CHARM PHYSICS at TAU-CHARM FACTORY

Peter Kim
SLAC

Absolute Measurement of D Branching Ratios

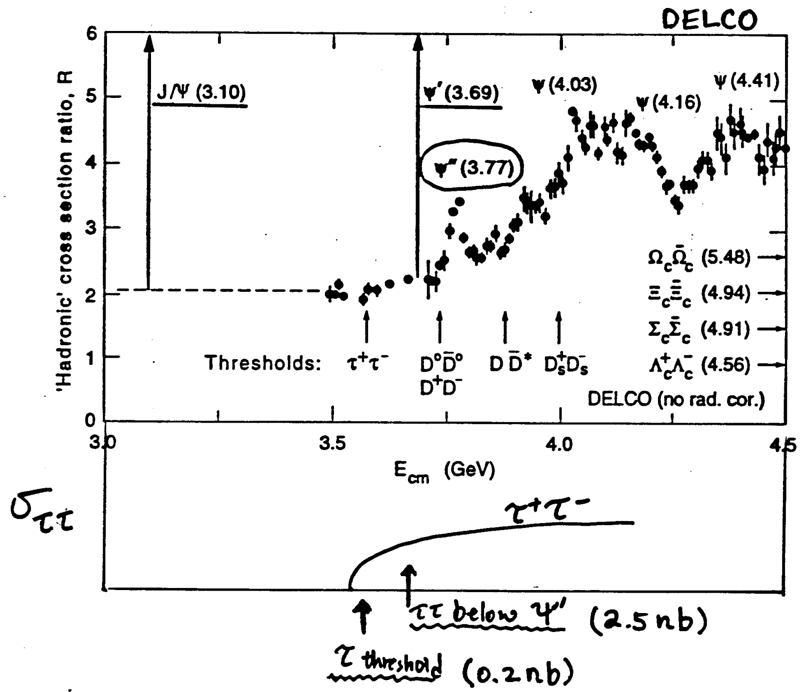
DD-bar Mixing & CP Violation ➔ T. Liu's Talk

Leptonic Decays: D → l nu

Rare Charm Decays

Tau-Charm Physics Workshop
SLAC, Mar 6-9, 1999

e^+e^- CROSS SECTIONS NEAR 4 GeV



ψ'' (3770) ~ 10 nb cross section

→ $D^0 \bar{D}^0$ (5.3 nb)

→ $D^+ D^-$ (4.7 nb)

10 fb^{-1}

1 year at $1\times10^{33} cm^{-2} s^{-1}$

5.3×10^7 Events

4.7×10^7 Events

(200 million u,d,s continuum Background Events...)

D Meson Reconstruction at ψ''

$E_{beam} = E_D \Rightarrow$ Beam-constrained mass

$$M = \sqrt{E_{beam} - |\Sigma P_i|^2}$$

$$E_{beam} - \Sigma E_i = 0$$

$\sigma(M_{D\ \text{Beam-const.}}) = 0.6$ MeV

$D^0 \rightarrow$	BR	# Detected/yr
$K^-\pi^+$	0.042	2.7×10^6
$\bar{K}^0\pi^0$	0.020	2.1×10^5
$\bar{K}^0\pi^+\pi^-$	0.064	9.4×10^5
$K^-\pi^+\pi^0$	0.130	3.0×10^6
$K^-\pi^+\pi^+\pi^-$	0.091	3.3×10^6
$\bar{K}^0\phi$	0.010	3.1×10^4
$\pi^+\pi^-$	0.002	1.6×10^5
K^+K^-	0.005	2.5×10^5
$K^-\pi^+\pi^0\pi^0$	0.149	1.2×10^6
Total		1.2×10^7
$D^+ \rightarrow$		
$\bar{K}^0\pi^+$	.0320	4.1×10^5
$K^-\pi^+\pi^+$	0.091	3.6×10^6
$\bar{K}^0\pi^+\pi^0$	0.130	5.9×10^5
$\bar{K}^0\pi^+\pi^-\pi^+$	0.066	3.5×10^5
$K^+K^-\pi^+$	0.011	3.5×10^5
$\bar{K}^0K$	0.010	1.1×10^5
$K^-\pi^+\pi^+\pi^-\pi^+$	0.007	4.2×10^4
Total		5.5×10^6
$D_s \rightarrow$		
$\phi\pi$	0.030	1.1×10^5
$S^*\pi$	0.009	1.0×10^5
$\bar{K}^0K^+$	0.030	1.7×10^5
$\eta\pi^+$	0.080	3.4×10^5
$K^{*}K^+$	0.030	1.1×10^5
Total		8.3×10^5

$\psi(4.03) \rightarrow D_s^+ D_s^-$

$\rightarrow D\bar{D}^{(*)}$

$D^+ \rightarrow \ell\nu X = 17\% \times 2$!

