Recent tau results from *BABAR*

Alberto Lusiani
INFN and Scuola Normale Superiore
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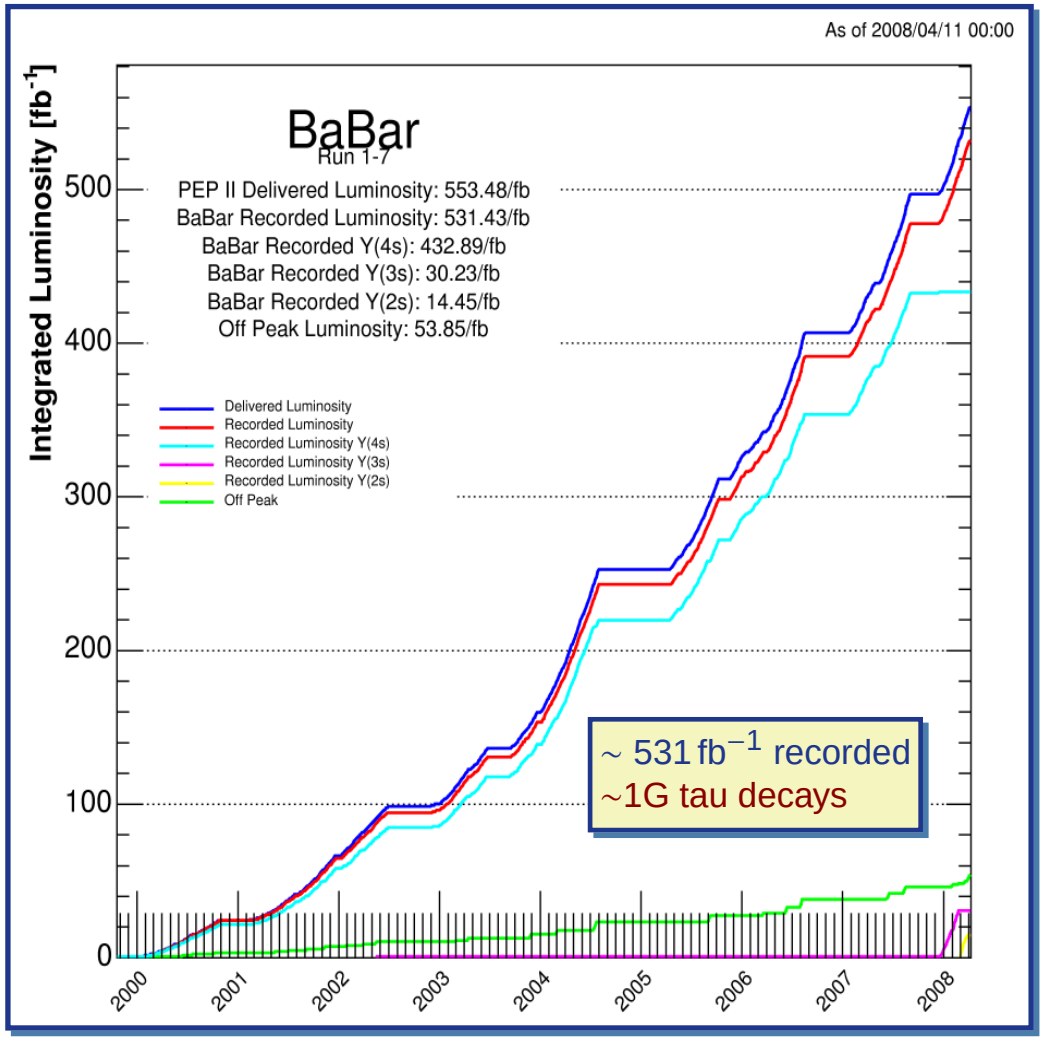
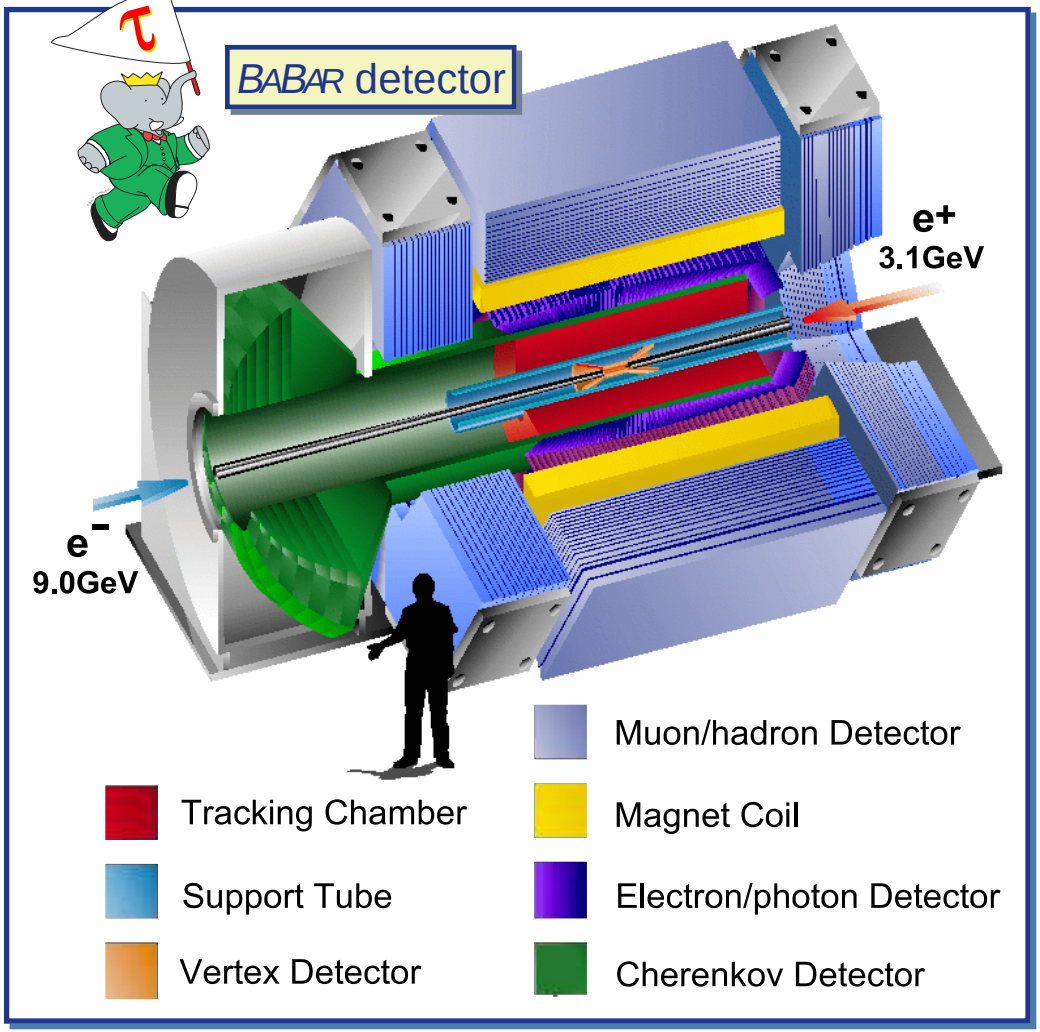
BABAR is a Tau Factory, $\sigma(\tau^+\tau^-) \approx 0.9\ nb \approx \sigma(B\bar{B}) \approx 1.1\ nb$



