Measurements of q^2 Dependence of $D^0 \to K^- \mu^+ \nu$ and $\pi^- \mu^+ \nu$ Form Factors.

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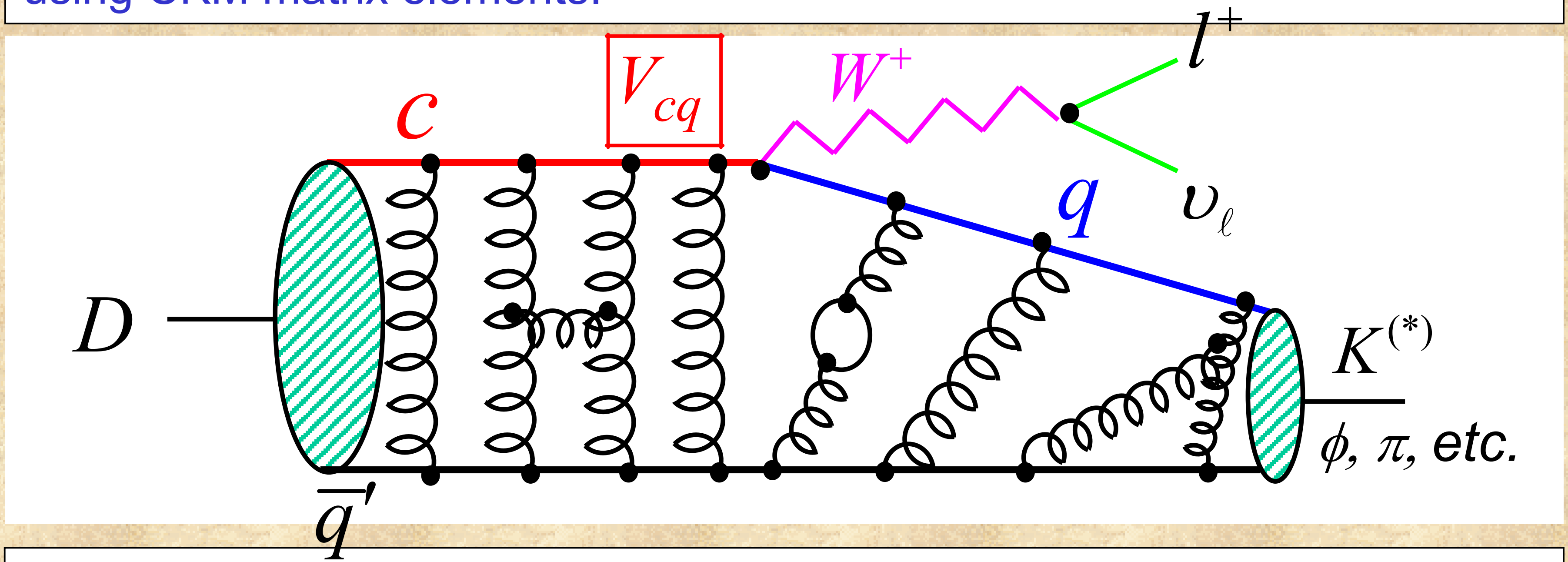
Content (**hep-ex/0410037, PLB 607 (2005) 233**)

- Part I: Theories of charm semileptonic decays.
- Part II: Reconstructing $D^0 \to K^- \mu^+ \nu$ and $\pi^- \mu^+ \nu$.
- Part III: q^2 dependence, $f_+(q^2)$
  - a. Deconvolution approach: Non-parametric analysis.
  - b. Parametric fit.
- Part VII: Summary

I: Charm semileptonic decay as tests of LQCD

The decay rates are computed from first principles (Feynman diagrams) using CKM matrix elements.



The hadronic complications are contained in the form factors, which can be calculated via non-perturbative Lattice QCD, HQET or quark models.

Charm SL decays provide a high quality lattice calibration, which is crucial in reducing systematic errors in the Unitarity Triangle. The techniques validated by charm decays can be applied to beauty decays.

