Recent (Charm) Electroweak Results from CLEO

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- III: Semileptonic D decays: Exclusive
- IV: Semileptonic D decays: Inclusive
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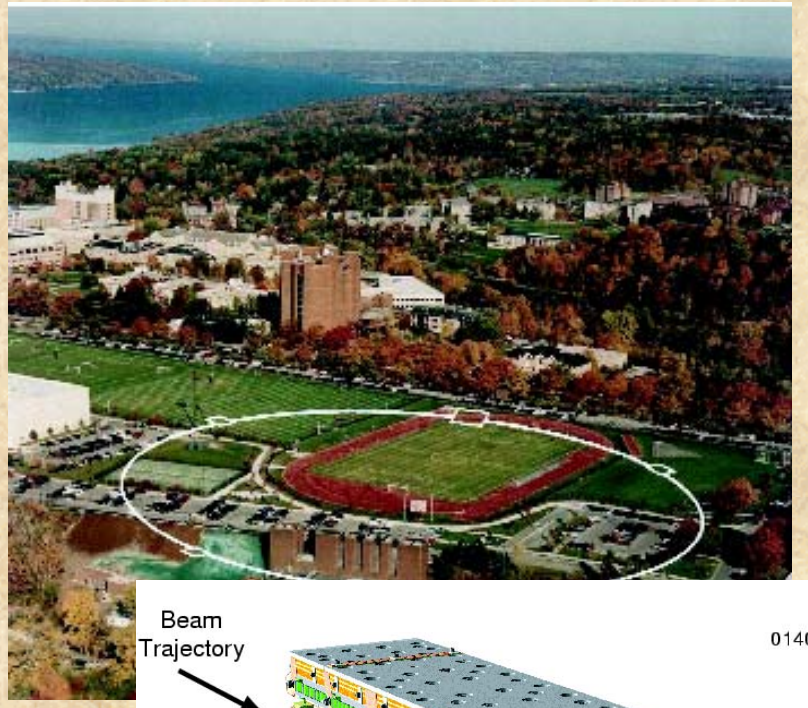
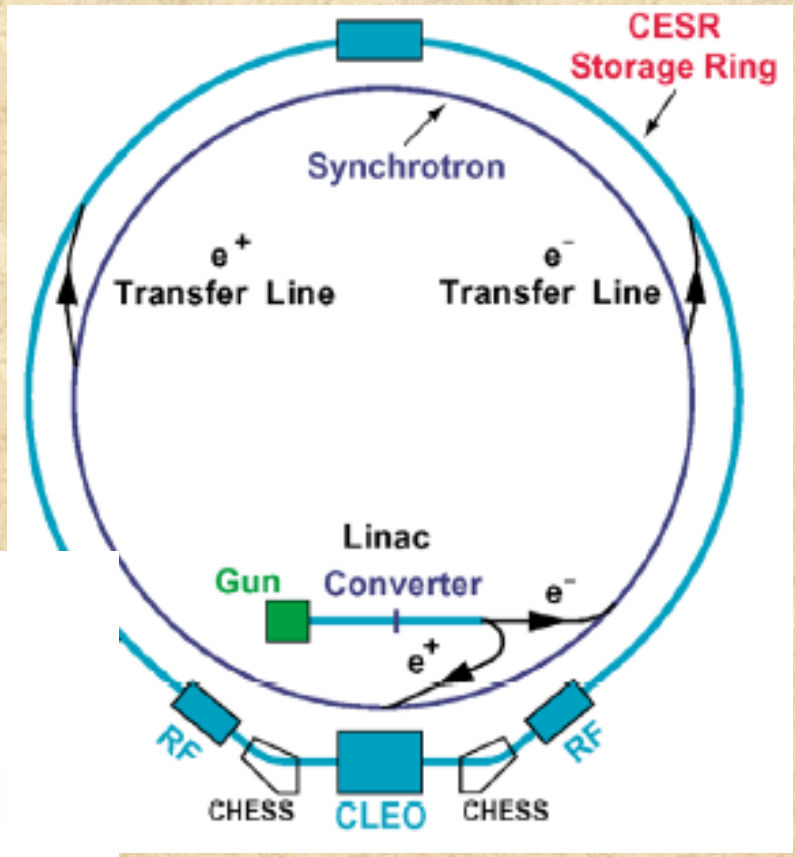
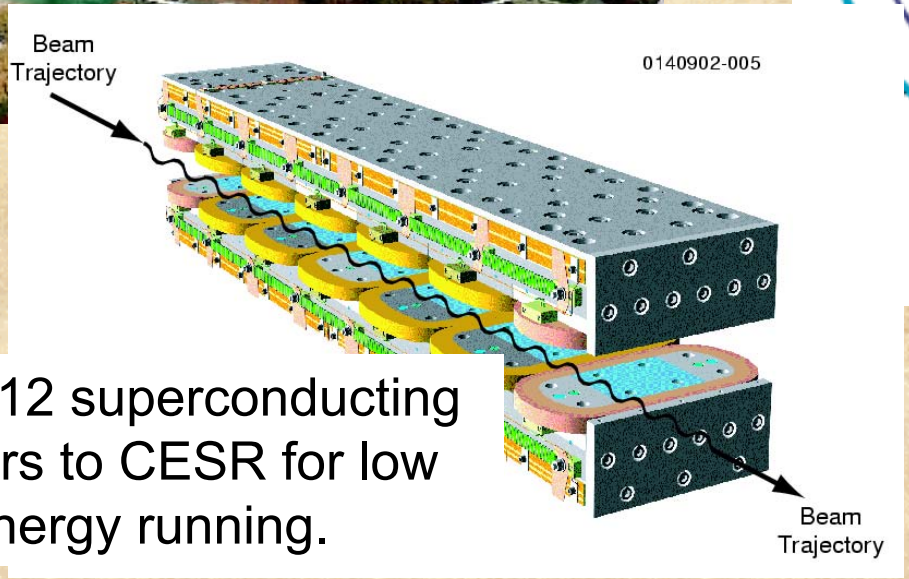
- VI: CPV from CLEO II.V
- VII: Summary & Future.

I. The Cornell Electron Storage Ring (CESR)







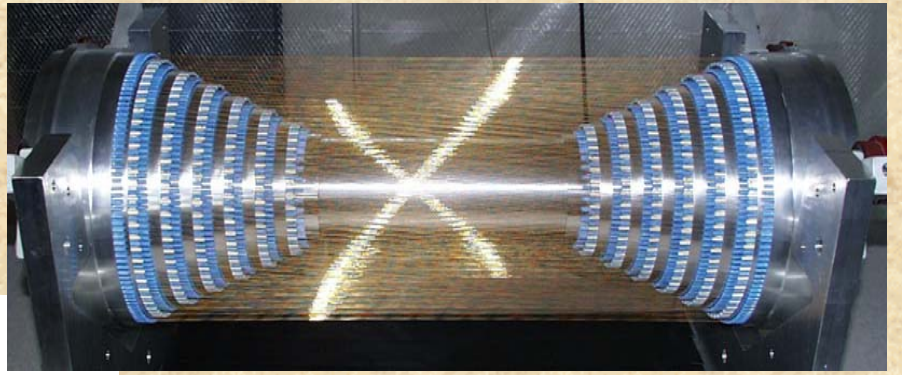
Added 12 superconducting wigglers to CESR for low energy running.

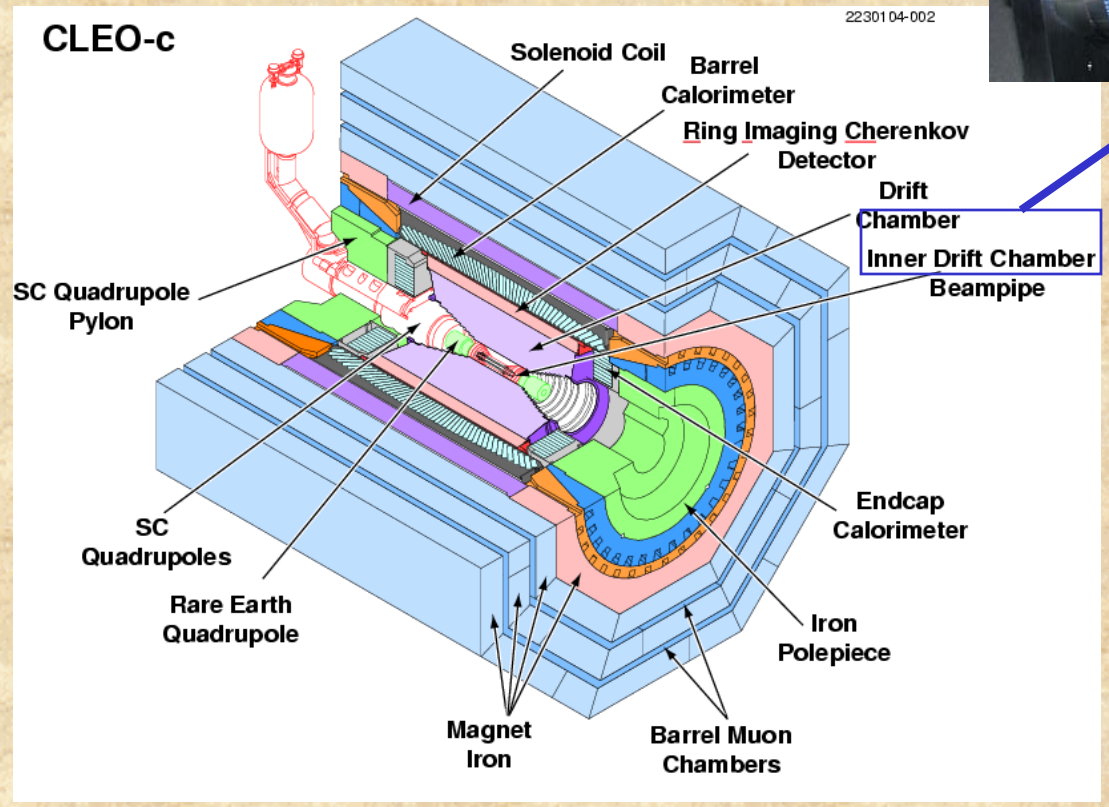
E_{beam} = 1.5 – 5.6 GeV

The CLEO-c Detector

Run plan: ψ', $\psi(3770)$ and Ds, J/ ψ thresholds.

CLEO-c ≅ CLEO III det.

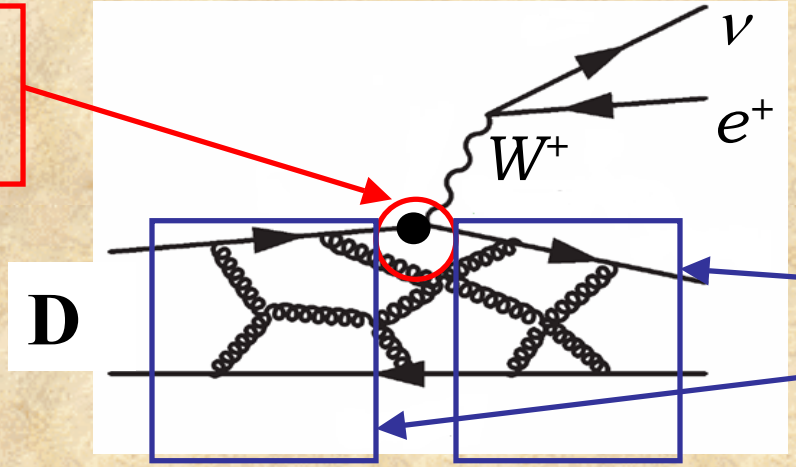




- New inner drift chamber replaced old silicon vertex
- 1T B field (old 1.5 T)
- Track (93% of 4π): σ = 0.6% @ 1 GeV
- PID: Rich (80% of 4π), dE/dx, EM calorimeter, muon (> 1GeV)
- Eγ: σ = 2.2% @ 1 GeV, 5% @ 100 MeV.