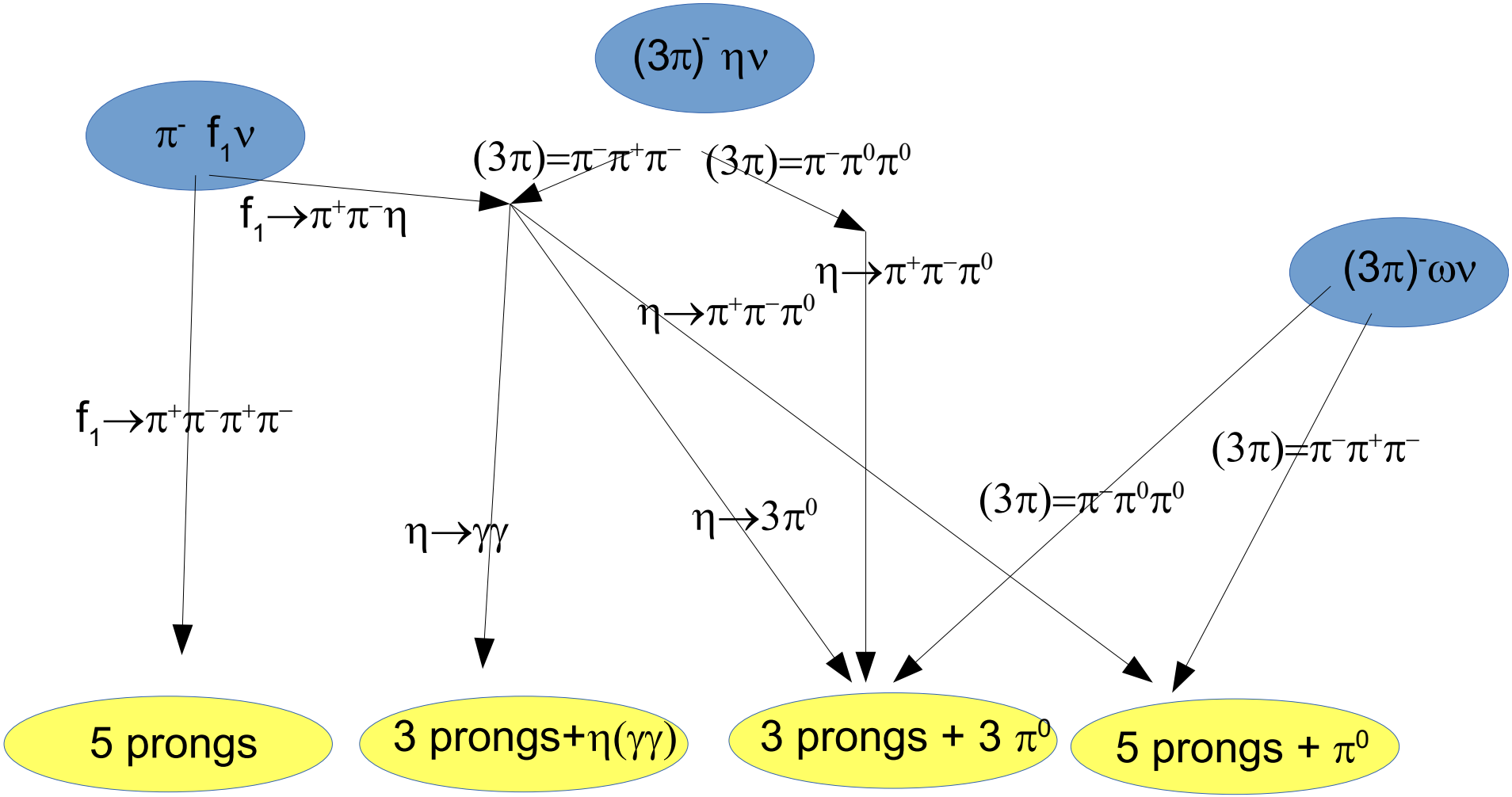


Recent tau physics results from *BABAR*

- Phys Rev D 86 092010 (2012) high multiplicity tau decays
  - 23 final states BRs (resonant and non-resonant)
  - search for 2nd-class current $\tau \to \pi\eta'\nu$
- Phys Rev D - RC 86 092013 (2012) tau decays containing two K_S
  - $\mathcal{B}[\tau \to \pi K_S K_S(\pi^0)\nu]$
  - $\mathcal{B}[\tau \to K K_S K_S(\pi^0)\nu]$
- preliminary 2013 result on 3-prong hadronic tau decays
  - Invariant mass spectra
  - [Branching ratios already published (PRL 100, p011801, 2008)]

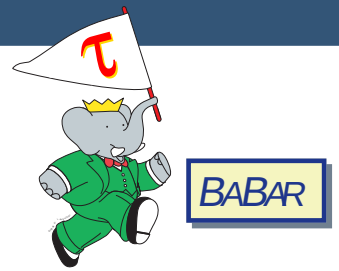
High multiplicity tau decays

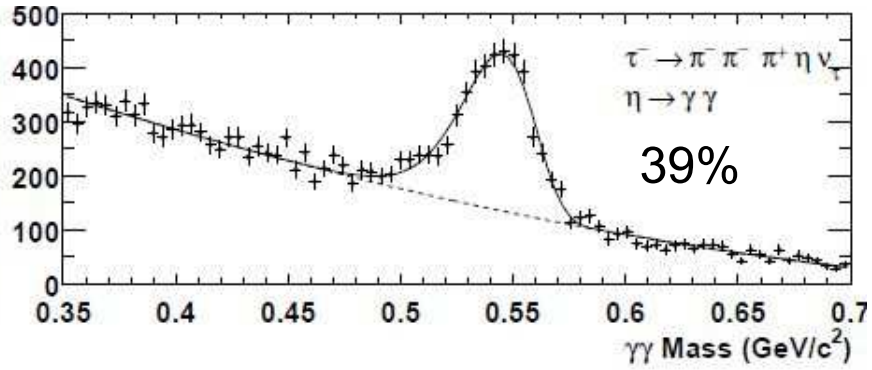
PRD 86 092010 (2012)

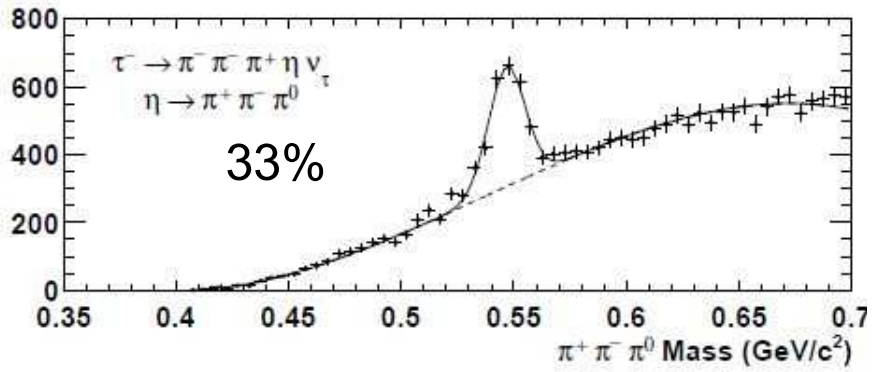


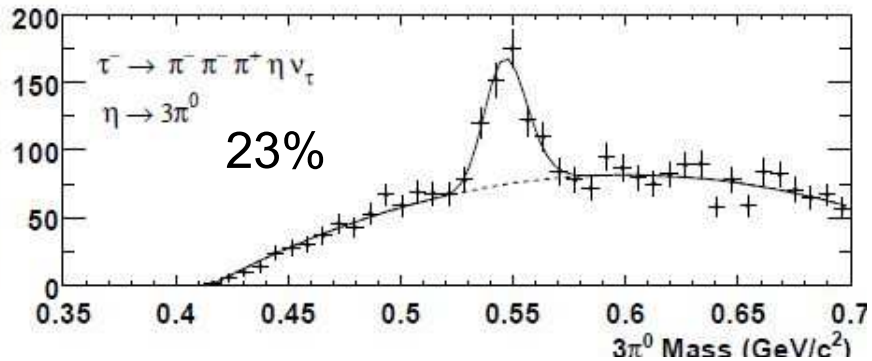
23 decay modes

High multiplicity tau decays: 3 different η decay modes









- most bkg from $q\bar{q}$
- Monte Carlo $q\bar{q}$ bkg rescaled with data

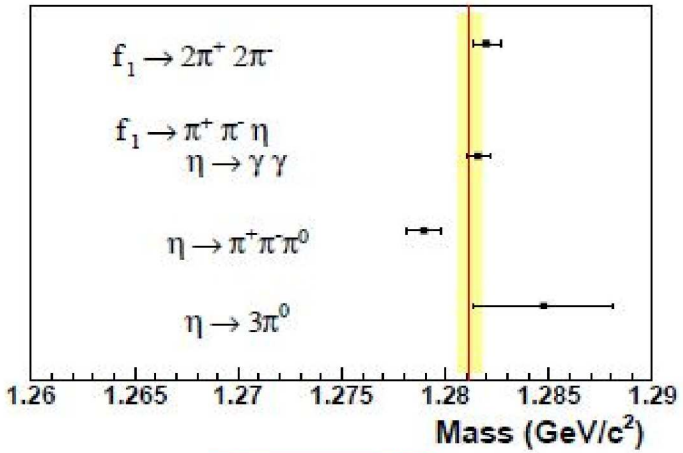
BABAR

High multiplicity tau decays: f_1 mass

$\tau^- \to \pi^- f_1 \nu_\tau$, $f1 \to \pi^-\pi^+\pi^-\pi^+$ or $f_1 \to \eta\pi^-\pi^+$

- *4 different final states in reconstruction*
- *Lineshape from MC + resolution correction*
- *Extraction of f_1 mass using a non-relativistic Breit-Wigner*

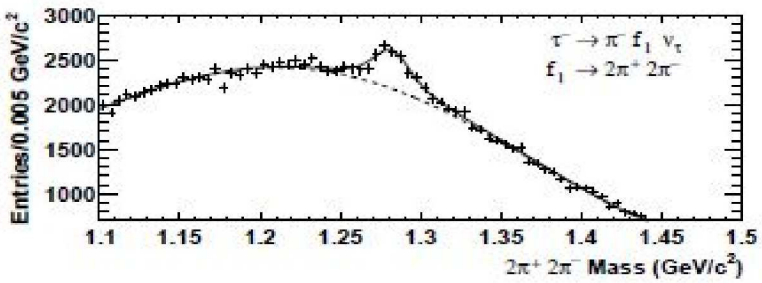
  $m(f_1) = (1.28116 \pm 0.00039 \pm 0.00045)\,GeV/c^2$

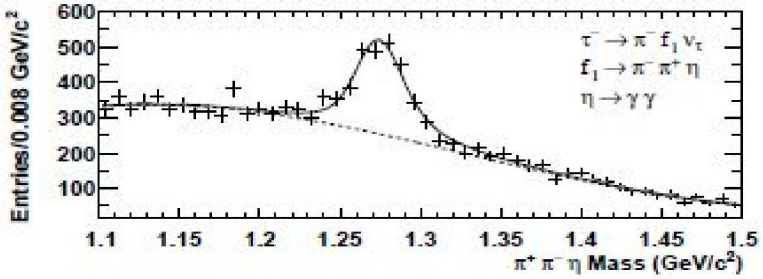


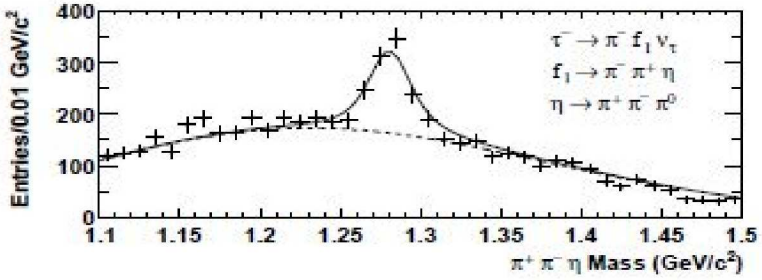
$\tau^- \to \pi^- f_1 \nu_\tau$ via $f_1 \to 2\pi^+2\pi^-$ $(5.20 \pm 0.31 \pm 0.37) \times 10^{-5}$

