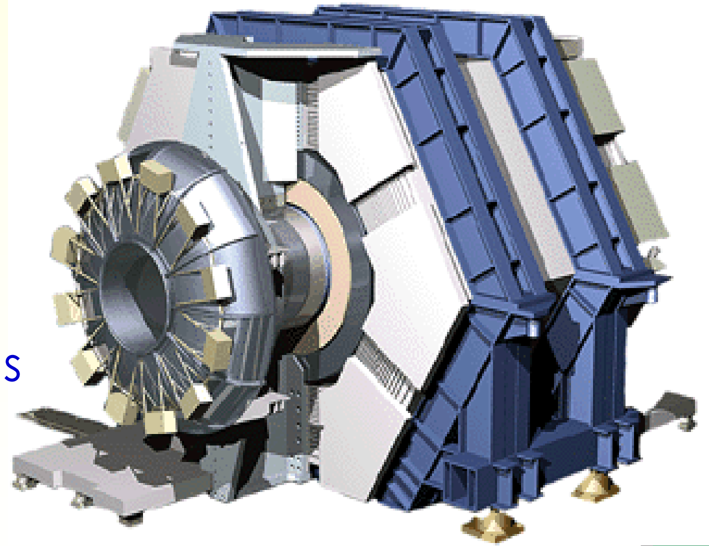
Review of Standard Tau Decays from B Factories

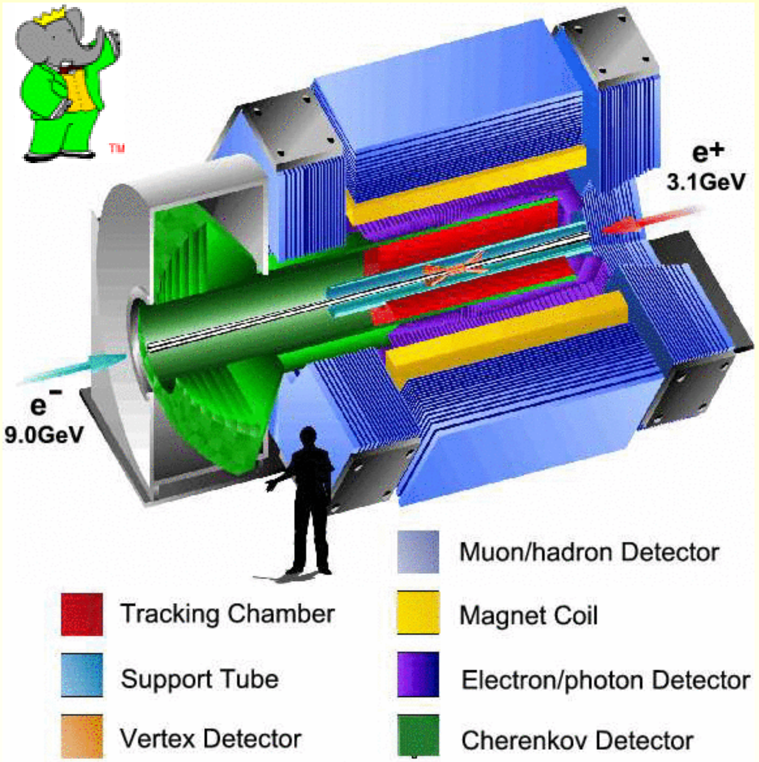
Fabrizio Salvatore, RHUL

- Tau mass measurement
- Tau decays to strange particles:
  - Measurement of V_{us} using $\tau \rightarrow s$ decays
  - $\tau \rightarrow KK\pi\nu_\tau$, $KKK\nu_\tau$ branching fractions
  - ϕ resonance in $KK\pi$ and KKK final states
- Tau decays in modes including η mesons
- Rare tau decays
  - $\tau \rightarrow 5\pi 2\pi^0 \nu_\tau$



PHIPSI08 International workshop on e^+e^- collisions from Phi to Psi

B Factories Detectors

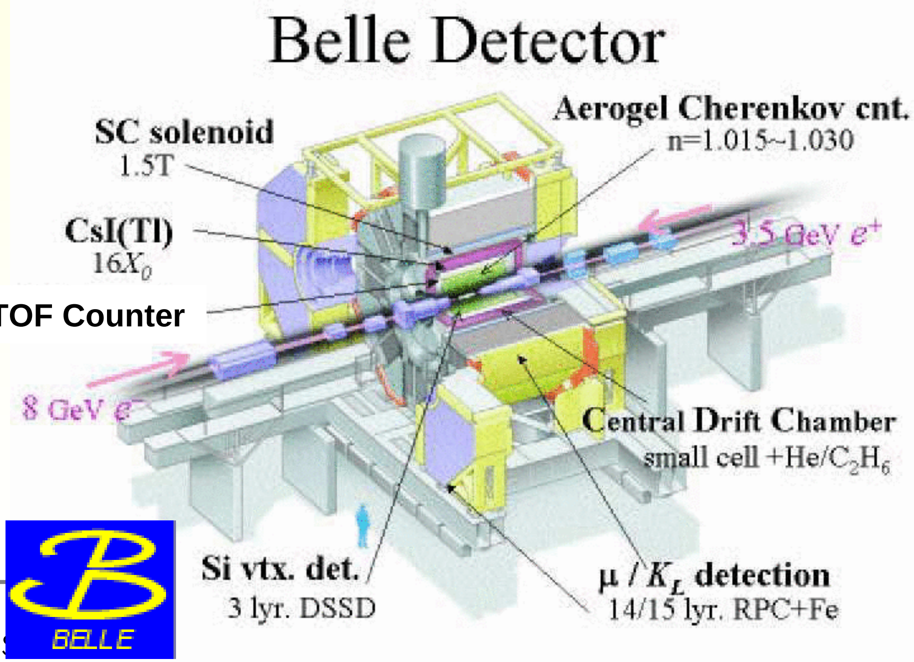


Asymmetric energy colliders:

$\sqrt{s} = 10.58\ \text{GeV at}\ \Upsilon(4s)\ \text{peak}$

$\sigma(B\overline{B}) \approx 1.1 nb \approx \sigma(\tau^+\tau^-) \approx 0.9 nb$

More than just B Factories !

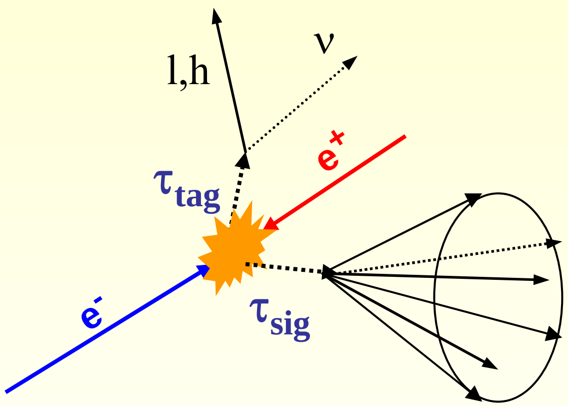


$\int Ldt \sim 530\ fb^{-1}$ BABAR

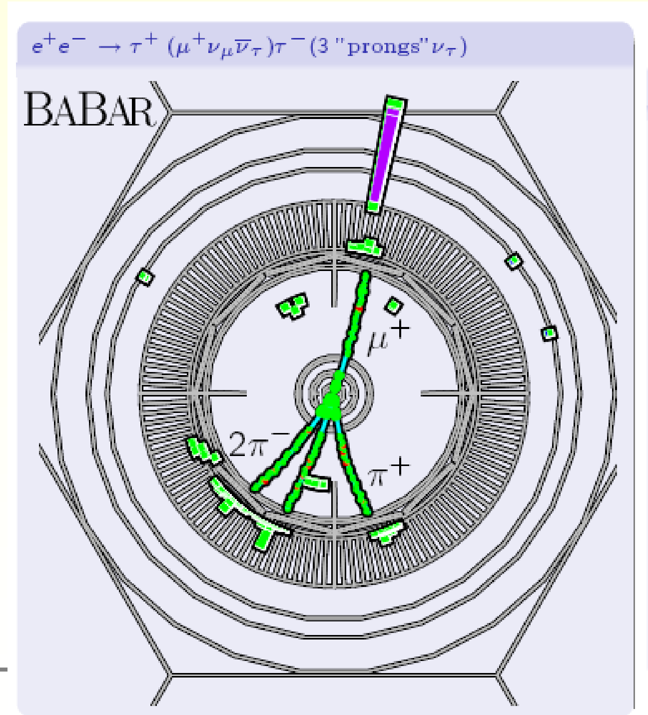
$\int Ldt \sim 800\ fb^{-1}$ Belle

Tau pair events @ B Factory

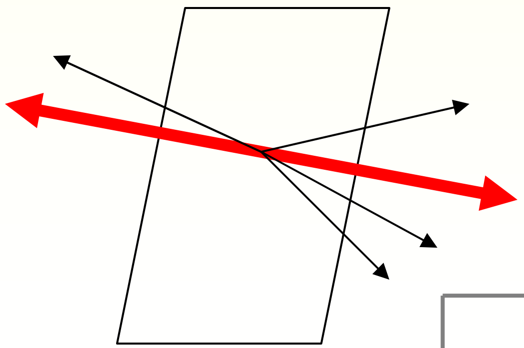
- Tau products are well collimated in the CM system



