1. Charmonium Summary

2. Experimental Charm Summary

Walter Toki
(Colorado State University)

Charmonium Summary

The charmonium section of the tau charm workshop included talks by Yifan Gu (ψ' physics), Kam Seth (charmonium results from $p\bar{p}$ gas jet experiments) and Walter Toki (topics in J/ψ and ψ' decays). This summary will discuss (1) the existing data, (2) the expected rates at a tau charm factory,(3) a survey of the physics topics, and (4) calibration procedures.

CHARMONIUM EXPERIMENTS

The previous e^+e^- experiments on J/ψ and ψ' physics include the Mark II, Crystal Ball, Mark III, and DM2 and the only running experimeint is BES. The existing data sets are listed below.

Table 1. J/ψ and ψ' Data Sets		
Experiment	J/ψ data	ψ' data
Mark II	1.3M	1M
Crystal Ball	2M	1.3M
MarkIII	5.8M	.3M
DM2	8M	-
BES	9M	1.5M

Another important charmonium experiment is the antiproton experiment[1], E760, with a proton gas jet target in the FNAL antiproton accumulator. This experiment has produced in $p\bar{p}$ collisions the J/ψ, ψ', χ_c, η_c and recently the $^1P_1$. The experiment can measure very precisely the masses and widths by using a cooled antiproton beam whose momentum spread is very small. Typically the center of mass energy spread is 0.5 KeV (full width). The widths have been measured for several resonances. The experiment has been approved for another fixed target run in 1995 (E835).

TAU CHARM FACTORY RATES

In a tau charm factory, the projected luminosity is $10^{33}\ cm^{-2}sec^{-1}$ with a energy spread of ~1 MeV. With a monochrometer, the energy spread can be reduced to 0.14 MeV to increase the peak luminosity for narrow resonances. Using the particle data book values for the Γ(hadron) and Γ(ee) for the J/ψ and ψ', we can estimate the peak luminosity.[2]

Table 2.			
Resonance	peak cross section	instantaneous rate at $10^{33}\ cm^{-2}sec^{-1}$	number of events per day(50% efficiency)
J/ψ	~2600 nb	2.6 Khz	112×10^6
ψ'	~800 nb	0.8 Khz	34×10^6
J/ψ with mono-chrometer	~16000 nb	16 Khz	688×10^6
ψ' with mono-chrometer	~5000 nb	5 Khz	215×10^6

[1] Kam Seth talk, this workshop.

[2] P. Yennie, Phys. Rev. Lett., 34,239(1975)

The instantaneous rate is several kilohertz and the number of events logged per day will be several hundred million with the monochrometer. This would certainly strain current DAQ technologies, but fixed target experiments are surviving such rates. The online data rate (for ~10Kbytes per event) would need a through put of ~160Mbytes/sec and storage would be about 1 terabyte per 100M events which is about 200 8mm tapes at 5 Gbytes per tape. In several years the storage handling technology should improve enough to be adequate for this data rate.

PHYSICS TOPICS

The physics of the J/ψ and ψ' include topics of charmonium, gluonium studies and light quark spectroscopy. In the case of charmonium and gluonium studies, we would extrapolate a factor 10 increase in statistics over current samples in one day of running at full luminosity. In one or more months, a sample 100-1000 times larger then the existing data sample is possible.

Gluonium Resonances

The search for gluonium bound states focuses in 2 gluon bound states with $J^{PC}= 0^{++},0^{-+},1^{++}$. The lowest lying scalar glueball is expected around 1.5 GeV. A possible candidate[3] is the scalar signal observed in $J/\psi \to \gamma KK$ in the mass region of the theta. The analysis requires high statistics to extract moments of angular distributions to separate out the different partial waves. An important improvement in future tau charm factories will be high resolution crystal calorimetry for reconstruction of photons and very good forward acceptance. Many spin-parity analyses need to differentiate between $1+\cos\theta^2$ and $\sin\theta^2$ angular distributions and if the acceptance is less than $|\cos\theta|<0.7$, such measurements could be ambiguous. Besides the search for the scalar glueball, there are the iota and $\xi(2.2)$ resonances observed in radiative J/ψ decays which do not fit into the $q\bar{q}$ model. High statistic studies could determine the spin-parity and search for other decay modes of these resonances.

