Search for Lepton Flavor Violation at BELLE : $\tau \to \ell hh$

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for the Belle collaboration

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Introduction

Observation of Lepton flavor violation (LFV) is *"unreachable"* if one is only guided by the non-zero neutrino masses observed in recent experiments.
Many new physics models indicate that it may be possibile to observe in current accelerator experiments.

$\Rightarrow$ **LFV is clear and unmistakeable evidence for new physics**

and

can be searched for by using the large τ samples available at KEKB.

$N_{\tau\tau} = 144{,}000{,}000$ events
($\int Ldt = 158$ /fb
@e^+(8.0GeV)e^-(3.5GeV) CM)

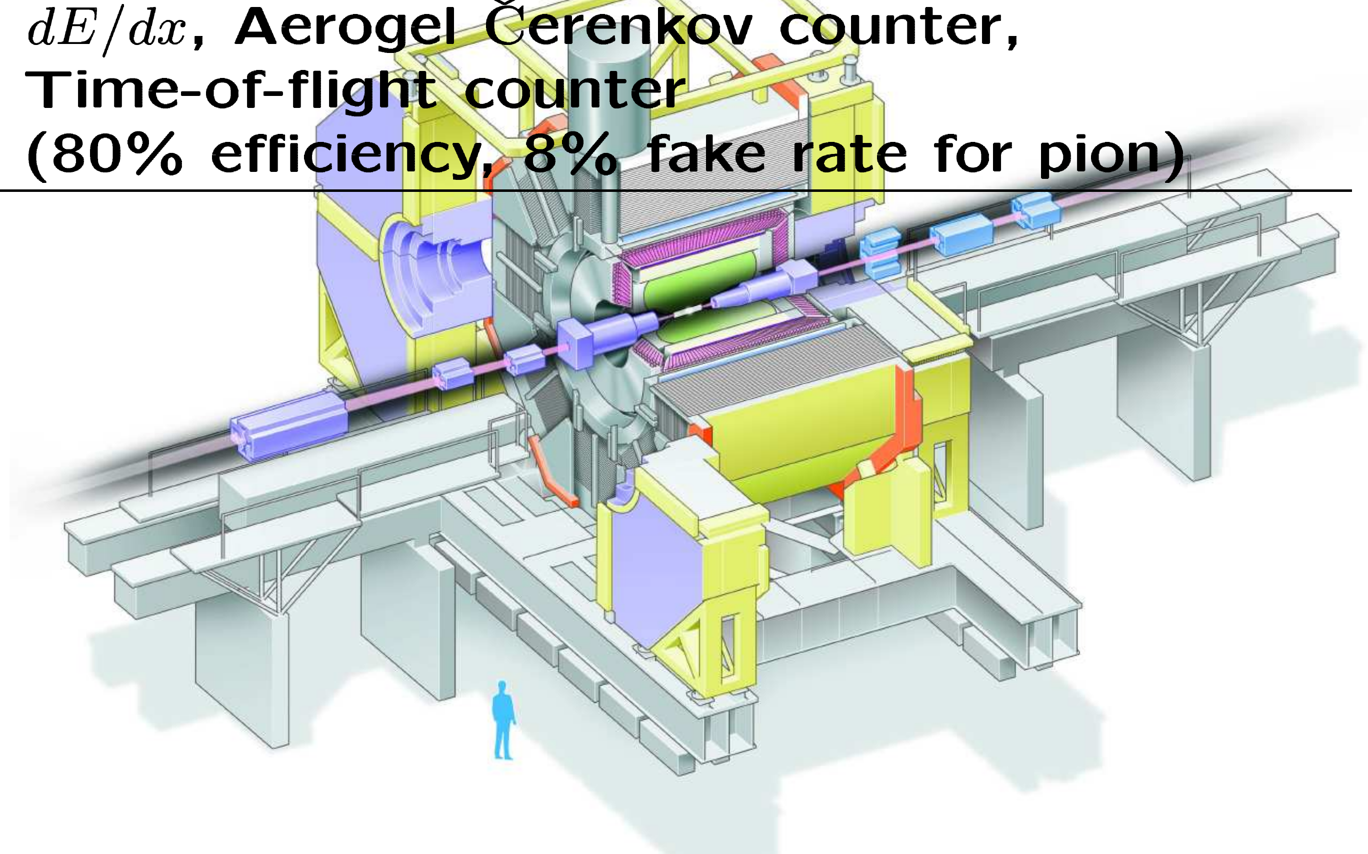
Upper limits of $\tau \to 3$-$charged$ LFV mode ($\times 10^{-7}$)

Mode	PDG2004 value (CLEO98)	BELLE results PLB 589 (2004) 103
$\tau^- \to e^-e^+e^-$	29	3.5
$\tau^- \to e^-\mu^+\mu^-$	18	2.0
$\tau^- \to e^+\mu^-\mu^-$	15	2.0
$\tau^- \to \mu^-e^+e^-$	17	1.9
$\tau^- \to \mu^+e^-e^-$	15	2.0
$\tau^- \to \mu^-\mu^+\mu^-$	19	2.0
$\tau^- \to e^-\pi^+\pi^-$	22	
$\tau^- \to e^+\pi^-\pi^-$	19	
$\tau^- \to \mu^-\pi^+\pi^-$	82	
$\tau^- \to \mu^+\pi^-\pi^-$	34	
$\tau^- \to e^-\pi^+K^-$	64	
$\tau^- \to e^-\pi^-K^+$	38	
$\tau^- \to e^+\pi^-K^-$	21	
$\tau^- \to e^-K^-K^+$	60	
$\tau^- \to e^+K^-K^-$	68	
$\tau^- \to \mu^-\pi^+K^-$	75	
$\tau^- \to \mu^-\pi^-K^+$	74	
$\tau^- \to \mu^+\pi^-K^-$	70	
$\tau^- \to \mu^-K^-K^+$	150	
$\tau^- \to \mu^+K^-K^-$	60	

Belle detector

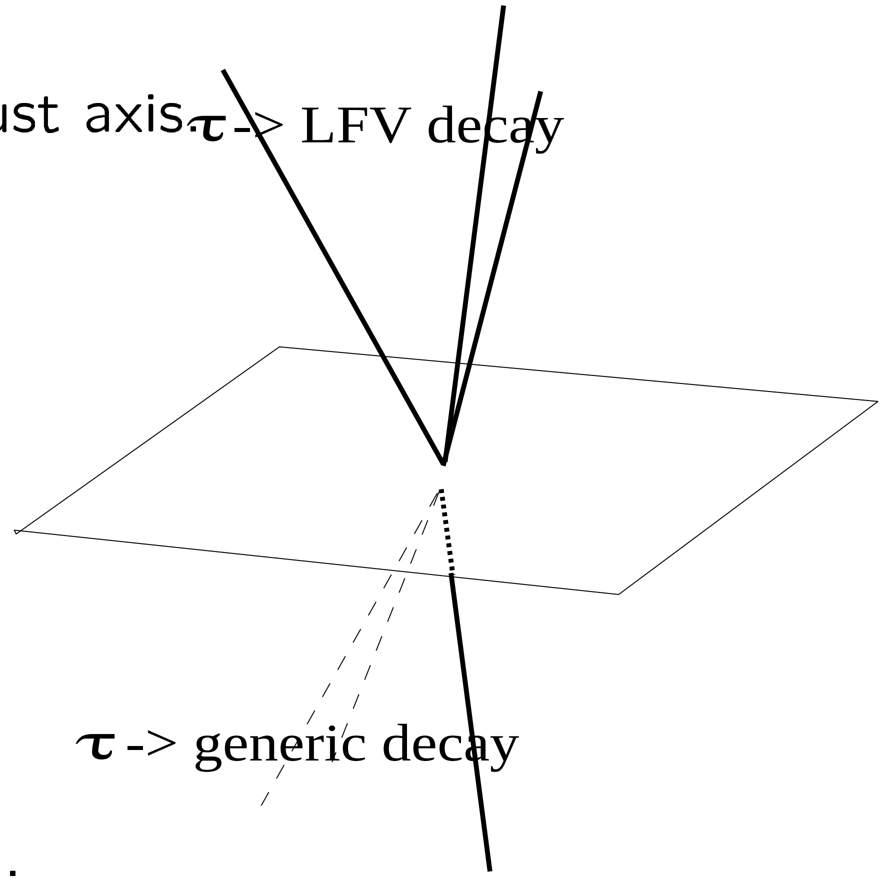
General purpose detector with excellent capabilities for precise vertex determination and particle identification.

