Measurements of τ hadronic branching fractions and spectra, and search for 2nd class current τ decays

Meeting of the APS Division of Particles and Fields (DPF2013), Santa Cruz, 13-17 August 2013

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Outline

Introducing the *BaBar* experiment

Methodology

τ hadronic branching fractions

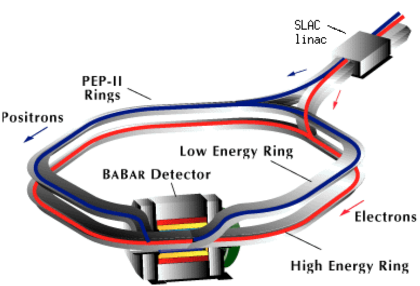
- One-prong decays including $2K_s^0$
- High-multiplicity (3 or 5 prong) decays excluding K_s^0
- Search for decays involving η' (958) and 2nd class current

τ invariant mass distributions for three-prong hadronic decays

- $\tau^- \to \pi^- \pi^+ \pi^- \nu_\tau$
- $\tau^- \to K^- \pi^+ \pi^- \nu_\tau$
- $\tau^- \to K^- K^+ \pi^- \nu_\tau$
- $\tau^- \to K^- K^+ K^- \nu_\tau$

Summary

The *BABAR* experiment

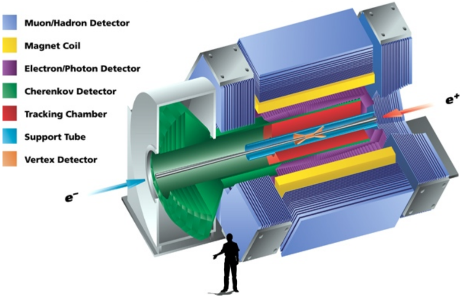


- Located at PEP-II asymmetric e^+e^- collider at the SLAC National Accelerator Laboratory
- Operated from 1999 to 2008
- Centre-of-mass energy $\sqrt{s} = 10.58\,\text{GeV}$, just above the $B\bar{B}$ treshold
- Multipurpose detector recorded over $511\,\text{fb}^{-1}$ of data
- *B*-factory: optimized for *B* physics but excellent for τ and *c* studies

General methodology

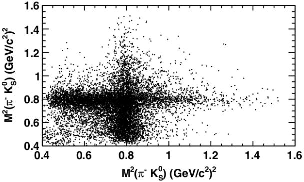
- Data sample
  - Use integrated luminosity $\mathcal{L} = 468\,\text{fb}^{-1}$ ($\approx 430 \times 10^6$ τ pairs)
  - $\tau^+\tau^-$ production simulated with KK2F, decays with Taula and detector interaction from GEANT4

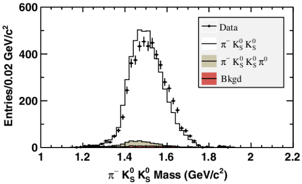
- Selection
  - Divide event perpendicular to the thrust axis
  - "tag" hemisphere: $\tau^- \to e^-\nu_\tau\overline{\nu}_e$ or $\tau^- \to \mu^-\nu_\tau\overline{\nu}_\mu$ (charge conjugaison implied)
  - "signal" hemisphere: 1,3 or 5 "prongs" (tracks)
  - Use PID information from all subdetectors of *BABAR*

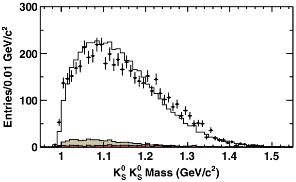


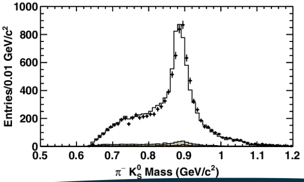
Branching fraction of $\tau^- \to (\pi^-, K^-) K^0_S\, K^0_S\, (\pi^0) \nu_\tau$ decays