Impact of CLEO-c Measurements

Electroweak Physics: V_{cq}



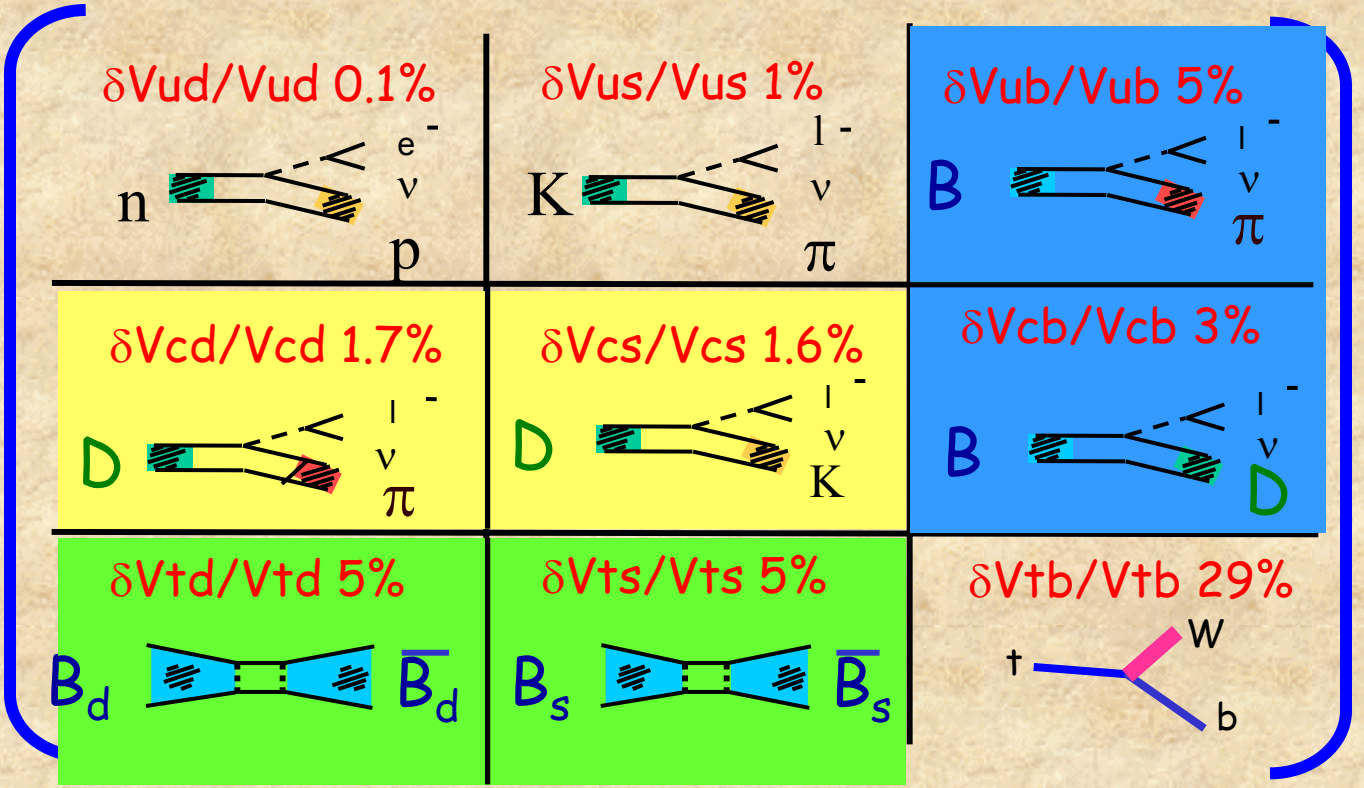
An example of semileptonic decay

QCD: form factors

- Leptonic decays give **f_D and f_{Ds}**
  - validate Lattice QCD and improve f_B
- Semileptonic decays give **V_{cs}, V_{cd}** and form factors
  - test theoretical form factor models
  - enhance LQCD calculations, which will improve B decay form factors.
  - test CKM unitarity.
- Improved (already) BF measurements of many important normalization modes and more coming.
- Hadronic decays measure strong phases, needed for CPV.
- Initial state is coherent: Ideal for charm mixing and CPV.

The Future of Precision Flavor Physics

The Goal: Measure all CKM matrix elements and associated phases in order to over-constrain the unitary triangles.

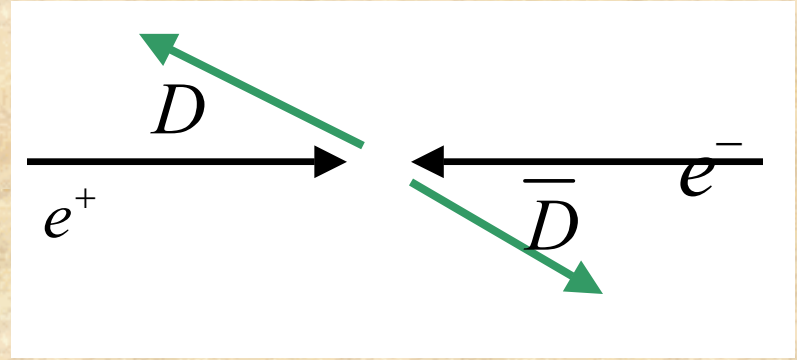


CLEO-c

CLEO-c + Lattice QCD +B factories

CLEO-c + Lattice QCD +B factories + ppbar

ψ(3770) Analysis Techniques



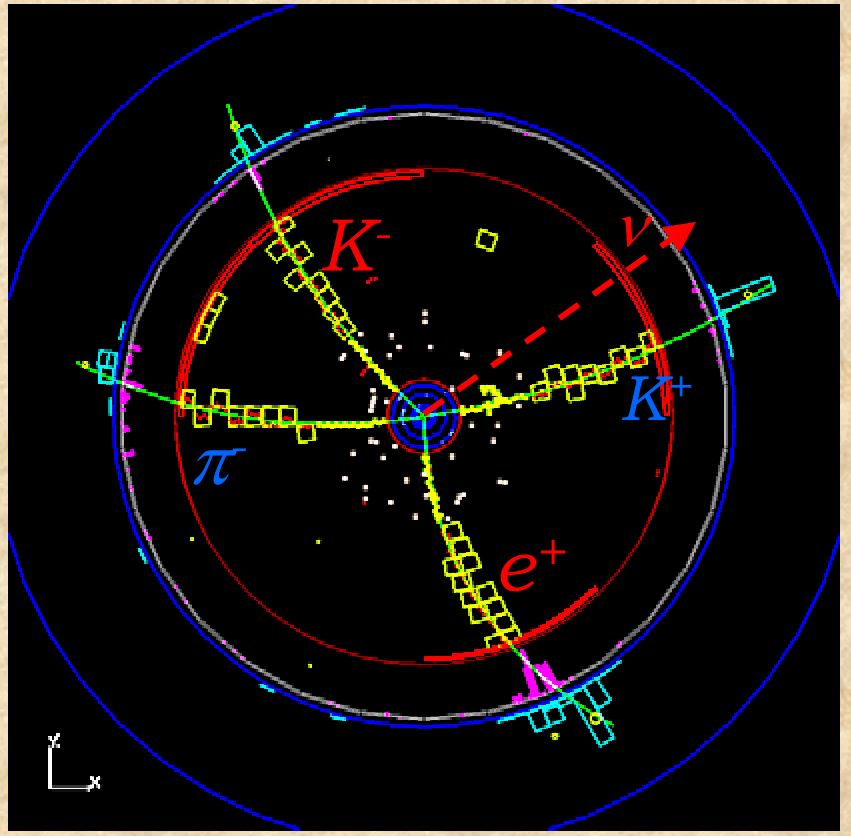
Fully reconstruct 1st D "the tag", then analyze decay of 2nd D to extract exclusive or inclusive properties.

ψ(3770) ~ DDbar threshold

➔ No extra fragmentation = simpler geometry / combination

➔ Clean neutrino reconstruction

➔ High tagging efficiency at 25% of all D's produced.



$$\psi(3770) \rightarrow D^0 \overline{D^0}$$

$$\overline{D^0} \rightarrow K^+\pi^-, D^0 \rightarrow K^-e^+\nu$$

Examples of CLEO-c Tagged *D* samples

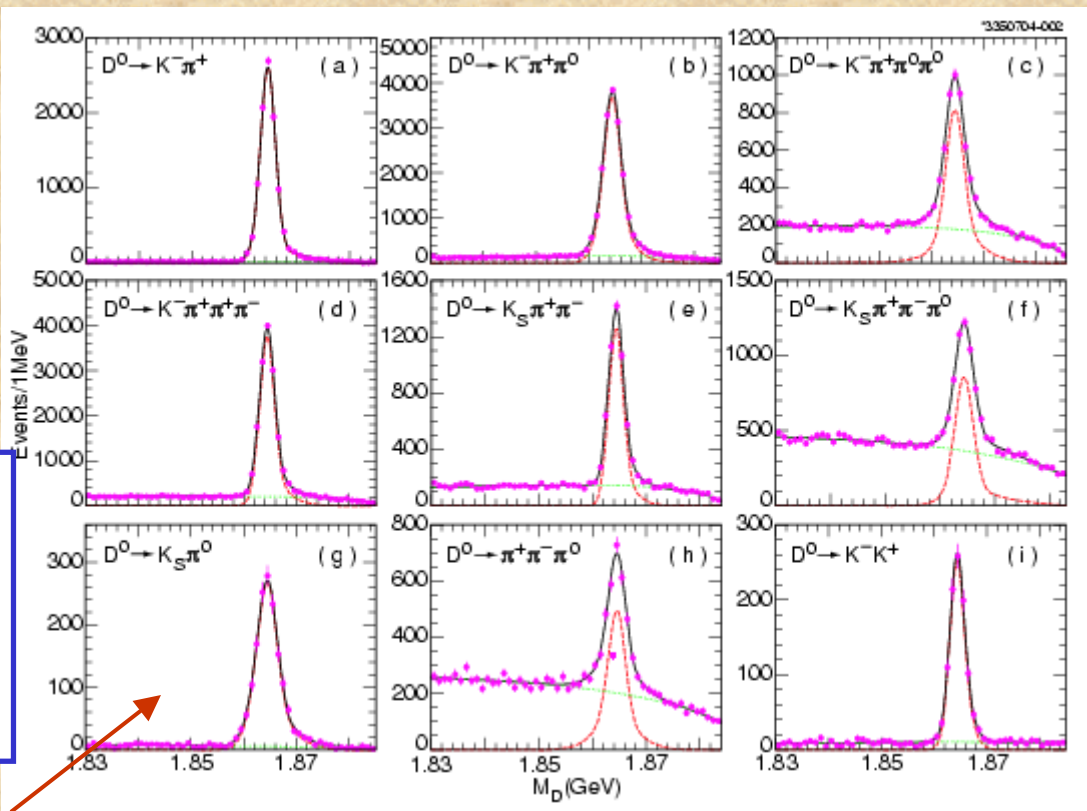
From Dec 03 to Mar 04, we collected the first 60pb^{-1} @ 3770 MeV with 6 wigglers, corresponding to 360,000 DDbar pairs.

