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Searches for second-class currents at Babar

Kim Alwyn

University of Manchester
representing the BaBar Collaboration

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Second-Class Currents

- Weak hadronic currents in τ decays can be classified as:

  - first-class currents (FCC): $J^{PG} = 0^{++}, 0^{--}, 1^{+-}, 1^{-+}$
  - second-class currents (SCC): $J^{PG} = 0^{+-}, 0^{-+}, 1^{++}, 1^{--}$

S. Weinberg
(Phys. Rev. **112**, 1375 (1958))

$$\hat{G} = \hat{C}\, e^{i\pi \hat{I}_2}$$

- No evidence has been found for SCC
- SCC are associated with a decay constant proportional to the mass difference between up and down quarks, vanishing in limit of perfect isospin symmetry
- Expected to have branching fraction values of order 10^{-5}
- The τ^- lepton provides clean ways to look for SCC

Searches for second-class currents in τ decays

*the use of charge-conjugate reactions is implied throughout talk

$\tau^- \to \omega\pi^-\nu_\tau$

- Proceeds dominantly through FCC with $J^{PG} = 1^{-+}$
  - decays through a P-wave
- May potentially decay through SCC with $J^{PG} = 0^{-+}$ or 1^{++}
  - decays through S- and D-waves
  - may be mediated by $b_1(1235)$
- Angular analysis reveals whether there is any SCC contribution

$\tau^- \to \eta\pi^-\nu_\tau$

- Must be produced through SCC with $J^{PG} = 0^{+-}$ or 1^{--}
  - can be mediated by $a_0(980)$ or $\pi_1(1400)$

$\tau^- \to \eta'(958)\pi^-\nu_\tau$

- Must also be produced through SCC with $J^{PG} = 0^{+-}$ or 1^{--}

Previously Published Results

$\tau^- \to \omega\pi^-\nu_\tau$

- Ratio of second-class (non-vector) to first-class (vector) currents < 5.4% at 90% confidence level (CL)

CLEO (Phys. Rev. D **61**, 072003 (2000))

$\tau^- \to \eta\pi^-\nu_\tau$

- BF($\tau^- \to \eta\pi^-\nu_\tau$) < 1.4 x 10^{-4} at 95% CL

CLEO (Phys. Rev. Lett. **76**, 4119 (1996))

$\tau^- \to \eta'(958)\pi^-\nu_\tau$

- BF($\tau^- \to \eta'(958)\pi^-\nu_\tau$) < 7.2 x 10^{-6} at 90% CL
- Described in my talk at Tau 2008

Babar (Phys. Rev. D **77**, 112002 (2008))