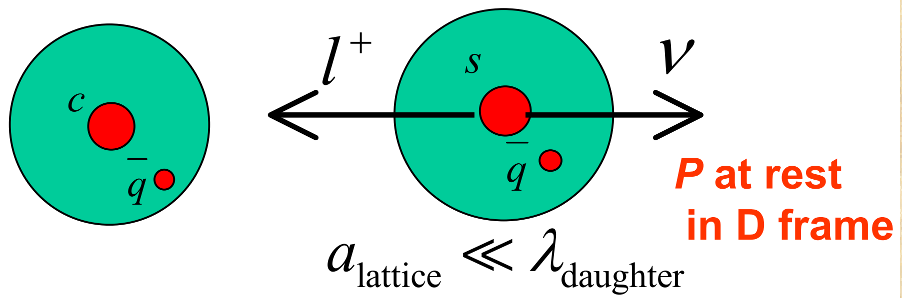
Theories of D → Pseudoscalar *l* ν decays

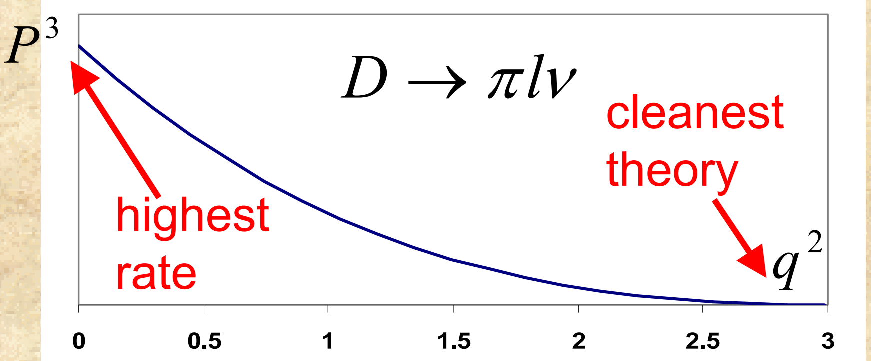
Simple kinematics → Easy to extract form factors.

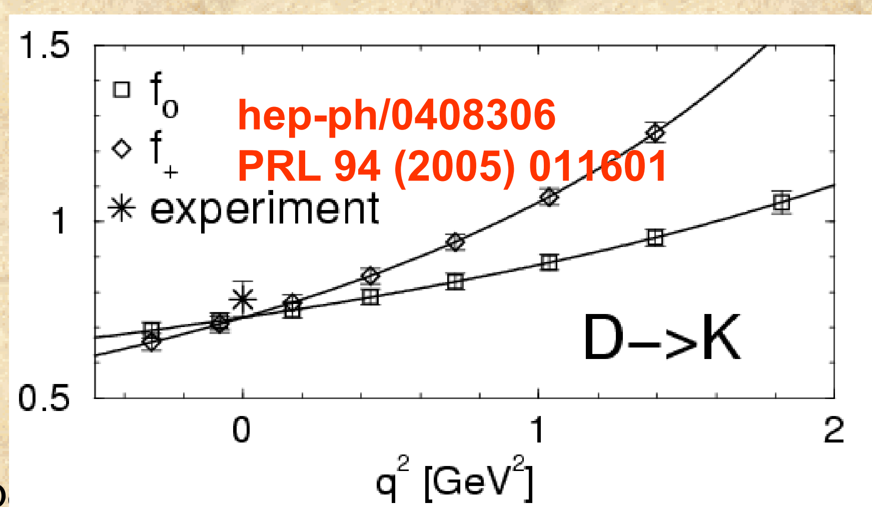
$$\frac{d\Gamma\left(D \to P\ell\nu\right)}{dq^2} = \frac{G_F^2 \left|V_{cq}\right|^2 P_P^3}{24\pi^3}\left\{\left|f_+(q^2)\right|^2 + O(m_l^2)\right\}$$

But a major disconnection exists between experiment and theory. In the past, theories worked best where experiments worked worst.

$q^2 = q^2_{\max}$ **is the easiest point for LQCD calculation.**







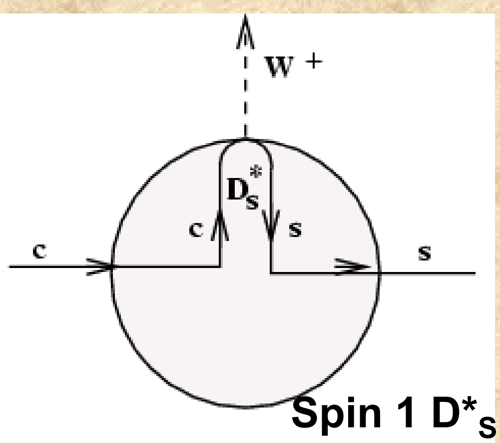
The lattice community is actively fixing the situation and calculating f+ as a function of q^2.

What do we measure?

Until <u>quite</u> recently, one required a specific parameterized form to bridge the gap between a theory and an experiment, since neither an experiment nor a theory had clean $f_+(q^2)$ information. Now we have enough data, hence,

- Method I: $f_+(q^2)$ shape obtained non-parametrically by deconvolution.
- Method II: Or fit $f_+(q^2)$ using specific forms.