~60,000 tagged D^0 decays

Basic selection / fit variables are …

$$\Delta E = E(D) - E_{\text{beam}}$$

$$M_{BC} = \sqrt{E_{\text{beam}}^2 - |p(D)|^2}$$

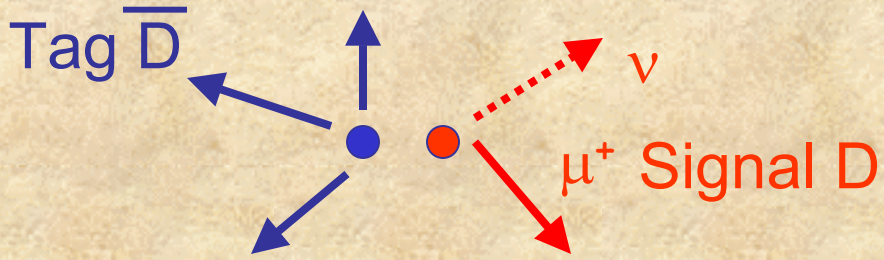


Signal: Gaussian + bifurcated Gaussian

Background: ARGUS function

Preliminary M_{BC} plots from semileptonic BF study

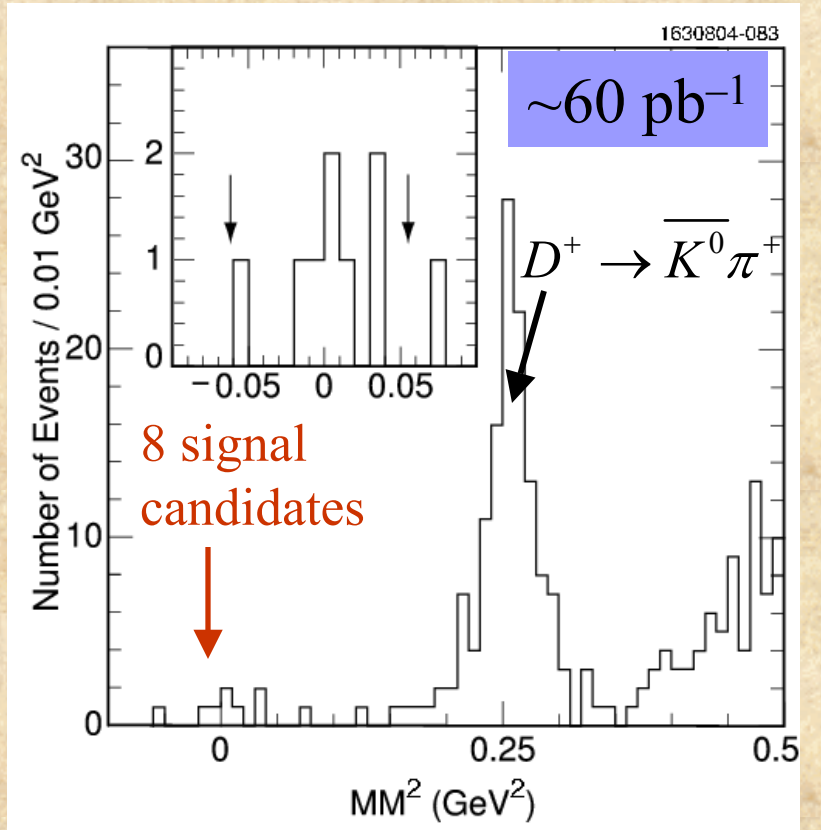
II. Leptonic Decays: $D^+ \rightarrow \mu^+\nu$

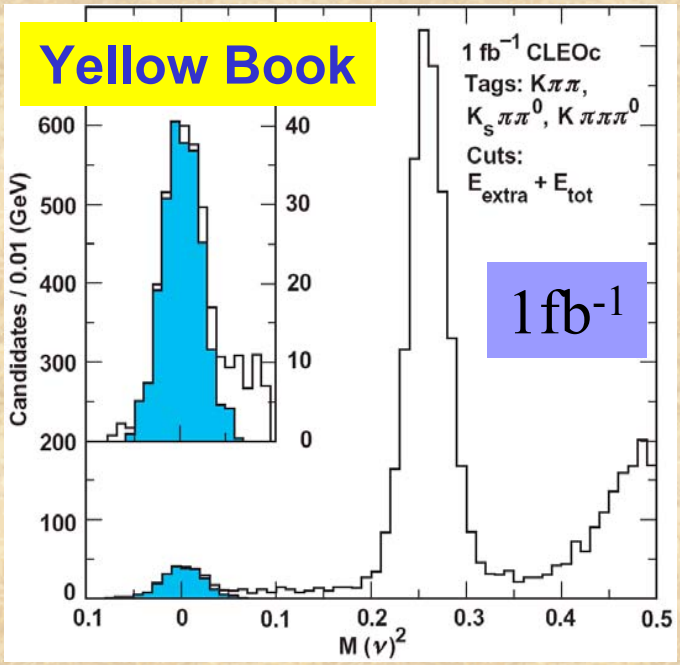


- A "D^- hadronic tag" is required.
- An additional charged track as μ^+ and no extra shower > 250 MeV as a signal.
- Fit "missing-mass"^{2}

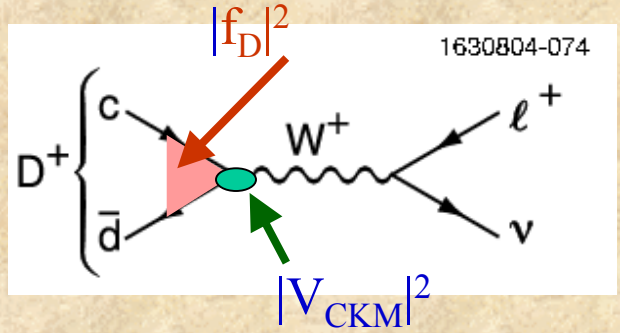
$$MM^2 = \left(E_{beam} - E_{\mu^+}\right)^2 - \left(-\vec{p}_{D^-} - \vec{p}_{\mu^+}\right)^2$$

Phys. Rev. D, 70, 112004 (2004)





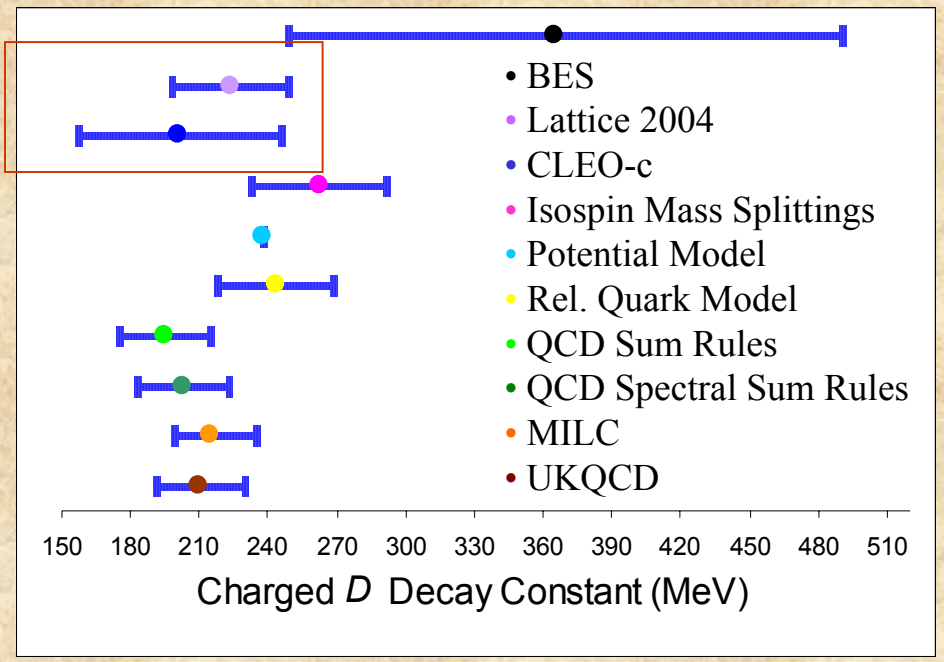
f_D from Absolute Br($D^+ \to \mu^+\nu$)



$$B(D^+ \to \mu\nu)/\tau_{D^+} = \frac{G_F^2}{8\pi} f_{D^+}^2 m_\mu^2 M_{D^+} \left(1 - \frac{m_\mu^2}{M_{D^+}^2}\right) |V_{cd}|^2$$

V_{cd} (1.1%) from 3 generation unitarity

τ_{D+} (0.3%) well-measured



ICHEP 2004

The first CLEO-c paper published. Phys. Rev. D, **70**, 112004 (2004)

- Based on 60 pb^{-1}, 28651 tags and 8 signal events.
- Background is ~ one event.

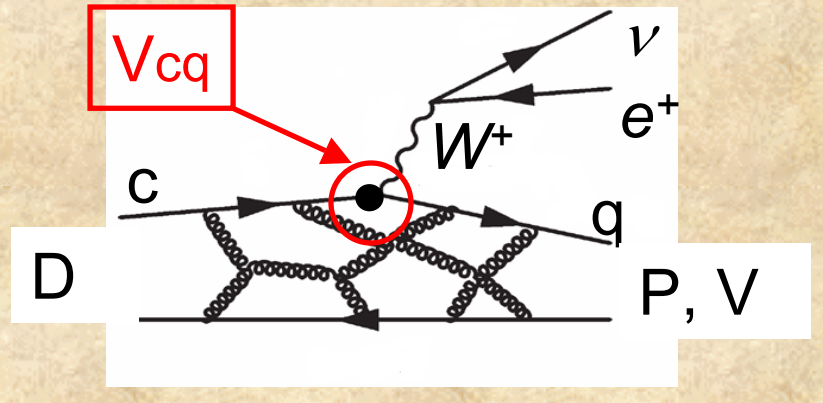
$$B(D^+ \to \mu^+\nu) = (3.5 \pm 1.4 \pm 0.6) \times 10^{-4}$$
$$f_{D^+} = (202 \pm 41 \pm 17)\ \text{MeV}$$

Mark III <290 MeV

BES I: 1 event (1998)

BES II: 3 events (2004)
f_D ~ 371 MeV

III. Exclusive Semileptonic BF.



Analysis Techniques

Fit to U

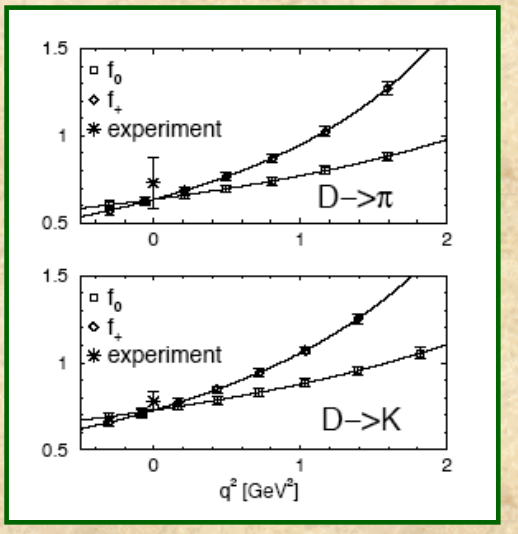
MC

$$B = \frac{N_{signal} / \varepsilon_{signal}}{N_{tag} / \varepsilon_{tag}} = \frac{N_{signal} / \varepsilon_{Xev}}{N_{tag}}$$

