AN OVERVIEW OF CHARMED MESON PHYSICS ACCESSIBLE TO A HIGH LUMINOSITY COLLIDER OPERATED NEAR CHARM PAIR THRESHOLDS[†]

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INTRODUCTION

The second generation up-type quark, charm, may be the only quark for which Cabibbo allowed, singly Cabibbo forbidden, doubly Cabibbo forbidden, second order weak and perhaps even CP violating transitions will be measurable.

The charm physics at the Tau-Charm Factory is thus organized along those lines, namely; weak hadronic decays (allowed thru doubly forbidden), pure and semi-leptonic decays (allowed and forbidden), rare decays, second order weak decays, and CP violating decays.

The pure leptonic decays allow us to probe the quark overlap in the charm meson in a theoretically unambiguous fashion. These measurements would provide important benchmarks for Lattice QCD. The semileptonic decays provide information on the dynamics of heavy quark decay, one vertex being wholly uninfluenced by QCD. The full range of allowed, forbidden and doubly forbidden hadronic decays test our detailed understanding of the hadronic weak current and the contributions of perturbative and non-perturbative QCD to a heavy quark system. They clearly represent the most difficult processes to untangle, but benefit from the detailed studies of the leptonic and semileptonic processes accessible to the Tau-Charm Factory. The rare decays provide a test of the Standard Model (SM), and

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are sensitive to the exchange of massive new (10-100's TeV) particles. Since couplings to new particles may be flavour dependent, these decays provide complementary information to that obtained in rare Kaon decay experiments. $D^0\bar{D}^0$ mixing is one of the few second order weak processes still accessible to experiment. It is potentially very interesting since it's rate may be heavily influenced by the presence of intermediate states in the second order weak decay. The origin of CP violation remains a mystery to this day. Within the context of the Standard Model (the three-generation KM matrix) it is expected to be extremely small for D^0 decays. No measurements or limits (at any sensitivity) exist at present.

I will introduce all of these subjects briefly. More detailed analyses are available as noted in other contributions to the workshop proceedings. More detail on $D^0\bar{D}^0$ mixing and CP violation in the D meson system is covered in these proceedings by G. Gladding and I.I.Y. Bigi, respectively. R. Willey has detailed the theoretical expectations for rare decay processes, in the proceedings.

CHARM MESON PHYSICS NEAR THRESHOLD

The *precision* study of charm near threshold that we propose at the Tau-Charm Factory distinguishes itself from the *survey* experiments possible (and proposed) in the high energy continuum or employing the secondary production of charm from B meson decays, in several important ways. The distinguishing features offered by Tau-Charm are: the large and well measured charm cross section (σ_D), (10× greater than available at 10 GeV/c^2), see Table I; the exclusive nature of production that *guarantees* both low combinatorics backgrounds and production kinematics essential for background rejection (relaxing the hardware performance requirements) and finally, the ability to simultaneously measure all charmed physics backgrounds. In addition, the most difficult measurements rely on the quantum statistics of the production and decay process to separate rare signals and backgrounds; this is a feature truly unique to the Tau-Charm Factory.

The well known primary technique that we propose to employ is the *single or double tagging* method wherein one or both charmed mesons are *tagged* by reconstruction of its mass; the recoil system is a-priori known to be another charmed meson with known charm and known 4-momentum, thus suppressing both non-charm and combinatorics backgrounds and allowing neutrinos to be *seen*.[1][2] Table II summarizes the expectation for single tagging capabilities per year. With improved photon detection efficiency, an additional factor of two or more in D^0 and D^+ tagging may be possible. The D_s are poorly known at present, so that a major improvement over the 3% tagging efficiency could be anticipated.

Table I. Charm Production Cross Sections and Rates

Center of Mass Energy (GeV/c)	Produced Species	Cross Section (nb)	Pairs Produced ($\times 10^{-8}$)
3.770	$D^0\bar{D}^0$	5.8 ± 0.8	1.0
3.770	D^+D^-	4.2 ± 0.7	0.8
4.028	$D_s\bar{D}_s$	0.7 ± 0.2	0.24
4.140	$D_s\bar{D}_s^*$	0.9 ± 0.2	0.32

ABSOLUTE BRANCHING FRACTIONS OF D^0,D^+,D_s AND CHARMED BARYONS

One of the immediate results of the highly efficient single and double tagging procedure coupled with pair production of the mesons, is that the absolute branching fractions for charmed D^0, D^+ and D_s mesons can be set. From our past work in MarkIII, we know that about 5000 single tags will result in a 20% determination of the absolute scale of the D^0 and D^+. Thus an increase of about 1000× would result in measurements limited only by systematics at the 1% level.

At present, no direct knowledge of the D_s absolute scale is known. Measurements at higher energy in the continuum suggest that the $\phi\pi^+$ branching ratio is consistent with $2 \pm 1\%$, however this relies on knowledge of the charm cross section and assumptions about fragmentation which in turn rely on D^0, D^+, and D^* absolute charmed meson and baryon branching fractions.

In one year at 10^{33} cm^{-2} sec^{-1} at a Tau-Charm Factory, using four well known decay modes ($\phi\pi^+$, $S^*\pi^+$, $\bar{K}^0K^+$, and $\bar{K}^{*0}K^+$), about 5×10^5 single D_s tags can be reconstructed. The number of double tags from pairing these channels is $4950 \times Br(\phi\pi^+)/3\%$. This implies that the error on the absolute scale of D_s decays will be below 3%, even if the $\phi\pi^+$ branching fraction is as small as 1%. The advantage of this measurement is that it relies *only* on the pair production of the D_s mesons. The Tau-Charm Factory, while not optimized for operation at $\sqrt(s) = 5$ GeV, could perform similar absolute measurements of charm baryon branching fractions, since they are known to be pair produced copiously at each threshold.

UNRESOLVED FEATURES OF D HADRONIC DECAYS AND THE MISSING D_s DECAY PROBLEM

Significant progress has been made in understanding the mechanism(s) of the Cabibbo allowed and singly suppressed hadronic weak decays of charmed mesons; weak annihilation, W-exchange, and interference effects have been proposed to explain the complicated pattern of observed decays. We anticipate that in the next few years further progress will be made, expecially at fixed target experiments and at BES, when about 10× larger datasets become available for study of the charmed mesons. From these datasets, we anticipate that some uncertainties in D^0 and D^+ decays will be further reduced, while D_s decays will start to be measured at a level that we now measure charged final states of the D^0 and D^+. What questions will still remain?

Experimentally, while we now have cataloged about $85 \pm 15\%$ of the D^0 and D^+ decays, the D_s decays remains largely unmeasured. Table III for example, summarizes our current knowledge of the D_s where we see that if the $\phi\pi^+$ branching ratio is taken as 2% and the semileptonic decays taken as 16%, then less than 50% of the D_s final states are known. Since the anticipated strength of the weak-annihilation process remains unconfirmed, the D_s may decay *differently* than the D^0 and D^+. Unlike the D^0 and D^+, which thus far appear to be dominated by quasi two-body final states roughly following the factorization model of Bauer, Stech and Wirbel, and the QCD Sum Rule approach of Blok and Shifman, the D_s may have an enhanced non-resonant width. This possibility was already suggested by Blok and Shifman when it became clear that the lifetime of the D_s could not be reconciled with the sum of the partial decay widths of their model and the semileptonic decays of the D^0 and D^+. Should this enhancement be occuring, then the next generation of experiments will likely fail to uncover the nature of the D_s hadronic decays, since it will decay into many final states containing neutrals (π^0 and η) and multi-neutrals, for which the detectors are inadequate. This is where we anticipate that the Tau-Charm detector, coupled with charm-threshold constraints will have adequate sensitivity to uncover even the most complicated

Table II. Well Established Single Tag Modes

$D^0 \rightarrow$	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
$K^{0*}K^+$	0.030	1.1×10^5
Total		8.3×10^5

final states. Figure 1 shows an example of the reconstruction at 4.028 GeV of $D_s \rightarrow \eta\pi^+\pi^+\pi^-$ with the $\eta \rightarrow \pi^+\pi^-\pi^0$ and $\pi^0 \rightarrow \gamma\gamma$, in the midst of other hadronic decays.

