m^2_{\rm pole}})}$$

measure $f_+(0)$ and α

m_{pole} = expected vector meson mass

...and simple pole

$$f_+(q^2) = \frac{f_+(0)}{(1 - \frac{q^2}{m^2_{\rm pole}})}$$

measure $f_+(0)$ and m_{pole}

measured m_{pole} should agree with expected vector meson masses... but it doesn't: spectrum distorted by contribution from other singularities than the D^*_s pole

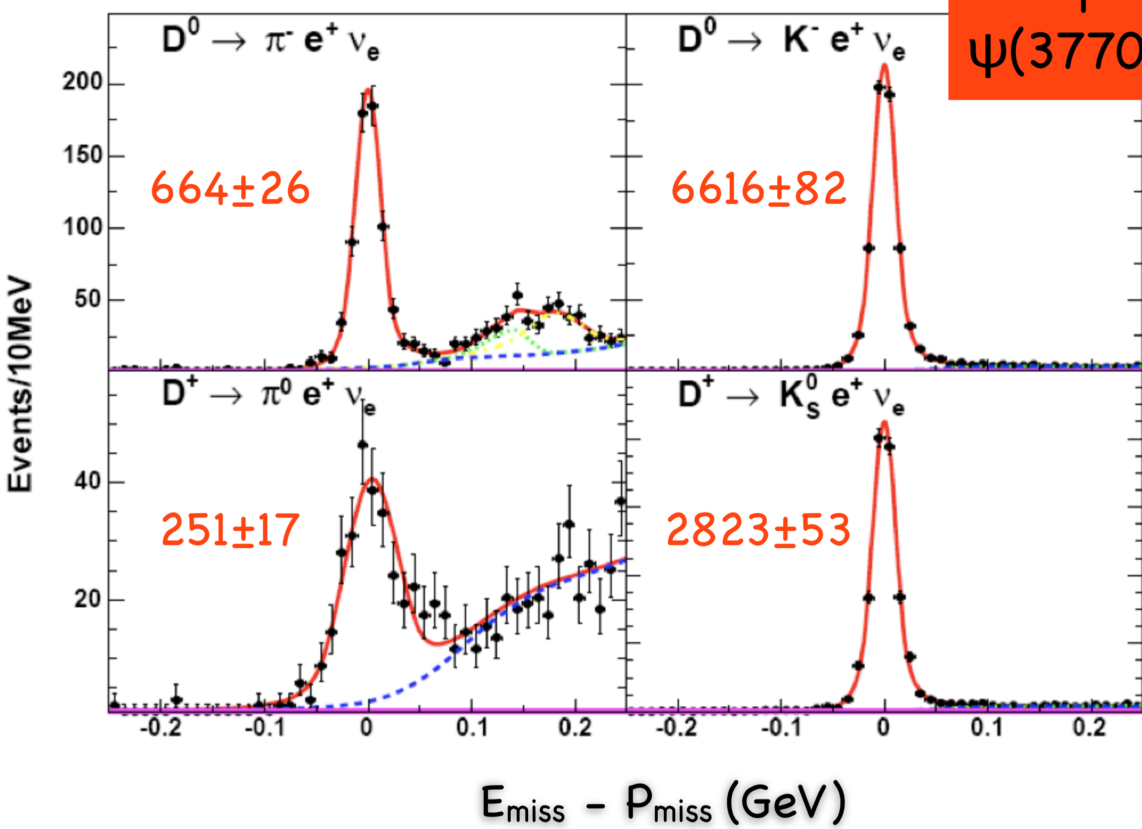
$D \rightarrow \pi/K l \nu$

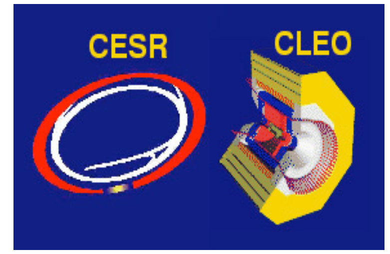
tagging technique: look at
$e^+e^- \rightarrow D^0\bar{D}^0$ (CLEO)
$e^+e^- \rightarrow D^{(*)}_{tag}D^{*}_{sig}X$ (Belle)
fully reconstruct one D in hadronic channels
advantage: D momentum is well known, therefore
excellent q^2 resolution
disadvantage: limited statistics

untagged technique: reconstruct ν 4-momentum
from total energy in the event; require consistency
in energy and/or beam-energy constrained mass
advantage: higher statistics
disadvantage: higher backgrounds/systematic
uncertainties (controlled with dedicated
measurements)