Tracking	**:**	**Silicon detector, Drift Chanber**
Photon detection	**:**	**CsI electromagnetic calorimeter**
Electron identification	**:**	$dE/dx, E/p$ **(90% efficiency, 0.2% fake rate for hadron)**
Muon identification	**:**	**14-layer RPC muon detector** **(90% efficiency, 2% fake rate for hadron)**
Kaon identification	**:**	dE/dx**, Aerogel Čerenkov counter,** **Time-of-flight counter** **(80% efficiency, 8% fake rate for pion)**



Analysis Method

First, an event is divided in 2 hemisphare using a plane perpendicular to the event thrust axis.



$e^+e^- \to \tau\tau$

Signal side tau decay into LFV:

$\tau \longrightarrow \ell hh$ **(**$\ell = e$ or μ**,** $h = \pi$ or K**)**

Other side:

$\tau \longrightarrow$ **"1-prong" (83.35%)**

tracks from each tau decay can be separated in the e^+e^- center-of-mass system.

— **4 charged traks with zero total charge**

— **3prong (1 lepton and 2 pion/Kaon) vs 1prong event topology (@e^+e^- CM)**

— **Number of photon in signal side $\leq$ 2**
other side $\leq$ 1

$q\bar{q}$ continuum ($q = u, d, s$) background suppression

by limiting the decay mode of 1-prong side only:

Leptonic modes: $\tau \to \ell \nu_\ell \nu_\tau$

— 1-prong side track is e or

— 1-prong side track is μ

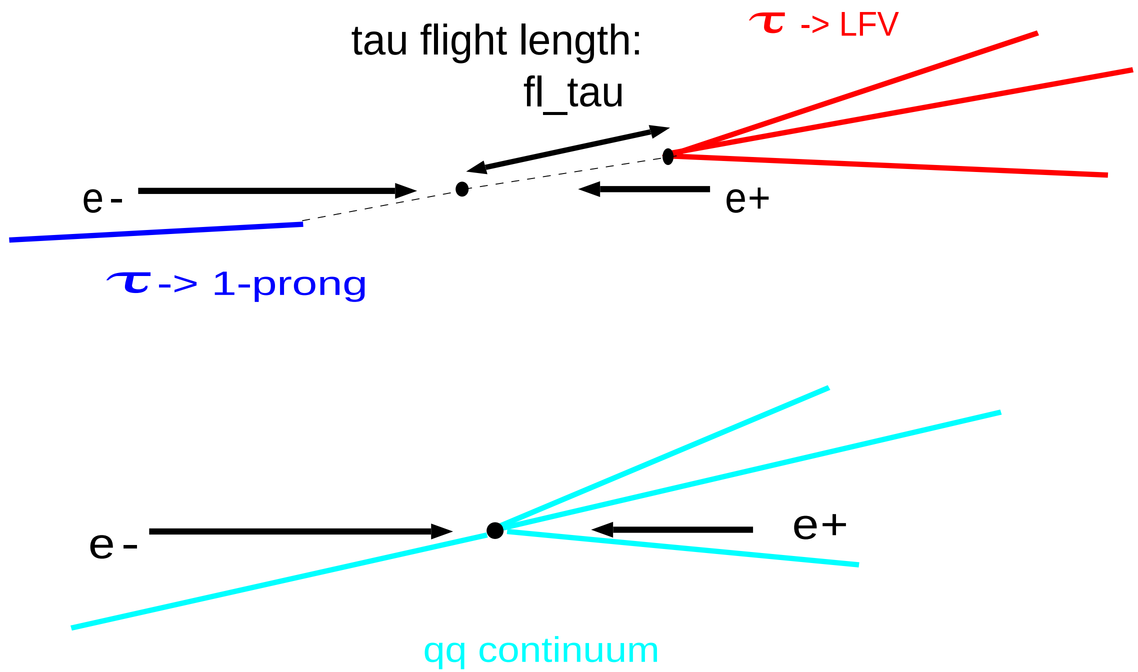
Pionic mode: $\tau \to \pi \nu_\tau$, $\pi \pi^0 \nu_\tau$...