In addition to the missing D_s decays problem alluded to, even the high statistics experiments to date have been unsuccessful in providing a detailed understanding of the observed strength of the W-exchange process, and in shedding any light at all on final-state inter-

Table III. D_s Branching Ratios Relative to $\phi\pi$

Decay Mode	Experiment	Result or Limit
$D_s \rightarrow \bar{K}^0 K^+$	MKIII	$0.92 \pm 0.32 \pm 0.20$
	CLEO	$0.99 \pm 0.17 \pm 0.06$
$D_s \rightarrow \bar{K}^{*+} K^0$	CLEO	$1.2 \pm 0.21 \pm 0.07$
$D_s \rightarrow \bar{K}^{*0} K^+$	E691	$0.87 \pm 0.13 \pm 0.05$
	ARGUS	1.44 ± 0.37
	MKIII	$0.84 \pm 0.30 \pm 0.22$
	CLEO	$1.05 \pm 0.17 \pm 0.06$
$D_s \rightarrow \rho\pi^+$	E691	< 0.08 at 90% CL
$D_s \rightarrow S^*\pi^+$	E691	$0.28 \pm 0.1 \pm .03$
$D_s \rightarrow \eta\pi^+$	E691	< 1.5 at 90 % CL
	MarkII	3.0 ± 1.1
$D_s \rightarrow \eta'\pi^+$	MarkII	4.8 ± 2.1
	NA14	5.7 ± 1.5
$D_s \rightarrow \omega\pi^+$	E691	< 0.5 at 90 CL%
$D_s \rightarrow \bar{K}^{*0} K^{*+}$	NA32	2.3 ± 1.2
$D_s \rightarrow \phi\pi\pi^0$	E691	$2.4 \pm 1.0 \pm 0.5$
	NA14	< 2.6 at 90% CL
$D_s \rightarrow (K^- K^+ \pi^+)_{NR}$	E691	$0.25 \pm .07 \pm .05$
	NA32	0.96 ± 0.32
$D_s \rightarrow (\pi^- \pi^+ \pi^+)_{NR}$	E691	$0.29 \pm .09 \pm .03$
$D_s \rightarrow (\pi^- \pi^+ \pi^+ \pi^- \pi^+)_{NR}$	E691	< 0.29 at 90% CL
$D_s \rightarrow \phi\pi^- \pi^+ \pi^+$	E691	$0.42 \pm 0.13 \pm .07$
	NA32	0.39 ± 0.17
	ARGUS	$0.41 \pm 0.13 \pm 0.11$
$D_s \rightarrow (K^- K^+ \pi^+ \pi^0)_{NR}$	E691	< 2.4 at 90% CL
$D_s \rightarrow (K^- K^+ \pi^- \pi^+ \pi^+)_{NR}$	E691	< 0.32 at 90% CL
	NA32	0.11 ± 0.07

actions, SU(3) violations, rescattering processes and Penguin decays; all of which may strongly influence charm decays and heavier B meson decays. These processes will all require a *two to three orders of magnitude* increase in statistics, to hope to achieve a true understanding of their nature. Penguin decays, of great importance in understanding the radiative and hadronic widths of heavy mesons, will require the maximum luminosity and capabilities of the Tau-Charm Factory. Their importance will be discussed in the section on rare decays. Beyond the Cabibbo allowed and singly suppressed decays, lie the doubly suppressed decays, having branching fractions relative to allowed decays of $tan^4(\theta_c) \sim 0.003$. These decays offer another place to test our understanding of the hadronic weak current, since the pattern of their decays should differ markedly from that of the singly suppressed decays. From work in Mark III, we know that these can be approached *only* by the use of D tagging, because of the ease in confusing allowed decays that undergo two particle identity interchanges, that result in reflections back to the D mass.

Furthermore, the clearest understanding of doubly Cabibbo suppressed decays can be reached by measuring the pattern of D^+ decays, where the signature is not confused by a mixing component that may be present in D^0 decays. D^+ doubly Cabibbo suppressed decays have an added attraction, because unlike allowed D^+ decays, they do not suffer from interference effects, and hence may be significantly enhanced. This was first calculated by Bigi.[3]

At the present time, no experiment has reported evidence for D^0 or D^+ doubly Cabibbo suppressed decays (DCSD). As pointed out, one of the severe experimental problems is the kinematic reflection from non-suppressed decays. From studies in the MarkIII detector, we expect that the improvements planned for the Tau-Charm detector, coupled with the clean tagging of D mesons will allow reductions in background to a doubly Cabibbo suppressed signal to the $\sim$ 10% level for the all charged modes shown in Table IV. Table IV gives estimates for our sensitivity to doubly Cabibbo suppressed decays. Even at a Tau-Charm Factory, only a few hundred events can be reconstructed per year.

Table IV. Double Cabibbo Suppressed D^+ Decays

Channel $D^+ \rightarrow$	$\tan^4 \theta_c$ coeff.	Events Detected
$K^+\pi^0$	0.02	142
$K^+\omega$	0.01	56
$K^+\rho^0$	0.07	498
$K^{*0}\pi^+$	0.06	232
$K^{*0}\rho^+$	0.01	42
$K^{*+}\pi^0$	0.05	106
$K^+\pi^-\pi^+$	0.07	512

PURE LEPTONIC DECAYS

Pure leptonic decays of the D^+ and D_s are presently an experimentally unexplored area of great theoretical interest. The partial width for these decays (see Figure 2) is proportional to the product of the weak hadronic current (J_{had}) and the leptonic current (J_l). The axial vector current J_{had} is defined by the Van Royen - Weisskopf equation:

$$< 0 \mid J^{\alpha}_{hadronic} \mid D^+ >= iV_{cd}P^{\alpha}f_D$$

in terms of the weak decay constant f_D. The weak decay constant f_D is thus a fundamental constant characterizing the overlap of the c and d(s) quarks in the $D^+(D_s)$ and contains the QCD corrections which modify the $W^+q\bar{q}$ vertex. To emphasize this, f_D can be written in terms of the wavefunctions of the heavy and light quarks and the meson mass:

$${f_D}^2 = \frac{\mid \Psi(0) \mid^2}{M_D}.$$

Precision measurements of the leptonic decays of the D^+ and D_s allows the unambiguous determination of f_D or f_{D_s}:

$$B(D^+ \to \mu^+\nu) = \frac{G_F^2}{8\pi} f_D^2\, \tau_D\, M_D\, m_\mu^2 \mid V_{cd} \mid^2 \left(1 - \frac{m_\mu^2}{M_D^2}\right)^2$$

where M_D is the meson mass, m_μ the muon mass, V_{cd} the KM matrix element, G_F the Fermi constant, and τ_D the lifetime of the D^+.

