Search for New physics in Lepton Flavor Violating τ decays at Belle

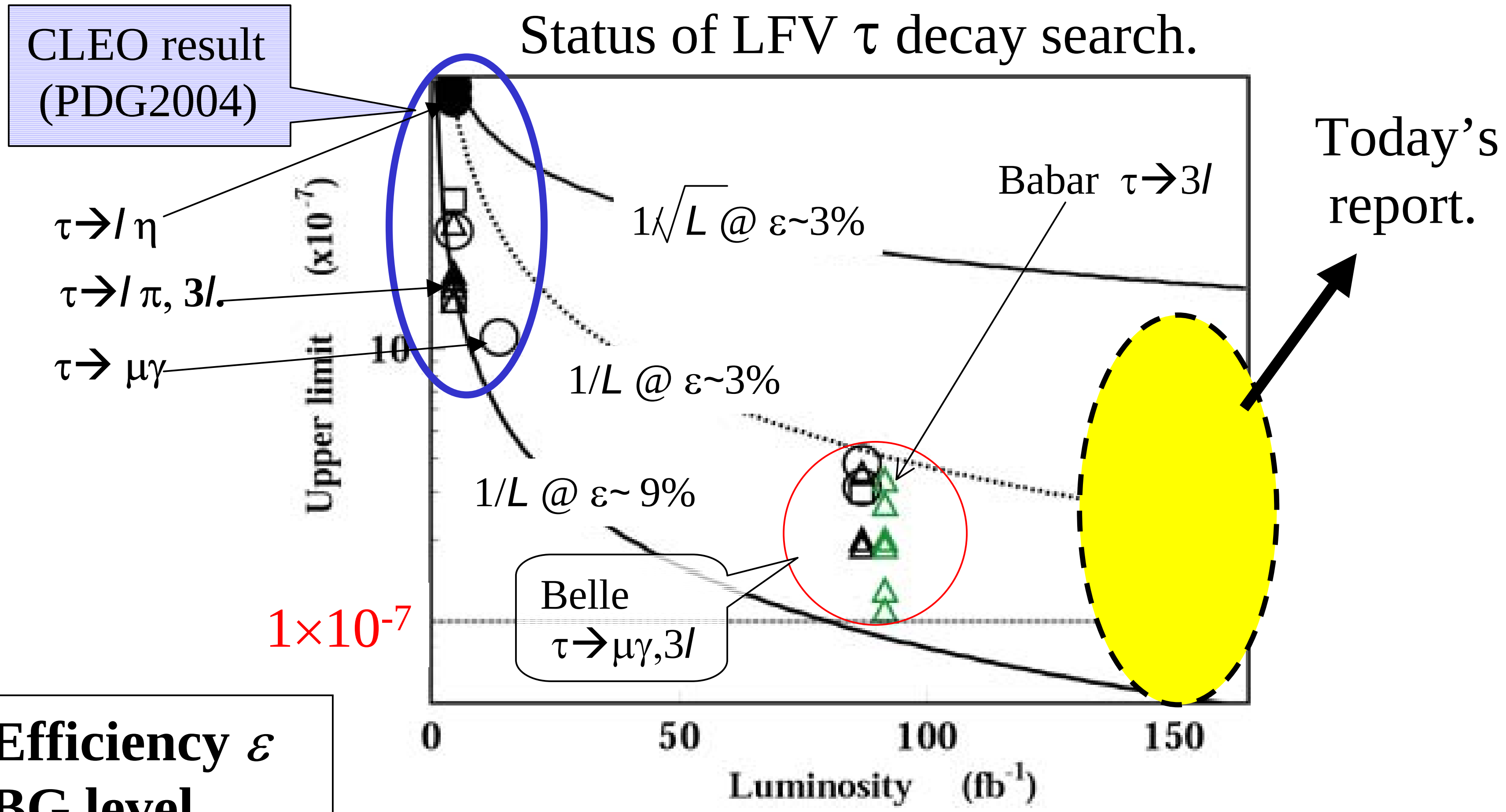
Contents

- Introduction
- KEKB & Belle
- Analysis
  $\tau \to l\ \pi^0, l\ \eta, l\ \eta'$
- Discussion & Summary

Y. Enari, Belle collaboration
Nagoya University

Introduction

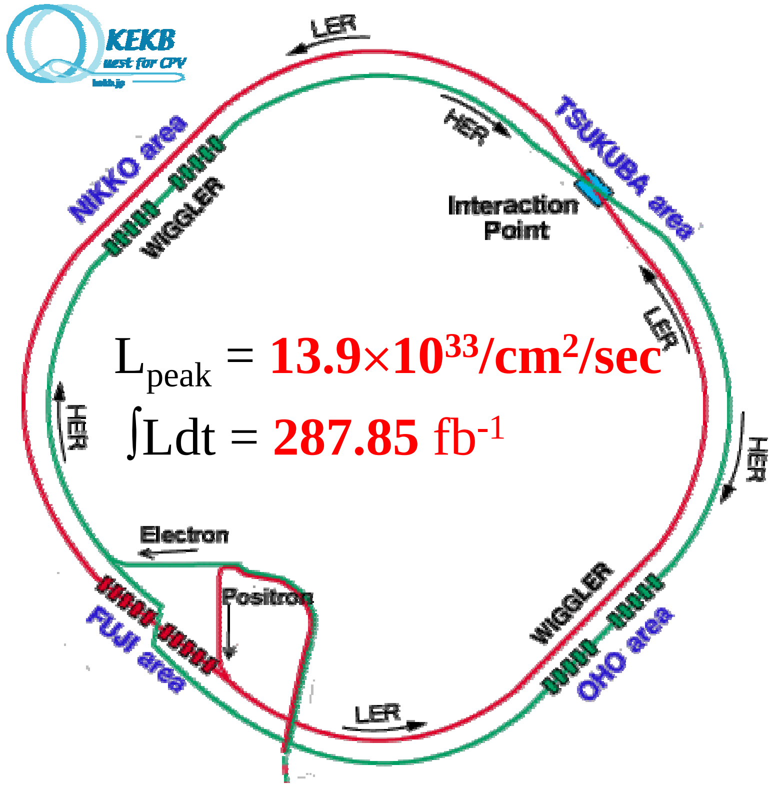
- Search for New physics in τ decay.



- **Efficiency** ε
- **BG level**

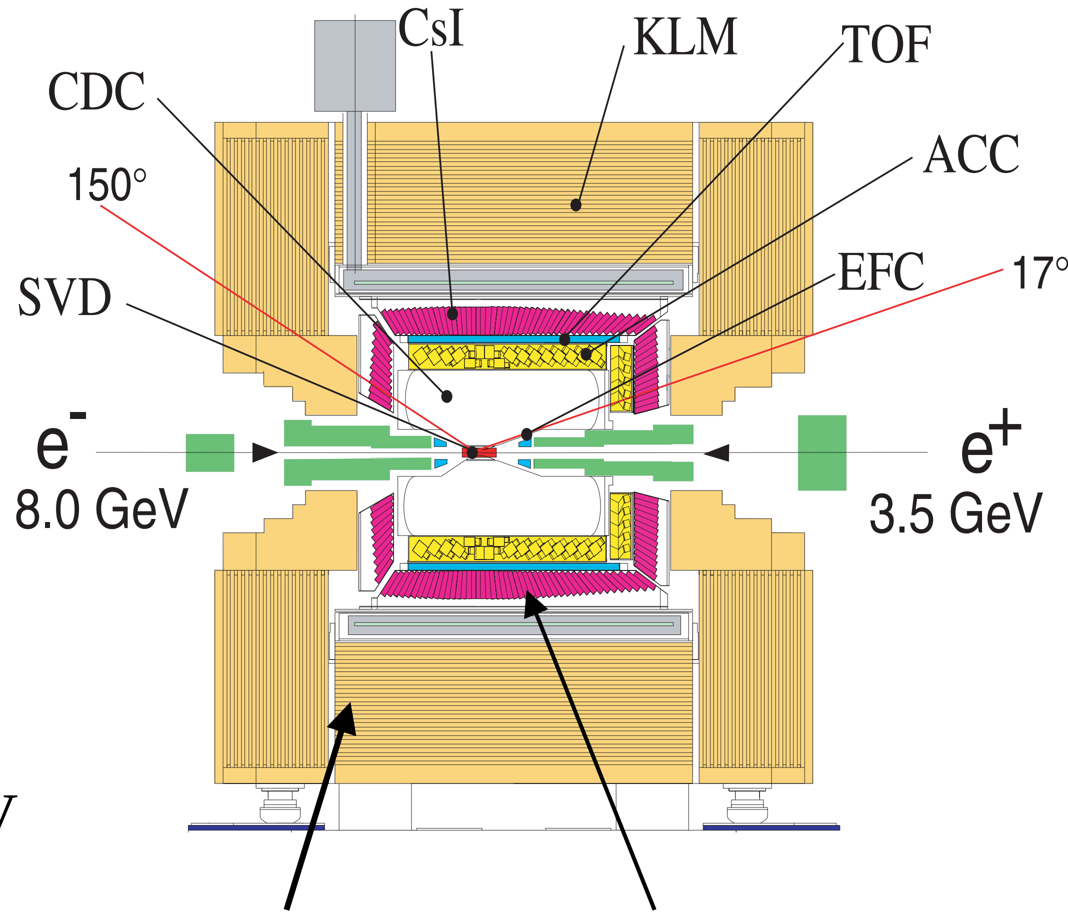
In MSSM, Br of LFV decay may have $O(10^{-7} \sim 10^{-9})$.