- Four poorly-measured decay channels that include $2K^0_S$
- $\tau^- \to \pi^-\, K^0_S\, K^0_S\, \nu_\tau$: background in *CP* violation searches measuring rate asymmetry in $\tau^- \to \pi^-\, K^0_S\, \nu_\tau$
- Better understanding required in a future high-$\mathcal{L}$ *B* Factory measurement
- See Phys. Rev. D **86** 092013 (2012)









Branching fraction of $\tau^- \to (\pi^-, K^-) K^0_S\, K^0_S\, (\pi^0) \nu_\tau$ decays

- Branching fraction for $\tau^- \to \pi^- K^0_S K^0_S \nu_\tau$ agrees with previous measurements from ALEPH and CLEO
- First measurement for $\tau^- \to \pi^- K^0_S K^0_S \pi^0 \nu_\tau$ and first limits for the charged kaon decays
- Main systematic uncertainty sources: tracking, PID, topological selection. For $1\pi^0$ modes: selection efficiency

Decay mode	**Data events**	**Estimated background**	**Efficiency (%)**	**Branching ratio**[†] **(10^{-5})**
$\tau^- \to$				
$\pi^- K^0_S K^0_S \nu_\tau$	4985	98 ± 17	4.93 ± 0.03	$23.1 \pm 0.4 \pm 0.8$
$\pi^- K^0_S K^0_S \pi^0 \nu_\tau$	409	35 ± 7	2.65 ± 0.02	$1.60 \pm 0.20 \pm 0.22$
$K^- K^0_S K^0_S \nu_\tau$	23	20.0 ± 0.5	3.85 ± 0.04	≤ 0.063
$K^- K^0_S K^0_S \pi^0 \nu_\tau$	1	0.15 ± 0.02	1.37 ± 0.03	≤ 0.040

[†] or 90% CL limit

Study of high-multiplicity three-prong five-prong τ decays

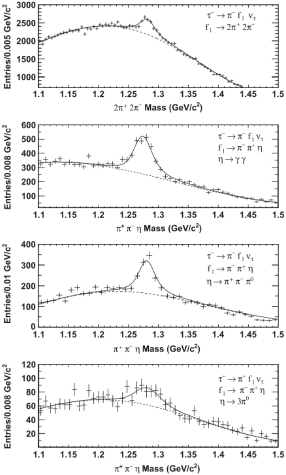
- Phys. Rev. D **86**, 092010 (2012)
- Study of rare modes and search for forbidden processes
- 23 branching fractions measured
- Divided into
  - resonant modes (η, f_1, ω)
  - “nonresonant” modes
  - involving η' (958)
  - with either one or two $K^{\pm}$
    (not presented here)
- Measurement of $m_{f_1} = (1281.16 \pm 0.39 \pm 0.45)\,\mathrm{MeV}/c^2$
- New or more precise $\mathcal{B}$ measurements

Resonant modes:

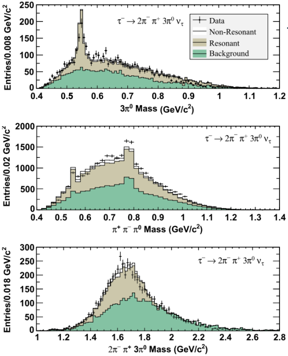
- $\tau^- \to \pi^- f_1 \nu_\tau$
  - $f_1 \to 2\pi^+ 2\pi^-$
  - $f_1 \to \pi^+ \pi^- \eta$
- $\tau^- \to 2\pi^- \pi^+ \eta \nu_\tau$
  - $\eta \to \gamma\gamma$
  - $\eta \to 3\pi^0$
  - $\eta \to \pi^- \pi^+ \pi^0$
- $\tau^- \to 2\pi^0 \pi^- \eta \nu_\tau$
  - $\eta \to \pi^- \pi^+ \pi^0$
- $\tau^- \to 2\pi^- \pi^+ \omega \nu_\tau$
  - $\omega \to \pi^- \pi^+ \pi^0$
- $\tau^- \to 2\pi^0 \pi^- \omega \nu_\tau$
  - $\omega \to \pi^- \pi^+ \pi^0$

