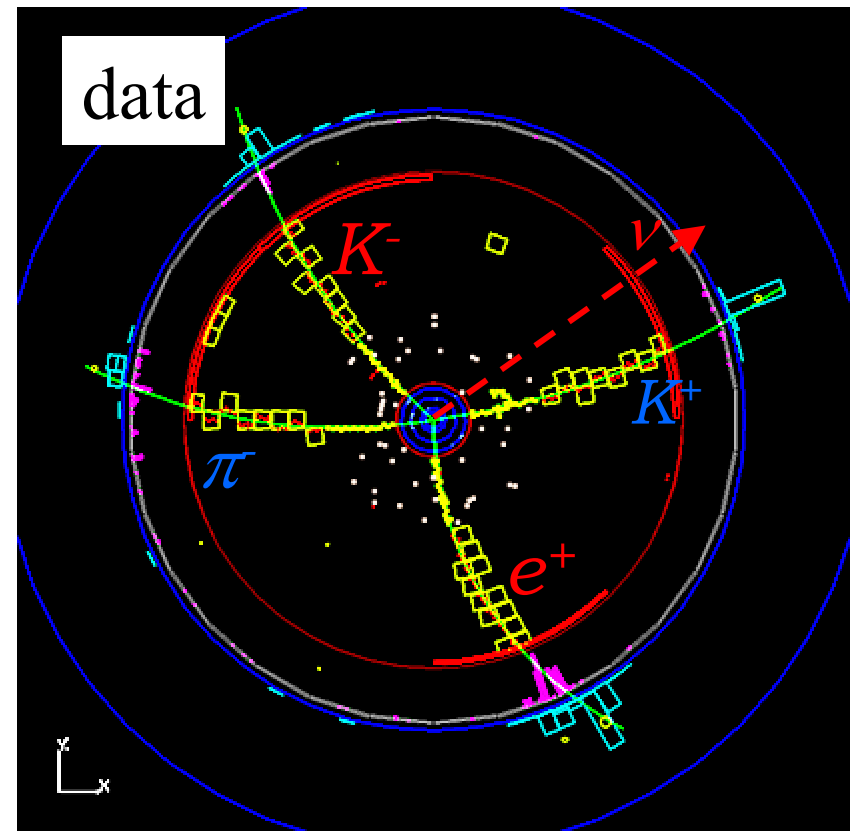# Charm results from CLEOIII, CLEO-c

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Univ. of Pittsburgh

OUTLINE:
1. Introduction to CLEO
2. D 3-body decays
3. Semileptonic D decay

First results from 60pb^{-1} CLEO-c data set taken fall 2003/winter 2004!

data

K^- ν K^+ π e^+

$\psi(3770) \rightarrow D^0 \overline{D^0}$
$\overline{D^0} \rightarrow K^+ \pi^-, \; D^0 \rightarrow K^- e^+ \nu$

What is CLEO?

- **e^+e^- symmetric collider** at cm energy 7-10.6, 3-4.6 GeV
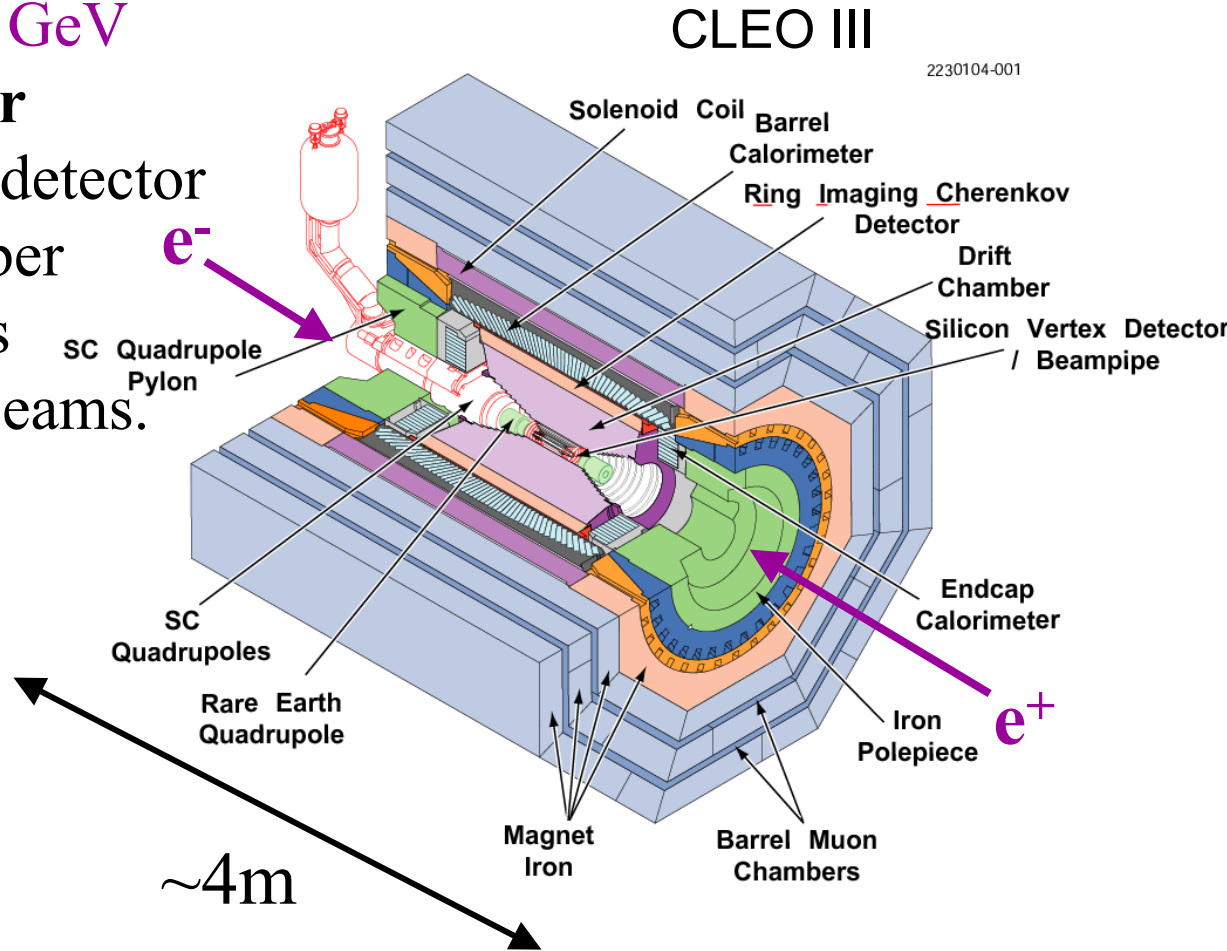- **Standard HEP detector**
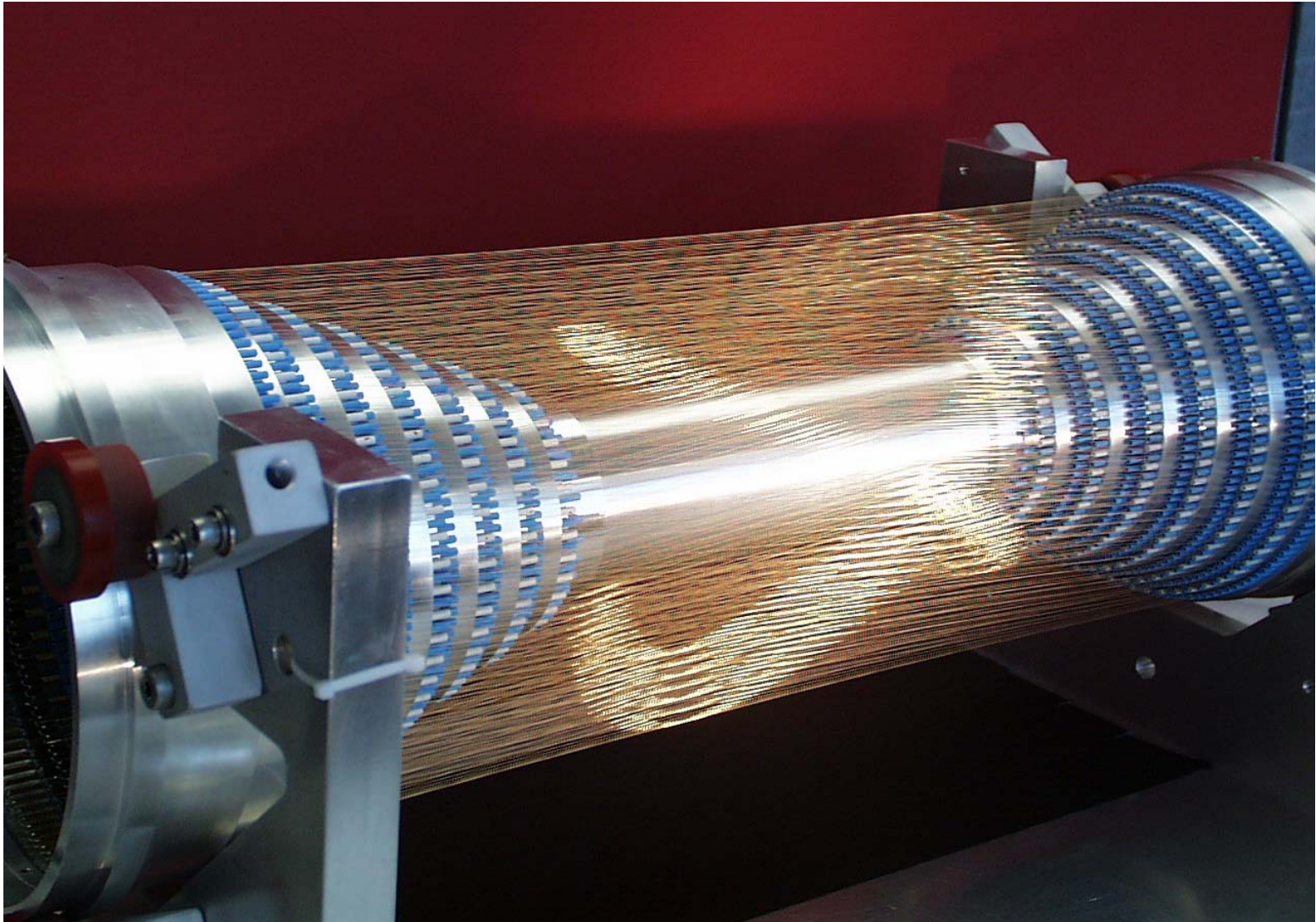- CLEO III had Si vertex detector
- CLEO-c has drift chamber
- CESR-c has 12 wigglers added for low energy beams.