KEKB & Belle detector



L_{peak} = **13.9×10^{33}/cm^2/sec**

$\int Ldt$ = **287.85 fb^{-1}**



Cross section @$\sqrt{s}$ =10.58GeV

$\tau^+\tau^-$: 0.9 nb

$B\bar{B}$: 1.0 nb

KEKB is τ Factory!!!.

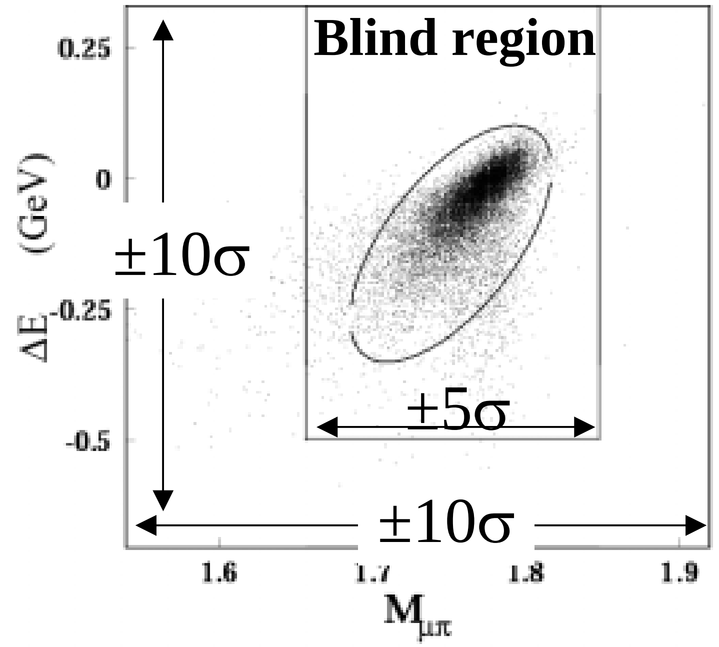
μ-ID
eff. = 87.5%
fake = 1.4 %

e-ID
eff. = 92.4%
fake = 0.25 %

Analysis method at Belle.

- **<u>Modes</u>**
  - $\tau \rightarrow e\gamma, \mu\gamma, 3l$
  - $\tau \rightarrow l\,\pi^0, l\,\eta, l\,\eta'$
  - $\tau \rightarrow p\gamma, p\pi, \Lambda\pi$

- **<u>Blind analysis</u>**



Invariant mass :

$$M_{\mu\eta} = \sqrt{E^2_{\mu\eta} - p^2_{\mu\eta}}$$

Energy difference :

$$\Delta E = E^{CM}_{\mu\eta} - E^{CM}_{beam}$$

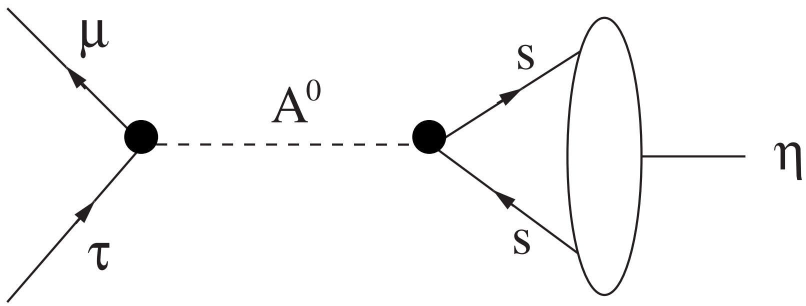
Blind region: $-0.5 < \Delta E < 0.5$ (GeV), $-5\sigma < M_{\mu\eta} < 5\sigma$

- **<u>Evaluation # of signal event</u>**

  - Low BG level
    → Counting signal candidates using elliptical region
  - High BG level
    → Likelihood fit.

Motivation - $\tau \to l\pi^0, l\eta, l\eta'$ -

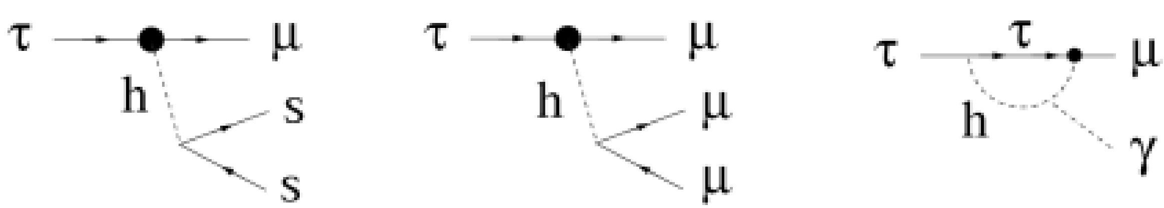
- In MSSM at large tanβ, $\tau \to \mu\eta$ may have a large branching ratio by Higgs mediated process.



M. Sher, Phys.Rev.D66 05731(2002)
K.S.Babu PRL,89,241802 (2002)
A. Dedes, et.al. PLB 549,2442 (2002)

$$Br(\tau \to \mu\eta) = 0.84 \times 10^{-6} \times \left(\frac{\tan\beta}{60}\right)^6 \left(\frac{100}{m_A}\right)^4$$

- Comparison $\tau \to 3l$ mode.



Br(τ→μη) : Br(τ→3μ) : Br(τ→μγ) = 8 : 1.5 : 1

a. $(m_s/m_\mu)^2$
b. color factor
c. phase space

Using our data of 140M ττ, we can put constraint on tanβ and m_A

Selection criteria ($\tau \to l\,\pi^0, l\,\eta, l\,\eta'$)

