Tests of *CP* and *CPT* in the τ Sector at *BABAR*

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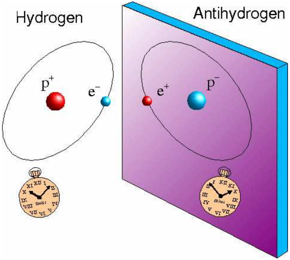
Testing of Symmetries

- Discrete symmetries constitute an important part of the Standard Model (SM)
- Results for the tests of *CPT* and *CP* presented here:
  - *CPT* test: Is $M_{\tau^+} = M_{\tau^-}$? (PRD 80, 092005)
  - *CP* test: Is $\Gamma\left(\tau^+ \to \pi^+ K_S^0\, \overline{\nu}_\tau\right) = \Gamma\left(\tau^- \to \pi^- K_S^0\, \nu_\tau\right)$? (New preliminary results)
- To test these symmetries, precision measurements are required
- *BABAR* has recorded over 900 million τ decays

Test on *CPT* in the τ Sector

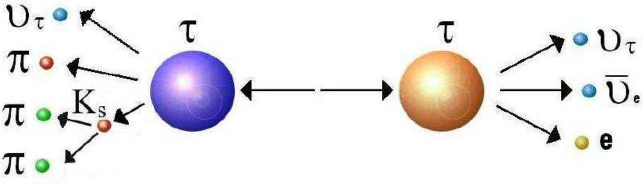


- *CPT* theorem states that all observables are invariant under *CPT* transformation $\Rightarrow M_{\tau^-} = M_{\tau^+}$
  $\therefore$ Precise measurement of the mass difference between τ^- and τ^+ can test *CPT* invariance (τ mass results also published in the *BABAR* analysis)
- Current limit (90% C.L.) from Belle (Phys. Rev. Lett. **99** [2007] 011801):

$$\frac{|M(\tau^+) - M(\tau^-)|}{M_{Average}} < 2.8 \times 10^{-4}$$

- Current PDG τ mass: $(1776.82 \pm 0.16)\,\mathrm{MeV}/c^2$

CP Violation in τ Decays

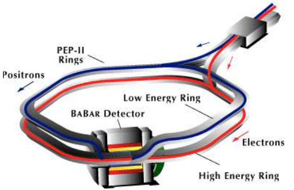


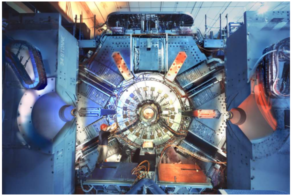
- *CP* violation has not been observed in the lepton sector
- Bigi and Sanda predict that there is a decay rate asymmetry for $\tau^- \to \pi^- K^0_S\, \nu_\tau$ [Phys.Lett. B625 (2005) 47-52]

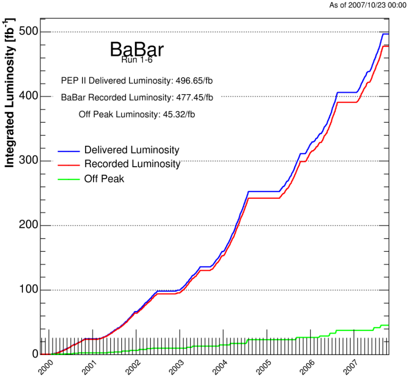
$$A_Q = \frac{\Gamma\left(\tau^+ \to \pi^+ K^0_S\, \overline{\nu}_\tau\right) - \Gamma\left(\tau^- \to \pi^- K^0_S\, \nu_\tau\right)}{\Gamma\left(\tau^+ \to \pi^+ K^0_S\, \overline{\nu}_\tau\right) + \Gamma\left(\tau^- \to \pi^- K^0_S\, \nu_\tau\right)}$$

  due to the K^0_S in the decay
- The asymmetry is predicted to be $(0.33 \pm 0.01)\%$ based on previous K^0_S-K^0_L experiments

PEP-II and the *BABAR* Experiment

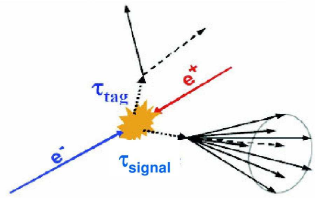






- Only $\Upsilon(4S)$ used ($>$400 fb^{-1})
- 900 million τ pairs

Selection Criteria

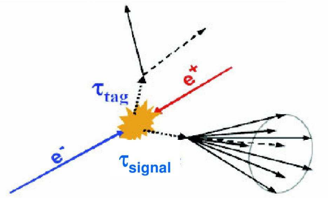


Signal side: 3-prong Tag side: 1-prong

CPT analysis selection:

- 423 fb^{-1} of $\Upsilon(4S)$ resonance data used, amount to 388 million $\tau^+\ \tau^-$ pairs
- Signal mode: $\tau^- \rightarrow \pi^-\ \pi^-\ \pi^+\ \nu_\tau$ due to large branching fraction
- No K^0_S, π^0, or leptons in the signal hemisphere
- Two-photon processes are also vetoed by kinematic cuts
- Tagged with $\tau^- \rightarrow e^-\nu\overline{\nu}$ and $\tau^- \rightarrow \mu^-\nu\overline{\nu}$

Selection Criteria

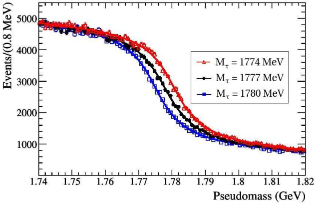


Signal side: 1-prong + K_S^0
Tag side: 1-prong

CP analysis selection:

- $476\ \text{fb}^{-1}$ of $\Upsilon(4S)$ resonance data used, amount to 437 million $\tau^+\ \tau^-$ pairs
- Kinematic-based preselection criteria
- Likelihood-based selection to further refine sample
- Signal: $\tau^- \to h^- K_S^0 \left(\geq 0\pi^0\right) \nu_\tau$
- Tagged with $\tau^- \to e^- \nu \overline{\nu}$

CPT Analysis Strategy



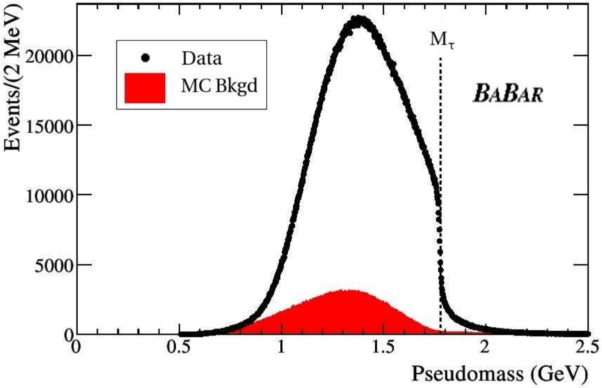
- "Pseudomass" variable is used to measure M_τ:

$$M_p = \sqrt{M_h^2 + 2\left(\sqrt{s}/2 - E_h^*\right)\left(E_h^* - P_h^*\right)}$$

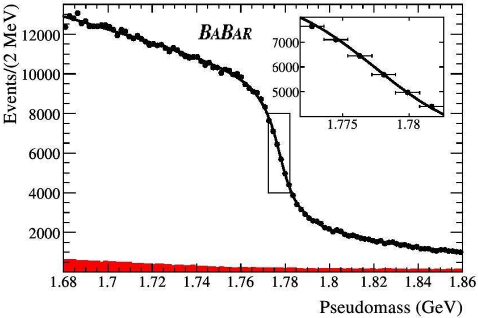
  where M_h, E_h^* and P_h^* are invariant mass, energy and (3-)momentum of the hadronic system, respectively, in CM frame

- At M_τ, M_p drops off steeply

CPT Analysis: Pseudomass



CPT: Fit on the Pseudomass Distribution



Fitting $F(M_p)$ to the data, where:

$$F(M_p) = (p_3 + p_4 M_p) tan^{-1}\left(\frac{p_1 - M_p}{p_2}\right) + p_5 + p_6 M_p$$

p_i are the fit parameters

CPT: Analysis Results

Final results: (PRD 80, 092005)

- $M_\tau = 1776.68 \pm 0.12(stat) \pm 0.41(syst)\,\mathrm{MeV}/c^2$
- $\frac{M(\tau^+)-M(\tau^-)}{M_{Average}} = (-3.4 \pm 1.3[stat] \pm 0.3[syst]) \times 10^{-4}$

  $\Rightarrow$ 90% C.L. UL $= 5.5 \times 10^{-4}$

TABLE VII: Systematic uncertainties in M_τ.

Source	Uncertainty (MeV)
Momentum Reconstruction	0.39
CM Energy	0.09
MC Modeling	0.05
MC Statistics	0.05
Fit Range	0.05
Parameterization	0.03
Total	**0.41**

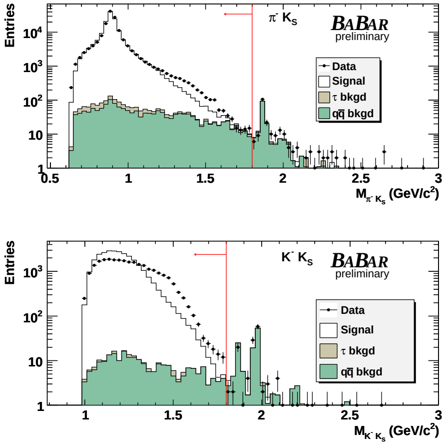
CP Analysis Strategy

- Signal modes used in the analysis:

Mode	Branching Fraction (PDG '10)
$\tau^- \rightarrow \pi^- K^0_S \left(\geq 0\pi^0\right) \nu_\tau$	11.6×10^{-3}
$\tau^- \rightarrow K^- K^0_S \left(\geq 0\pi^0\right) \nu_\tau$	3.1×10^{-3}
$\tau^- \rightarrow \pi^- K^0 \overline{K}^0 \left(\geq 0\pi^0\right) \nu_\tau$	2.0×10^{-3}

- The use of this "inclusive" technique has the advantages of:
  - eliminating PID errors due to identifying the charged hadron in the decay
  - optimising statistics
- Downside: Reduction of the charge asymmetry to $(0.17 \pm 0.01)\%$
- For this study, only look at e-tagged events

CP: Hadronic Mass Plots



Invariant mass of the π^- K_S^0 (top) and K^- K_S^0 (bottom) systems

CP: MC Study

Source	Fractions (%)	Asymmetry(%)
Monte Carlo	100	0.04 ± 0.15
Total Signal	98.5±0.2	
$\pi^- \ K_s^0 \ (\geq 0\pi^0)\nu_\tau$	66.5±0.2	0.13 ± 0.19
$K^- \ K_s^0 \ (\geq 0\pi^0) \ \nu_\tau$	19.14±0.07	-0.19 ± 0.32
$\pi^- \ K^0 \ \overline{K}^0 \ \nu_\tau$	12.82±0.05	-0.16 ± 0.39
Total Background	1.51±0.02	
τ background	0.243±0.007	
uds	0.197±0.007	
$c\overline{c}$	1.07±0.02	

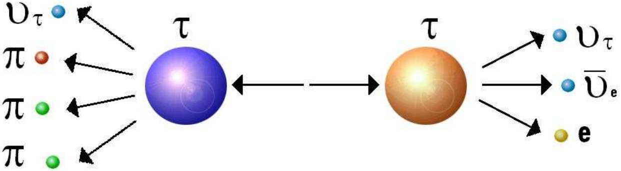
- MC is used to study selection biases
- No asymmetry observed in the Monte Carlo
- 230k data events and 235k MC events pass through all selection criteria

CP: Results

- The final measured asymmetry is (-0.10±0.21±0.22)% (*BABAR* preliminary)
- Systematic uncertainties:

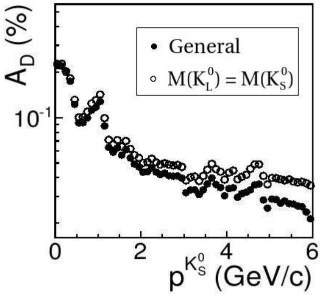
Selection Uncertainty	0.15%
Detector Uncertainty	0.12%
K^0-$\overline{K}^0$ Nuclear Interaction	0.10%
Total Systematic Uncertainties	0.22%

CP: Detector Uncertainty



- Control sample ($\tau^- \rightarrow \pi^- \pi^- \pi^+ \nu_\tau$ without K^0_S) is used to test any biases in the detector that are not modelled in the MC
- No decay rate asymmetry is expected in the control sample
- Detector uncertainty is the difference in asymmetries between data and MC control samples

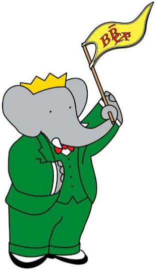
CP: K^0-$\overline{K}^0$ Nuclear Interaction



Asymmetry due to K^0-$\overline{K}^0$ nuclear interaction vs. momentum of K_s^0

- A paper by Ko et al. (arXiv:1006.1938v1 [hep-ex]) points out that the difference in nuclear interaction cross sections between K^0 and $\overline{K}^0$ can change the measured decay rate asymmetry for all decays with K_s^0
- Full impact is still under study for τ decays, but Ko et al. state that this effect is $<0.1\%$
- A 0.10% uncertainty is added to the total systematic uncertainties (a conservative estimate)

Summary



- *CPT* test:

$$\frac{|M(\tau^+) - M(\tau^-)|}{M_{Average}} < 5.5 \times 10^{-4}$$

$\rightarrow$ Compared with Belle's $\frac{|M(\tau^+)-M(\tau^-)|}{M_{Average}} < 2.8 \times 10^{-4}$

$M_\tau = 1776.68 \pm 0.12\ \text{(stat)} \pm 0.14\ \text{(syst)}\ \mathrm{MeV}/c^2$

- *CP* test (new preliminary result):

$$A_Q = (-0.10 \pm 0.21[stat] \pm 0.22[syst])\%$$

$\rightarrow$ Measured for the first time