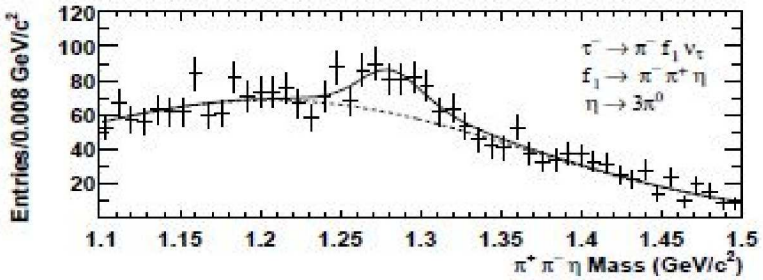
$\tau^- \to \pi^- f_1 \nu_\tau$ via $f_1 \to \pi^+\pi^-\eta$ $(1.26 \pm 0.06 \pm 0.06) \times 10^{-4}$

$\mathcal{B}(f_1 \to 2\pi^+2\pi^-)/\mathcal{B}(f_1 \to \pi\pi\eta)$ $0.28 \pm 0.02 \pm 0.02$





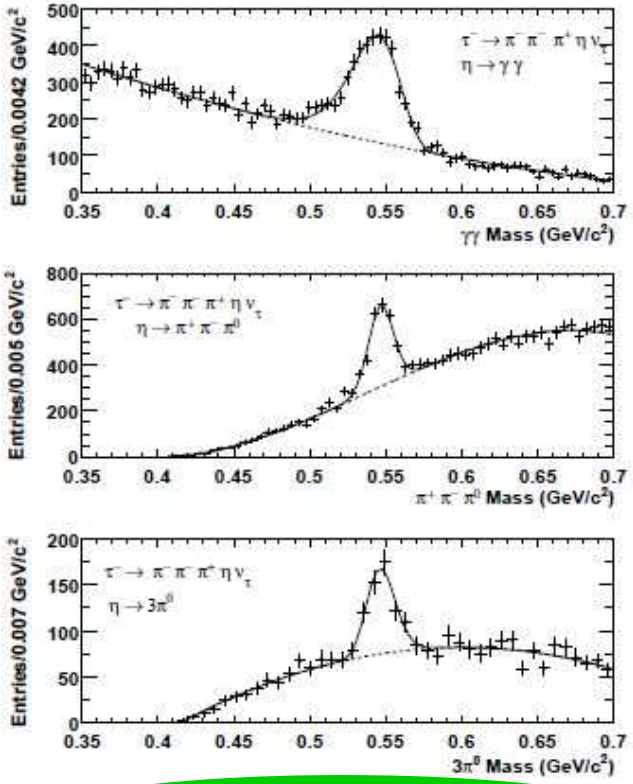




High multi. . . : final states with $(3\pi)^-$ and one η or ω resonance

$\tau^- \to 2\pi^+\pi^-\eta\,\nu$

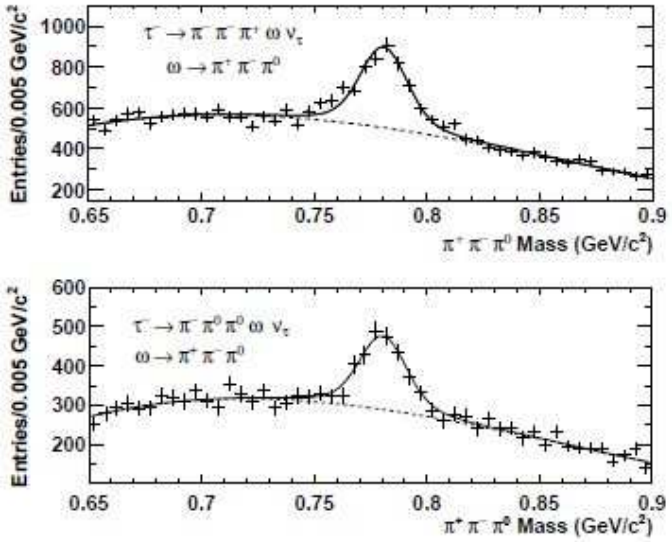
Fit: Novosibirsk function + polynomial bkg



$\tau^- \to 2\pi^-\pi^+\eta\nu_\tau$ (including f_1) $(2.25 \pm 0.07 \pm 0.12) \times 10^{-4}$
$\tau^- \to 2\pi^-\pi^+\eta\nu_\tau$ (excluding f_1) $(0.99 \pm 0.09 \pm 0.13) \times 10^{-4}$
$\tau^- \to \pi^- 2\pi^0\eta\nu_\tau$ (including f_1) $(2.01 \pm 0.34 \pm 0.22) \times 10^{-4}$

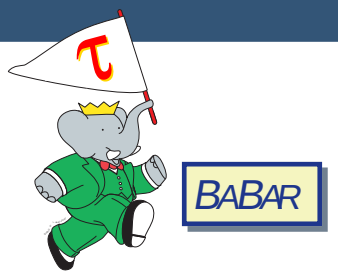
$\tau^- \to 2\pi^-\pi^+\omega\,\nu_\tau$

Fit: Breit-Wigner + polynomial bkg

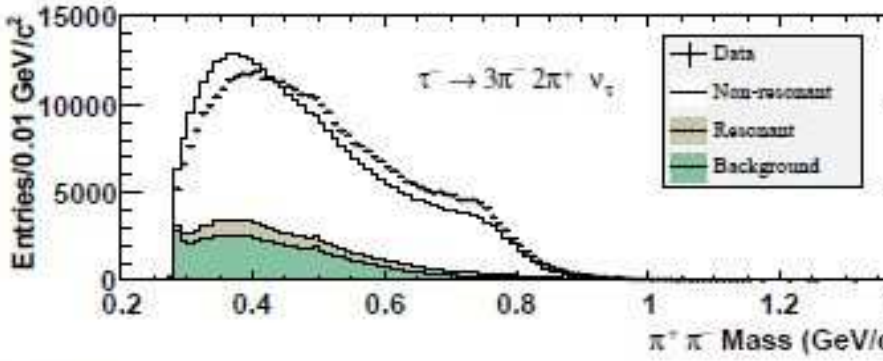


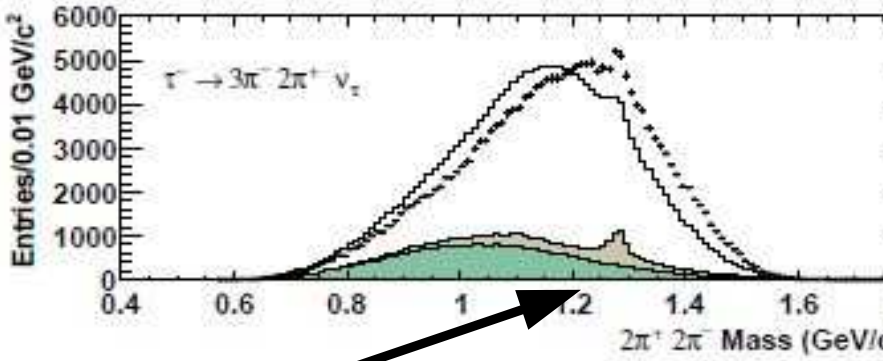
$\tau^- \to 2\pi^-\pi^+\omega\nu_\tau$ $(8.4 \pm 0.4 \pm 0.6) \times 10^{-5}$
$\tau^- \to \pi^- 2\pi^0\omega\nu_\tau$ $(7.3 \pm 1.2 \pm 1.2) \times 10^{-5}$

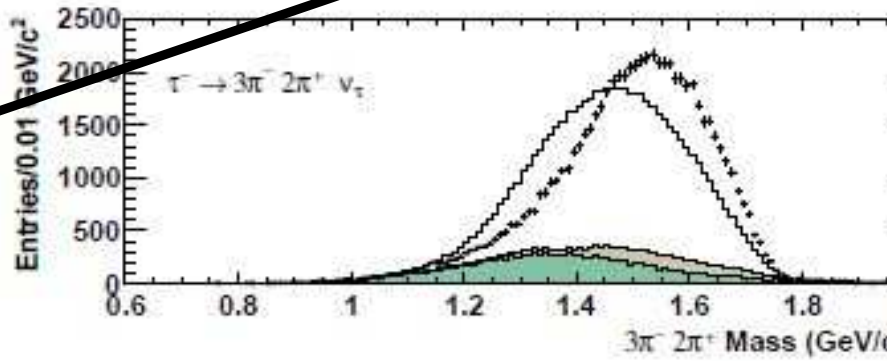
High multiplicity tau decays: $\tau^- \to 3\pi^- 2\pi^+ \nu$



- *Inclusive measurement and subtraction of resonant contribution and bkg*
- *Account only for resonances with $\Gamma < 100$ MeV because of complex lineshape and phase-space effects*