$f_+(q^2)$ parameterization



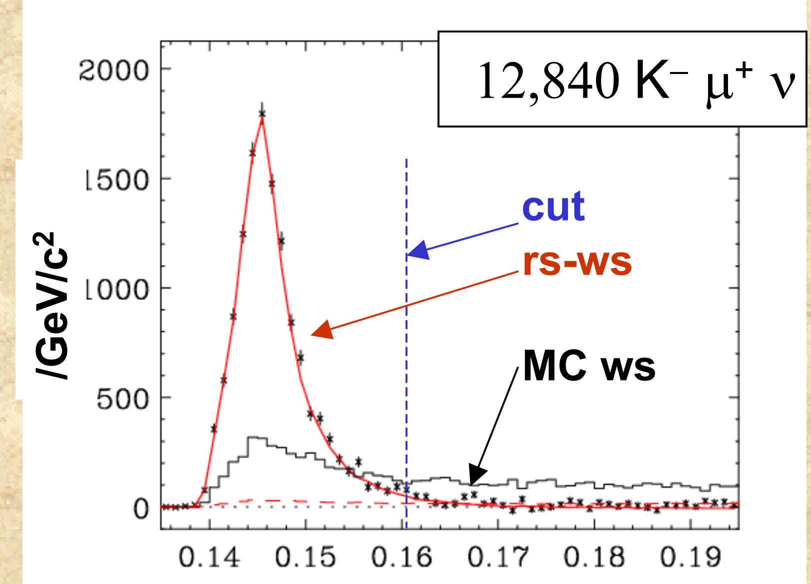
Spin 1 D^*_s

(old) pole	$f_+ \propto \dfrac{1}{1-q^2/m^2_{\text{pole}}}$
(old) ISGW1	$f_+ \propto \exp\left(\alpha q^2\right)$
ISGW2	**Updated version.**
modified pole	$f_+ \propto \dfrac{1}{(1-q^2/m^2_{D^*})(1-\alpha q^2/m^2_{D^*})}$

II. Reconstructing $D^0 \to K^- \mu^+ \nu$ and $\pi^- \mu^+ \nu$.

Selection

- A good muon candidate.
- Cerenkov ID for K/π candidates.
- Good CL's for D production/decay vertices, and L/σ > 5 between two vertices.
- D* tag required, and wrong sign soft $\tilde{\pi}^-$ subtraction.



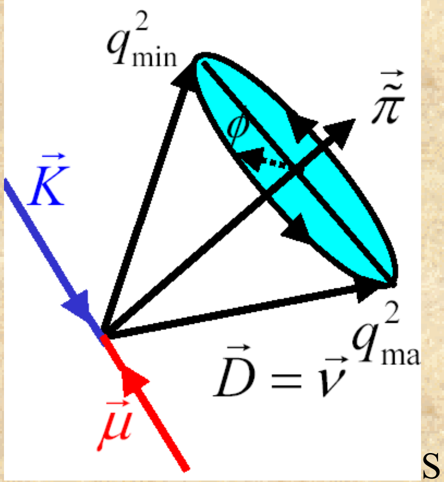
$$m\left(K\mu\nu+\tilde{\pi}\right)-m\left(K\mu\nu\right)$$