$D \to \pi/Kl\nu$ tagged

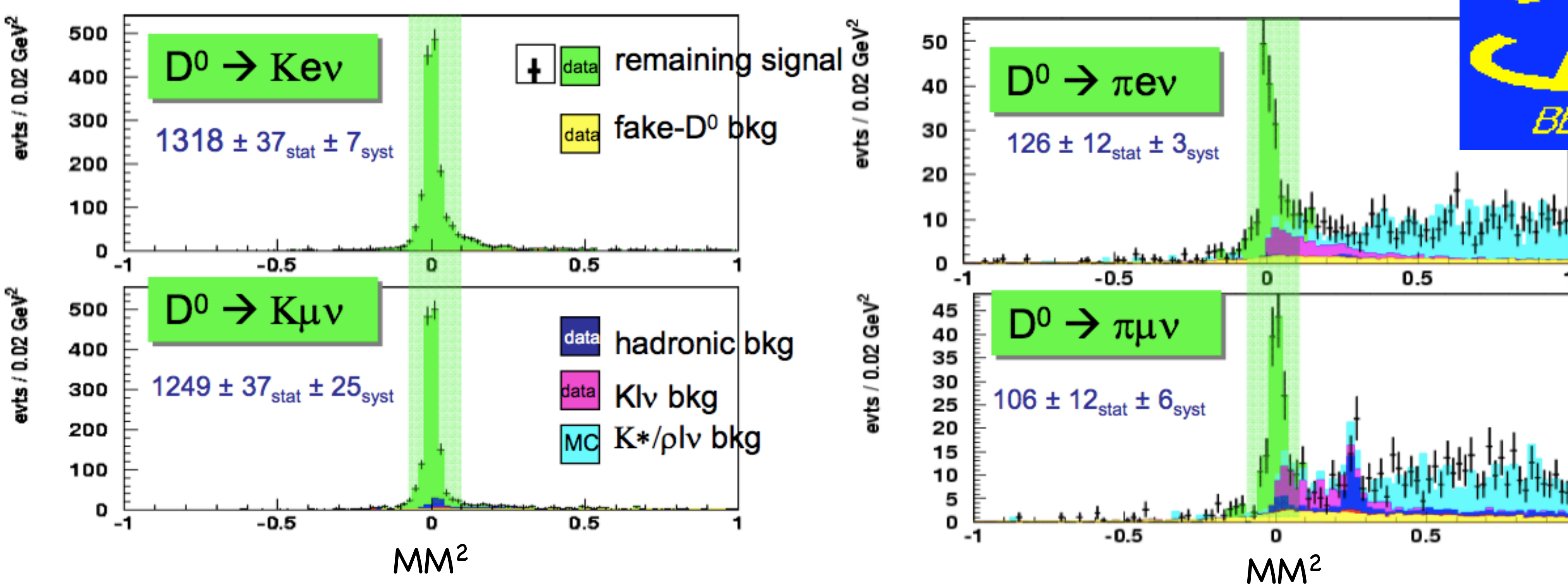
282 pb^{-1}
$\psi(3770)$





Good separation of signal and background

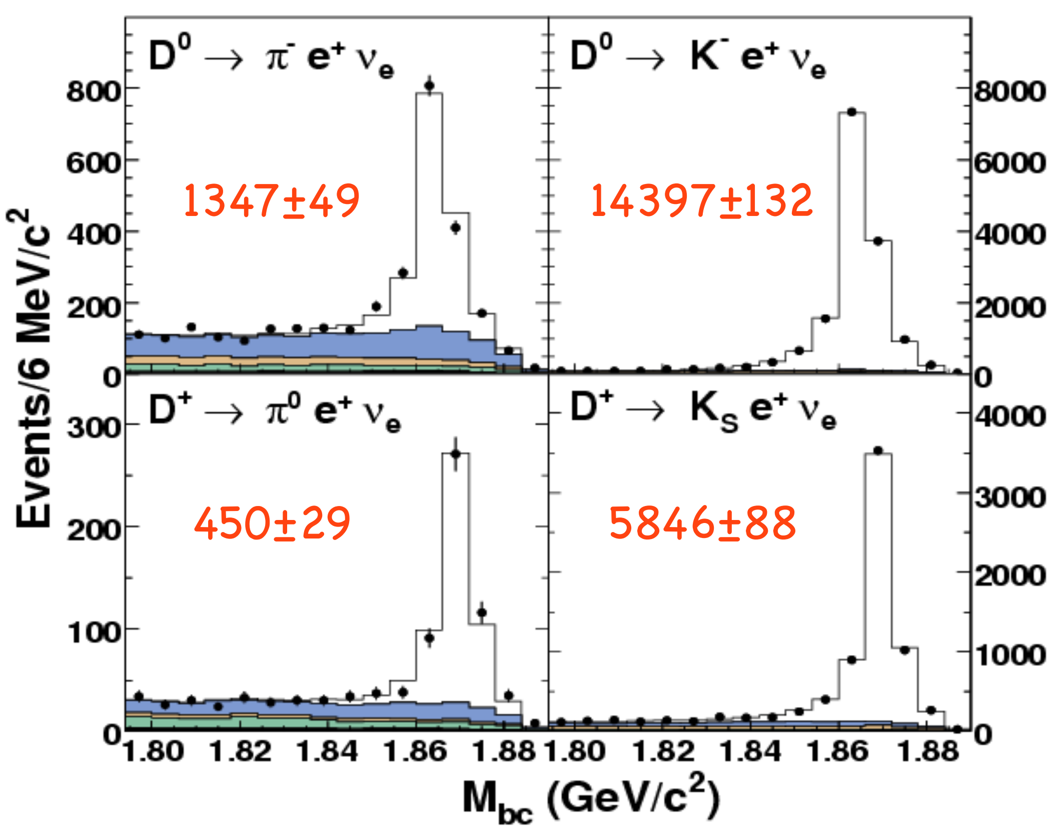
PRL 97:061804,2006



$D \to \pi/Kl\nu$ untagged

$282\ pb^{-1}$
$\psi(3770)$

PRD 77:112005,2008

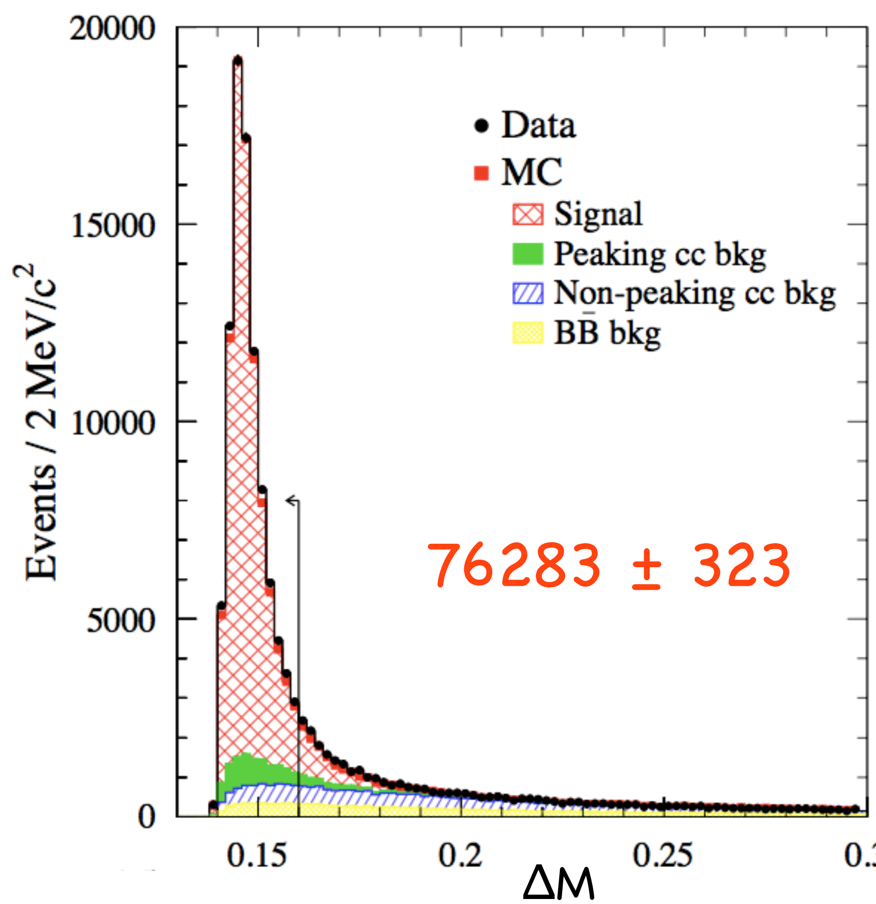


$$\Delta E = E_K + E_e + |p_{miss}| - E_{beam}$$

$$M_{bc} = \sqrt{E^2_{beam} - (p_K + p_e + p'_{miss})^2}$$

$75\ fb^{-1}$
