Measurement of $\tau^- \to K^- \pi^+ \pi^- \nu_\tau$ branching ratio at BELLE

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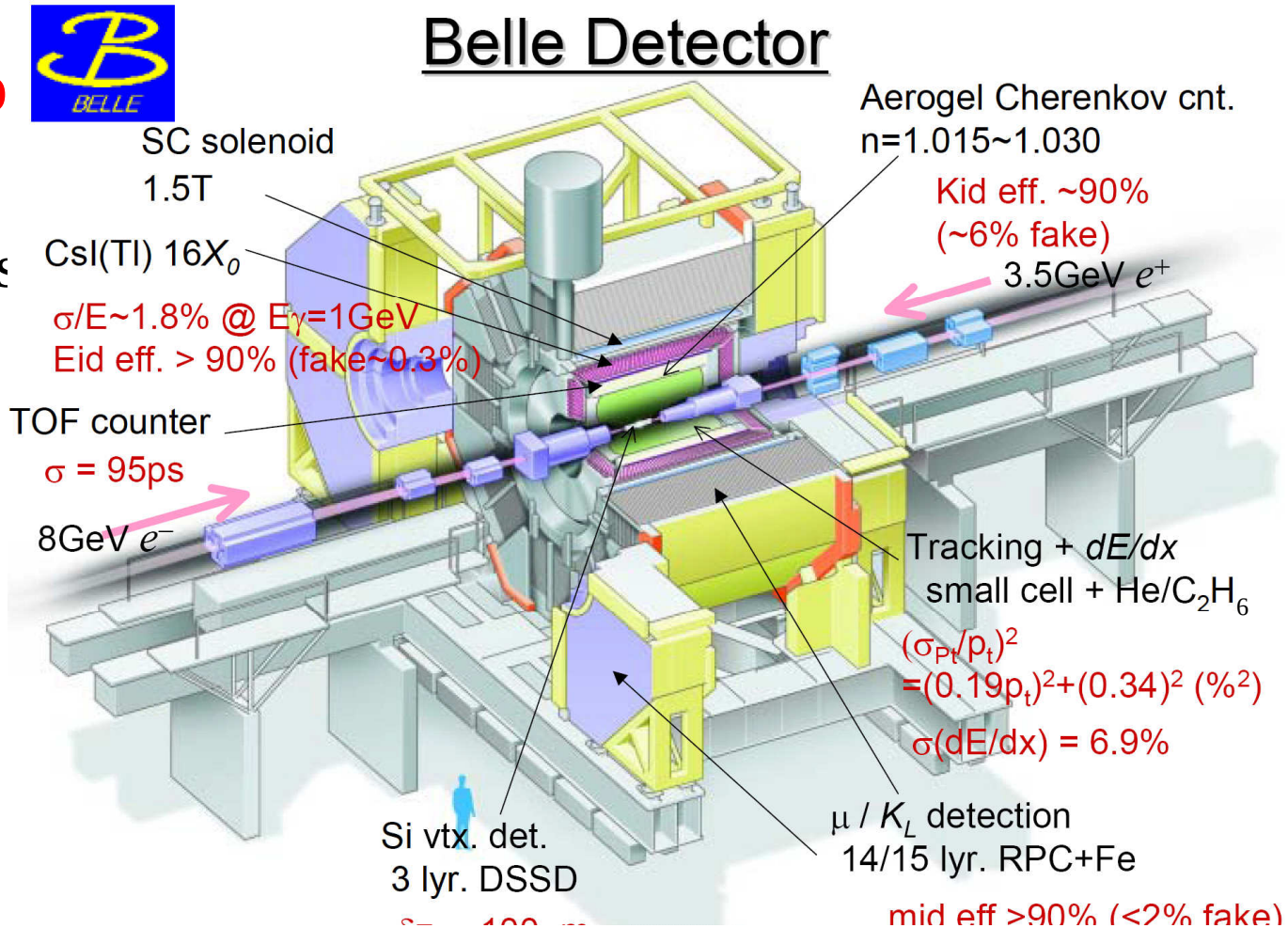
Introduction