Other important topics include hybrids and 4 quark states. The search for such states requires a "smoking gun test" which is a test that decisively separates the candidate from conventional $q\bar{q}$ mesons. Such searches include finding states with exotic quantum numbers ($J^{PC}=0^{-+},1^{-+},2^{-+}$) such as a p wave $\eta\pi^{\circ}$ state or exotic flavor states such as ones with hidden strangeness ($\phi\pi$ and $\phi\omega$). A search for hybrid state of $c\bar{c}$+glue could be successful by finding a resonance decaying into $\eta\psi$. Discovering such states,which are not possible in the $q\bar{q}$ quark model, would lead to new physics.

Charmonium Topics

Charmonium physics has many topics accessible in the ψ' decays. The topics discussed here are

(1) search for the η_c'
(2) hadronic decays of the η_c and normalization of the $\eta_c \to p\bar{p}$
(3) study of the hadronic decays of the χ_c's
(4) study of $\eta_c \to \gamma\gamma$ and $J/\psi \to \gamma\gamma\gamma$
(5) study of $ee \to D^*D^*$ at 4 GeV

[3] Liang Ping Chen, Phd Thesis, University of Vanderbilt,

The η_c' was reported by Crystal Ball and recently the Particle Data Group has removed it from its listing because it has not been confirmed. The E760 experiment will search for this state, but of course depending on where they start their scan, they could miss it entirely. A tau charm factory could search for this state in radiative decays in hadronic states such as $\psi' \to \gamma\eta_c'$, $\eta_c' \to KK\pi, \eta\pi\pi, p\bar{p}$. The η_c' decays should be similar to the η_c hadronic decays.

The E760 experiment has measured the widths of J/ψ, ψ', χ_c, η_c via $p\bar{p} \to X \to ee, \gamma\gamma, \gamma J/\psi$. In order to measure the branching ratios, E760, needs the absolute branching ratios of J/ψ, ψ', χ_c, $\eta_c \to p\bar{p}$. A tau charm factory could measure for example the absolute branching ratios of the η_c by measuring both the inclusive rate $\psi' \to \gamma\eta_c$ by measuring the inclusive photon spectrum and the exclusive decay $\psi' \to \gamma\eta_c$, $\eta_c \to p\bar{p}$. This technique could be adapted to the other states and provide a complete measurement.

Very little is known about the decays of the χ_c's. These are the p wave $J^{PC}=0^{++}$, 1^{++}, 2^{++} $c\bar{c}$ states. The scalar state should decay via 2 gluons. It could very interesting to compare the pattern of hadronic decays to the J/ψ (which decays via 3 gluons). Since all the other light quark scalars are mired in problems of over lapping resonances, a complete measurement of the hadronic decays would be interesting. Also the hadronic decays in the $c\bar{c}$ states in scalar, axial vector, vector, and tensor modes could reveal a pattern of how gluons hadronize. If they are drastically different (as in the ψ' or J/ψ), then our understanding of QCD is possibly incomplete.

Several PQCD tests are possible by measuring the rates for $\eta_c \to \gamma\gamma$ and $J/\psi \to \gamma\gamma\gamma$. These modes provide very useful tests of the Charmonium model and are analogous to and as important as the leptonic decays. The $\eta_c \to \gamma\gamma$ decay has been measured with widely varying numbers. A tau charm factory[4] could obtain $\sim 10^4$ $\eta_c \to \gamma\gamma$ and $\sim 10^4$ $J/\psi \to \gamma\gamma\gamma$ reconstructed events and produce definitive measurements.

Near D*D threshold at ~4 GeV, there are large peaks in R(ee→hadrons) at 4.03, 4.16 and 4.4 GeV. What is particularly striking is that the cross section for D*D* is much larger than D*D at 4.03 GeV. Perhaps this is caused by the formation of a molecule. As seen in radiative J/ψ decays, the coupling of two vector states seems to be unexpectedly very large. A tau charm factory could clarify these nature of these peaks by measuring what these peaks in R are decaying into.