- Select events with one leptonic (tag) and one hadronic tau decay



- Divide event into two hemispheres (thrust axis)



Tau mass and test of CPT

- In SM, high precision measurements of mass, lifetime and BF of τ can be used to test lepton universality
  - Present limit on m_τ dominated by BES (PRD 53 (1996) 20)
    - Accuracy ~ 0.3 MeV;
      also obtained by KEDR collaboration (arXiv:0611.046[hep-ex])
    - Similar accuracy reached by Belle experiment
    - Significant improvement expected by combining these high precision measurements
  - Analysis of τ lepton decays allows to measure separately m_{τ^+} and m_{τ^-} and test CPT theorem
    - Similar test from OPAL:
      $(m_{\tau^+} - m_{\tau^-})/m_{avg} < 3.0\times10^{-3}$ @ 90% CL (PL B492 (2000) 23)
    - Many systematic errors cancel in the difference
    - Cannot be measured by threshold experiments
    - Significant improvement with current τ statistics at B Factories

Tau mass results

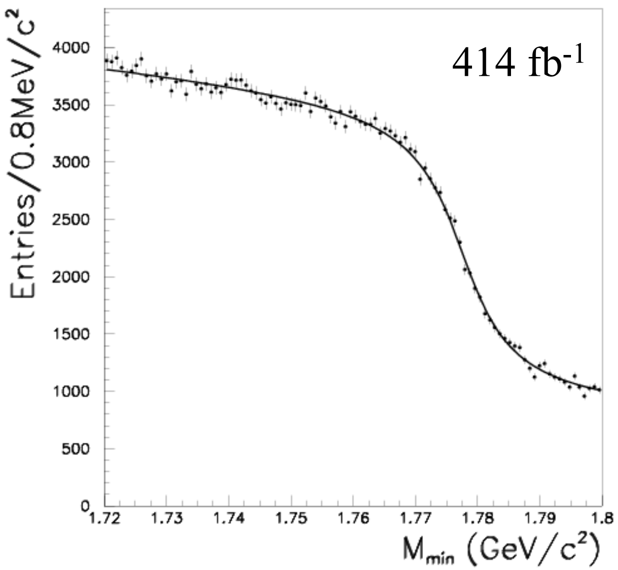
- Analysis uses pseudo-mass technique:

$$M_{\min} = \sqrt{M_X^2 + 2(E_{beam} - E_X)(E_X - P_X)}$$

- $M_{min} \leq m_\tau$; in absence of ISR and FSR, M_{min} has an edge at m_t
- Use $\tau^- \to l^- \nu_l \nu_\tau;\ \tau^+ \to \pi^+\pi^-\pi^+(\pi^0)\nu_\tau$ decays

  and fit M_{min}

  $F(X) = (p_3+p_4X)\mathrm{atan}((X-p_1)/p_2) + p_5 + p_6X$



$m_\tau = 1776.61 \pm 0.13 \pm 0.35$ MeV

Dominant systematic: beam and tracking uncertainties

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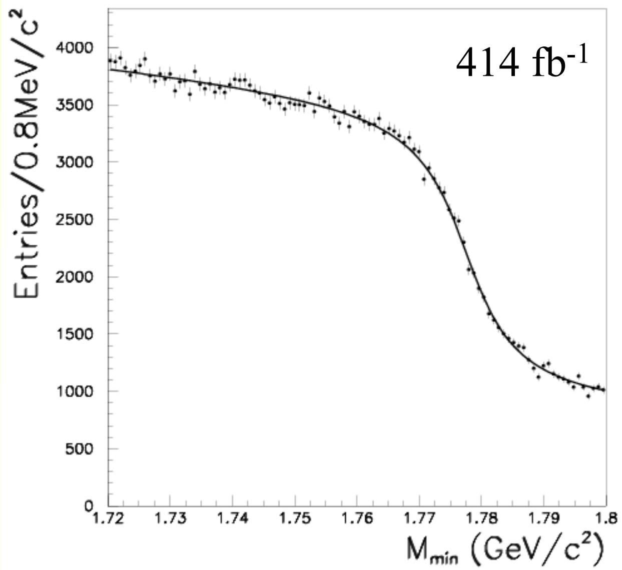
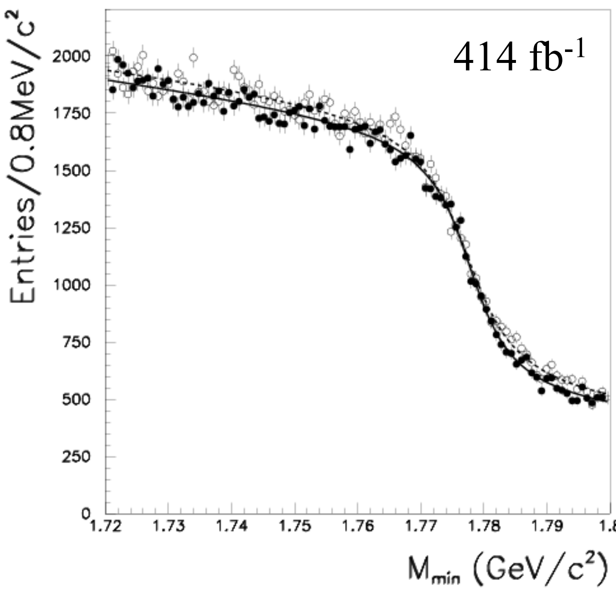




$m_\tau = 1776.61 \pm 0.13 \pm 0.35$ MeV

Dominant systematic: beam and tracking uncertainties

- Fit separately $m_{\tau+}$ and $m_{\tau-}$

$|m_{\tau+} - m_{\tau-}|/m_{avg} < 2.8\times10^{-4}$ @90%CL

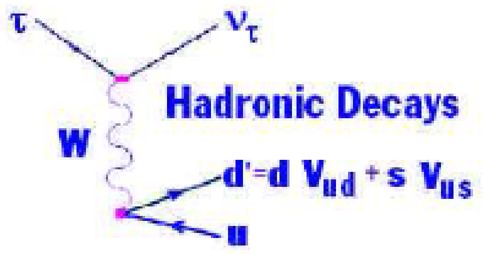
PRL 99 (2007) 011801

Tau decays to strange particles

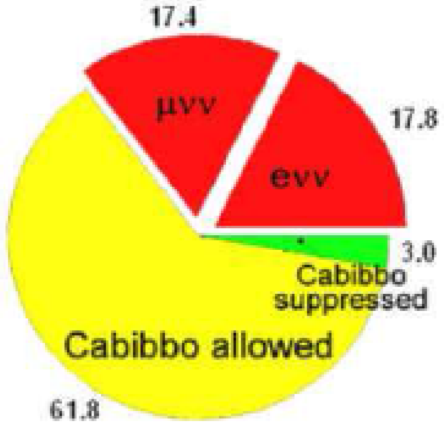
- Hadronic tau decays provide clean laboratory for the study of the hadronic weak current
- For τ decays to states with $\Delta s=1$, isospin symmetry breaking and OPE can be used to determine $|V_{us}|$ and m_s
- In $\tau \to s$ decays the uncertainty on $|V_{us}|$ and m_s is dominated by experimental uncertainties:
  - $|V_{us}|$: ~ O(1%) [from 3-body leptonic kaon decays]
  - m_s : ~ O(10 MeV) [from Lattice QCD]
- Use large statistics collected at B Factories to reduce uncertainties
  - $|V_{us}| \rightarrow 0.7\%$
  - If spectral function is measured → simultaneous fit of $|V_{us}|$ and m_s