- $\tau^- \to K^- \pi^+ \pi^- \nu$ decay
  - Hadronic tau decays with kaons provide a good probe of strange secto r of weak charged current.
  - Cabibbo-suppressed decay
  - Contribution to strange spectral function, strange quark mass and Vus
  - Possible resonance
    - $K_1(1270) \to K^*(892)\pi$, $K^*(892) \to K\pi$ (42% ?)
    - $K_1(1270) \to K\rho(770)$, $\rho(770) \to \pi\pi$ (16% ?)
    - $K_1(1400) \to K^*(892)\pi$, $K^*(892) \to K\pi$ (>40% ?)
  - All these requires BR and invariant mass distribution study.
- Main Background :
  - $\tau \to \pi\pi^+\pi^-\nu_t$, (BR = 9.33%), $\tau \to KK\pi\nu_t$ (BR = 0.153%), $\tau \to KK_s\nu_t$ (BR = 0.077%)
  - Kaon identification is the most important in this analysis, because of large branching ratio of $\tau \to \pi\pi^+\pi^-\nu_t$
- Four 3-prong modes should be measured simultaneously.

KEKB/Belle experiment

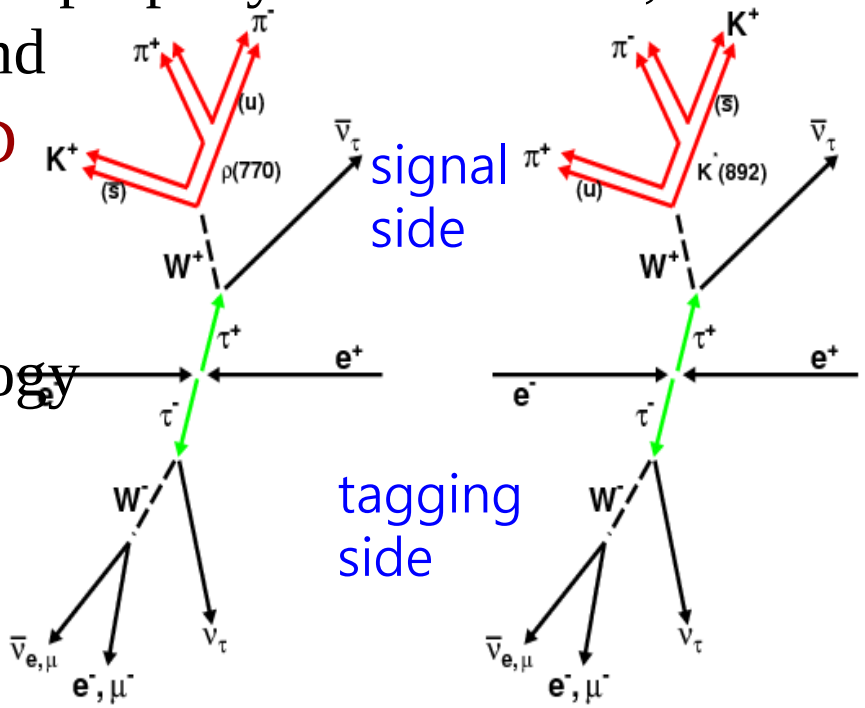
- High intensity e^+e^- co lider on Y(4S)
  - World highest luminos ty of $1.7 \times 10^{34}/cm^2/s$
  - Similar cross-section with BB (~0.9nb)

    → τ-factory!
  - Good PID ability and vertex resolution



Event selection for $\tau \to hhh\nu$

1. Tau candidate selection
   - Number of charged track = 4 and sum of charge = 0, with proper Calorimeter energy, vertex, and transverse momentum requirement
2. Background suppression
   - Require missing momentum should be properly reconstructed, to suppress 2-γ and q-qbar background
   - Tight likelihood ratio cut for Kaon ID
   - Select a event with one e or μ, and three K or π
   - Event shape : thrust, 3-1 prong topology
   - Invariant mass cut
     : require tau mass range



3. Final event selection

- No Ks, π^0, energetic gamma candidate

: signal
: BG

Cuts	Efficiency (N(passed) / N(total))			
	$\tau\to K\pi\pi\nu$	$\tau\to Ks\pi\nu$	$\tau\to\pi\pi\pi\pi^0\nu$	$e^+e^-\to qq$
tau pair selection	**0.77**	**0.63**	**0.78**	
N(trk) = 4	**0.53**	**0.16**	**0.51**	**0.20**
Missing mass	**0.45**	**8.5×10^{-2}**	**0.43**	**0.13**
PID	**0.33**	**6.1×10^{-2}**	**0.33**	**8.3×10^{-3}**
Thrust cut/3-1 prong	**0.31**	**5.7×10^{-2}**	**0.30**	**6.9×10^{-4}**
Inv. mass cut	**0.30**	**5.6×10^{-2}**	**0.29**	**2.9×10^{-4}**
N(Ks) = 0	**0.30**	**2.0×10^{-2}**	**0.29**	**2.6×10^{-4}**
N(π^0) = 0	**0.28**	**1.8×10^{-2}**	**0.14**	**6.6×10^{-5}**
N(γ) = 0	**0.28**	**1.8×10^{-2}**	**0.06**	**4.0×10^{-5}**

