CPV Search in $\tau \rightarrow \pi\pi^0\nu_\tau$ Decays

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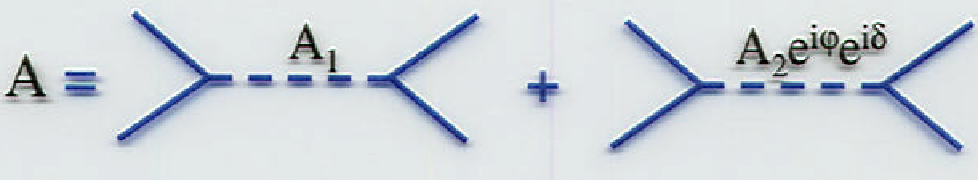
Introduction

Familiar story:

- CPV observed in K-system (K_S, K_L)
- CPV sought/expected in B-system ($B \Rightarrow \psi K_S$)
- CPV searches in μ, τ decays less popular

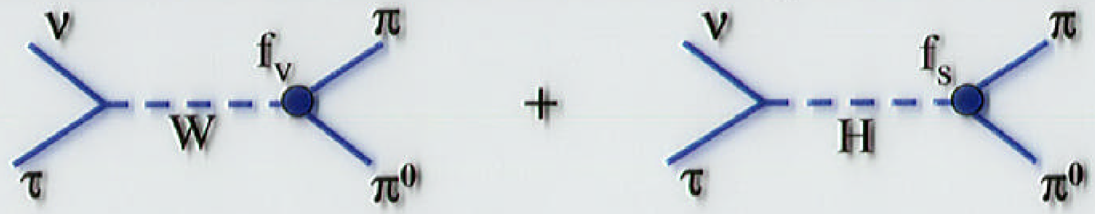
➡ Novel CPV search technique in τ decays

- Overall technique is general
- Easily interpretable in MHDM
- Search done w/ CLEO detector



$$P \sim |A|^2 \equiv A_1^{\,2} + A_2^{\,2} + 2A_1A_2\cos\varphi\cos\delta - \underbrace{2A_1A_2\overset{CP_{odd}}{\sin\varphi}\overset{CP_{even}}{\sin\delta}}_{CP_{odd}}$$

$$\boxed{\text{CPV: } \sin\varphi \, \sin\delta \neq 0}$$

$A =$ 

Maximize CPV sensitivity: Use specific model → 3 Higgs Doublet Model
(S. Weinberg, **PRL** 37 (1976) 657)

CP_{even}

$A_{SM} \sim J_{lep}|f_v|e^{i\delta v}(p_\pi - p_{\pi 0})$ w/ $|f_v| = BW[\rho(770)]$

CP_{odd} CP_{even}

$A_H \sim J_{lep}|\Lambda|\, e^{i\varphi}|f_s|\, e^{i\delta s}\, M_{\pi\pi 0}$

w/ $|f_s|$ model dependent:

$|f_s| = 1$
$= BW[a_0(980)]$
$= BW[a_0(1450)]$

$\tau \to \pi\pi^0\nu$ final state:

- $BR(\ \tau \to \pi\pi^0\nu\ ) \approx 25\%$
- High selection efficiency

Optimal CP Sensitive Variable

$P \sim |A|^2$

$P = P_{even} + P_{odd}$

P's are computed from f_v, f_s, Λ and kinematic quantities

What CP-odd observable ξ to use?

- Choice of ξ not unique
- Select ξ for smallest statistical error

CP sensitive variable: $\boxed{\xi = \frac{P_{odd}}{P_{even}}}$

Atwood + Soni, **PRD**, 45 (1992) 2405

Gunion + Grzadkowski, **PRD**, 77 (1992) 5172

ξ is complicated function. No immediate intuitive appeal.