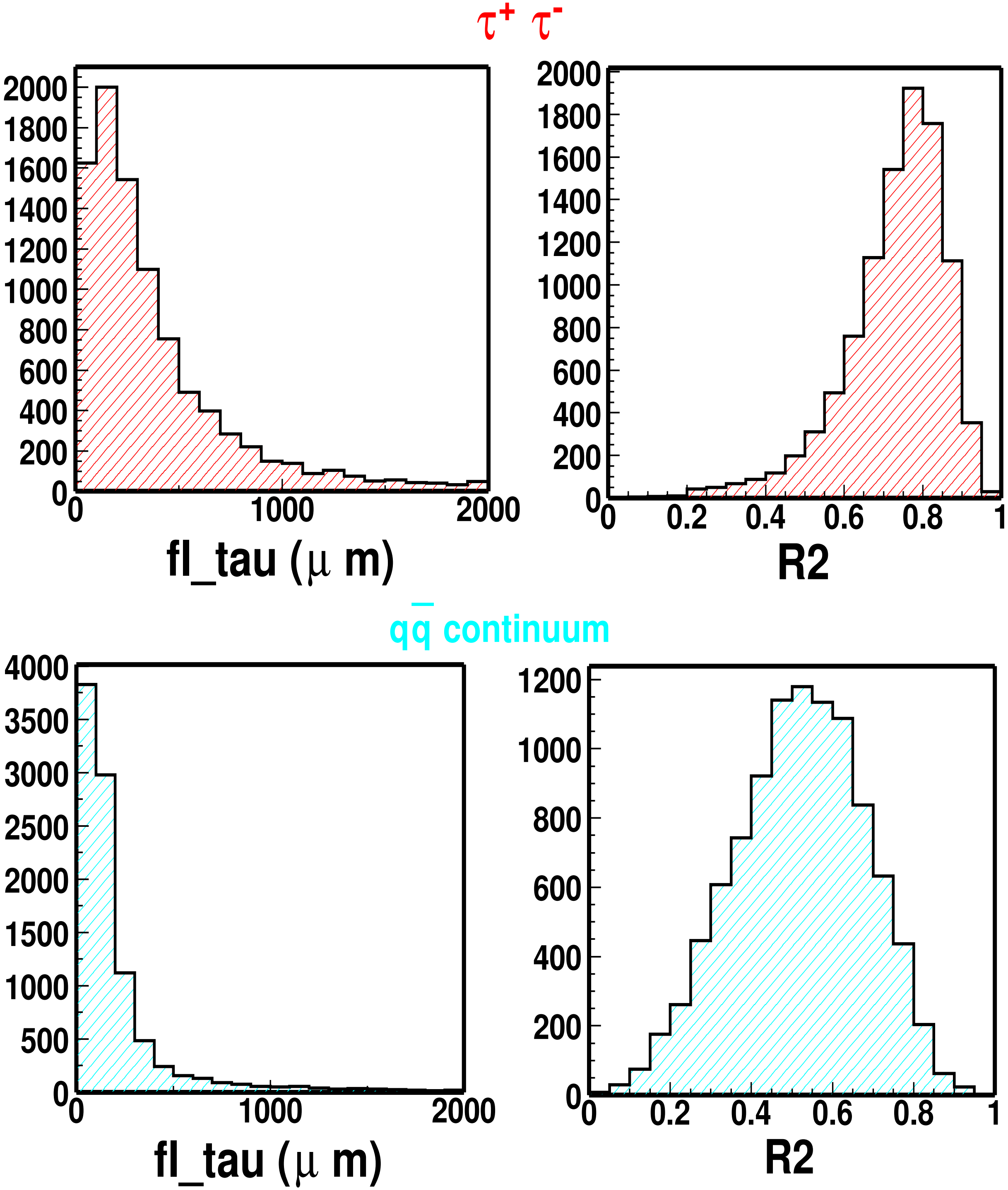
— 1-prong side track is not e,

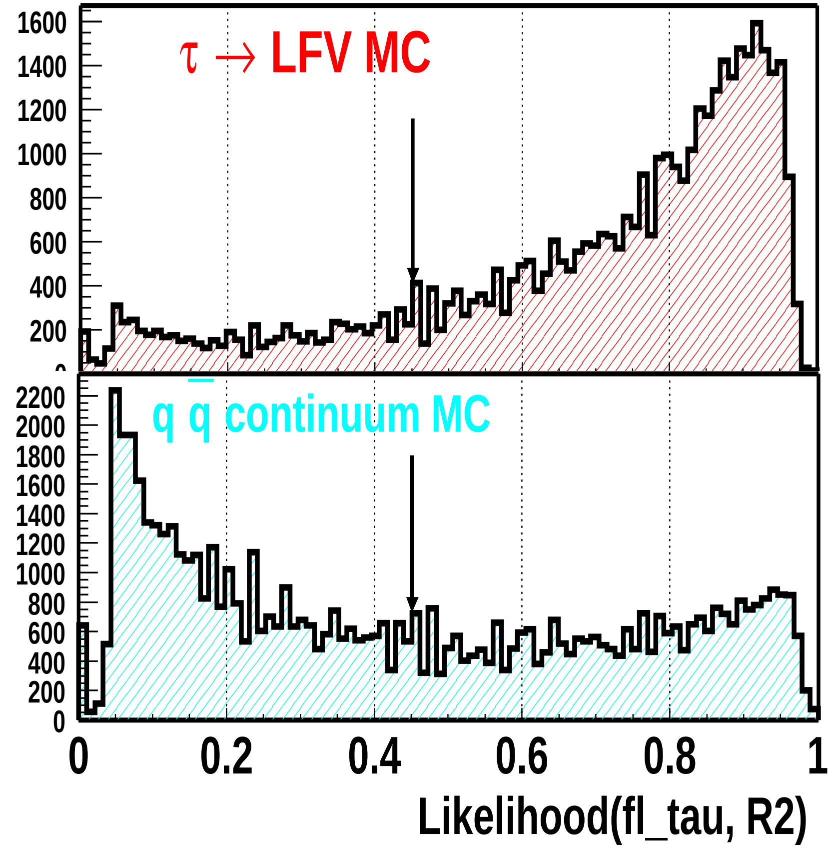
1-prong side track is not μ,

1-prong side track is not K and

Event likelihood consists of τ flight length and Fox-Wolfram moments $R2$







After likelihood selection,
$q\bar{q}$ continuum $\rightarrow$ 40%,
signal efficiency $\rightarrow$ 85%.

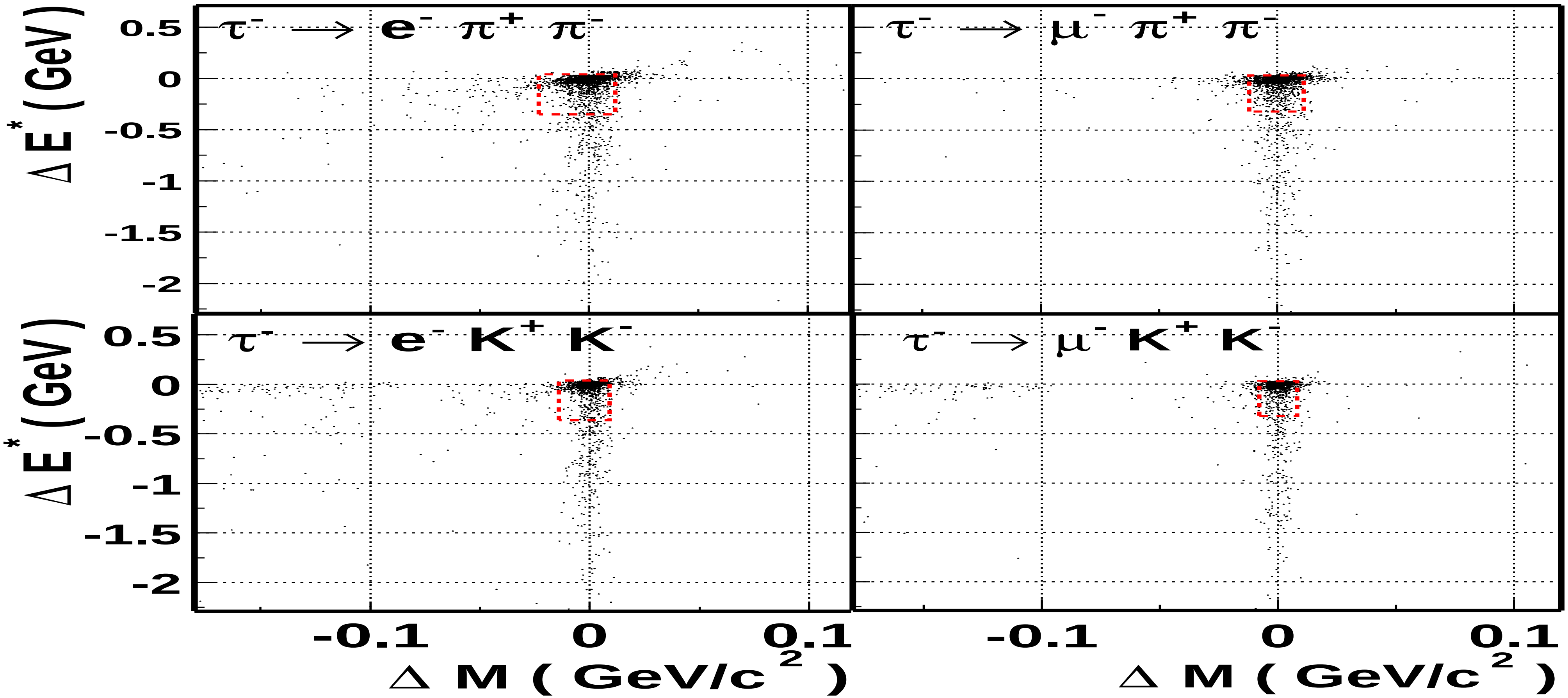
After all selection criteria,
$q\bar{q}$ continuum $\rightarrow 2 \times 10^{-5}$,
signal efficiency $\rightarrow$ 60%.

Signal Monte Carlo

Generated by using KORALB & TAUOLA assuming phase spase decay.