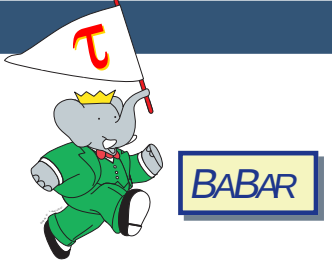




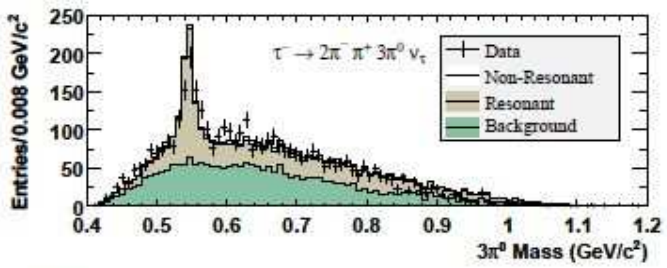
Small contribution from resonant decays

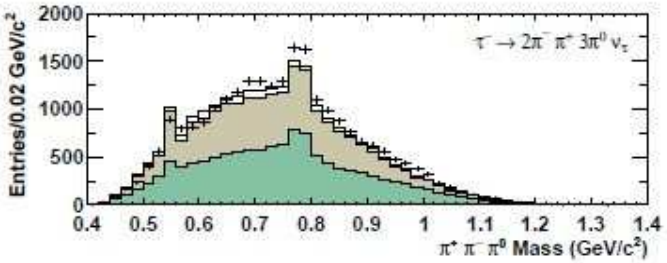
$\tau^- \to 3\pi^- 2\pi^+ \nu_\tau$ (excluding ω, f_1)	$(7.68 \pm 0.04 \pm 0.40) \times 10^{-4}$
$\tau^- \to 3\pi^- 2\pi^+ \nu_\tau$ (excluding ω)	$(8.33 \pm 0.04 \pm 0.43) \times 10^{-4}$

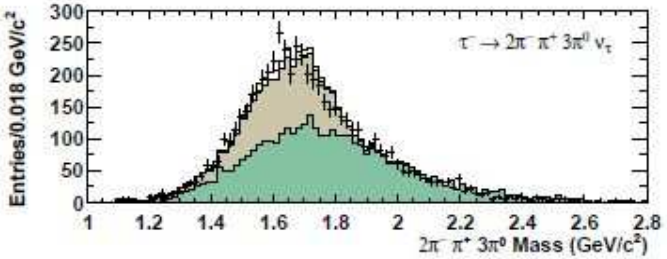
High multiplicity tau decays: $\tau^- \to 3\pi^-2\pi^+\pi^0\nu$ and $\tau^- \to 2\pi^-\pi^+3\pi^0\nu$



$\tau^- \to 2\pi^-\pi^+3\pi^0\nu$

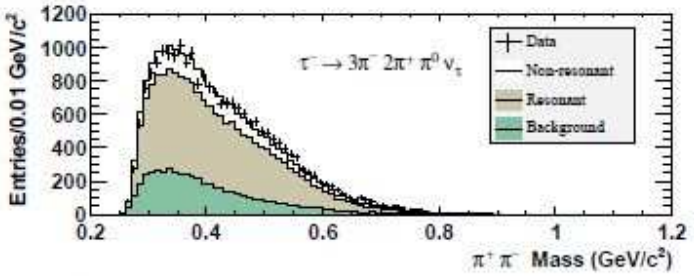


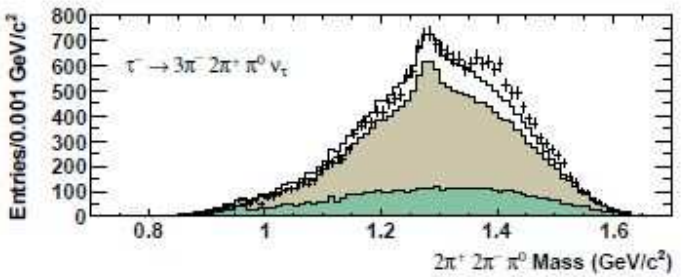


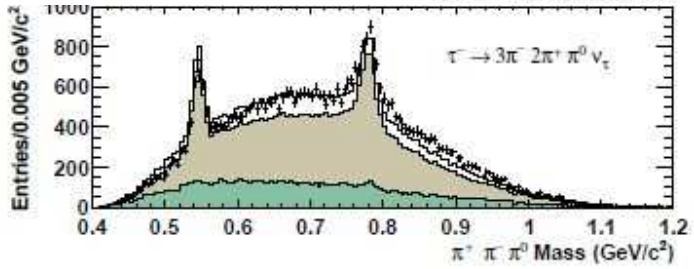


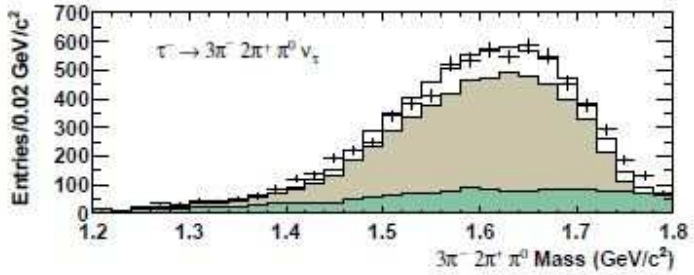
$\tau^- \to 2\pi^-\pi^+3\pi^0\nu_\tau$ (excluding η, ω, f_1)	$(1.0 \pm 0.8 \pm 3.0) \times 10^{-5}$
$\tau^- \to 2\pi^-\pi^+3\pi^0\nu_\tau$ (excluding η, f_1)	$(16.9 \pm 0.8 \pm 4.3) \times 10^{-5}$
$\tau^- \to 2\pi^-\pi^+3\pi^0\nu_\tau$	$(2.07 \pm 0.18 \pm 0.37) \times 10^{-4}$

$\tau^- \to 3\pi^-2\pi^+\pi^0\nu$

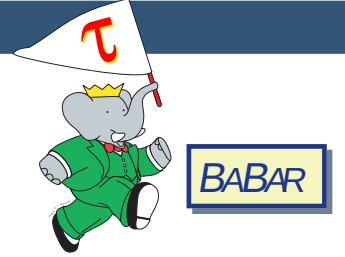






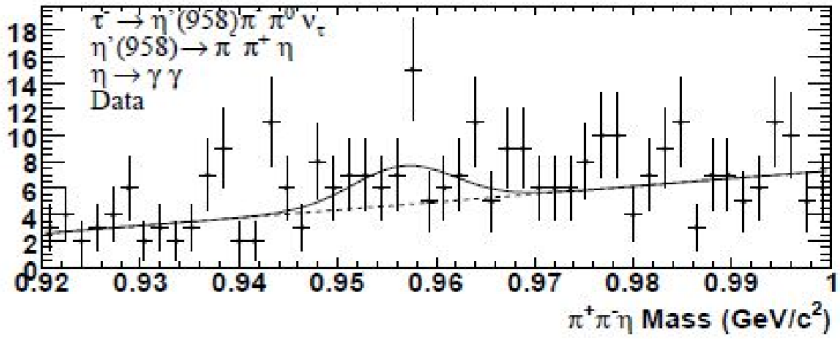


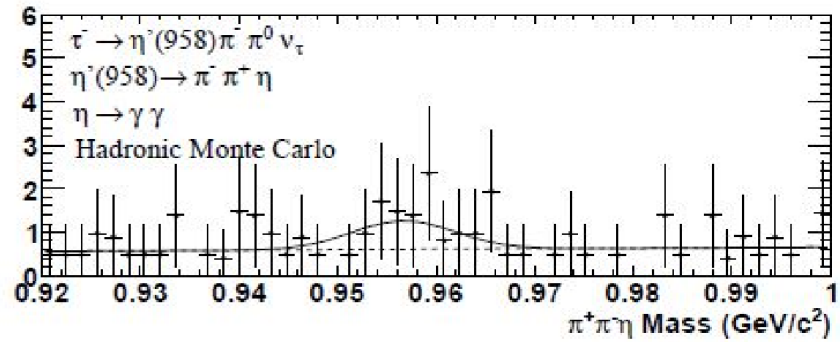
$\tau^- \to 3\pi^-2\pi^+\pi^0\nu_\tau$ (excluding η, ω, f_1)	$(3.6 \pm 0.3 \pm 0.9) \times 10^{-5}$
$\tau^- \to 3\pi^-2\pi^+\pi^0\nu_\tau$ (excluding η, f_1)	$(1.11 \pm 0.04 \pm 0.09) \times 10^{-4}$
$\tau^- \to 3\pi^-2\pi^+\pi^0\nu_\tau$	$(1.65 \pm 0.05 \pm 0.09) \times 10^{-4}$