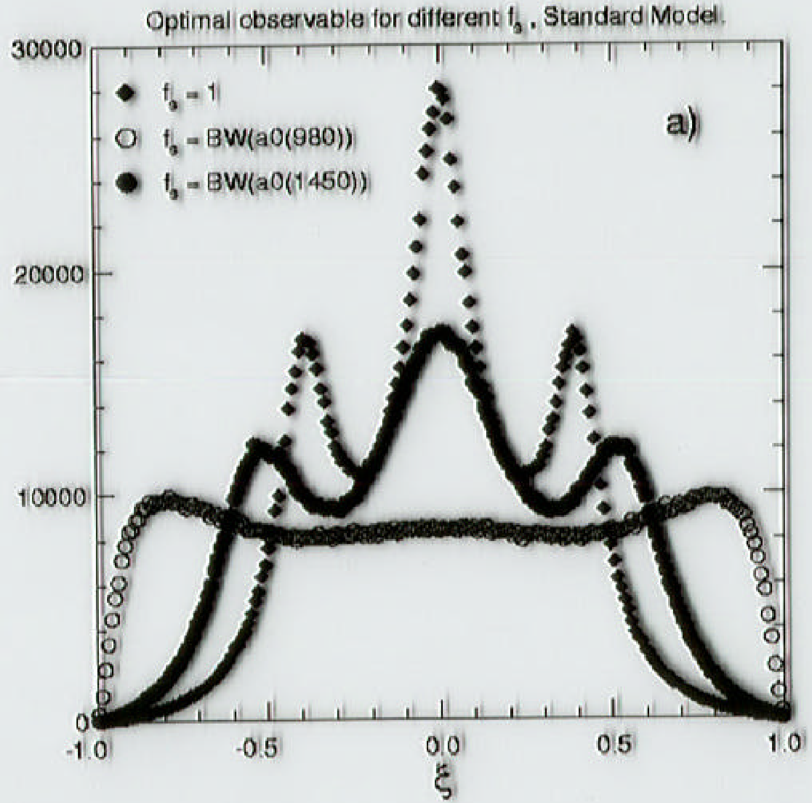
$$\langle \xi \rangle = \underbrace{\mathrm{Im}(\Lambda)}_{\lambda} \int \frac{P_{odd}^2}{P_{even}} \, dLips$$

$$= c_1 \lambda + c_3 \lambda^3 + c_5 \lambda^5 + \ldots$$

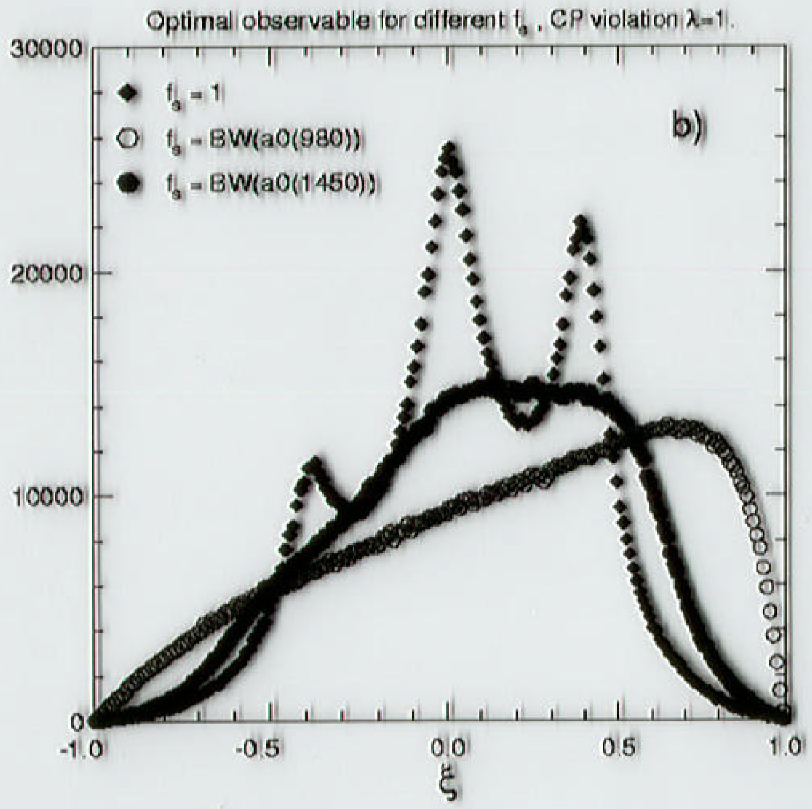
$$\boxed{\langle \xi \rangle \neq 0 \Rightarrow CPV}$$

Monte Carlo ξ Distribution: [redacted] 3HDM

No CPV ($\lambda = 0$)



'Maximal' CPV ($\lambda = 1$)



