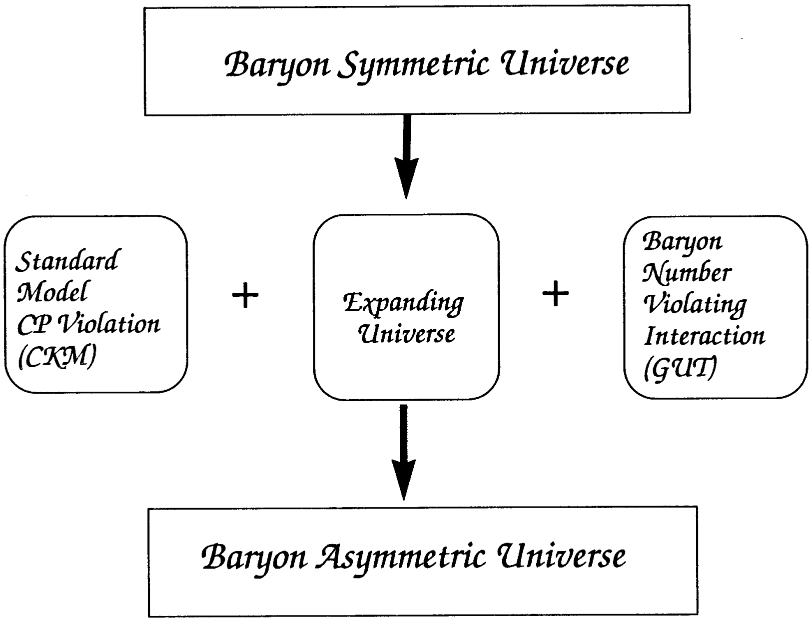
CP Violation in Taus at CLEO/BABAR/BTCF

Colin Jessop

Overview

1. General introduction to CP violation in taus
   (See Tom Rizzo's talk for detailed theoretical analysis)
2. Description of recent CLEO analysis
3. How can this analysis be improved at BaBar
4. How can this analysis be improved at BTCF

Baryogenesis and CP Violation



Baryon Symmetric Universe

Standard Model CP Violation (CKM)

+

Expanding Universe

+

Baryon Number Violating Interaction (GUT)

Baryon Asymmetric Universe

NO : Baryon number density wrong by x 10^{4-8}

Standard Model CP Violation

- Accounts for CP violation in kaon system

- Predicts large asymmetries in rare B decays

- NO CP violation in leptons

BUT: No fundamental reason why there should not be CP violation in leptons

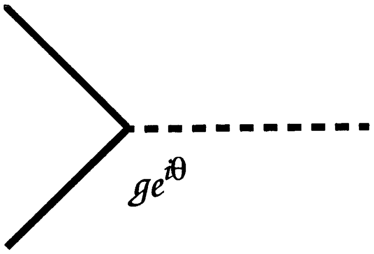
Search For

$$\left(\tau^{-} \rightarrow X^{-} \nu\right) \neq \left(\tau^{+} \rightarrow X^{+} \bar{\nu}\right)$$

CP Violation in Gauge Field Theory

- *CP violation is a phase in the Lagrangian*

$$\text{CP:} \quad e^{i\theta} \rightarrow e^{-i\theta}$$

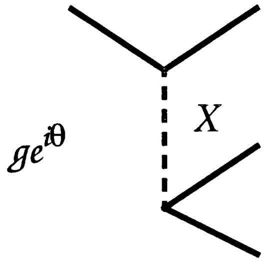


- *Phase cannot be rotated away by different gauge*

- *Connected with symmetry breaking*

CP Violation in Leptons

Can introduce a CP violating coupling in leptons without regard to a particular model



X could be
Scalar, Vector or Tensor

g is in units of standard model (W) coupling

Poor constraints on $|g|$ in tau's (Michel Parameters)

Observing a CP violating Phase

Absolute value of a phase has no physical meaning so observe in interference effects

Need two amplitudes of relative strength g with a CP even (Δ) and a CP odd (θ) relative phase difference

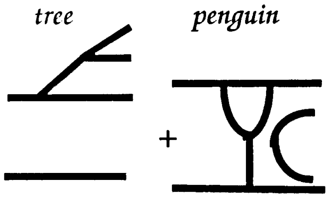
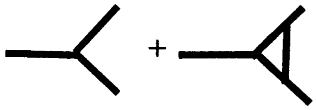
$$M = \left|1 + g e^{i\Delta} e^{i\theta}\right|^2 = 1 + 2g\cos(\Delta + \theta) + g^2$$

$$\overline{M} = \left|1 + g e^{i\Delta} e^{-i\theta}\right|^2 = 1 + 2g\cos(\Delta - \theta) + g^2$$

Define an asymmetry ($g < 1$)

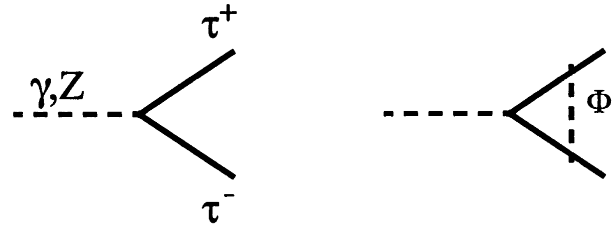
$$\boxed{A_{cp} = \frac{\overline{M} - M}{\overline{M} + M} = g\sin\Delta\sin\theta}$$