Fit to M_{BC}

$$\frac{d\Gamma_P}{dq^2} = \frac{G_F^2 \left|V_{cq}\right|^2}{24\pi^3} p_P^3 \left|f_p^+(q^2)\right|^2$$

Decay rate for $D \rightarrow P$

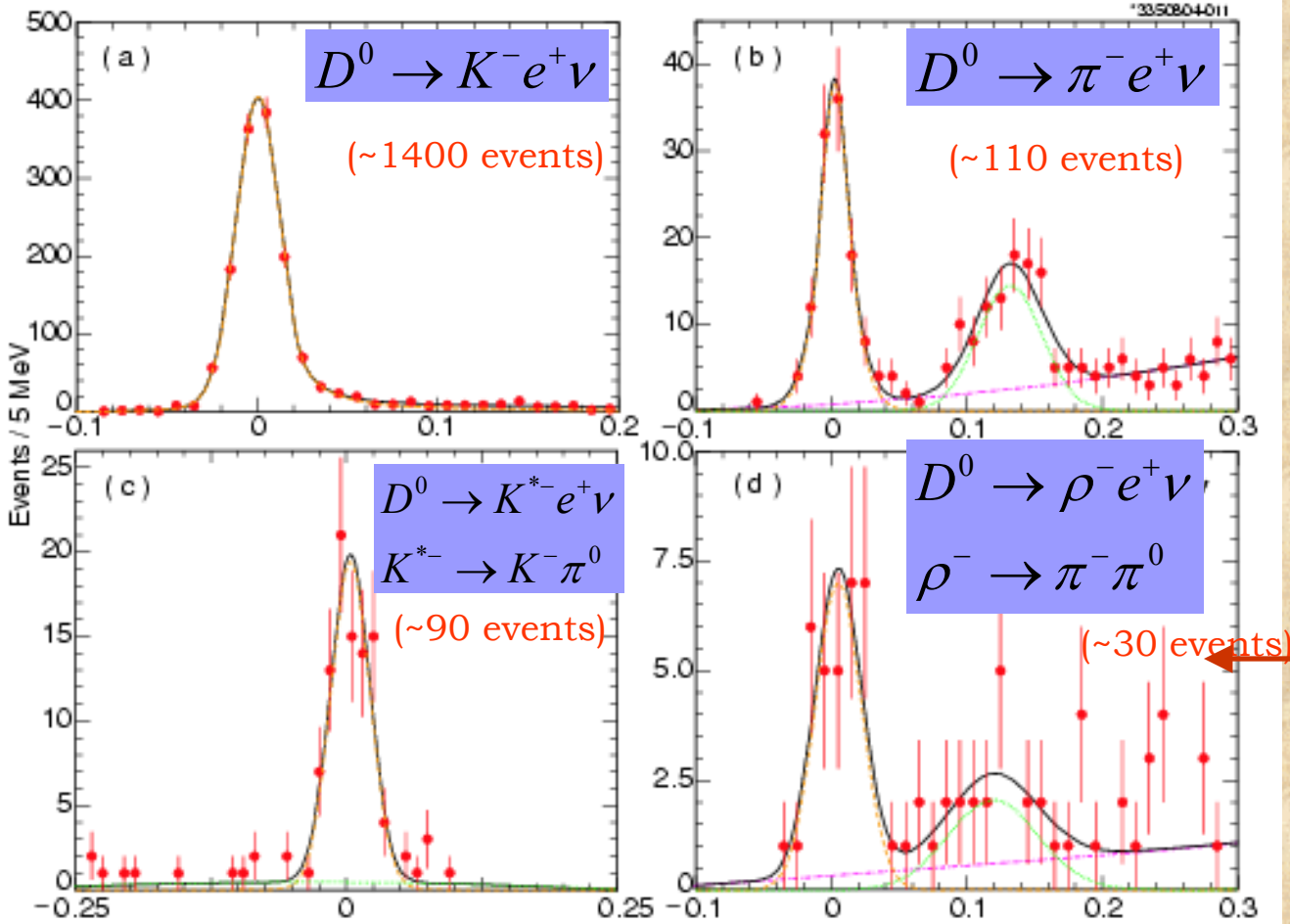


Latest LQCD, PRL 94, 011601 (2005)

- Reconstruct one hadronic D tag.
- Reconstruct a semileptonic signal candidate from the remaining tracks/showers.
- Fit kinematic variable U (= Emiss – |Pmiss|) for the missing neutrino of the signal.

Signal Candidates of Neutral Semileptonic Modes.

Cabibbo favored modes Cabibbo suppressed modes



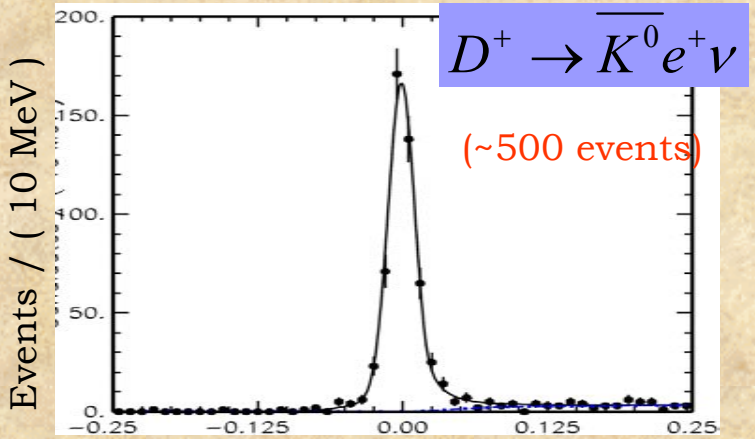
The first 60pb^{-1}

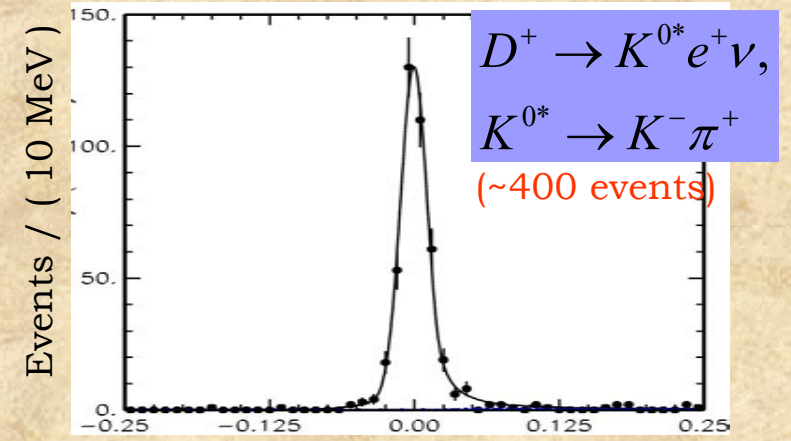
First Observation

Preliminary U (= Emiss – |Pmiss|) ***plots***

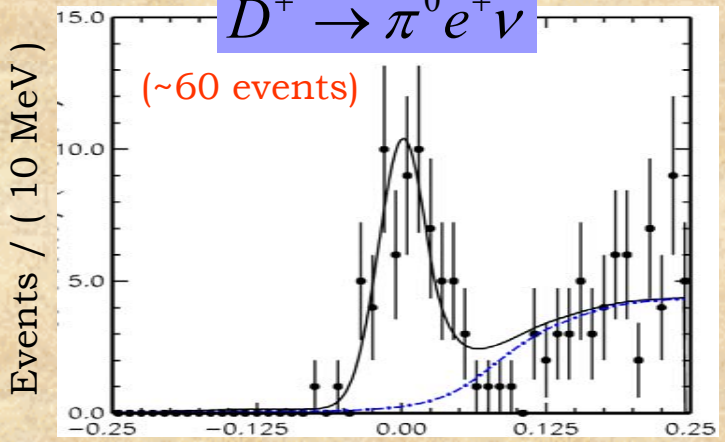
Signal Candidates of Charged Semileptonic Modes.

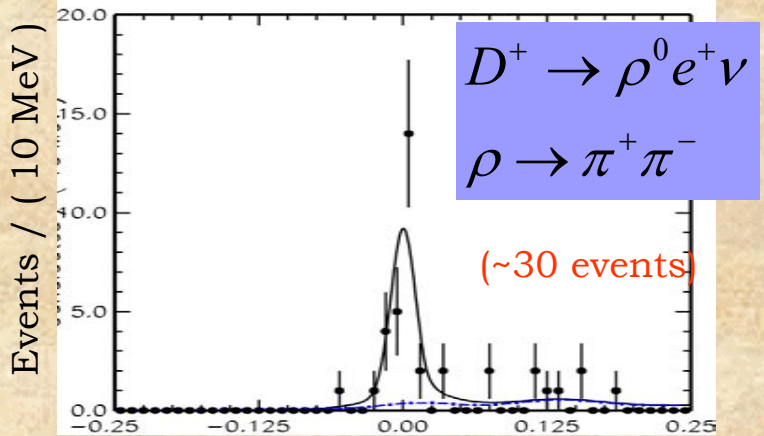
Cabibbo favored modes





Cabibbo suppressed modes

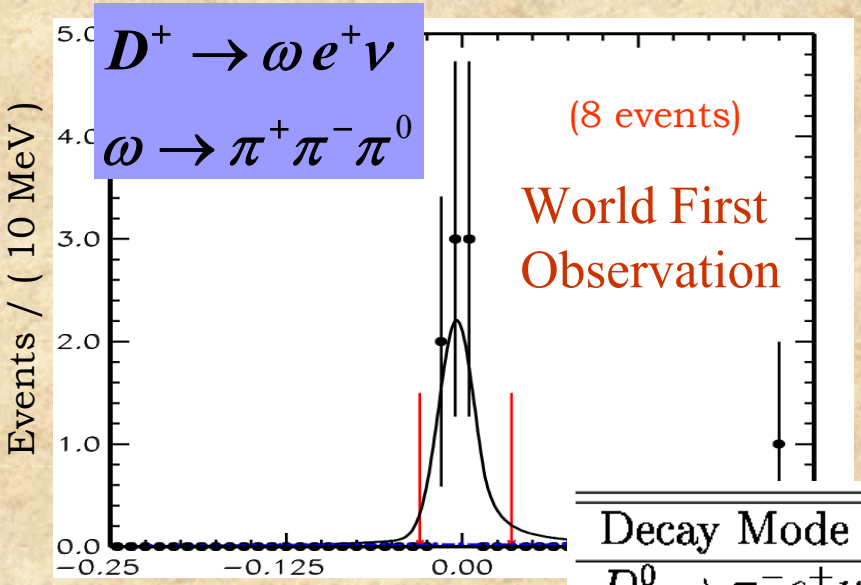




Preliminary U (= Emiss – |Pmiss|) ***plots***

The first 60pb^{-1}

The Preliminary Exclusive BF.