Naively, the decay constants scale like the square root of the inverse of the heavy quark mass (the $1/M_D$ term) times the reduced mass (μ_{cd}) to a power between one and two, ($\Psi(0)$ term). This $1/M_D$ dependence already appears to be reproduced in Lattice calculations for the D mesons.[5] Thus, by measuring two distinct decay constants to adequate precision, say f_D and f_{D_s}, it will be possible to distinguish among models and reliably extrapolate to the B system for which precise measurements are unobtainable. The same Lattice calculations for B mesons are considerably more difficult than for D mesons, making the early comparison of precise charm measurements of *both* f_D and f_{D_s} important benchmark tests in the development of Lattice QCD. Table V summarizes the theoretical ranges for decay constants.[6]

Table V. Theoretical Estimates of Weak Decay Constants

Author	Year	Type	f_D	f_{Ds}	f_{Bd}	f_B/f_D
Mathur and Yamawaki	(81)	QCD SUM RULE	192	232	241	1.3
Aliev and Eletskii	(83)	QCD SUM RULE	170	-	132	0.8
Shifman	(87)	QCD SUM RULE	170	-	110/130	0.7/0.8
Narison	(87)	QCD SUM RULE	173	-	187	1.1
Dominguez and Paver	(87)	QCD SUM RULE	220	270	140/210	0.6/1.0
Reinders	(88)	QCD SUM RULE	170	-	132	0.8
Kraseman	(80)	POTENTIAL	150	210	125	0.8
Suzuki	(85)	POTENTIAL	138	-	89	0.6
Godfrey and Isgur	(85-86)	POTENTIAL	234	391	191	0.8
Bernard	(88)	LATTICE	174	234	105	0.6
DeGrand and Loft	(88)	LATTICE	134	157	-	-
Golowich	(80)	BAG	147	166	-	-

All second order weak processes involving hadrons - such as $D\bar{D}$ and $B\bar{B}$ mixing involve box diagrams whose evaluation requires QCD corrections to J_{had}. The standard vacuum insertion calculation involves the replacement of the second order weak matrix element by the square of the same axial vector matrix element that appears in the leptonic decays, now multiplied by a parameter B that contains the QCD corrections under that simplifying assumption. The reliability of calculations of the B parameter is directly related to the ability to correctly calculate the weak decay constants themselves, since both involve the addition of gluonic corrections to the weak - hadronic process.

In a Tau-Charm Factory, the measurement of $D^+ \to \mu^+\nu$, and $D_s \to \mu^+\nu$ are straightforward.[7] Tagged events are sought containing only one additional muon, and with missing mass near zero. The pure leptonic decays $D_s \to \tau\nu$, with $\tau \to l\nu\nu$ or $\tau \to \pi\nu$ are also detectable although the monochromatic nature of the lepton and the missing mass constraint are lost. We rely on the D tagging, the hermeticity and low energy efficiency of the detector for photons, and the K_L^0 rejection. The lowest lying neutral D_s decays are required to be *independently measured* allowing a precise background calculation to be made. Figure 3 shows the possible channels, and the backgrounds expected in each case.

Figure 4 shows an estimate for the number of reconstructed events in the three charmed meson channels considered. We measure f_D and f_{D_s} each to a few percent; $D_s \to \tau\nu$ can be reduced to a statistical error of about 1%. More details are presented in the paper in these proceedings by P. Kim, as well as a discussion of the sensitivity of these measurements to the presence of a mass dependent (non-universal) coupling to the final state leptons - induced for example by a light charged Higgs.

SEMILEPTONIC DECAYS AND PRECISION DETERMINATIONS OF KM PARAMETERS

At the present time, knowledge of the KM matrix in the first two generations is restricted to precision measurements in the first row alone; V_{ud} and V_{us} are measured at the 0.1% and 1% level, respectively. Measurements in the charm row are only at the $\sim$ 20% level now, with errors dominated by statistics and systematics:

$\mid V_{cd} \mid^2 = 0.058 \pm 0.014$	(CDHS)
$\mid V_{cs} \mid^2 = 0.530 \pm 0.080 \pm 0.060/f_+(0)^2$	(MKIII)
$\mid V_{cs} \mid^2 = 0.590 \pm 0.070 \pm 0.090/f_+(0)^2$	(E691)
$\mid \frac{V_{cd}}{V_{cs}} \mid^2 = 0.057 \ {}^{+0.038}_{-0.015} \pm 0.005$	(MKIII)

Only with the imposition of the theoretical assumption of KM matrix unitarity and the additional constraint to a three generations, can the allowed range of elements in the charm sector of the KM matrix be reduced. Making these assumptions by definition precludes a test of the Standard Model.

After leptonic decays, the Dl_3 decays represent the next level of difficulty for theoretical interpretation. The partial width for Dl_3 decays involves two form factors $f_+(q^2)$ and $f_-(q^2)$ in addition to the KM parameter. The f_- form factor is multiplied by the square of the lepton mass; the term becomes vanishingly small, leaving:

$$\Gamma(D \to Kl\nu) = \frac{{G_F}^2}{16\pi^3} {M_D}^5 \mid V_{cs} \mid^2 \int \mid f_+(q^2) \mid^2 (2x_e - 2x_K x_e - {x_e}^2 - 1 - \lambda^2)$$

The f_+ form factor is usually parametrized as a simple pole:

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

Measuring Dl_3 decay rates and the q^2 dependence of the f_+ in D and D_s it is possible to extract $V_{cd} \times f_+(0)$ and $V_{cs} \times f_+(0)$. Because SU(4) is a badly broken symmetry, $f_+(0)$ deviates strongly from unity (unlike in the kaon system). Reliance on theory is imperative to extract the KM parameters. Ratios of rates will yield ratios of KM parameters with the form factor uncertainty reduced to the SU(3) breaking level only ($\approx 5\%$). The theoretical values for $f_+(0)$ come from potential models, QCD sum rules, and Lattice calculations and range from 0.58 to 0.75.[8] Current calculations are summarized in Table VI, and more details are available in the writeups of N. Paver[9], A. Soni[10] and B. Ward[11], in these proceedings.

Table VI. Estimates of $f_+(0)$

Author	Method	$f_+(0)$
Bauer, Stech and Wirbel	Rel. Pot.	0.73-0.75
Grinstein and Wise	Non-Rel. Pot.	0.58
Paver and Dominguez	QCD Sum Rule	0.75 ± 0.05
Soni and Bernard	Lattice	0.75 ± 0.20

In Dl_4 decays four form factors appear; another vector ($V(q^2)$) and three axial vector ($A_0(q^2), A_1(q^2), \text{and} A_2(q^2)$). One, $A_2(q^2)$, is generally inaccessible, being multiplied by the square of a lepton mass. The overall q^2 dependence may be factored into a sum of simple pole-like terms and the matrix element formed in terms of two angles in the decay. These are the K or π decay angle (θ) in the K^* or ρ rest frame, and the angle (ϕ) of the decay plane of the W^+ ($\rightarrow l\nu$) relative to the decay plane of the K^* or ρ.

If adequate statistics ($\sim 10^5$) are obtained, measuring the Dl_4 rates and the q^2 dependence of the form factors (in the θ, ϕ plane) allows one to determine their relative values and hence V_{cd} or V_{cs} up to a single constant.

Precise and background free measurements of the relative magnitude and shape of the form factors in Dl_3 and Dl_4 decays should provide all the constraints necessary to either select among or improve the existing models of D and B meson decay. The ability to measure efficiently over the full kinematic range is particulaly important here. Once confidence in a model is established, the reliability of the estimate of form factors at $q^2 = 0$ is improved and the extraction of V_{cd} and V_{cs} (the overall normalizations) with smaller theoretical errors, becomes possible.