Collaboration=
Carleton, Carnegie Mellon, Cornell, Florida, George Mason, Illinois, Kansas, Northwestern, Minnesota, Pittsburgh, Puerto Rico, Purdue, Rochester, RPI, SMU, Syracuse, Vanderbilt and Wayne State.
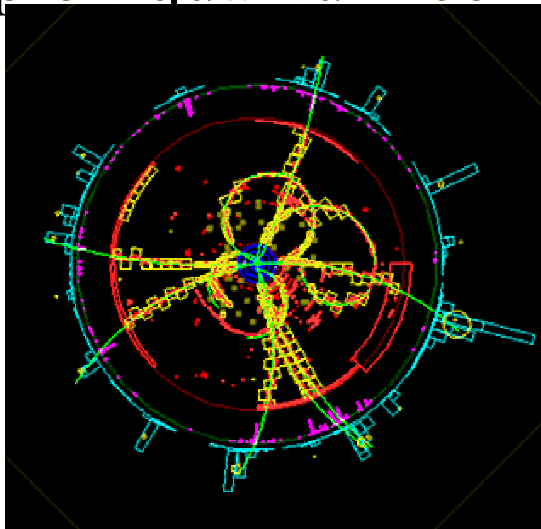
CLEO III

2230104-001

e⁻

e⁺

~4m

Solenoid Coil
Barrel Calorimeter
Ring Imaging Cherenkov Detector
Drift Chamber
Silicon Vertex Detector / Beampipe
SC Quadrupole Pylon
SC Quadrupoles
Rare Earth Quadrupole
Magnet Iron
Barrel Muon Chambers
Iron Polepiece
Endcap Calorimeter

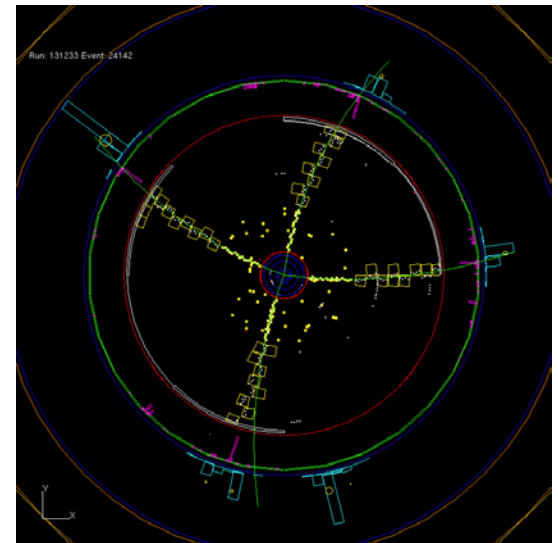# *New drift chamber (ZD) for vertexing*

Techniques

- B factories, $p\bar{p}$ colliders
  - Tag with $D^{*+} \rightarrow D^0 \pi^+$, $D^{*-} \rightarrow \overline{D^0}\pi^-$.
  - Background suppression excellent$\rightarrow$poor
- Charm factory, $\psi(3770) \rightarrow \overline{D^0}D^0$ (~rest)
  - Tag with common decay, e.g. $D^0 \rightarrow K^-\pi^+$
  - threshold $\Rightarrow$cleaner, smaller cross section
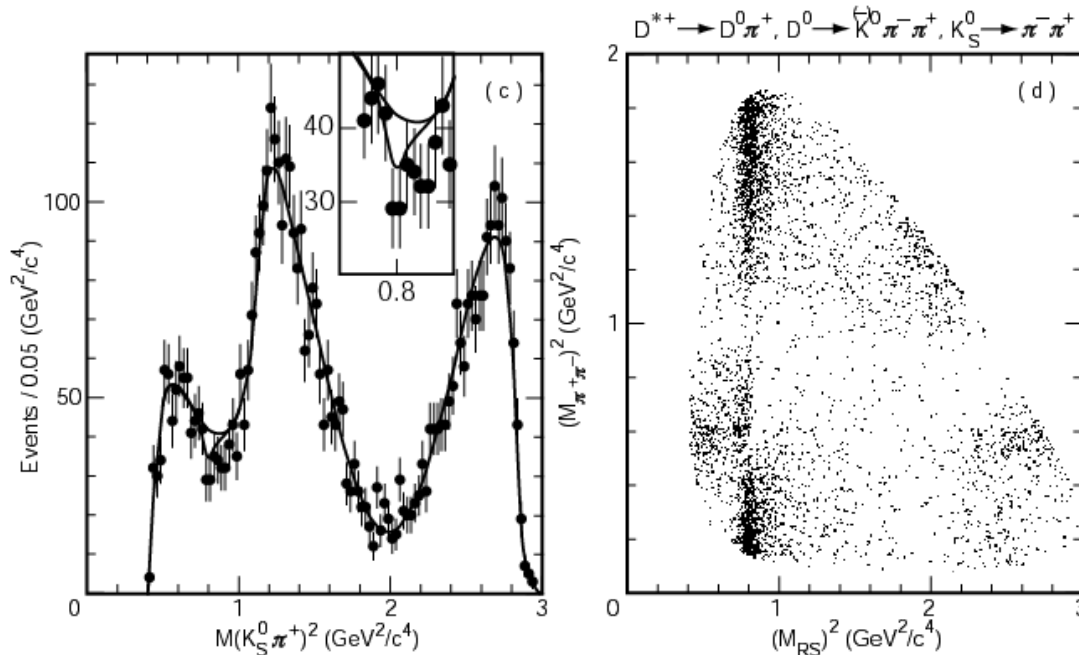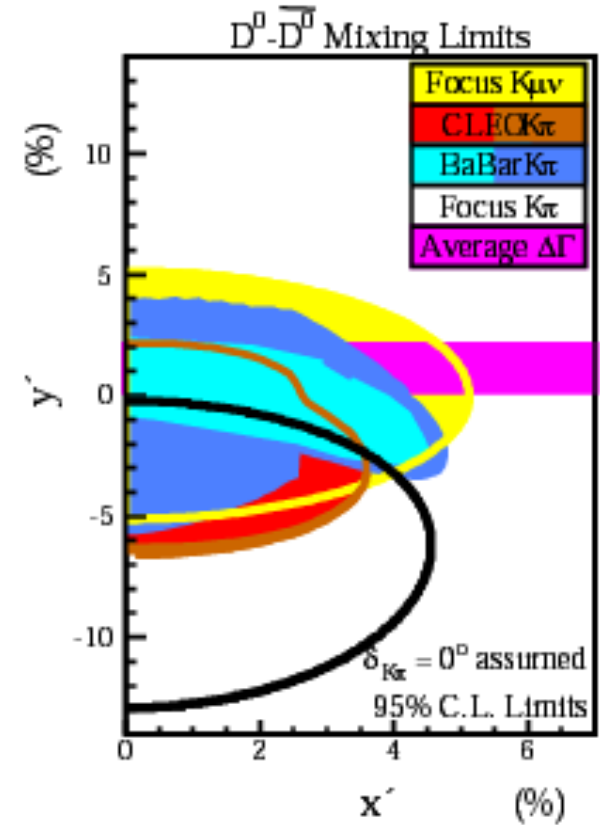 - Exploit quantum correlations