(Semileptonic tags ?)

BASELINE TCF DETECTOR PERFORMANCE

Jasper Kirkby
CERN
5 January 1999

Table 1: Baseline performance of a generic τcF detector, based on current BF detectors and previous τcF studies. The symbol '$\oplus$' denotes addition in quadrature.

Item	Baseline τcF detector performance
Charged particles:	
Momentum resolution: σ_p/p(GeV/c)	$0.2\%p \oplus 0.2\%/\beta$
Angular resolution: $\sigma_{\theta,\phi}$ (mr)	$2/p\beta$
p_t^{min}(MeV/c) for efficient reconstruction	50
Acceptance	95%
Photons:	
Energy resolution: σ_E/E(GeV)	$1\%/\sqrt{E} \oplus 2\%$
Angular resolution: $\sigma_{\theta,\phi}$ (mr)	$4/\sqrt{E} \oplus 2$
2γ angular separation (mr)	50
E^{min}(MeV) for efficient detection	10
Acceptance	95%
Particle identification (inc. Če.):	
K/π separation	$< 10^{-6}$ below 1.5 GeV/c
e/π separation	10^{-4}
μ/π separation	2%/p(GeV/c) + 2%
Acceptance	90%
Additional particle identification:	
p_t^{min}(MeV/c) for efficient ν tagging by E_{miss}	100
K_L^0 acceptance × detection efficiency	80%
μ polarisation acceptance	20%

K_L^0 Veto efficiency ?

$\sigma_{E_{beam}}$ = 1.3 MeV ⇒ σ_w = 1.7 MeV at E_{beam}=2GeV

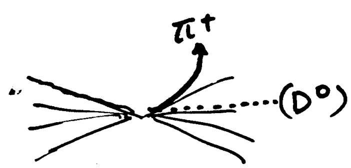
ABSOLUTE MEASUREMENT OF D BRANCHING RATIO

$\psi''(3770)$

- $D^0 \to K^-\pi^+$ — $(5.4 \pm 0.8)\%$ MARK II (1981), using $\sigma_{\psi''}$ meas.
- $(4.2 \pm 0.4 \pm 0.4)\%$ MARK III (1988) — Double-tag events
  - $D^0 \to K^-\pi^+$
  - $\bar{D} \to$ reconst. tag

$\sqrt{s} = 10\,GeV - 90\,GeV$ (HRS at 29 GeV)

Tagging of D^0 with $D^{*+} \to D^0 \pi^+$ soft pion



PLOT $\cos\theta_{\pi^+, JetAxis}$

$Br(D^0 \to K^-\pi^+) = (3.81 \pm 0.15 \pm 0.16)\%$ CLEO (1998)

$= (3.90 \pm 0.09 \pm 0.12)\%$ ALEPH (1997)

$\langle$world Average$\rangle$ = $3.88 \pm 0.10\%$ PDG 98

* Charm Deficit in B decays persists ...

* soft π tagging at higher energy : model dependent on Fragmentation model.

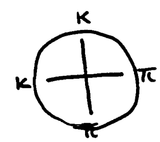
We need ABSOLUTE MEASUREMENT with Double-tags.