In Table VII estimates of the expected rates for the numerous channels in the spectator-type semileptonic decays that are accessible to a Tau-Charm Factory.[12] Figure 5 shows the use of tagging, kinematics and calorimetry to efficiently isolate Cabibbo allowed and suppressed decays, by reconstruction of the missing mass (the ν in the semileptonic decay). These measurements are expected to be almost background free; the technique has already been demonstrated by the MarkIII in real data.[13] Without the tagging and kinematic constraint, the leakage from soft missing neutrals both from hadronic and semileptonic decays cannot be adequately rejected, even with the best crystal calorimeter.

Table VII. Estimates For Exclusive Semileptonic Decays

$D^0 \rightarrow$	BR	Evts. Detected/year
$K^- e^+ \nu$	0.034	0.29×10^6
$K^{*-} e^+ \nu$	0.06	1.53×10^5
$\pi^- e^+ \nu$	0.004	0.37×10^5
$\rho^- e^+ \nu$	0.004	0.16×10^5
$D^+ \rightarrow$		
$\bar{K}^0 e^+ \nu$	0.07	0.11×10^6
$K^{*0} e^+ \nu$	0.05	1.99×10^5
$\pi^0 e^+ \nu$	0.004	0.14×10^5
$\eta e^+ \nu$	0.0015	0.33×10^4
$\eta' e^+ \nu$	0.0005	0.92×10^3
$\rho^0 e^+ \nu$	0.0025	0.13×10^5
$\omega e^+ \nu$	0.0025	0.55×10^4
$F \rightarrow$		
$\eta e^+ \nu$	0.02	0.67×10^4
$\eta' e^+ \nu$	0.006	0.15×10^4
$\phi e^+ \nu$	0.034	0.44×10^4
$K^0 e^+ \nu$	0.002	0.47×10^3
$K^{*0} e^+ \nu$	0.0013	0.45×10^3

The semimuonic decays and the sensitivity to additional terms in the Dl_3 pole expansion are discussed in more detail in the paper by J. Izen, in these proceedings.

In the next generation of experiments before Tau-Charm, the statistical error on the KM parameter V_{cs} may be driven down below the 10% level; V_{cd} has not yet been measured in hadro or photoproduction because of larger backgrounds. Without measuring the full spectrum of semileptonic decays, the theoretical uncertainties will not however change significantly from their present levels, and will thereby prevent the truly precise determinations of the KM parameters at the level of $\sim 1\%$ which is the ultimate goal of the Tau-Charm experiments.

With the sensitivity suggested in Table VII, it is clear that the Tau-Charm Factory can also provide information on final states not accessible through semileptonic spectator graphs (see Figure 6) such as $D \rightarrow ggl\nu$ and resonant $D \rightarrow (\text{glueball})l\nu$. The couplings to the $\eta\prime$, the θ and the iota in a semileptonic decay may provide new insights into their gluonic makeup. Branching fractions as small as $\sim 10^{-3}$ will produce 10's of detected (background free) events in these channels.

RARE D DECAYS

Experimental tests of extensions to the Standard Model (SM) require either the observation of new particles or their manifestations. Bigi has argued[14] that such extensions with new scalars or vector bosons (Y), will have rates scaling like: $B(D \rightarrow l^+l^-X) \propto \frac{g^2_{qY} \times g^2_{Yl}}{M^4_Y}$. Flavor changing neutral currents in the Standard Model (ie: lepton family number violating decays, LFNV), are forbidden to all orders. Any observed non-zero rate thus signals the onset of New Physics. Examples of such decays are D^0 or $D^+ \rightarrow e^+\mu^-X$, where X is a light hadron. Lepton family number conserving decays (LFNC) can be simulated by effective FCNC, that are allowed in the SM *only* through higher order weak and/or electromagnetic processes. (See Figure 7, where the simplest examples such as D^0 or $D^+ \rightarrow l^+l^-X$ shown.) These one-loop induced FCNC are the most sensitive to New Physics. They compliment all searches in the down quark sector because the couplings to new particles may *a priori* be flavor dependent, either through mass-dependent couplings or through mixing angles.

All of these classes of decays are expected to occur at rates $\leq 10^{-7}$ in the SM.[15] This occurs because of the need for quark annihilation ($\sim f^2_D/M^2_D$) in the D, and in the case of two body decays, a reduction from the helicity suppression ($\sim M_l^2/M_D^2$) associated with the lepton chirality. Estimates are that long range effects may bring the SM allowed processes up in rate to 10^{-6} to 10^{-7}. If that is so, then sorting New Physics from Old requires the measurement of the full pattern of rare decays.

When helicity suppression is factored out of current limits, (all are at the few $\times 10^{-4}$ level[16]) the mass reach of these is ~0.2 TeV (choosing unit couplings for g_{qY} and g_{Yl}). The Tau-Charm factory brings these into the TeV range for the helicity suppressed class of decays. The non-helicity suppressed channels will provide sensitivity to the ~ 20 to 200 TeV scale (Table VIII).[17] To reduce combinatoric background requires however the low multiplicity nature of charm events near threshold. This explicit feature has already been exploited in at least one recent MarkIII search.[18]

Table VIII. Sensitivity to Rare Decays

Channel	Estimated Background	Limit at 90% CL	Signal at 5σ
$D^0 \to e^+e^-$	$\leq$0.2 evts	3×10^{-8}	6.0×10^{-8}
$D^0 \to \mu^+e^-$	$\leq$1.3 evts	5×10^{-8}	1.2×10^{-7}
$D^0 \to \mu^+\mu^-$	$\leq$10. evts	8×10^{-8}	2.9×10^{-7}
$D^0 \to \rho^0e^+e^-$	$\leq$1.6 evts	4×10^{-8}	1.3×10^{-7}
$D^0 \to K^0e^+e^-$	$\leq$1.5 evts	2×10^{-7}	7.3×10^{-7}
$D^0 \to \nu\bar{\nu}$	$\leq$22. evts	-	8.0×10^{-6}

In addition to rare decays in the previous class, there are also ordinary radiative decays and Penguin - type hadronic and radiative decays. The hadronic decays lead to ordinary Cabibbo suppressed final states, and thus present a problem in untangling them from much larger "ordinary" physics.[19] The electromagnetic Penguins are GIM suppressed[20] to a level of O(10^{-8}): $A \sim \frac{(m_s^2-m_d^2)}{M_W^2}$. Rescattering processes (long range effects) may however enhance the electromagnetic graphs (see Figure 8) to a level of O(10^{-5}). Furthermore, a number of recent calculations suggest that QCD radiative corrections may enhance the Penguin graph even further.[21] At a level of 10^{-5}, decays like $D^+ \to \gamma\rho^+$ should be easily detectable in the Tau-Charm Factory.[22] The importance of seeking Penguins in charm decay where the tree graph is very small is to establish the strength of long range rescattering and QCD radiative corrections. Both these "corrections" must exist for B decay, and in fact may *dominate* the more interesting t-quark contribution. Thus, if the class of Penguin decays is found in D decay to be large ($O(10^{-5})$), it may be impossible to unambiguously resolve the t-quark contribution to electromagnetic-penguin B decay.