Before B Factories: BF ($\tau \rightarrow s$)

$$B_{had} = 1 - B_e - B_\mu$$



$$R_{\tau,Strange} = R_\tau - R_{\tau,non-Strange}$$



Strange τ Decays:

Mode	$\mathcal{B}(10^{-3})$
K^-	6.81 ± 0.23
$K^-\pi^0$	4.54 ± 0.30
$\bar{K}^0\pi^-$	8.78 ± 0.38
$K^-\pi^0\pi^0$	0.58 ± 0.24
$\bar{K}^0\pi^-\pi^0$	3.60 ± 0.40
$K^-\pi^+\pi^-$	3.30 ± 0.28
$K^-\eta$	0.27 ± 0.06
$(\bar{K}3\pi)^-$ (estimated)	0.74 ± 0.30
$K_1(1270)^- \rightarrow K^-\omega$	0.67 ± 0.21
$(\bar{K}4\pi)^-$ (estimated) and $K^{*-}\eta$	0.40 ± 0.12
Sum	29.69 ± 0.86

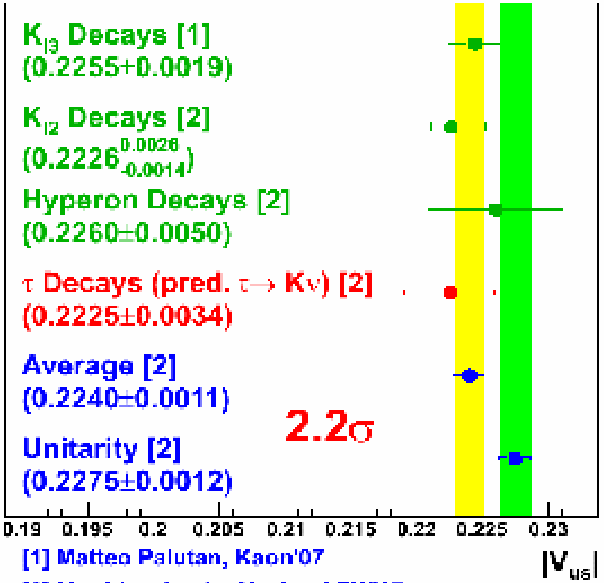
Davier, Hocker, Zhang(RMP 78, 1043, 2006)

Before B Factories: $|V_{us}|$ and m_s

Hadronic Width: $R_\tau = \dfrac{\Gamma(\tau^- \to \upsilon_\tau \text{hadrons}^-)}{\Gamma(\tau^- \to \upsilon_\tau \bar{\upsilon}_e e^-)}$

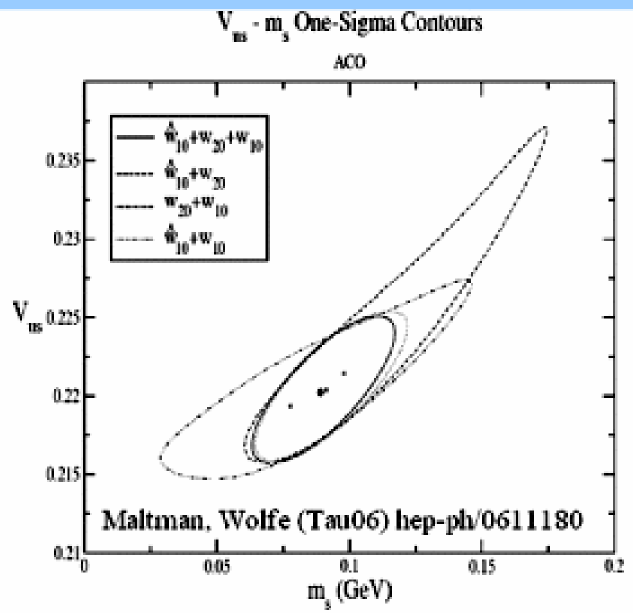
Flavour SU(3) Breaking: $\delta R^{kl}_{\tau,\text{Theory}}(m_s) = \dfrac{R^{kl}_{\tau,\text{non-Strange}}}{|V_{ud}|^2} - \dfrac{R^{kl}_{\tau,\text{Strange}}}{|V_{us}|^2}$

Extract |Vus| with Fixed m_s



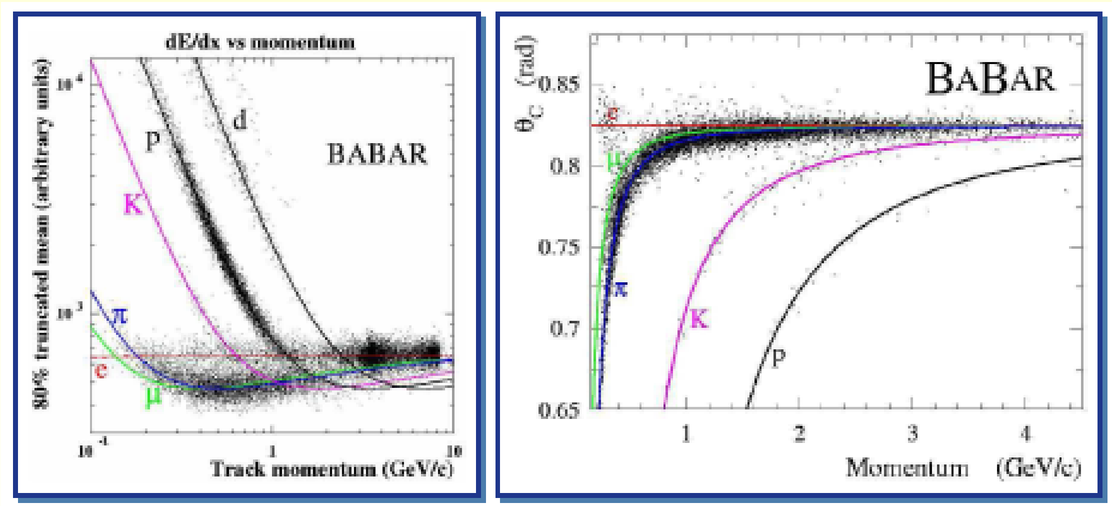
[1] Matteo Palutan, Kaon'07
[2] Matthias Jamin, Moriond EW'07