τCF

N_{D^0} tag : 12 million

($D^0 \to K^-\pi^+$ tag $= 2.7 \times 10^6$) ⇐ Limit Systematic Uncertainties

Look for 4-prong events



$K^+\pi^- \leftarrow \bar{D}^0$, $D^0 \to K^-\pi^+$

⇒ 90,000 Reconstructed Events

- SYSTEMATIC ERRORS

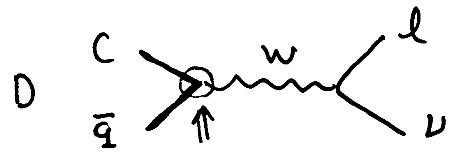
  $K^-\pi^+$ reco : 1 %/track

  tag side : N_{tag} Fit

  ϵ_{tag} vs. charge multiplicity

  } 2-3 %

LEPTONIC DECAYS



$|f_D \cdot V_{cd}|^2$ $\qquad$ $f_D^2 \propto \frac{|\psi(0)|^2}{M_D}$

$$\Gamma(D^+ \to \ell^+ \nu) = \frac{G_F^2}{8\pi} f_D^2 \cdot m_D \cdot m_\ell^2 \cdot |V_{cd}|^2 \cdot \left(1 - \frac{m_\ell^2}{m_D^2}\right)^2$$

Various Lattice QCD Calculation $\Rightarrow$ $f_D \simeq 220$ MeV
($\pm$ 50 MeV ...) $\qquad$ $f_B \simeq 130$ MeV

$f_D = 220$ MeV $\Rightarrow$

$$\begin{cases} Br(D^+ \to \tau\nu) = 1.0 \times 10^{-3} \\ Br(D^+ \to \mu\nu) = 4 \times 10^{-4} \\ Br(D_s \to \tau\nu) = 5 \times 10^{-2} \\ Br(D_s \to \mu\nu) = 5 \times 10^{-3} \end{cases}$$

Exp.	MODE	N_{evt}	f_{D_s}
WA 75	$\mu\nu$	6	$282 \pm 30 \pm 43 \pm 34$
E653	$\mu\nu$	$23 \pm 6 \pm 1$	$190 \pm 34 \pm 20 \pm 26$
BES	$\mu\nu$	3	$430 \pm ^{150}_{140} \pm 40$
CLEO	$\mu\nu$	182 ± 22	$280 \pm 19 \pm 28 \pm 34$
DELPHI	$\tau\nu$	10.8 ± 5.4	~ 330
L3	$\tau\nu$	15.6 ± 6.0	$309 \pm 58 \pm 33 \pm 38$

CLEO → B-factory : Systematic errors will Dominate

E653

emulsion target

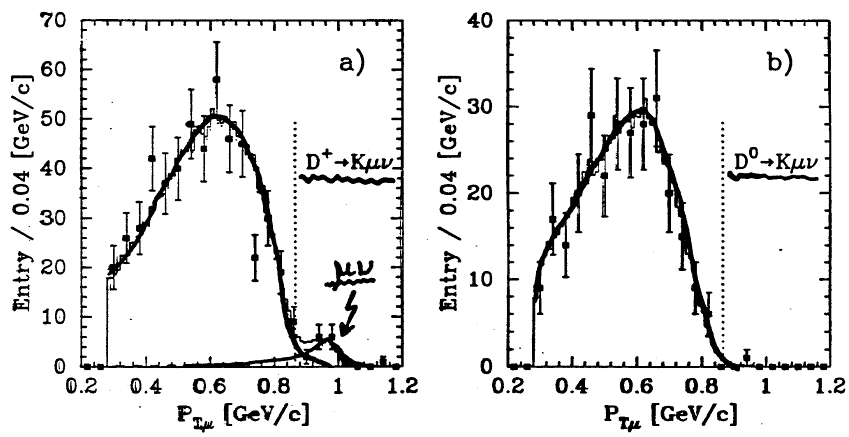
600 GeV/c π^- beam

μ trigger → 8.2×10^6 events ($P_{t(\mu)} > 800$ MeV)

Vertexing in Silicon Strip Detector & Emulsion

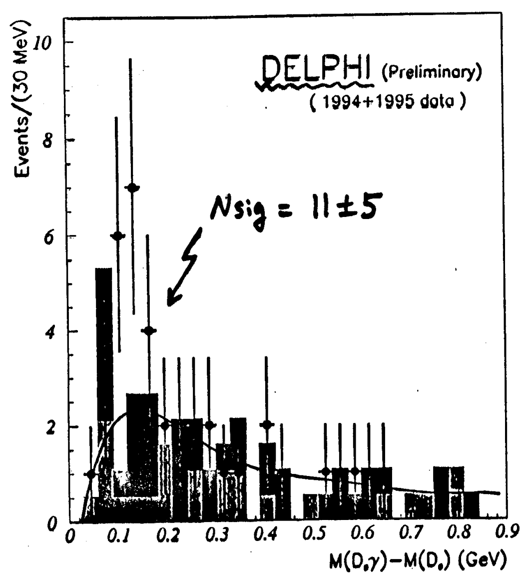
- 531 KINK (1-prong)
- 276 V (2-prong)