$\Delta E^{CM} \equiv E^{CM}_{\ell hh} - E^{CM}_{beam}$

$\Delta M \equiv M_{\ell hh} - M_{\tau}$

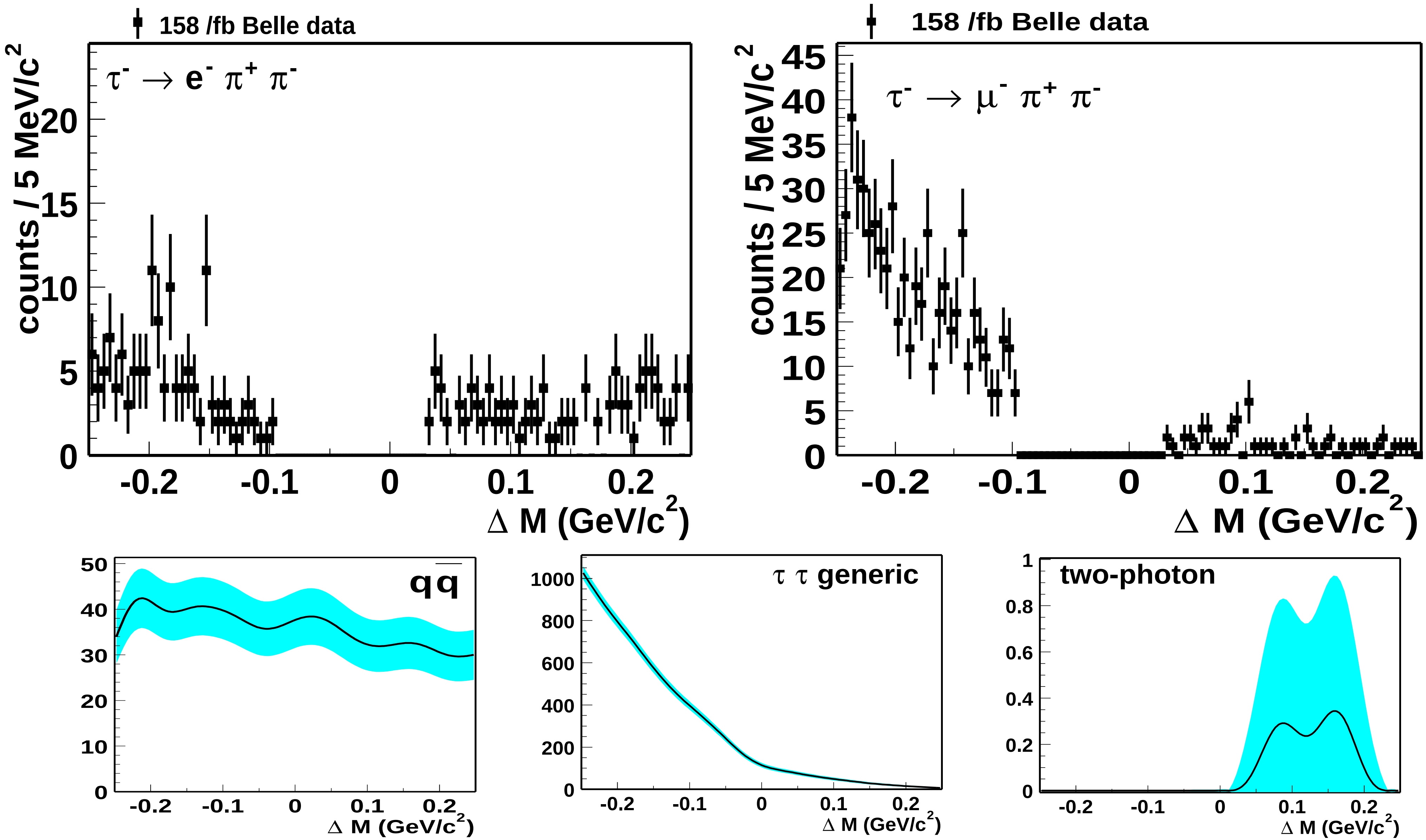


Signal area (red box) is defined by taking the area of 90% yield.

(width of ΔE^{CM} = 0.33-0.38 GeV, ΔM = 16-34 MeV/c^2)

Background Estimation

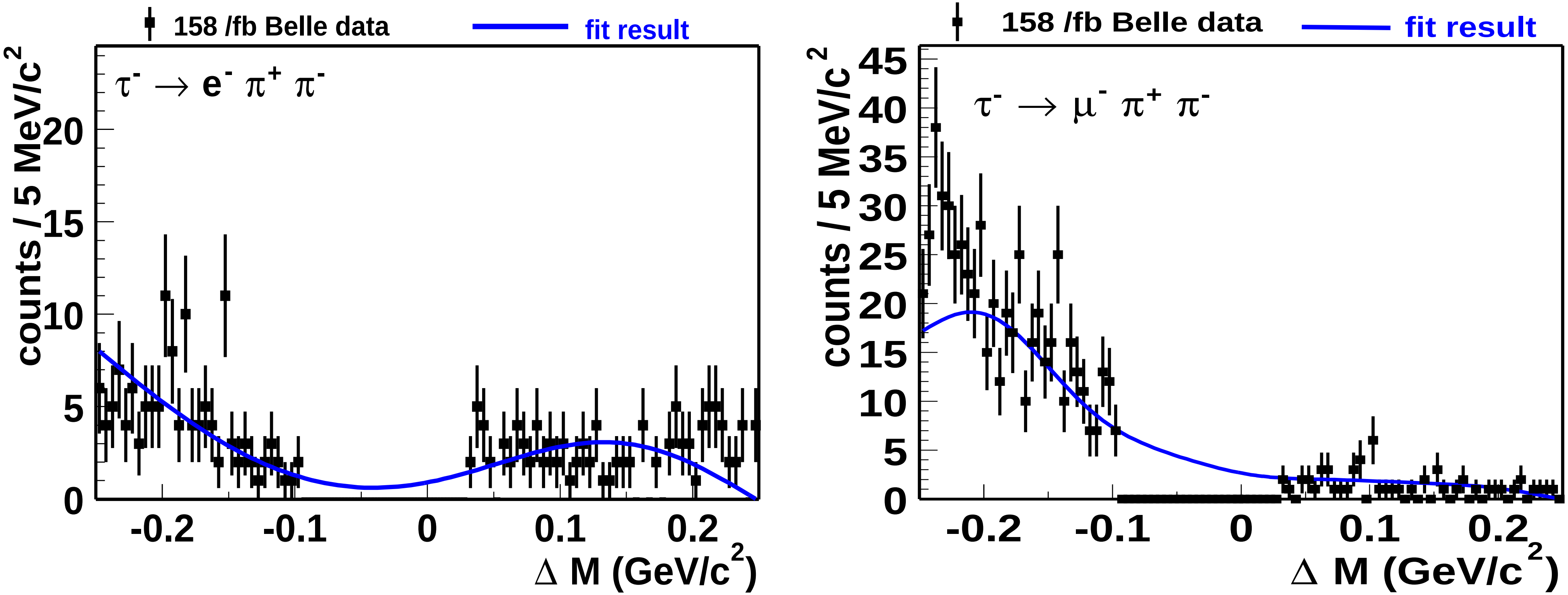
Fitting experimental data ΔM distributions after applying all selection criteria.



Background shapes determined by Monte Carlo.

Background Estimation — fit result

Fited experimental data ΔM distributions after applying all selection criteria using MC based function.



Main contribution

$\Delta M < 0$: $\tau\tau$ generic

$\Delta M > 0$: $q\bar{q}$ and two-photon (only for $\tau^- \to e^- h^+ h^-$ modes)

$\Delta M > 0$ (only for $\tau^- \to e^- h^+ h^-$ modes): two-photon

$e^+e^- \to e^+e^-\mu^+\mu^- \to e^+(e^-h^+h^-)$ ($\mu \to h$ fake)