Simultaneously extract |Vus| and m_s

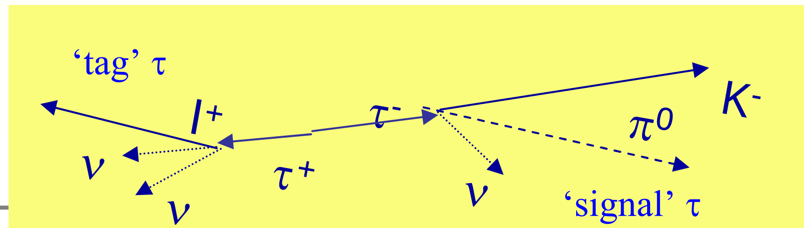


$\tau \rightarrow K^- \pi^0 \nu_\tau$ decay

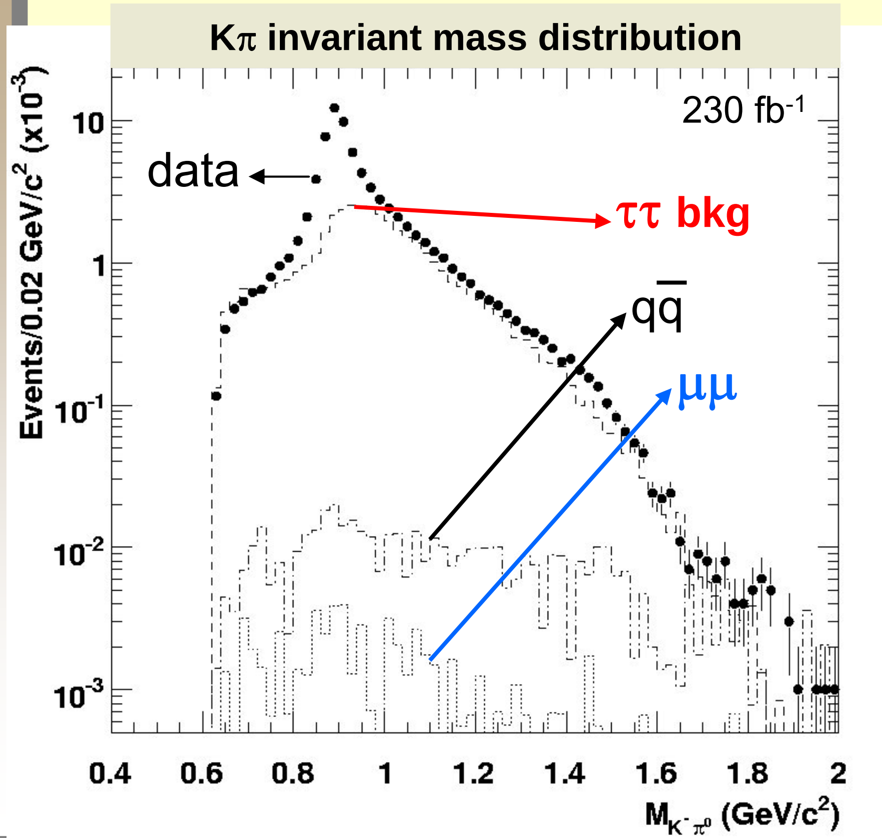
- Good K/π separation
  - Discriminate Cabibbo suppressed $\tau \rightarrow s$ signal from $\tau \rightarrow d$ bg

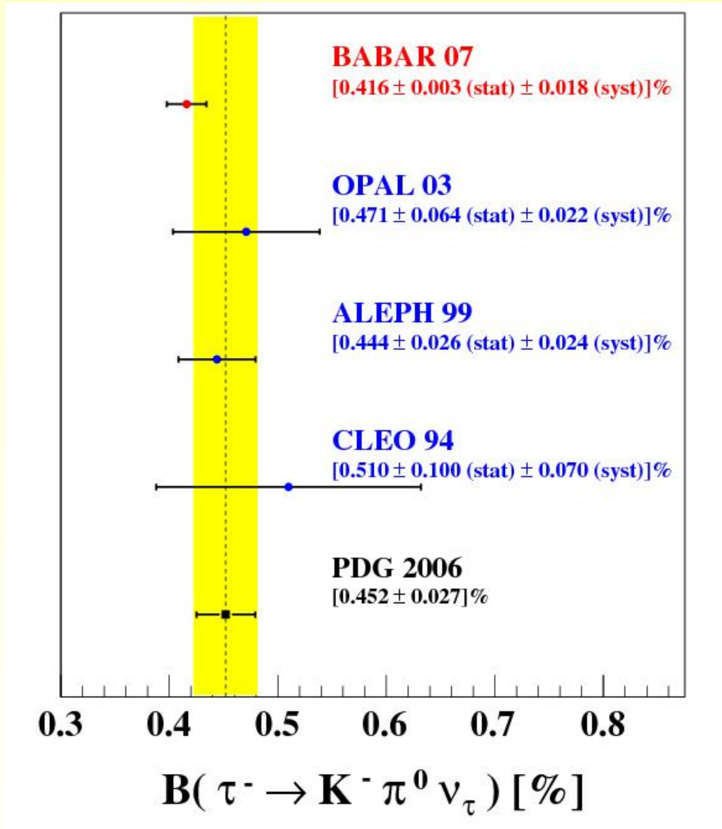


- 1-1 topology for signal events:
  - "Tag & probe" technique



BF ($\tau^- \rightarrow K^-\pi^0 \nu_\tau$)

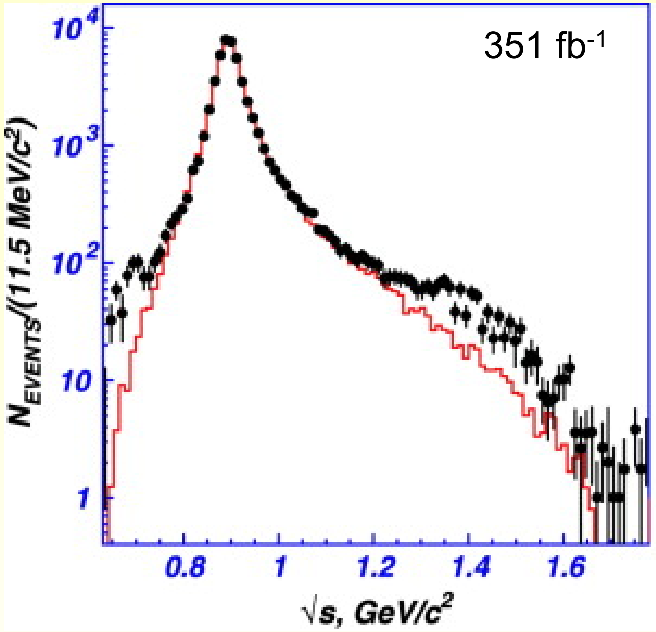


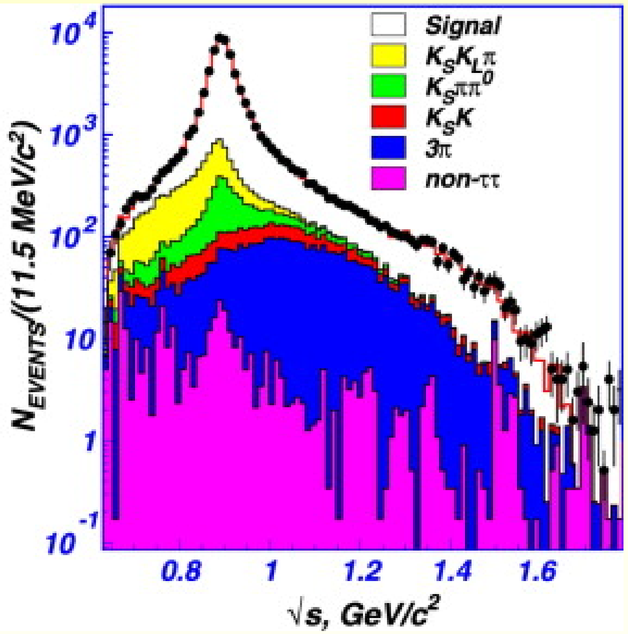


PRD 76 (2007) 051104(R)

ε	(2.267±0.008)%
N^{data}	78 112
N^{BG}	38 247 ± 159

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





	BF(%)
$\tau^- \rightarrow K_s\pi^- \nu_\tau$	0.404 ± 0.002(stat) ± 0.013(syst)
$\tau^- \rightarrow \bar{K}^0\pi^- \nu_\tau$	0.808 ± 0.004(stat) ± 0.026(syst)
$\tau^- \rightarrow K^*\nu_\tau$, $K^* \rightarrow K_s\pi^-$	0.377 ± 0.002(stat) ± 0.012(syst) ± 0.012(mod)