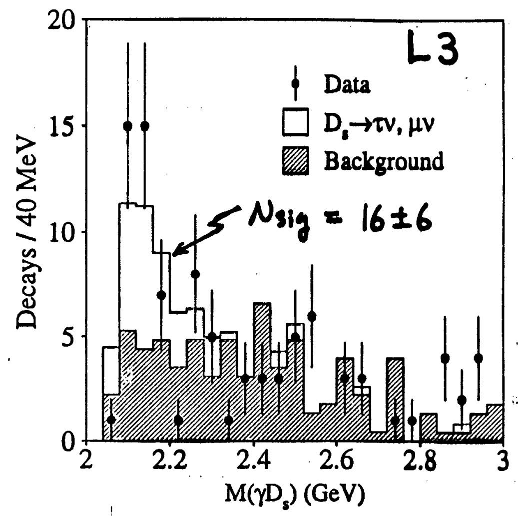
Muon P_t relative to BEAM AXIS

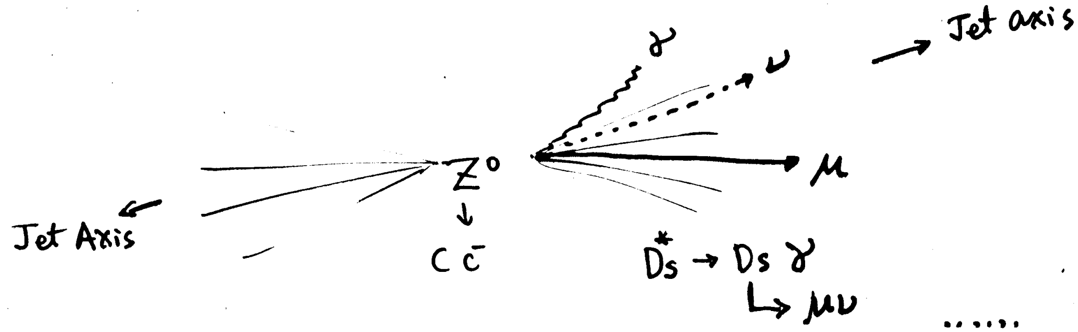


$N_{evt} = 23 \pm 6 \pm 1$

Normalize to $\phi\mu\nu$ ⇒ $f_{D_s} = 190 \pm 34 \pm 20 \pm 26$ MeV


DELPHI (Preliminary)
(1994+1995 data)
Nsig = 11±5
Events/(30 MeV)
M(D,γ)−M(D,) (GeV)


L3
Data
D→τν, μν
Background
Nsig = 16±6
Decays / 40 MeV
M(γD) (GeV)


Jet Axis
Z0
c c̄
γ
ν
μ
Jet axis
D*s → Ds γ
↳ μν
......

$D_s \to \mu\nu$ Analysis at CLEO

$$D_s^* \to D_s \gamma$$
$$\quad \hookrightarrow \mu\nu$$

- neutrino reconstruction Technique

$$\begin{cases} E_\nu = E_{CM} - E_{obs.} \\ \vec{P}_\nu = -\sum_i \vec{P}_{obs\,i} \end{cases}$$

Hermiticity of CLEO detector Crucial!

- Determine $\vec{P}_{D_s}$ using $\vec{P}_\mu$ & $\vec{P}_\nu$

- Look for $D_s^* \to D_s\gamma$ signal.