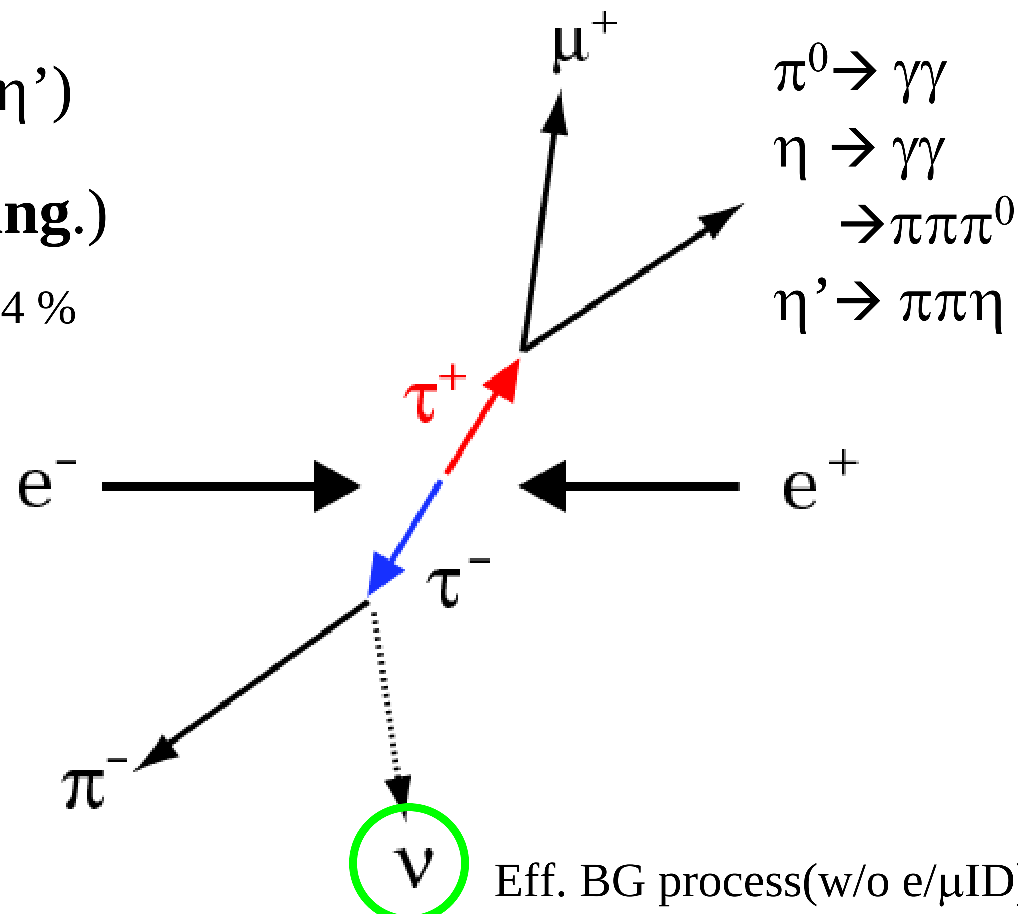
- Signal event reconstruction

  signal side (e/μ + π^0, η, η')

  +

  tag side (1 trk + n_γ + **missing**.)

  $Br(\tau \to 1\ \text{prong}) = 84\ \%$



- BG suppression

  For QED BG.

  - NOT $\mu(e)$ (for 1-1prong)
  - $5 < E^{CM}_{total} < 10.\text{GeV}$

  For $q\bar{q}$ and $\tau^+\tau^-$ BG

  - π^0 veto for η's γ
  - $0.5 < \cos\theta_{\mu\eta} < 0.95$
  - $M_{tag} < 1.777\ \text{GeV}/c^2$
  - missing momentum towards tag side.
  - p_{miss} vs. m_{miss}^2 2-D cut.

Eff. BG process(w/o e/μID)

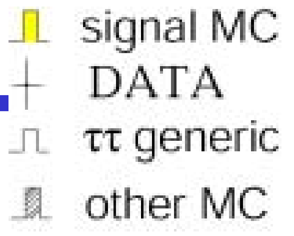
eff.($\tau\tau$) $= 3.8 \times 10^{-6}$.

eff.(uds) $= 3.0 \times 10^{-7}$.

eff.($\mu\mu$) $= 3.4 \times 10^{-8}$.

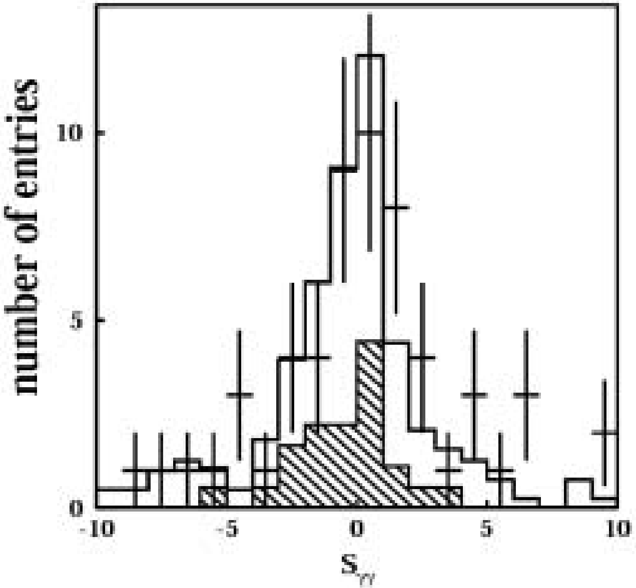
eff.(ee) $= 3.0 \times 10^{-7}$.

Mass distribution (μID; $1.3 < M_{\mu\eta} < 2.1$; with Blind)

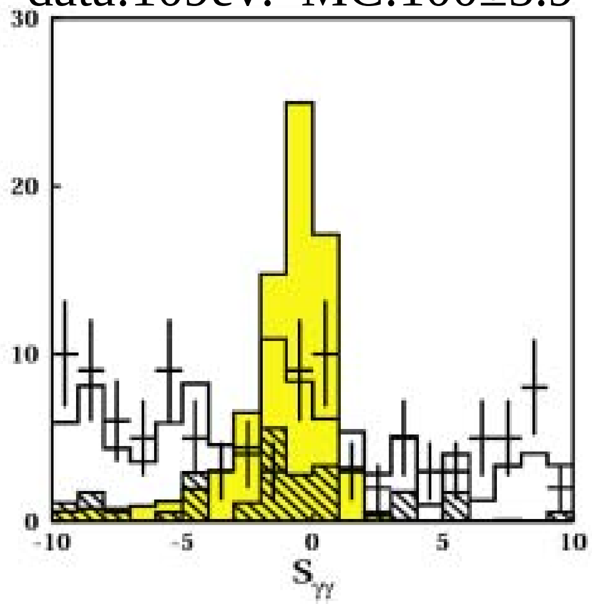


- π^0, η, η' mass peak.

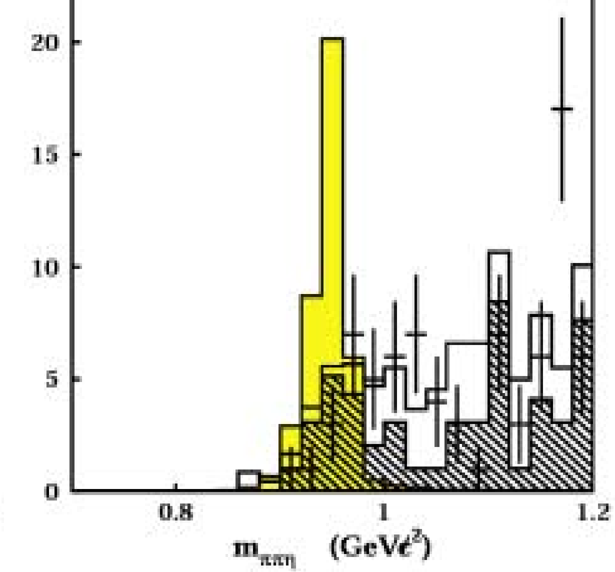
data:57ev. MC:48.1±4.0



data:109ev. MC:100±5.9



data: 77ev. MC:81.6 ± 8.4



$$-3 < \frac{(m_{\gamma\gamma} - m_{\pi 0})}{\sigma_{\gamma\gamma}} < 3$$

$\sigma_{\gamma\gamma}$ ~5.2 MeV/c^2

$$-5 < \frac{(m_{\gamma\gamma} - m_{\pi 0})}{\sigma_{\gamma\gamma}} < 3$$

$\sigma_{\gamma\gamma}$ ~12 MeV/c^2

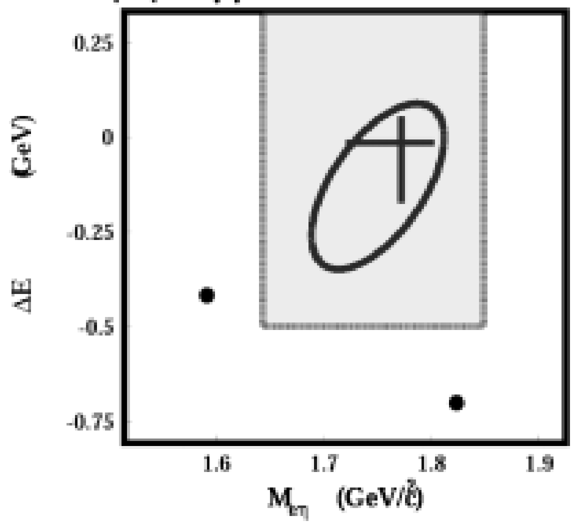
$$0.907 < m_{\eta'} < 0.982$$

(3σ region)