Preliminary U
(= Emiss – |Pmiss|)

The first 60pb^{-1}

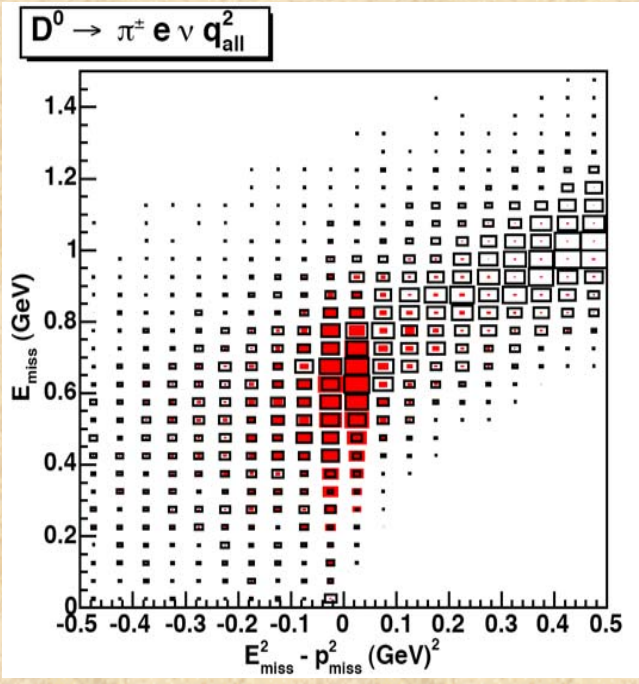
Preliminary

Decay Mode	$\mathcal{B}$ (%) (here)	$\mathcal{B}$ (%) (PDG-04)
$D^0 \to \pi^- e^+ \nu$	$0.25 \pm 0.03 \pm 0.02$	0.36 ± 0.06
$D^0 \to K^- e^+ \nu$	$3.52 \pm 0.10 \pm 0.25$	3.58 ± 0.18
$D^0 \to K^{*-}(K^- \pi^0) e^+ \nu$	$2.07 \pm 0.23 \pm 0.18$	2.15 ± 0.35
$D^0 \to \rho^- e^+ \nu$	$0.19 \pm 0.04 \pm 0.02$	N/A
$D^+ \to \bar{K}^0 e^+ \nu$	$8.71 \pm 0.38 \pm 0.37$	6.7 ± 0.9
$D^+ \to \bar{K}^{*0}(K^- \pi^+) e^+ \nu$	$5.70 \pm 0.28 \pm 0.25$	5.5 ± 0.7
$D^+ \to \pi^0 e^+ \nu$	$0.44 \pm 0.06 \pm 0.03$	0.31 ± 0.15
$D^+ \to \rho^0(\pi^+ \pi^-) e^+ \nu$	$0.21 \pm 0.04 \pm 0.02$	0.25 ± 0.10
$D^+ \to \omega(\pi^+ \pi^- \pi^0) e^+ \nu$	$0.17 \pm 0.06 \pm 0.01$	N/A

Or We Can Do Without D Tagging!

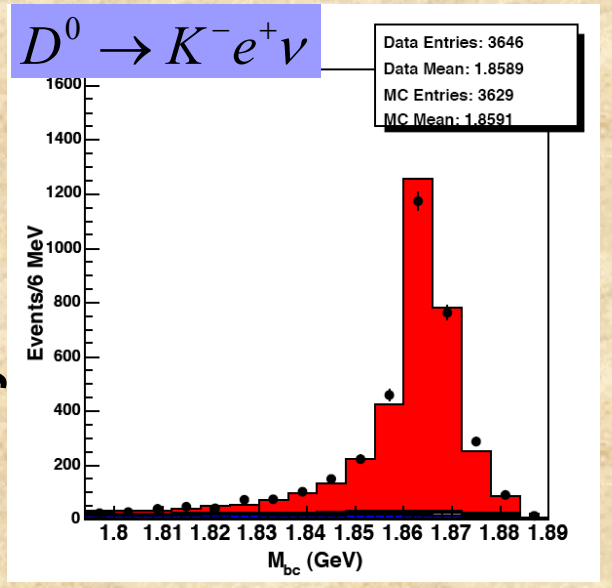
With D Tag, we have cleaner signal sample, but we loose statistics. What if we do not use D Tagging? Let's try for D $\rightarrow$ K/π e ν decays.

- Require a signal: one $e^{\pm}$ and one K or π
- Assume the other tracks/showeres are coming from the other D, ID them using dE/dx, RICH and EM calorimeter information. $\rightarrow$ Calculate P_{miss}
- Fit on ΔE, M_{BC}

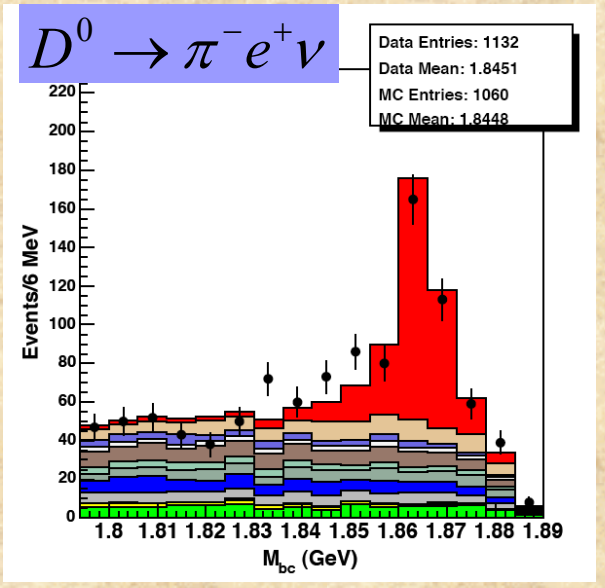


Semileptonic Events without D Tagging

Preliminary



Data
$K^{\pm}$ e ν
$\pi^{\pm}$ e ν
$D^0\bar{D}^0$ Bkgd
π^0 e ν
$K_S(\pi^+\pi)$ e ν
K^0_{other} e ν
D^+D^- Bkgd
τ MC
Cont MC
Fakes



Data
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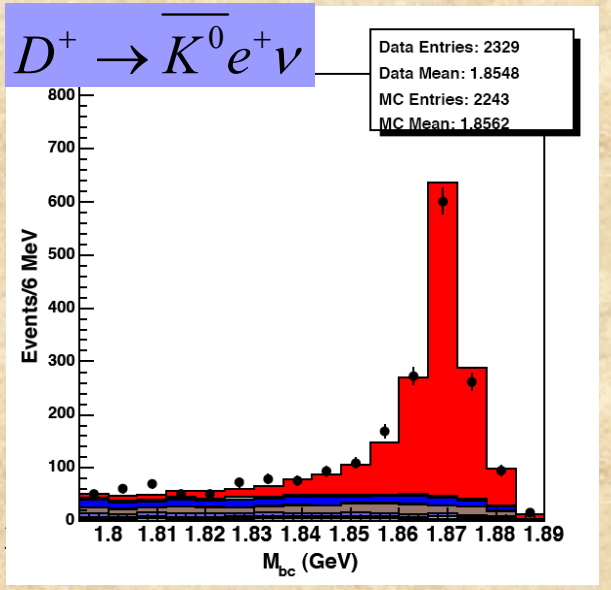
Cont MC
Fakes



Data
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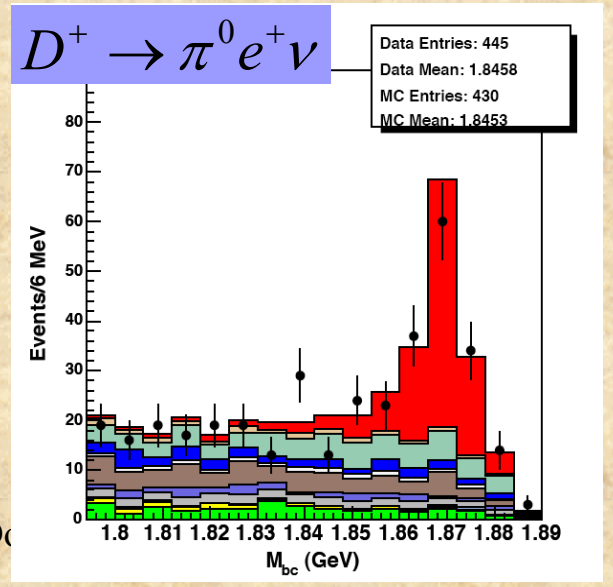
π^0 e ν
$D^0\bar{D}^0$ Bkgd
$\pi^{\pm}$ e ν
$K^{\pm}$ e ν
K^0_{other} e ν
D^+D^- Bkgd
τ MC
Cont MC
Fakes



Data
π^0 e ν
$K_S(\pi^+\pi)$ e ν
$D^0\bar{D}^0$ Bkgd
$\pi^{\pm}$ e ν
$K^{\pm}$ e ν
K^0_{other} e ν
D^+D^- Bkgd
τ MC
Cont MC
Fakes

IV. Inclusive Semileptonic BF.

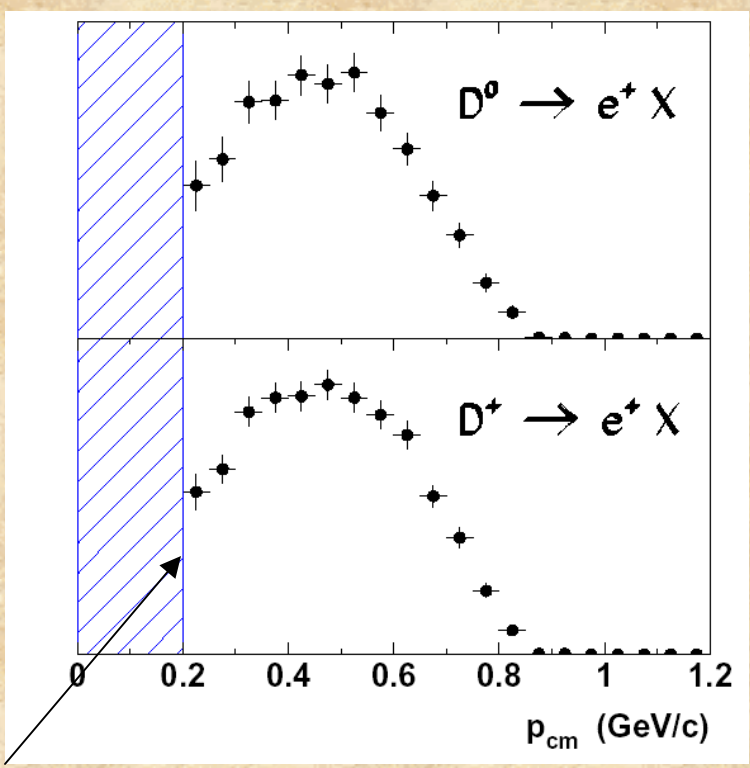
PDG(2004) $B(D^0 \rightarrow X\, e^+\, \nu) = 6.87 \pm 0.28\ \%$

PDG(2004) $B(D^+ \rightarrow X\, e^+\, \nu) = 17.2 \pm 1.9\ \%$

Preliminary
P(e+) spectra

Analysis Techniques

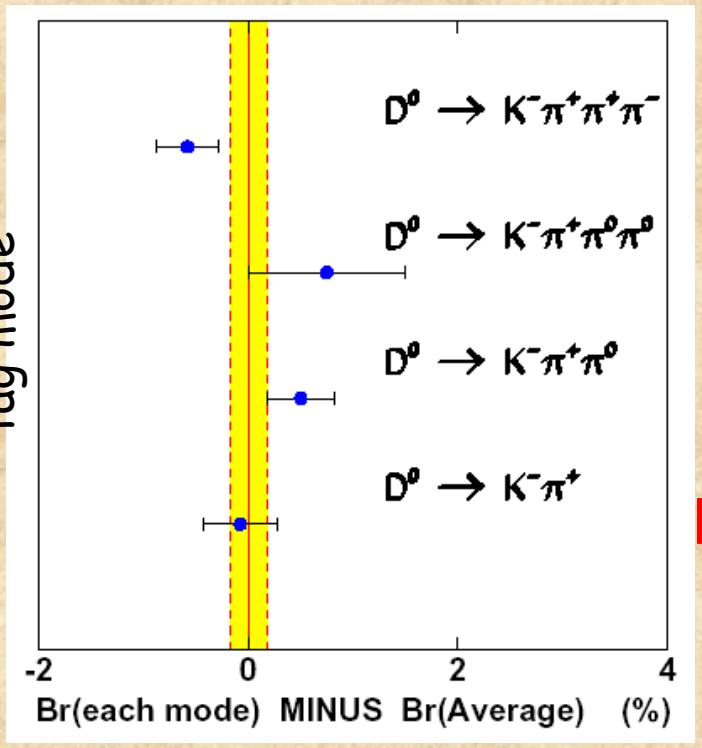
- Reconstruct one hadronic D tag.
- Signal e+ : ID'd by dE/dx, RICH and E/p calorimeter
- Right/Wrong sign defined by K charge for D0, signal side charge for D+ → background subtraction by wrong sign events.