Small Q^2 in $D_s^* \to D_s\gamma$

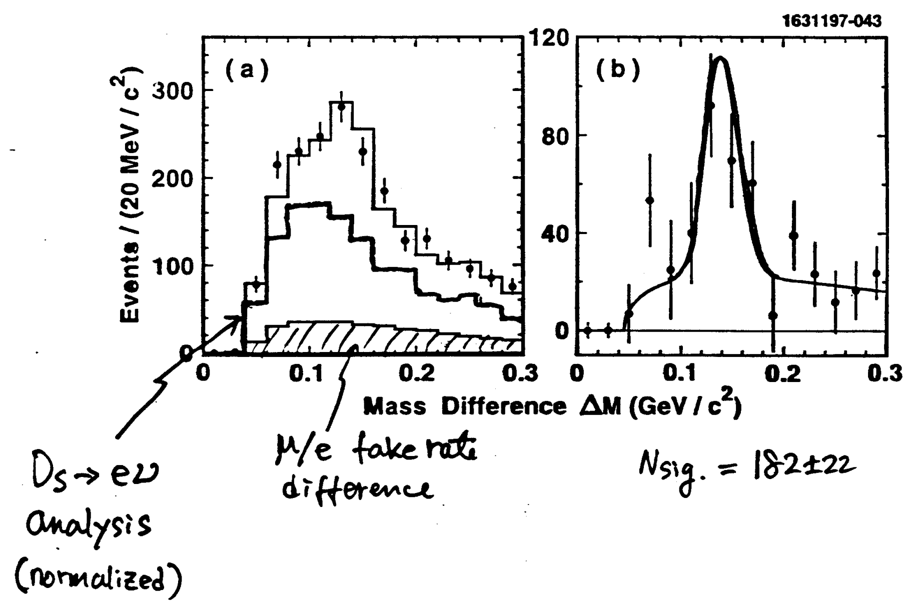
$\Rightarrow$ Poor measurement of $\vec{P}_{D_s}$ does not degrade $\Delta m = D_s^* - D_s$ mass diff. too much.

Largest Source of Background

$D \to X \ell \nu$ Semileptonic Decays

$X e \nu$, $X \mu \nu$] Same size contributions

(within ϵ difference, fake rate diff.)



$N_{sig.} = 182 \pm 22$

Systematic errors in $D_s \to \mu\nu$ (CLEO)

TABLE II. Systematic Errors on Width Ratio (%)

	Source of Error	Value	Size of error (%)
ID	Muon fake rate	(0.69±0.05)%	9
ID	Electron fake rate	(0.21±0.03)%	7
ID	$\pi/K/p$ fractions (sources of fakes)	67%/20%/13%	7
•	μ/e normalization	1.01±0.03	9
•	Detection efficiency	(4.2±0.3)%	7
✓	D_s^{*+}/D_s^+ production ratio	1.08±0.13	8
✓	$\phi\pi^+$ normalization	24740±1200±810	3
	Total systematic error		20

B-Factory 10 - 15 % ? poor Hermiticity at Asymmetric B-factory

TCF

$N_{evt} = 300 \Rightarrow 6\%$

Systematic error similar to $K\pi$ absolute meas. ~ 3 %

$\Rightarrow$ 3 % uncertainty in f_D

$D^+ \to \mu^+ \nu$ Analysis at TCF

- USE 5.5×10^6 $D^\pm$ tag sample.

  $\Rightarrow$ $\vec{P}_{D^+}$ direction

- PLOT $|\text{Missing Mass}|^2 = (E_{CM} - E_{\bar{D}} - E_\mu)^2 - P_{obs}^2$

  $\Rightarrow$ narrow peak at zero.