Analysis of $\tau^- \to \omega\pi^-\nu_\tau$ and $\tau^- \to \eta\pi^-\nu_\tau$

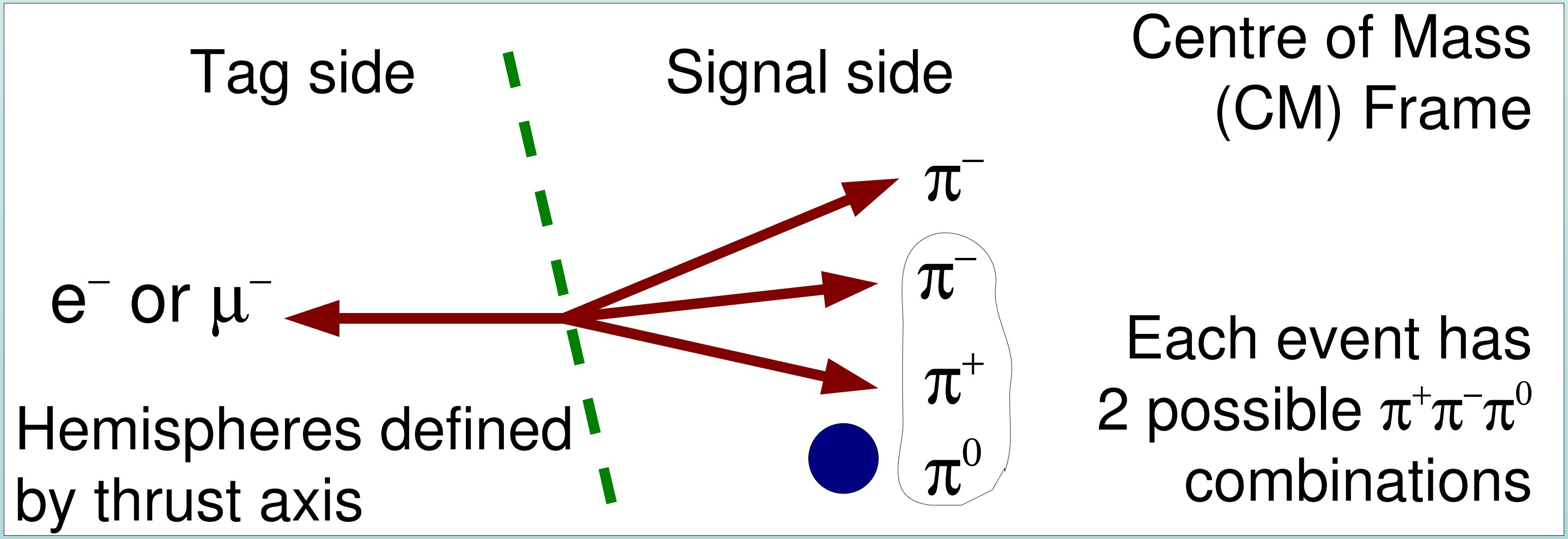
1. Topology selection
2. Event selection for $\tau^- \to \omega\pi^-\nu_\tau$, with $\omega \to \pi^+\pi^-\pi^0$
3. Angular analysis of $\tau^- \to \omega\pi^-\nu_\tau$
4. Event selection for $\tau^- \to \eta\pi^-\nu_\tau$, with $\eta \to \pi^+\pi^-\pi^0$
5. Search for $\tau^- \to \eta\pi^-\nu_\tau$

Monte Carlo samples

- τ-pair production is simulated by KK2F, τ decays by Tauola, continuum $q\bar{q}$ by JETSET and radiation in decays is simulated by Photos
- Dedicated Monte Carlo (MC) samples are made for: $\tau^- \to \eta\pi^-\nu_\tau$, $\tau^- \to \eta K^-\nu_\tau$, $\tau^- \to \eta\pi^-\pi^0\nu_\tau$, $\tau^- \to \eta\pi^- K^0\nu_\tau$ and $\tau^- \to \eta K^-\pi^0\nu_\tau$

Topology Selection

- Analyses require the same topology
  - τ-pairs produced back-to-back in CM frame
  - select events with 1-3 topology of charged particles
- 1-prong side for tagging:
  - track identified as either e^- or μ^-
- 3-prong side has signal mode:
  - $\pi^+\pi^-\pi^0$ from ω or η, plus a bachelor π^-
- Single π^0 candidate required on signal side:
  - reconstructed from 2 photons on signal side