$\tau\to hhh\nu$ selection efficiency

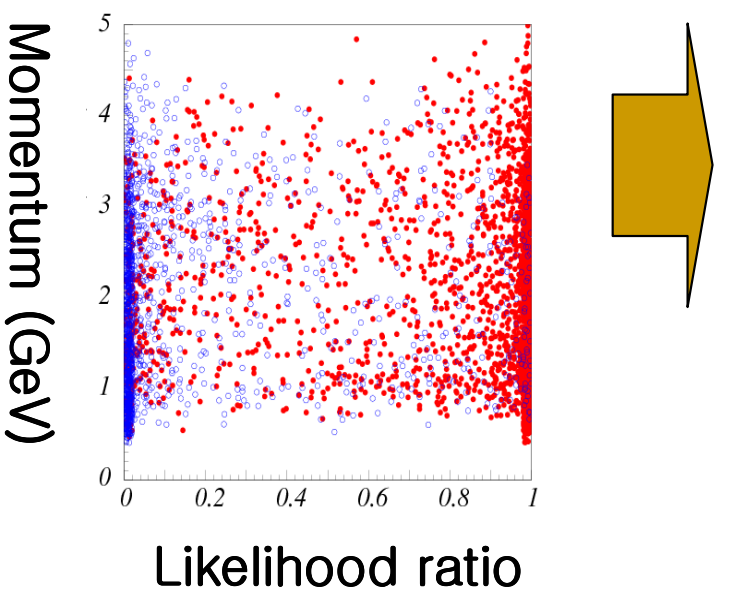
In $\tau\to K\pi\pi\nu$ real data : **qq events ratio : 0.84%**
Two photon events ratio : 0.12%

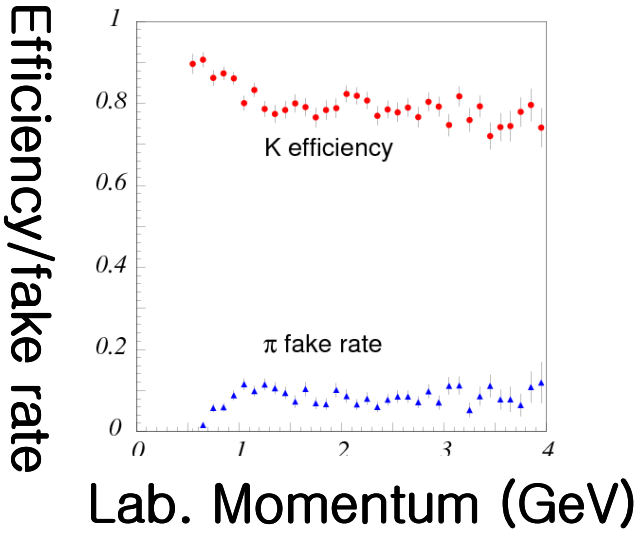
Suppressed sufficiently!

K/π separation

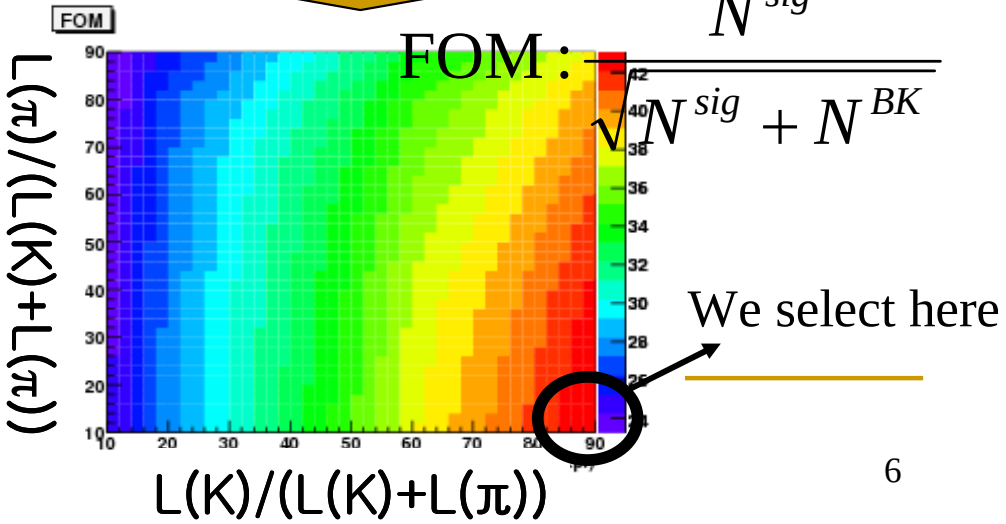
Used dE/dx, Cherenkov angle, and time of flight for K/π Likelihood ratio : L(K)/(L(K)+L(π))

