Recent BaBar τ Physics Results

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Outline

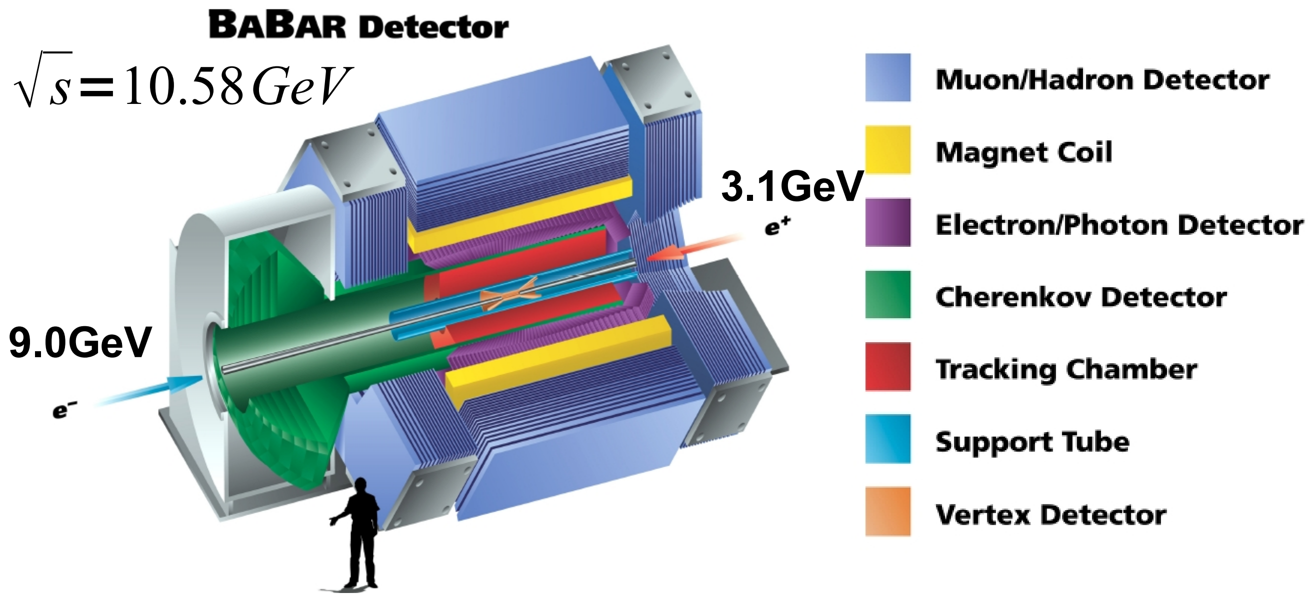
In this talk: Most recent τ-physics results from BaBar:

1. CP violation in τ decays
2. Measurements of $\tau^- \rightarrow \pi^- \eta \nu$ and $\tau^- \rightarrow K^- \eta \nu$
3. Study of 1-prong τ decays:
   Test of lepton universality & determination of the CKM matrix element $|V_{us}|$
4. Lepton flavor violation

τ dataset at BaBar:

- $\sigma_{\tau\tau}$ = 0.9 nb
- $\mathcal{L}$ = 531 fb^{-1}

→ almost 500 million ττ pairs



Search for CP Violation in $\tau^- \to K_S^0 \pi^- \nu_\tau$ decays (I)

Standard Model prediction: Transition amplitudes are the same

$$T(\tau^- \to \pi^- \overline{K}^0 \nu_\tau) = T(\tau^+ \to \pi^+ K^0 \overline{\nu}_\tau)$$

A decay rate asymmetry due to CP violation in the kaon sector is predicted:

$$|K_S^0\rangle = p|K^0\rangle + q|\overline{K}^0\rangle$$

$$|K_L^0\rangle = p|K^0\rangle - q|\overline{K}^0\rangle$$

Prediction by Bigi and Sanda
Phys. Lett. B 625, 47 (2005)

$$A_Q = \frac{\Gamma(\tau^+ \to \pi^+ K_S^0 \overline{\nu}_\tau) - \Gamma(\tau^- \to \pi^- K_S^0 \nu_\tau)}{\Gamma(\tau^+ \to \pi^+ K_S^0 \overline{\nu}_\tau) + \Gamma(\tau^- \to \pi^- K_S^0 \nu_\tau)} = |p|^2 - |q|^2 = (0.33 \pm 0.01)\%$$

A deviation of the measured A_Q from the predicted value would be a hint of New Physics, e.g. an additional CP violating phase could arise from an exotic charged Higgs boson.