$D^0\bar{D}^0$ MIXING AND CP VIOLATION

$D^0\bar{D}^0$ mixing and CP violation in the D^0 meson system are discussed in depth by G. Gladding and I.I.Y. Bigi, in these proceedings. For completeness, I outline here some of the features of the Tau-Charm measurements in these areas.

In the SM, $D^0\bar{D}^0$ mixing is a second order weak interaction occurring either through the box diagrams or through long distance effects (see Figure 9).[23] The mixing parameter r_D is defined as the ratio of the number of events exhibiting mixing to the number of events not exhibiting mixing. In an experiment not measuring time-evolution, but integrating over time, r_D is related to the mass matrix parameters ΔM, $\Delta\Gamma$ and Γ: $r_D = \frac{(\frac{\Delta M}{\Gamma})^2 + (\frac{\Delta\Gamma}{2\Gamma})^2}{2}$. Box contributions to r_D are expected to be small $r_D \leq 10^{-6}$ due to GIM cancellations. Long range contributions to r_D, (also second order weak decays), from ΔM and $\Delta\Gamma$ may be equal in magnitude and each as large as $\sim$ few $\times\ 10^{-2}$, leading us to expect to observe a mixing signature at the level $r_D \sim 10^{-4} - 10^{-5}$

Historically, the principle experimental backgrounds leading to "mixing like" final states comes from doubly Cabibbo suppressed decays (DCSD). Having branching fractions of $O(\tan^4\theta_c) = 0.003$), these decays may dominate a mixing signature. In the absence of time-evolution information (an experimental challenge for all but the highest energy machines), it has been suggested by Bigi[20] that a set of measurements at two or more energies can be used in conjunction with quantum statistics, to sort out mixing from doubly Cabibbo suppressed decays or New Physics. It is also possible using the interference term, to measure $\frac{\Delta M}{\Gamma}$ and $\frac{\Delta\Gamma}{\Gamma}$ separately. This is illustrated in Table IX where two sets of measurements are made. First, final states where both D^0 mesons decay semileptonically (thereby eliminating DCSD background), and second, where both decay hadronically, but to identical final states. In that case, Bose statistics forbids DCSD when the D^0 mesons are in an relative l=1 state. When the D^0 are in an l=0 state, then mixing and DCSD interfere, allowing a measurement of both.

Table IX. Establishing Mixing and DCSD

$e^+e^- \rightarrow$	No Mixing Signature No New Physics	Mixing Signature
	$\frac{K^\mp\pi^\pm K^\mp\pi^\pm}{K^-\pi^+K^+\pi^-}$	
$D^0\bar{D}^0$	0	r_D
$D^0\bar{D}^0\ \gamma$	$4tan^4\theta_c \mid \hat{\rho} \mid^2$	$3r_D + 8(\frac{\Delta\Gamma}{2\Gamma})tan^2\theta_c\hat{\rho}$ $+4tan^4\theta_c \mid \hat{\rho} \mid^2$
$D^0\bar{D}^0\ \pi^0$	0	r_D
	$\frac{K^\mp l^\pm K^\mp l^\pm}{K^\mp l^\pm K^\pm l^\mp}$	
$D^0\bar{D}^0$	0	r_D
$D^0\bar{D}^0\ \gamma$	0	$3r_D$
$D^0\bar{D}^0\ \pi^0$	0	r_D

The quantity $\hat{\rho}$ is defined by Bigi's convention: $\hat{\rho} = \frac{1}{tan^2\theta_c}\frac{T(D^0\rightarrow K^+\pi^-)}{T(D^0\rightarrow K^-\pi^+)}$. The doubly Cabibbo suppressed amplitudes can be measured in parallel with tagged events.

At a Tau-Charm Factory preliminary analysis suggests that we can reconstruct at the $\psi(3770)$, in excess of 1.0×10^5 events in the two categories of Table IX.[24] Backgrounds appear to be reducible *only* by the combination of detector particle identification and threshold kinematic constraints. At any of the higher energies suggested (4.03 or 4.14 GeV/c^2), similar numbers of events should be reconstructible. One study has been done to verify this conclusion.[25] Similar studies using $D^{*+} \rightarrow \pi^+ D^0$ have also been done.[26] This implies that $D^0\bar{D}^0$ mixing should be *measurable* at the level of $r_D \approx 10^{-4}$, and unambiguously *observable* above background for values of $r_D \approx 10^{-5}$ by several independent techniques.

CP violation in the D^0 system is expected to be small, however *no* measurments exist at the present time. Searches can be carried out at the 10^{-2} to 10^{-3} level by looking at CP asymmetries *induced by mixing* (see the paper by U. Karshon, these proceedings), or by looking for *direct* CP violation that induces asymmetries in the decays of the D^0 and $\bar{D}^0$ into Cabibbo suppressed CP eigenstates fed by two possible amplitudes (eg: annihilation and penguins). In the latter case, the Tau-Charm Factory may be sensitive below the 10^{-2}

level. While mixing may be small, and asymmetries are inherently difficult to measure, CP violation may be explored in the production and decay of the $\psi(3770)$ into two equal-CP eigenstates. Here, rather than measuring an asymmetry, one would look for the presence of CP violating $\psi(3770)$ decays (for example $\psi(3770) \rightarrow K^+K^- + \pi^+\pi^-$). By having the efficiency to reconstruct several thousand events (for 100% CP violation) we expect to achieve 10^{-2} to 10^{-3} sensitivity, if adequate background rejection is attained.

CONCLUSIONS

Differing from the e^+e^- survey experiments of the past and present, and higher energy experiments of the future, the Tau-Charm Factory operated at a peak luminosity of few $\times 10^{33} cm^{-2} sec^{-1}$ and coupled to a fourth generation detector should be able to probe the region of the physics of charm quark decays lying three or more orders of magnitude below present measurements. The unique kinematics of threshold charm production coupled with a *customized* detector, should allow the collection of a sample of 10^7 - 10^8 cleanly tagged D^0,D^+ and D_s, each year, making possible the unparalleled control of experimental systematics and backgrounds that are essential for the detailed studies of rarer charm decay processes being proposed.

REFERENCES

1. R. M. Baltrusaitis *et al.*, Phys. Rev. Lett. 54 (1985) 1976.
2. R. M. Baltrusaitis *et al.*, Phys. Rev. Lett. 55 (1985) 150.
3. See the discussion in I.I.Y.Bigi, reference 14.
4. E. D. Commins and P. H.-Bucksbaum, *Weak Interactions of Leptons and Quarks*, (Cambridge University Press, Cambridge, UK, 1983), pp. 155-156.
5. A. Soni, private communication and
   C. Bernard *et al.*, Phys.Rev. D38 (1988) 3540.
6. H. Krasemann, Phys. Lett 96B (1980) 397.
   E. Golowich, Phys. Lett. 91B (1980) 271.
   V. Mathur *et al.*, Phys. Lett. 107B (1981) 127.
   T. Aliev *et al.*, Sov. J. Nucl.Phys. 38 (1983) 6.
   M. Suzuki, Phys.Lett. 142B (1984) 207.
   S. Godfrey *et al.*, Phys. Rev. D32 (1985) 189.
   S. Godfrey, Phys. Rev. D33 (1986) 1391.
   C. Dominguez *et al.*, Phys. Lett. 197B (1987) 423.
   L. Reinders, Phys. Rev. D38 (1988) 947.
   C. Bernard *et al.*, Phys. Rev. D38 (1988) 3540.
   T. DeGrand *et al.*, Phys. Rev. D38 (1988) 954.
7. P. Kim, Proceedings of the Tau-Charm Workshop, SLAC-REPORT 343.
8. C. Bernard *et al.*, Phys.Rev. D38 (1988) 3540.
   C. Dominguez *et al.*, Phys. Lett. 207B (1988) 499.
   C. Dominguez *et al.*, Phys. Lett. 197B (1987) 423.
   B. Grinstein *et al.*, Phys. Rev. D39 (1989) 799.
   B. Grinstein *et al.*, CALTECH 68-1311 (1986).
   B. Grinstein *et al.*, Phys. Rev. Lett. 56 (1986) 298.
   M. Bauer *et al.*, Z. Phys. C29 (1985) 637.