Examples of Interference Effects

Type	*Example*	*CP even Phase*	*Leptons*
1. Mixing	$\begin{tikzcd} B_0 \arrow[rr] \arrow[dr] & & f \\ & \bar{B}_0 \arrow[ur] & \end{tikzcd}$	$\Delta m.t$	*No*
2. Direct		δ_{tree}-$\delta_{penguin}$	*Yes*
3. Dipole		*i*	*Yes* *(suppressed)*

Dipole Moments

Sensitive to neutral non-SM couplings



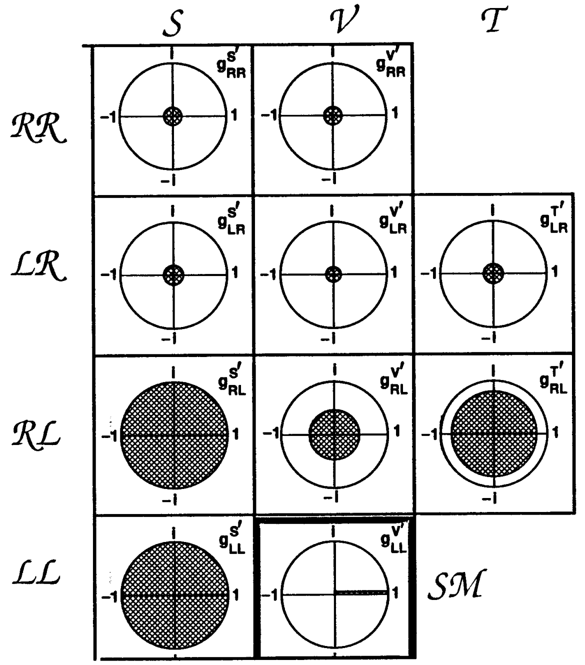
SM contribution at 3 loop level $|d_\tau| \sim 10^{-33} ecm$

Non SM (eg. neutral multi-Higgs) $|d_\tau| \sim 10^{-20} ecm$

Analyses from LEP $|d_\tau| < 1.1\times10^{-17} ecm$

Smaller effects at CLEO but higher statistics would give comparable sensitivity

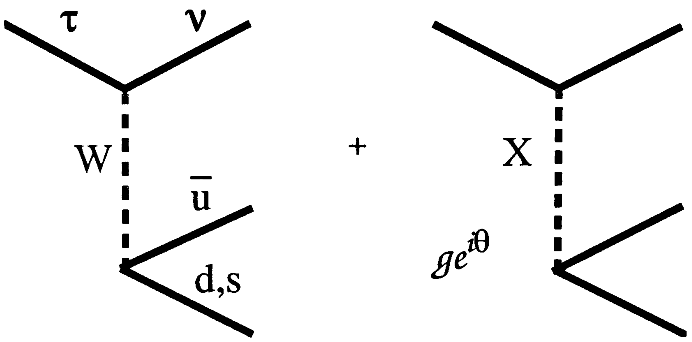
Constraints on g_{ij}^{SVT} from Michels



Shaded areas are allowed regions in units of standard model coupling strength (i.e $g_{sm}= g_{LL}{}^{V}=1$)

CP violation in Tau Decay

Two amplitudes with relative CP odd and CP even phase



$A_W = e^{i\delta_W}$ $A_X = ge^{i\delta_X} e$

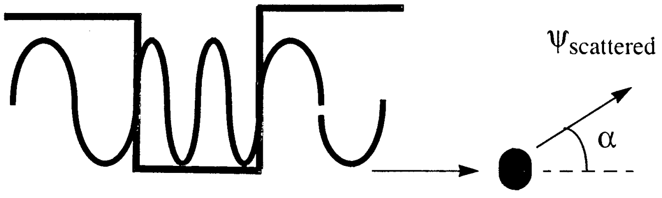
X is new interaction with strength g relative to W exchange with relative CP odd (θ) *and CP even* ($\Delta = \delta_W - \delta_X \neq 0$) *phase difference*

Δ *from strong phases*

$$\boxed{A_{cp}(\tau^{+} - \tau^{-}) \propto g \sin\Delta \sin\theta}$$

Strong Phases

Strong Phases related to hadron-hadron scattering.



$$\psi_{\text{scattered}} = \sum_l A_l e^{i\delta_l} P_l(\cos\alpha)$$

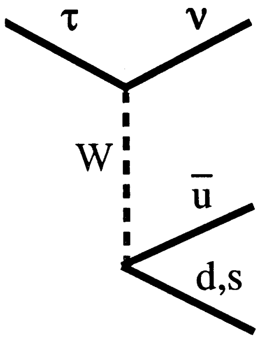
$l=0 \quad P_l(\cos\alpha) = 1$ *S Wave*

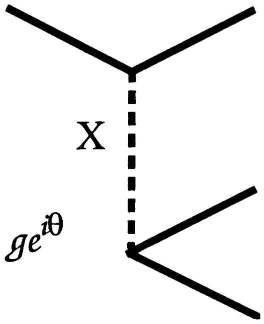
$l=1 \quad P_l(\cos\alpha) = \cos\alpha$ *P Wave*

$$\psi\psi^* = \left|g e^{i\delta_0} + e^{i\delta_1}\cos\alpha\right|^2 = \left(g^2 + g\cos(\delta_0 - \delta_1)\cos\alpha + \cos^2\alpha\right)$$

S *S-P* *P*

CP violation in Tau Decay





Tau decays dominated by vector resonances (P wave) but small components of scalar resonances possible