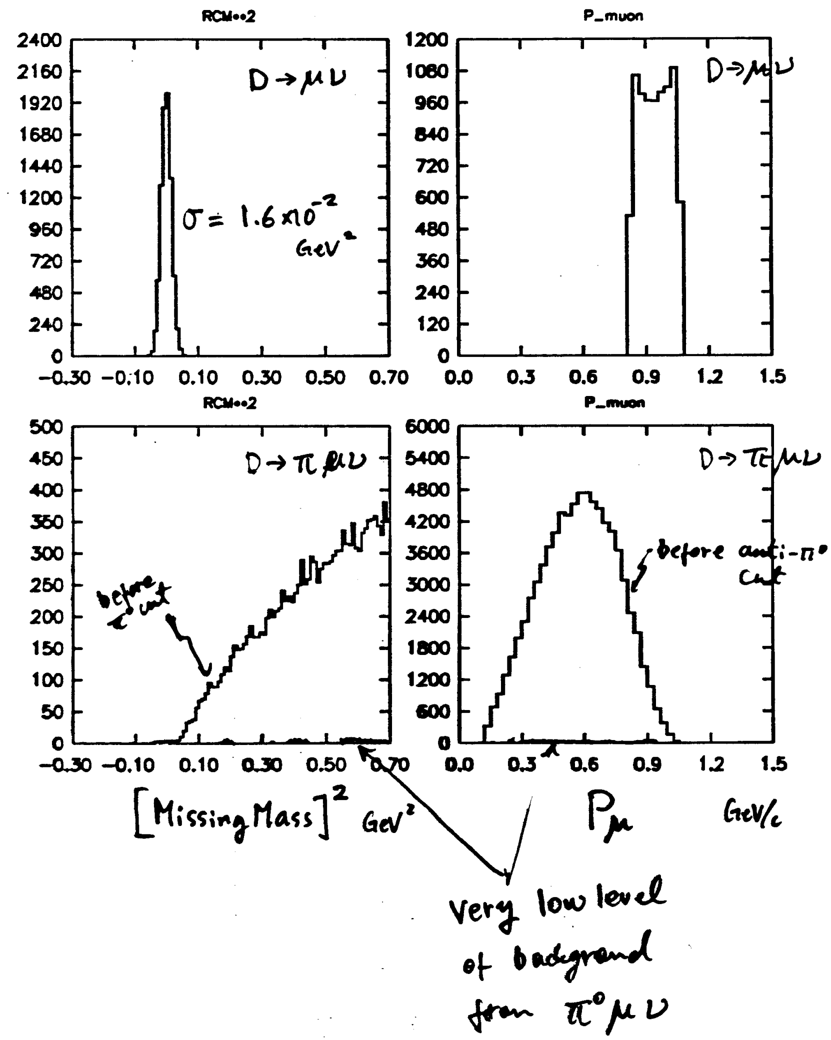
- NO extra tracks or showers

Simple Detector Simulation

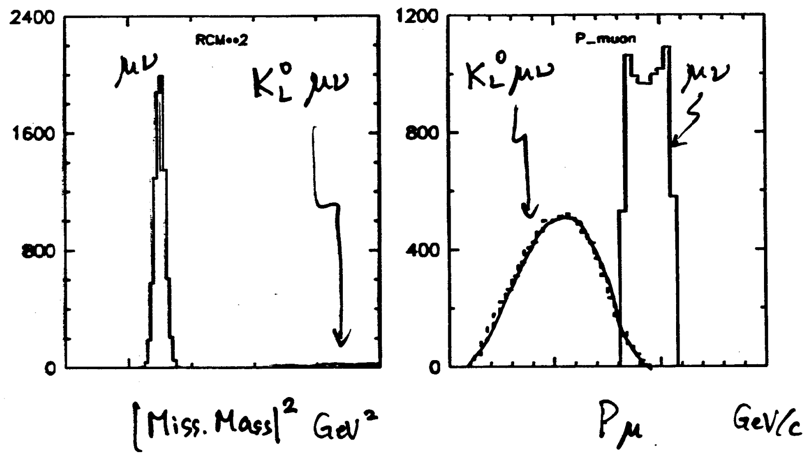
Sources of Background

$\left\{ \begin{array}{ll} K_L^0 \mu \nu & \text{B.R.} = 3.5 \times 10^{-2} \\ \pi^0 \mu \nu & \text{B.R.} = 3 \times 10^{-3} \end{array} \right.$

$\left\{ \begin{array}{l} K_L^0 \underset{\sim}{\pi}^+ \\ \pi^0 \underset{\sim}{\pi}^+ \end{array} \right.$ 4% μ/π misid at 1 GeV/c (90% efficiency)



RCM**2
P_muon
D→μν
σ = 1.6×10^{-2} GeV^2
D→πμν
before π⁰ cut
before anti-π⁰ cut
[Missing Mass]^2 GeV^2
P_μ GeV/c
Very low level of background from π⁰μν



K_L^0 Veto : assumed 98%

$N_{sig} = 300 \Rightarrow Br(D \to \mu\nu)$ at 6% uncertainty (Statisteal)

* Tried $\underline{D^- \to K^- \pi^+ \ell \nu \text{ tag}}$ vs. $\underline{D^+ \to \mu\nu}$