9. N. Paver, Proceedings of the Tau-Charm Factory Workshop, SLAC-REPORT 343.
10. A. Soni, Proceedings of the Tau-Charm Factory Workshop, SLAC-REPORT 343.
11. B. Ward, Proceedings of the Tau-Charm Factory Workshop, SLAC-REPORT 343.
12. J. Izen, Proceedings of the Tau-Charm Factory Workshop, SLAC-REPORT 343.
13. J. Adler *et al.*, Phys. Rev. Lett. 62 (1989), 1821.
14. I.I.Y. Bigi, Proc. of the Sixteenth SLAC Summer Institute (1988) 30.
15. R. Willey, Proceedings of the Tau-Charm Factory Workshop, SLAC-REPORT 343.
    I.I.Y. Bigi, Proc. of the Sixteenth SLAC Summer Institute (1988) 30.
16. C. Grab, Proc. of the Rare Decay Symposium, Vancouver, Canada, Nov. 30-Dec. 3, (1988). Also SLAC-PUB-4809.
17. Ian Stockdale, Proceedings of the Tau-Charm Factory Workshop, SLAC-REPORT 343.
18. J. Adler *et al.*, SLAC-PUB 4671 (1989). To be published in Phys. Rev. D.
19. P. X. Yen, Modern Phys. Lett. No. 11 (1986),
    J. Finjord Nuclear Phys. B181 (1981) 74.
20. See the discussion in I.I.Y.Bigi, reference 14.
21. See for example B. Grinstein *et al.*, Phys. Lett. 202B (1988) 138
22. T. Browder, Proceedings of the Tau-Charm Factory Workshop, SLAC-REPORT 343.
23. L. Wolfenstein Phys.Lett. 164B (1985) 170.
    J. Donoghue *et al.*, Phys. Rev. D33 (1986) 179.
24. G. Gladding, Proceedings of the Tau-Charm Factory Workshop, SLAC-REPORT 343.
25. U. Karshon, Proceedings of the Tau-Charm Factory Workshop, SLAC-REPORT 343.
26. C. Simopoulos, Proceedings of the Tau-Charm Factory Workshop, SLAC-REPORT 343.

FIGURE CAPTIONS

1. Reconstruction of $D_s \rightarrow \eta\pi^+\pi^+\pi^-$ with the $\eta \rightarrow \pi^+\pi^-\pi^0$ and $\pi^0 \rightarrow \gamma\gamma$.
2. D^+ or $D_s \rightarrow \mu\nu$ or $\tau\nu$.
3. (a)Missing mass for $D^+ \rightarrow \mu\nu$, shaded areas are backgrounds , (b)Missing mass for $D_s \rightarrow \mu\nu$, (c)Missing mass for $D_s \rightarrow \tau\nu,\tau \rightarrow e\nu\nu$,and (d)Missing mass for $D_s \rightarrow \tau\nu,\tau \rightarrow \mu\nu\nu$.
4. Detected pure leptonic events. Dotted ($D_s \rightarrow \tau\nu$), Dot-Dashed ($D_s \rightarrow \mu\nu$), Solid ($D^+ \rightarrow \mu\nu$), Limit region for $B \rightarrow \tau\nu$ based on 90% CL values of V_{bu}, assuming 10^5 tagged B_u and the same detection efficiency as for the dotted line.
5. Cabibbo allowed and suppressed semileptonic decays. The shaded regions indicate background levels obtainable with (a-b) Cerenkov-glass calorimetry, and (c-d) scintillating crystal calorimetry.
6. Examples of non-spectator semileptonic decay.
7. (a)Examples of flavor changing neutral currents involving new scalars or vectors, or (b) effective flavor changing neutral currents involving higher order weak decays.
8. (a)The rescattering contribution simulating (b) the Penguin graph.
9. (a)The box diagram and (b) schematic of mixing through intermediate final states.

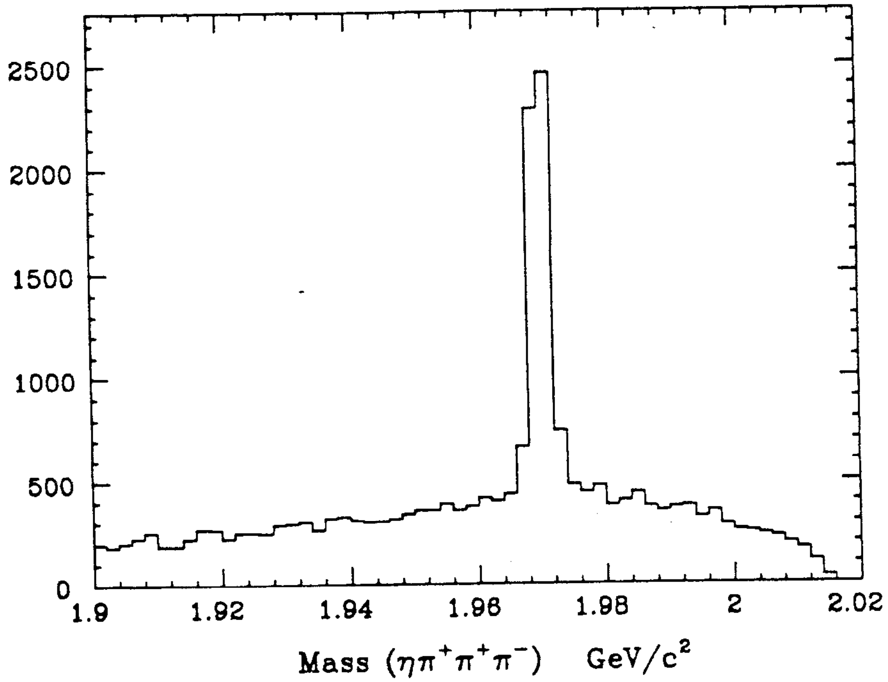

2500
2000
1500
1000
500
0
1.9
1.92
1.94
1.96
1.98
2
2.02
Mass $(\eta\pi^+\pi^+\pi^-)$ GeV/c^2