Results for high-multiplicity three-prong five-prong τ decays

Resonant: f_1 decays



Nonresonant: $\tau^- \to 2\pi^-\pi^+3\pi^0\nu_\tau$



90% CL limit:

$\mathcal{B}(\tau^- \to 2\pi^-\pi^+3\pi^0\nu_\tau) < 5.8 \times 10^{-5}$

Summary of the results:

Decay mode	**Branching ratio (10^{-5})**
Resonant	
$2\pi^-\pi^+\eta\nu_\tau$	$22.5 \pm 0.7 \pm 1.2$
$\pi^-2\pi^0\eta\nu_\tau$	$20.1 \pm 3.4 \pm 2.2$
$\pi^-f_1\eta\nu_\tau$ ↳$2\pi^+2\pi^-$	$5.2 \pm 0.31 \pm 0.37$
$\pi^-f_1\eta\nu_\tau$ ↳$\pi^+\pi^-\eta$	$12.6 \pm 0.6 \pm 0.6$
$2\pi^-\pi^+\omega\nu_\tau$	$8.4 \pm 0.4 \pm 0.6$
$\pi^-2\pi^0\omega\nu_\tau$	$7.3 \pm 1.2 \pm 1.2$
Nonesonnant	
$3\pi^-2\pi^+\nu_\tau$	$76.8 \pm 0.4 \pm 4.0$
$2\pi^-\pi^+3\pi^0\nu_\tau$	$1.0 \pm 0.8 \pm 3.0$
$3\pi^-2\pi^+\pi^0\nu_\tau$	$3.6 \pm 0.3 \pm 0.9$
Inclusive (incl. η, ω, f_1)	
$2\pi^-\pi^+3\pi^0\nu_\tau$	$20.7 \pm 1.8 \pm 3.7$
$3\pi^-2\pi^+\nu_\tau$	$83.3 \pm 0.4 \pm 4.3$
$3\pi^-2\pi^+\pi^0\nu_\tau$	$16.5 \pm 0.5 \pm 0.9$

Search for decays involving η' (958)

- Hadronic currents of spin-parity J^P are classified according to their transformation properties under G parity:
  - 1st class: $J^{PG} = 0^{++}, 0^{--}, 1^{+-}, 1^{-+}$ (dominate)
  - 2nd class: $J^{PG} = 0^{+-}, 0^{-+}, 1^{++}, 1^{--}$ (0 if $m_u = m_d$)
- Search for allowed first-class current decays:
  - $\tau^- \to \pi^- \pi^0 \eta'$ (958)ν_τ
  - $\tau^- \to K^- \eta'$ (958)ν_τ
- Search for second-class current decay
  - $\tau^- \to \pi^- \eta'$ (958)ν_τ
  - Branching fraction predicted $< 1.4 \times 10^{-6}$
- Reconstruction with $\eta'(985) \to \pi^-\pi^+\eta$

$$\mathcal{B}\left(\tau^- \to \pi^-\pi^0\eta'(958)\nu_\tau\right) < 1.2 \times 10^{-5}$$
$$\mathcal{B}\left(\tau^- \to K^-\eta'(958)\nu_\tau\right) < 2.4 \times 10^{-6}$$
$$\mathcal{B}\left(\tau^- \to \pi^-\eta'(958)\nu_\tau\right) < 4.0 \times 10^{-6}$$

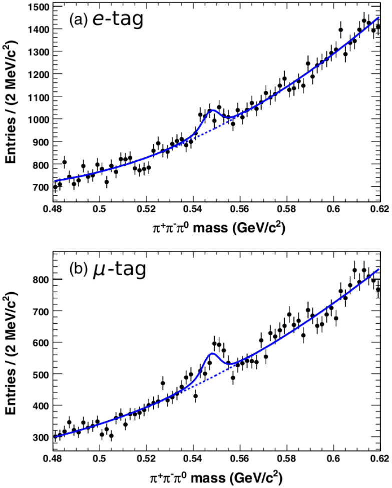
Search for 2nd class current decay $\tau^- \to \eta\pi^-\nu_\tau$