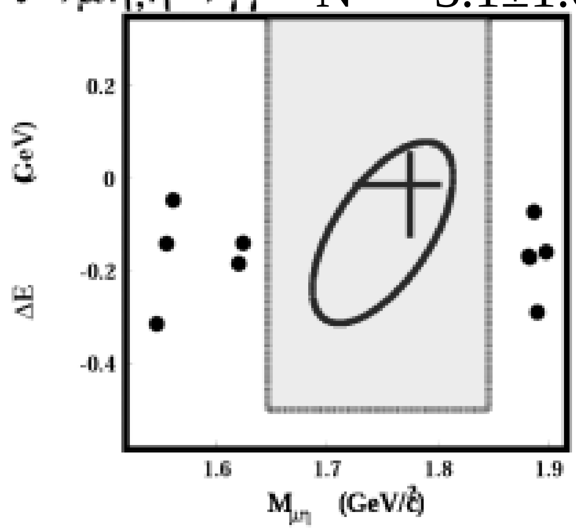
σ ~ 14 MeV/c^2

ΔE vs $M_{inv.}$: $\tau \rightarrow l\,\pi^0, l\,\eta, l\,\eta'$

$\tau \rightarrow e\eta, \eta \rightarrow \gamma\gamma$ $N^{exp}=0.15\pm0.15$



$\tau \rightarrow \mu\eta, \eta \rightarrow \gamma\gamma$ $N^{exp}=3.1\pm1.0$



BG estimation

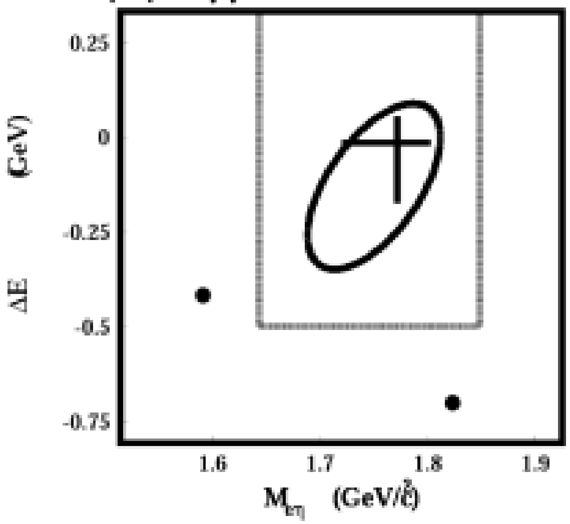
N^{exp} is calculated from the side band events with assuming a flat distribution.

Open blind.

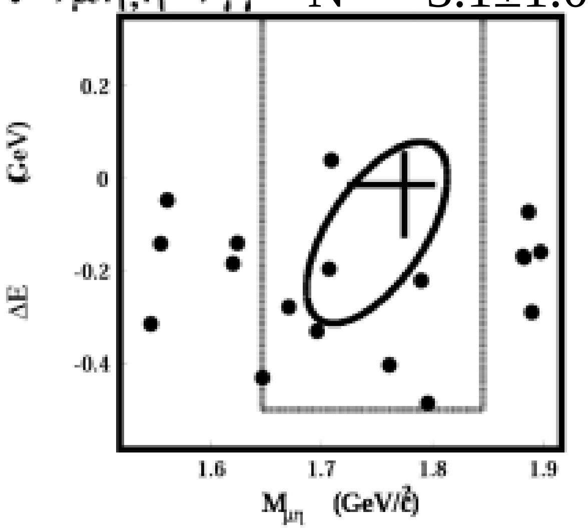
Mode	Subdecay	eff. ϵ (%)	N^{exp}
$\tau^- \rightarrow e^-\eta$	$\eta \rightarrow \gamma\gamma$	5.7	0.15 ± 0.15
	$\eta \rightarrow \pi^+\pi^-\pi^0$	6.8	0.23 ± 0.23
$\tau^- \rightarrow \mu^-\eta$	$\eta \rightarrow \gamma\gamma$	8.0	3.1 ± 1.0
	$\eta \rightarrow \pi^+\pi^-\pi^0$	7.2	0.60 ± 0.42
$\tau^- \rightarrow e^-\pi^0$	$\pi^0 \rightarrow \gamma\gamma$	4.7	$0.0^{+0.40}_{-0.0}$
$\tau^- \rightarrow \mu^-\pi^0$	$\pi^0 \rightarrow \gamma\gamma$	6.4	2.7 ± 0.7
$\tau^- \rightarrow e^-\eta'$	$\eta' \rightarrow \pi^+\pi^-\eta$	8.5	0.16 ± 0.16
$\tau^- \rightarrow \mu^-\eta'$	$\eta' \rightarrow \pi^+\pi^-\eta$	8.4	1.4 ± 0.6

ΔE vs $M_{inv.}$: $\tau \rightarrow l\,\pi^0, l\,\eta, l\,\eta'$

$\tau\to e\eta, \eta\to\gamma\gamma$ $N^{exp}=0.15\pm0.15$



$\tau\to \mu\eta, \eta\to\gamma\gamma$ $N^{exp}=3.1\pm1.0$



BG estimation

N^{exp} is calculated from the side band events with assuming a flat distribution.

Open blind.

Mode	Subdecay	eff. ϵ (%)	N^{exp}	N^{obs}
$\tau^- \to e^-\eta$	$\eta\to\gamma\gamma$	5.7	0.15 ± 0.15	0
	$\eta\to\pi^+\pi^-\pi^0$	6.8	0.23 ± 0.23	0
$\tau^- \to \mu^-\eta$	$\eta\to\gamma\gamma$	8.0	3.1 ± 1.0	1
	$\eta\to\pi^+\pi^-\pi^0$	7.2	0.60 ± 0.42	0
$\tau^- \to e^-\pi^0$	$\pi^0\to\gamma\gamma$	4.7	$0.0^{+0.40}_{-0.0}$	0
$\tau^- \to \mu^-\pi^0$	$\pi^0\to\gamma\gamma$	6.4	2.7 ± 0.7	5
$\tau^- \to e^-\eta'$	$\eta'\to\pi^+\pi^-\eta$	8.5	0.16 ± 0.16	1
$\tau^- \to \mu^-\eta'$	$\eta'\to\pi^+\pi^-\eta$	8.4	1.4 ± 0.6	0

Systematic uncertainties

- eID:1%, μID: 2%, track: 2%, π^0 veto 5.5%
  Beam BG:2.3% Trigger:1.4% → 4.5~8.7%
- BG estimation: If $N^{exp}<1$, assume $N^{exp}=0$.

Result

Br is obtained from

$$B = \frac{s0}{2(\varepsilon B_X N_{\tau\tau})}$$

s0: signal events

ε : efficiency

$N_{\tau\tau}$: # of τ pairs (140M ττ)

B_X : B of sub-decay

- Upper limit evaluation (**PO**isson **L**imit **E**stimator program)
  - Feldman-Cousins method J. Conrad et al., PRD 012002 (2003)

Systematic uncertainty: using the Gaussian error.

Preliminary

Mode	Subdecay mode	U.L. of $\mathcal{B}$ @ 90% C.L.
$\tau^- \to e^-\eta$	$\eta \to \gamma\gamma$	3.9×10^{-7}
	$\eta \to \pi^+\pi^-\pi^0$	5.6×10^{-7}
$\tau^- \to e^-\eta$	combined	2.3×10^{-7}
$\tau^- \to \mu^-\eta$	$\eta \to \gamma\gamma$	2.4×10^{-7}
	$\eta \to \pi^+\pi^-\pi^0$	5.4×10^{-7}
$\tau^- \to \mu^-\eta$	combined	1.3×10^{-7}
$\tau^- \to e^-\pi^0$	$\pi^0 \to \gamma\gamma$	1.9×10^{-7}
$\tau^- \to \mu^-\pi^0$	$\pi^0 \to \gamma\gamma$	4.3×10^{-7}
$\tau^- \to e^-\eta'$	$\eta' \to \pi^+\pi^-\eta$	10×10^{-7}
$\tau^- \to \mu^-\eta'$	$\eta' \to \pi^+\pi^-\eta$	4.1×10^{-7}

10-70 times tighter limit from PDG2004

First search!!

Discussion - $\tau \rightarrow \mu\eta$ - (1)

Comparison with CLEO result

	CLEO		Belle
• Statistics	$4.7\mathrm{fb}^{-1}$	$\times 33$ →	$154\mathrm{fb}^{-1}$
• Signal efficiency			
$\eta \rightarrow \gamma\gamma$	$7.2\% \times B_\eta$	→	$8.0\% \times B_\eta$
$\eta \rightarrow \pi^+\pi^-\pi^0$	**not use**	**$\times$ 1.7**	**$7.2\% \times B_\eta$**
• Observed events	0	→	1

Keeping BG level low.