Kühn and Mirkes,
Phys. Lett. B 398, 407 (1997)

Search for CP Violation in $\tau^- \to K_S^0 \pi^- \nu_\tau$ decays (II)

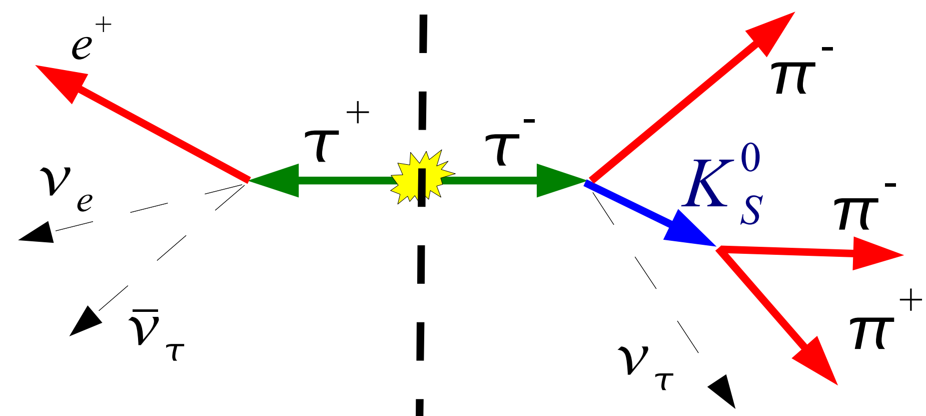
Reconstruct:

$$\tau^- \to h^- K_S^0 (\geq 0\pi^0)\nu_\tau$$

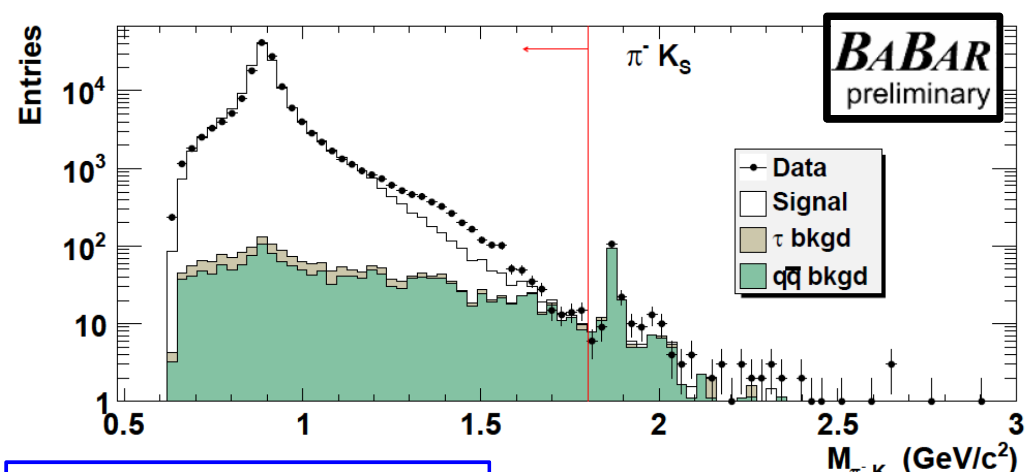
π^0's are expected not to change asymmetry

- Electron tag
- Displaced vertex of two tracks ($\to K_S^0$)
- $M_{rec} < 1.8$ GeV

Selected event topology



Invariant mass of the hadronic final state



Presented at TAU2010

Modes considered as signal:

Source	Fractions (%)
$\pi^- \; K_S^0 \; (\geq 0\pi^0)\nu_\tau$	66.5 ± 0.2
$K^- \; K_S^0 \; (\geq 0\pi^0) \; \nu_\tau$	19.14 ± 0.07
$\pi^- \; K^0 \; \overline{K}^0 \; \nu_\tau$	12.82 ± 0.05

Asymmetry prediction for this composition of the sample:
$A_Q = (0.17 \pm 0.01)\%$

Search for CP Violation in $\tau^- \rightarrow K_S^0 \pi^- \nu_\tau$ decays (III)

Systematic uncertainties:

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

Control sample
$\tau^- \rightarrow \pi^- \pi^- \pi^+ (\geq 0\pi^0) \nu_\tau$

Correction due to different nuclear reaction cross section of K^0 and $\overline{K}^0$ with detector material
→ Full impact is still under study

Integrated luminosity: 476 fb^{-1}

Presented at TAU2010

$$A_Q = (-0.10 \pm 0.21(\mathrm{stat}) \pm 0.22(\mathrm{syst}))\%$$

BABAR preliminary

- consistent with prediction for selected event sample: $A_Q = (0.17 \pm 0.01)\%$