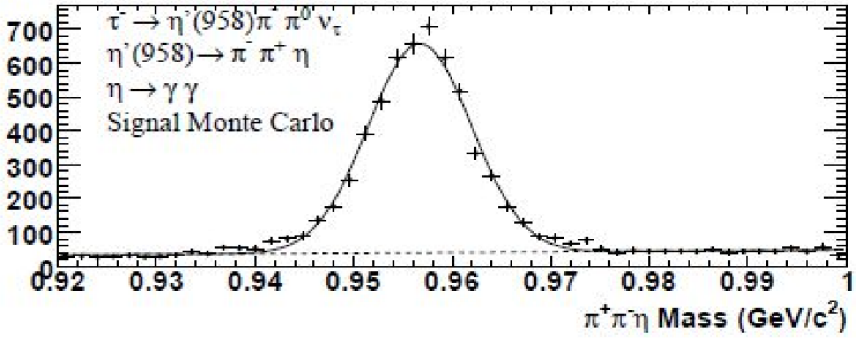


High multi. . . : search for $\tau \to \pi\eta'(958)\nu$ second class currrent

- *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 $m_u = m_d$)*
- *Allowed first class current decays:*
  - $\tau^- \to K^- \eta' \nu_\tau$
  - $\tau^- \to \pi^- \pi^0 \eta' \nu_\tau$
- *Forbidden 2nd class current decay:*
  - $\tau^- \to \pi^- \eta' \nu_\tau$
  - *Predicted to be $< 1.4 \times 10^{-6}$*
- *Analysis strategy:*
  - *Reconstruct $\eta'(958)$ from $\eta' \to \pi^+ \pi^- \eta$*
  - *$\eta \to \gamma\gamma$, $\eta \to \pi^-\pi^+\pi^0$, $\eta \to 3\pi^0$ used only for $\tau^- \to \pi^- \eta' \nu_\tau$*



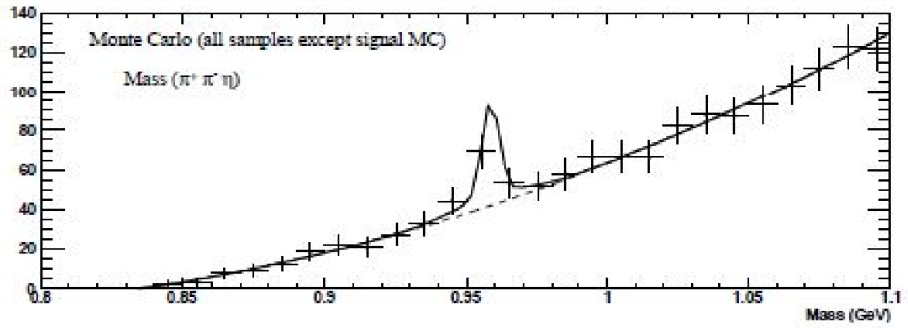




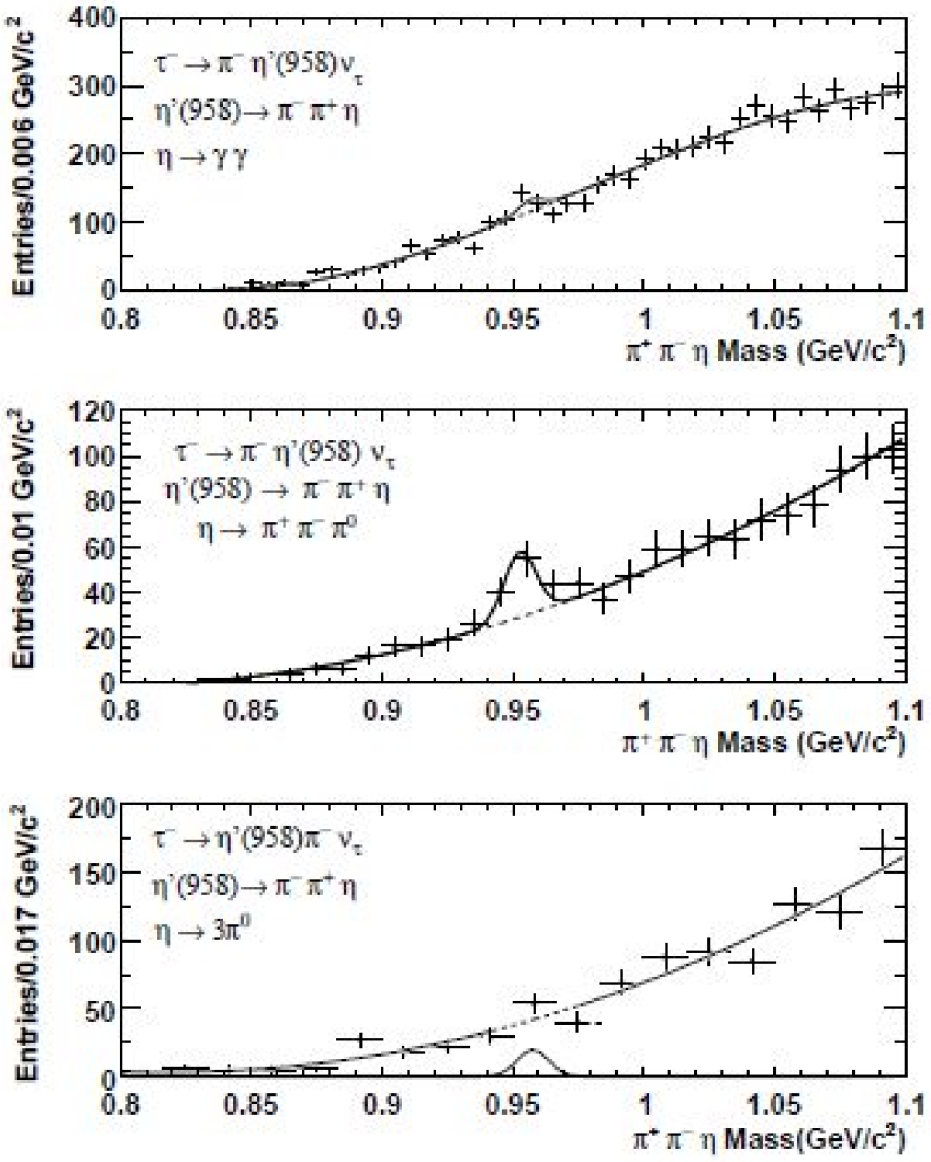
High multi. . . : search for $\tau \to \pi\eta'(958)\nu$ second class currrent

Fit to $\pi^+ \pi^- \eta$ invariant mass for channels with high stat, cut-and-count otherwise

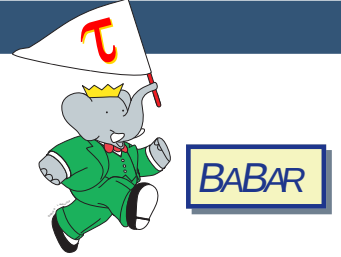
- *No peak is seen for allowed first class current decays:*
  - *$BR(\tau^- \to K^- \eta' \nu_\tau) < 2.4 \times 10^{-6}$ at 90% CL*
  - *$BR(\tau^- \to \pi^- \pi^0 \eta' \nu_\tau) < 1.2 \times 10^{-5}$ at 90% CL*
- *Peak in $\tau^- \to \pi^- \eta' \nu_\tau$, $\eta \to \pi^-\pi^+\pi^0$ fully accounted for by qq background*



- *Limit on 2nd-class current decay:*
  - *$BR(\tau^- \to \pi^- \eta' \nu_\tau) < 4 \times 10^{-6}$ at 90% CL*

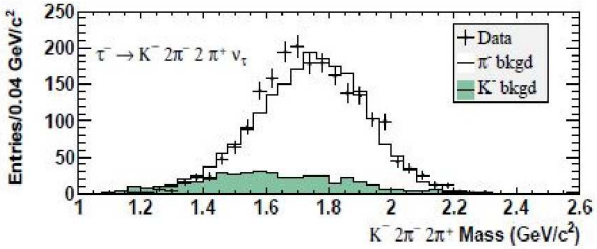


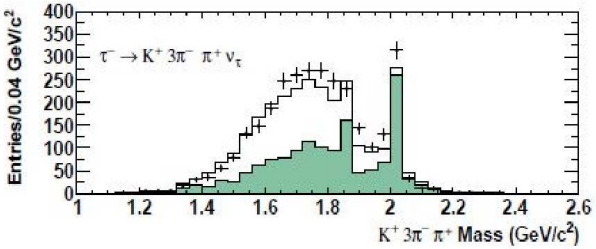
High multiplicity tau decays: final states with kaons

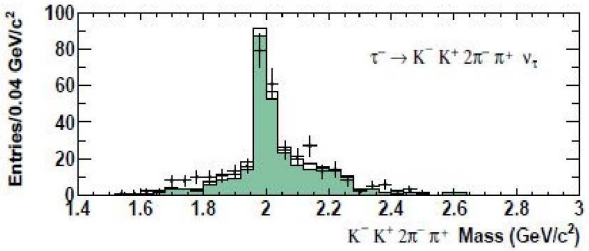


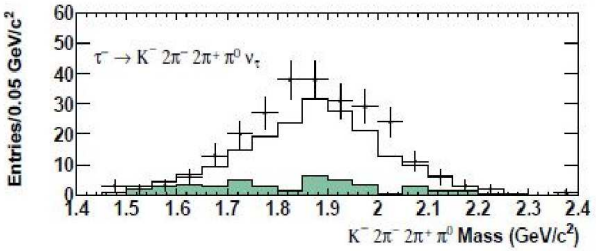
First search for high multiplicity decays involving kaons

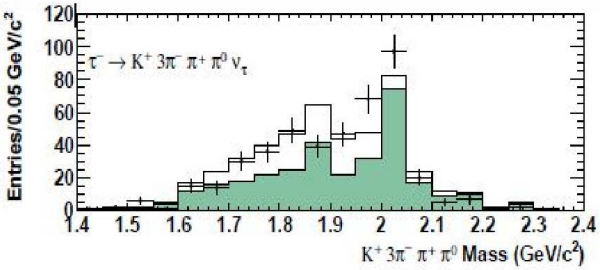
- *Searches for:*
  - $\tau^- \to K^- 2\pi^- 2\pi^+ \nu_\tau$
  - $\tau^- \to K^+ 3\pi^- \pi^+ \nu_\tau$
  - $\tau^- \to K^- K^+ 2\pi^- \pi^+ \nu_\tau$
  - $\tau^- \to K^- 2\pi^- 2\pi^+ \pi^0 \nu_\tau$
  - $\tau^- \to K^+ 3\pi^- \pi^+ \pi^0 \nu_\tau$