Upper limit : $B(\tau \rightarrow \mu\eta) < 9.6 \times 10^{-6}$

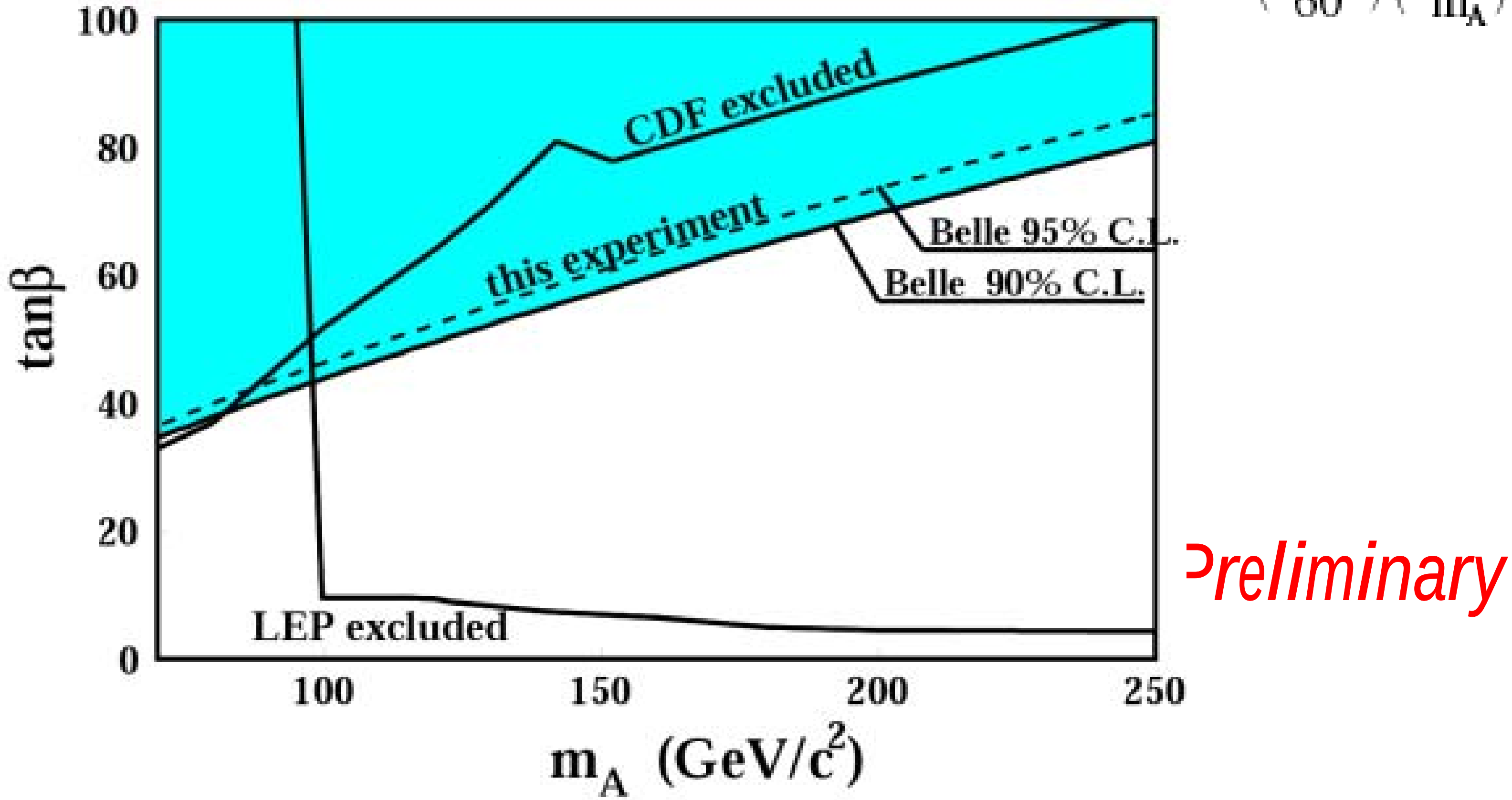
↓

$\boldsymbol{B(\tau \rightarrow \mu\eta) < 1.3 \times 10^{-7}}$ **@ 90% C.L.**

Discussion - $\tau \to \mu\eta$ - (2)

Constraint on $\tan\beta$ vs m_A

$$Br(\tau \to \mu\eta) = 0.84 \times 10^{-6} \times \left(\frac{\tan\beta}{60}\right)^6 \left(\frac{100}{m_A}\right)^4$$



- CDF result : measurement ($p\bar{p} \to A/\phi bb \to bbbb$) PRL 86,4472 (2002)
- LEP result : LEP Higgs Working Group,

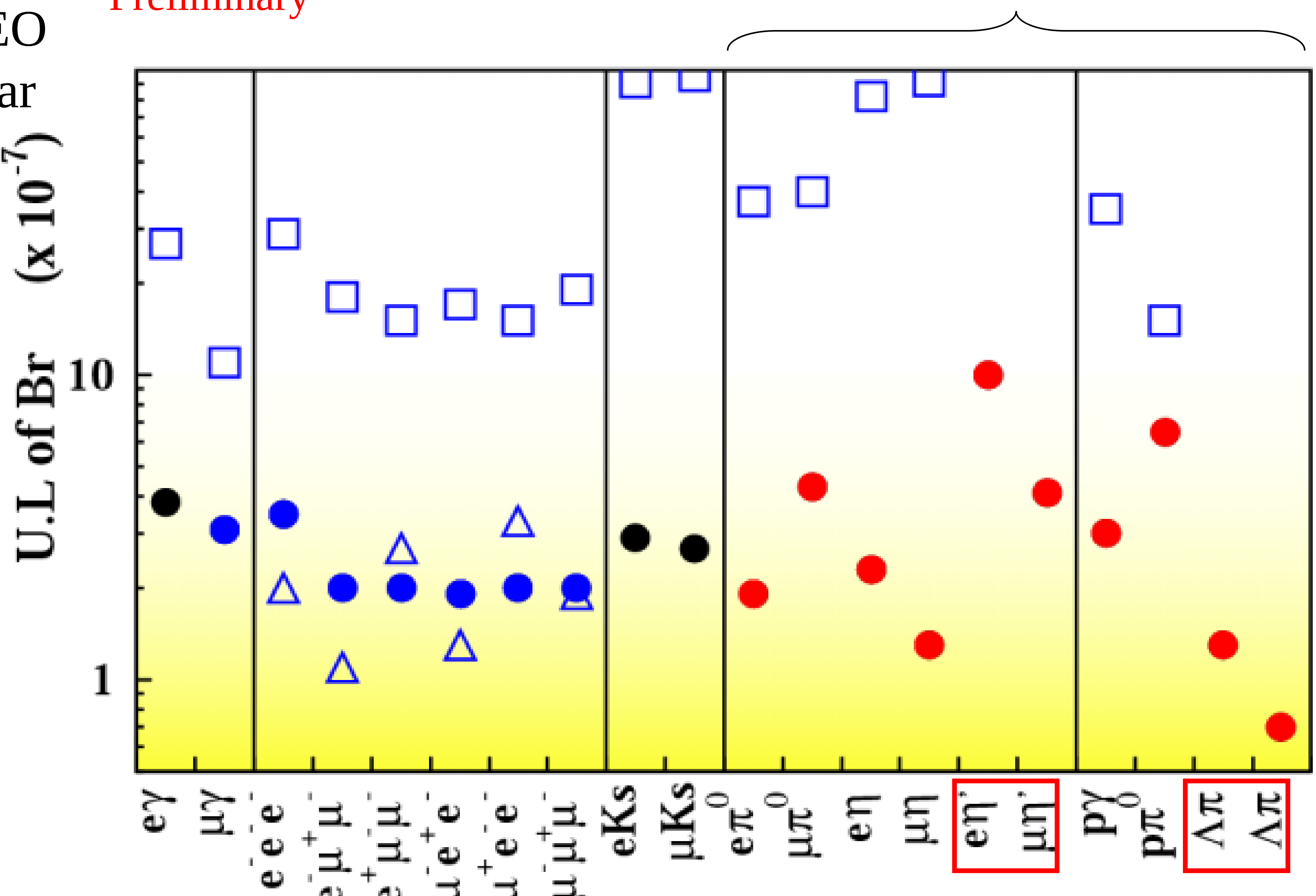
http://lephiggs.web.cern/LEPHIGGS/paper/Note2001-04

Status of LFV search in Belle

● Belle
□ CLEO
△ Babar

Published
Preliminary

New result of this summer.