Used $D^{*+} \to D^0(\to K^-\pi^+)\,\pi^+$ to measure efficiency, fake rate and their systematics





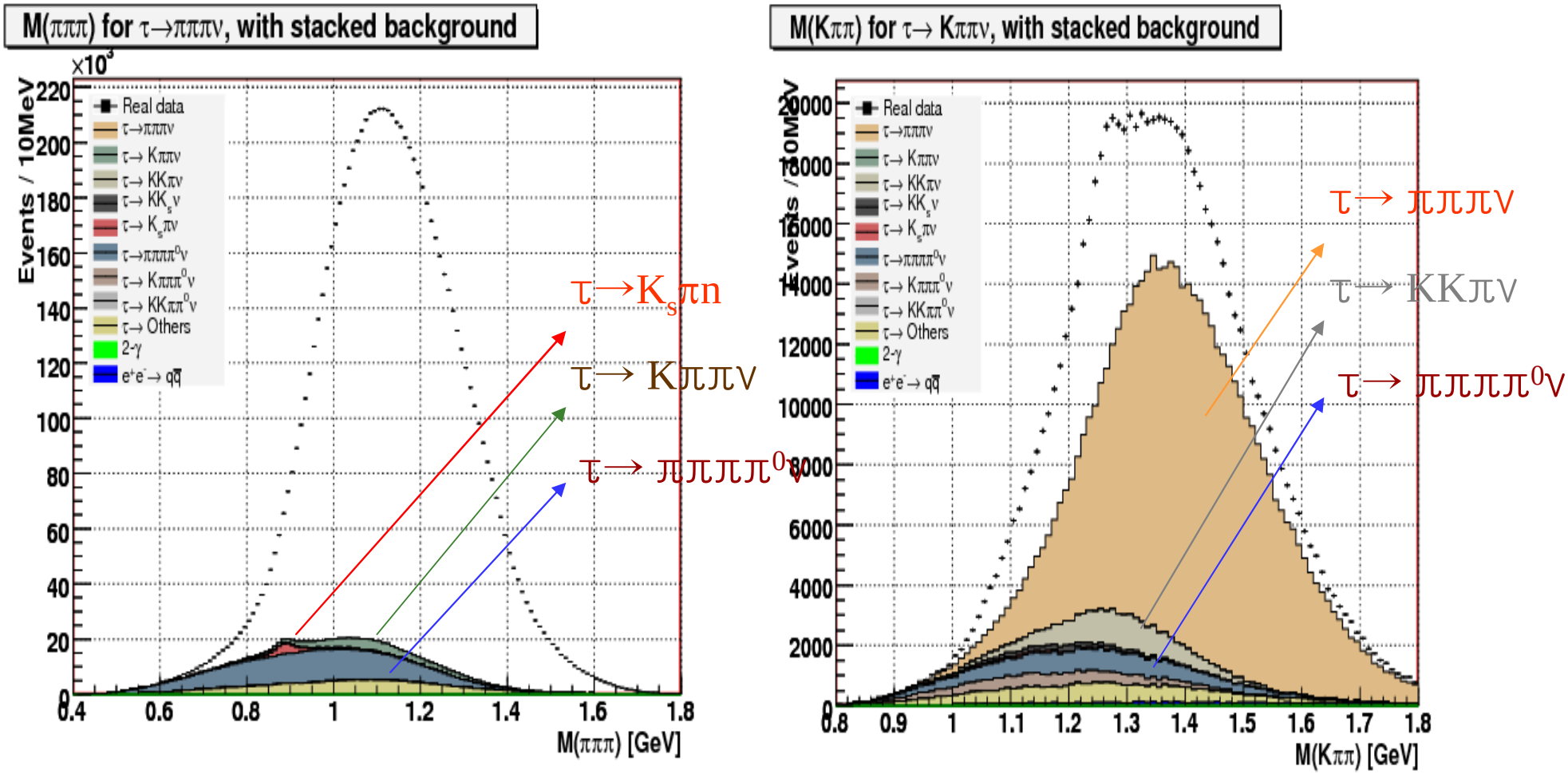
Construct figure of merit to select best cut for Kaon ID likelihood ratio,
When signal : Kππ decay
Background : πππ, KKπ decay