- Future prospects: muon tagged sample will be included in analysis

Measurement of $\tau^- \rightarrow K^- \eta \nu_\tau$ and $\tau^- \rightarrow \pi^- \eta \nu_\tau$ (I)

Motivation:

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

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

FCC and SCC have opposite G-parity: $G = Ce^{i\pi I_2}$

G-partiy:
combination of charge conjugation and isospin rotation

• SCC are associated with a decay constant proportional to mass difference between up and down quarks, vanishing in limit of perfect isospin symmetry

No evidence has been found for SCC

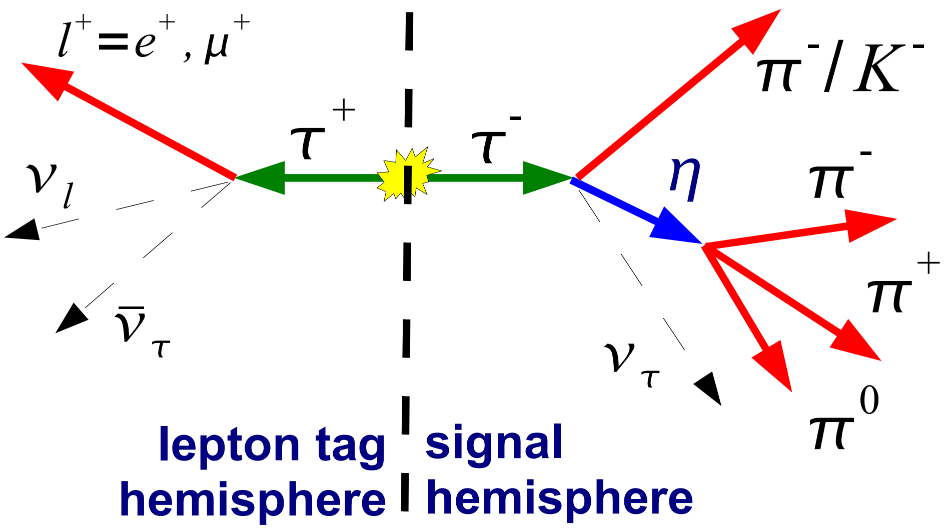
→ Search for decay $\tau^- \rightarrow \pi^- \eta \nu$ which must be produced through SCC

→ Also measure FCC decay $\tau^- \rightarrow K^- \eta \nu$

published in
Phys.Rev.D83:032002, 2011

Measurement of $\tau^- \to K^- \eta \nu_\tau$ and $\tau^- \to \pi^- \eta \nu_\tau$ (II)

Selected event topology:

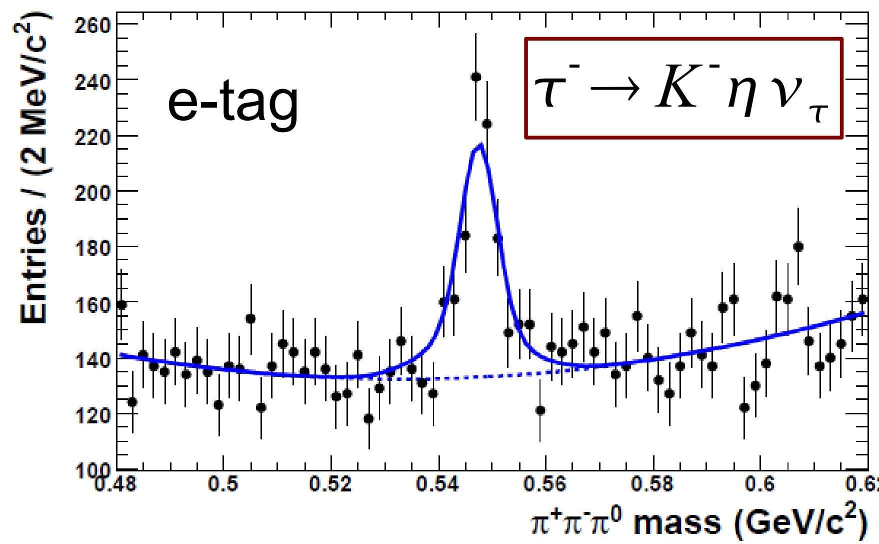


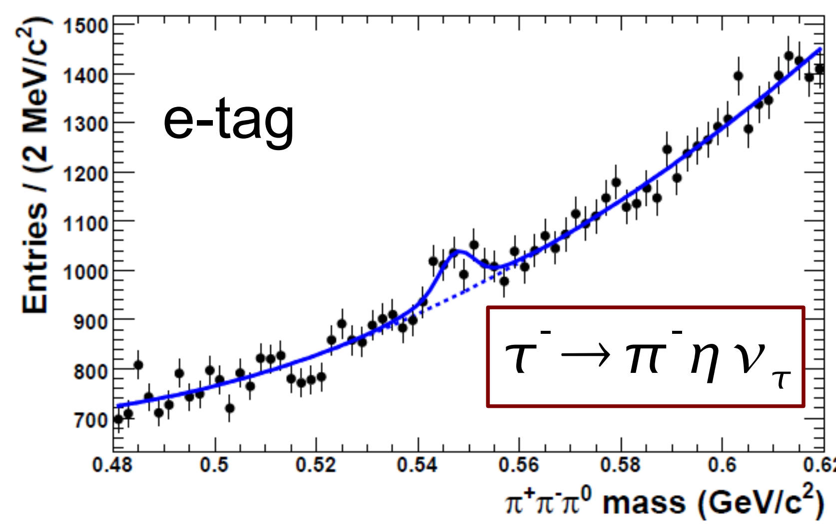
- Lepton tag (electron or muon)
- η decay mode: $\eta \to \pi^+\pi^-\pi^0$
- For $\tau^- \to K^-\eta\nu$: Kaon ID for bachelor charged particle

Method of measurement:

- Fit to $\pi^+\pi^-\pi^0$ mass spectra to determine number of η mesons
- Similar fits to MC samples determine expected background from non-signal channels

Invariant $\pi^+\pi^-\pi^0$ mass



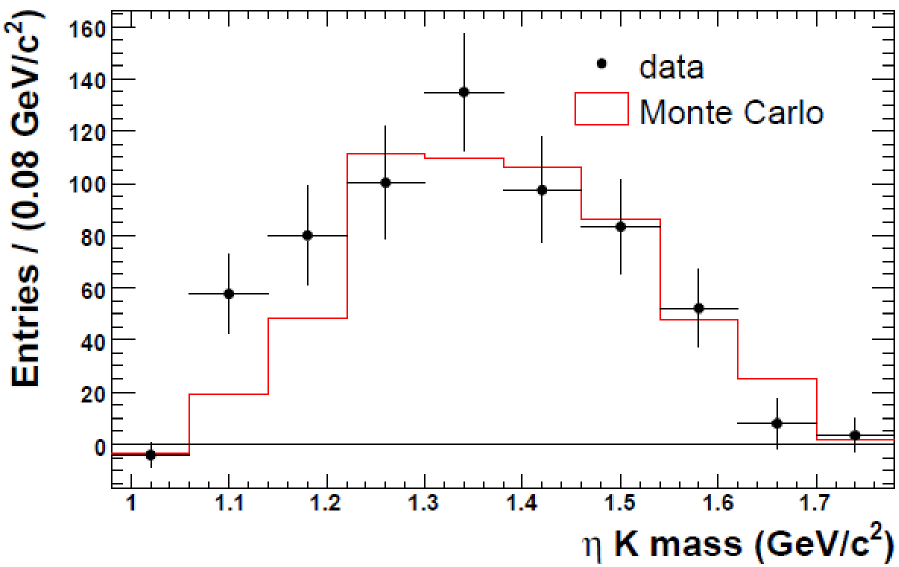


similar distributions also for μ-tag

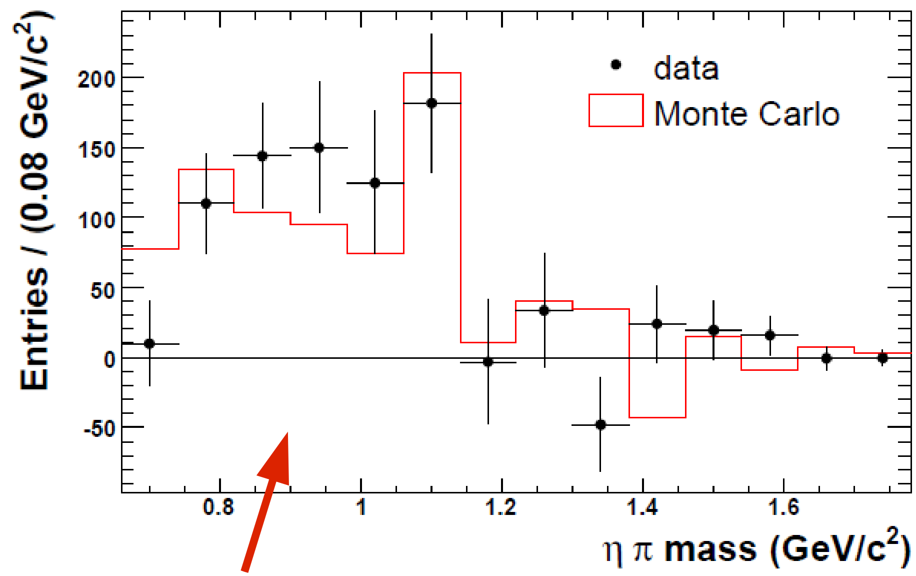
Phys.Rev.D83:032002, 2011

Measurement of $\tau^- \to K^- \eta \nu_\tau$ and $\tau^- \to \pi^- \eta \nu_\tau$ (III)