J/ψ and ψ' Comparisons

There has been a long standing puzzle in the suppression of the decay of $\psi' \to \rho\pi$ relative to $J/\psi \to \rho\pi$. Theoretically we would expect the hadronic widths to scale as the leptonic widths. Scaling by this factor, the $\psi' \to \rho\pi$ is suppressed by many orders of magnitude relative to the $J/\psi \to \rho\pi$ rate. In general the decays into vector-pseudoscalar seems to be suppressed whereas other hadronic modes are seen. Many models have been created to explain this discrepancy. A recent possibly related problem is the CDF collider results seem to indicate a suppression of the ψ' production from QCD models[5] whereas the J/ψ rate is as expected. Perhaps this has a connection to the puzzling behavior of the ψ'.

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[4]Ronan Mir, Proceedings of the Tau-Charm Factory Workshop, June 1989, SLAC-Report 343, ed. Lydia Beers.

[5]Ian Hinchliffe, invited talk, Div. of Particles and Fields, University of New Mexico, August 1994.

The main advance in understanding the hadronic decays of the ψ' will come from getting a large statistics ψ' sample to measure the pattern of hadronic ψ' decays relative to the J/ψ. An intriging possible explanation is that the unusual pattern of ψ' hadronic decays is caused by interference of a nearby vector glueball to the ψ' or the J/ψ.

Light Quark Spectroscopy

The J/ψ will be copiously produced and it also has numerous modes into light quark mesons and baryons. Many reactions that might be easily tagged, such as $J/\psi \rightarrow p\bar{p}+X$, there $X=\eta, \eta', \omega, \phi$, etc. have large BR's ($10^{-3}$-$10^{-4}$). To study a particle one reconstructs the $p\bar{p}$ and selects that the recoil mass against the $p\bar{p}$ is the particle of interest. With a sample of 10^{10} J/ψ events the total production rates would be 10^6-10^7 in each mode. A list of rates are given below.

Table 3.

$J/\psi \rightarrow p\bar{p}+X$ reaction	BR	#Events/ 10^{10} J/ψ
$J/\psi \rightarrow p\bar{p}$	2×10^{-3}	2×10^{7}
$J/\psi \rightarrow p\bar{p}\eta$	2×10^{-3}	2×10^{7}
$J/\psi \rightarrow p\bar{p}\eta'$	9×10^{-4}	9×10^{6}
$J/\psi \rightarrow p\bar{p}\omega$	1.3×10^{-3}	1.3×10^{7}
$J/\psi \rightarrow p\bar{p}\phi$	1×10^{-4}	10^{6}

It may be possible to improve the branching ratios of some decay modes of the light quark mesons. Many of the meson decays have branching ratios that are known to ~1% for the large branching fractions (>50%) and ~10% for smaller branching fractions (~10% or less). With a tagged sample of 100K-1M events it would be feasible for a tau charm factory to measure the decays of these mesons to a precision of few tenths of a 1%.

Additionally, one could look in $J/\psi \rightarrow p\bar{p}+X$ for the missing mass recoiling from the $p\bar{p}$ system (and after removing baryon-antibaryon backgrounds) to search for light quark recoiling mesons. Another search in $J/\psi \rightarrow \phi+X$ could include the missing mass recoiling from a ϕ to search for $s\bar{s}$ recoiling mesons. At very high statistics this missing mass technique could be a powerful tool to search for new resonances.

Another area of interest in the light quark production is the decay $J/\psi \rightarrow \Lambda\bar{\Lambda}$ and $\Xi\Xi$ to search for asymmetries in angular distributions. There has been interest[6] in measuring asymmetries, caused by CP violation, in the decay angle distribution of the Λ decays.

CALIBRATION STUDIES

The J/ψ and ψ' provide excellent very high rate signals useable for calibration studies of the detector. The next generation of tau charm factories will measure precision absolute branching ratios and decay angular distributions for studies of CP violation in tau decays[7] and charm decays.[8] In most charm and tau measurements the results will be systematics limited and not statistics limited, Such measurements require a well understood detector in order to reduce systematic errors. The J/ψ and ψ' have many "reference" reactions that

[6] E. Gonzalez and J. Illana, CERN-PPE/94-33, February 1994.
[7] Paul Tsai talk, this workshop.
[8] JoAnne Hewitt talk, this workshop.

can be studied. Depending upon the particular reaction, the J/ψ and ψ′ decays can provide under controlled conditions a given particle type, charged tracks with fixed momentum, photons showers with known energy and direction, reactions with known decay angle distributions. A sample of high rate reactions for different particles are listed below.