Data

- Tau candidate with 668.9 fb^{-1} collected by BELLE detector (615M $\tau\tau$ pair)
- Tau generic MC generated by KKMC and TAUOLA package : ~ 1340 fb^{-1}

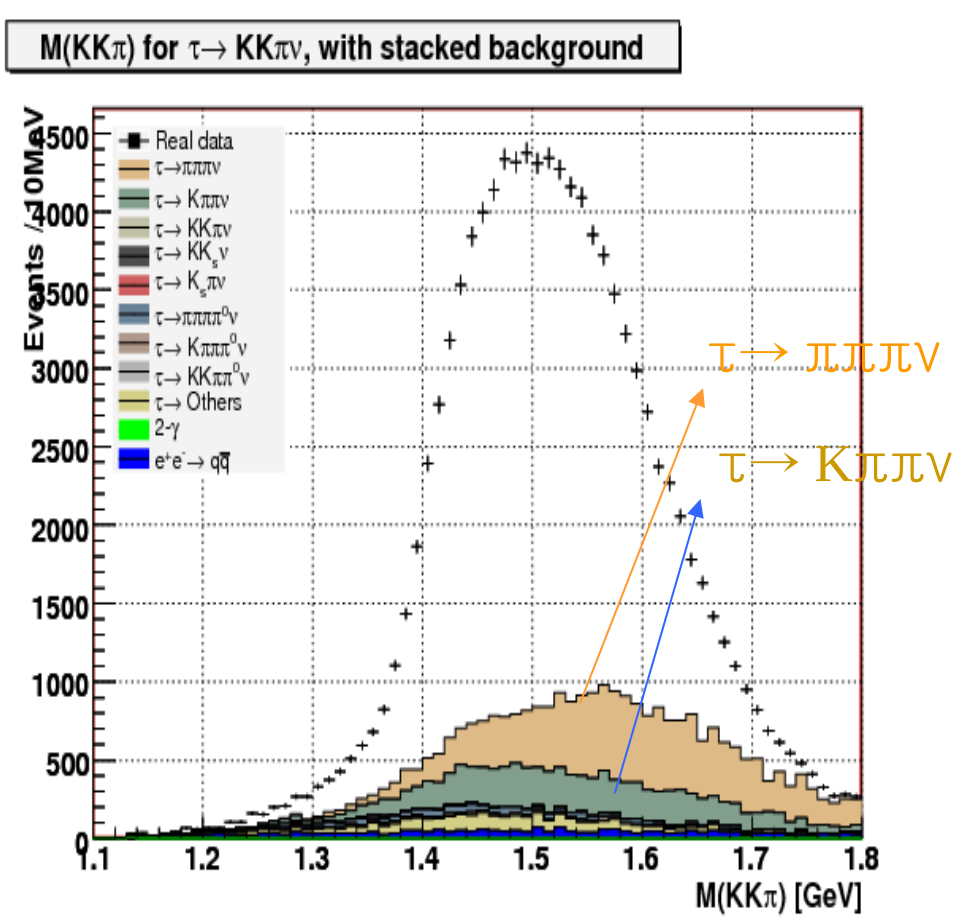
Comparison of M_{INV} distribution of $\tau^- \to \pi^-\pi^+\pi^-\nu$, $\tau^- \to K^-\pi^+\pi^-\nu$