Experimental details

- Select $\tau \Rightarrow \pi\pi^0\nu$ decays
- $\int L\mathrm{d}t \sim$ 13.3 $\mathrm{fb}^{-1} \equiv 12.2 \times 10^6$ τ-pairs @ $\sqrt{s} \sim \Psi(4S)$
- BKG's : $ee \Rightarrow \tau\,\tau$

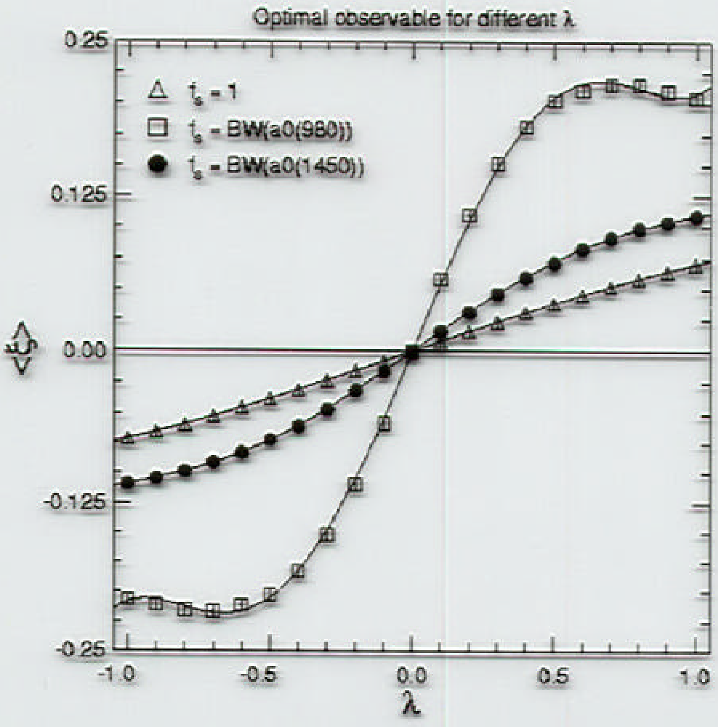
$$ee \Rightarrow \tau\,\tau,\quad \tau \longrightarrow \pi\pi^0\nu,\quad \tau \longrightarrow a_1\nu$$

Total contamination from other τ decays $\equiv 10\%$

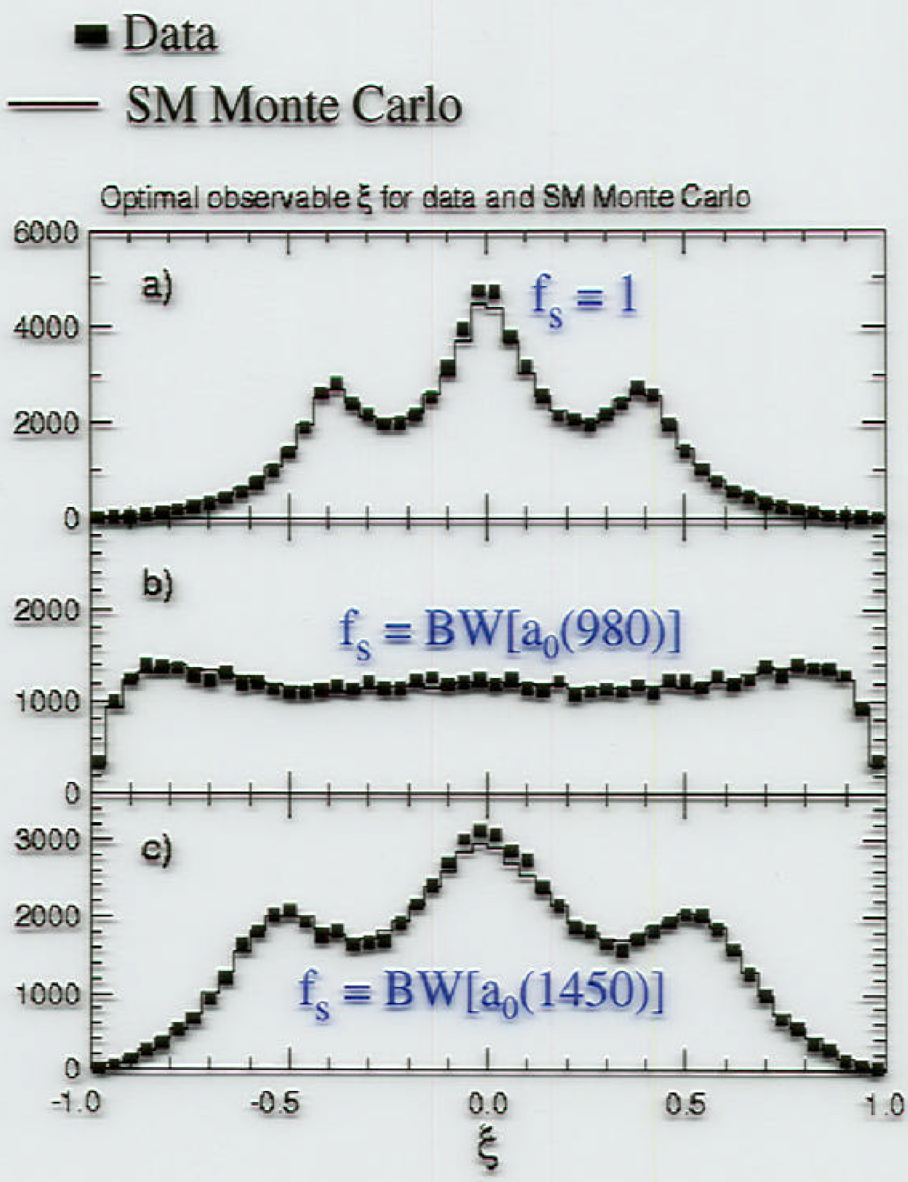
$$\left.\begin{array}{l} ee \Rightarrow qq \\ ee \Rightarrow ee\gamma\gamma \end{array}\right\} \text{negligible}$$