If X is scalar then produces S wave only and S-P interference will be CP violating

S-P interference has cosα dependence

$$A_{CP} = \frac{N^{+}(\cos\alpha) - N^{-}(\cos\alpha)}{N^{+}(\cos\alpha) + N^{-}(\cos\alpha)} = K_{\exp} g \sin\Delta_{strong} \sin\theta_{CP} \cos\alpha_{angle}$$

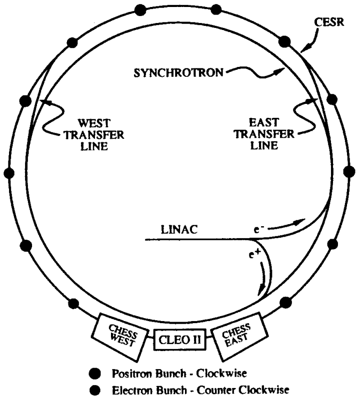
Choice of Tau decay Mode

	$\tau^- \to \bar{u}d\nu$	$\tau^- \to \bar{u}s\nu$
Resonance	$\rho^- \to \pi^-\pi^0$	$K^* \to K\pi$
Statistics	Cabbibo Favored (x20)	Cabbibo Suppressed
Isospin*	suppressed (x1/30)	-
Higgs	mass suppressed (x1/20)	-
Experiment	poor angle (π^0)	Good $K^* \to (K_S \to \pi^+\pi^-)\pi^-$

$$\boxed{\tau^- \to K^*\nu \to \left(K_S \to \pi^+\pi^-\right)\pi^-}$$

* Bose statistics imply isospin breaking for s wave ππ state

Facilities CESR and PEPII



CESR II (present)

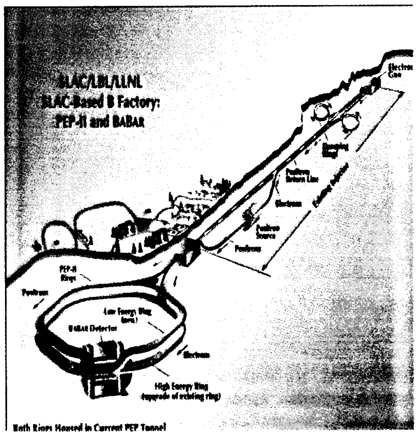
Symmetric:

5.27 GeV e- 5.27 GeV e+

2 million $\tau^+\tau^-$/year

CESR III (November 99)

15 million $\tau^+\tau^-$/year



PEP II (May 99)

Asymmetric

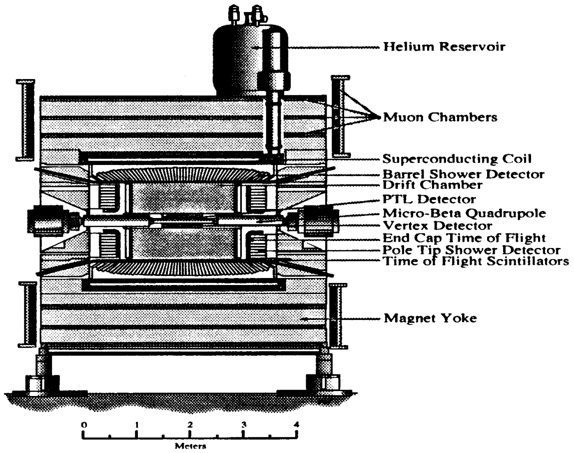
9.0 GeV e- 3.1 GeV e+

30 milliion $\tau^+\tau^-$/year

Tau/Charm Factory(?)

60 million $\tau^+\tau^-$/year

The CLEO Detector



CLEO II: Mostly can exclude nearly all backgrounds except other taus

No cerenkov PID - $\tau^+ \to K^+\nu \ = \ \tau^+ \to \pi^+\nu$

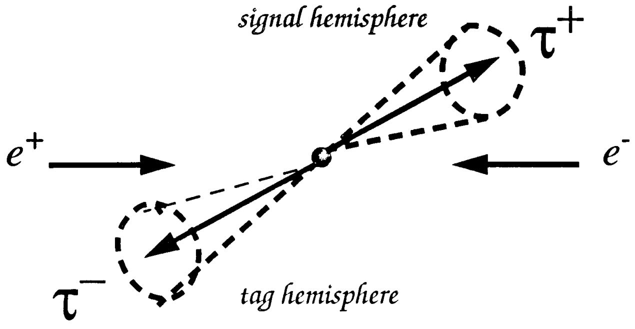
Poor resolution in end cap EM $\tau^+ \to \pi^0\pi^+\nu = \tau^+ \to \pi^+\nu$

CLEO II.5: SVX added (no new results yet)

CLEO III: New SVX, Drift Chamber, RICH, retstacked endcap EM

General features of Taus at CLEO

E_{cm}=10.56 GeV M_{tau}=1.77 GeV



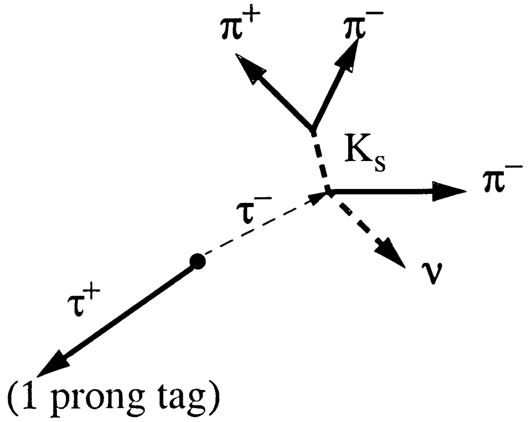
Distinctive charged track topology 1 vs 1, 1 vs 3,1 vs 5