Fig. 1

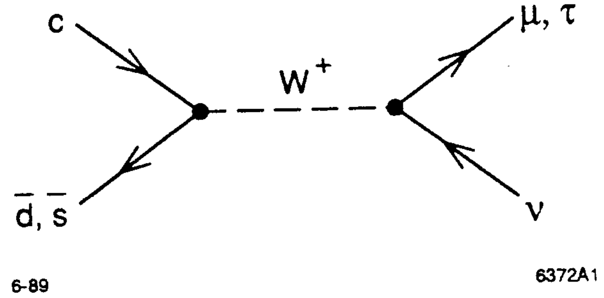
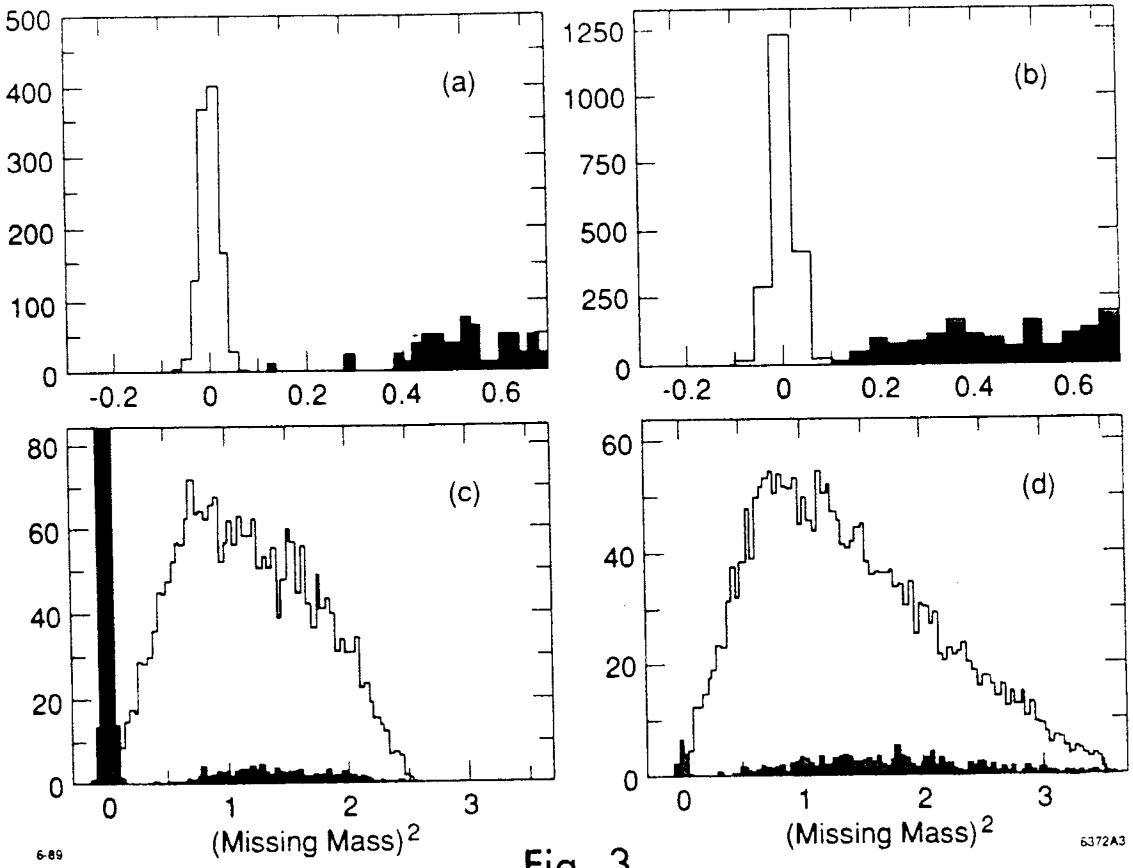

c
$\bar{d}, \bar{s}$
W^+
μ, τ
ν
6-89
6372A1

Fig. 2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400
300
200
100
0
(a)
-0.2
0
0.2
0.4
0.6
1250
1000
750
500
250
0
(b)
-0.2
0
0.2
0.4
0.6
80
60
40
20
0
(c)
0
1
2
3
(Missing Mass)^2
60
40
20
0
(d)
0
1
2
3
(Missing Mass)^2
6-89
6372A3

Fig. 3

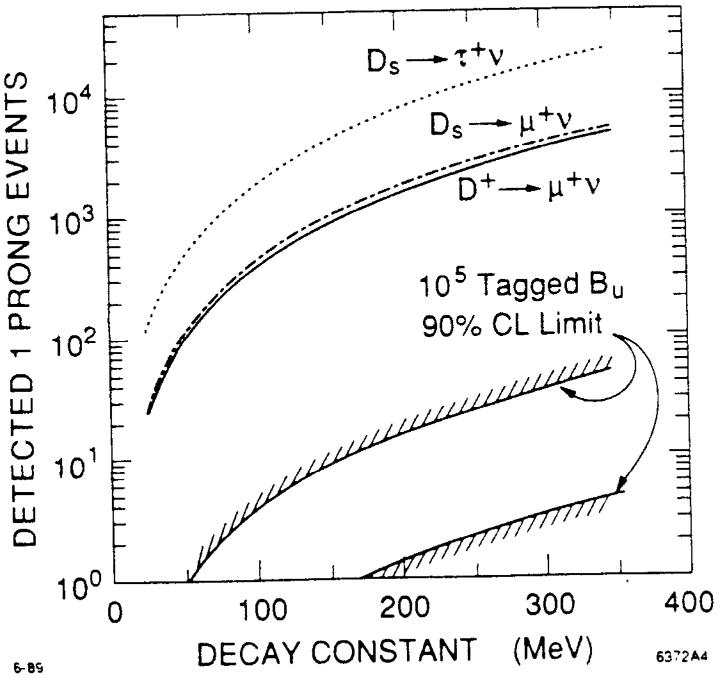
$D_s \to \tau^+\nu$
$D_s \to \mu^+\nu$
$D^+ \to \mu^+\nu$
10^5 Tagged B_u
90% CL Limit
10^4
10^3
10^2
10^1
10^0
DETECTED 1 PRONG EVENTS
0
100
200
300
400
DECAY CONSTANT (MeV)
6-89
6372A4

Fig. 4

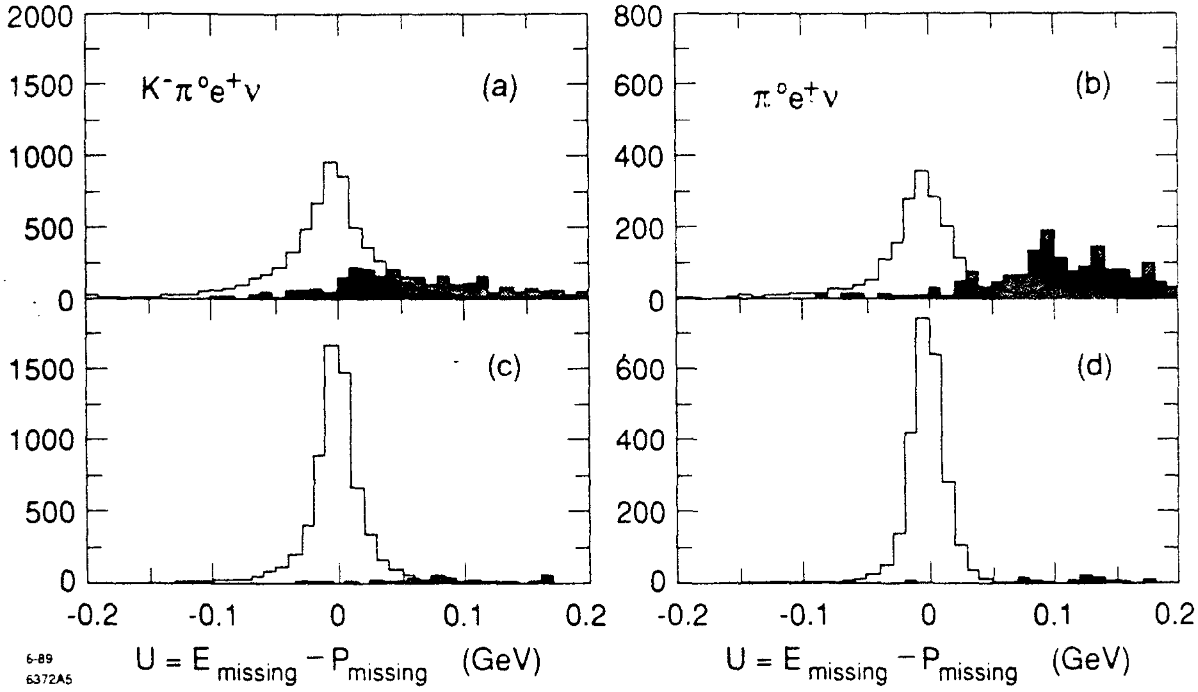
K⁻π°e⁺ν
(a)
π°e⁺ν
(b)
(c)
(d)
2000
1500
1000
500
0
800
600
400
200
-0.2
-0.1
0
0.1
0.2
U = E missing − P missing (GeV)
6-89
6372A5