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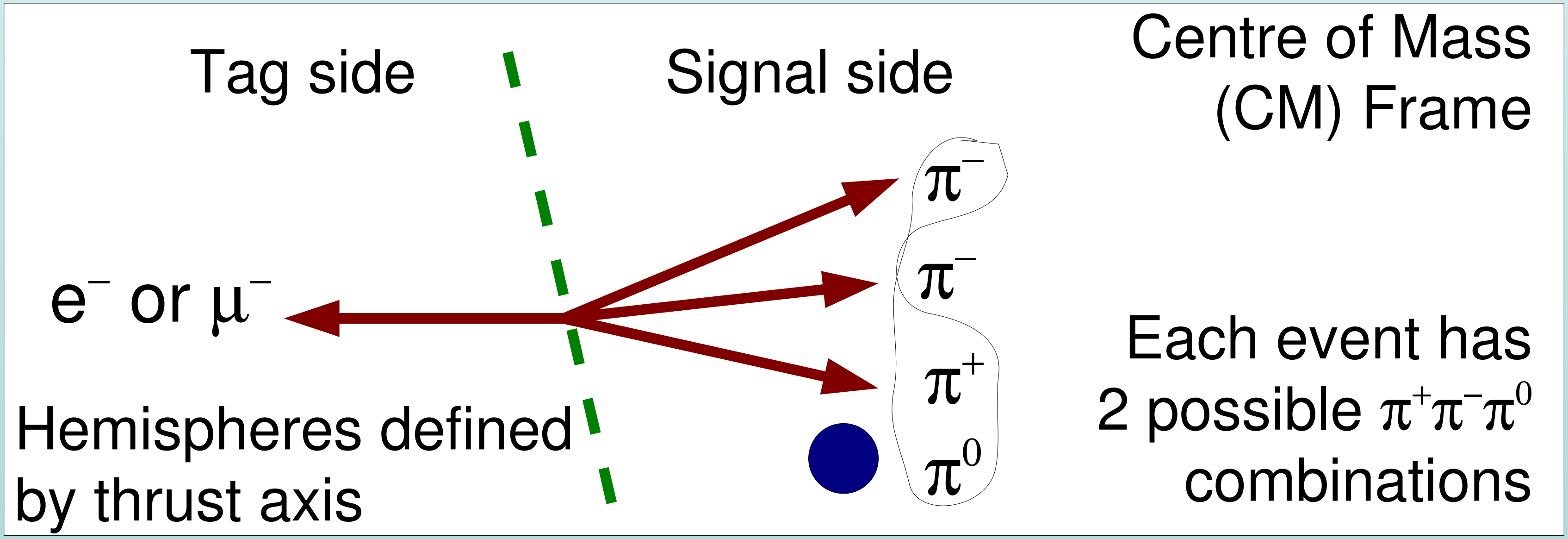
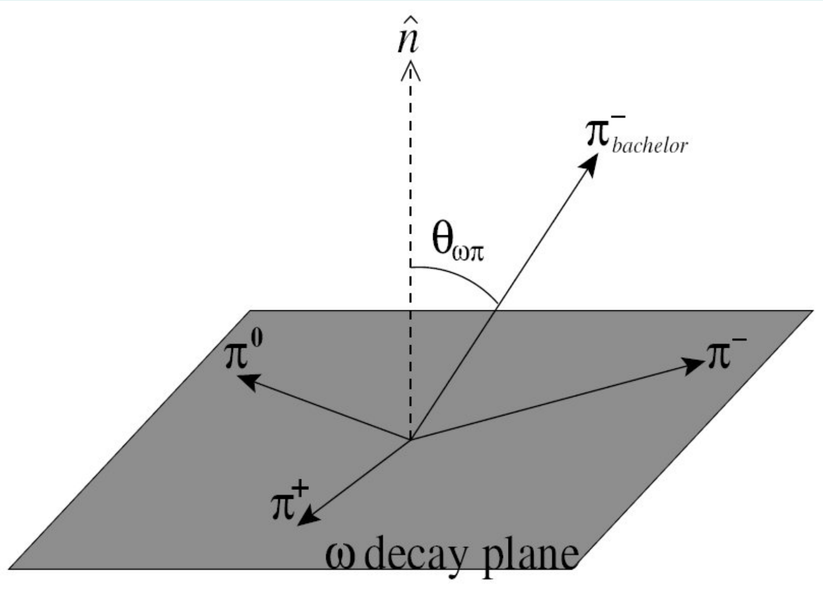


Event Selection for $\tau^- \to \omega\pi^-\nu_\tau$

- Data sample has integrated luminosity of 347 fb^{-1} (320 million τ-pairs)
- Aim to select $\tau^- \to \omega\pi^-\nu_\tau$ events with $\omega \to \pi^+\pi^-\pi^0$
- Signal side has $\omega \to \pi^+\pi^-\pi^0$ plus a bachelor π^-:
  - all 3 tracks are identified as pions
- Total event energy < 11.5 GeV
- Thrust > 0.875 & $\cos\theta_{Thrust} < 0.9$
- $M(\pi^+\pi^-) > 0.09$ GeV/c^2 with electron mass hypothesis
- $M(\pi^+\pi^-\pi^0\pi^-) < M(\tau^-)$