CLEO III data:

CLEO-c data:

Charm Dalitz Plot Analyses

- New & improved hadronic BF
- Study light meson properties
- Search for $D\overline{D}$ mixing, CP violation
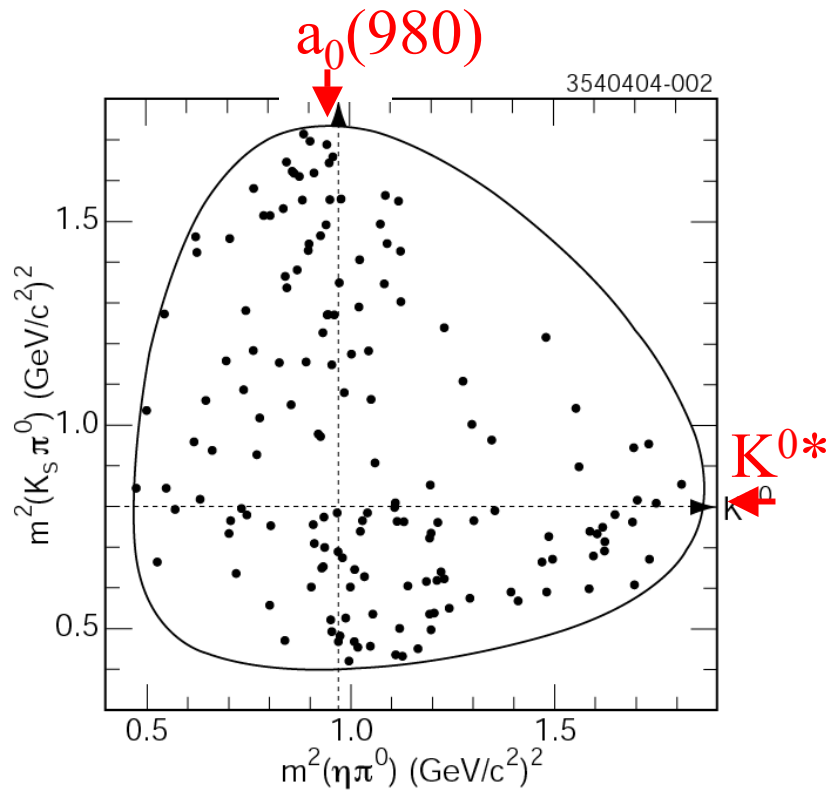
CLEO II: $D \rightarrow K_s\pi^+\pi^-$

$x=\Delta m/\Gamma$

$y=\Delta\Gamma/2\Gamma$

$Rmix=\sqrt{x^2+y^2}$

CLEO II.V: $D \rightarrow K_s \eta \pi^0$
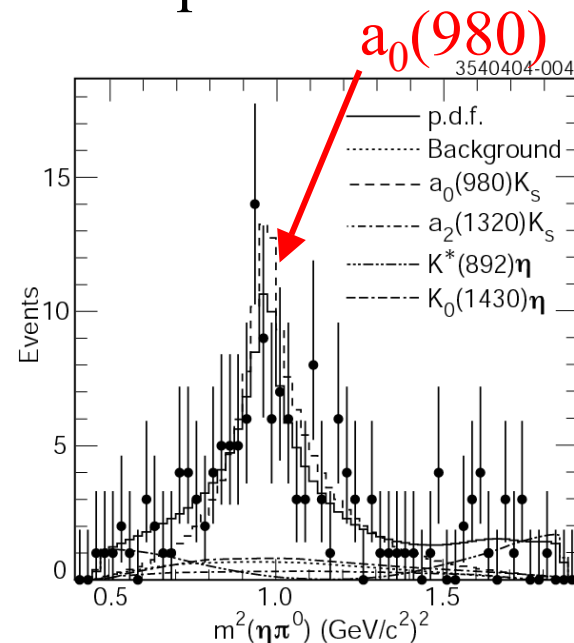
$a_0(980)$

K^{0*}

- First observation of this mode!
- Small sample (155 events), but very clean.
- With more statistics, will have impact on κ, σ puzzle
- Accepted for PRL