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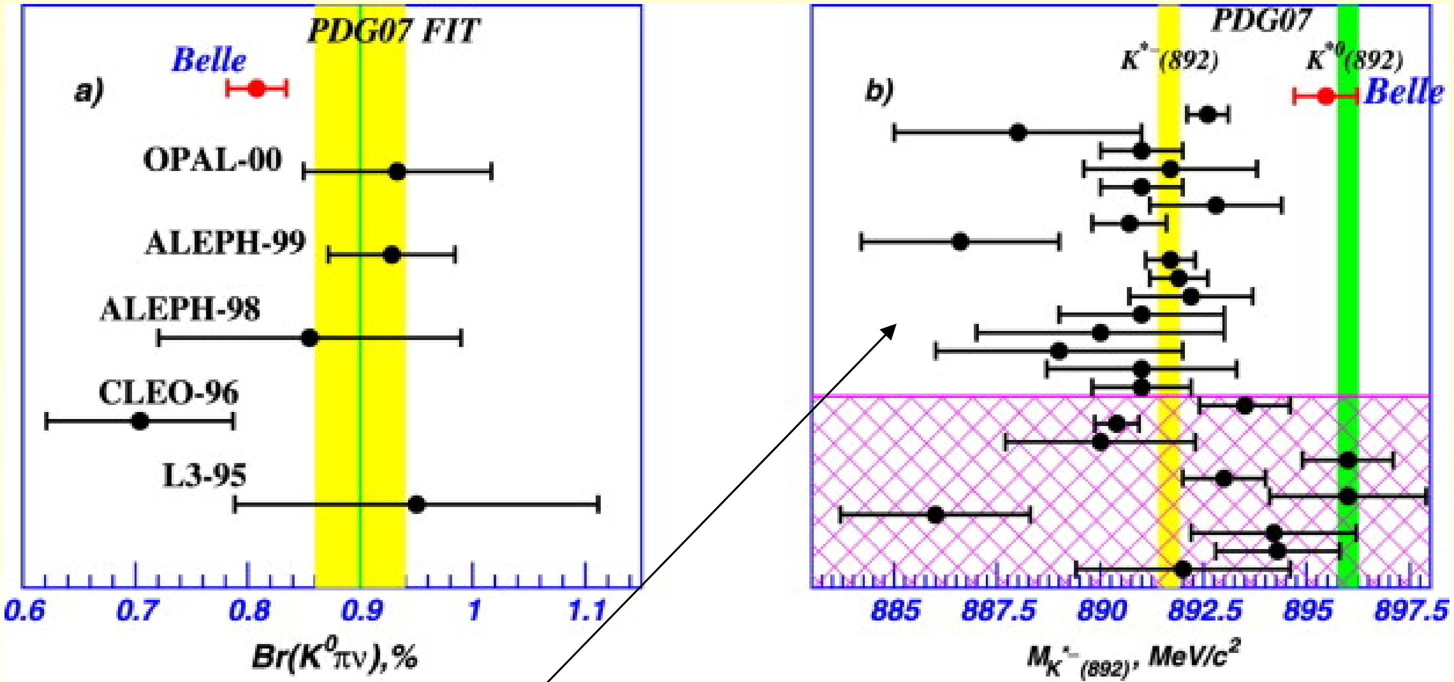
Comparison of BF and m(K*) with PDG



Best description of K* mass spectrum obtained considering the K*(800)+K*(892)+K*(1410) and K*(800)+K*(892)+K*(1430) models

$m(K^*(892)^-)$	895.7 ± 0.20(stat) ± 0.44(syst) ± 0.59(mod) MeV/c^2
$\Gamma(K^*(892)^-)$	46.2 ± 0.6(stat) ± 1.0(syst) ± 0.7(mod) MeV

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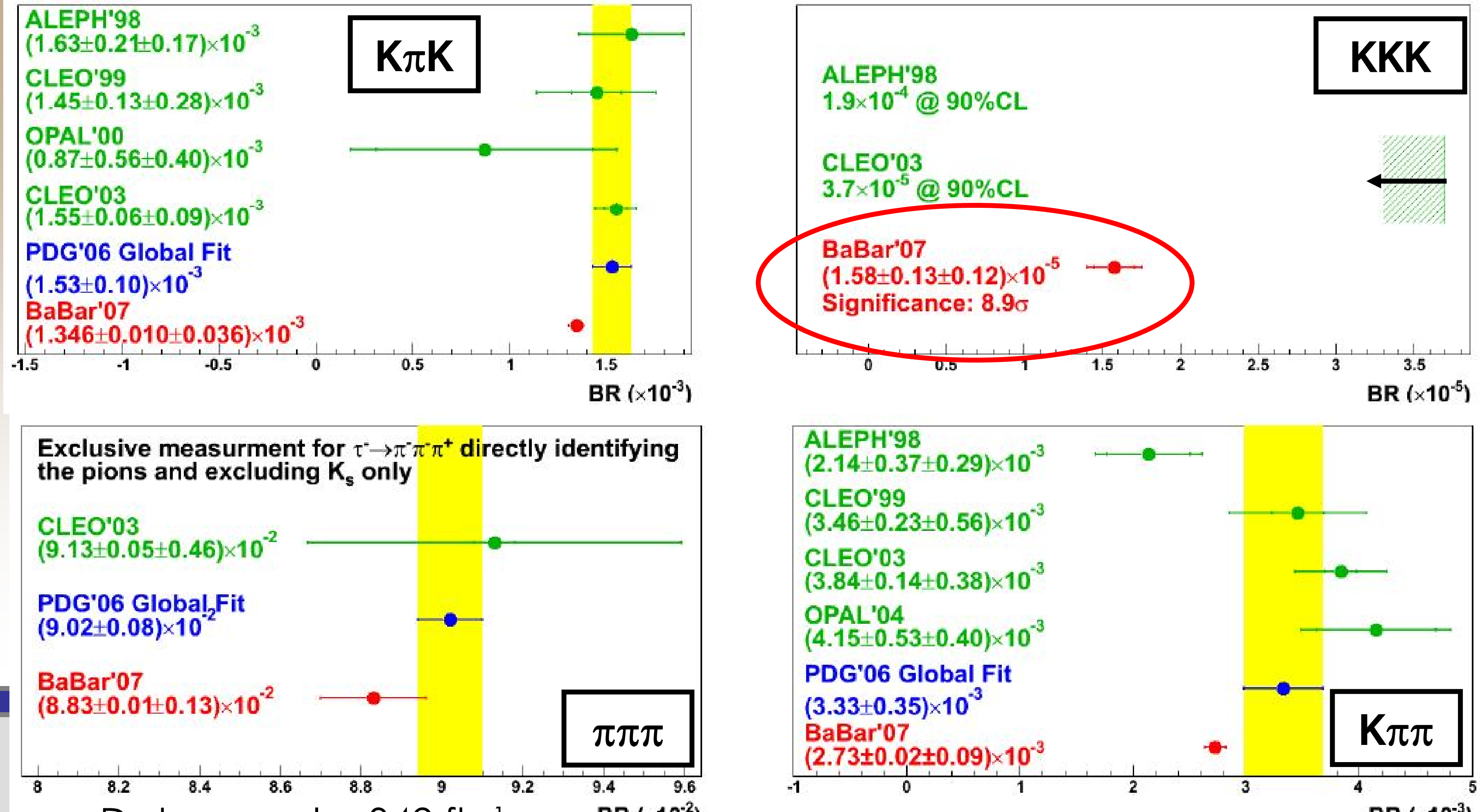
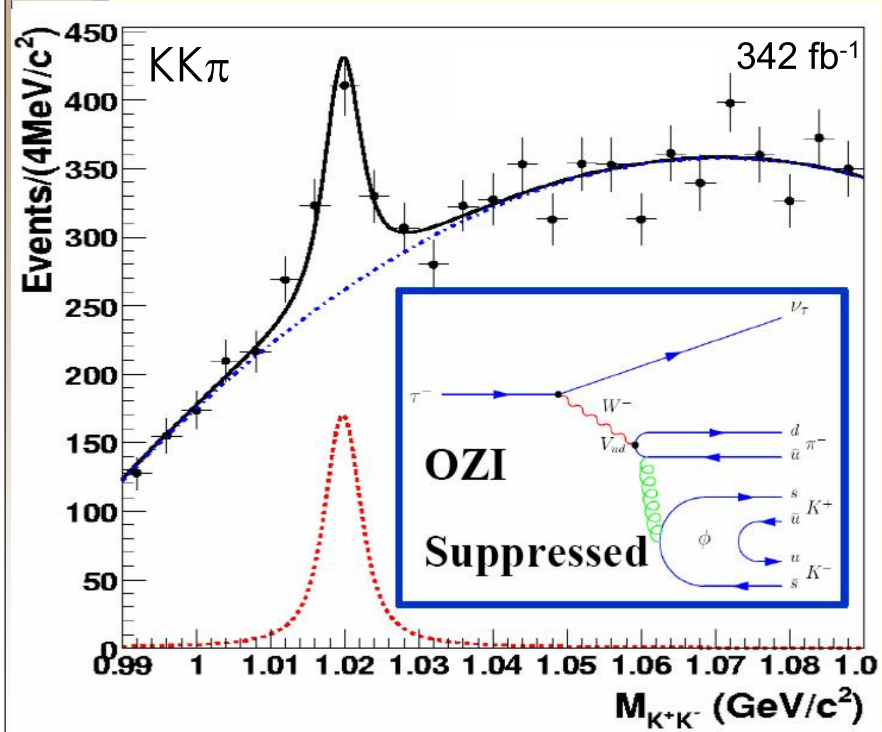
Exclusive BF ($\tau^- \rightarrow h^- h^+ h^- \nu_\tau$)