Invariant ηK mass



Invariant $\eta\pi^-$ mass



MC sample does not contain $\tau \to \pi\, \eta\, \nu$ events.

Phys.Rev.D83:032002, 2011

Integrated luminosity: 470 fb^{-1}

$$\mathcal{B}(\tau^- \to K^- \eta \nu_\tau) = (1.42 \pm 0.11(\mathrm{stat}) \pm 0.07(\mathrm{syst})) \times 10^{-4}$$

- compatible with current world average: BF($\tau^- \to K^- \eta\, \nu$) = (1.61 ± 0.10) x 10^{-4}

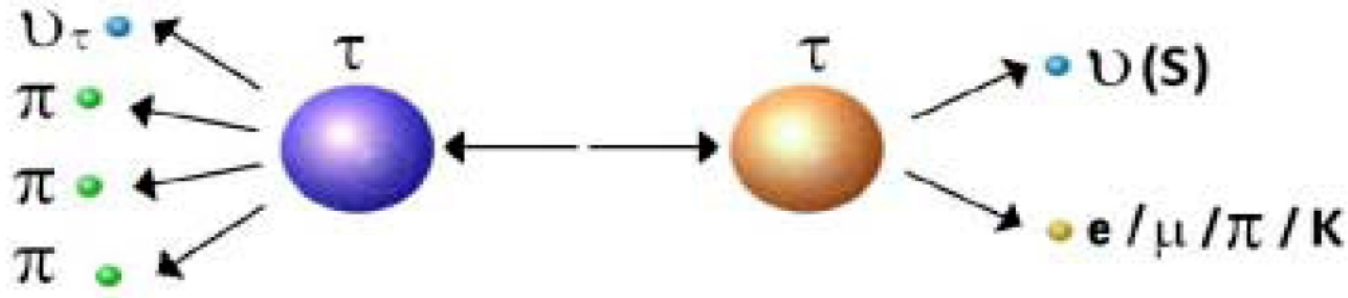
$$\mathcal{B}(\tau^- \to \pi^- \eta \nu_\tau) < 9.9 \times 10^{-5} \text{ at } 95\%\mathrm{CL}$$

- best upper limit so far: BF($\tau^- \to \pi^- \eta\, \nu$) < 1.4 x 10^{-4} @95% CL from CLEO

Measurement of 1-prong τ decays (I)

Select $\tau\tau$ events with
- one τ decaying into 3 charged pions and neutrino (hadronic tag)
- the other τ into the signal decay

3-prong hadronic Tag



1-prong signal

Measure ratios:

$$\frac{BF(\tau^- \rightarrow \mu^- \nu_\tau \nu_\mu)}{BF(\tau^- \rightarrow e^- \nu_\tau \bar{\nu}_e)} \quad \frac{BF(\tau^- \rightarrow \pi^- \nu_\tau)}{BF(\tau^- \rightarrow e^- \nu_\tau \bar{\nu}_e)} \quad \frac{BF(\tau^- \rightarrow K^- \nu_\tau)}{BF(\tau^- \rightarrow e^- \nu_\tau \bar{\nu}_e)} \quad \frac{BF(\tau^- \rightarrow K^- \nu_\tau)}{BF(\tau^- \rightarrow \pi^- \nu_\tau)}$$

- Dominant systematic effects:
  - → particle identification
  - → background suppression
  - → detector response (drift chamber, EMC)
- Some systematic effects partially cancel (luminosity, efficiency)

published in
Phys. Rev. Lett 105, 051602
(2010)

Measurement of 1-prong τ decays (II)