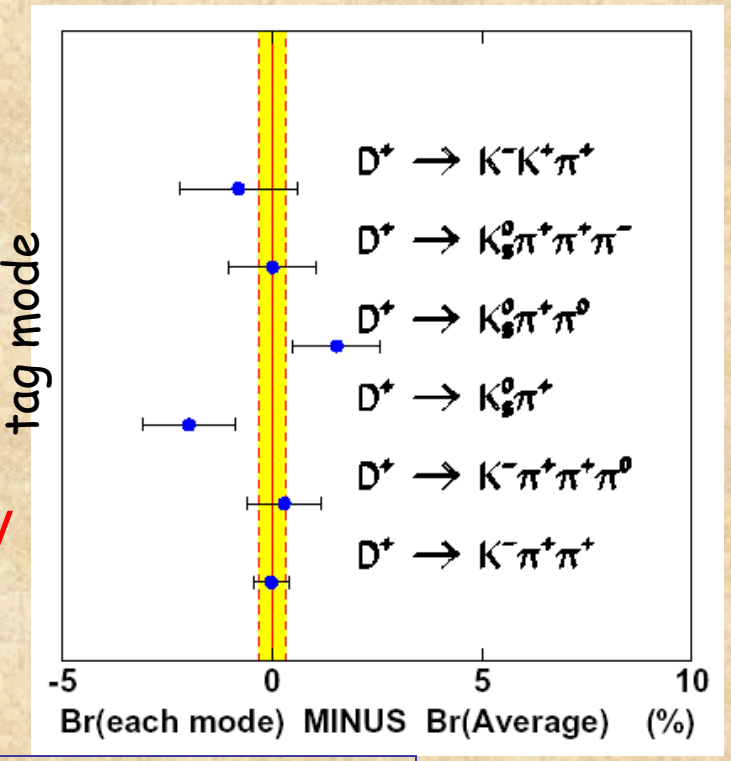
Cut-off

CLEO-c
(in D rest frame)

Expected Uncertainty from the First 60 pb^{-1}



Preliminary
No BR yet

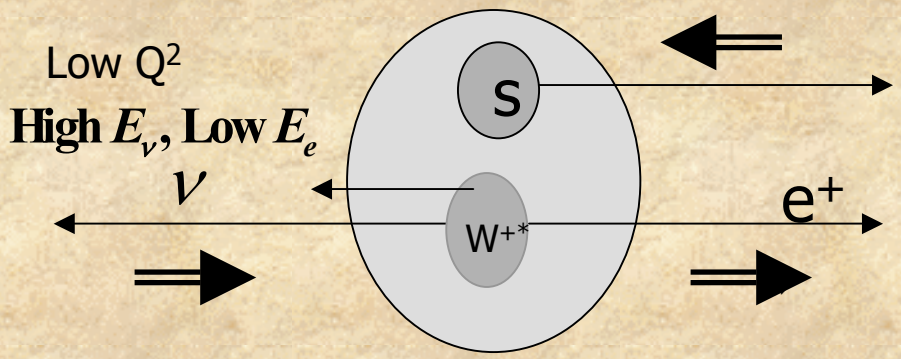


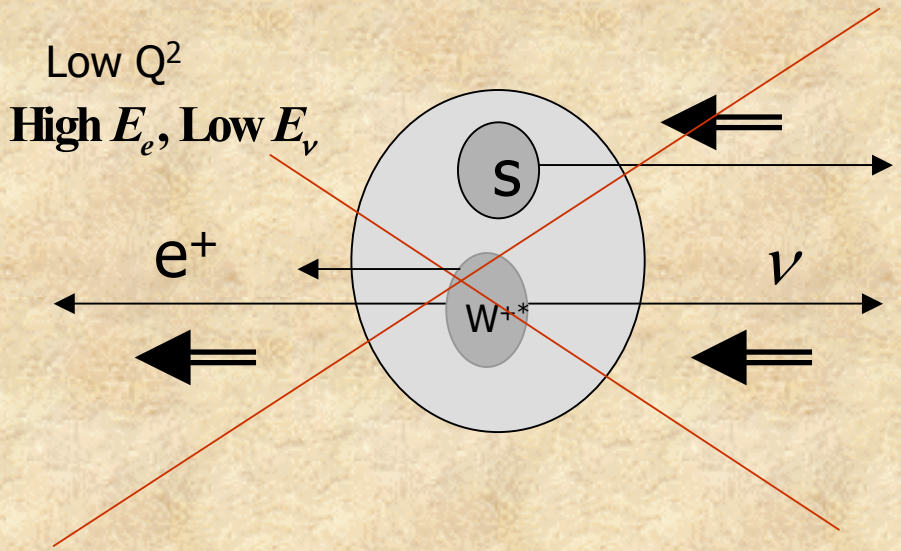
$$D^0 \to e^+X: \begin{cases} \text{CLEO-c}: & \sigma_{BR}(\text{stat}) \sim 0.2\% \\ \text{PDG}: & \sigma_{BR}(\text{stat} \oplus \text{sys}) \sim 0.3\% \end{cases}$$

$$D^+ \to e^+X: \begin{cases} \text{CLEO-c}: & \sigma_{BR}(\text{stat}) \sim 0.3\% \\ \text{PDG}: & \sigma_{BR}(\text{stat} \oplus \text{sys}) \sim 1.9\% \end{cases}$$

V: Inclusive BF of D →Xlν, lν

Electron and Neutrino Spectra are Different!





Conservation of angular momentum → ν get boost from W+ in the lab frame.

Analysis Techniques

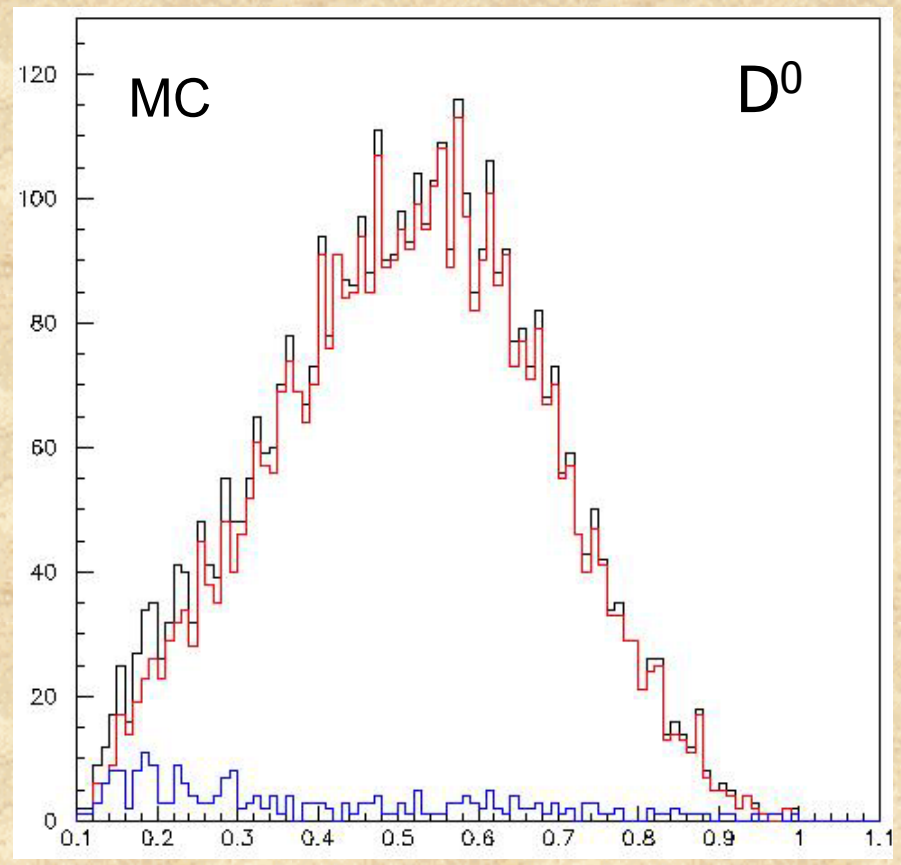
- Reconstruct one hadronic D tag.
- Signal side: ID'd by dE/dx, RICH and E/p calorimeter, than add all.
- Get Pmiss and Mmiss^2.
- K_L suppression is important.