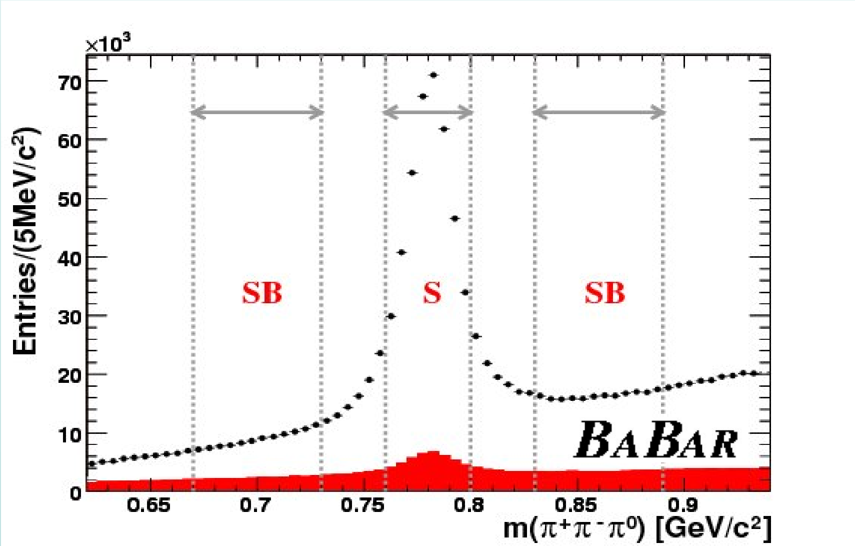


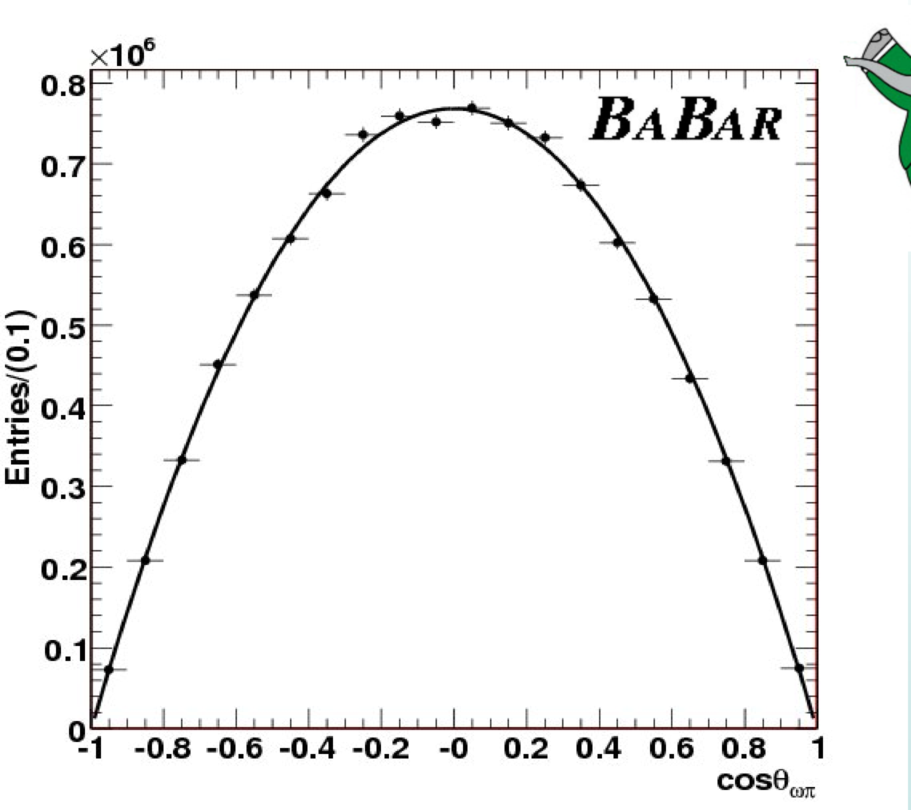
- Angle θ is between:
  - normal to the $\omega \to \pi^+\pi^-\pi^0$ decay plane (in ω rest frame) and direction of bachelor π^-
- Angle θ calculated for each ω candidate
- Expected angular distribution for FCC P-wave is proportional to $1-\cos^2\theta$

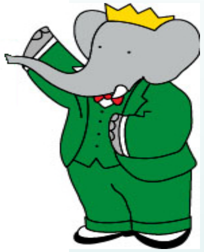
Search for Second-Class Current in $\tau^- \to \omega\pi^-\nu_\tau$

Three types of backgrounds are subtracted from θ distribution:

1. combinatoric background from events in sideband regions of $\pi^+\pi^-\pi^0$ mass spectrum
2. $q\bar{q}$ background
3. background from $\tau^- \to \omega\pi^-\pi^0\nu_\tau$







- The $\cos\theta$ distribution is fitted with a function proportional to $1-\cos^2\theta$
- This is consistent with FCC

Fraction of SCC in this decay mode < 0.69% at 90% CL
BF($\tau^- \to \omega\pi^-\nu_\tau$(SCC)) < 1.3×10^{-4} at 90% CL

Babar (Phys. Rev. Lett. **103**, 041802 (2009))