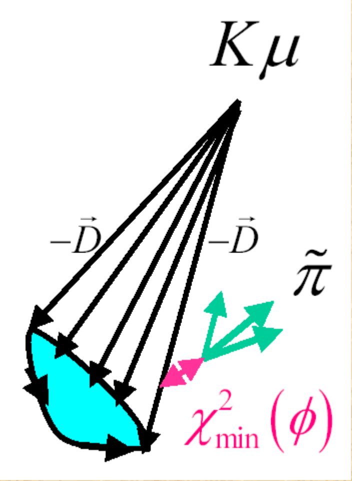
Neutrino Reconstruction

$$D^{*+} \to D^0 \tilde{\pi}^+$$

$$K^-\mu^+\nu$$

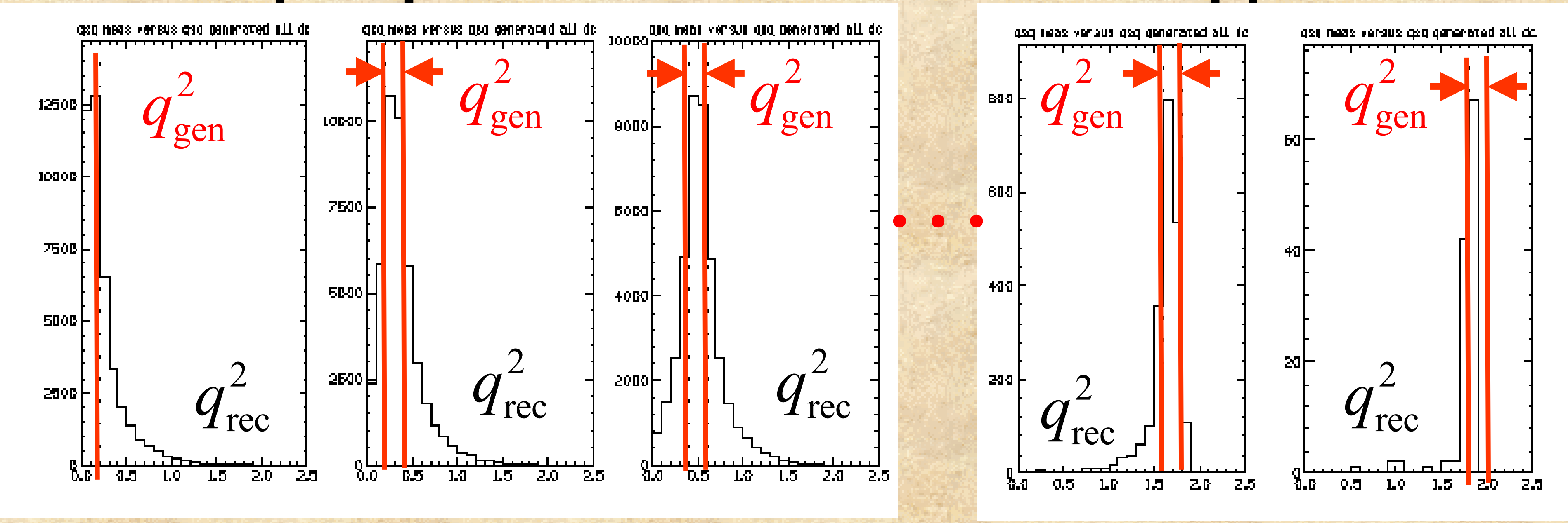
$$\pi^-\mu^+\nu$$





- $K\mu$ rest frame
- The D and D* mass constraints→ the neutrino lies on a cone around the soft pion.
- Pick the ϕ that points the D closest to the primary vertex.

III.a q^2 dependence: Deconvolution approach.



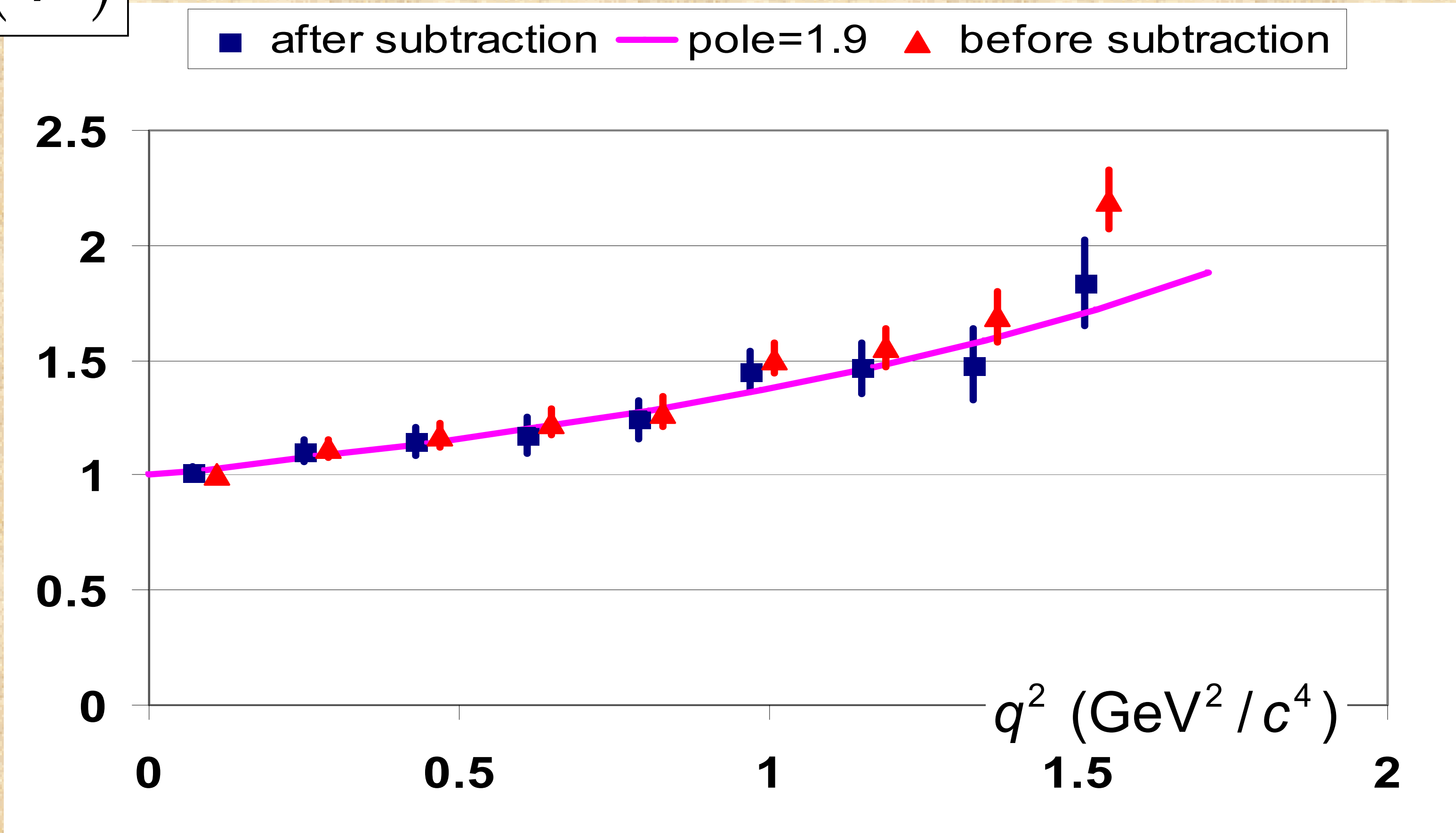
A deconvolution matrix is constructed from the number of events generated in the i-th q^2 bin that end up reconstructed in the j-th q^2 bin. This matrix is then used to correct data for resolution and efficiency.