Tag modes are $\tau \to e, \mu, \pi/k, \rho \to \pi^+\pi^0$

Neutrinos in decay : *Missing* P_T

Many tau modes contain π^0*'s*

$\tau^- \rightarrow K_s \pi^- \nu$ *Signal Definition*



K_s travels a few mm - require displaced vertex

$M_{\pi\pi}$ consistent with K_s

Want to measure τ-K_s/π angle but tau flight direction is unknown

Cuts and Backgrounds

All cuts are standard CLEO cuts used in previous analysis

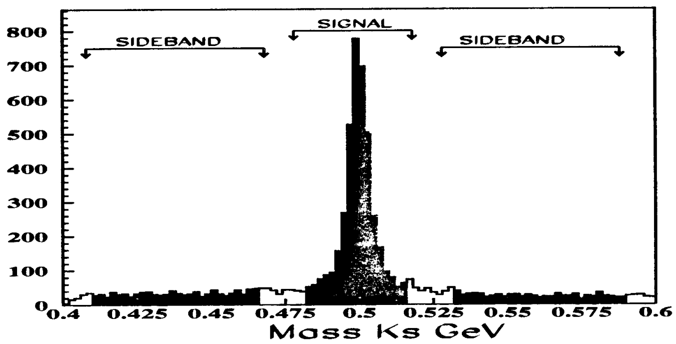
Essential to veto on π^0 *and isolated photons* ***(removes continuum and tau feeddown)***

No K^+/π^+ *seperation (background:* $\tau^- \rightarrow K_S K^- \nu$ *)*

No K_L *identification (background:* $\tau^- \rightarrow K_S K_L \pi^- \nu$

No Precision vertexing (background $\tau^- \rightarrow a_1^- \nu \rightarrow \pi^- \pi^+ \pi^- \nu$ *)*

Final Data Sample

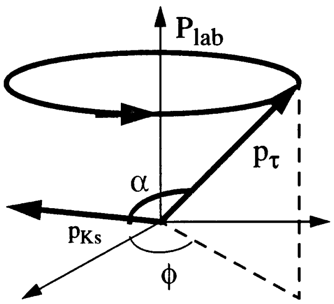


Mode	N Signal	N Sideband
$\tau \to K_S \pi \nu$	2590	83
$\tau \to K_S K \nu$	626	19
$\tau \to a_1 (\pi^0) \nu$	417	1768
$\tau \to K_S K_L \pi \nu$	250	6
Others	286	205
Total	4169	2081

Definition of cos α

Work in Center of Mass frame of observable particles

Tau flight direction lies on cone about lab direction



α *unmeasurable*

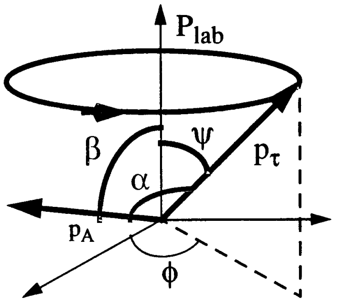
ϕ *unmeasurable*

S wave - Isotropic (from Scalar exchange)

P wave - $\cos^2 \alpha$ *(W exchange)*

S-P wave interference $\cos \alpha$

Observable angles



α *unmeasurable*

ϕ *unmeasurable*

β *measurable*

ψ *measurable*

$$\cos\alpha = \cos\beta\cos\psi + \sin\cancel{\beta\sin\psi}\cos\Phi$$

$\int\cos\phi d\phi = 0$ *causes 50 % loss of sensitivity*

Replace $\cos\alpha$ *with* $\cos\beta\cos\psi$

Monte Carlo Simulation

$$A_{cp} \propto g \sin\Delta_{strong} \sin\theta_{cp} \cos\beta_{angle} \cos\psi_{angle}$$

Hadronic interactions in final state are described by a hadronic form factor (F_{W} for SM decay , F_s for scalar decay)

Resonance is a Breit-Wigner (Average phase shift = $\pi/2$)

Standard Model $K\pi$ decays expected to bedominated by K^* vector resonance. Possible scalar resonance (K_0(1430))

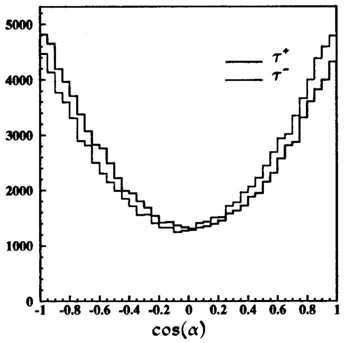
Modified TAUOLA MC with Higgs like scalar matrix element

F_{W} = Breit-Wigner F_s=1 (i.e non-resonant)