$a_0(980)$

$B(D^0 \rightarrow \bar{K}^0 \eta \pi^0) = 1.05 \pm 0.16 \pm 0.14 \pm 0.10\%$

3540404-002

3540404-004

p.d.f.
Background
$a_0(980)K_s$
$a_2(1320)K_s$
$K^*(892)\eta$
$K_0(1430)\eta$
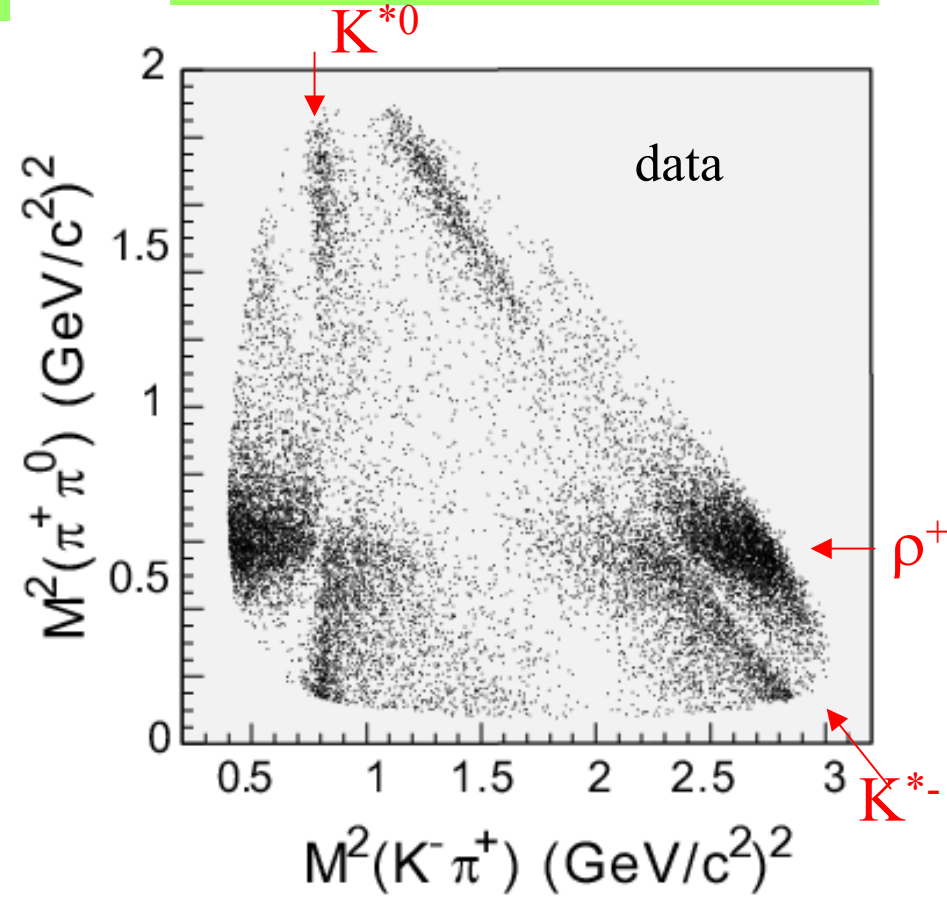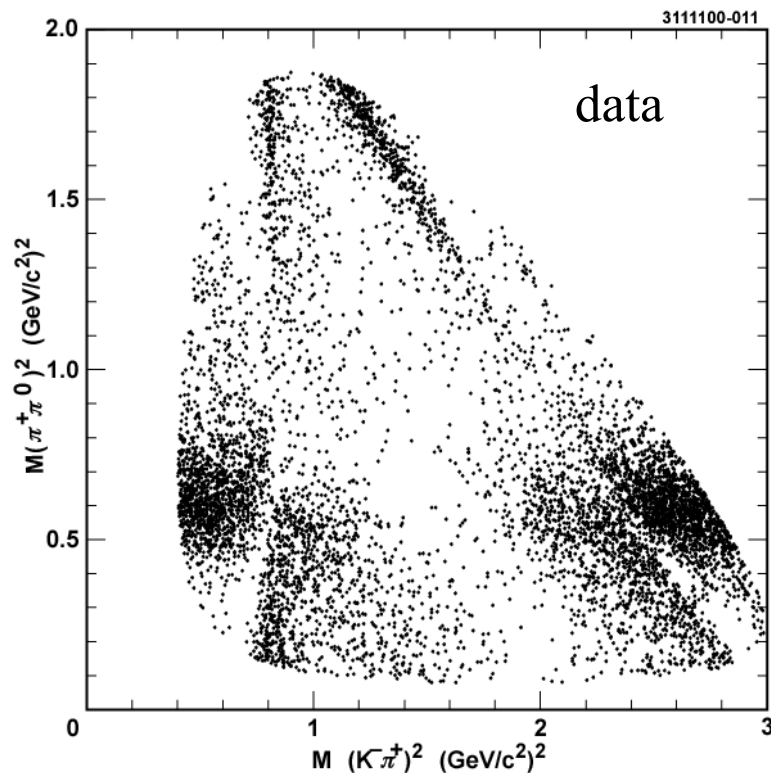
How do B and D factories compare?
e.g. $D^0 \rightarrow K^- \pi^+ \pi^0$ (BF=13.0%)

CLEO II pub., PRD 63 (2001)
- 7070 events/4.7 fb^{-1}
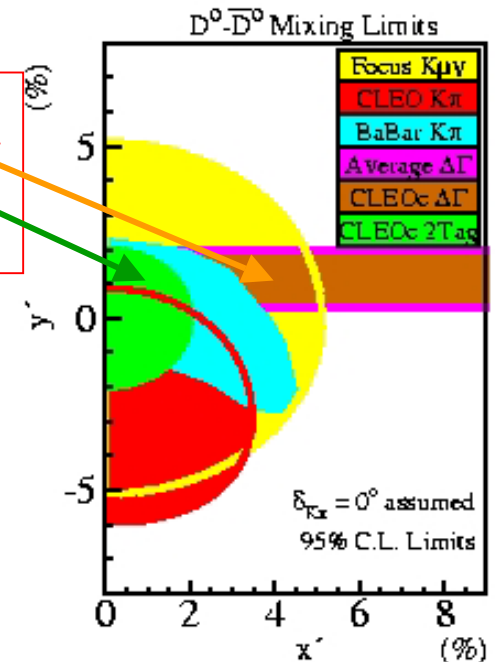- 1 ab^{-1} $\Rightarrow$ 1.5M

CLEO-c, first analysis
- 14590 events/50 pb^{-1}
- 3 fb^{-1} $\Rightarrow$ 1.15M
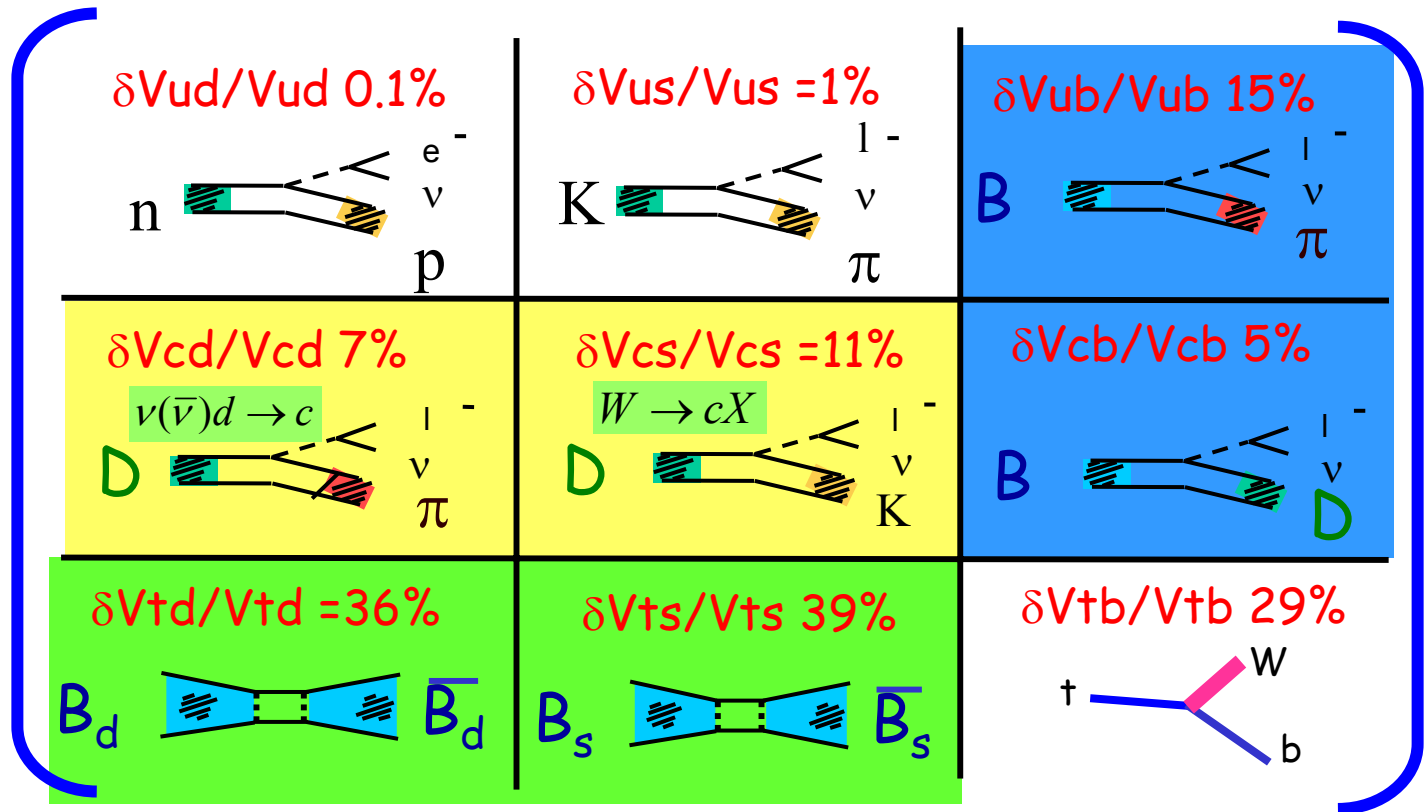
CLEO-c status, goals

- $\sim 3\text{fb}^{-1}$ (each) at $\psi(3770) \rightarrow D\bar{D}$, $e^+e^- \rightarrow D_s\bar{D}_s$
- Analyses underway or planned
  - $D \rightarrow K_s\pi^+\pi^-$, $K_s\pi^0\pi^0$, $D^+ \rightarrow K^-\pi^+\pi^+$
  - $D \rightarrow K^-\pi^+\pi^0$, $K^-K^+\pi^0$, $K^-\pi^+(K^+\pi^-)$
  - $D(\bar{D}) \rightarrow K^-e^+\nu(K^+e^-\nu)$
- Goals
  - Settle existence of κ (proposed
        $L=0$ $K\pi$ resonance)
  - strong phase, $\cos\delta < \pm 0.05$
  - $\sqrt{2R_{mix}} = \sqrt{x^2+y^2} < 2\%$ (95% c.l.)
  - $|y| < 0.6\%$ (95% c.l.)