- Phys. Rev. D **83**, 032002 (2011)
- Expected $\mathcal{B}(\tau^- \to \eta\pi^-\nu_\tau) <\sim 10^{-5}$
- Also measured $\mathcal{B}(\tau^- \to \eta K^-\nu_\tau)$

Decay mode	**Branching ratio (10^{-5})**
$\tau^- \to \eta K^-\nu_\tau$	$14.2 \pm 1.1 \pm 0.7$
$\tau^- \to \eta\pi^-\nu_\tau$	$3.4 \pm 3.4 \pm 2.1$

- η peak in $\tau^- \to \eta\pi^-\nu_\tau$
  - Is mostly background ($q\bar{q}$ and τ-pair decaying into channel with η)
- Limit on this 2nd class current signal (90% C.L.):

$$\mathcal{B}(\tau^- \to \eta\pi^-\nu_\tau) < 8.8 \times 10^{-5}$$



Exclusive invariant mass distributions for $\tau^- \rightarrow h^- h^- h^+ \nu_\tau$

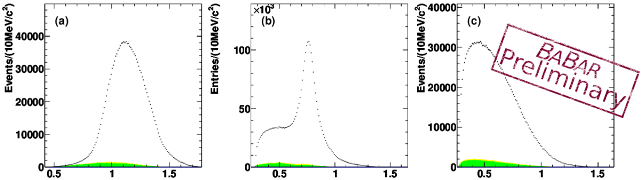
- Motivation:
  - The final state contains a rich spectrum of resonnances
  - Measurement of strange and non-strange spectral functions can be used for measuring m_S and $|V_{us}|$
  - Aims to improve simulation of hadronic τ decays
  - Also provide better theoretical understanding of the dynamics of their decay structure

- Methodology:
  - 1 lepton track "tag" + 3-prong "signal"
  - Backgrounds estimated from data-driven techniques (mostly cross-feed from other $\tau^- \rightarrow h^- h^- h^+ \nu_\tau$ decays)
  - Mass spectra unfloded as per NIM A **362**, 487 (1995)
  - Preliminary (unpublished) results

Exclusive invariant mass distributions for $\tau^- \to \pi^- \pi^+ \pi^- \nu_\tau$

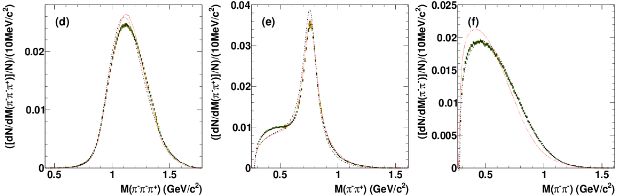
Top: reconstructed

⌶ Data ■ $\tau \to h^- h^- h^+ \nu_\tau$ cross-feed background ■ other τ backgrounds ■ non-τ backgrounds



Bottom: bkg-subtracted, unfolded, ε-corrected and normalized

⌶ Data±■(stat)±■(stat⊕syst) --- *BABAR* generator level MC ··· CLEO tune for Taula 2.8

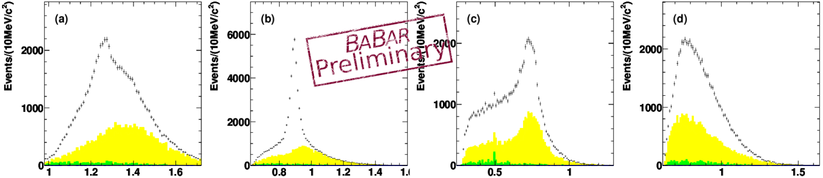


$m(\pi^-\pi^-\pi^+)$ $m(\pi^-\pi^+)$ $m(\pi^-\pi^-)$

Exclusive invariant mass distributions for $\tau^- \to K^- \pi^+ \pi^- \nu_\tau$

Top: reconstructed

Ɪ Data ■ $\tau \to h^- h^- h^+ \nu_\tau$ cross-feed background ■ other τ backgrounds ■ non-τ backgrounds