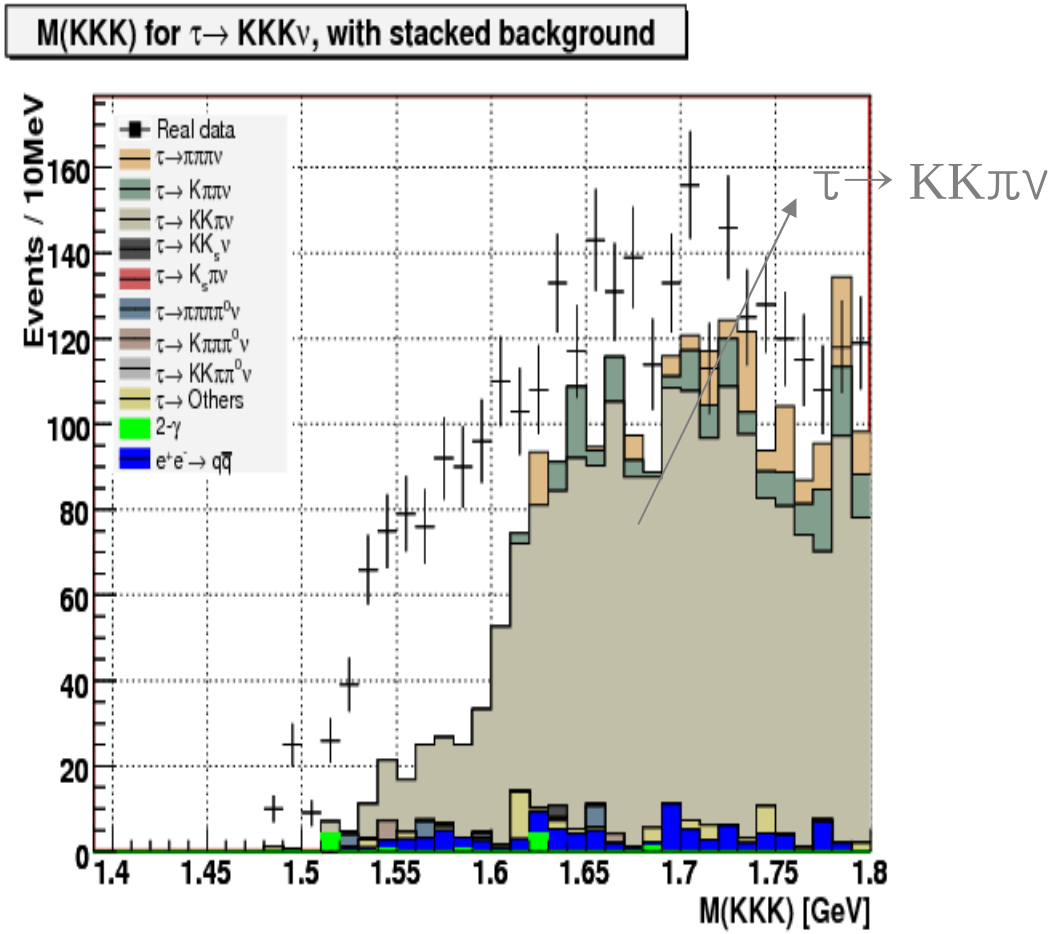


Black point : real data

Colored (stacked) histogram : background estimated from MC

Comparison of M_{INV} distribution of $\tau^- \to K^- K^+ \pi^- \nu$, $\tau^- \to K^- K^+ K \pi^- \nu$





Black point : real data

Colored (stacked) histogram : background estimated from MC

Branching ratio calculation

$$N_i^{true} = \varepsilon^{-1}_{ij} N_j^{rec}$$

N_i^{true} : Number of true event for i-th mode
N_i^{rec} : Number of reconstructed event for i-th mode
ε : efficiency migration matrix

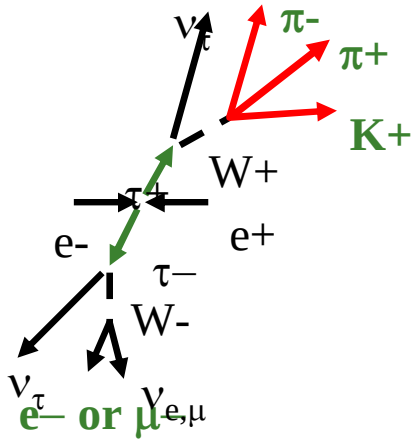
Efficiency migration matrix ε (%)

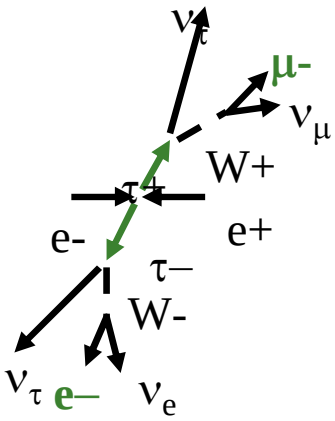
rec \ true	τ→πππν	τ→Kππν	τ→KKπν	τ→KKKν
τ→πππν	23.0	7.6	2.3	0.73
τ→Kππν	1.2	17.2	4.9	2.3
τ→KKπν	4.0×10^{-2}	0.47	12.9	6.0
τ→KKKν	2.8×10^{-4}	1.4×10^{-2}	0.28	9.4