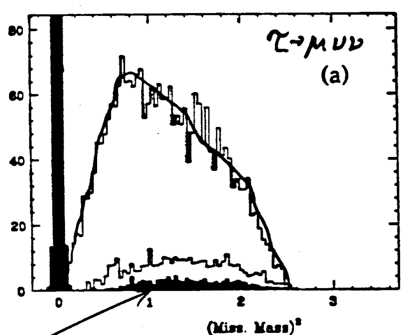
NO missing mass peak ⇒ P_μ measurement

TCF

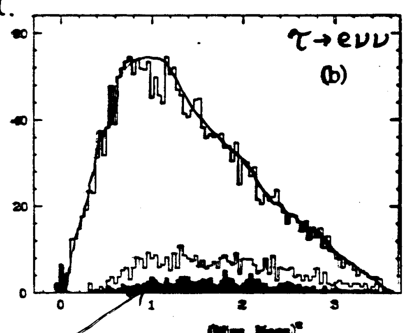
$D_s \to \tau \nu$
$\hookrightarrow e\nu\nu,\ \mu\nu\nu$

- e, μ ID at Low momentum
- No simple Signal peak
  $\Rightarrow$ require accurate background estimate

K_L^0 VETO !!!



$D^+ \to K_L \mu \nu$ dominant Background.



$D^+ \to K_L e \mu$

O(2000) signal events

Large Sys. errors

$D_s \to \mu\nu / D_s \to \tau\nu$ Ratio

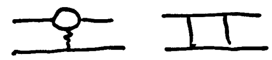
(5–10)% accuracy
Sensitive to New Physics

1 year running at
4.03 GeV ....

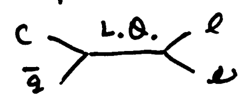
Probably Not

$D^+ \to \tau^+ \nu$ very difficult
(1/10 signal, ×10 background)

RARE CHARM DECAYS

LOOPS/Box $< 10^{-8}$ in SM 

INDIRECT SEARCH FOR NEW PHYSICS

- New particles in the loop
- New couplings e.g. 

RARE B Decays

mass-dep. Couplings favor b quark

Limits comparable to Rare D ...

$B \to \mu\mu X$ vs. $D \to \mu\mu X$

$N_B = 30 \times 10^6$ at B-factory
(1 year; 3×10^{33})

RARE K Decays

Limits approaching $10^{-10} - 10^{-11}$

KTeV

$K^+ \to \pi^+ \nu \bar{\nu}$

⇘ ⇙

PRECISION MEAS. at the Z^0 ⇗

Window of opportunity in charm sector getting

Smaller

Experimental Limits

- D → Charged final states with Leptons

  e.g. $D \to K\mu\mu$, $e\mu\mu$, ...] SELEX, FOCUS, CDF/DØ, BTeV

  $\to \mu\mu X$

- D → final states with neutrals

  $D \to \pi^- \nu\nu$, $K\nu\nu$

  {New phyics} ⇒ $K\nu\nu$

  ⇒ $K\ell\ell$ limit more strict !!!

- Radiative D decays

  $D \to K^*\gamma$, $\rho\gamma$ < few $\times 10^{-4}$ CLEO

  Long Dist effect at 10^{-5} level (J. Hewett) ⇗

  B-Factory: merged π^0, Combinatorial BKGD

  TCF { 10^{-5} level with Tag sample; 10^{-6} ? no tag

  $D \to \gamma$ "nothing" (unknown background level)

  ↑ better understanding of $q\bar{q}$ cont

Conclusion

1 year Running at $\psi''(3770)$

$\mathcal{L} = 1 \times 10^{33}\ cm^{-2}s^{-1}$

⇒ ABSOLUTE D BRANCHING RATIO : ~3 % meas.

(Systematically Limited)

⇒ f_D measurement : 3 % uncertainty

(Statistically Limited)

$D\bar{D}$ mixing / CP violation search

complementary to B-factories / hadronic Machi

Look for $\psi'' \rightarrow$ CP-odd configuration of CP-eigen states $(K^+K^-)(\pi^+\pi^-)$

Rare Decays

Radiative Decays $(D \rightarrow \gamma X)$ at 10^{-5} level

New Phyics will be of "unexpected" type.