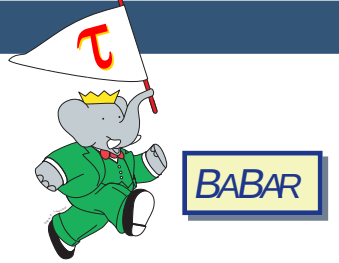




- *No detailed theoretical calculations available*
- *BR expected at most O(10^{-5}-10^{-6}) from (V_{us}/V_{ud})*
- *Invariant mass dist. compatible with background*

Kaonic decays (90% upper level confidence limit)

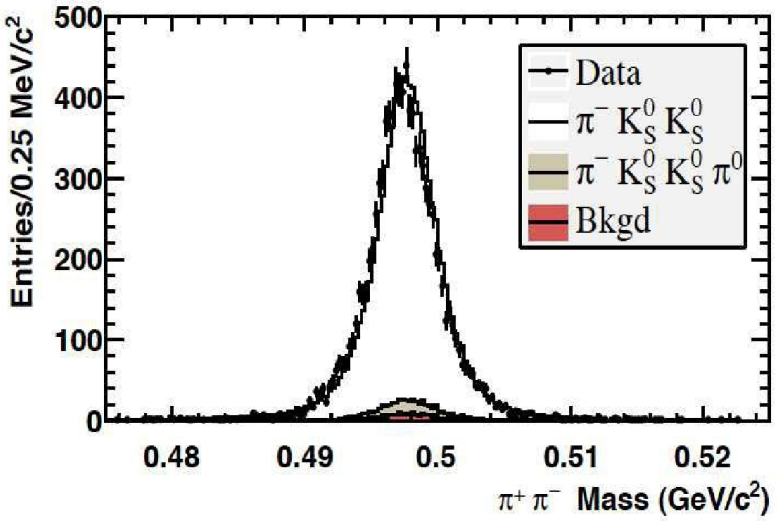
$\tau^- \to K^- 2\pi^- 2\pi^+ \nu_\tau$	$< 2.4 \times 10^{-6}$
$\tau^- \to K^+ 3\pi^- \pi^+ \nu_\tau$	$< 5.0 \times 10^{-6}$
$\tau^- \to K^- K^+ 2\pi^- \pi^+ \nu_\tau$	$< 4.5 \times 10^{-7}$
$\tau^- \to K^- 2\pi^- 2\pi^+ \pi^0 \nu_\tau$	$< 1.9 \times 10^{-6}$
$\tau^- \to K^+ 3\pi^- \pi^+ \pi^0 \nu_\tau$	$< 8 \times 10^{-7}$



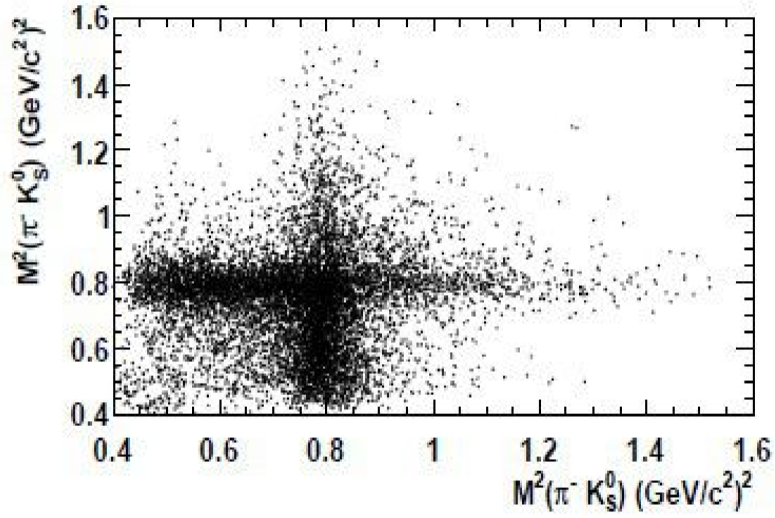
$\mathcal{B}[\tau \to \pi K_S K_S(\pi^0)\nu]$ and $\mathcal{B}[\tau \to K K_S K_S(\pi^0)\nu]$

PRD RC 86 092013 (2012)

- *Four branching fractions poorly known experimentally:*
  - $\tau^- \to \pi^- K^0_S K^0_S \nu_\tau$
  - $\tau^- \to \pi^- K^0_S K^0_S \pi^0 \nu_\tau$
  - $\tau^- \to K^- K^0_S K^0_S \nu_\tau$
  - $\tau^- \to K^- K^0_S K^0_S \pi^0 \nu_\tau$
- *Important background sources for CPV measurements in $\tau \to \pi K^0_S \nu_\tau$ particularly interesting for future experiments*

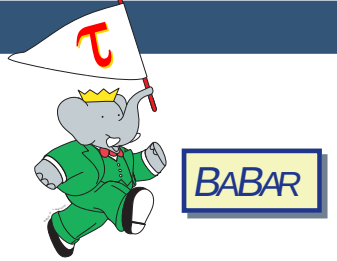


- *Require charged lepton tag*
- *One "prompt" pion on signal side*
- *K^0_S candidates from $\pi^+\pi^-$ with displaced vertex w.r.t. beam-spot (> 3σ)*
- *π^0 candidates from photon pairs with $0.115 < m(\gamma\gamma) < 0.150$ GeV/c² (E_{min} = 30 MeV)*



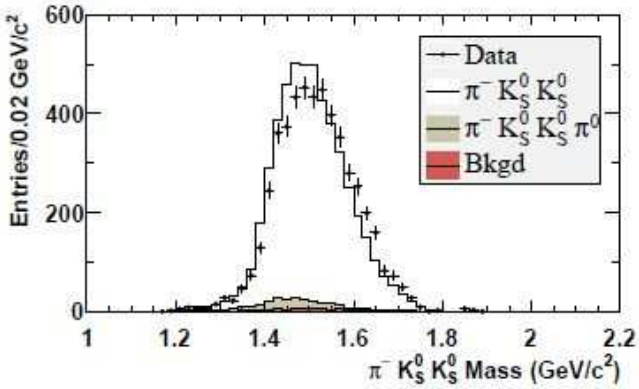
$\mathcal{B}(\tau \to \pi K_S K_S(\pi^0)\nu$ and $\mathcal{B}(\tau \to K K_S K_S(\pi^0)\nu$

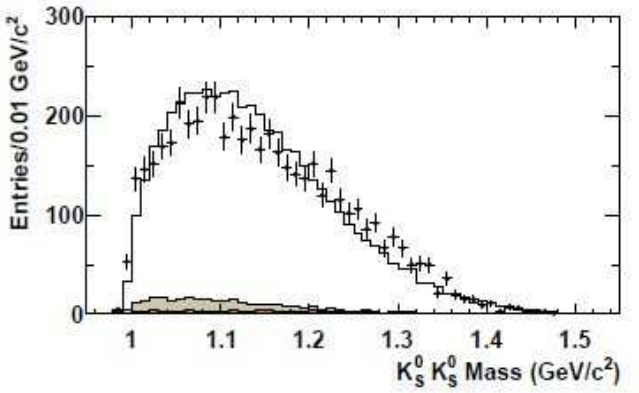
PRD RC 86 092013 (2012)



- *Branching fractions for π determined simultaneously to account for cross-feed*
- *Dominant background from qq production*

- *Measurement of $\tau \to \pi K^0_s K^0_s \nu_\tau$ agrees with CLEO and ALEPH*
- *First observation of $\tau \to \pi K^0_s K^0_s \pi^0 \nu_\tau$ decay*
- *No evidence for $\tau \to K K^0_s K^0_s (\pi^0) \nu_\tau$ decays*
- *Upper limits (at 90% CL) set on $\tau \to \pi K^0_s K^0_s \nu_\tau$ and $\tau \to \pi K^0_s K^0_s \pi^0 \nu_\tau$*

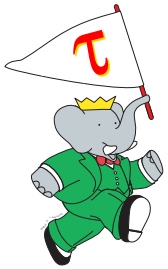




Decay mode	Data events	Estimated background	Efficiency (%)	Branching ratio† (10^{-5})
$\tau^- \to$				
$\pi^- K^0_S K^0_S \nu_\tau$	4985	98 ± 17	4.93 ± 0.03	$23.1 \pm 0.4 \pm 0.8$
$\pi^- K^0_S K^0_S \pi^0 \nu_\tau$	409	35 ± 7	2.65 ± 0.02	$1.60 \pm 0.20 \pm 0.22$
$K^- K^0_S K^0_S \nu_\tau$	23	20.0 ± 0.5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

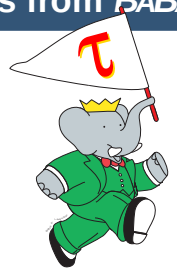
3-prong hadronic spectra



BABAR preliminary

- branching fractions $\mathcal{B}(\tau \to hhh\nu)$, $h = \pi, K$ already published by BABAR (PRL100, 011801, 2008)
- motivation
  - final states contains a rich spectrum of low energy QCD resonances
  - strange spectral functions can be used to extract $|V_{us}|$ and m_s
  - improve theoretical understanding
  - improve Minte Carlosimulations
- analysis strategy
  - use leptonic tags to reduce hadronic backgrounds
  - simultaneous measurements provides data-driven cross-feed bkg determinations
  - remaining bkg subtracted with Monte Carlo
  - efficiency unfolding using Monte Carlo
  - resolution unfolding with Bayesian method (NIM A 362, 487, 1995)