Table 4.

Particle Type to be produced	Reaction
photon	$ee \rightarrow \gamma ee, \gamma\mu\mu, \rho\pi$
electron	$ee \rightarrow ee, \gamma ee$
muon	$ee \rightarrow \mu\mu, \gamma\mu\mu,$
pion (charged and neutral)	$J/\psi \rightarrow \rho\pi$ and $\psi' \rightarrow \pi\pi J/\psi, J/\psi \rightarrow ee, \mu\mu$
charged kaon	$J/\psi \rightarrow K^*K$
K_L	$J/\psi \rightarrow K_L K_S$
neutron, antineutron	$J/\psi \rightarrow n\bar{p}\pi,\ \bar{n}p\pi$
proton, antiproton	$J/\psi \rightarrow p\bar{p}, p\bar{p}\pi^{\circ}$
$\eta \rightarrow \gamma\gamma, 3\pi$	$J/\psi \rightarrow p\bar{p}\eta, \gamma\eta'$

In addition to these modes, there are decays such as $J/\psi \rightarrow \rho\pi$ where the matrix element is exactly known. This enables precision comparisons between the monte carlo and the high statistics data . This will be very important to verify that the detector is bias free when used to test for CP violation tests in angular distributions.

SUMMARY

Charmonium physics is uniquely possible in a tau charm factory. The expected increase in data samples is a factor 100-1000 over current experiments. The physics potential and opportunities are

(1) In gluonium physics, search for a bound state of 2 or more gluons by careful spin parity analysis of states produced in radiative J/ψ decays.

(2) In ψ′ decays, there are many charmonium measurements which currently are either poorly measured or non-existent. These include the two and three photon width of the η_c and J/ψ , the discovery of the η'_c, the measurement of the hadronic decays of the χ_c and the normalization of the $p\bar{p}$ decays of the charmonium states observed by E760.

(3) Further progress in understanding the hadronic ψ′ decays require a large statistics sample to measure the pattern of hadronic decays. A careful comparison to the J/ψ hadronic decays should clarify this puzzle.

(4) The ultra high rate of the J/ψ decays permits the possibility of high statistics study of light quark mesons. It appears a tau charm factory could contribute many branching ratio measurements.

(5) Finally, the ultra high rates of the J/ψ and ψ′ decays permits a careful study of the detector acceptances which will be necessary to make further progress in tau and charm physics.

SUMMARY of the EXPERIMENTAL CHARM SECTION

The experimental Charm physics section in the tau charm factory workshop included talks on b factories (Dave Besson and Hitoshi Yamamoto), fixed target experiments (John Cumulat), and CP violation possibilities (Joe Izen). In this section, comparisons of charm experiments in the fixed target (E831,E781), B factories (CLEO, KEK, SLAC) and tau-charm factories will be made. Additional information is taken from Future of High-Sensitivity Charm Experiments at Fermilab[1] and the Tau-charm Factory Workshop at SLAC.[2] We begin with a summary of relevant charm experiments and then a physics running scenario will be given. The physics topics of the absolute branching ratios of charm mesons, $D\overline{D}$ mixing and CP violation searches will be discussed in detail. Finally, conclusions will be drawn concerning the prospects for charm physics from a tau charm factory in an era with charm results from fixed target experiments and b factories.

Charm Experiments

The experiments publishing charm results include BES, CLEOII, E687 and E791. The future approved experiments include CLEOIII[3], E781[4,5], E831[6], SLAC B factory[7], and the KEK B factory. The experiments under discussion but not yet approved include the tau charm factories at Beijing[8], Argonne[9], Dubna[10], and Novosibirsk[11] and the fixed target experiment Charm 2000[12] at Fermilab.