Summary

- Search for LFV τ decay using 154fb^{-1}.

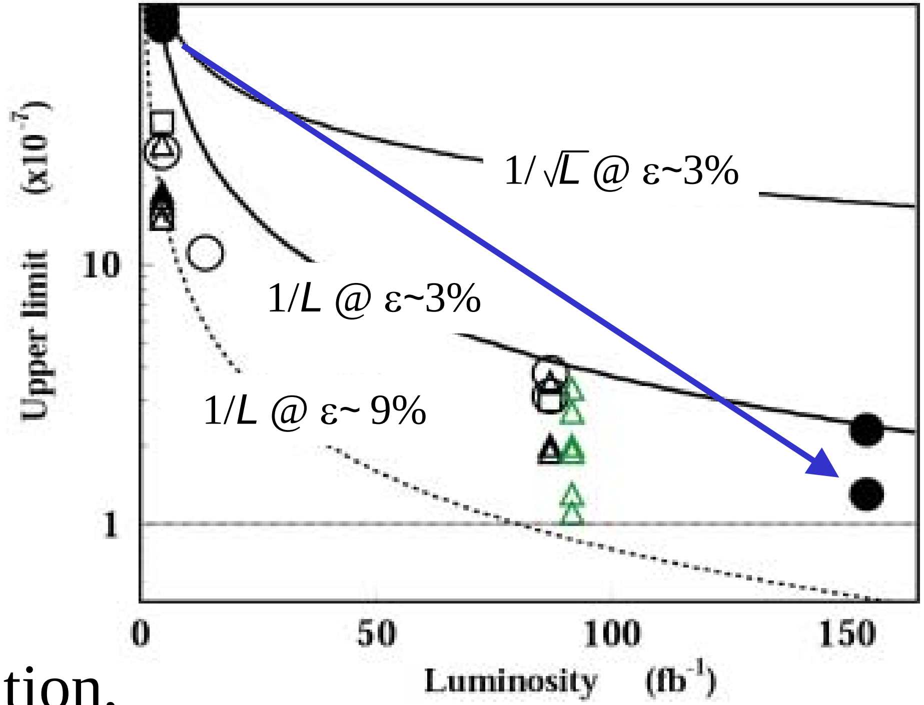
  $B(\tau \to l\,\pi^0, l\,\eta, l\,\eta') < 1.3 \sim 10\times10^{-7}$ @ 90%C.L..

  - 10-70 times tighter bounds.
  - First searches in $\tau \to e\eta', \mu\eta'$.
- From Belle,

  Set U.L. for 20 LFV modes.

  $B < O(10^{-7})$ @90%C.L.

  First searches in $\tau^- \to \bar{\Lambda}\pi^-, \Lambda\pi^-$



Near Future:

- Thanks to KEKB successful operation,

  now we have data of 287 fb^{-1}.

  We will obtain the data of >100fb^{-1}/year.

  – Update and Search other modes.

Stay Tuned !!!

Backup slide

Summary table of LFV search in Belle

Preliminary result

$\mathcal{B} < O(10^{-7})$ are obtained

Mode	$\int \mathcal{L}\, dt$	U.L. of $\mathcal{B}$
$\tau^- \to e^- \pi^0$	$154 fb^{-1}$	1.9×10^{-7}
$\tau^- \to \mu^- \pi^0$		4.3×10^{-7}
$\tau^- \to e^- \eta$		2.3×10^{-7}
$\tau^- \to \mu^- \eta$		1.3×10^{-7}
$\tau^- \to e^- \eta'$		10×10^{-7}
$\tau^- \to \mu^- \eta'$		4.1×10^{-7}
$\tau^- \to \bar{p} \gamma$	$87 fb^{-1}$	3.0×10^{-7}
$\tau^- \to \bar{p} \pi^0$	$154 fb^{-1}$	6.5×10^{-7}
$\tau^- \to \bar{\Lambda} \pi^-$	$154 fb^{-1}$	1.3×10^{-7}
$\tau^- \to \Lambda \pi^-$		0.7×10^{-7}

Mode	$\int \mathcal{L}\, dt$	U.L. of $\mathcal{B}$
$\tau^- \to e^- \gamma$	$87\ fb^{-1}$	3.8×10^{-7}
$\tau^- \to \mu^- \gamma$		3.1×10^{-7}
$\tau^- \to e^- e^+ e^-$	$87\ fb^{-1}$	3.5×10^{-7}
$\tau^- \to e^- \mu^+ \mu^-$		2.0×10^{-7}
$\tau^- \to e^+ \mu^- \mu^-$		2.0×10^{-7}
$\tau^- \to \mu^- e^- e^+$		1.9×10^{-7}
$\tau^- \to \mu^+ e^- e^-$		2.0×10^{-7}
$\tau^- \to \mu^- \mu^+ \mu^-$		2.0×10^{-7}
$\tau^- \to e^- K_s$	$46 fb^{-1}$	2.9×10^{-7}
$\tau^- \to \mu^- K_s$		2.7×10^{-7}

First search results.

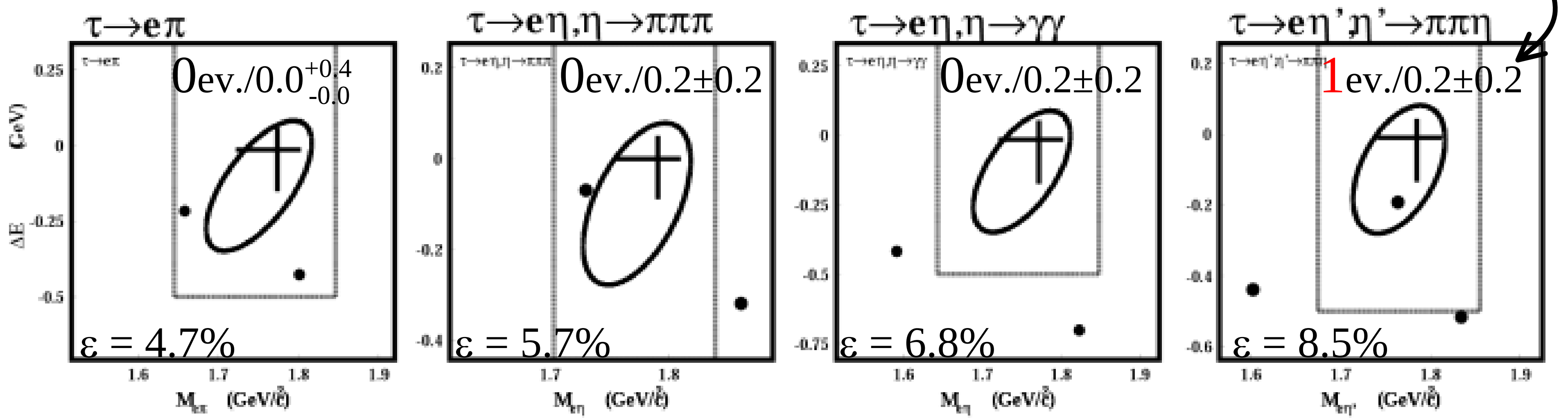
New result in this summer.