$\Upsilon(4S)$

PRD 76:052005,2007

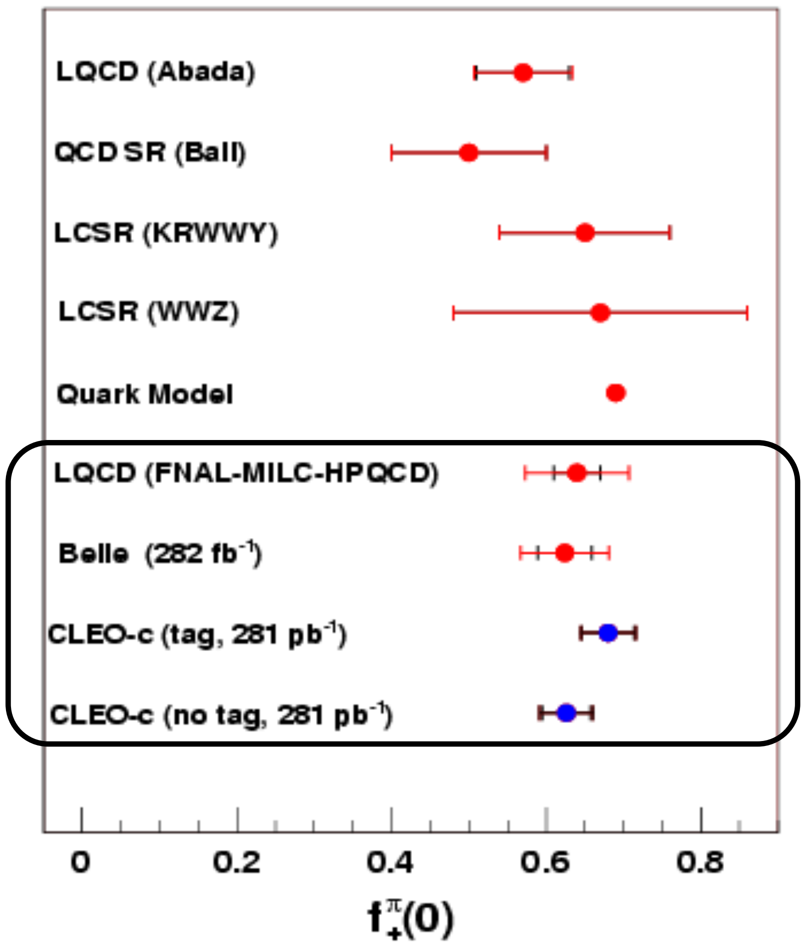


D^0 originates from $D^{*+} \to D^0\pi^+$

$$\Delta M = m(D^0\pi^+) - m(D^0)$$

q^2 distribution is unfolded

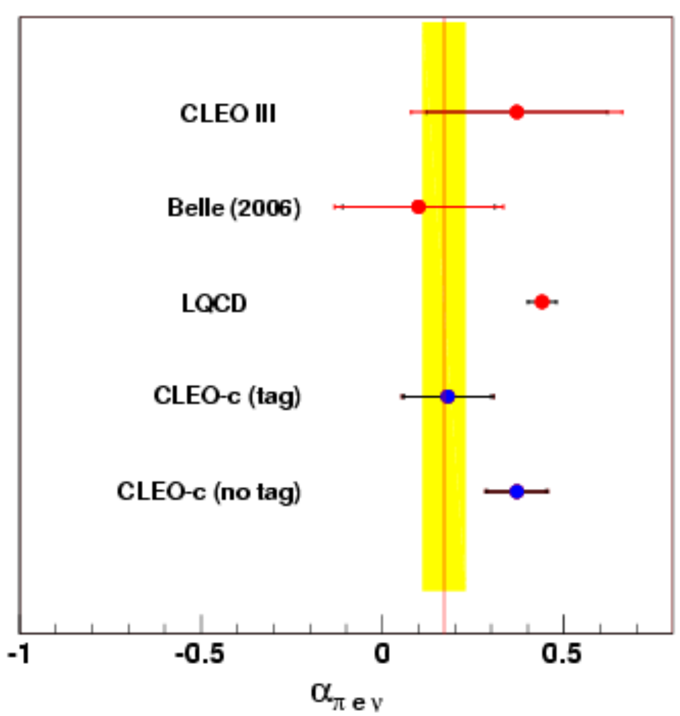
$D \to \pi l \nu$



FNAL-MILC-HPQCD provide unquenched calculation of $f_+(0)$ at the 10% level: 0.64±0.07

hep-ph/0408306
PRL 94:011601,2005

To be compared with experimental precision of 3-6%



Modified pole parameterization:

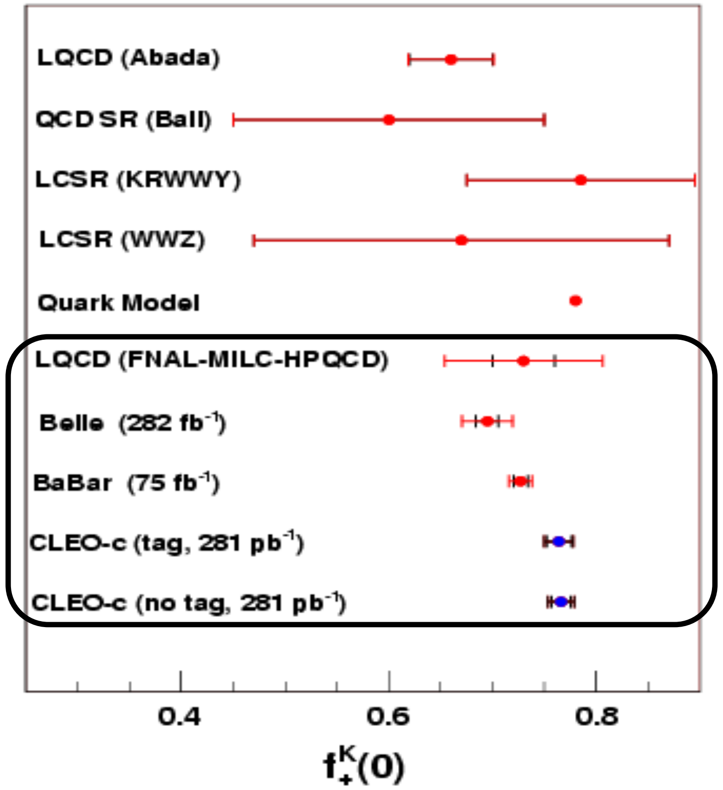
CLEO tagged: $f_+(0) = 0.680 \pm 0.034 \pm 0.06 \pm 0.09$ $D^0 + D^+$

Belle tagged: $f_+(0) = 0.624 \pm 0.020 \pm 0.030$ D^0

CLEO untagged: $f_+(0) = 0.626 \pm 0.031 \pm 0.013 \pm 0.008$ $D^0 + D^+$

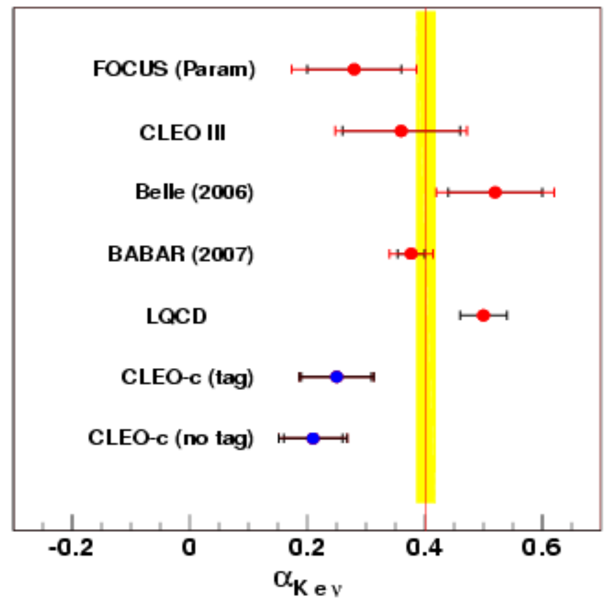
Good compatibility between theory and experiment

$D \to Kl\nu$

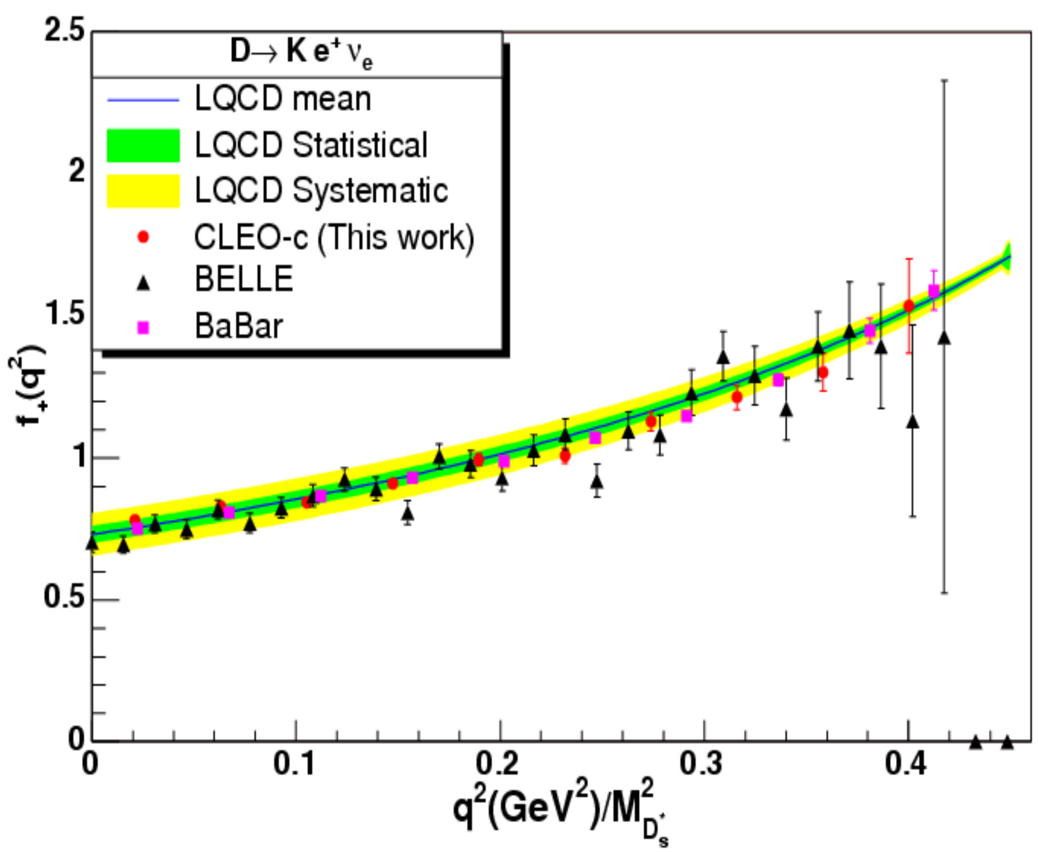


Again, FNAL-MILC-HPQCD provide unquenched calculation of $f_+(0)$ at the 10% level: 0.73 ± 0.08

hep-ph/0408306



To be compared with experimental precision of 1.5-3%



Modified pole parameterization:

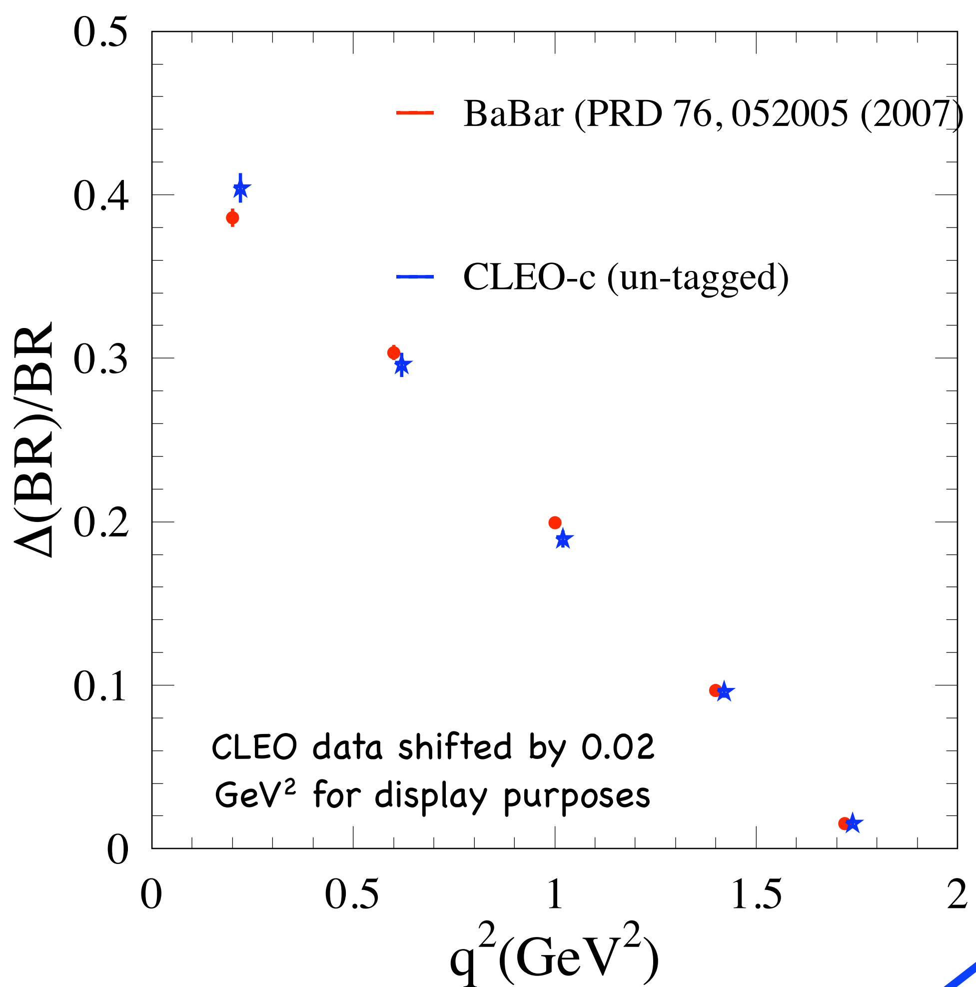
CLEO tagged:	$f_+(0) = 0.764 \pm 0.012 \pm 0.007 \pm 0.001$	$D^0 + D^+$
Belle tagged:	$f_+(0) = 0.695 \pm 0.007 \pm 0.022$	D^0

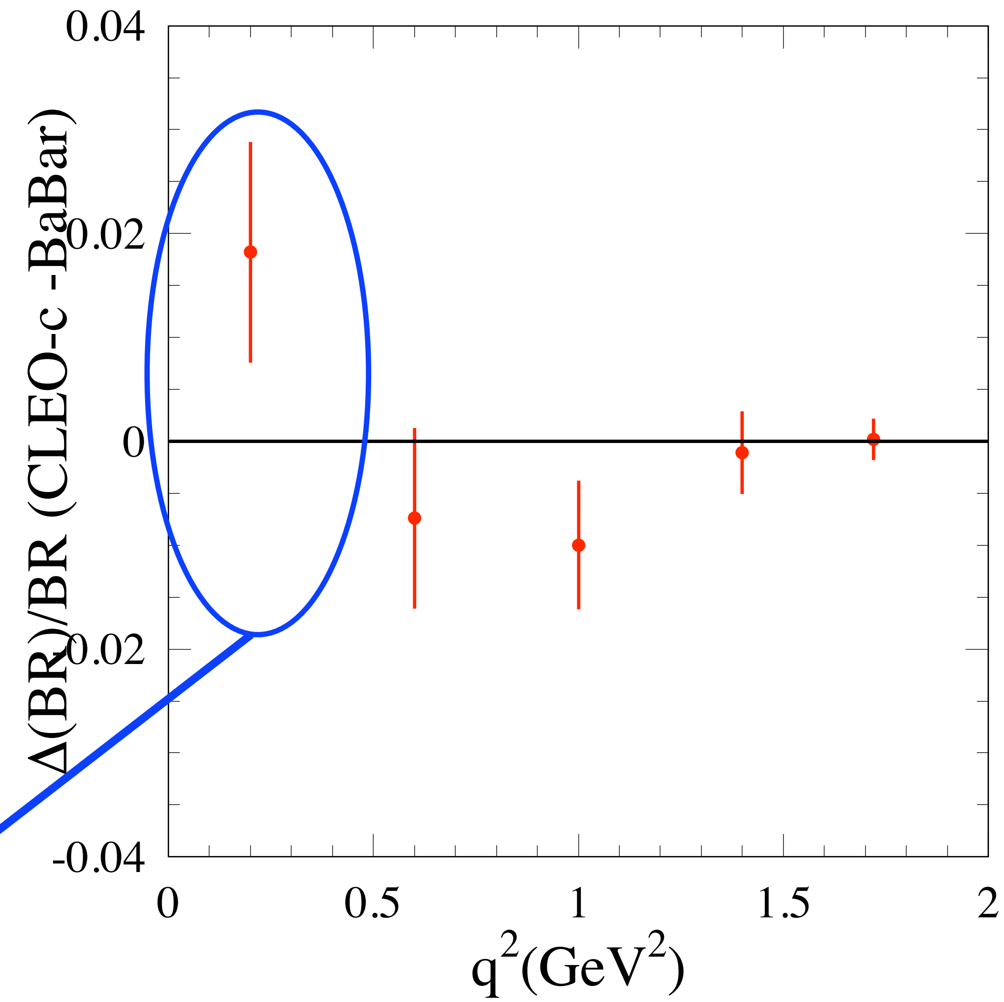
CLEO untagged:	$f_+(0) = 0.766 \pm 0.009 \pm 0.009 \pm 0.001$	$D^0 + D^+$
BABAR untagged:	$f_+(0) = 0.727 \pm 0.007 \pm 0.005 \pm 0.007$	D^0