Event Selection for $\tau^- \to \eta \pi^- \nu_\tau$

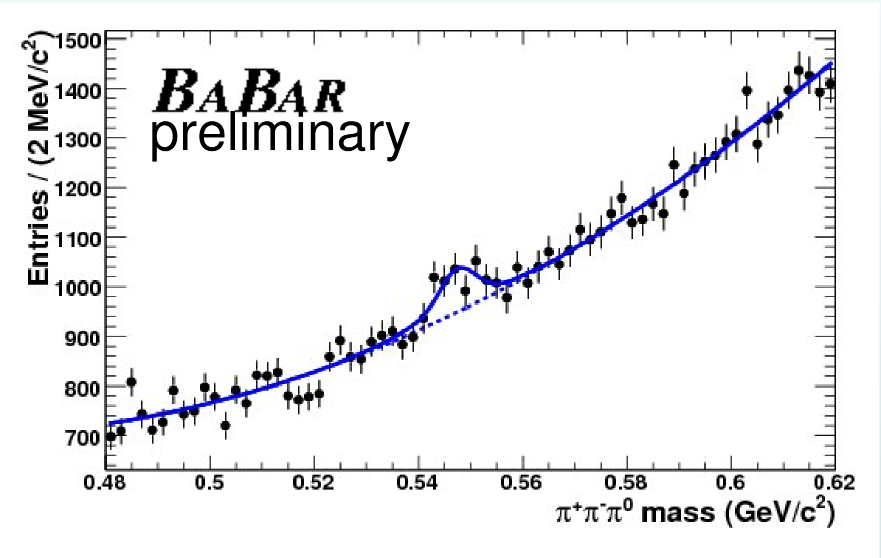
- Data sample has integrated luminosity of 470 fb^{-1} (430 million τ-pairs)
- Aim to select $\tau^- \to \eta \pi^- \nu_\tau$ events with $\eta \to \pi^+ \pi^- \pi^0$
- Signal side has $\eta \to \pi^+ \pi^- \pi^0$ plus a bachelor π^-:
  - assume that tracks used for η are pions
  - bachelor track is identified as π^-
- Total event energy < 80% of initial energy
- Thrust > 0.95 & $\cos \theta_{Thrust} < 0.8$
- No additional signal-side photons with energy > 100 MeV (in laboratory frame)

Method Overview

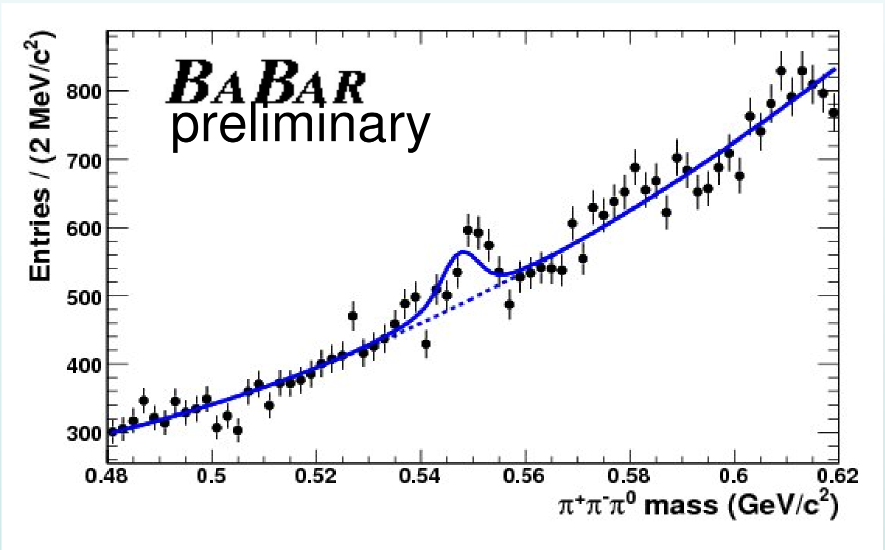
- Fit $\pi^+ \pi^- \pi^{-0}$ mass spectra to determine number of η mesons
- Use MC samples to estimate number of η mesons expected from background modes
- Don't trust simulation of $u\bar{u}+d\bar{d}+s\bar{s}$ (uds) events so uds MC is calibrated with data
- Any excess signal, above what is expected from backgrounds, would be evidence of SCC