CLEO-c goal
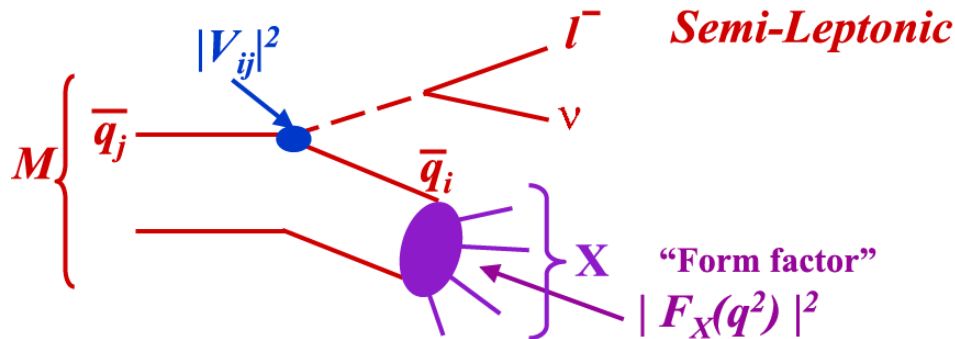
Big goal is to constrain CKM matrix
various labs, theory all have a role

$\delta Vud/Vud$ 0.1%	$\delta Vus/Vus$ =1%	$\delta Vub/Vub$ 15%
$\delta Vcd/Vcd$ 7%	$\delta Vcs/Vcs$ =11%	$\delta Vcb/Vcb$ 5%
$\delta Vtd/Vtd$ =36%	$\delta Vts/Vts$ 39%	$\delta Vtb/Vtb$ 29%

$\nu(\bar{\nu})d \to c$

$W \to cX$

CLEO-c

CLEO-c + Lattice QCD +B factories

CLEO-c + Lattice QCD +B factories + ppbar

theory

Semi-Leptonic

$|V_{ij}|^2$

M { $\bar{q}_j$ $\bar{q}_i$ }

l^-

ν

X

"Form factor"

$|F_X(q^2)|^2$

$$\frac{d\Gamma}{dq^2} = \frac{G_F^2}{24\pi^3}|V_{cd}|^2 p_\pi^3 |f_+(q^2)|^2$$

$D^0 \to \pi l\nu$

phenom

Lattice QCD

$\square$ f_0
$\diamond$ f_+
$*$ experiment

$D^0 \to \pi l\nu$

Form factor

q² (GeV²)
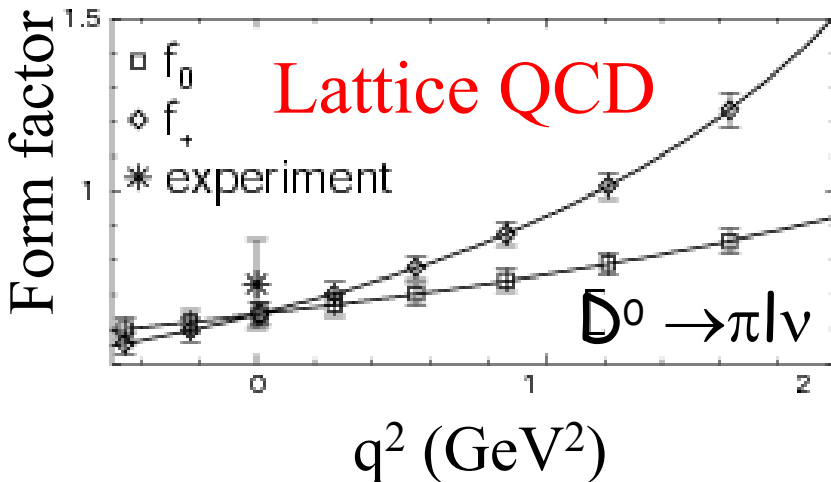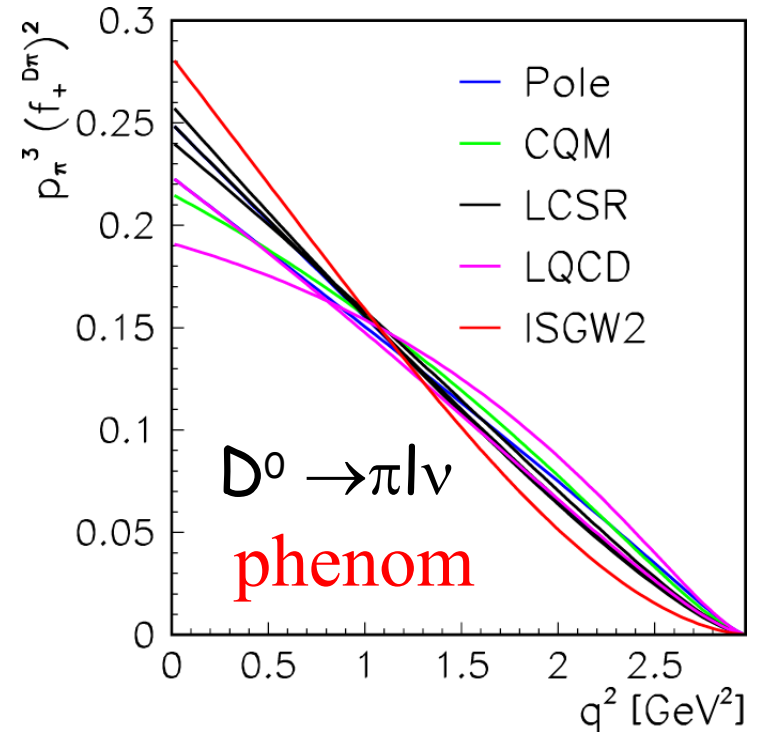
Phenom is interesting, incomplete
Lattice QCD (Okamoto, 2004)
Interesting interplay of **weak**
and **strong** interaction!

PDG on D semileptonic decays

- $D \to K^- e^+ \nu$ $3.58 \pm 0.18\%$
- $D \to K^- \mu^+ \nu$ $3.19 \pm 0.17\%$
- $D \to \pi^- e^+ \nu$ $0.36 \pm 0.06\%$ Cabibbo suppr.
- $D \to K^{*-} e^+ \nu$ $2.15 \pm 0.35\%$ vector
- $D \to \rho^- e^+ \nu$????   vector
- Data on Form factors sketchy
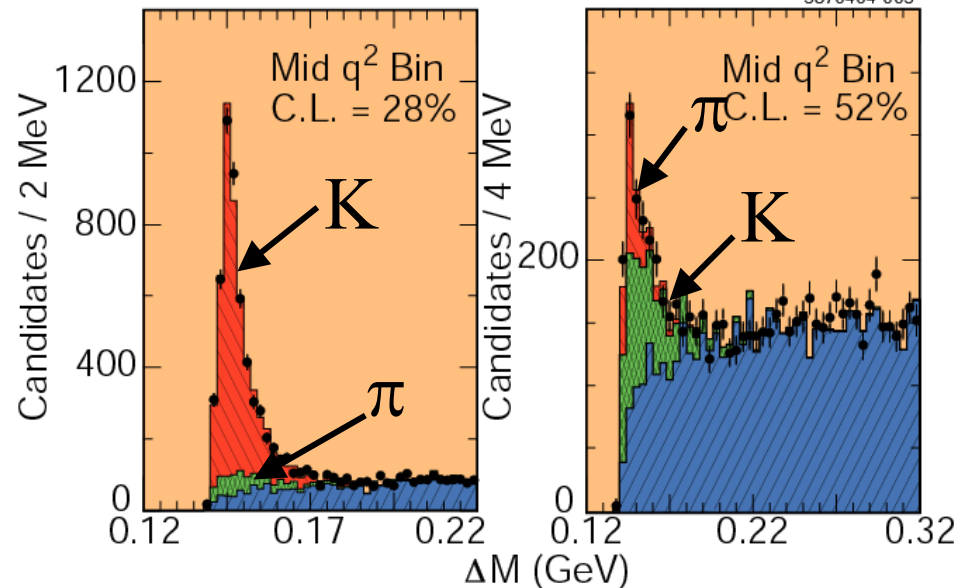
CLEO3 has new results (final) for $D \to \pi^- e^+ \nu$
CLEOc has preliminary results for all channels!