Good compatibility between theory and experiment

D → Klν

Good agreement between BABAR and CLEO is also evident in the q^2 dependence of the partial branching fraction:





more data ➠ better control of systematic effects, especially radiative correction, important at low q^2

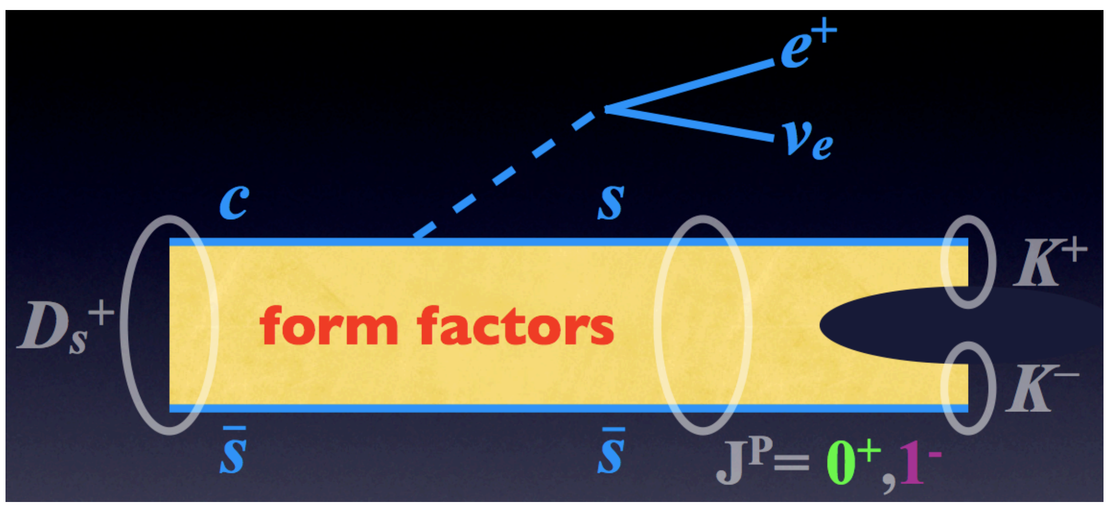
$D_s \to KKe\nu$

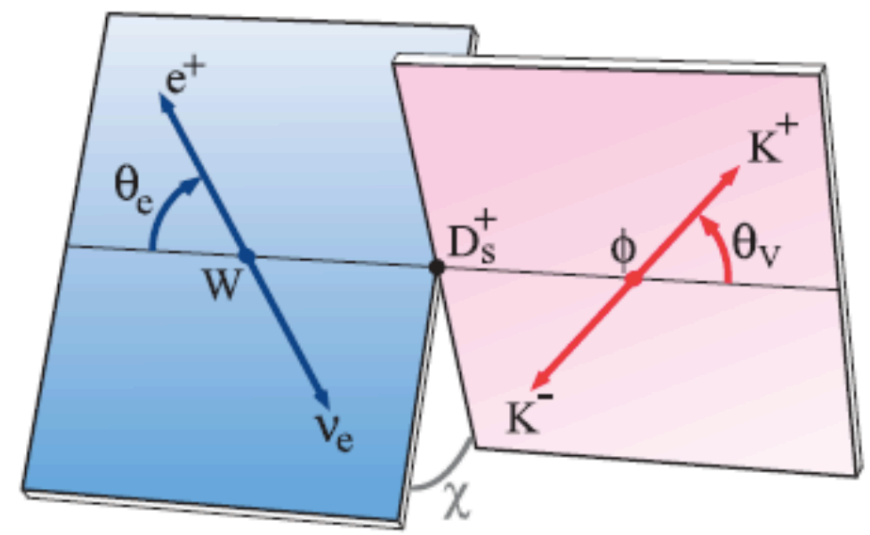
Higher mass of spectator quark ➠ LQCD prediction should be more accurate

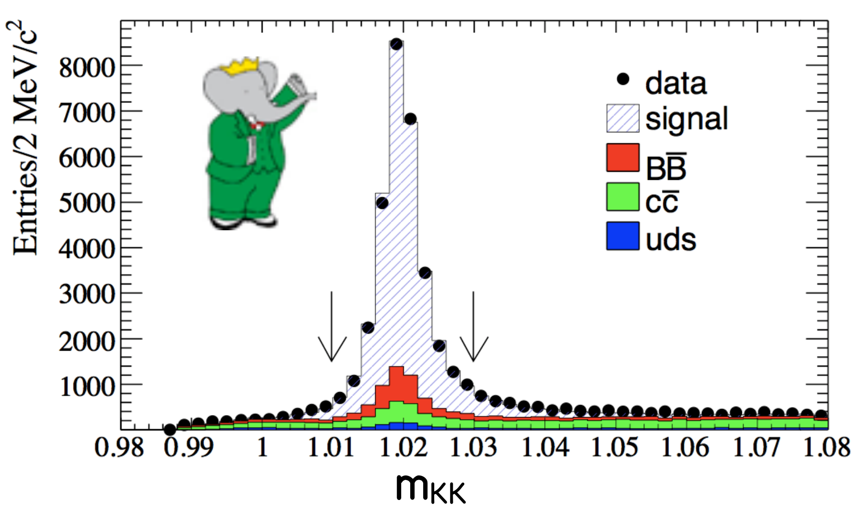
narrow φ simplifies J=1 FF analysis

sensitive to possible J=0 contributions

Lower production rate, higher backgrounds







Differential decay rate depends on 5 variables:

m_{KK}, q^2, $\cos(\theta_e)$, $\cos(\theta_K)$, χ

$D_s \to KKe\nu$

$J^P=1^-$

Assume simple pole dominance:

$$A_{1,2}(q^2) = \frac{A_{1,2}(0)}{1 - q^2/m_A^2} \qquad V(q^2) = \frac{V(0)}{1 - q^2/m_V^2}$$

m_A = 2.5 GeV/c^2 ~ m_{Ds1} $\qquad$ m_V = 2.1 GeV/c^2 ~ m_{Ds^*}

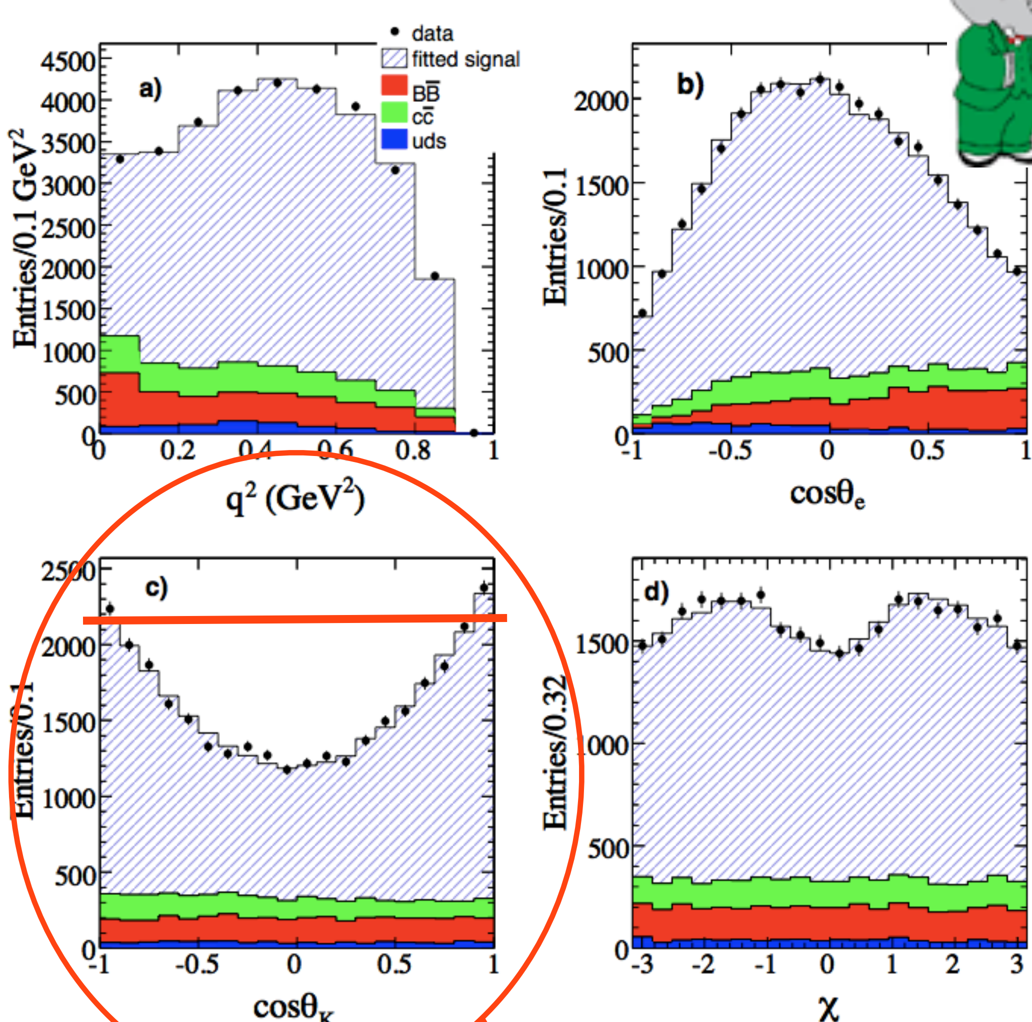
We measure m_A , r_V = $V(0)/A_1(0)$, r_2 = $A_2(0)/A_1(0)$

$J^P=0^+$

$$\mathcal{F}_{10} = r_0 \frac{p_{KK}\ m_{D_s}}{1 - \frac{q^2}{m_A^2}} \frac{m_{f_0}\ g_\pi}{m_{f_0}^2 - m^2 - i m_{f_0} \Gamma_{f_0}^0}$$