Search for $\tau^-\to\eta\pi^-\nu_\tau$

- Select $\tau^-\to\pi^+\pi^-\pi^0\pi^-\nu_\tau$ candidates (bachelor identified as π^-)
- Require $m(\pi^-\pi^+\pi^0\pi^-) < m(\tau)$



e-tag events in data



μ-tag events in data

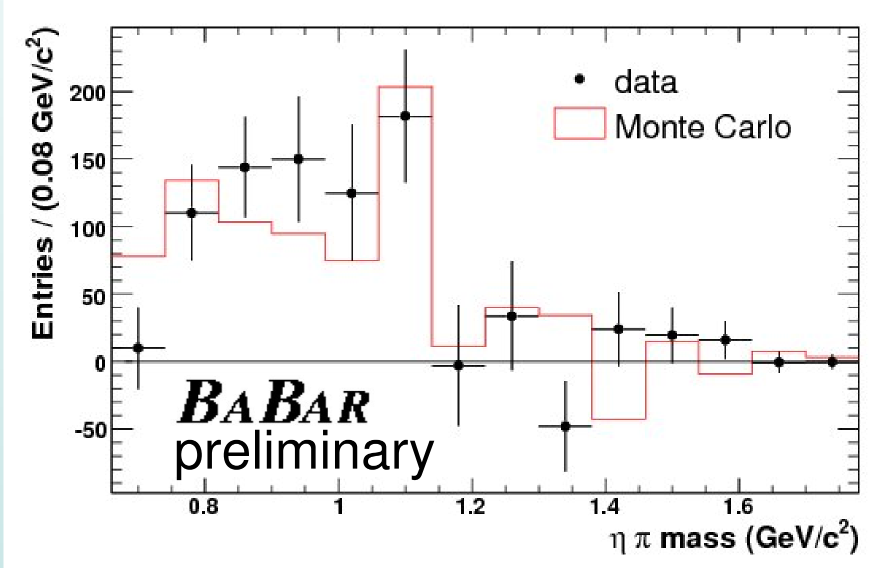
*Note the suppressed zero on the y-axis

- Plot $\pi^+\pi^-\pi^0$ mass spectra
- Binned maximum likelihood fits (range 0.48 - 0.62 GeV/c^2)
  - double Gaussian (η peak) + quadratic polynomial (background)
  - parameters found by fitting high-statistics samples (MC & π-tag data)
- Similar fits to MC samples determine expected backgrounds from non-signal channels

Search for $\tau^- \to \eta\pi^-\nu_\tau$

Background contribution	Expected number of events	
	e-tag	μ-tag
uds	20 ±9 ±14	64 ±13 ±43
$c\bar{c}$	74 ±20 ±19	54 ±15 ±13
$\tau^- \to \eta\pi^-\pi^0\nu_\tau$	215 ±14 ±12	118 ±11 ±7
$\tau^- \to \eta K^0\pi^-\nu_\tau$	100 ±2 ±17	71 ±2 ±12
$\tau^- \to \eta K^-\nu_\tau$	35 ±1 ±2	26 ±1 ±1
$\tau^- \to \eta K^-\pi^0\nu_\tau$	0.6 ±0.2 ±0.1	0.24 ±0.16 ±0.06
Total background	445 ±27 ±31	333 ±23 ±47
Combined e- and μ-tag	$778 \pm 35 \pm 73$	
Measured in Data	Number of events in data	
	489 ±111 ±15	424 ±74 ±13
Combined e- and μ-tag	$913 \pm 134 \pm 20$	
Signal	Measured data−background	
	44 ±111 ±43	91 ±74 ±54
Combined e- and μ-tag	$135 \pm 134 \pm 83$	

Efficiency for signal is $(0.472 \pm 0.006)\%$



The $\eta\pi^-$ mass distributions for data and MC, for e-tag and μ-tag events, obtained from sideband subtraction method