CLEO III D → (K,π)eν

D→K⁻e⁺ν   D→π⁻e⁺ν

$$\Delta M = M(\pi_s hl\nu) - M(hl\nu)$$

- Best BF ratio meas., first form factor result for D→πeν
- Results subm. to PRL

$$\frac{B(D^0 \to \pi e\nu)}{B(D^0 \to Ke\nu)} = 0.082 \pm 0.006 \pm 0.005$$
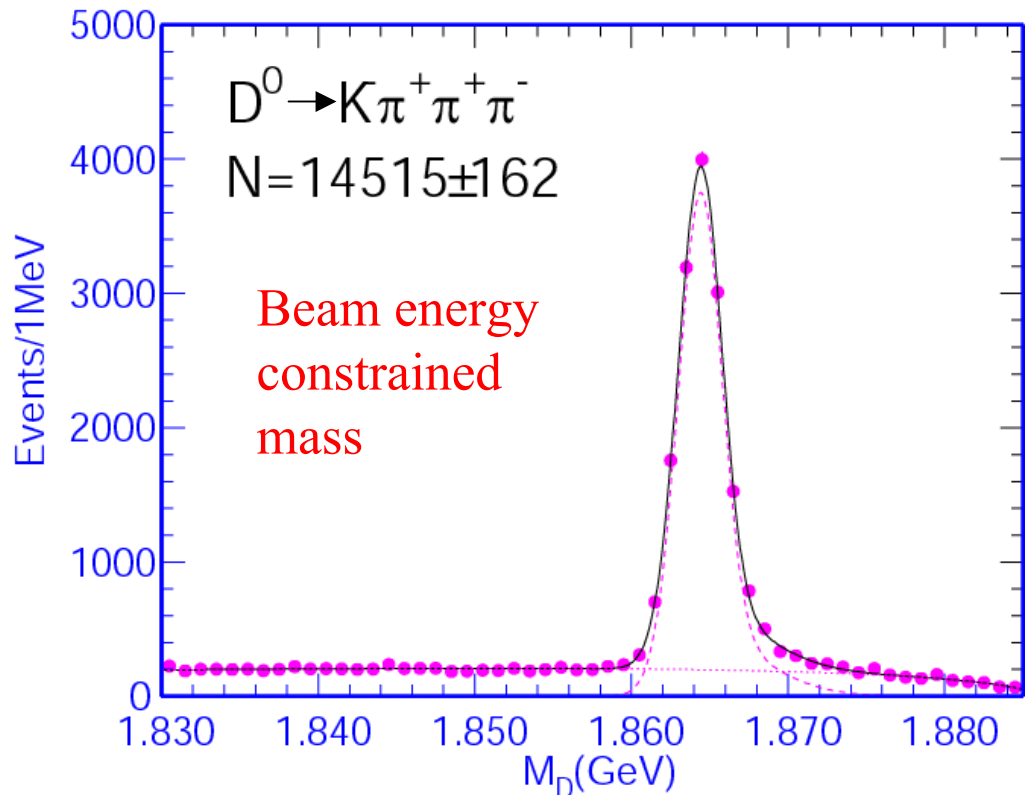
$$vs\, RPP(2004) = 0.101 \pm 0.017$$
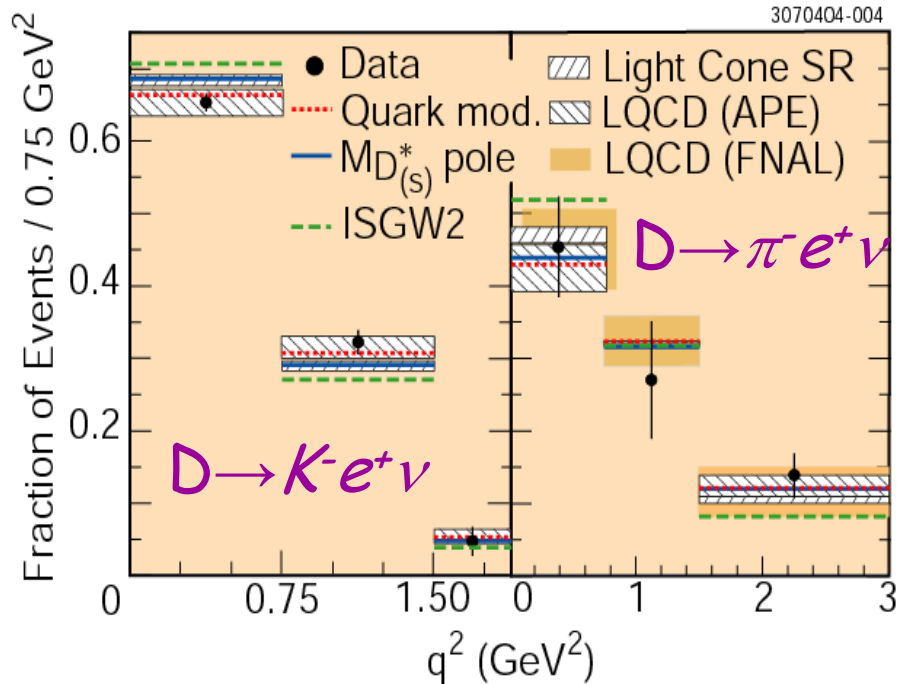
CLEO-c tagging

Modes: $K^-\pi^+$, $K^-\pi^+\pi^0$, $K^-\pi^+\pi^0\pi^0$, $K^-\pi^+\pi^+\pi^-$,
$K_s\pi^+\pi^-$, $K_s\pi^+\pi^-\pi^0$, $K_s\pi^0$, $\pi^-\pi^+\pi^0$, K^-K^+

$\Sigma BF=44.9\%$
$\Sigma(BF*\varepsilon_{tag})=2*12.8\%$
$=25.6\%$

Total= 59432 ± 364
tagged events

$D^0 \rightarrow K\pi^+\pi^+\pi^-$
$N=14515\pm162$

Beam energy constrained mass

CLEO-c has better event definition e.g., $D \rightarrow \pi e \nu$

3070404-003

Mid q^2 Bin
C.L. = 52%

π

K   mistag

Candidates / 4 MeV

200

0

0.12   0.22   0.32

ΔM(GeV)

Events/5 MeV

$D^0 \rightarrow \pi e \nu$

$D^0 \rightarrow Ke^+\nu$
D^0 other decays
$D^0 \rightarrow \bar{\rho}e^+\nu$
$D^0 \rightarrow K^* e^+\nu$
D^+ Decays