$$
\begin{pmatrix}
N^{G1}_{M1}/\tilde{f}^2_1 & N^{G2}_{M1}/\tilde{f}^2_2 & N^{G3}_{M1}/\tilde{f}^2_3 \\
N^{G1}_{M2}/\tilde{f}^2_1 & N^{G2}_{M2}/\tilde{f}^2_2 & N^{G3}_{M2}/\tilde{f}^2_3 \\
N^{G1}_{M3}/\tilde{f}^2_1 & N^{G2}_{M3}/\tilde{f}^2_2 & N^{G3}_{M3}/\tilde{f}^2_3
\end{pmatrix}^{-1}
\begin{pmatrix} \tilde{M}_1 \\ \tilde{M}_2 \\ \tilde{M}_3 \end{pmatrix}
=
\begin{pmatrix} f^2\left(q^2_1\right) \\ f^2\left(q^2_2\right) \\ f^2\left(q^2_3\right) \end{pmatrix}
$$

We actually use a 10 $\times$ 10 matrix

Correcting for charm backgrounds in $D^0 \to K^- \mu^+ \nu$

$f_+\left(q^2\right)$

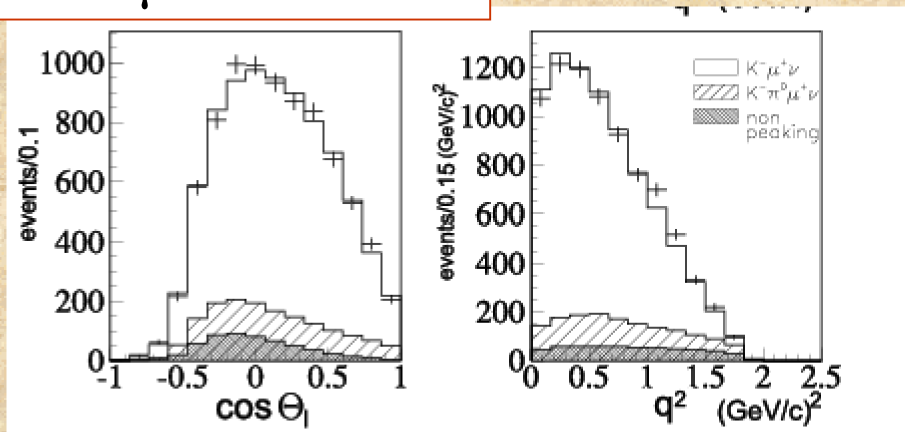


The background only affects the highest q^2 bins.

After subtracting known charm backgrounds, $f_+(q^2)$ is an excellent match to a pole form with m_{pole}= 1.91 ± 0.04 ± 0.05 GeV/c^2 or α = 0.32 (CL 87%, 82%).