Fig. 5

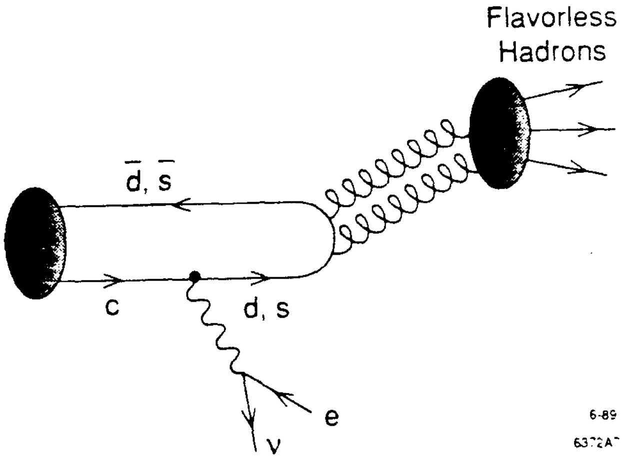
Flavorless
Hadrons
d̄, s̄
c
d, s
e
ν
6-89
6372A7

Fig. 6

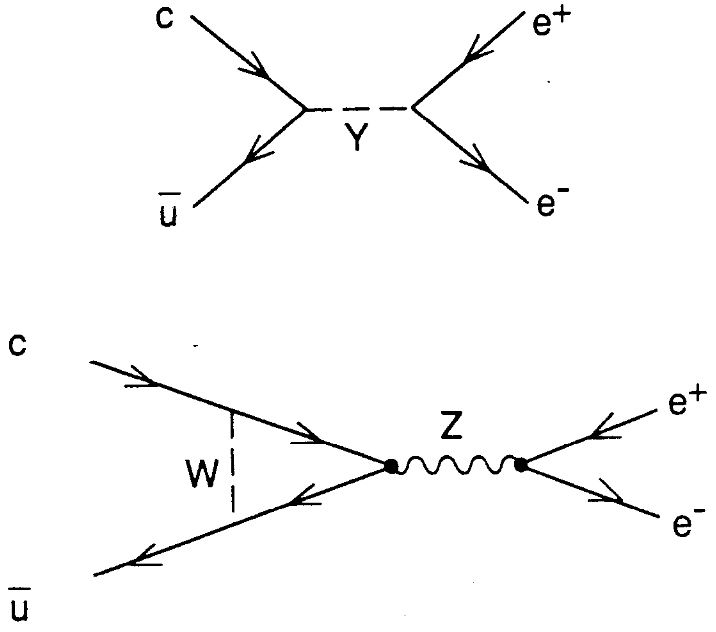

Fig. 7

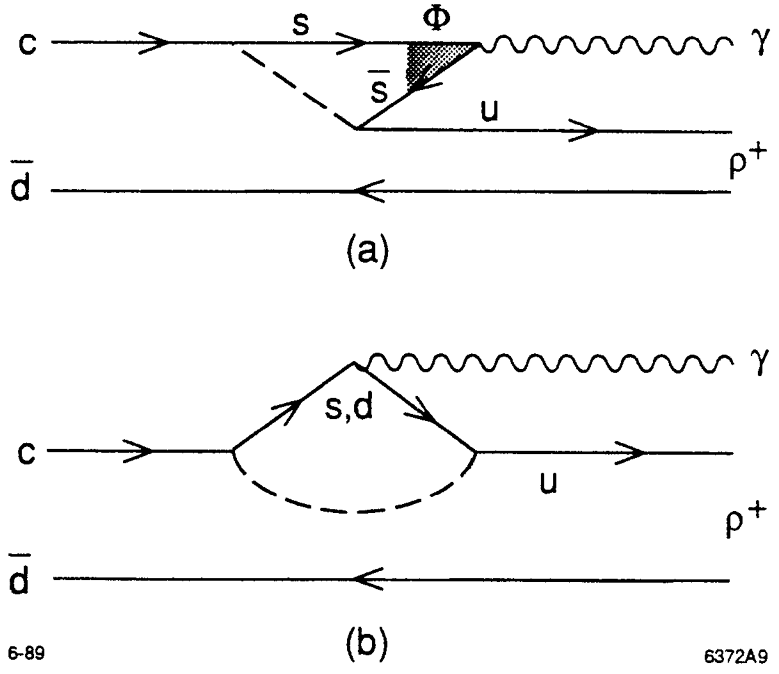

Fig. 8

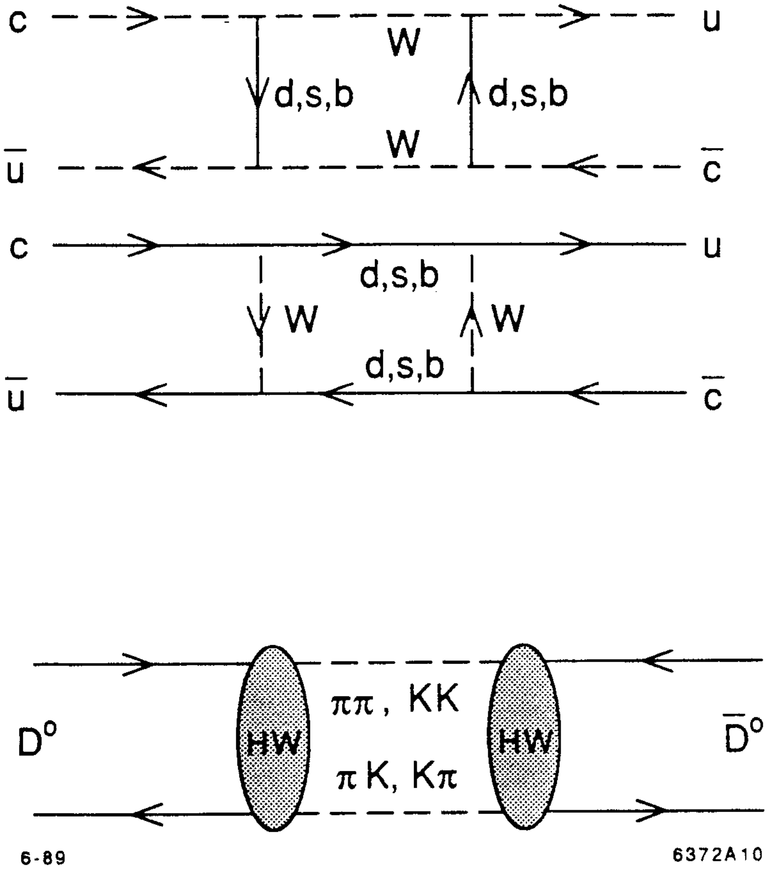

Fig. 9