<u>Experiment E831</u>

The E831 experiment is a continuation of E687. The E687 experiment was a photoproduction experiment with ~10^7 produced charm events and ~100K reconstructed charm events. The E831 experiment is extrapolated to improve a factor 10 over E687. The improvements will come from a factor 5 increase in beam flux and a factor 2 in the DAQ and efficiency. The detector also will be improved with better π° detection and reconstruction. This experiment is expected to run in the next fixed target run in Fermilab and with two running periods (E687 had a similar amount of time).

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[1]Proceedings of the Future of High-sensitivity Charm Experiments (Charm2000 Workshop), Fermilab, June 7-9, 1994, editors Daniel Kaplan and Simon Kwan.
[2]Proceedings of the Tau-Charm Factory Workshop, May 23-27, SLAC, editor Lydia Beers.
[3]Dave Besson talk and Hitoshi Yamamoto talk, this workshop.
[4]Jim Russ, Proceedings of the CHARM2000 Workshop, Fermilab, June 7-9, 1994, editors Daniel Kaplan and Simon Kwan.
[5]John Cumalat talk, this workshop.
[6]Jim Russ, Proceedings of the CHARM2000 Workshop, Fermilab, June 7-9, 1994, editors Daniel Kaplan and Simon Kwan.
[7]Letter of Intent, SLAC Report, SLAC-443, June 1994.
[8]Zhipeng Zheng talk, this workshop.
[9]Jose Repond talk, this workshop.
[10]Georgei Chelkov , this workshop.
[11]A. Skrinsky, this workshop.
[12]Dan Kaplan, Proceedings of the CHARM2000 Workshop, Fermilab, June 7-9, 1994, editors Daniel Kaplan and Simon Kwan.

Experiment E781

The E781 experiment is a charm-strange baryon experiment. The experiment will use a hyperon beam of Σ's with a 10^6 hz flux to produce charm-strange baryons. The experiment is expected to reconstruct ~100K $\Lambda c \rightarrow pK\pi$, 5K $\Omega c \rightarrow \Xi K\pi\pi$ and 50K $\Xi c \rightarrow \Xi\pi\pi$. The sample is roughly 100 times that of WA89. The lifetimes will be measured to ~3% precision and the baryon semileptonic decays will be determined. This experiment is expected to start running in the next fixed target run at Fermilab.

BES

The BES detector is under going a collider and detector upgrade to be completed by the end 1995. The detector upgrade includes a new drift chamber, a new TOF scintillator with FM phototubes, and a high resolution inner tracker. The collider upgrade includes a minibeta scheme and single interaction region running to increase the luminosity to ~2-3x10^{31} cm^{2}sec^{-1} at 4 GeV center of mass energy. This is about a factor 15-20 more peak luminosity than SPEAR had achieved. Thus far the BES group has logged ~9M J/ψ events, ~1.5M ψ' events, and ~22 pb^{-1} at 4.03 GeV. After the upgrade, the BES group may start a ψ'' run.

CLEO

The charm results in CLEO are from the continuum produced charm which has a hard momentum distribution. Usually a momentum cut can separate continuum charm from b→c charm which is soft. This fact permits the thrust axis to approximate the charm direction and this enables a useful cut to determine charm momentum and direction. In addition, CLEO can use the low Q decays of the D* to tag the soft charged or neutral pion. This is a powerful method to increase the D signal to noise ratio and to measure branching ratios.

The CLEOII detector has logged about 3.6 fb^{-1} and in Fall 1994 it will stop to install the SVX silicon detector. The detector will under go another upgrade[13], CLEOIII, with the addition of a new silicon detector, a new drift chamber, a new particle identification system and new CsI endcap calorimeter. This upgrade is to be completed in 1997. CESR will start the phase II upgrade, Fall 94-97, to increase the luminosity to 6x10^{32}. The next improvement in Phase III will aim to achieve a luminosity of 1-2x10^{33}. In terms of integrated luminosity the projections for 1997 are 15 fb^{-1} per year with 2/3 data on the 4s resonance and 1/3 data below the 4s. In phase III, the integrated rate should roughly double.

SLAC/KEK B factories

The SLAC b factory is scheduled[14] to begin checkout in the 2nd quarter of 1999 and KEK b factory is expected to follow a similar schedule. The machines are designed to operate in an asymmetric ring at 3x10^{33}. At turn on it might take an additional year or more to achieve the design luminosity.