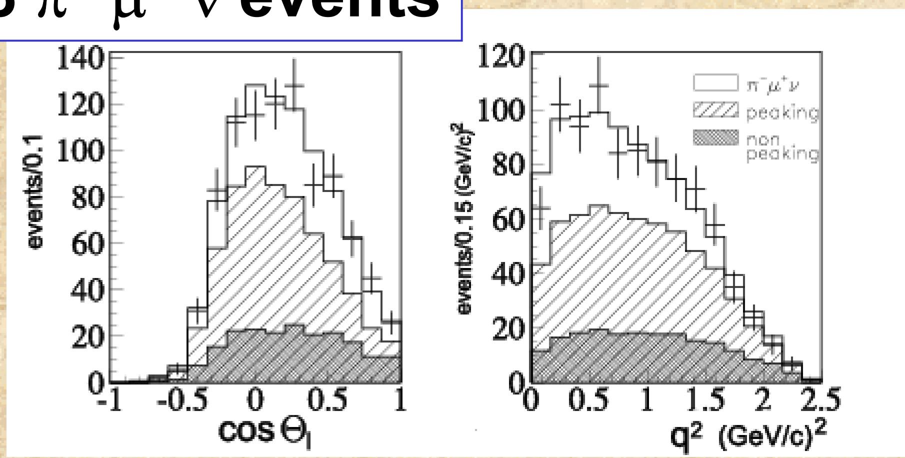
III.b Parameterized $f_+(q^2)$ for $D^0 \to K^- \mu^+ \nu / \pi^- \mu^+ \nu$

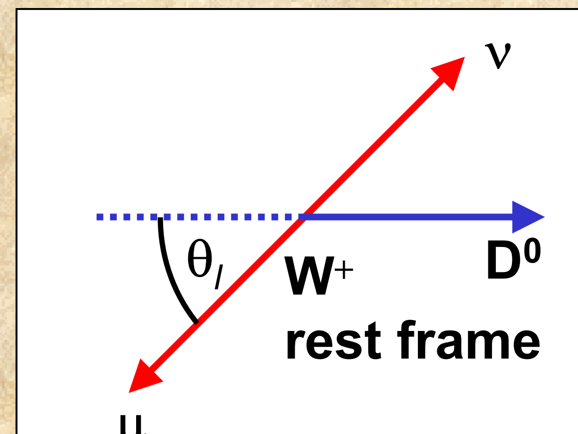
6574 $K^- \mu^+ \nu$ events



- 2-dim fit: $\cos\theta_l$, q^2
- Signal ~ MC with reweighted intensity.
- Backgrounds are floated within known uncertainties.