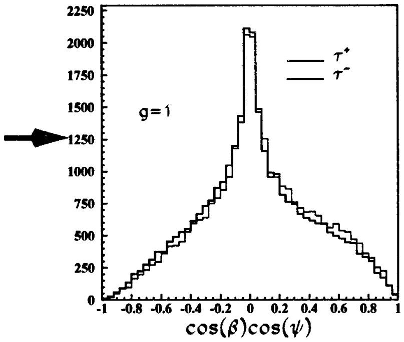
$\Delta_{\mathrm{strong}} = \pi/2$

Scalar resonance will enhance effects

Monte-Carlo Simulation



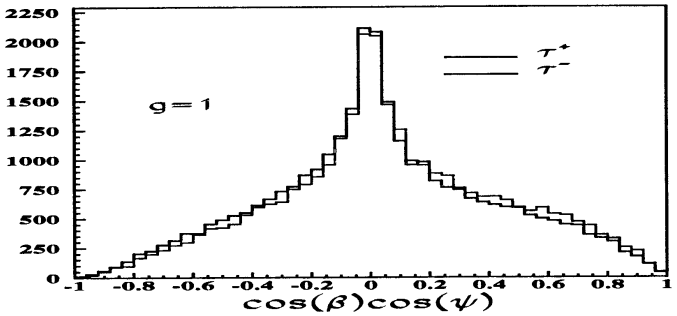
Generator MC - No cuts
(Flight direction known)



Full GEANT - All cuts
(Flight direction unknown)

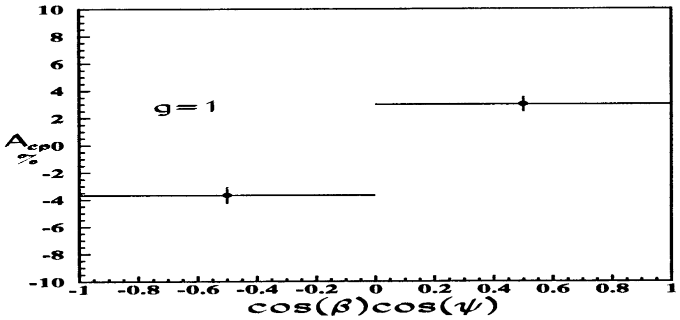
$\mathcal{A}_{cp}$ *is difference distribution linear in* $\cos\beta\cos\psi$

Monte-Carlo Simulation

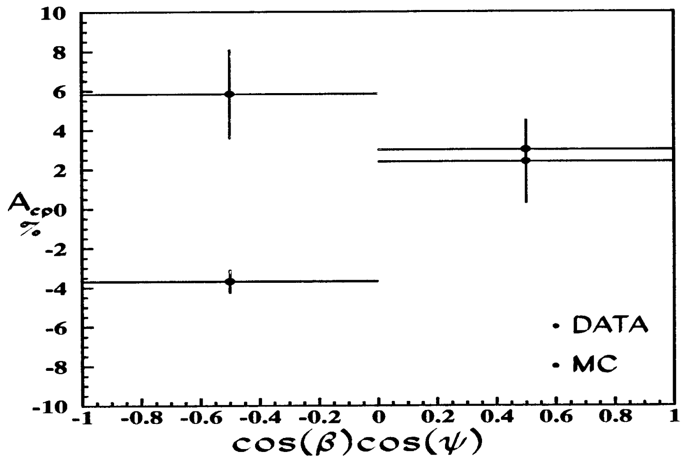


$\mathcal{A}_{cp}$ = -3.3g %

$\mathcal{A}_{cp}$=+3.3g%



DATA vs MC



	A^{-}_{CP}(%)	A^{+}_{CP}(%)
DATA	5.8±2.3	2.4±2.1
MC	-3.3g±0.3	+3.3g±0.3

Systematics

$N(events) = \varepsilon(efficiency)\sigma(cross-\text{sec}tion)(\int 1dt)(luminosity)$

$$A_{observed} = \frac{\varepsilon^{+}\sigma^{+} - \varepsilon^{-}\sigma^{-}}{\varepsilon^{+}\sigma^{+} + \varepsilon^{-}\sigma^{-}}$$

$A_{obs} \neq 0$ *if* $\sigma^{+} \neq \sigma^{-}$ *physics CP violation* - A_{cp}

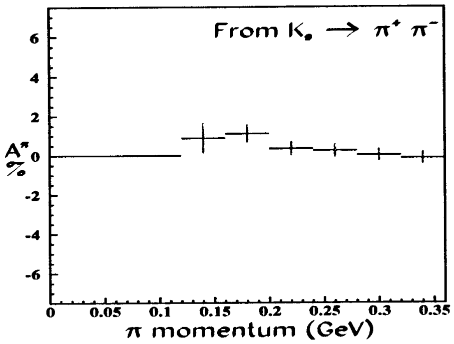
or $\varepsilon^{+} \neq \varepsilon^{-}$ *detector CP violation* - A_{det}

For small Asym $A_{obs} = \mathrm{A_{cp}} + \mathrm{A_{det}}$

Sample with zero or suppressed physics CP violation can be used to estimate detector effects

(CP violating detector effects difficult to model)