[13]The CLEO III Detector, Design and Physics Goals, February 1994.

[14]Letter of Intent, SLAC Report, SLAC-443, June 1994.

CHARM2000

At the meeting, Charm2000, at Fermilab in June 1994, experimentalists considered future charm experiments after the year 2000. This would be the next generation experiment after E831. The expectations for a hypothetical "Charm2000" experiment are to reconstruct 10^8 charm decays. The measurements from such an experiment would include high precision lifetimes, relative branching ratios, decay length search for $D\overline{D}$ mixing, direct CP tests and the search for rare decays.

Charm Physics Schedule

Below is a table containing a possible schedule of charm results given the above experiments. Included are the Charm2000 and tcf experiments.

Charm Experiment Schedule Scenario[15]			
YEAR	Fixed Target	B factory	tau charm
1994	E687 Publishing	CLEOII ~3 inv fb	
1995	E791 Publishing	CLEOII, L~10^{32}	BES L~5×10^{31}
1996	E831,E781	CLEOII ~15 inv fb	
1997	Main Injector Upgrade	CLEOIII, L~10^{33}	BES upgrade publishing
1998	Main Injector Upgrade		
1999	Collider Run	SLAC run, L ~$(1\text{-}3)\times10^{33}$ KEK run, L ~$(1\text{-}3)\times10^{33}$	
2000	Collider Run		
2001	Charm 2000 run	SLAC,KEK publishing	tcf run, L ~10^{33}
2002		CLEOIII ~20 inv fb SLAC ~30 inv fb KEK ~30 inv fb	
2003	Charm 2000 publishing		tcf publishing
2004+	??	??	??

From this table we would expect by the end of the 1990's, CLEO to have factor ~10 more (30-50 fb^{-1}) charm data relative to their current data and the E831 experiment should have also a factor ~10 more data relative to the E687 experiment. The b factories should start running about the year 2000 and the tcf might come as early as 2 years later.

Physics topics

Absolute Charm Branching Ratios

The best measurements of the absolute charm branching ratios (D^+, D°, Ds, D^{*+}, $D^{*\circ}$) come from CLEO. The fractional statistical error for the D° is 2% and the systematic error is 4.3% . The fractional statistical error for the D^+ is 6.5% and the systematic error is 9%. For the Ds, the measurement is problematical because model independent measurements using double tags have too few events and model dependent measurements assume knowledge of uncertain partial widths.

[15] R. J. Morrison, Proceedings of the CHARM2000 Workshop, Fermilab, June 7-9, 1994, editors Daniel Kaplan and Simon Kwan.

By the end of the 1990's we would expect CLEO to obtain a factor 10 more data leading to statistical errors ~0.5%.

Why do we need more precise branching ratios? The main reasons include, normalization of cross sections in hadroproduction, determination of partial widths to compare to theory, and setting the scale for B decays which use many charm modes[16]. This "engineering" aspect becomes very important as measurements using these modes become more precise. The poorly measured absolute branching ratios will limit such important parameters as $|V_{cb}|$.

In the next generation of B factories and fixed target experiments, the statistical error in these measurements will dramatically drop and systematic errors will dominate. The precision in B factories may be limited due to track reconstruction uncertainties.[17] Precise monte carlo simulations and many cross checks will be needed to properly estimate systematic errors. To the extent that the backgrounds underneath the signal are not understood and the monte carlo distributions do not match the data, the systematic errors will be uncertain. Estimates for the systematic errors are 2-3% from CLEOIII and E831. Complete knowledge of the branching ratios may be necessary to estimate backgrounds which largely come from charm itself.

The tau charm factory will measure the charm absolute branching ratios using associated pair production of charm mesons in pairs. By measuring inclusive charm decays and exclusive charm decays in pairs, the absolute branching ratios can be measured without uncertainties due to production rates. The expected precision[18] is ~1% for a year of running at 10^{33}. It may be also possible to use similar techniques of tagging D* decays with $\pi^{\pm}$ and π° as is being done by CLEO. This would require very careful low mass design of the inner detector and the beam pipe.