MC Example of Emiss Spectra

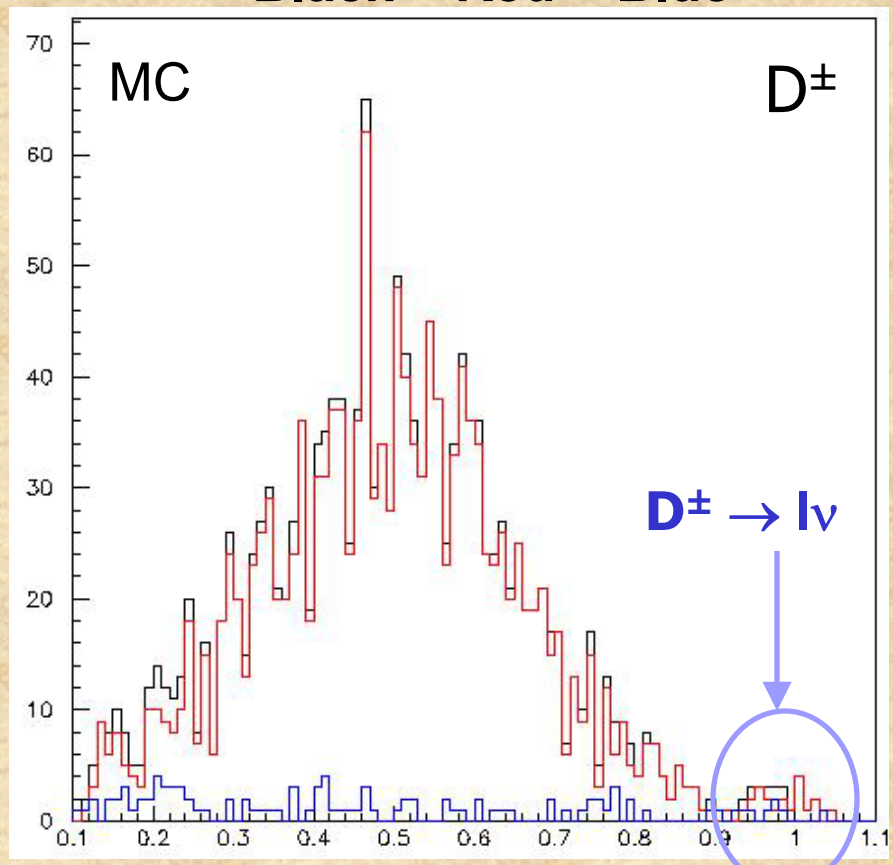
Red = signal

Blue = background

Black = Red + Blue

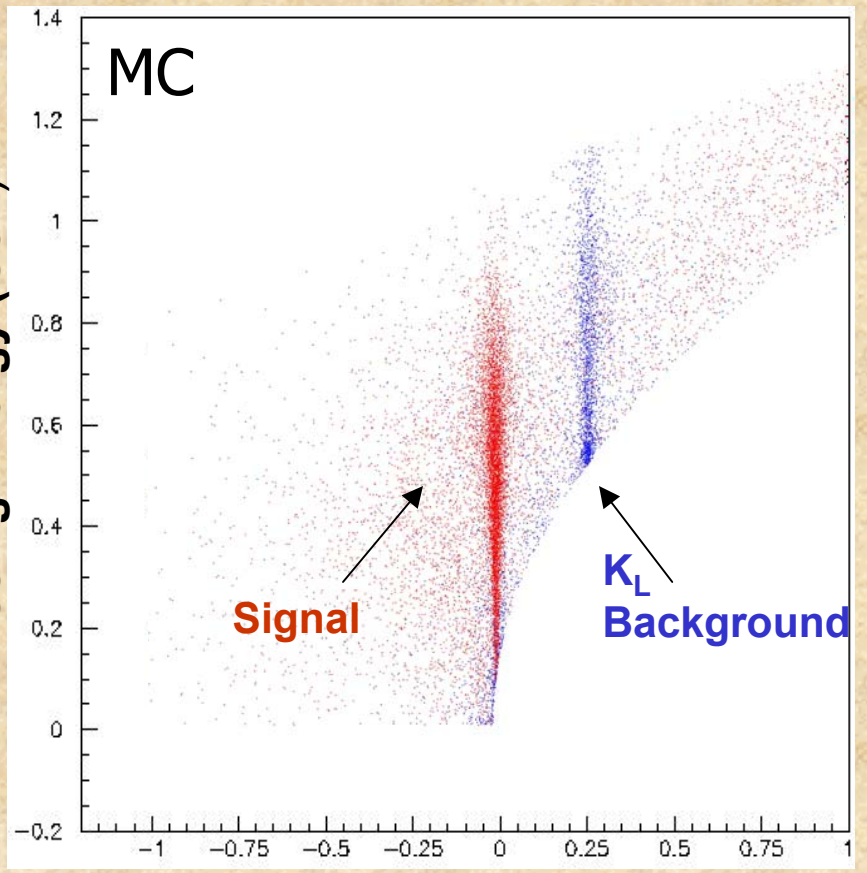


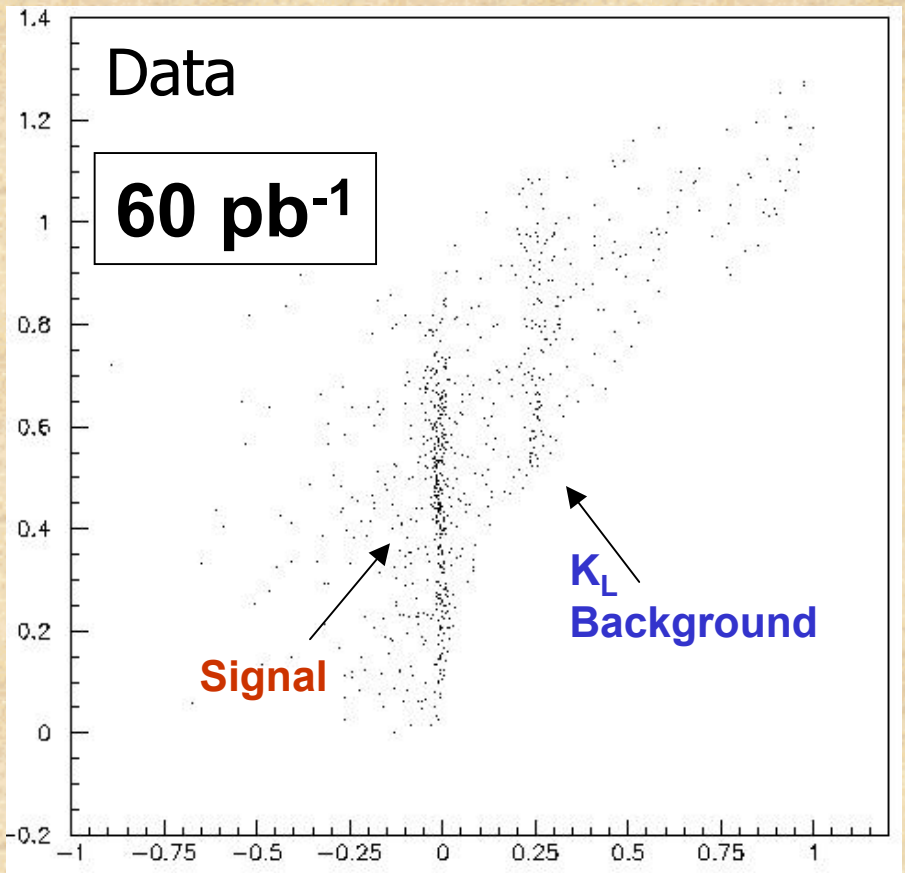
E_{miss}(GeV)



E_{miss}(GeV)

The Inclusive D → Xlν, lν Candidates

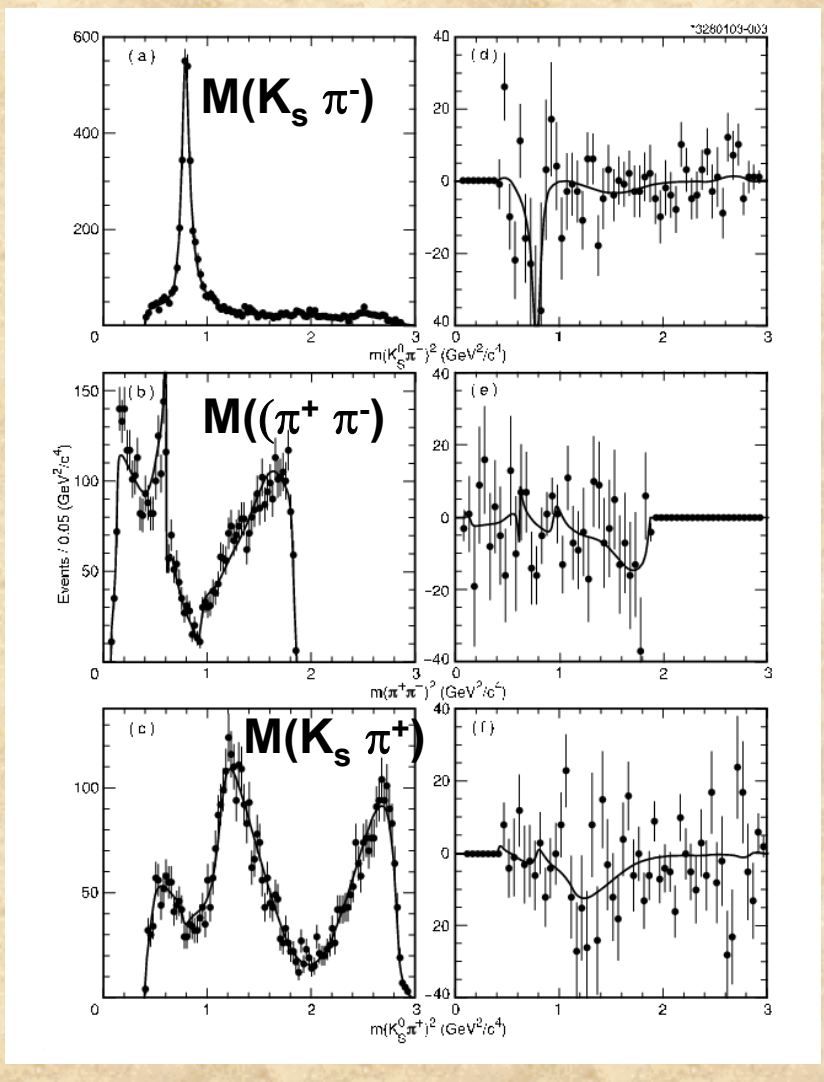




VI. CPV search in $D^0 \to K_s \pi^+ \pi^-$ from CLEO II.V

- PRL 92, 142001 (2004)
- D0 / D0bar tagged by $D^* \to D^0 \pi^+$(slow).
- Standard Model prediction at 10^{-6} for this channel from K mixing. → sensitive to new physics
- Dalitz technique studies decay <u>amplitude</u>, not decay rate. → sensitivity increase.

D0 + D0bar D0 - D0bar



$$A_{CP} = \int \frac{|\mathcal{M}|^2 - |\overline{\mathcal{M}}|^2}{|\mathcal{M}|^2 + |\overline{\mathcal{M}}|^2} dm^2_{KS} dm^2_{\pi\pi} / \int dm^2_{KS} dm^2_{\pi\pi}.$$

$$A_{CP} = -0.009 \pm 0.021^{+0.010+0.013}_{-0.043-0.037}$$

VII: Summary and Future

(1) New results on BF $D^+ \to \mu\nu$ and f_D

$$B(D^+ \to \mu^+\nu) = (3.5 \pm 1.4 \pm 0.6) \times 10^{-4}$$
$$f_{D^+} = (202 \pm 41 \pm 17)\ \text{MeV}$$

(2) Exclusive BF of semileptonic decays coming (pretty) soon.

- With just 60 pb^{-1}, stastistical power of many decay modes already at the world best.
- The world first events of $D^0 \to \rho^- e^+ \nu$ and $D^+ \to \omega e^+ \nu$
- We have two analysis options available: With and wo DTag

(3) Inclusive BF of D $\to$Xeν and D $\to$Xlν, lν coming.

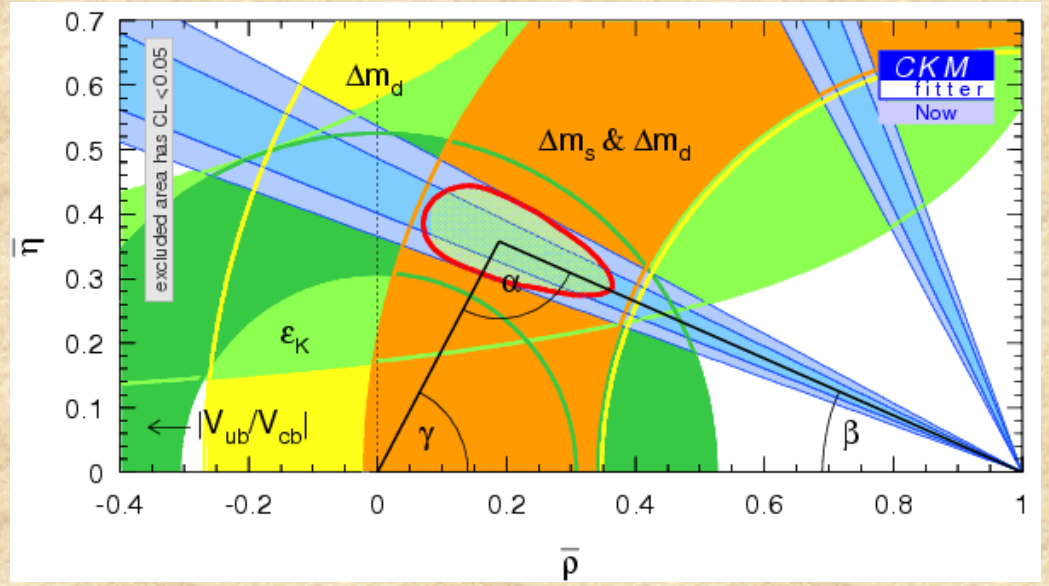
(4) Currently we are running at ψ(3770) with 12 "8-pole" wigglers.