To lowest order $\langle\xi\rangle \equiv c\lambda$

- Use MC to determine c



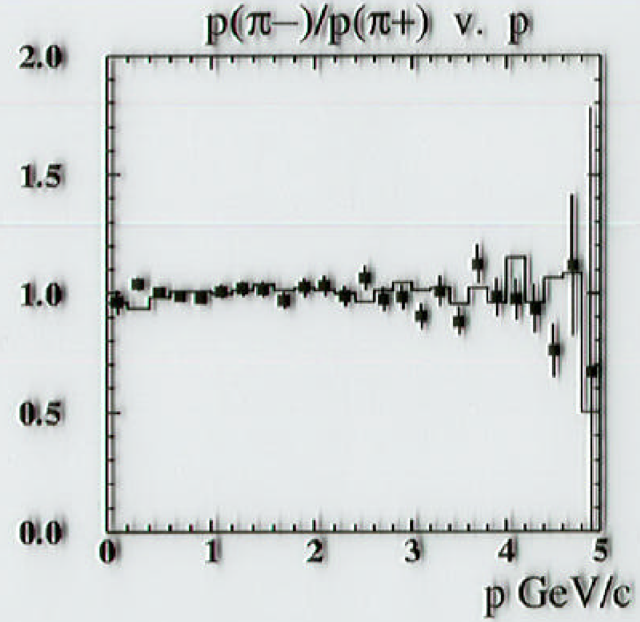
ξ Distribution



f	$\langle\xi\rangle \times 10^{-3}$	$\lambda \times 10^{-2}$	λ @ 90% CL
$f_s = 1$	-0.8 ± 1.4	-1.2 ± 2.1	$-0.046 < \lambda < 0.022$
$f_s = BW[a_0(980)]$	-0.6 ± 2.4	-0.1 ± 0.4	$-0.008 < \lambda < 0.006$
$f_s = BW[a_0(1450)]$	0.2 ± 1.2	0.1 ± 1.2	$-0.019 < \lambda < 0.021$

Systematic Error Checks

- O'all detector response asymmetry checked w/ $\tau \rightarrow q\, q\, \nu$ decays
- Track reconstruction efficiency v. $\pm q$
- $p(\pi)$, $p(\pi^0)$ reconstruction errors ? $\Rightarrow$
- ξ asymmetry from BKG ?