288 $\pi^- \mu^+ \nu$ events

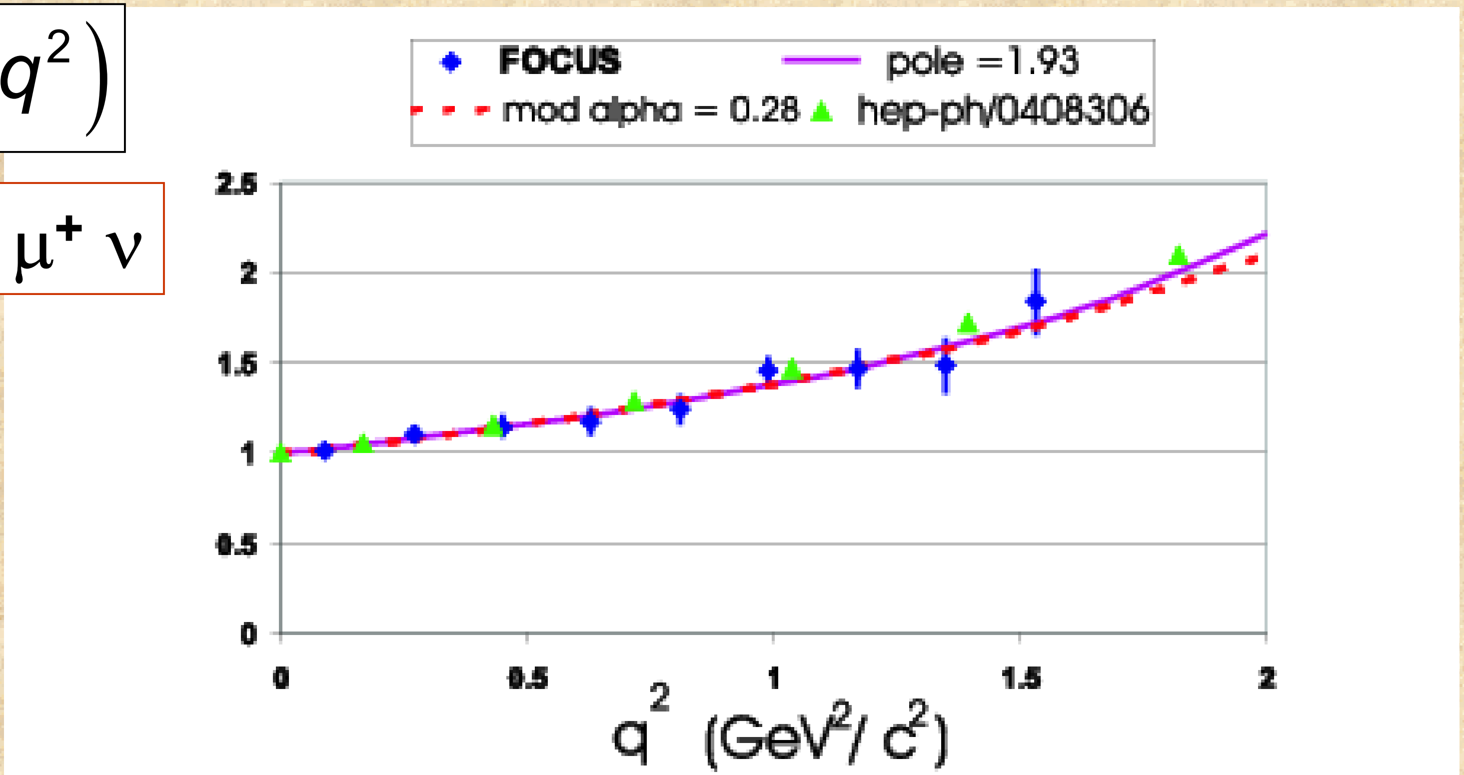




Comparing to Lattice Gauge Result

$f_+\left(q^2\right)$

K⁻ μ⁺ ν

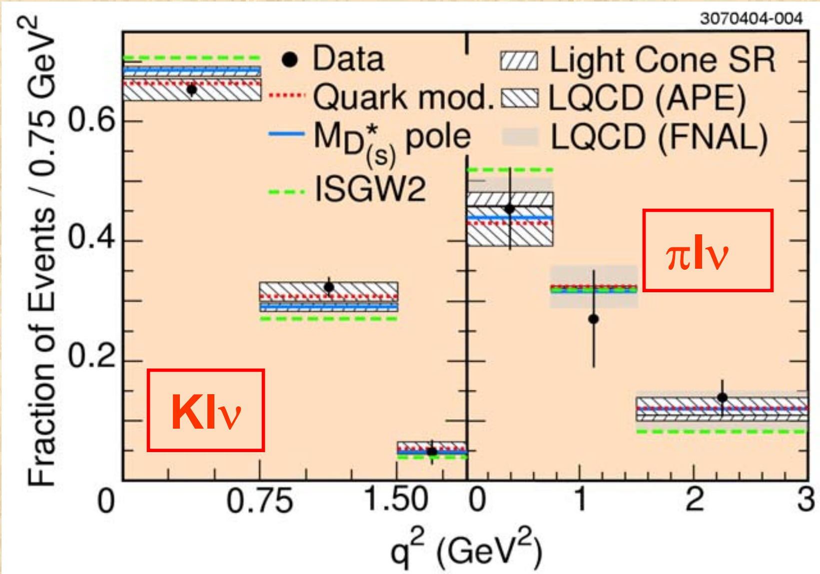


$$K^-\mu^+\upsilon : m_{pole} = 1.93 \pm 0.05 \pm 0.03\ GeV/c^2,\quad \alpha = 0.28 \pm 0.08 \pm 0.07$$