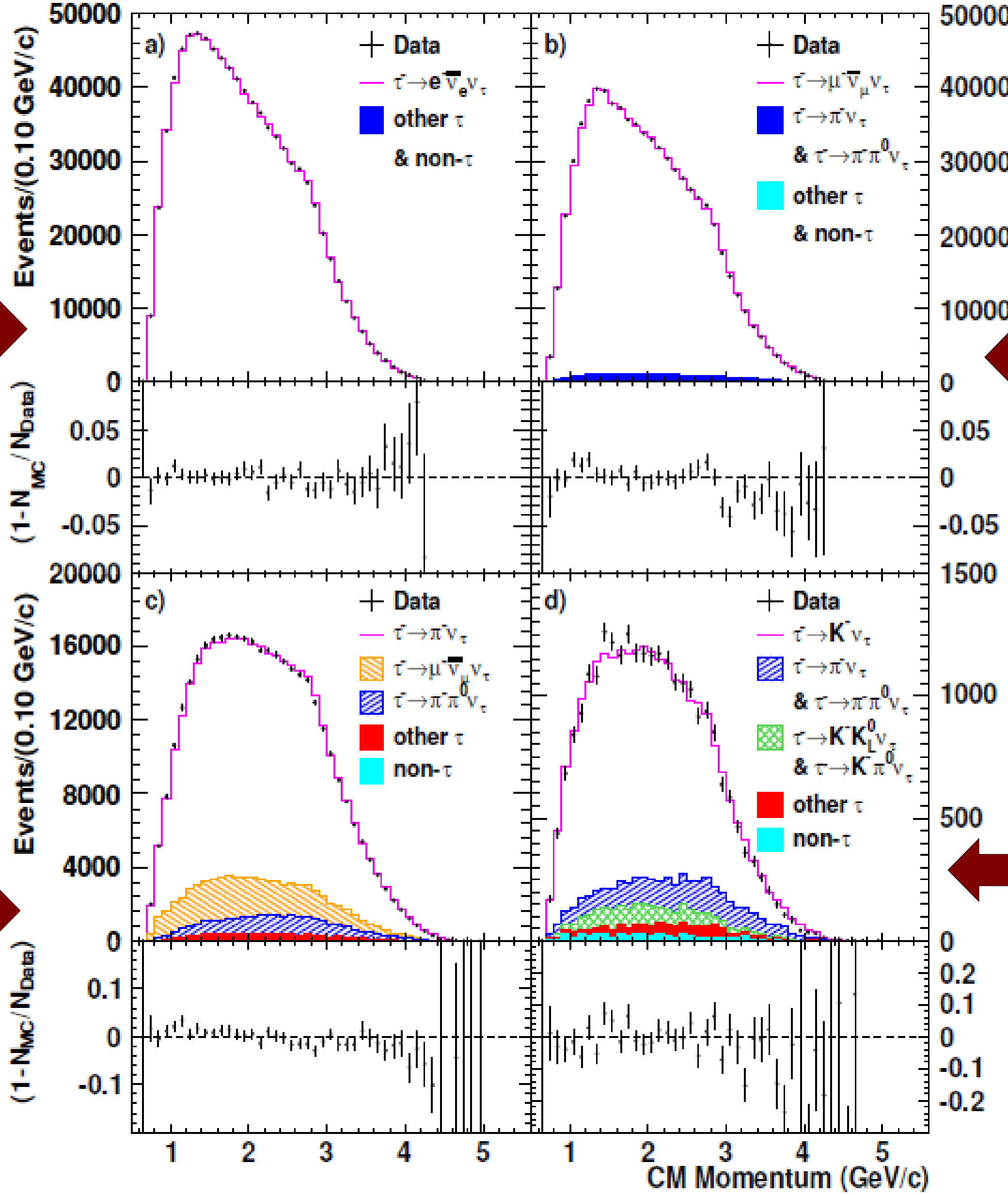
Charged particle momentum in center-of-mass frame

$\tau^- \rightarrow e^- \nu_\tau \overline{\nu}_e$

- Purity: 99.7%

$\tau^- \rightarrow \mu^- \nu_\tau \overline{\nu}_\mu$

- Purity: 97.3%



$\tau^- \rightarrow \pi^- \nu_\tau$

- Purity: 78.7%
- Main background contributions:

$\tau^- \rightarrow \mu^- \nu_\tau \overline{\nu}_\mu$

$\tau^- \rightarrow \pi^- \pi^0 \nu_\tau$

$\tau^- \rightarrow K^- \nu_\tau$

- Purity: 76.6%
- Main background contributions:

$\tau^- \rightarrow \pi^- \nu_\tau$

$\tau^- \rightarrow \pi^- \pi^0 \nu_\tau$

$\tau^- \rightarrow K^- K_L^0 \nu_\tau$

$\tau^- \rightarrow K^- \pi^0 \nu_\tau$

Integrated luminosity:
467 fb^{-1}

Phys. Rev. Lett 105, 051602 (2010)