$BF(\tau^- \to \eta\pi^-\nu_\tau) = (3.4 \pm 3.4 \pm 2.1)\times10^{-5}$

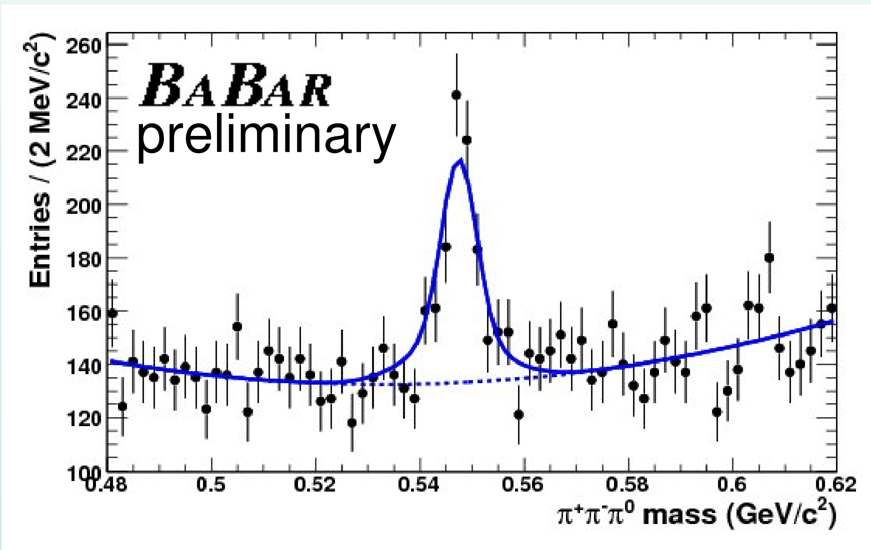
$BF(\tau^- \to \eta\pi^-\nu_\tau) < 9.9\times10^{-5}$ @ 95% CL (preliminary)

CLEO limit: $BF(\tau^- \to \eta\pi^-\nu_\tau) < 1.4\times10^{-4}$ @ 95% CL

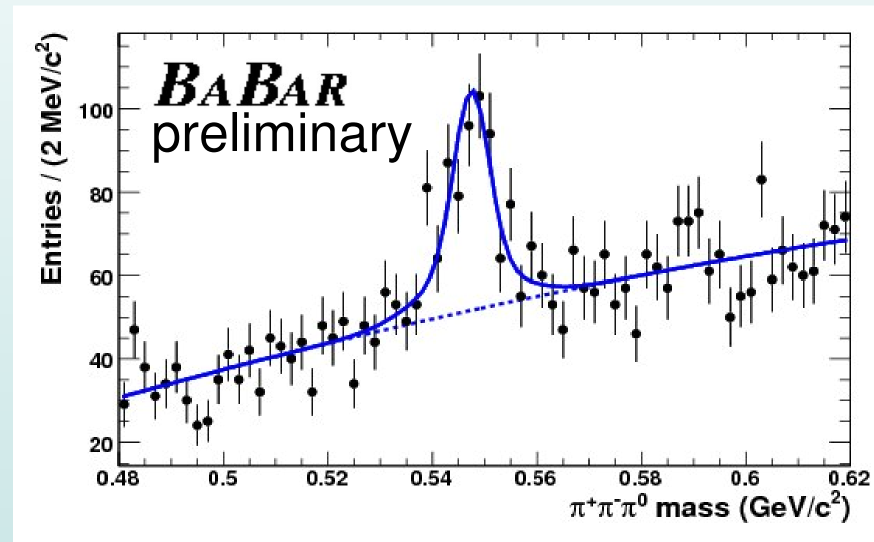
Limit is driven by background uncertainty which could not be driven down by increased statistics

Measurement of $\tau^- \to \eta K^- \nu_\tau$ branching fraction

- Select $\tau^- \to \pi^+\pi^-\pi^0 K^- \nu_\tau$ candidates (bachelor identified as K^-)
- Require $m(\pi^-\pi^+\pi^0 K^-) < m(\tau)$