We measure r_0

$D_s \to KKe\nu$



$N_{sig} = 25341 \pm 178 \pm 488$

$r_V = 1.849 \pm 0.060 \pm 0.095$

$r_2 = 0.763 \pm 0.071 \pm 0.065$

1.35 ± 0.08

0.98 ± 0.09

hep-lat/0109035

$r_0 = 15.1 \pm 2.6 \pm 1.0$ GeV^{-1}

S-wave contribution

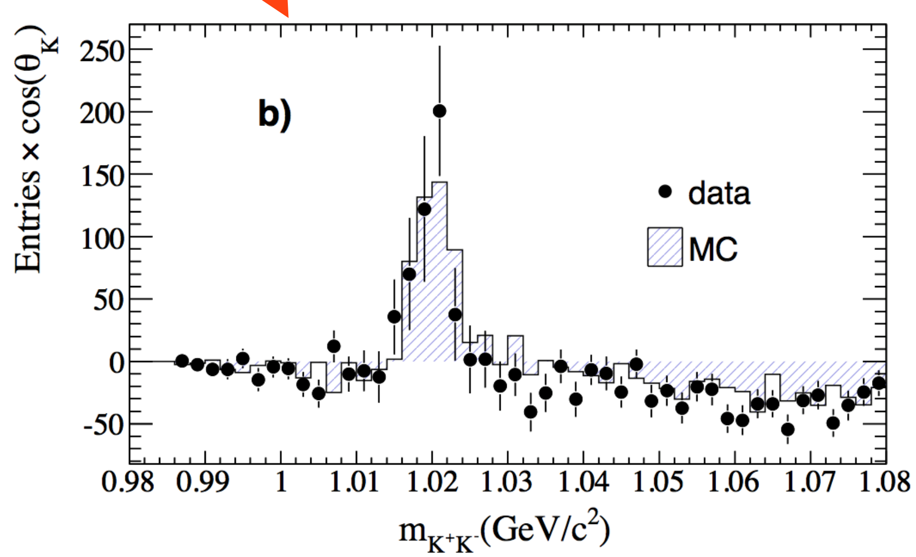
0.22±0.12% of the KKev decay rate

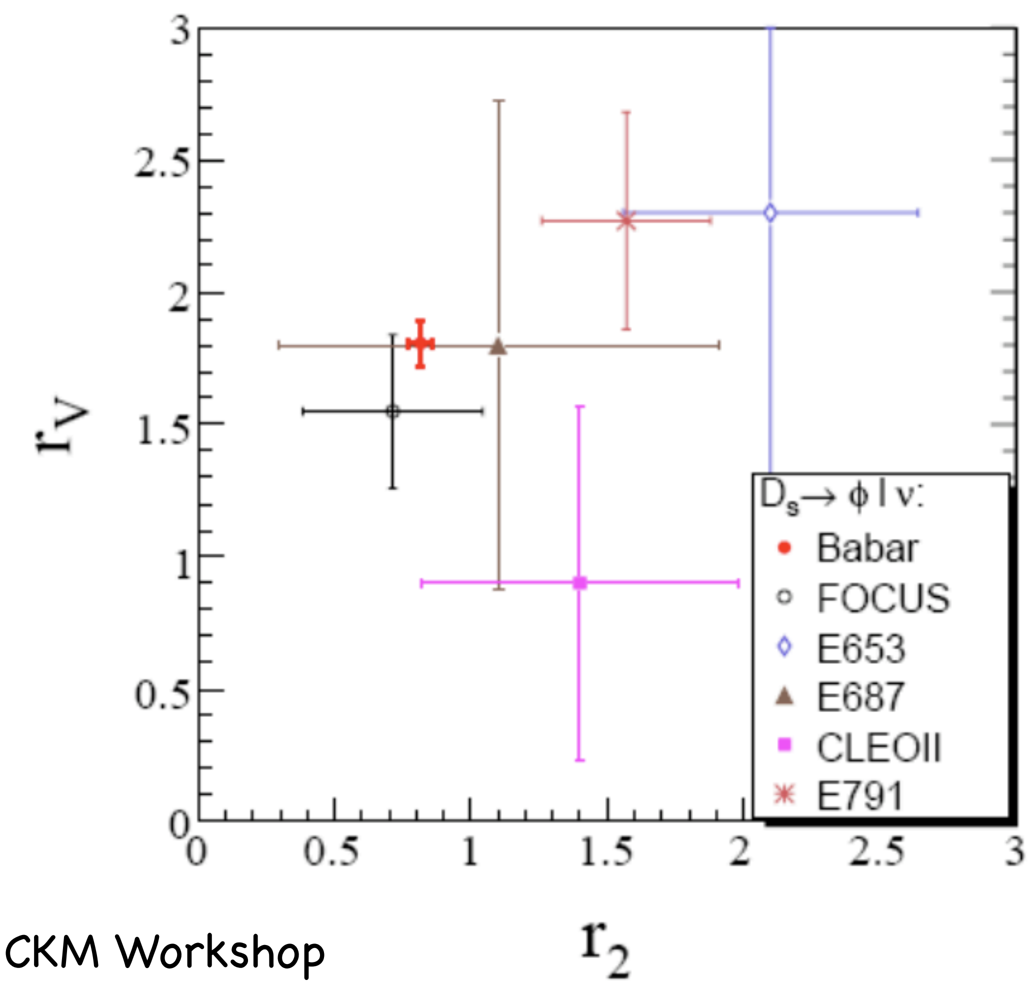
$m_A = 2.28^{+0.23}_{-0.18} \pm 0.18$ GeV/c^2

$A_1(0) = 0.607 \pm 0.011 \pm 0.019 \pm 0.018$ GeV/c^2

0.63 ± 0.02

PRD **78**, 051101(R) (2008)





Future Prospects

BABAR is working on the untagged analysis of $D \rightarrow \pi e \nu$ decays

All the experiments mentioned here have not exploited yet their full dataset ⇒ it is worthwhile to redo the $D \rightarrow \pi / K l \nu$ analyses

expect sizable reduction on statistical and systematic uncertainties

BABAR is working on $D \rightarrow V e \nu$ decays, namely $D^+ \rightarrow K^- \pi^+ e^+ \nu$ and $D^0 \rightarrow K_S \pi e \nu$

CLEO has presented preliminary results on $D \rightarrow \rho e \nu$

provide input on r_V, r_2 and q^2 dependence of vector FF

Other interesting channels that may be analyzed: $D_s \rightarrow \eta / \eta' e \nu$ or $D^+ \rightarrow \pi^+ \pi^- e^+ \nu$

Conclusions

Semileptonic D decays are an excellent testing ground for LQCD, that is continuing to improve its predictions

Precision measurements of FFs are available from several experiments

In particular, FF normalization is known at the 3% level for $D \rightarrow \pi l \nu$ and 1.5% for $D \rightarrow K l \nu$

LQCD prediction at 10% level

BABAR has measured the FF parameters in the $D \rightarrow KKe\nu$ decay, finding evidence of a small S-wave contribution