<u>DD mixing</u>

Charm mixing has been estimated[19] using both short distance effects (which are very, very small) and long distance effects which recently have also be estimated to be very small. The recent standard model estimate is $r_D \sim 10^{-8}$. Anything seen above this limit would lead to new physics. Recently CLEO[20] published the observation of double cabbibo suppressed decays (DCSD) at the level of 1% which is rather large. This was seen several years ago in a few events in Mark III.[21,22] The large difference in the rates of $D^{\circ} \to KK, \pi\pi$ (both CP eigenmodes) and now the somewhat

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[16] Ikaros Bigi talk, this workshop.

[17] Dave Besson talk, this workshop.

[18] Rafe Schindler, Proceedings of the Tau-Charm Factory Workshop, May 23-27, 1989, editor Lydia V. Beers.

[19] JoAnne Hewitt talk, this workshop.

[20] D. Cinabro etal., Phys. Rev. Lett., 72, 1406 (1994) and see Ted Liu, Proceedings of the CHARM2000 Workshop, Fermilab, June 7-9, 1994, editors Daniel Kaplan and Simon Kwan.

[21] Jonathan Labs, SLAC Phd thesis

[22] Gary Gladding, Proceedings of International Symposium on Production and Decay of Heavy Flavors, 178 (1988).

large value of DCSD is surprising, although theoretically not unlikely.[23] Perhaps some interesting physics is lurking underneath?

The best $D\overline{D}$ mixing limit is $r_D<3.7\times10^{-3}$ from E691 (also E791 and E687 are presenting limits in the summer conferences[24]). The technique used charged D* decays and compared the sign of the soft charged pion to the Kaon charge in $D^\circ \rightarrow K\pi$ and $K\pi\pi\pi$. By fitting the time dependence the fixed target experiments can in principle separate the mixing component from the DCSD events by fitting time dependence. Of course the larger the DCSD component is, the more difficult the task of separating out (or limiting) a mixing signal will be. It is also possible for the DCSD amplitude to interfere and enhance the mixing signal. In the future, the fixed target results will be very important to check this time dependence to separate out the unmixed and DCSD signal.

In the tau charm factory several methods are possible[25] to search for mixing. They are
(1) Search for $\psi'' \rightarrow D^\circ \overline{D}^\circ \rightarrow (K^-\pi^+)(K^-\pi^+)$. A quantum statistics argument[26] forbids this channel for DCSD but not for mixing.
(2) Search for like sign dimuons from $\psi'' \rightarrow D^\circ \overline{D}^\circ \rightarrow (K\mu^\pm \nu)(K\mu^\pm \nu)$
(3) Search for $D^{*+}D^- \rightarrow [\pi^+ D^\circ][K\mu^\pm \nu]$
Each of these methods have been estimated by monte carlo simulation[27] to reach a sensitivity of $r_D \sim 10^{-4}$ in one year of running at 10^{33}. Combining these limits will provide a $\sim 10^{-5}$ limit

CP violation

CP violation in particle decays can occur via two amplitudes that interfere leading to observable effects in differences in a partial decay rate and its CP conjugate decay rate. The possible CP violating modes to search for include (1) indirect CP violation where the D° and $\overline{D}^\circ$ decay into CP eigenstates which interfere with two different mixing amplitudes or (2) direct CP violation where there are two amplitudes in the decay that interfere with strong phases. In the indirect case the result does not depend on strong phases, whereas the direct case requires non-zero strong phase shifts and knowledge of the relative phase shift if the weak CP phase is to be extracted. The CP asymmetry is usually defined as the ratio of the difference over the sum of partial rates $\Gamma(D \rightarrow f)$ and the CP partial rates $\overline{\Gamma}(\overline{D} \rightarrow \overline{f})$,

$$A_{cp} = \frac{\Gamma - \overline{\Gamma}}{\Gamma + \overline{\Gamma}}$$

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23 Gustavo Burdman, Proceedings of the CHARM2000 Workshop, Fermilab, June 7-9, 1994, editors Daniel Kaplan and Simon Kwan.
24 Jim Wiss, Proceedings of the CHARM2000 Workshop, Fermilab, June 7-9, 1994, editors Daniel Kaplan and Simon Kwan.
25 Gary Gladding, Proceedings of the Tau-Charm Factory Workshop, May 23-27, 1989, editor Lydia V. Beers.
26 Hitoshi Yamamoto, Phd thesis, Caltech (1985).
27 Gary Gladding, Proceedings of International Symposium on Production and Decay of Heavy Flavors, 178 (1988).