CP Violating Tracking Effects



$$A^{\pi} = \frac{P(\pi^{+}) - P(\pi^{-})}{P(\pi^{+}) + P(\pi^{-})}$$

Accounts for approx 1% of asymmetry if assume is same for $\pi/\mu/k/e$

Due to misalignment and lorentz angle effects

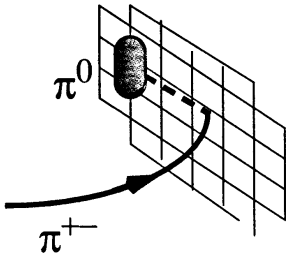
CP Violating Calorimeter Effects

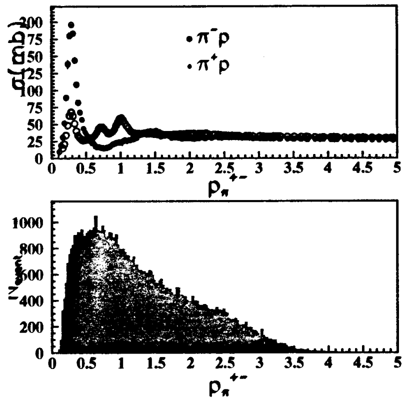
Nuclear Interactions in CsI

$\pi^+ n \rightarrow \pi^0 p$

$\pi^- p \rightarrow \pi^0 n$

$\#n \neq \#p$





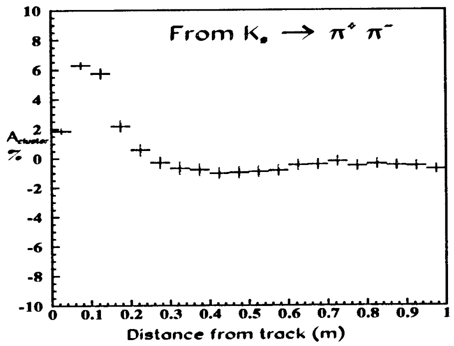
Affects π^0/photon veto

Momentum dependent

Same for K^{+-}

Cut to avoid effects

CP Violating Calorimeter Effects

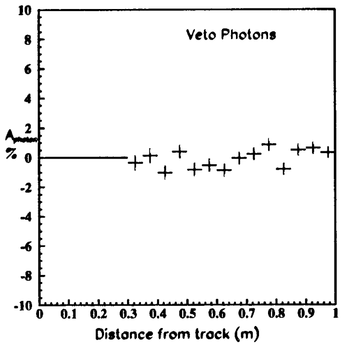


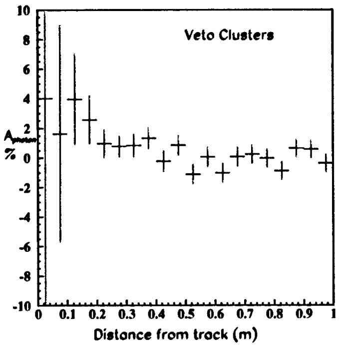
$$A^{cluster} = \frac{N(\pi^+) - N(\pi^-)}{N(\pi^+) + N(\pi^-)}$$

N = number of clusters at distance d from track projection

Large asymmetry but can cut to reduce

CP Violating Calorimeter Effects





Momentum dependent

Different for clusters and photon-like clusters

Different for kaons and pions but no k/π seperation

Approximately 1-2 % of asymmetry

Obviating detector effects

1. Model in MC : - very difficult effects to model detector imperfections and nuclear interactions

2. Cut around : Higher track and cluster thresholds but significant loss of statistics

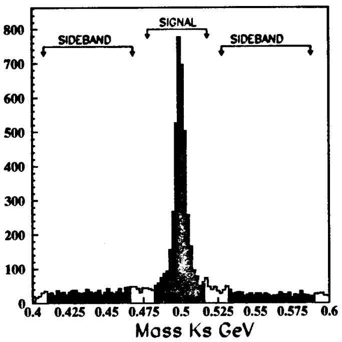
3. Measure in control sample:

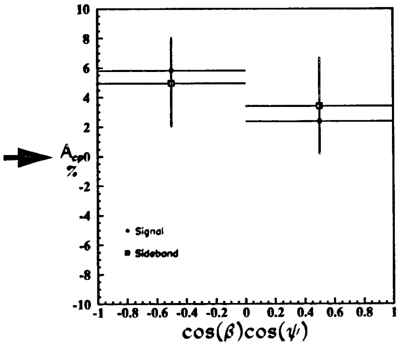
Recall $A_{obs} = A_{cp} + A_{det}$

Find sample with suppressed CP violation effects with same p,E distributions

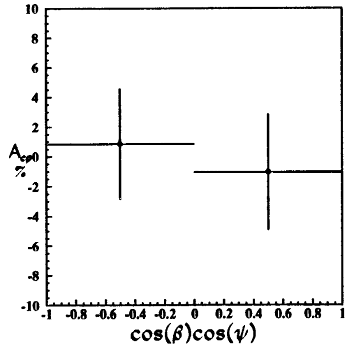
Use sideband to subtract detector effects - but significant loss of sensitivity

Sideband Subtracted Asymmetry





subtract



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CLEO Results

	$A^{-}_{CP}(\%)$	$A^{+}_{CP}(\%)$
Signal	5.8±2.3	2.4±2.1
Sideband	4.8±3.0	3.4±3.3
Subtracted	0.8±3.7	−1.0±3.9

(Subtracted asym. insensitive to cut changes)