- Efficiency : 10 ~ 20%
- Fake rate from ππ to Kππ is sufficiently small

Normalization by (τ→evν;τ→μνν)

Normalized by a event that one tau decay to τ→evν
and the other tau decay to τ→μνν



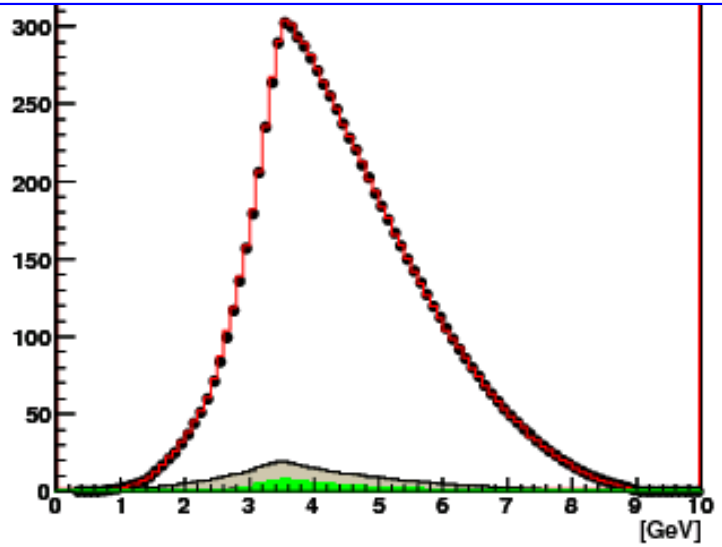


$$Br_{\tau\to K\pi\pi\nu} = \frac{N_{Sig,K\pi\pi}}{2N_{\tau\tau}\varepsilon_{K\pi\pi}(Br_{\tau\to e\nu\nu}+Br_{\tau\to\mu\nu\nu})} \qquad Br_{\tau\to e\nu\nu}\times Br_{\tau\to\mu\nu\nu} = \frac{N_{Sig,e\mu}}{2N_{\tau\tau}\varepsilon_{e\mu}}$$

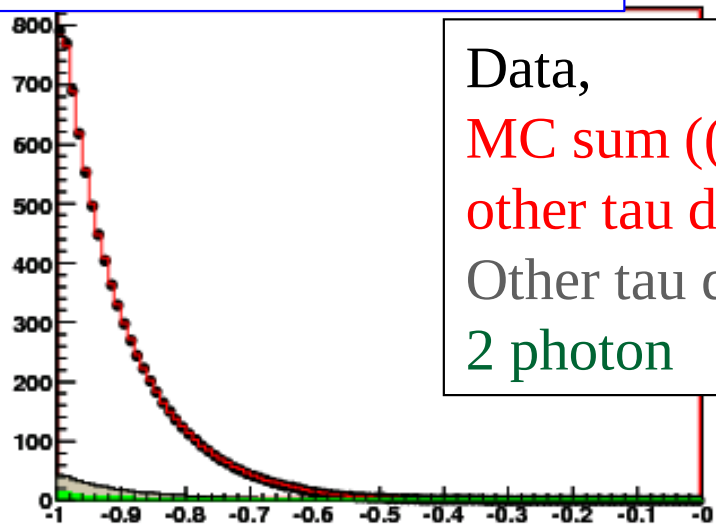
$$\Rightarrow \quad Br_{\tau\to K\pi\pi\nu} = \frac{N_{sig,K\pi\pi}\cdot\varepsilon_{e\mu}}{N_{sig,e\mu}\cdot\varepsilon_{K\pi\pi}}\cdot\frac{Br_{\tau\to e\nu\nu}\cdot Br_{\tau\to\mu\nu\nu}}{Br_{\tau\to e\nu\nu}+Br_{\tau\to\mu\nu\nu}}$$

Need precise measurement

$\sqrt{(E_e + E_\mu)^2 - (\vec{p}_e + \vec{p}_\mu)^2}$ distribution



$\cos(e, \mu)$ distribution



Data,
MC sum ((e;μ) signal MC + other tau decay + 2 photon)
Other tau decay,
2 photon

Extract (τ→eνν;τ→μνν) event number by subtracting MC background from data

List of systematic errors

	$\tau\to\pi\pi\pi\nu$	$\tau\to K\pi\pi\nu$	$\tau\to KK\pi\nu$	$\tau\to KKK\nu$
Track find eff.	3.2	3.2	3.2	3.1
Eff. mig. matrix (including PID)	1.5	1.7	1.9	2.3
Trigger eff.	0.5	0.5	0.6	0.6
Luminosity	0.1	0.1	0.1	0.1