$$f_-(0)/f_+(0) = -1.7^{+1.5}_{-1.4} \pm 0.3$$

$$\pi^-\mu^+\upsilon : m_{pole} = 1.91^{+0.30}_{-0.15} \pm 0.07\ GeV/c^2$$

Other q^2 information in $D^0 \to K^- l^+ \nu / \pi^- l^+ \nu$



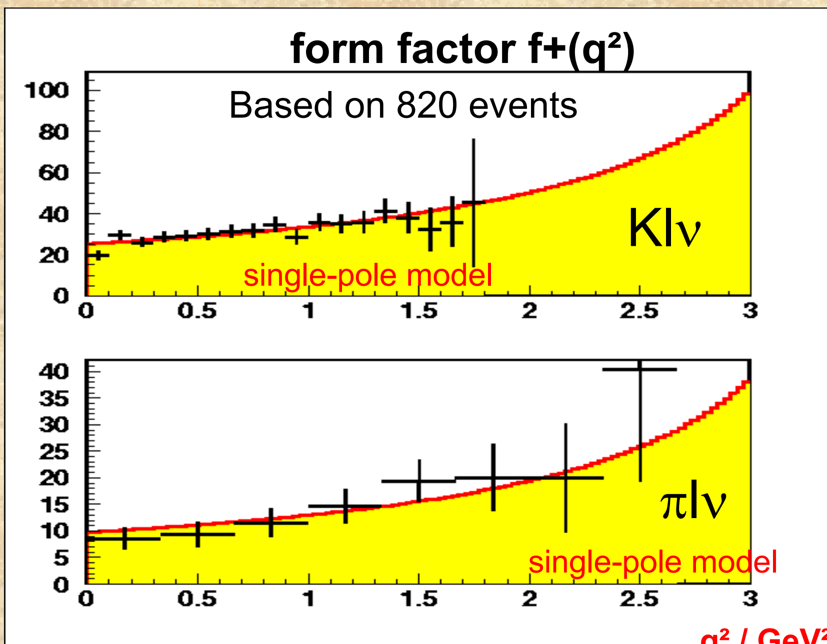
Cleo 2004 $K l \nu$ pole mass is

$$1.89 \pm 0.05^{+0.04}_{-0.03}\ \mathrm{GeV},$$

$\pi l \nu$ pole mass is

$$1.86^{+0.10+0.07}_{-0.06-0.03}\ \mathrm{GeV}$$

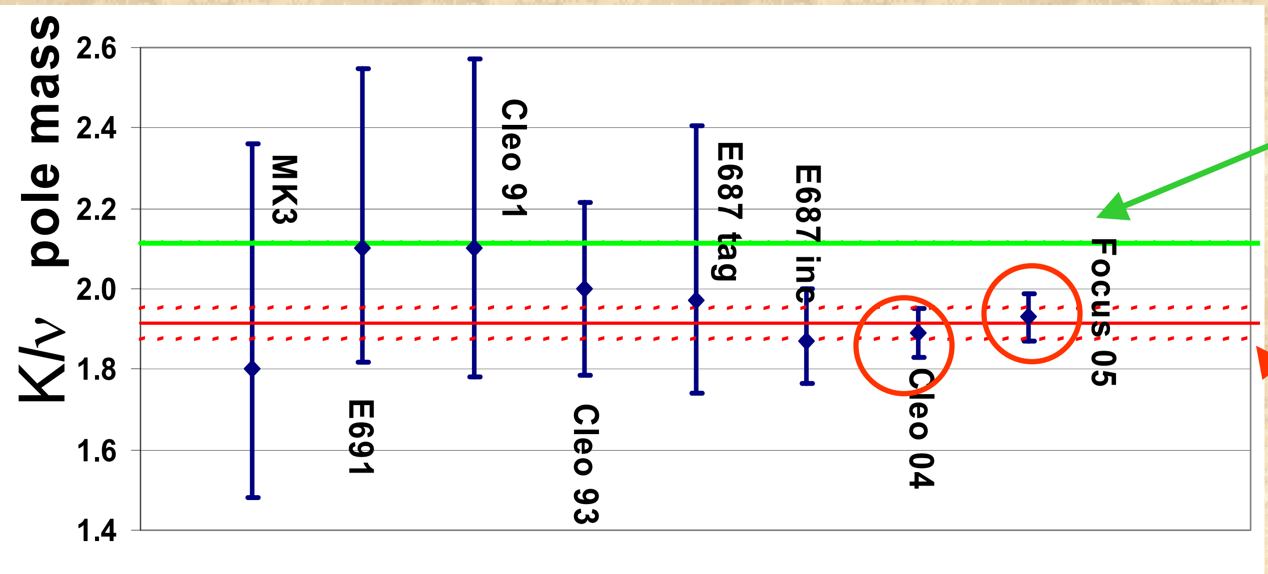
It disfavors ISGW2 form by ~4.2σ



Preliminary study

Summary of $D^0 \to K^- l^+ \nu / \pi^- l^+ \nu$ Results

New world average for $K^- l^+ \nu$



Clearly the data does not favor the simple Ds* pole

$1.91 \pm 0.04 \; GeV/c^2$

New world average for $\pi^- l^+ \nu$

$1.88^{+0.10}_{-0.07} \; GeV/c^2$

$$\frac{d\Gamma(D \to P\ell\nu)}{dq^2} = \frac{G_F^2 |V_{cq}|^2 P_P^3}{24\pi^3} |f_+(q^2)|^2$$

$$f_+ = \frac{f_+(0)}{1 - q^2/m_{\text{pole}}^2}$$

Question slides