Measurement of 1-prong τ decays (III):
Lepton universality

Test of weak coupling universality for leptons: $g = g_e = g_\mu = g_\tau$

$$\left(\frac{g_\mu}{g_e}\right)_\tau = \sqrt{\frac{\mathcal{B}(\tau^- \to \mu^- \nu_\tau \overline{\nu}_\mu)}{\mathcal{B}(\tau^- \to e^- \nu_\tau \overline{\nu}_e)} \frac{f(m_e^2/m_\tau^2)}{f(m_\mu^2/m_\tau^2)}} = 1.0036 \pm 0.0020$$

$$f(x) = 1 - 8x + 8x^3 - x^4 - 12x^2 \log x$$

- consistent with SM expectation

$$\left(\frac{g_\tau}{g_\mu}\right)_h = \sqrt{\frac{\mathcal{B}(\tau^- \to h^- \nu_\tau)}{\mathcal{B}(h^- \to \mu^- \overline{\nu}_\mu)} \frac{2 m_h m_\mu^2 \tau_h}{(1+\delta_h) m_\tau^3 \tau_\tau} \left(\frac{1 - m_\mu^2/m_h^2}{1 - m_h^2/m_\tau^2}\right)^2} = 0.9850 \pm 0.0054$$

Radiative corrections:
$\delta_K = (0.90 \pm 0.22)\%$
$\delta_\pi = (0.16 \pm 0.14)\%$
Phys. Rev. Lett. 71,3629 (1993)
Nucl.Phys.B 438,17(1995)
Phys.Lett.B 334(1994)199

- 2.8σ below SM expectation
- within 2σ of world average

Phys. Rev. Lett 105, 051602 (2010)

Measurement of 1-prong τ decays (IV): $|V_{us}|$ from $B(\tau^- \to K^- \nu_\tau)$ and $\frac{B(\tau^- \to K^- \nu_\tau)}{B(\tau^- \to \pi^- \nu_\tau)}$

$$\mathcal{B}(\tau^- \to K^- \nu_\tau) = (0.692 \pm 0.006(\text{stat}) \pm 0.010(\text{syst})) \times 10^{-2}$$

$$\frac{\mathcal{B}(\tau^- \to K^- \nu_\tau)}{\mathcal{B}(\tau^- \to \pi^- \nu_\tau)} = (6.531 \pm 0.056(\text{stat}) \pm 0.093(\text{syst})) \times 10^{-2}$$

published in Phys. Rev. Lett 105, 051602 (2010)

$$\frac{\mathcal{B}(\tau^- \to K^- \nu_\tau)}{\mathcal{B}(\tau^- \to \pi^- \nu_\tau)} = \frac{|V_{us}|^2}{|V_{ud}|^2} \frac{f_K^2}{f_\pi^2} \frac{(1 - m_K^2/m_\tau^2)^2}{(1 - m_\pi^2/m_\tau^2)^2} (1 - \delta_{LD})$$

$|V_{us}| = 0.2255 \pm 0.0024$

- consistent with $|V_{us}| = 0.2255 \pm 0.0010$ predicted from the CKM unitarity condition $|V_{ud}|^2+|V_{us}|^2+|V_{ub}|^2=1$