$D \rightarrow Ke\nu$

25

20

15

10

5

-0.1 -0.05 0 0.05 0.1 0.15 0.2 0.25 0.3

$E_{miss}-p_{miss}$(GeV)
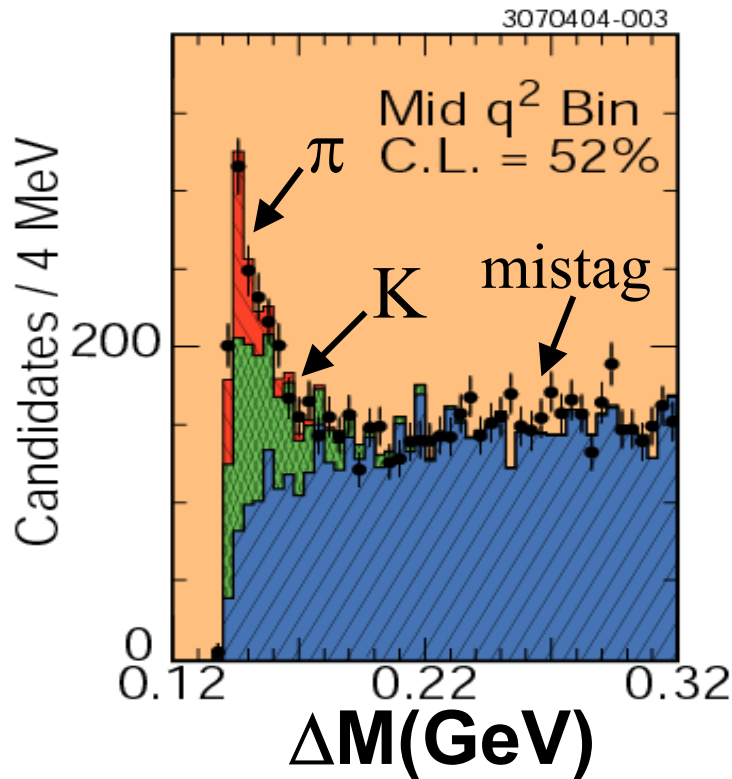
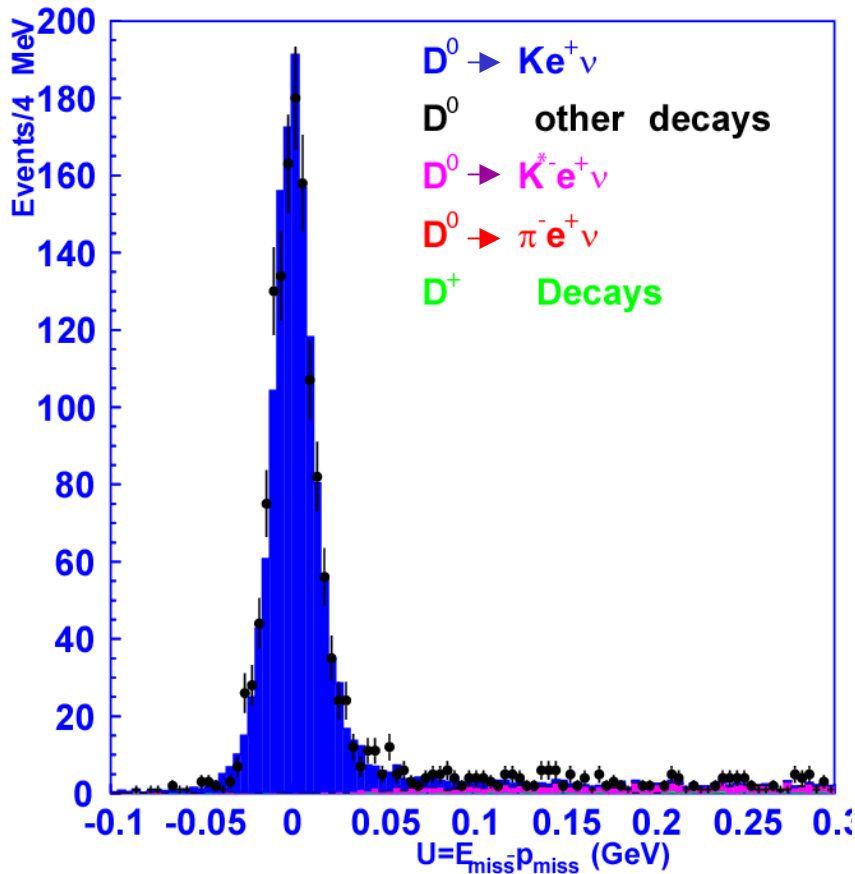**CLEO III**: 6.7 fb^{-1} at Υ(4S)

tag π_{slow}
Excellent π/K with RICH
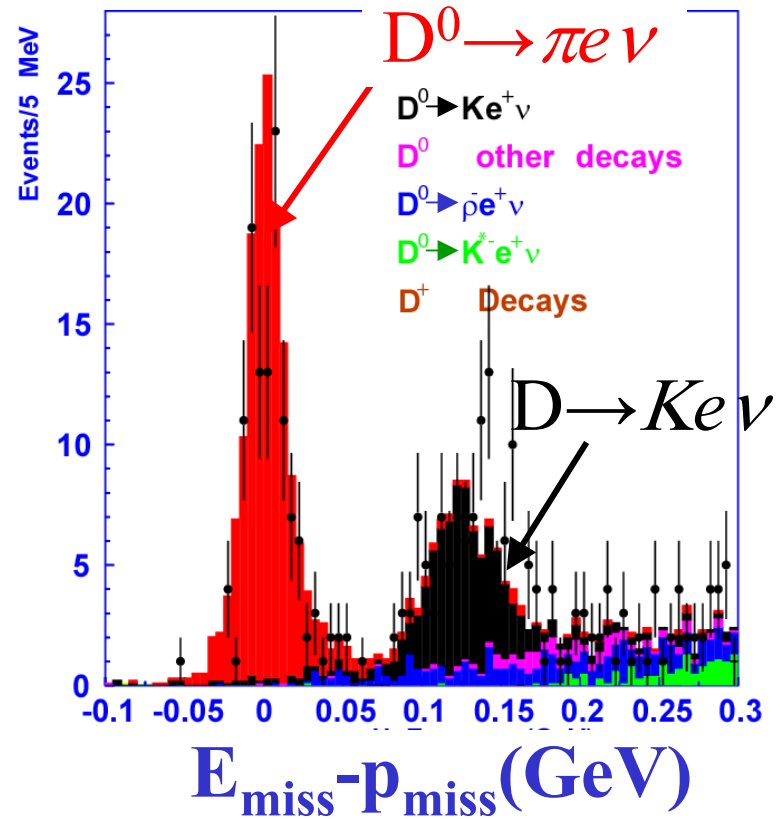
CLEO-c: 109±11 events