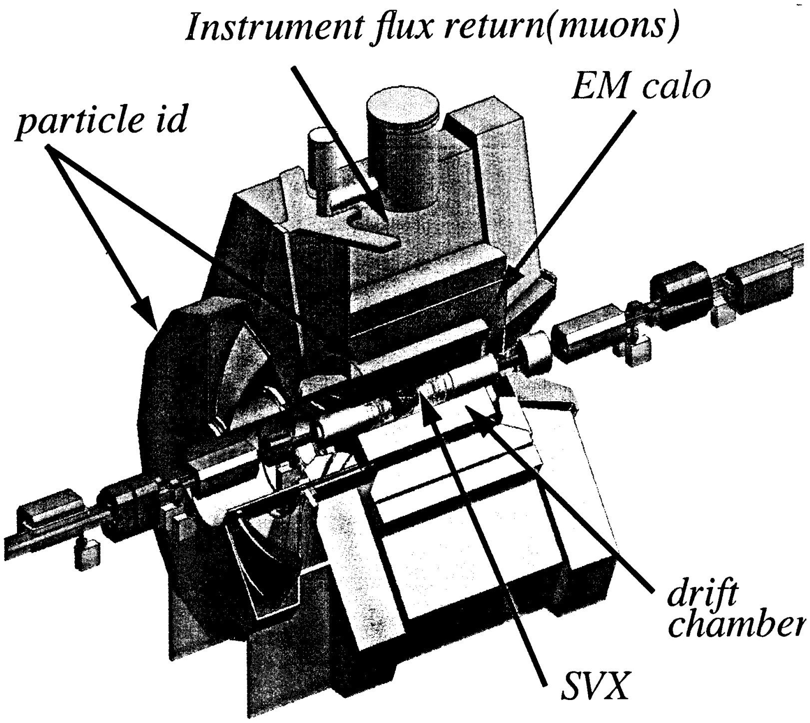
MC expectation is reduced by non CP violating backgrounds (asymmetry is diluted)

MC	(−1.6±0.1)Im(g)	(1.6±0.1)Im(g)

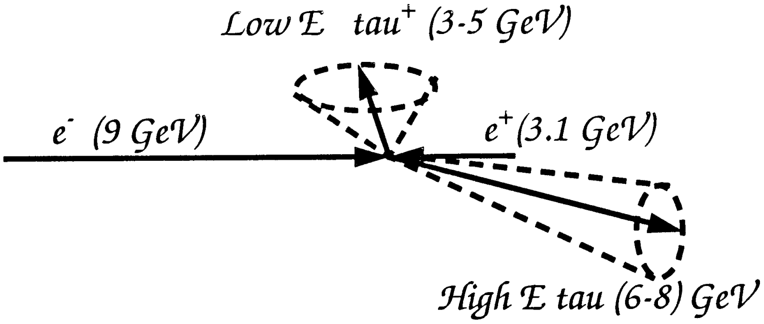
**g could be enhanced significantly by scalar resonance*

$$-1.7 < Im(g) < 0.6$$

The BaBar Detector



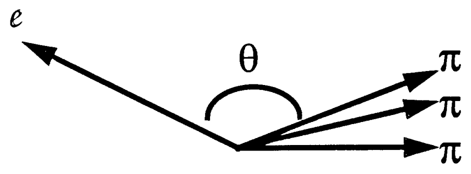
General features of taus at BaBar

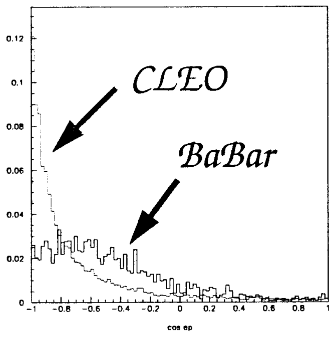


Distinctive two jet topology but not back to back

Other characteristics similar to CLEO

General features of taus at BaBar

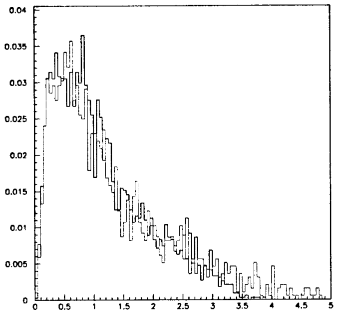




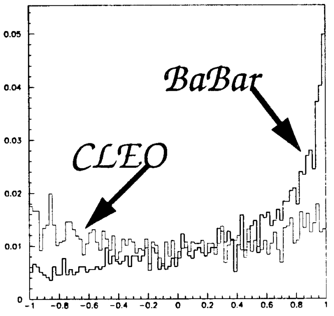
cos θ

Geometric Seperation of two taus possible

Acceptance of taus BaBar vs CLEO



Pion Momentum



Pion cos θ

Momentum distribution similar

Angular acceptance better for CLEO than BaBar
For 1 vs 3 topology :

BaBar has 90% acceptance of CLEO
(assuming 100% track eff -0.9 to +0.95 in cos)

Analysis at BaBar vs CLEO

Assume Missing Energy,Visible energy eff same

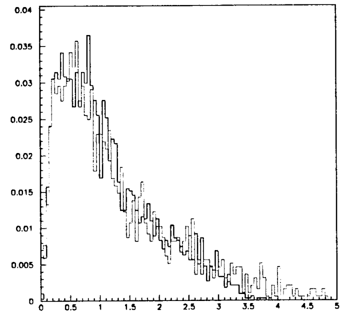
Assume K_s finding ef
f same

Photon vetos may not be as effective due to machine backgrounds at BaBar

Left with only other tau backgrounds as before (recall approx 60% purity with bkg due to k/π seperation problem,no K_L detection and no svx)

k/π seperation at 4 sigma in BaBar
K_L reconstruction eff 50%
Precsion vertices give no fake Ks
BaBar 85% purity