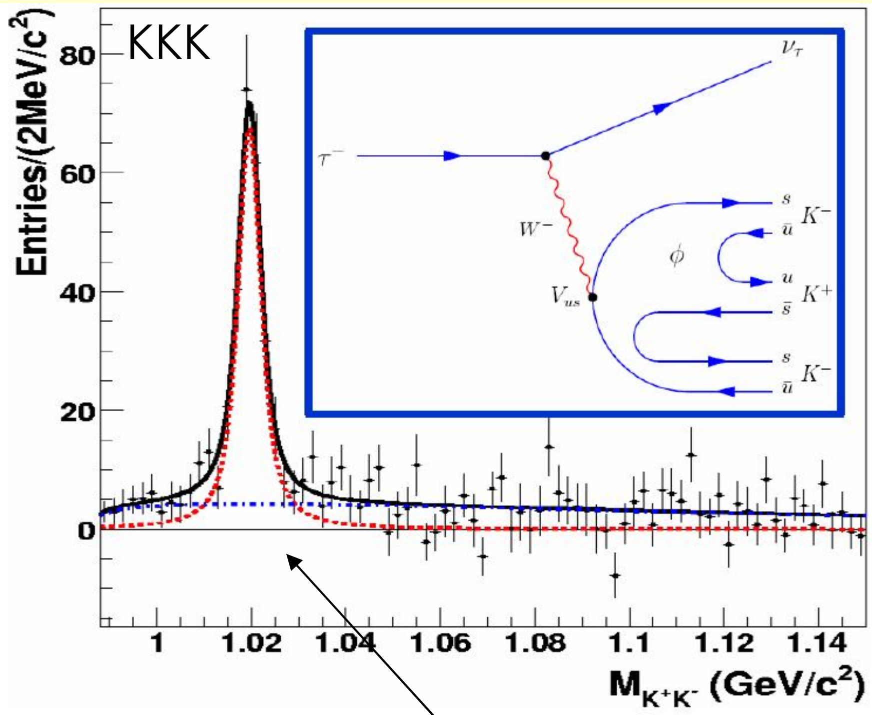


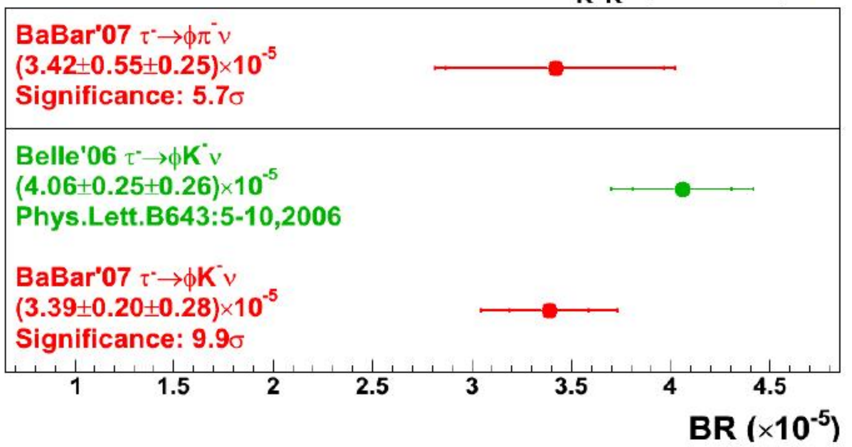
Data sample: 342 fb^{-1}

PRL 100 (2008) 011801

ϕ peak in $\tau \to KK\pi\nu_\tau$ and $\tau \to KKK\nu_\tau$





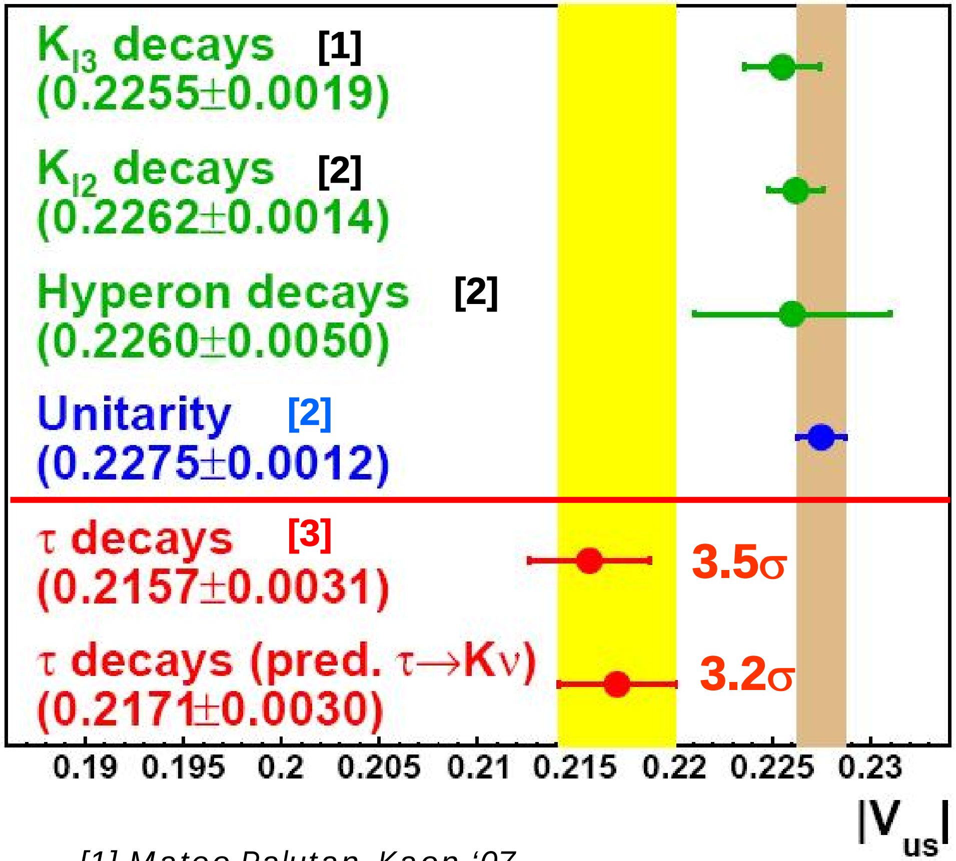


Resonant decay is consistent with saturating $\tau^{-} \to K^-K^+K^- \nu_\tau$ channel

$\mathcal{B}(\tau^{-} \to K^-K^+K^- \nu_\tau \text{ ex. } \Phi) < 2.5 \times 10^{-6}$

PRL 100 (2008) 011801

Update on V_{us} using B Factory results



[1] Mateo Palutan, Kaon '07
[2] Matthias Jamin, Moriond EW '07
[3] Swagato Banerjee arXiv:0707.3058 [hep-ex]

Updated Results:

BABAR:

- $\tau^- \rightarrow K^- \pi^0 \nu_\tau$
  PRD 76 (2007) 051104 (R)
- $\tau^- \rightarrow K^- \pi^+ \pi^- \nu_\tau$
  PRL 100 (2008) 011801

Belle:

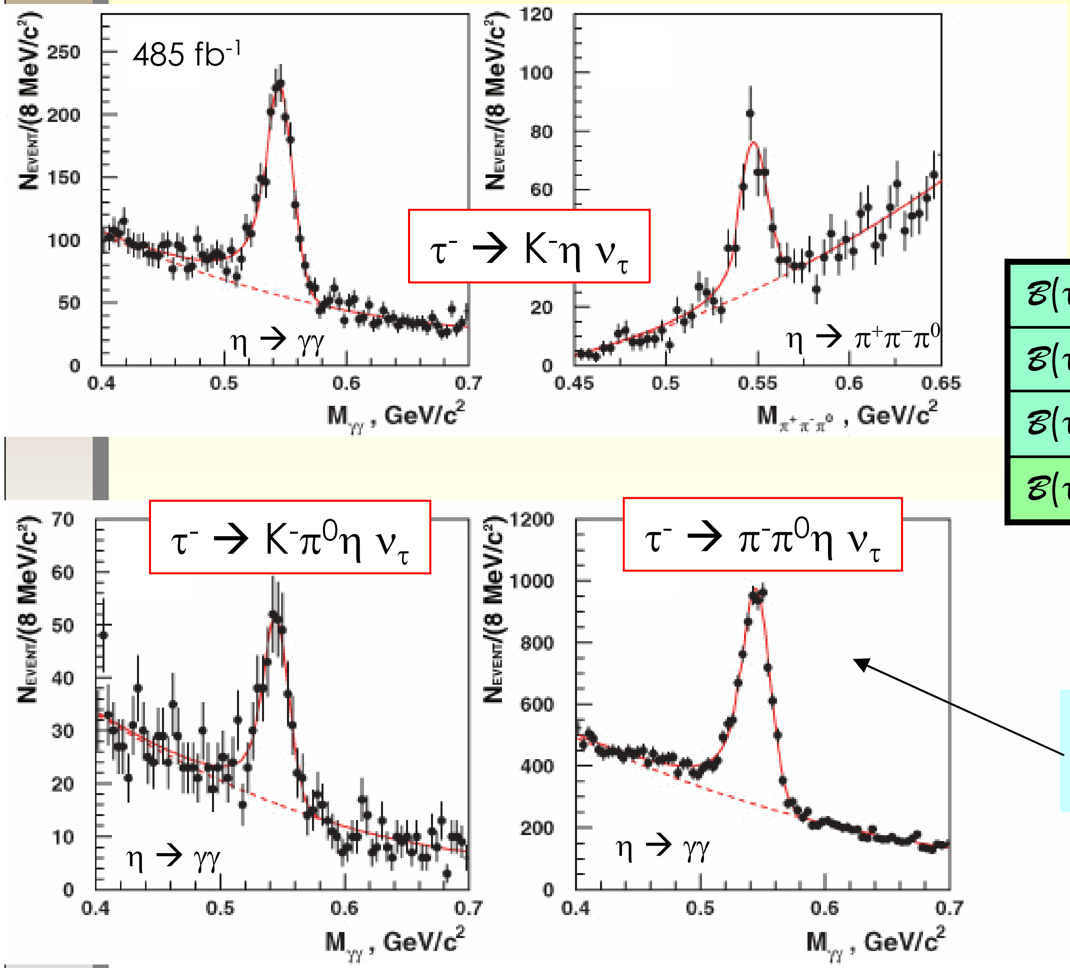
- $\tau^- \rightarrow K^0 \pi^- \nu_\tau$
  PLB 654 (2007) 65

- Theory prediction $\mathcal{B}(\tau \rightarrow K\nu_\tau)$ from $\mathcal{B}(K \rightarrow \mu\nu_\mu(\gamma))$ assuming $\mu - \tau$ universality
  arXiv:0707.3058v4 [hep-ex]

τ decays in modes with η meson

- Important for testing different theoretical models
  - E.g.: Weiss-Zumino-Witten (WZW) anomaly, chiral theory, relations to σ_{e+e-} following from (CVC)
- Studies of tau decay modes including η mesons have been previously reported by CLEO and ALEPH
  - Low statistics: 0.8 – 5 fb^{-1} used in the analysis
  - Difficult to discriminate between different predictions
- Belle's analysis uses 485 fb^{-1} of data
  - 100 times larger than any previous dataset
  - Better systematics thanks to precise estimation of peaking background

Branching fraction results



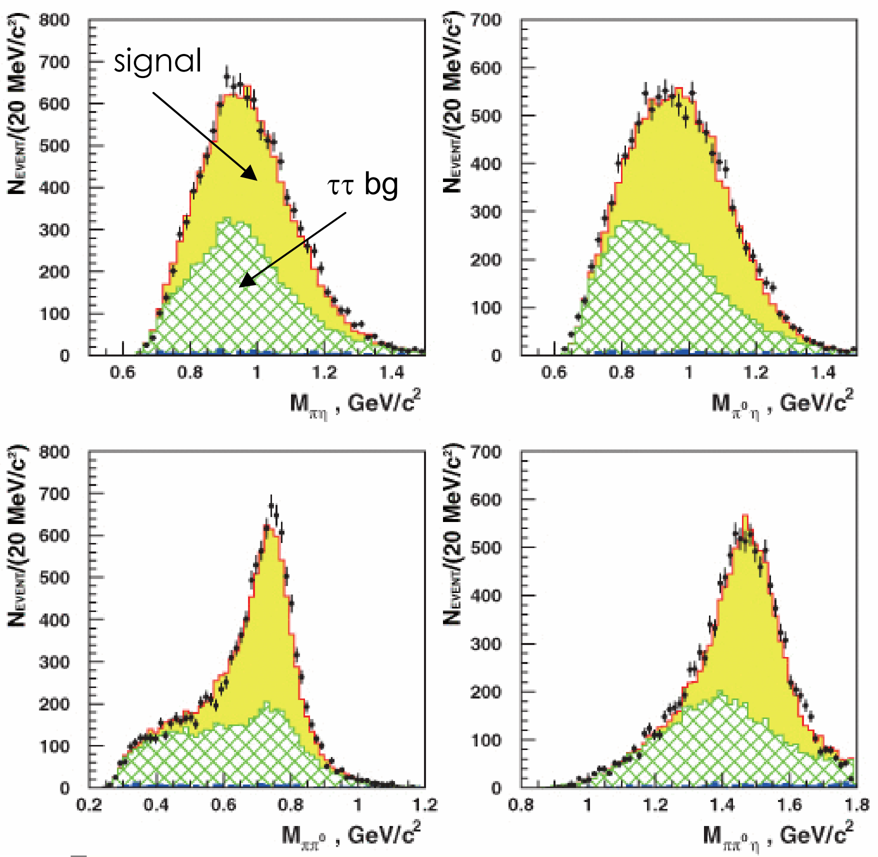
Improved accuracy in BF by factor 4-8 wrt previous measurements

$\mathcal{B}(\tau^- \to K^- \eta \nu_\tau)$	$(1.62 \pm 0.05 \pm 0.09)\times10^{-4}$
$\mathcal{B}(\tau^- \to K^- \pi^0 \eta \nu_\tau)$	$(4.7 \pm 1.1 \pm 0.4)\times10^{-5}$
$\mathcal{B}(\tau^- \to K^*(892)^- \eta \nu_\tau)$	$(1.13 \pm 0.19 \pm 0.07)\times10^{-4}$
$\mathcal{B}(\tau^- \to \pi^- \pi^0 \eta \nu_\tau)$	$(1.39 \pm 0.03 \pm 0.07)\times10^{-3}$

Fit $\gamma\gamma$ distribution using Crystal Ball + polynomial for bg

arXiv:0708.0733v1 [hep-ex])

Comparison with predictions



- $\mathcal{B}(\tau^- \rightarrow \pi^-\pi^0\eta\ \nu_\tau)$ consistent with prediction based on CVC and experimentally measured $e^+e^- \rightarrow \pi+\pi-\eta$ cross section
    - ➢ Good agreement between data and MC (TAUOLA)

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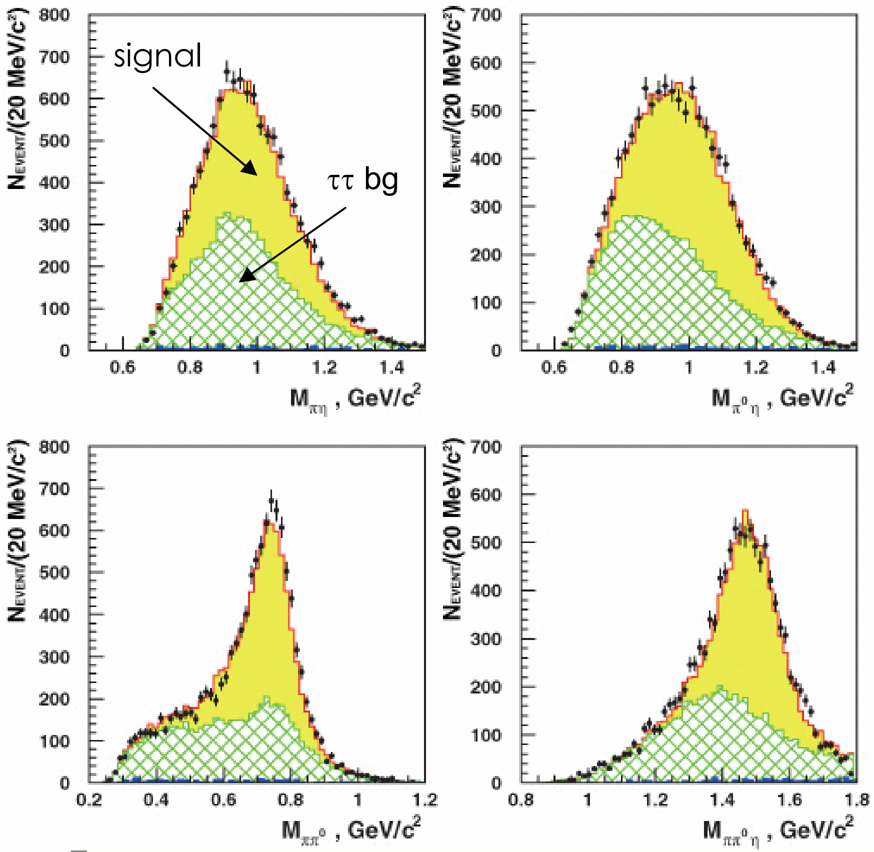