60 pb^{-1} at ψ(3770)
tag 9 hadronic decay modes

CLEO-c $D \to Ke\nu$, $K^*e\nu$

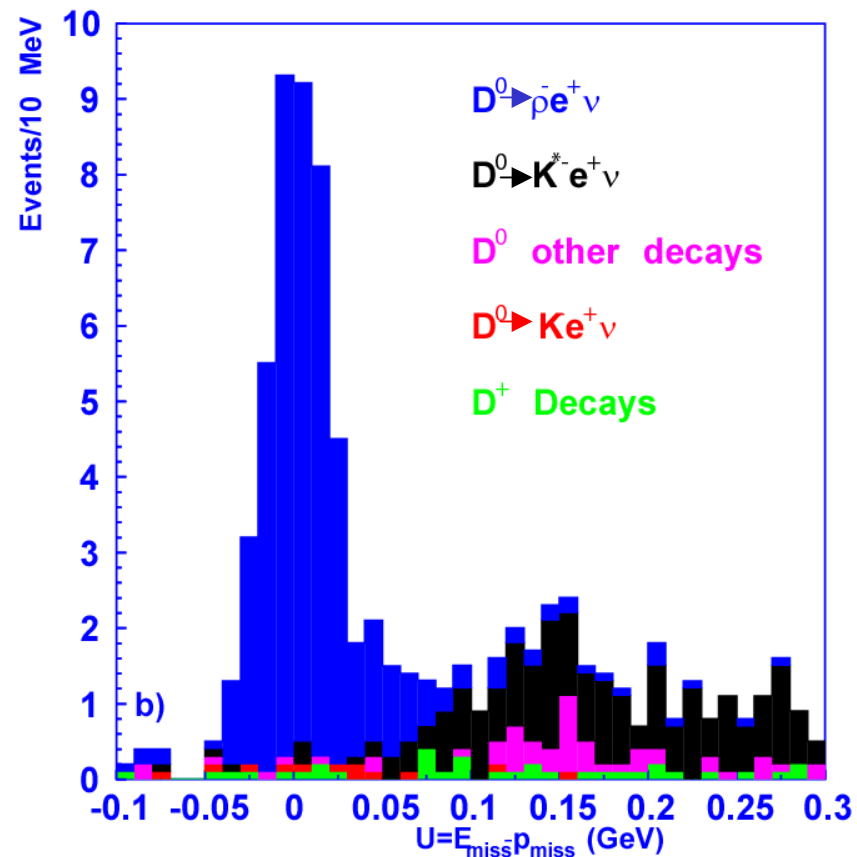D→Keν: 1405±39 events
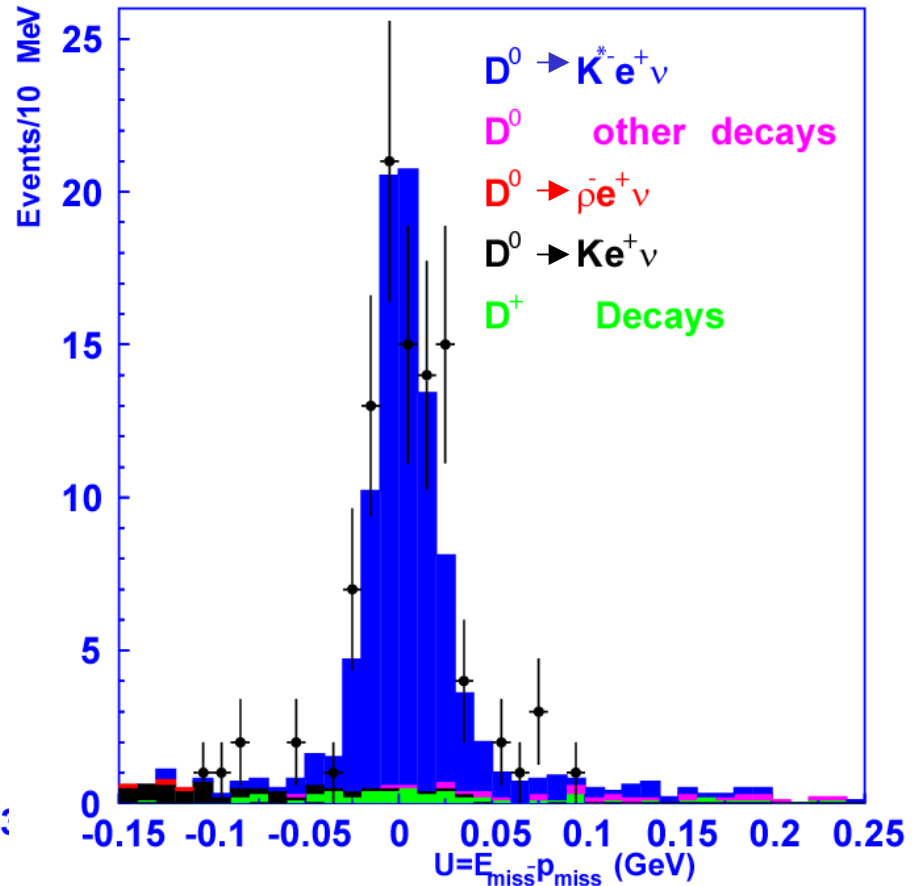
D→K*eν: N=88.0 ±9.7

Something new!
D→ρ semileptonic decay
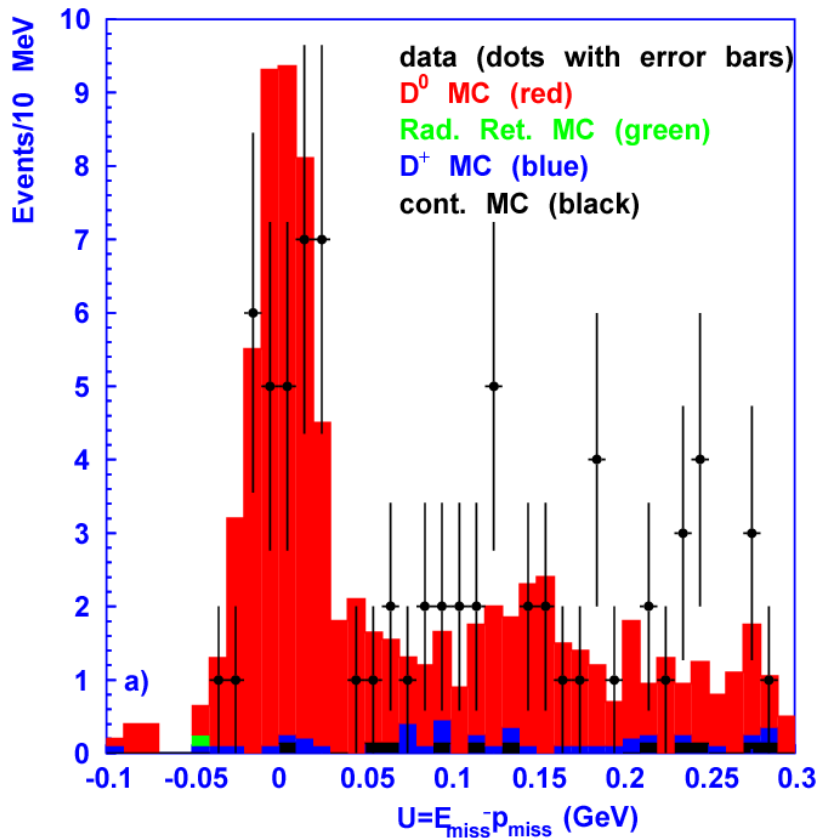
$N(D^0 \to \rho^- e^+ \nu) = 30.1 \pm 5.8$

BF with CLEO-c now (60 pb⁻¹)

mode	CLEO-c	PDG
$\mathsf{B}(D \to K^- e^+ \nu)$	3.52±0.10±0.25%	3.58±0.18%
$\mathsf{B}(D \to \pi^- e^+ \nu)$	0.25±0.03±0.02%	0.36±0.06%
$\mathsf{B}(D \to K^{*-} e^+ \nu)$	2.07±0.23±0.18%	2.15±0.35%
$\mathsf{B}(D \to \rho^- e^+ \nu)$	0.19±0.04±0.02%	-
$\dfrac{\mathbf{B}(D^0 \to \pi e \nu)}{\mathbf{B}(D^0 \to K e \nu)}$	0.070±0.007±0.003	0.101±0.017

CLEO III: 0.082 ±0.006 ±0.005

CLEO-c projected (3fb⁻¹)

q^2 dist. now

Data (uncorrected)

$D^0 \rightarrow K e^+ \nu$

- BF improvement dramatic
- FF, V_{cd}, V_{cs} separated with lattice FF(0).
- q^2 resolution ~0.03 GeV²
- $\delta V_{cd}/V_{cd} \cong 1.7\%$

$D \rightarrow K^- e^+ \nu$
$D \rightarrow K^{*-} e^+ \nu$
$D \rightarrow \pi^- e^+ \nu$
$D \rightarrow \rho^- e^+ \nu$
$D^+ \rightarrow K^0 e^+ \nu$
$D^+ \rightarrow K^{0*} e^+ \nu$
$D^+ \rightarrow \pi^0 e^+ \nu$
$D^+ \rightarrow \rho^0 e^+ \nu$
$D_s \rightarrow K^0 e^+ \nu$
$D_s \rightarrow K^{*0} e^+ \nu$
$D_s \rightarrow \phi e^+ \nu$

PDG

CLEO-c goal

Summary, Outlook

- New CLEO II.V, III results
  - Observe $D \rightarrow K_s \eta \pi^0$ decay BF for first time (η is unusual)
  - $D \rightarrow \pi l \nu$ and $D \rightarrow K l \nu$ form factor meas. (first time for π)
- CLEO-c results are coming quickly!!
  - $D \rightarrow \pi e \nu, K e \nu, K^* e \nu$ BF measured, accuracy $\approx$ PDG
  - $D \rightarrow \rho e \nu$ BF measured for first time
  - High quality **form factor, V_{cd}, V_{cs}** meas. to come
- CLEO-c and B factories are complementary
  - Statistics will be similar with 3 fb^{-1} and 1 ab^{-1}, resp.
  - CLEO-c has advantage where bkgd suppression important