Published results

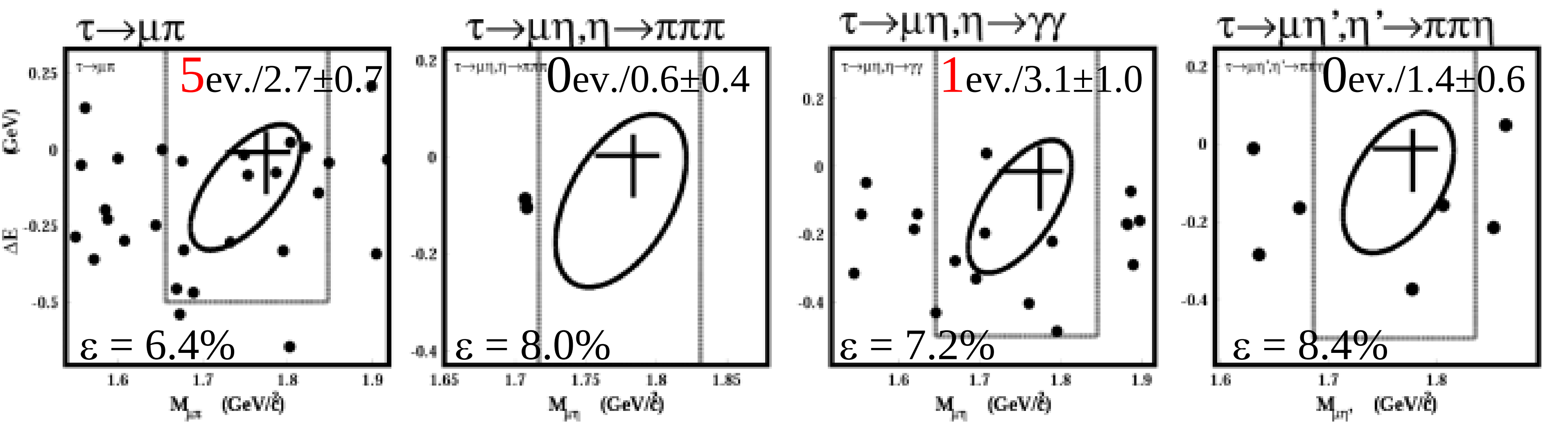
In total, we set U.L. in 20 mode.

Result: $\tau \to l\,\pi^0, l\,\eta, l\,\eta'$ *Preliminary*

N^{obs}/N^{exp}

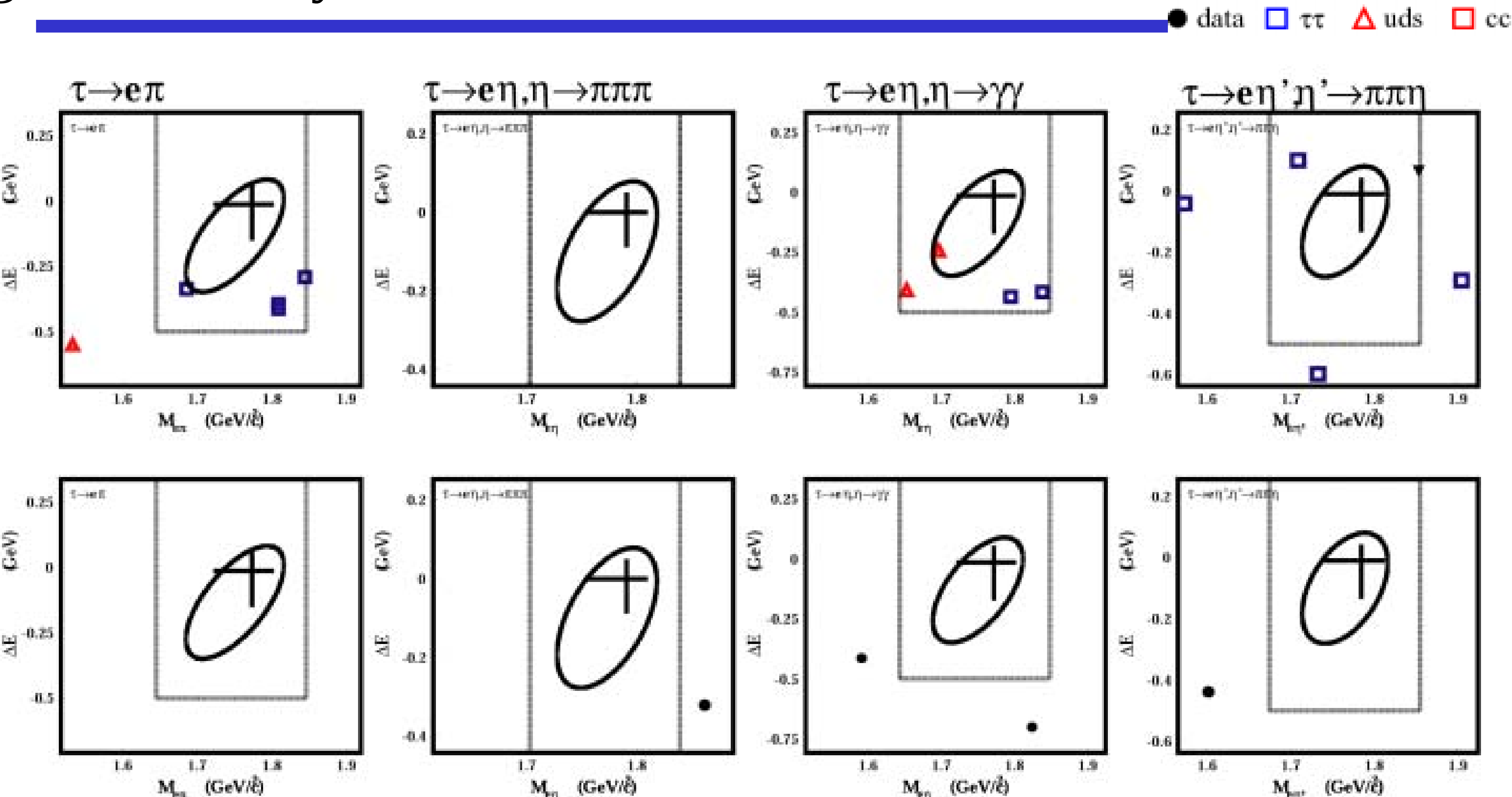


$B\,(\tau \to e\pi^0) <$ **1.9×10^{-7}** $B\,(\tau \to e\eta) <$ **2.3×10^{-7}** $B\,(\tau \to e\eta') <$ **10×10^{-7}**



$B\,(\tau \to \mu\pi^0) <$ **4.3×10^{-7}** $B\,(\tau \to \mu\eta) <$ **1.3×10^{-7}** $B\,(\tau \to \mu\eta') <$ **4.1×10^{-7}**