Obviate CP detector effects



Pion Momentum

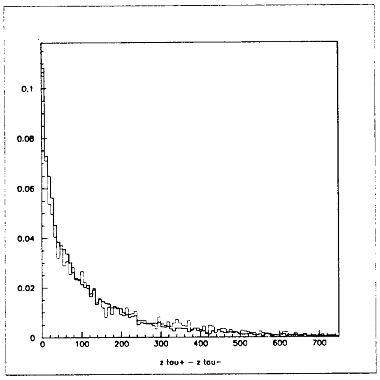
Increase thresholds to avoid detector effects

No sideband subtraction increases sesnitivity

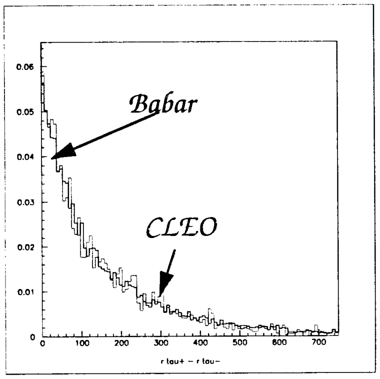
Statistics loss of 0.75 but sensitivity gain of 2

Effective statistical gain x 1.5

Lifetime of taus



Δz *between vertices* (μm)



Δxy *between vertices* (μm)

Single vertex resolution 60-80 μm

Vertexing help in getting cleaner 3 prong sample

3 vs 3 prong sample allows tau directions to be infered. 2 χ *sensitivity of 1-3 but 1/10 efficiency*

How much better at BaBar

1 year of BaBar running 30 million tau pairs

Improvements in terms of effective statistical increase

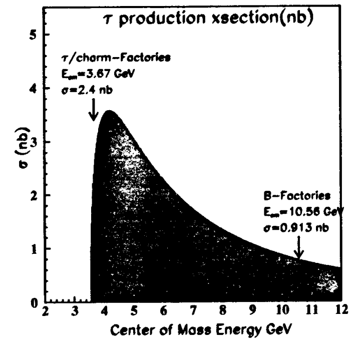
Luminosity	x 7
efficiency	x 0.9
purity	x 2.0
No detector effects	x 1.5
3 vs 3 added	x 1.2
Total	x 22

Asymmetries measured to 0.8 % (vs 4% previous)

Assuming measured to zero then

$\mathrm{Im}(g) < 0.1$ (1.2 previous)

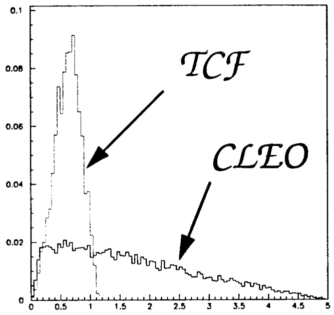
At a Tau-Charm Factory



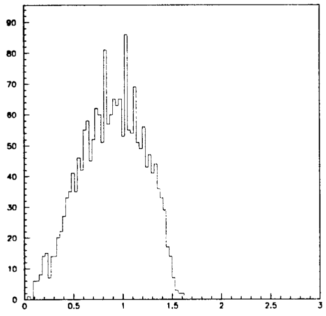
Assume same luminosity as B factory

60 Million tau pairs per year at 3.67 GeV

Identifying Taus at TCF



electron momentum

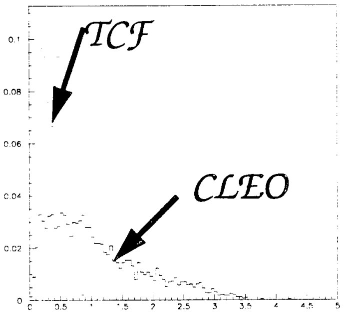


Missing Momentum

Marbella: lepton + missing P 50% efficiency

At 3.67 GeV below charm threshold
no non-tau bkg

Identifying Taus at TCF



pion momentum

Require pions $P > 50$ MeV $\cos\theta < 0.95$ (TCF)

For 3 pions 85 % efficient

Assume K_S finding efficiency 90% (CLEO)

Identifying Taus at TCF

Left with backgrounds from other taus (like CLEO)

Assume very efficient K/π seperation (dE/dx ToF)

Assume 50% efficiency for K_L id

Same a1 bkg as CLEO

Purity 80% versus CLEO 60%

Photon veto 80% (CLEO)

Overall $B.e_{lepton}.e_{miss}.e_{pion}.e_{ks}e_{photon}=$ 10%

(cf. CLEO 10% !)

How much better at BaBar/TCF

1(10) year of BaBar running 30(0) million tau pairs
1(10) year of TCF running 60(0) million tau pairs

Improvements in terms of effective statistical increase

	BaBar	TCF
Luminosity	x 7(0)	x14(0)
efficiency	x0.9	x 1
purity	x2.0	x 1.8
No detector effects	x1.5	x 1
3 vs 3 added	x1.2	x 1
Total	x 22(0)	x25(0)

Slight improvement in TCF over BaBar
Asymmetries measured to 0.8(0.25) % (vs 4% previous)
Assuming measured to zero then
Im(g) < 0.1(0.07) (1.2 previous)

Polarization

No experimental studies on polarization effects

Paper from Choi et al

Polarization introduces 3 additional asyms
(see Tom Rizzo's talk)

but each has same sensitivity as unpolarized
so no gain in this analysis

Conclusions

Description of recently published CLEO analysis
for CP violation taus decay

Comparison of prospects at BaBar and TCF

Comparable improvements at both
but very crude estimates and not much
thought on how to improve TCF efficiencies