$\boxed{\text{Negligible effects on } \langle \xi \rangle}$

Search for Scalar Mediated τ Decays

- SM: W-exchange: $dN/d\cos\theta_{\pi\pi 0} \equiv a + b\cos^2\theta_{\pi\pi 0}$

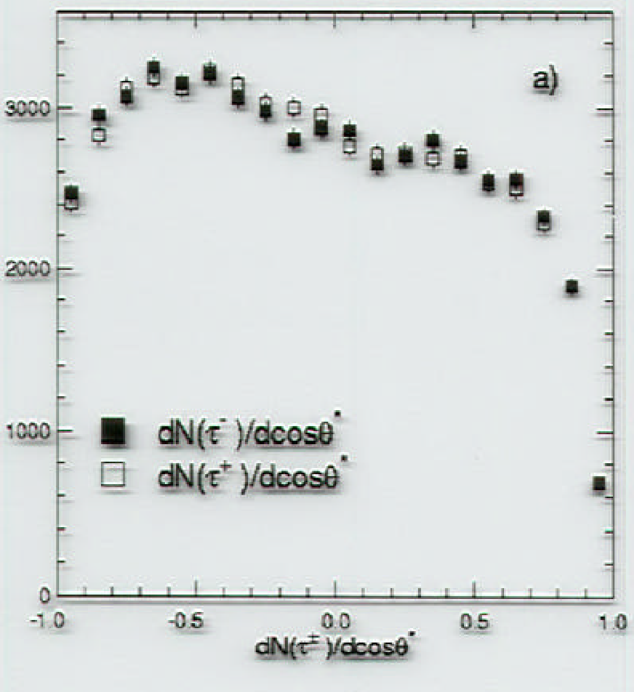
  $\theta \equiv$ helicity angle

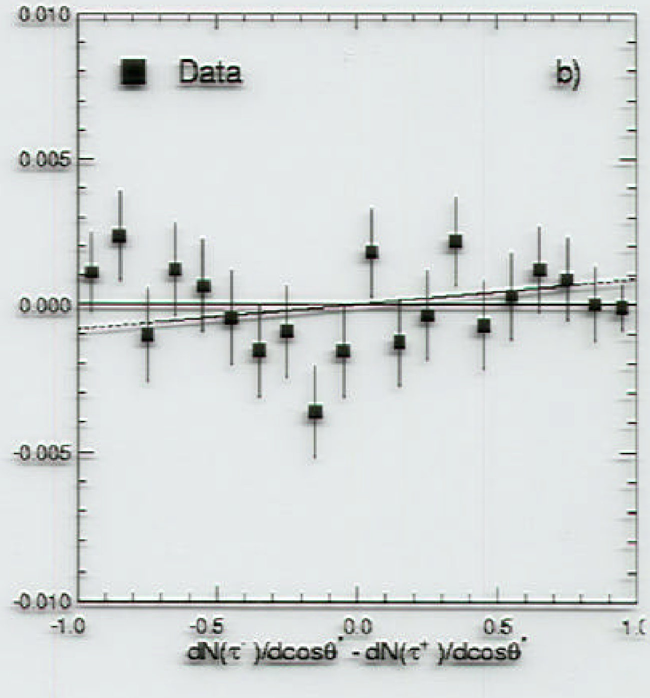
- non-SM w/ scalar exchanges:

$$dN/d\cos\theta_{\pi\pi 0} \equiv a + (c_1 \mathrm{Re}(\Lambda) + c_2 \mathrm{Im}(\Lambda))\cos\theta_{\pi\pi 0} + b\cos^2\theta_{\pi\pi 0}$$

- τ direction unknown, switch to θ*

$$\frac{dN(\tau+)}{d\cos\theta^*} - \frac{dN(\tau-)}{d\cos\theta^*} \sim c_2 \mathrm{Im}(\Lambda)\cos\theta^*$$





$$\boxed{-0.033 < \mathrm{Im}(\Lambda) < 0.089 \quad @\ 90\%\ \mathrm{CL}}$$

Summary

* Search for CPV in 3HDM w/ $f_s = 1$:

$-0.046 < \mathrm{Im}(\Lambda) < 0.022$ @ 90% CL (preliminary)

- $\langle\xi\rangle$ - technique, 1st of its type
- Improves previous CLEO result (PRL **81** (1998) 3823) by factor of ~ 4

* Pseudo-helicity angle distribution analysis w/ single $\tau \to \pi\pi^0\nu$ decays:

$-0.033 < \mathrm{Im}(\Lambda) < 0.089$ @ 90% CL (preliminary)