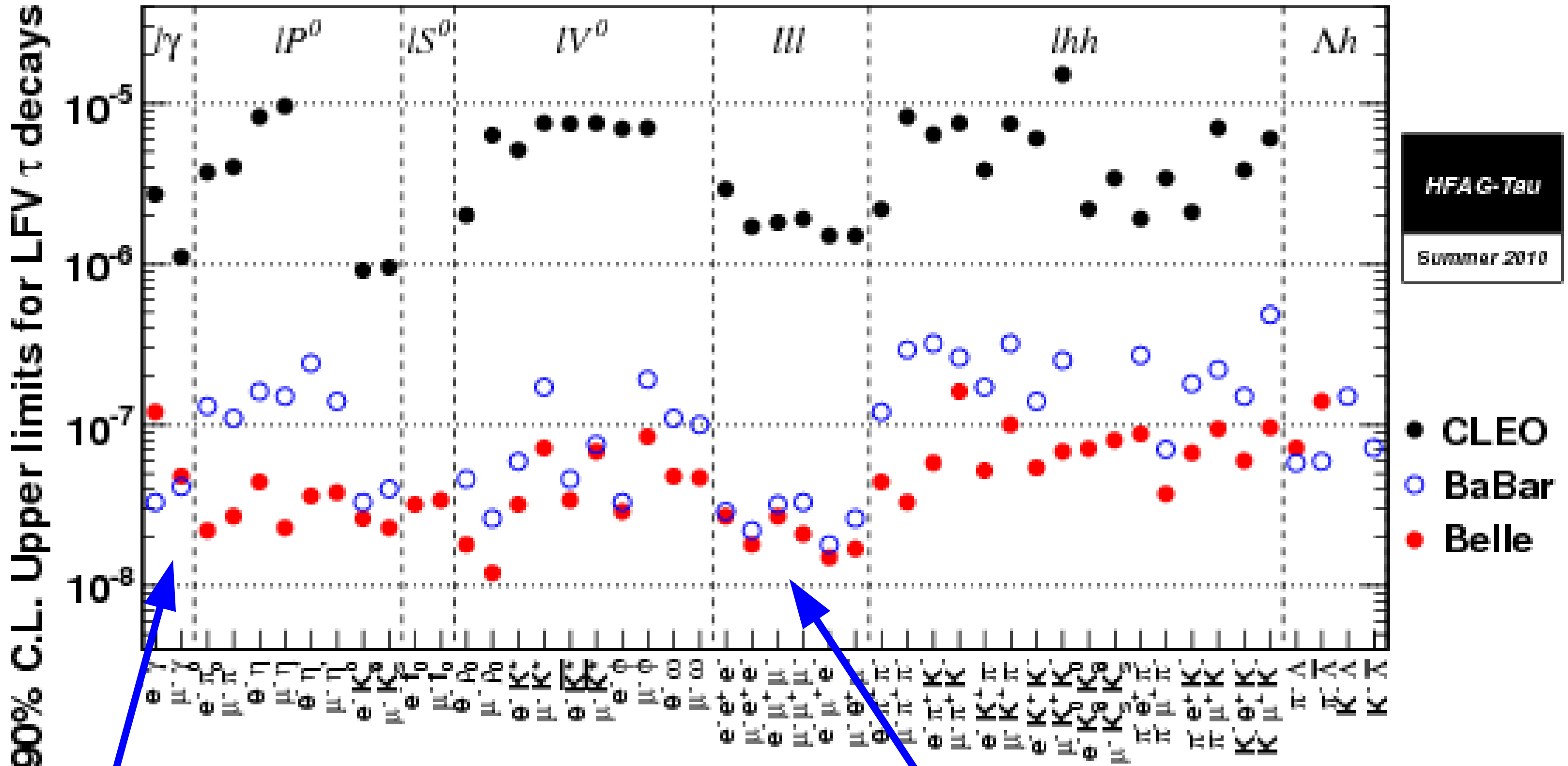
$$\mathcal{B}(\tau^- \to K^- \nu_\tau) = \frac{G_F^2 f_K^2 |V_{us}|^2 m_\tau^3 \tau_\tau}{16\pi\hbar} \left(1 - \frac{m_K^2}{m_\tau^2}\right)^2 S_{EW}$$

$|V_{us}| = 0.2193 \pm 0.0032$

- within 2σ of unitarity, and consistent with $|V_{us}|$ from K/π ratio

- Long-distance ew. correction: $\delta_{LD} = (0.03 \pm 0.44)\%$ (arXiv:0811.1429)
- $|V_{ud}| = 0.97425 \pm 0.00022$ (Towner, Hardy 2009)
- Ratio of the kaon and pion decay constants: $f_K / f_\pi = 1.189 \pm 0.007$ (E. Follana et al. PRL 100)
- Koan decay constant: $f_K = 157 \pm 2$ MeV (E. Follana et al. PRL 100)
- Short-dist. ew. radiative correction: $S_{EW} = 1.0201 \pm 0.0003$ (J.Erler, Rev. Mex. Fis 50, (2004))

Lepton Flavor Violation



BF($\tau \to e\gamma$) < 3.3 x 10^{-8} @90% CL
BF($\tau \to \mu\gamma$) < 4.4 x 10^{-8} @90% CL

- entire dataset of (963 ± 7)x10^6 τ decays collected by BaBar

Phys.Rev.Lett.104:021802, 2010.

BF's of $\tau \to lll$
(six decay modes considered)

- branching fractions are set in the range (1.8-3.3) X 10^{-8} @90% CL
- luminosity: 468 fb^{-1}

Phys.Rev.D81:111101, 2010.

Summary

- The BaBar experiment has collected a large τ-pair data sample
- Many different physics topics are studied in τ decays
- The most recent τ physics results from BaBar were shown in this talk
    1. CP violation in τ decays
    2. Searches for second class currents
    3. Test of lepton universality and determination of $|V_{us}|$
    4. Lepton flavor violation

- Future prospects:
    - → available data sample not yet fully exploited
    - → other analyses are ongoing