$e^+e^- \to e^+(e^-h^+h^-)$

Numenical Fitting Results

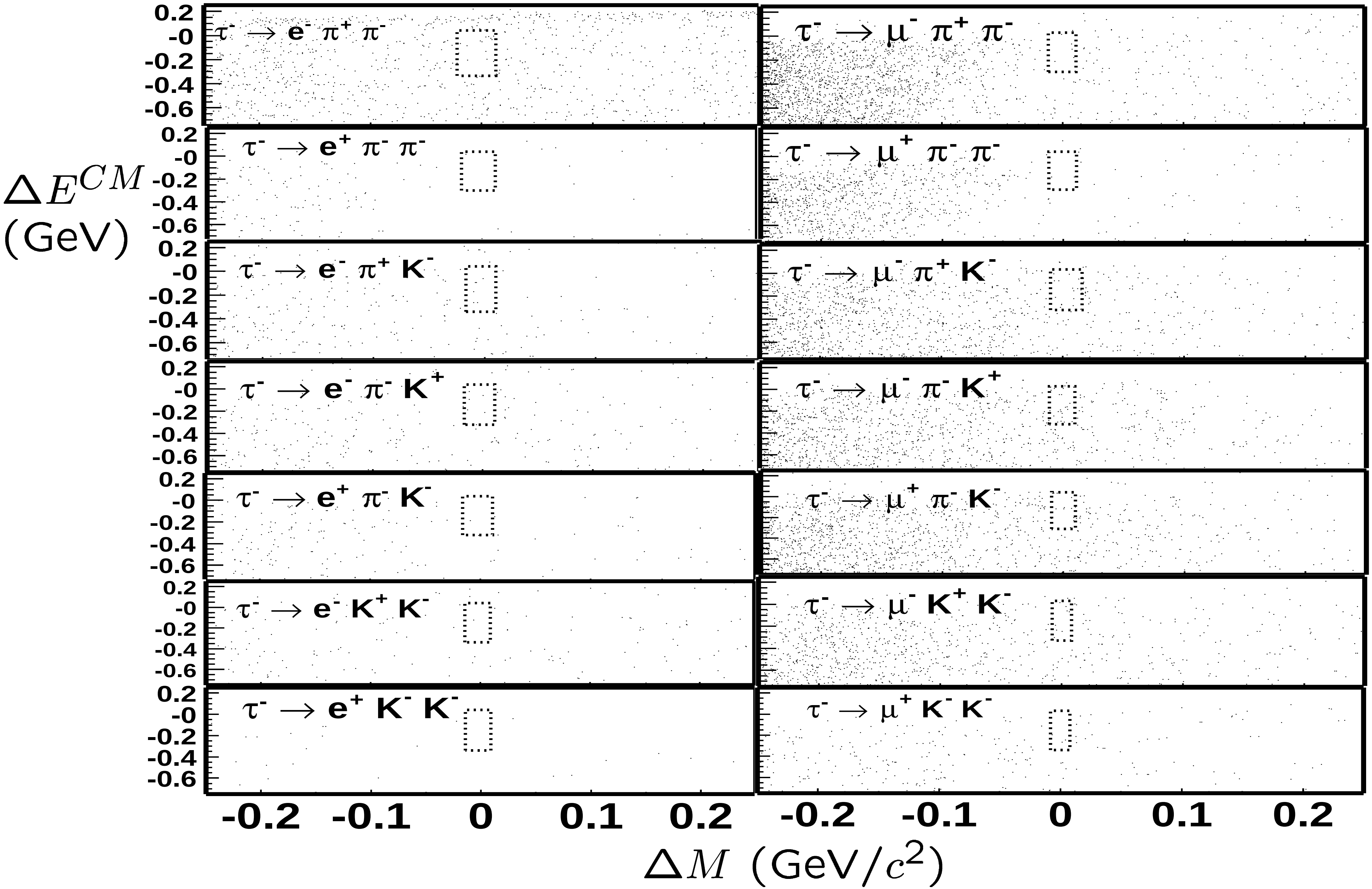
Mode	signal region
$\tau^- \to e^-\pi^+\pi^-$	$0.7^{+10.2}_{-0.7}$
$\tau^- \to e^+\pi^-\pi^-$	0.3±0.3
$\tau^- \to \mu^-\pi^+\pi^-$	14.7±3.8
$\tau^- \to \mu^+\pi^-\pi^-$	2.1±2.1
$\tau^- \to e^-\pi^+K^-$	4.8±2.0
$\tau^- \to e^-\pi^-K^+$	5.4±3.4
$\tau^- \to e^+\pi^-K^-$	1.0±1.0
$\tau^- \to e^-K^-K^+$	$1.4^{+1.8}_{-1.4}$
$\tau^- \to e^+K^-K^-$	0.0±0.0
$\tau^- \to \mu^-\pi^+K^-$	15.3±4.5
$\tau^- \to \mu^-\pi^-K^+$	14.1±3.1
$\tau^- \to \mu^+\pi^-K^-$	16.8±4.2
$\tau^- \to \mu^-K^-K^+$	5.3±2.3
$\tau^- \to \mu^+K^-K^-$	4.6±2.3

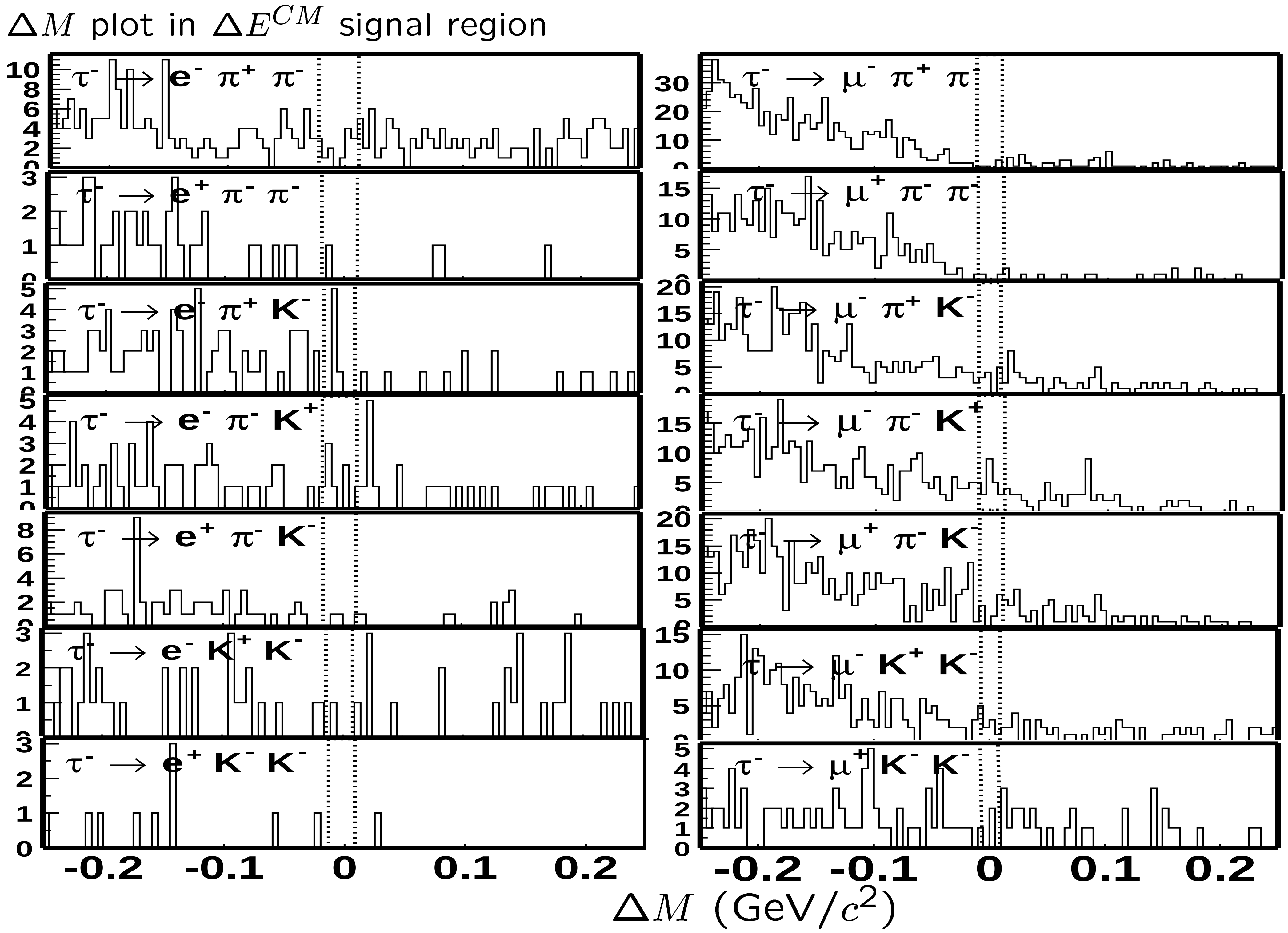
$$N(\tau \to \mu hh) > N(\tau \to ehh)$$

$\Rightarrow$ Main background source around the signal area:
— $\tau \to 3\pi\nu_\tau$
— 4-prong $q\bar{q}$ continuum
&
1π is mis-identified to ℓ.
Fake rate of $(\pi \to \mu) = 2\%$,
Fake rate of $(\pi \to e)) = 0.2\%$

Result

158 /fb Belle data





ΔM plot in ΔE^CM signal region
τ⁻ → e⁻ π⁺ π⁻
τ⁻ → μ⁻ π⁺ π⁻
τ⁻ → e⁺ π⁻ π⁻
τ⁻ → μ⁺ π⁻ π⁻
τ⁻ → e⁻ π⁺ K⁻
τ⁻ → μ⁻ π⁺ K⁻
τ⁻ → e⁻ π⁻ K⁺
τ⁻ → μ⁻ π⁻ K⁺
τ⁻ → e⁺ π⁻ K⁻
τ⁻ → μ⁺ π⁻ K⁻
τ⁻ → e⁻ K⁺ K⁻
τ⁻ → μ⁻ K⁺ K⁻
τ⁻ → e⁺ K⁻ K⁻
τ⁻ → μ⁺ K⁻ K⁻
-0.2
-0.1
0
0.1
0.2
ΔM (GeV/c²)

Systematics

For efficiency ϵ	$\Delta\epsilon/\epsilon(\%)$
Tracking	1.0 per track
Trigger	1.4
electron identification	1.1 per electron
muon identification	5.4 per muon
Kaon identification	1.0 per Kaon
Decay angular uncertainty	1.1 - 38 (mode by mode)
signal MC statistics	1.0
For number of τ-pair event N_{τ}	$\Delta N/N(\%)$
Luminosity	1.4