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  - ➢ Good agreement between data and MC (TAUOLA)
- Central value of $\mathcal{B}(\tau^- \rightarrow K^-\eta\,\nu_\tau)$ and $\mathcal{B}(\tau^- \rightarrow K^-\pi^0\eta\,\nu_\tau)$ slightly different from chiral theory prediction (Phys. Rev. D 55 (1997) 1436)
  - ➢ More tuning of MC needed
  - ➢ Further studies of final state dynamics and resonance formation in progress

Rare tau decays

$\tau^- \to (5\pi)^- 2\pi^0 \nu_\tau$ decay

BABAR has ~200 times more data

Previous Experimental limit:

$\mathcal{B}(\tau \to 5h\, 2\pi^0 \nu_\tau) < 1.1\times10^{-4}$ @ 90% CL (*CLEO 1994, 1.7 fb^{-1}*)

- Tiny phase space suppresses 8-body τ decays
- No BR prediction
- Decay is likely to go through $\tau \to 2\omega\pi\nu_\tau$ *(R. Sobie, PRD 60, 017301 (1999))*

Select signal using pseudo-mass

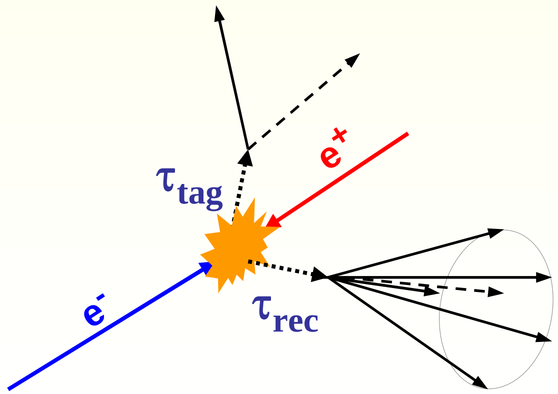
- assume neutrino is mass-less
- approximate τ direction by 7 tracks

$$m^{*2}_\tau = 2(E_{beam} - E_{7\pi})(E_{7\pi} - P_{7\pi}) + m_{7\pi}^2$$

- signal region: $1.3 < m^*_\tau < 1.8$ GeV/c^2

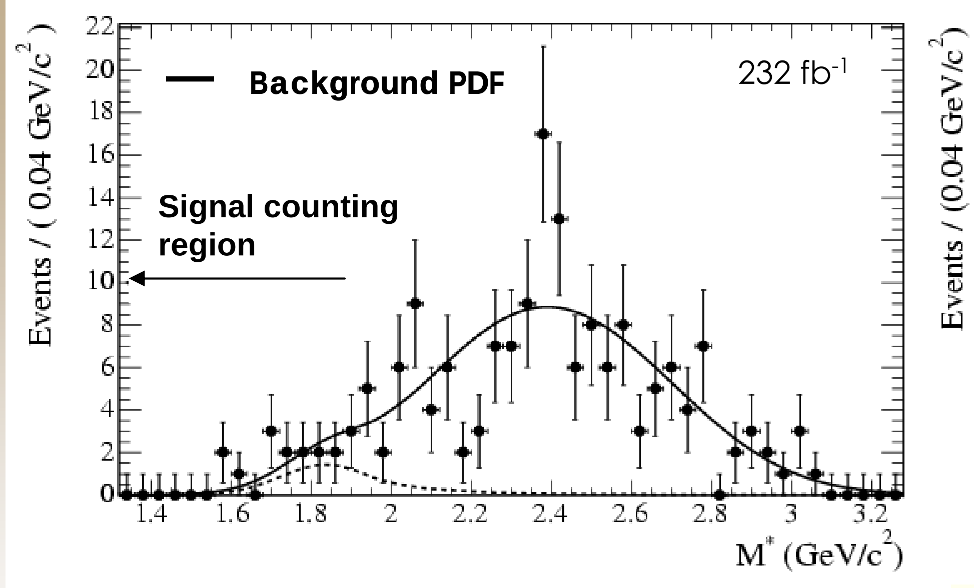
Improves rejection of $q\bar{q}$ background

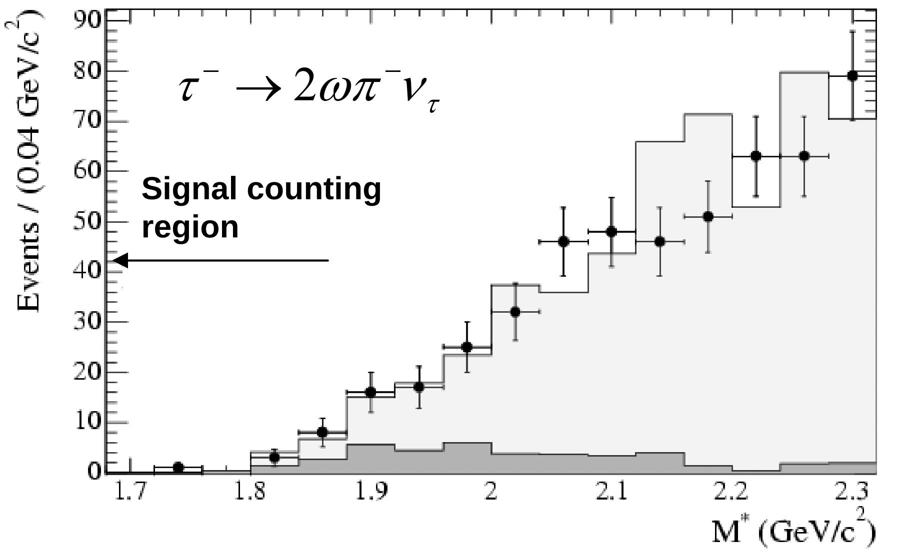
Standard “tag & probe” technique



5-prong τ decay

BF ($\tau \rightarrow 5\pi 2\pi^0 \nu_\tau$)





Signal efficiency	0.66 ± 0.05 %
Total expected bkg.	$6.5^{+2.0}_{-1.4}$
Observed events	10

Signal efficiency	1.53 ± 0.13 %
Total expected bkg.	$0.4^{+1.0}_{-0.4}$
Observed events	1

Multi-pion mode	PDG2004	BABAR	
$\tau \rightarrow 5\pi\, 2\pi^0\nu_\tau$	$< 1.1 \times 10^{-4}$	$< 3.4 \times 10^{-6}$	(PRD 74 (2006) 011103)
$\tau \rightarrow 2\omega\, \pi\nu_\tau$	N/A	$< 5.4 \times 10^{-7}$	(PRD 74 (2006) 011103)
$\tau \rightarrow 7\pi\, (\pi^0)\nu_\tau$	$< 2.4 \times 10^{-6}$	$< 3.0 \times 10^{-7}$	(PRD 72 (2005) 012003)

Conclusions

- Exciting tau physics programme at the B Factories
  - B Factories are also Tau Factories !
- Huge tau statistics allow unprecedented precision in measurements of properties of tau lepton
  - Measurement of tau mass and test of CPT theorem
  - τ decays to strange particles
    - Measurement of BFs and new measurement of $|V_{us}|$ from tau decays
    - First evidence of $\tau \rightarrow KKK \nu_\tau$ decay mode
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  - τ decays in modes containing η meson
    - Tests various theoretical models (WZW, chiral, CVC)
    - Important to study backgrounds for 2nd class currents
  - Rare tau decays

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Many more results to follow…