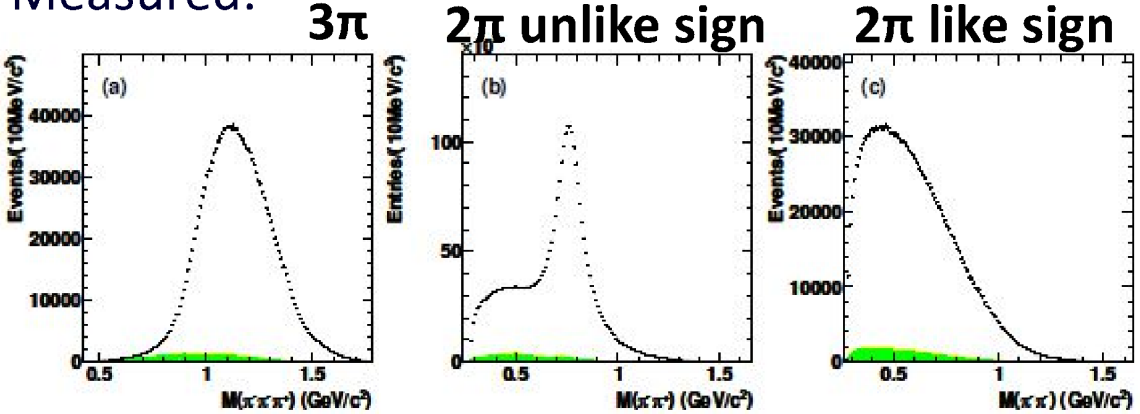
$\tau^- \to \pi^-\pi^+\pi^-\nu$ spectra

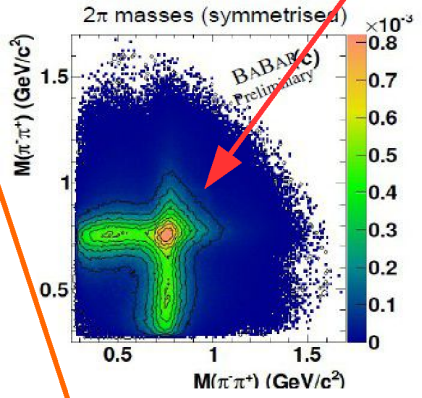


BABAR preliminary

Decay dominated by $a_1(1260)$ decaying to $\pi\rho$

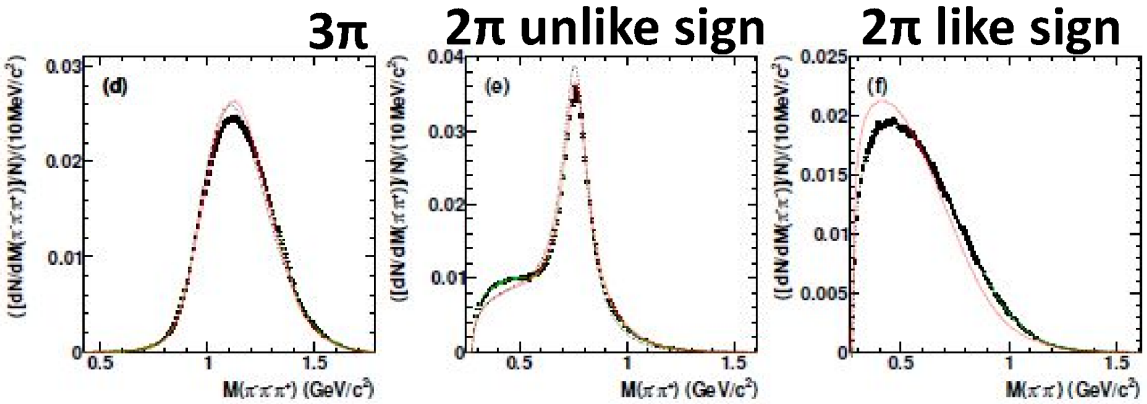
Measured:

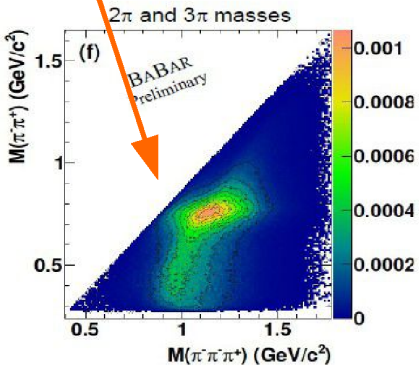




- Corrected*:

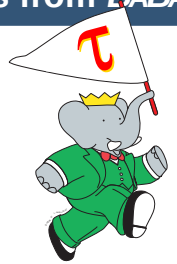
*Resolution unfolded, bkg-subtracted, corrected and normalized





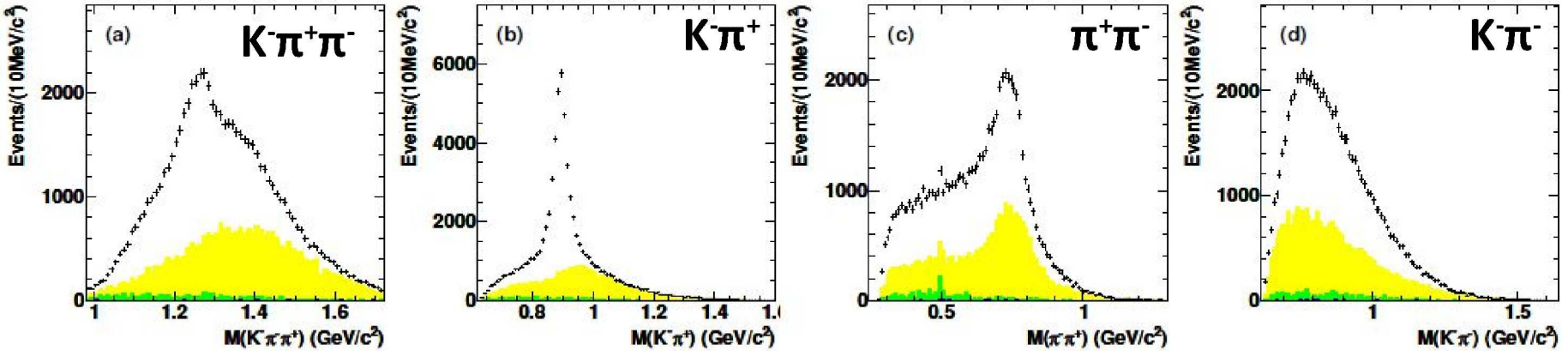
- Data
- τ bkg
- τ bkg (cross-feed)
- TAUOLA CLEO Tunes 1998
- TAUOLA BaBar Tunes

$\tau^- \to K^-\pi^+\pi^-\nu$ spectra



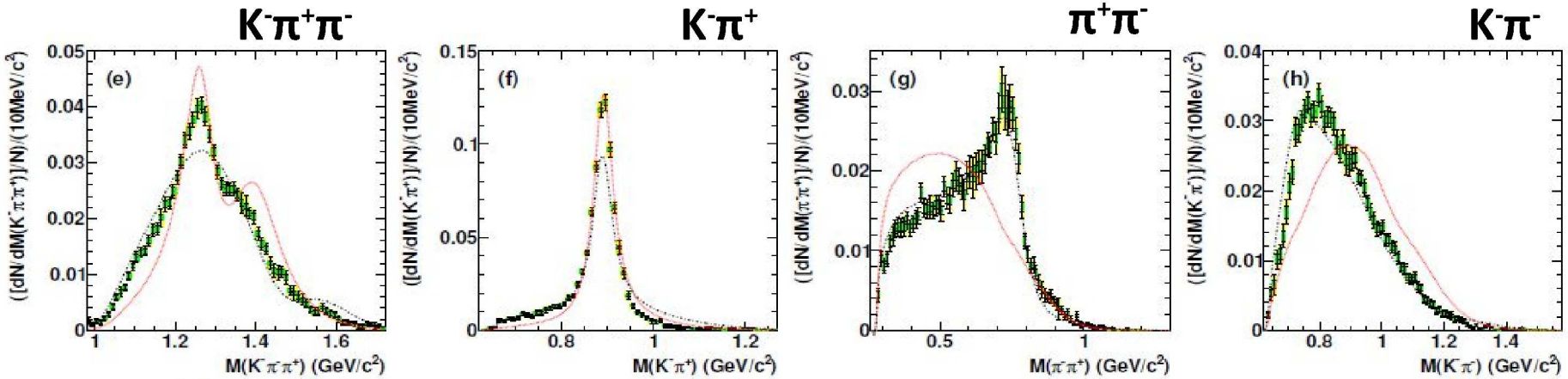
BABAR preliminary

- Measured:

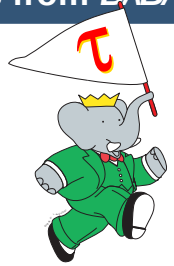


- Corrected*: Decay to $K_1(1270)$ and $K_1(1400)$, then ρ and $K^*(892)$

*Resolution unfolded, bkg-subtracted, corrected and normalized

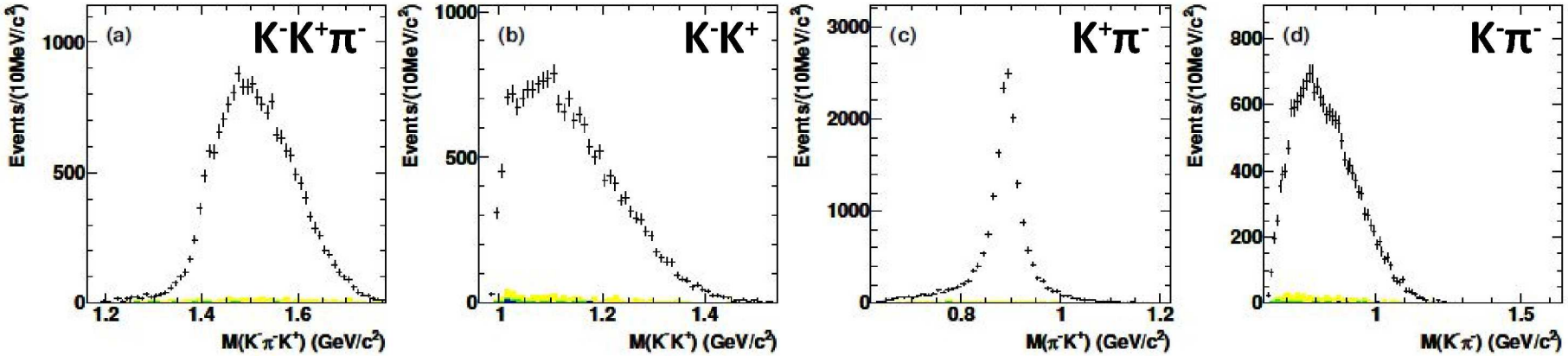


$\tau^- \to K^-K^+\pi^-\nu$ spectra



BABAR preliminary

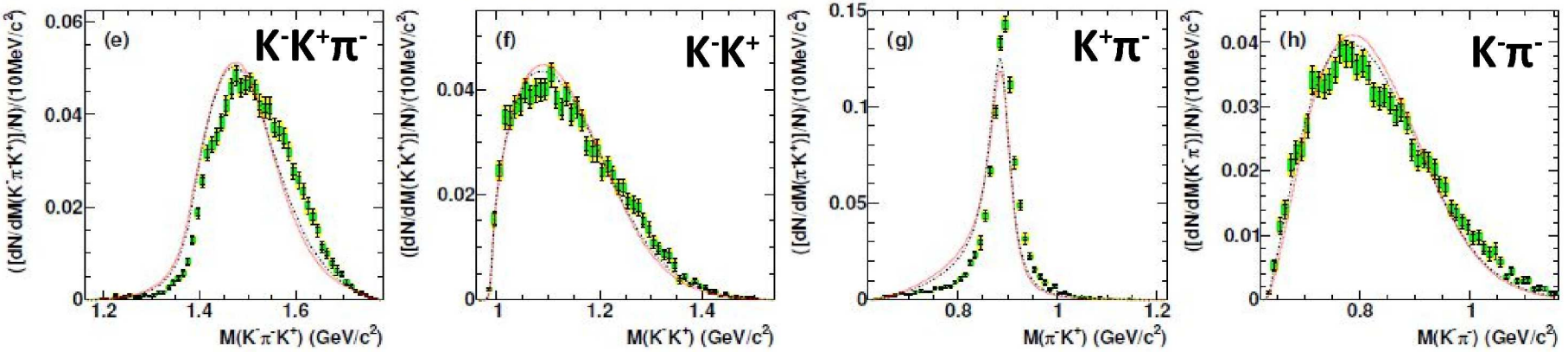
- Measured:



- Corrected*:

Mostly K*(892)

*Resolution unfolded, bkg-subtracted, corrected and normalized



Data

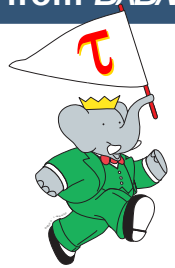
τ bkg

τ bkg (cross-feed)

TAUOLA CLEO Tunes 1998

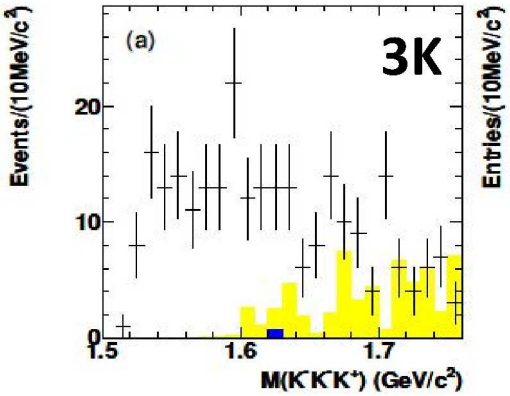
TAUOLA BaBar Tunes

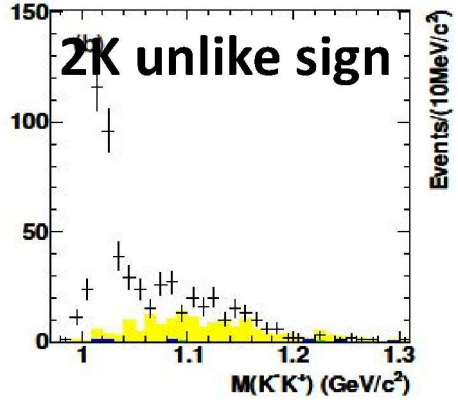
$\tau^- \to K^-K^+K^-\nu$ spectra

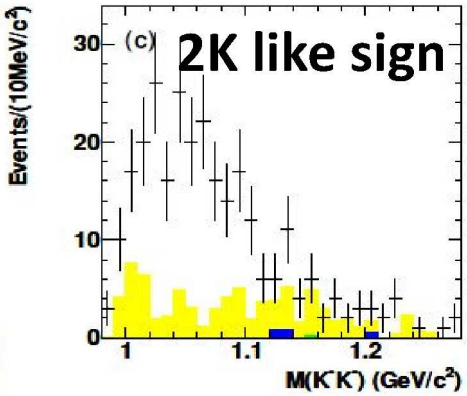


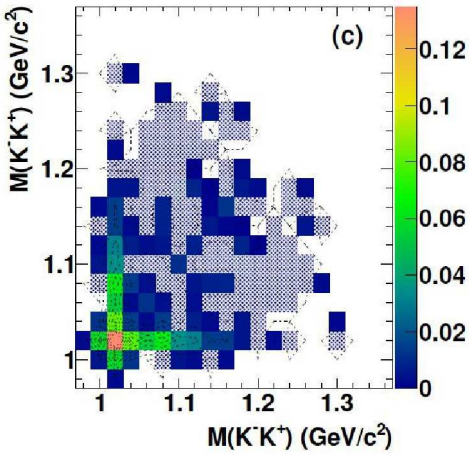
BABAR preliminary

- Measured:



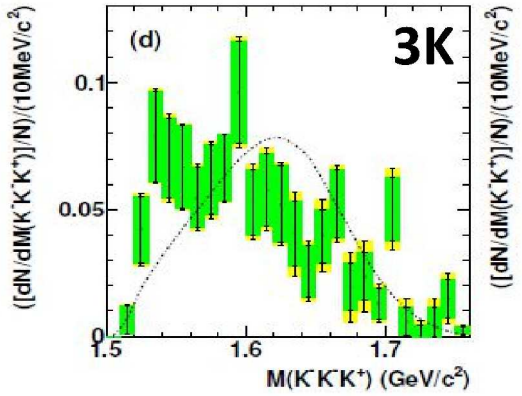


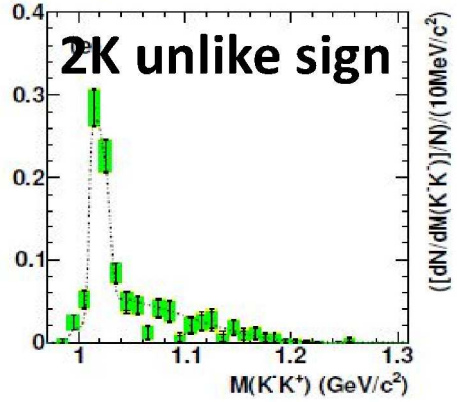


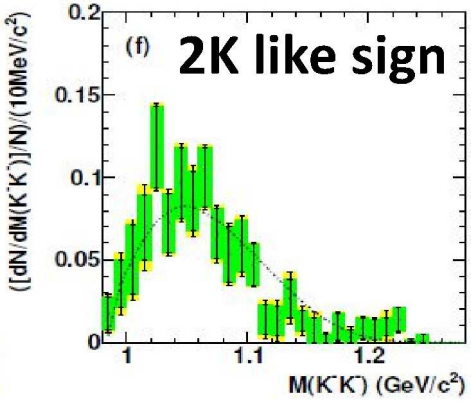


- Corrected*:

*Resolution unfolded, bkg-subtracted, corrected and normalized







■ Data

non-τ bkg

τ bkg (cross-feed)

TAUOLA CLEO Tunes 1998

TAUOLA BaBar Tunes

Summary

- *BABAR* collected a large clean sample of tau pairs
- many physics measurements has been published
  - ~100× improvements on LFV upper limits
  - precision measurements significantly improved where LEP/CLEO were statistics-limited
- recent results just presented include
  - measurements of several small high multiplicity tau branching fractions
    PRD 86 092010 (2012), PRD RC 86 092013 (2012)
  - precision high-statistics measurements of 3-prong tau decays invariant mass spectra (preliminary)
- several additional analyles are on-going (mostly hard ones and systematics-limited)