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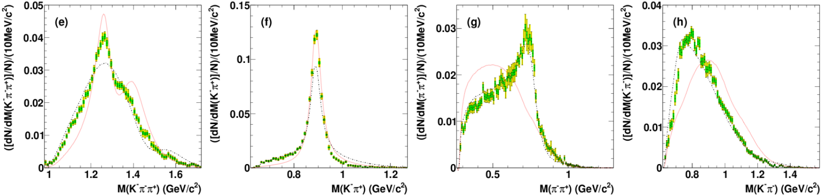
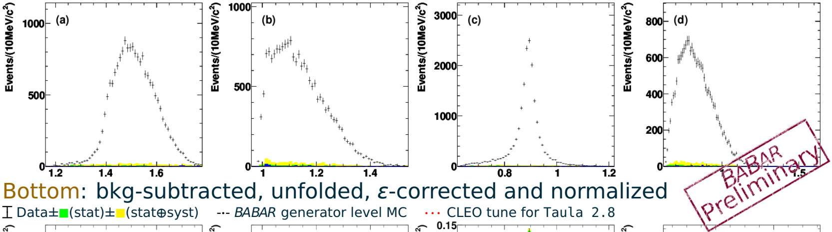


$m(K^-\pi^-\pi^+)$ $m(K^-\pi^+)$ $m(\pi^-\pi^+)$ $m(K^-\pi^-)$

Exclusive invariant mass distributions for $\tau^- \to K^- K^+ \pi^- \nu_\tau$

Top: reconstructed

⌶ Data ■ $\tau \to h^- h^- h^+ \nu_\tau$ cross-feed background ■ other τ backgrounds ■ non-τ backgrounds



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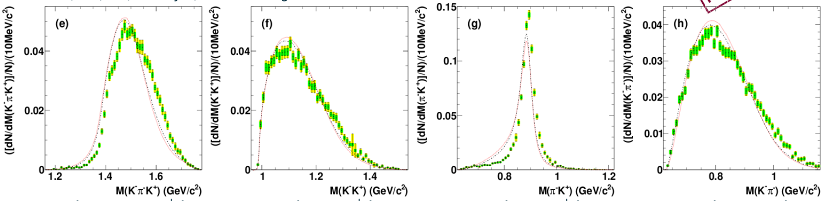
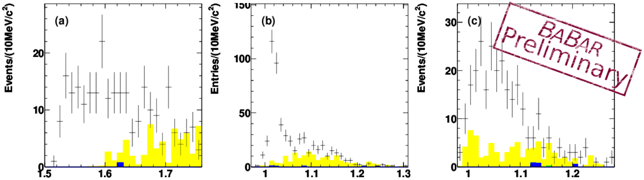


$m(K^-\pi^-K^+)$ $m(K^-K^+)$ $m(\pi^-K^+)$ $m(\pi^-K^-)$

Exclusive invariant mass distributions for $\tau^- \rightarrow K^- K^+ K^- \nu_\tau$

Top: reconstructed

Data; $\tau \rightarrow h^- h^- h^+ \nu_\tau$ cross-feed background; other τ backgrounds; non-τ backgrounds



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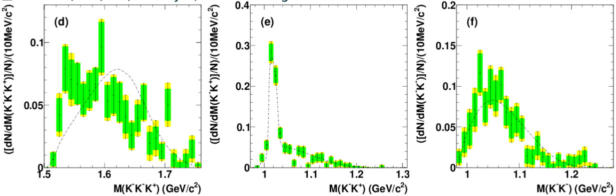
Data$\pm$(stat)$\pm$(stat$\oplus$syst); --- *BABAR* generator level MC; ··· CLEO tune for Taula 2.8



$m(K^-K^-K^+)$ $m(K^-K^+)$ $m(K^-K^-)$

Summary

- Many τ hadronic branching fractions measured at *BABAR*
- Best limits on 2^{nd} class current decays
- Invariant mass distributions for $\tau^- \to h^- h^- h^+ \nu_\tau$

The speaker would like to thank Dr. Randall Sobie, Dr. Ian Nugent and the *BABAR* Collaboration for their help in preparing this talk!