Upper limit for Signal event

Mode	Expected Background	Observed Events	Signal Efficiency (%)	U.L. on signal yield (90% CL)
$\tau^- \to e^-\pi^+\pi^-$	$0.7^{+10.2}_{-0.7}$	13	6.8±0.5	16.6
$\tau^- \to e^+\pi^-\pi^-$	0.3±0.3	1	6.9±0.3	4.1
$\tau^- \to \mu^-\pi^+\pi^-$	14.7±3.8	5	6.0±0.5	4.9
$\tau^- \to \mu^+\pi^-\pi^-$	2.1±2.1	3	5.9±0.6	5.9
$\tau^- \to e^-\pi^+K^-$	4.8±2.0	6	5.3±1.2	8.7
$\tau^- \to e^-\pi^-K^+$	5.4±3.4	6	5.5±1.0	8.9
$\tau^- \to e^+\pi^-K^-$	1.0±1.0	2	5.3±0.7	5.1
$\tau^- \to e^-K^-K^+$	$1.4^{+1.8}_{-1.4}$	1	4.2±0.3	3.6
$\tau^- \to e^+K^-K^-$	0.0±0.0	0	4.2±1.0	2.6
$\tau^- \to \mu^-\pi^+K^-$	15.3±4.5	10	4.6±0.8	8.4
$\tau^- \to \mu^-\pi^-K^+$	14.1±3.1	22	4.7±1.0	21.1
$\tau^- \to \mu^+\pi^-K^-$	16.8±4.2	12	4.8±1.3	10.9
$\tau^- \to \mu^-K^-K^+$	5.3±2.3	10	3.7±0.4	12.5
$\tau^- \to \mu^+K^-K^-$	4.6±2.3	2	3.7±1.4	5.6

U.L. of signal events are calculated by Feldman & Cousins statistics with systematic errors.
(POLE program (J. Conrad, Phys.Rev.D67:012002,2003))

Summary

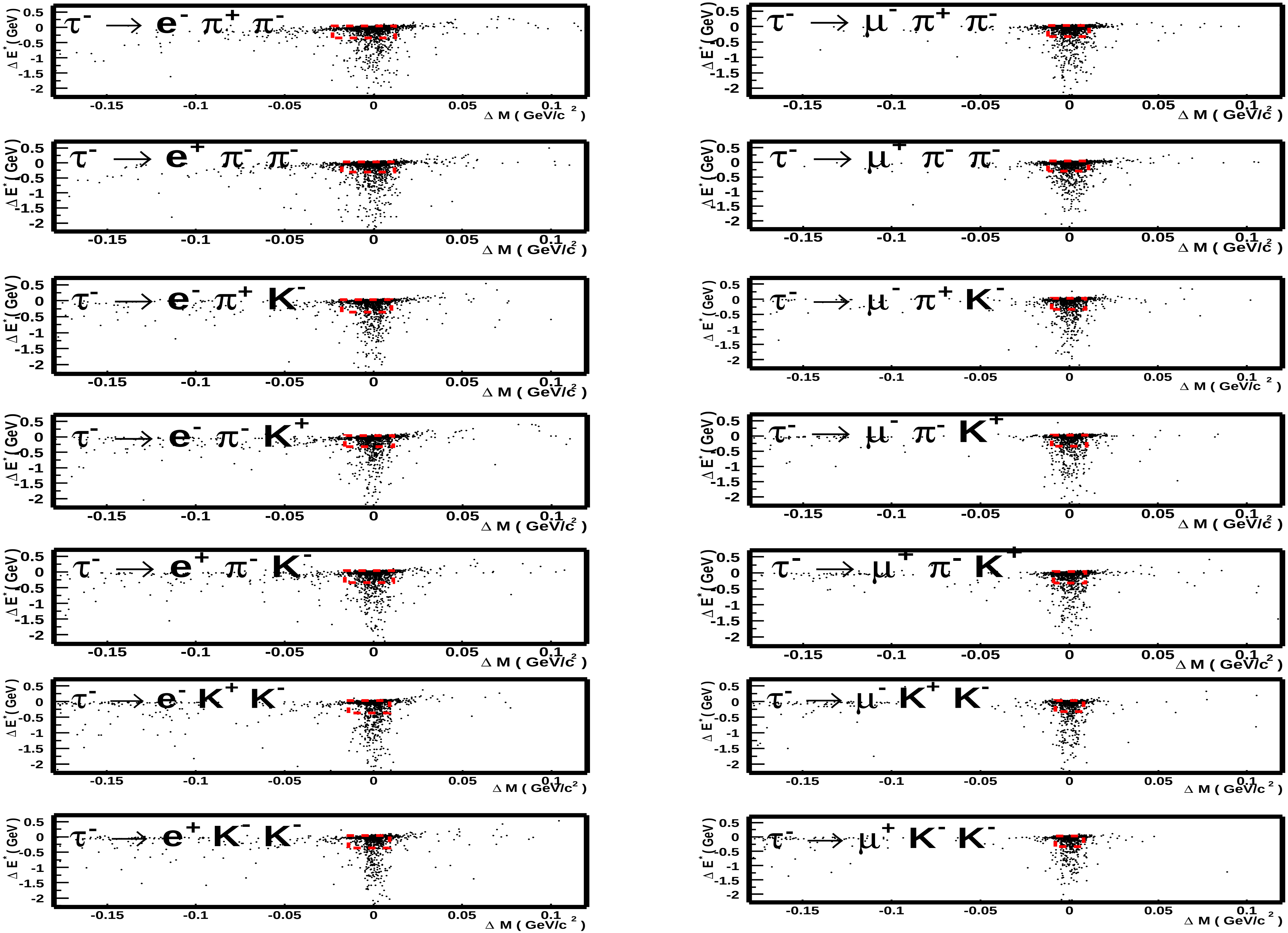
We have searched $\tau \to \ell hh$ LFV process using 158 /fb of Belle data.

There is no clear sign of signal.
We set upper limits of branching ratio of each decay mode.

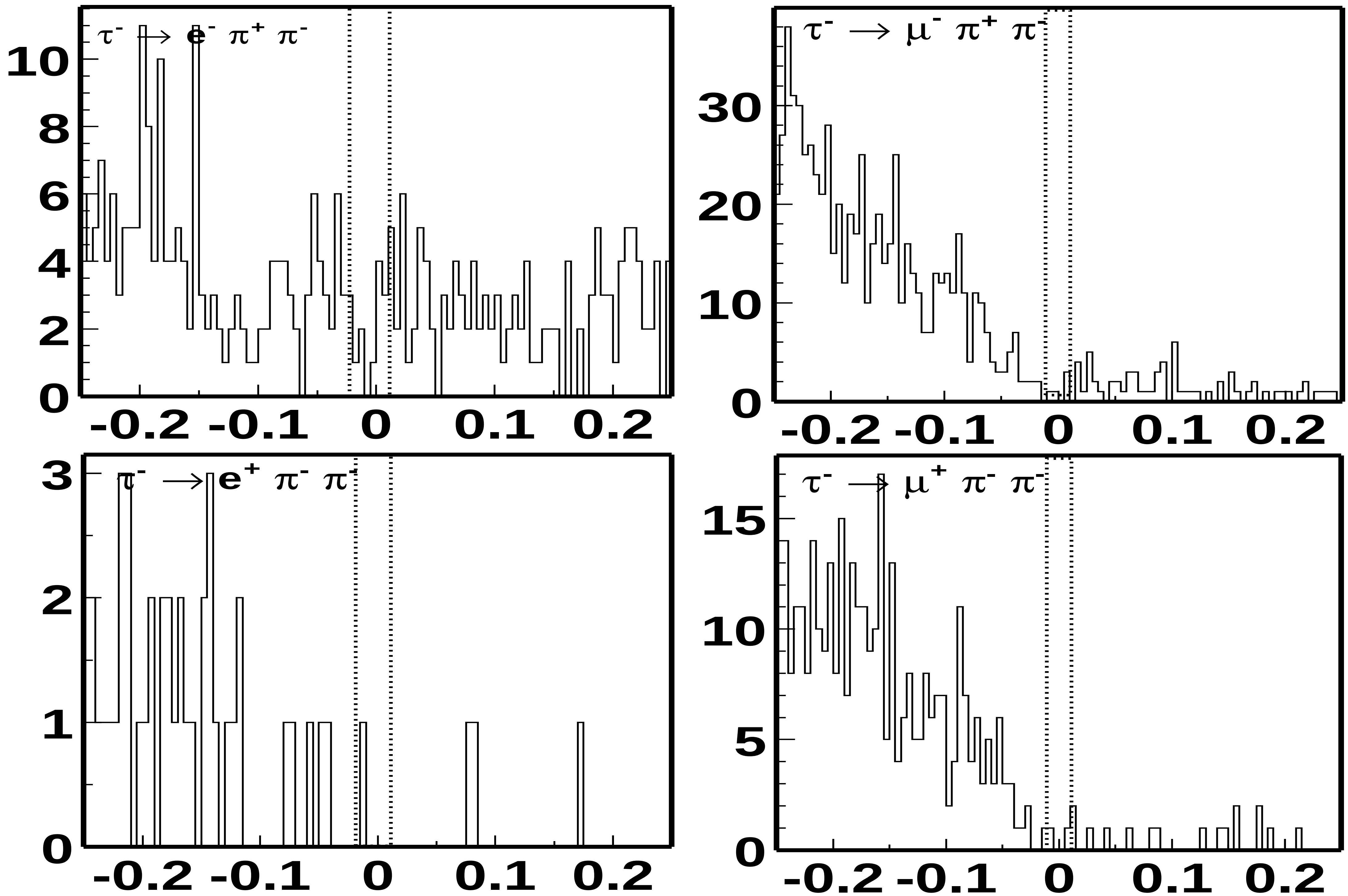
Factor 2.5-30 of improvement from PDG value.