More data is coming on ψ(3770), Ds threshold, etc.

f_{Ds}

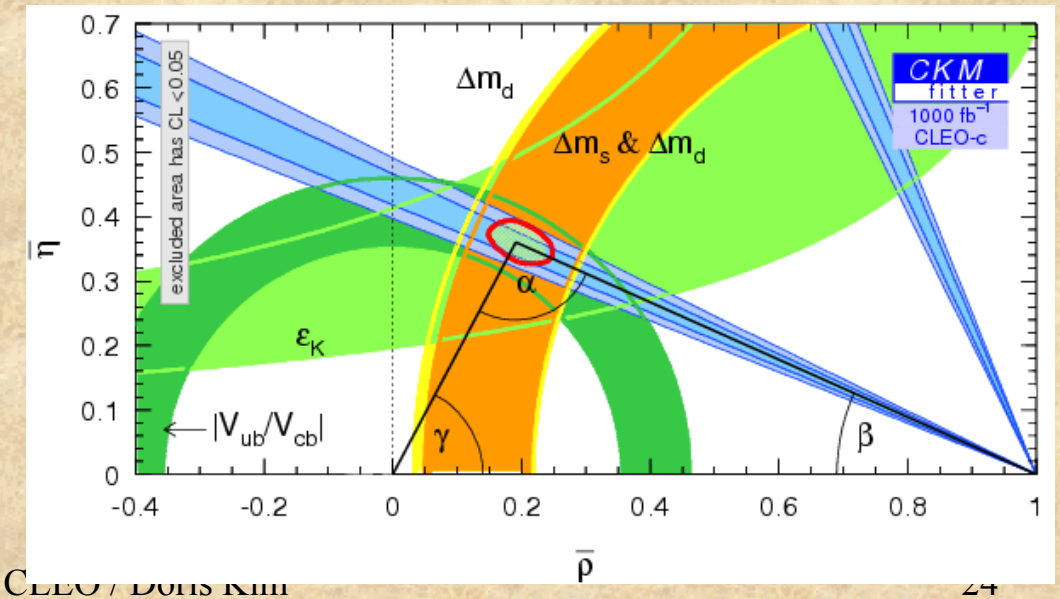
Question slides

CLEO-c Impacts on the Unitarity Triangle



Now: Theory Uncertainties Dominate

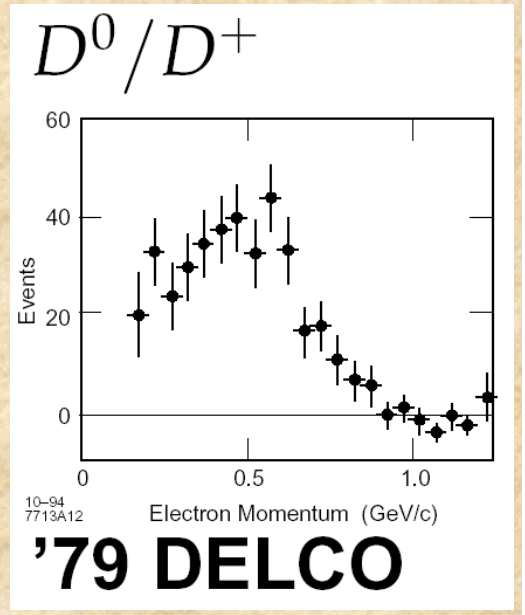
Future: With CLEO-c, improved LQCD and 500 fb^{-1} each from the B factories

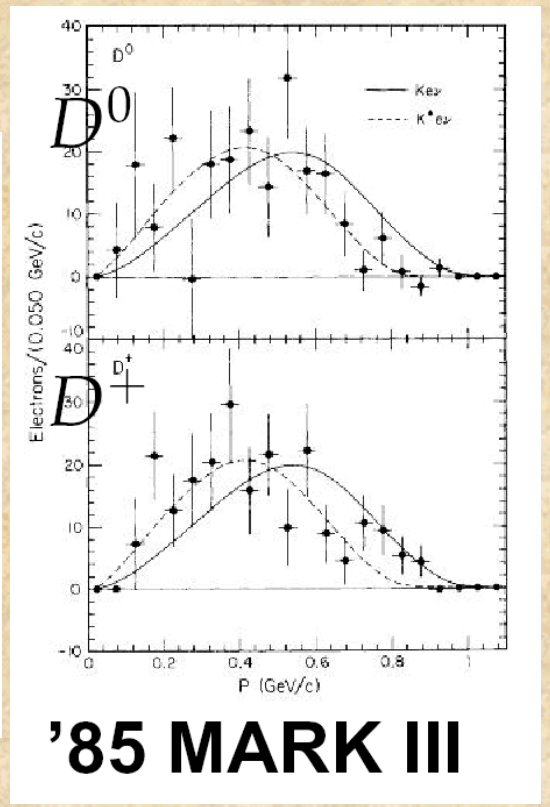


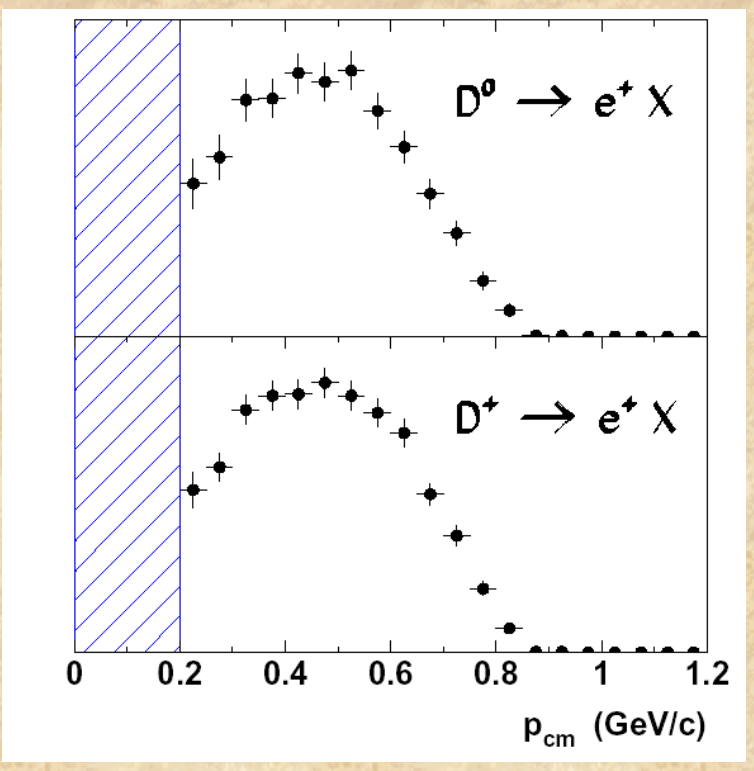
Electron Spectrum of Inclusive Events

time

Very Preliminary

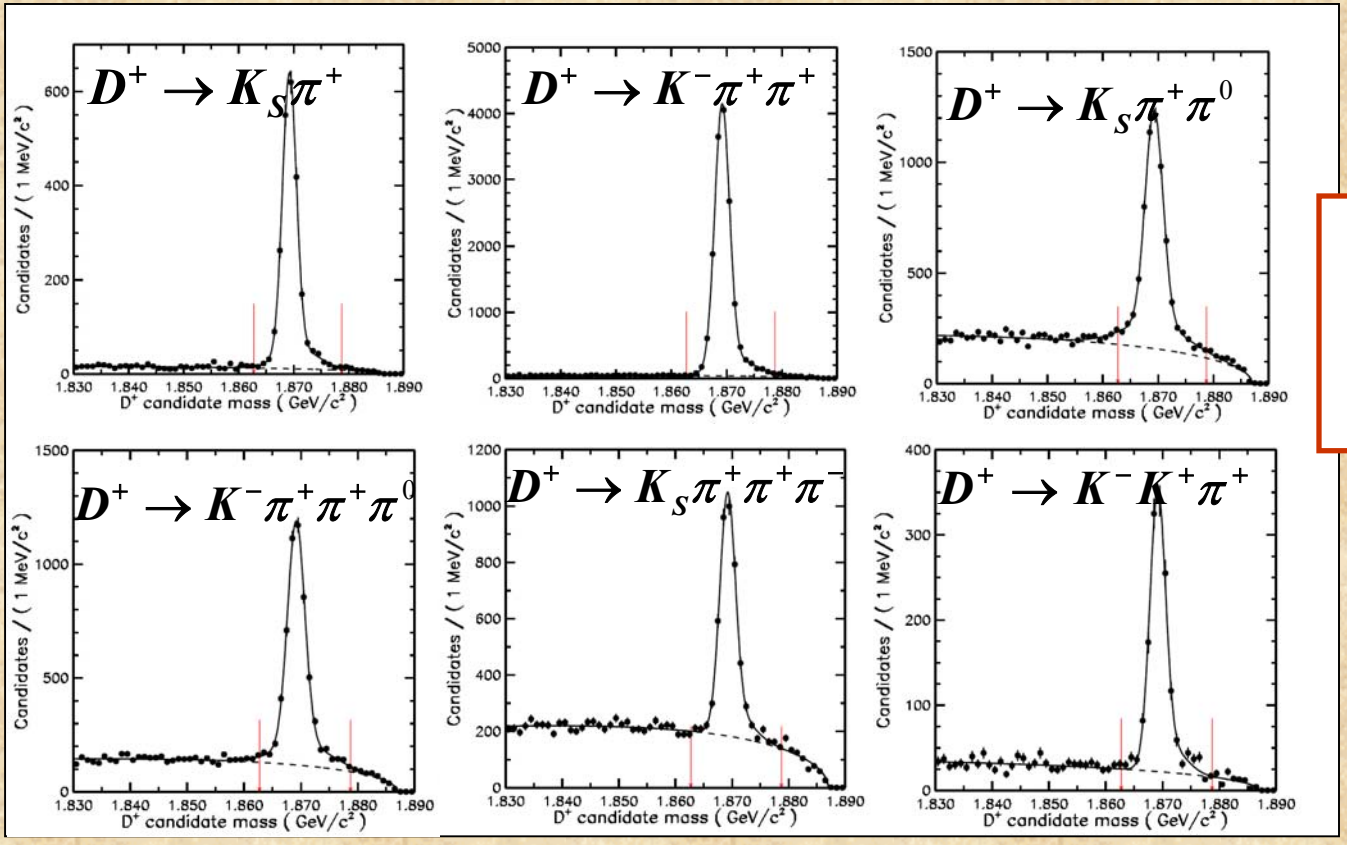






CLEO-c
(in D rest frame)

Charged D Meson Tags – Distributions of M_{bc}



~30,000 tagged $D^{\pm}$ decays

Preliminary M_{BC} plots from semileptonic BF study