- Track finding efficiency : estimated from $D^*\to\pi D^0$, $D^0\to\pi\pi Ks$, $Ks\to\pi^+\pi^-$
- Lepton ID error : estimated from $\gamma\gamma\to ee/\mu\mu$
- Kaon ID error : estimated from $D^{*+}\to D^0\pi_s^+$, $D^0\to K^-\pi^+$
- Trigger efficiency : ~86 $\pm$0.6%
- Luminosity error : 668.9 fb^{-1} $\pm$1.4%

	$\tau \to \pi\pi\pi\nu$	$\tau \to K\pi\pi\nu$	$\tau \to KK\pi\nu$	$\tau \to KKK\nu$
Gamma veto	0.8	2.5	1.1	1.0
BF correction	0.3	2.0	0.2	0.3
Lep. decay BF	0.2	0.2	0.2	0.2
Total (%)	3.7	4.9	3.9	4.0

- Gamma veto : Number of energetic gamma and its energy are changed
- BF correction : The error of generator level branching fraction from other modes
- Leptonic decay branching fraction : 0.352 ± 0.001

~ 4% for all modes. The track finding efficiency error is dominant.

Result on branching ratio

(Preliminary result)

	Branching ratio	Br (PDG2008)
$\tau^- \to \pi^-\pi^+\pi^-\nu$	$(8.41 \pm 0.00(st.)^{+0.32}_{-0.30}(sy.)) \times 10^{-2}$	$(9.03 \pm 0.06) \times 10^{-2}$
$\tau^- \to K^-\pi^+\pi^-\nu$	$(3.25 \pm 0.02(st.)^{+0.16}_{-0.15}(sy.)) \times 10^{-3}$	$(2.87 \pm 0.16) \times 10^{-3}$
$\tau^- \to K^-K^+\pi^-\nu$	$(1.53 \pm 0.01(st.)^{+0.06}_{-0.06}(sy.)) \times 10^{-3}$	$(1.40 \pm 0.05) \times 10^{-3}$
$\tau^- \to K^-K^+K^-\nu$	$(2.60 \pm 0.23(st.)^{+0.10}_{-0.10}(sy.)) \times 10^{-5}$	$(1.58 \pm 0.18) \times 10^{-5}$

Cf) CLEO result (2003)

	Branching ratio
$\tau^- \to \pi^-\pi^+\pi^-\nu$	$(9.13 \pm 0.05(st.) \pm 0.46\,(sy.)) \times 10^{-2}$
$\tau^- \to K^-\pi^+\pi^-\nu$	$(3.84 \pm 0.14(st.) \pm 0.38\,(sy.)) \times 10^{-3}$
$\tau^- \to K^-K^+\pi^-\nu$	$(1.55 \pm 0.06(st.) \pm 0.09\,(sy.)) \times 10^{-3}$
$\tau^- \to K^-K^+K^-\nu$	$< 3.7 \times 10^{-5}$ @ 90%

Summary

- Hadronic tau decays to final states with three charged had rons are studied with ~5x10^8 τ-pair decays.
- Evaluate BR of $\tau^- \rightarrow K^-\pi^+\pi^-\nu$, $\tau^- \rightarrow K^-K^+\pi^-\nu$, $K^-K^+K^-\nu$, si multaneously
  - **$B(\tau^- \rightarrow K^-\pi^+\pi^-\nu) = (3.25 \pm 0.02^{+0.16}_{-0.15}) \times 10^{-3}$**
    - $B(\tau^- \rightarrow \pi^-\pi^+\pi^-\nu) = (8.41 \pm 0.00(st.)^{+0.32}_{-0.30}(sy.)) \times 10^{-2}$
    - $B(\tau^- \rightarrow K^-K^+\pi^-\nu) = (1.53 \pm 0.01^{+0.06}_{-0.06}) \times 10^{-3}$
    - $B(\tau^- \rightarrow K^-K^+K^-\nu) = (2.60 \pm 0.23^{+0.10}_{-0.10}) \times 10^{-5}$
  - Selected proper event selection criteria for PID, and (e;μ) normalization : To reduce the systematic error
  - Consistent with CLEO result, inconsistent with recent PDG (which is contributed largely by the most recent precise measurement from BABAR) and higher systematic error level than BABAR result.