Mode	U.L. of branching ratio (90% C.L.)
$\tau^- \to e^-\pi^+\pi^-$	8.4×10^{-7}
$\tau^- \to e^+\pi^-\pi^-$	2.1×10^{-7}
$\tau^- \to \mu^-\pi^+\pi^-$	2.8×10^{-7}
$\tau^- \to \mu^+\pi^-\pi^-$	3.5×10^{-7}
$\tau^- \to e^-\pi^+K^-$	5.7×10^{-7}
$\tau^- \to e^-\pi^-K^+$	5.6×10^{-7}
$\tau^- \to e^+\pi^-K^-$	3.3×10^{-7}
$\tau^- \to e^-K^-K^+$	3.0×10^{-7}
$\tau^- \to e^+K^-K^-$	2.2×10^{-7}
$\tau^- \to \mu^-\pi^+K^-$	6.3×10^{-7}
$\tau^- \to \mu^-\pi^-K^+$	15.5×10^{-7}
$\tau^- \to \mu^+\pi^-K^-$	7.8×10^{-7}
$\tau^- \to \mu^-K^-K^+$	11.7×10^{-7}
$\tau^- \to \mu^+K^-K^-$	5.2×10^{-7}

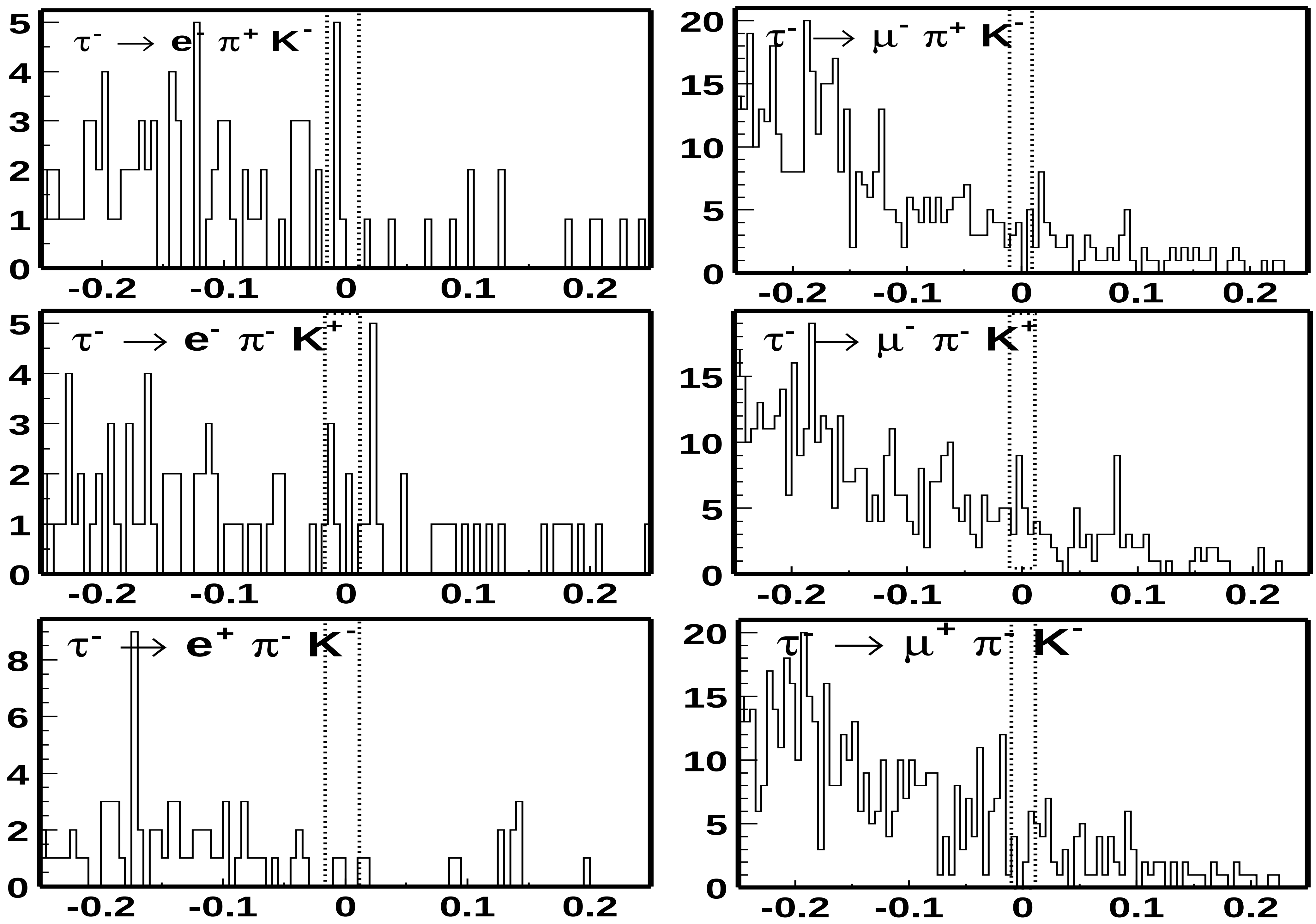
Backups



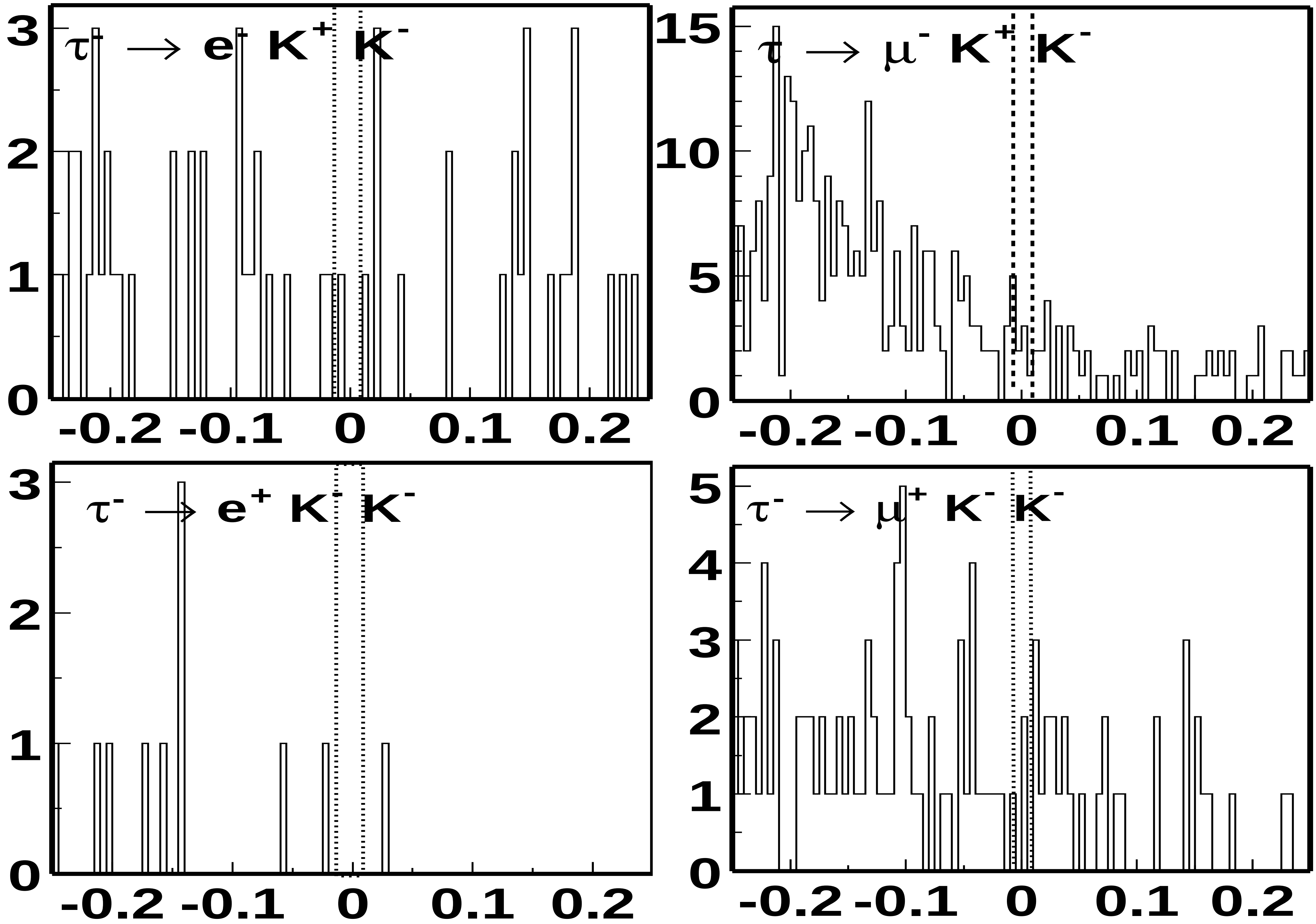
τ⁻ → e⁻ π⁺ π⁻
τ⁻ → μ⁻ π⁺ π⁻
τ⁻ → e⁺ π⁻ π⁻
τ⁻ → μ⁺ π⁻ π⁻
τ⁻ → e⁻ π⁺ K⁻
τ⁻ → μ⁻ π⁺ K⁻
τ⁻ → e⁻ π⁻ K⁺
τ⁻ → μ⁻ π⁻ K⁺
τ⁻ → e⁺ π⁻ K⁻