gnal efficiency and BG - electron modes -

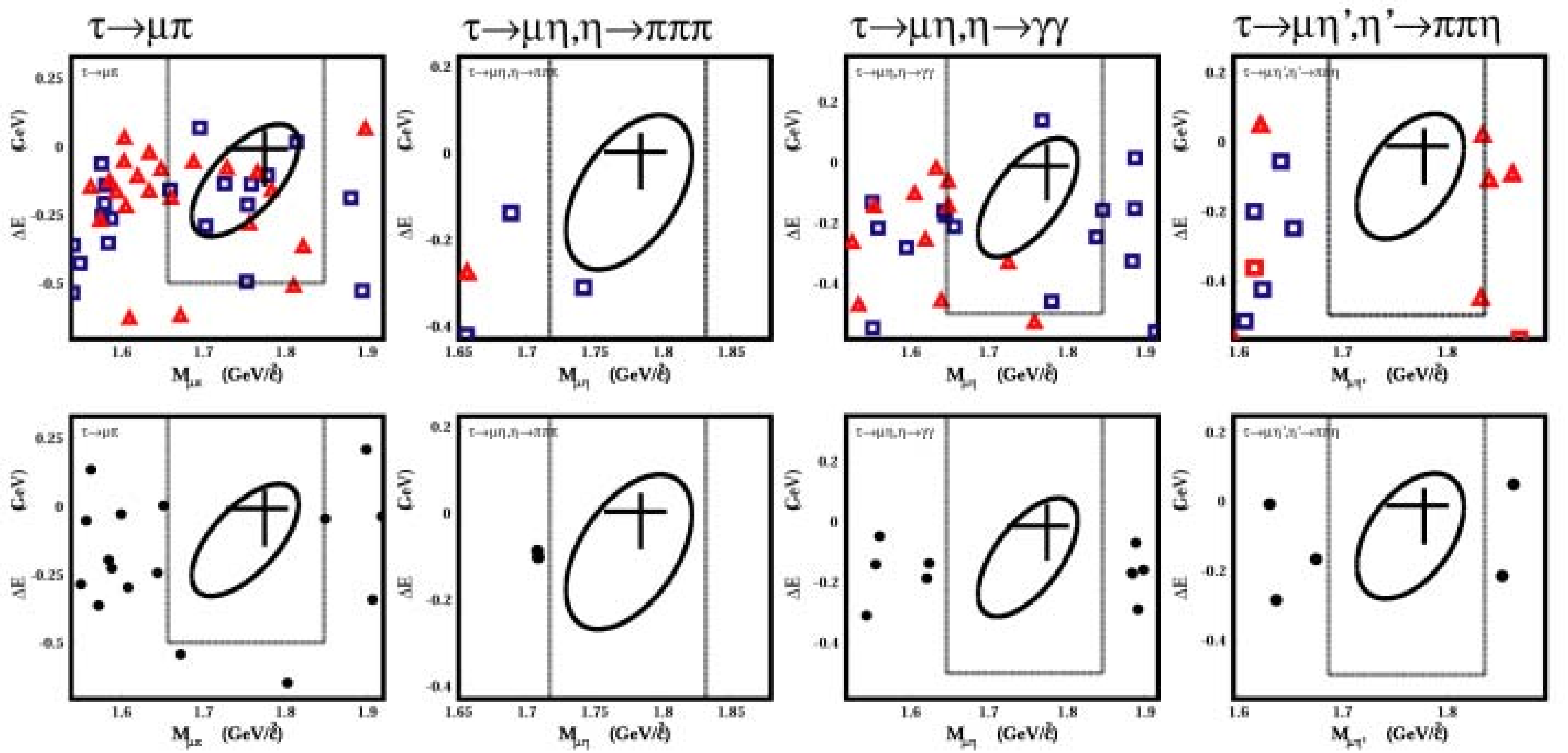


side band

	$\tau\to e\pi$	$\tau\to e\eta,\eta\to\pi\pi\pi$	$\tau\to e\eta,\eta\to\gamma\gamma$	$\tau\to e\eta',\eta'\to\pi\pi\eta$
MC :	0.7±0.7	0.0 ± 0.7	0.0 ± 0.7	0.8 ± 0.3
data :	0	1	1	1
b_0	$0\,^{+0.4}_{-0.0}$	0.23 ± 0.23	0.15 ± 0.15	0.16 ± 0.16

al efficiency and BG - muon mode -

● data □ ττ △ uds □ cc
(153.8, 428, 232, 160 fb^{-1}



side band

	$\tau\to\mu\pi$	$\tau\to\mu\eta,\eta\to\pi\pi\pi$	$\tau\to\mu\eta,\eta\to\gamma\gamma$	$\tau\to\mu\eta',\eta'\to\pi\pi\eta$
MC :	12.5±2.7	0.8 ± 0.3	9.2 ± 2.3	5.5 ± 1.9
data :	13	2	9	5
b_0	2.7 ± 0.7	0.6 ± 0.4	3.1 ± 1.0	1.4 ± 0.6

Systematic uncertainty

- Related sensitivity In Total : 4.5 ~ 8.7 %

Mode	$e^-\eta$, $\eta \to \gamma\gamma$	$e^-\eta$, $\eta \to 3\pi$	$\mu^-\eta$, $\eta \to \gamma\gamma$	$\mu^-\eta$, $\eta \to 3\pi$	$e^-\pi^0$, $\pi^0 \to \gamma\gamma$	$\mu^-\pi^0$, $\pi^0 \to \gamma\gamma$	$e^-\eta'$, $\eta \to \gamma\gamma$	$\mu^-\eta'$, $\eta \to \gamma\gamma$
Track recon.	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
η recon.	2.0	4.2	2.0	4.2	2.2	2.2	4.0	4.0
π^0 veto	5.5	–	5.5	–	–	–	5.5	5.5
e ID	1.0	1.0	–	–	1.0	–	1.0	–
μ ID	–	–	2.0	2.0	–	2.0	–	2.0
Trigger	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
Beam BG	2.3	2.1	2.3	2.1	2.3	2.3	2.3	2.2
Lumi	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
$\mathcal{B}$	0.7	1.8	0.7	1.8	–	–	3.4	3.4
MC stat.	1.4	1.7	1.1	1.6	0.9	0.8	1.2	1.1
MC models	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Total	7.2	6.1	7.3	6.3	4.5	4.8	8.6	8.7

- Related BG
  - Using statistical error as systematic error. (30~45%)
  - If b0 < 1, we set b0=0 in order to obtain conservative limit.

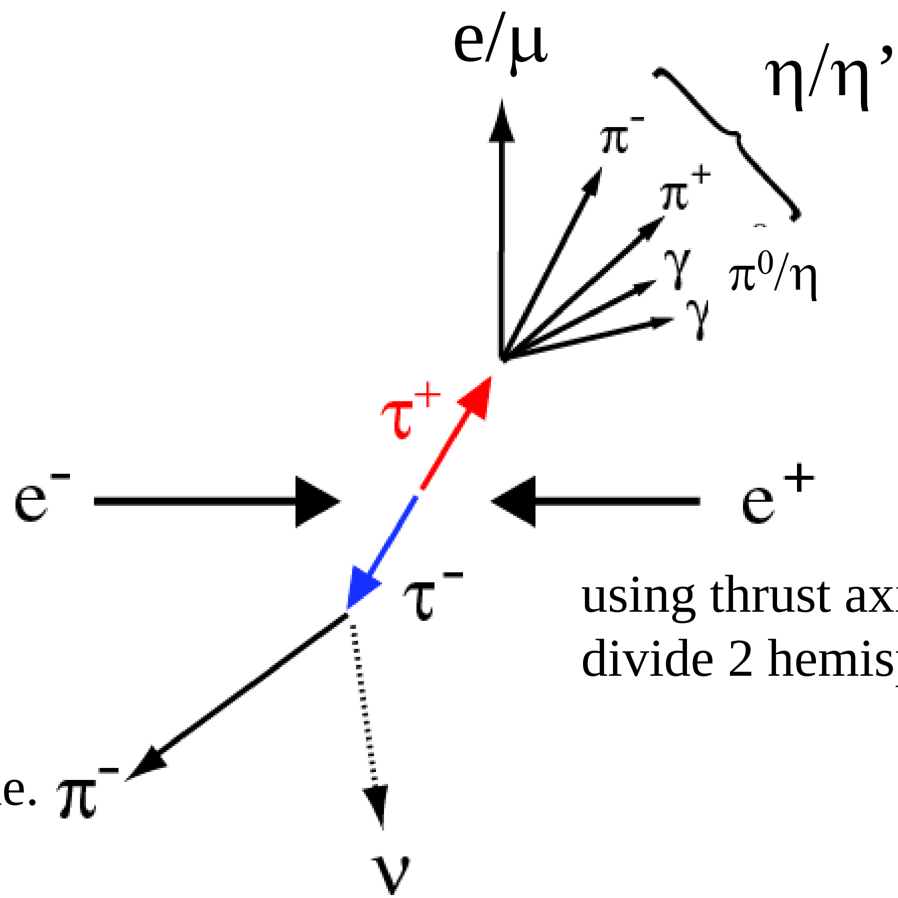
→ **POLE program**

2.1 Selection criteria (1-3 prong + η/η')

- 1-3 prong + $n_\gamma \geq 2$
  E_γ > 0.1 GeV , barrel and endcap
  p_{trk}>0.06GeV/c barrel.
  p_{trk} >0.1GeV/c endcap.
  net charge=0.
  dz_{rms} < 1cm, dr_{rms} < 1cm
  → to reject junk track.

signal side:
μ(e)–ID > 0.9 + 2trk(+,–).

- Missing momentum towards tag side.
- p_{miss} vs. m_{miss}^2 2-D cut.
- $0.5 < \cos\theta_{\mu\eta'} < 0.92$
- $-3\,\sigma < M_\eta < 3\,\sigma$



using thrust axis,
divide 2 hemisphere

for tag side,
$m_{tag} < 1.777$ GeV/c^2

2.2 Selection criteria (1-1 prong + π^0/η)

– 1-1 prong + $n_\gamma \geq 2$

signal side:

μ(e)–ID > 0.9 + 2 γ.

$P_{\mu(e)}$>0.7GeV/c, Eγ > 0.22GeV

– π^0 veto for η's γ

tag side:

– NOT μ(e)

– $M_{tag} < 1.777$ GeV/c^2

Kinematical cut.

– Missing momentum towards tag side.

– p_{miss} vs. m_{miss}^2 2-D cut.

– $0.5 < \cos\theta_{\mu\eta'} < 0.92$

– $-5\,\sigma < M_\eta < 3\,\sigma$