The direct case[28] may have large values of Acp ~ 10^{-3} depending on the mode. The main technique will be to search for many modes and hope to find a partial rate that differs from the CP partial rate. A particularly promising mode is $D^+ \to K^+K^{*o}$. For the D^+ mode, E687 has set a value for Acp of -.12±.13. The fixed target experiment, E831, projects a measurement of Acp to a precision of 0.04 and Charm2000 of 0.2-0.5%. In a tau-charm factory, the simpliest method is to measure the rates of $D^- \to K^-K^{*o}$ and $D^+ \to K^+K^{*o}$ and search for a difference.

The indirect case my be searched in either asymmetric collisions of $\psi'' \to D^o \overline{D}^o \to$(lepton tag)(CP eigen state) where the decay length is measured or in $ee \to D^*D \to \gamma D^o \overline{D}^o \to$(lepton tag)(CP eigen state) where the decay length time integrated. The former method is identical to the asymmetric collider and the latter is what CLEO hoped to use in their symmetric machine in $B^*B \to \gamma BB$. In a tau charm factory there is a large signal of $ee \to D^*D \to \gamma D^o \overline{D}^o$ which is suitable for a time integrated measurement. Monte carlo studies have been performed[29] and the expected precision in A_{cp} in a tau charm factory is about 1%.

<u>Other Charm Measurements</u>

For completeness we list by center of mass energy the different charm physics topics possible at a tau charm factory:

$ee \to \psi'' \to D\overline{D}$

(1) absolute branching ratios
(2) semileptonic branching ratios, exclusive semileptonic decays
(3) D^+ leptonic decays
(4) $D^o \overline{D}^o$ mixing with semileptonics and hadronic decays without DCSD
(5) direct CP violation search
(6) $D \to \gamma K^*$

$ee \to D^* \overline{D}$

(1) D^* branching ratios
(2) $D^o \overline{D}^o$ mixing
(3) indirect CP violation

$ee \to DsDs$

(1) absolute branching ratios
(2) semileptonic decays, exclusive semileptonic decays
(3) leptonic decays
(4) $Ds \to \gamma\rho$
(5) direct CP violation search

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[28] M. Golden and B. Grinstein, Phys. Lett., 222,501 (1989) and F. Buccella, etal., Phys. Lett. B302, 319 (1993).

[29] J. Ruf and T. Fry, CERN-PPE-94-20, February 1994, U. Karshon,Proceedings of the Tau-Charm Factory Workshop, May 23-27, 1989, editor Lydia V. Beers, and Joe Izen talk, this workshop.

$ee \to \Lambda\bar{\Lambda}, \Xi\Xi$
(1) absolute branching ratios
(2) semileptonic decays

Conclusions

The physics impact of precision charm measurements include
(1) Search for new physics with the standard model tests in mixing and CP violation searches
(2) "engineering" measurements to improve charm particles as a research tool for B physics and charm hadroproduction.
(3) Probe QCD corrections in charm decays

A tau charm factory has several unique and excellent capabilities to make significant charm measurements. The main technical advantages of a tau charm factory are:
(1) Particles of interest are produced near threshold in pairs $ee \to D\bar{D}$,DsDs,D*D, $\Lambda\bar{\Lambda}$ etc. This allows use of powerful kinematic constraints and yields simple well understood production distributions.
(2) At tau charm energies, charged and neutral tracks have low energy and low multiplicity. This allows better resolution, better particle identification and less combinatoric backgrounds.
(3) Very high statistics calibration modes from the J/ψ and ψ' will permit careful detector efficiency studies which are necessary to reduce systematic uncertainties.

The charm measurements in a tau charm factory are in many ways complementary to those from the b factories and fixed target experiments. Even more importantly, the measurements use vastly different techniques and have very different systematics. Many precision charm measurements have precisions approaching ~1% and will be largely systematics limited in b factories and fixed target experiments. A tau charm factory will provide an important cross check.