τ⁻ → μ⁺ π⁻ K⁺
τ⁻ → e⁻ K⁺ K⁻
τ⁻ → μ⁻ K⁺ K⁻
τ⁻ → e⁺ K⁻ K⁻
τ⁻ → μ⁺ K⁻ K⁻
Δ E* (GeV)
Δ M (GeV/c²)
0.5
0
-0.5
-1
-1.5
-2
-0.15
-0.1
-0.05
0
0.05
0.1



$\tau^- \rightarrow e^- \pi^+ \pi^-$
$\tau^- \rightarrow \mu^- \pi^+ \pi^-$
$\tau^- \rightarrow e^+ \pi^- \pi^-$
$\tau^- \rightarrow \mu^+ \pi^- \pi^-$
0
2
4
6
8
10
0
10
20
30
0
1
2
3
0
5
10
15
-0.2
-0.1
0
0.1
0.2

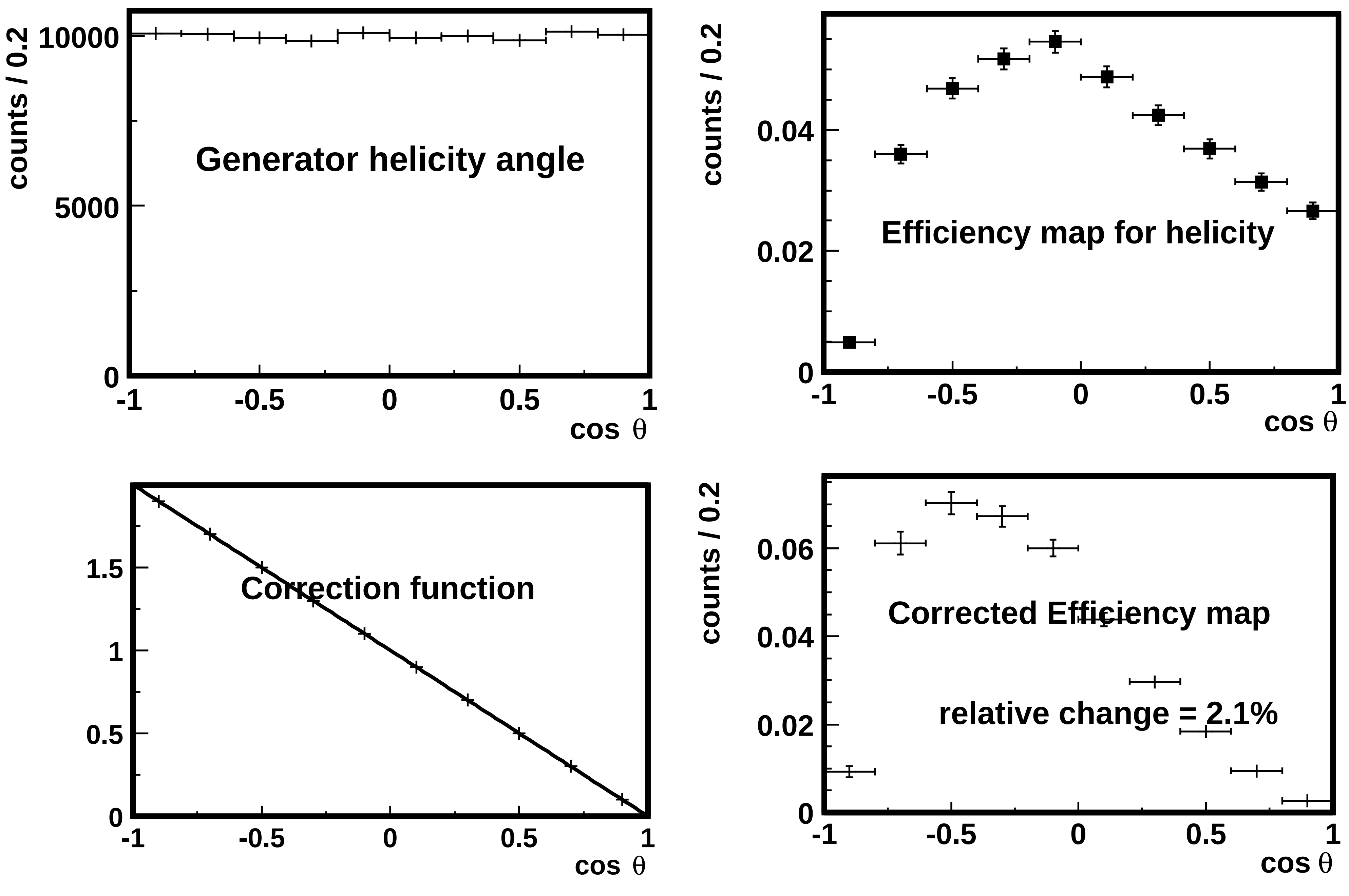


$\tau^- \to e^- \pi^+ K^-$
$\tau^- \to \mu^- \pi^+ K^-$
$\tau^- \to e^- \pi^- K^+$
$\tau^- \to \mu^- \pi^- K^+$
$\tau^- \to e^+ \pi^- K^-$
$\tau^- \to \mu^+ \pi^- K^-$



τ⁻ → e⁻ K⁺ K⁻
τ → μ⁻ K⁺ K⁻
τ⁻ → e⁺ K⁻ K⁻
τ⁻ → μ⁺ K⁻ K⁻
-0.2 -0.1 0 0.1 0.2

$\tau^- \to \mu^- \pi^+ \pi^-$ mode   helicity angle between τ^- and π^+



$\tau^- \to \mu^+ K^- K^-$ mode helicity angle between τ^- and μ^+