(a) e-tag events in data



(b) μ-tag events in data

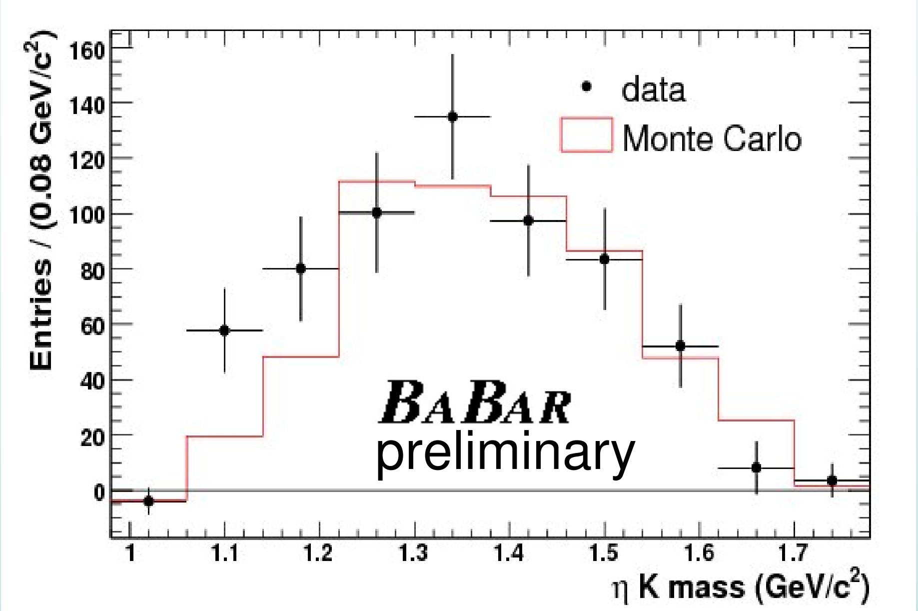
*Note the suppressed zero on the y-axis

- Plot $\pi^+\pi^-\pi^0$ mass spectra
- Fits done in the same way as for $\tau^- \to \eta\pi^-\nu_\tau$ analysis
- Similar fits to MC samples determine expected backgrounds from non-signal channels

Branching Fraction for $\tau^- \rightarrow \eta K^- \nu_\tau$

Background contribution	Expected number of events	
	e-tag	μ-tag
uds	4.5 ±2.7 ±2.3	8.9 ±4.7 ±4.5
$c\bar{c}$	13.8 ±8.3 ±3.5	0.7 ±5.5 ±0.2
$\tau^- \rightarrow \eta\pi^-\pi^0\nu_\tau$	13.3 ±3.7 ±0.7	2.9 ±2.0 ±0.2
$\tau^- \rightarrow \eta K^-\pi^0\nu_\tau$	8.4 ±0.5 ±2.1	5.0 ±0.4 ±1.3
$\tau^- \rightarrow \eta K^0\pi^-\nu_\tau$	3.9 ±0.5 ±0.7	2.3 ±0.4 ±0.4
Total background	44 ±10 ±5	20 ±8 ±5
Combined e- and μ-tag	$64 \pm 12 \pm 8$	
Measured in Data	Number of events in data	
	463 ±44 ±12	291 ±30 ±10
Combined e- and μ-tag	$754 \pm 53 \pm 16$	
Signal	Measured data−background	
	419 ±44 ±16	271 ±30 ±13
Combined e- and μ-tag	$690 \pm 53 \pm 22$	

Efficiency for signal is (0.578 ± 0.004)%



The ηK^- mass distributions for data and MC, for e-tag and μ-tag events, obtained from sideband subtraction method.
MC includes the signal mode, normalised with branching fraction reported here.

BF($\tau^- \rightarrow \eta K^- \nu_\tau$) = (1.42 ± 0.11 ± 0.07)x10^{-4} (preliminary)

Consistent with Belle result [Phys. Lett. B 672, 209 (2009)]

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Summary

BaBar

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BF($\tau^- \to \omega\pi^-\nu_\tau$(SCC)) < 1.3 x 10^{-4} @ 90% CL
Fraction of decays that proceed through SCC < 0.69% @ 90% CL

Order of magnitude lower than previous limit
of < 5.4% @ 90% CL

Phys. Rev. Lett. **103**, 041802 (2009)

BF($\tau^- \to \eta\pi^-\nu_\tau$) < 9.9 x 10^{-5} @ 95% CL

Improvement on previous limit
of < 1.4 x 10^{-4} @ 95% CL

Publication coming soon

BF($\tau^- \to \eta'(958)\pi^-\nu_\tau$) < 7.2 x 10^{-6} at 90% CL

Order of magnitude lower than previous limit
of < 7.4x10^{-5} @ 90% CL

Phys. Rev. D **77**, 112002 (2008)

BF($\tau^- \to \eta K^-\nu_\tau$) = 1.42 ± 0.11(stat) ± 0.07(sys) x 10^{-4}

Consistent with Belle: (1.58 ± 0.05 ± 0.08) x 10^{-4}
(used $\eta \to \gamma\gamma$ and $\eta \to \pi^+\pi^-\pi^0$ modes)
Belle and Babar give average of: (1.52 ± 0.08) x 10^{-4}

Publication coming soon