The search for $\tau \to l\,\gamma$ at Belle and Belle II

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Introduction: $\tau \rightarrow l\,\gamma$

- $\tau \rightarrow l\,\gamma$ is a prohibited decay in the SM for massless neutrinos
- extending the SM to include neutrino masses allows flavour mixing between generations → LFV can occur
- even so, LFV in the SM + massive neutrinos is suppressed and is unobservably small

$$BR(\tau \rightarrow \mu\gamma)_{\mathrm{SM}} < 10^{-40}$$

Introduction: $\tau \rightarrow l\,\gamma$

- unobservably small branching fraction for LFV processes allows New Physics (NP) to be probed without SM contamination
- of the tau processes, $\tau \rightarrow l\,\gamma$ decays predicted to be dominant
- why taus not muons? muons are easier to produce!
- expected branching fraction $\sim 10^{5-6}$ greater than $\mu \rightarrow e\,\gamma$ due to tau mass

Other LFV

LFV Process	Present Bound	Future Sensitivity
$\mu \to e\gamma$	5.7×10^{-13} [1]	$\approx 6 \times 10^{-14}$ [2]
$\mu \to 3e$	1.0×10^{-12}[3]	$\approx 10^{-16}$ [4]
$\mu^- \mathrm{Au} \to e^- \mathrm{Au}$	7.0×10^{-13} [5]	?
$\mu^- \mathrm{Ti} \to e^- \mathrm{Ti}$	4.3×10^{-12} [6]	?
$\mu^- \mathrm{Al} \to e^- \mathrm{Al}$	–	$\approx 10^{-16}$ [7, 8]
$\tau \to e\gamma$	3.3×10^{-8} [9]	$\sim 10^{-8} - 10^{-9}$ [10]
$\tau \to \mu\gamma$	4.4×10^{-8} [9]	$\sim 10^{-8} - 10^{-9}$ [10]
$\tau \to 3e$	2.7×10^{-8}[11]	$\sim 10^{-9} - 10^{-10}$ [10]
$\tau \to 3\mu$	2.1×10^{-8}[11]	$\sim 10^{-9} - 10^{-10}$ [10]

Table 1: Present and future experimental sensitivities for LFV processes (Paradisi, 2015)

Motivations for LFV searches

- 1) mechanisms to explain neutrino mixing necessarily introduce LFV (???)
- 2) interesting anomalies, such as $h \to \tau \mu$ excess, can ….?
- 3) many NP models predict LFV to occur, AND predict the branching fractions – experimentally determining LFV branching fractions can rule out certain models

- Okay I need more here

Neutrino mixing

$h \rightarrow \tau \mu$ excess

- CMS found some excess ???
- ATLAS found (not) an excess (?)
- *Aristizal Sierra* and *Vicente* (2014) propose an explanation of observed excess
- Type-III 2HDM (two Higgs doublet model) allows LFV

$h \to \tau\,\mu$ excess

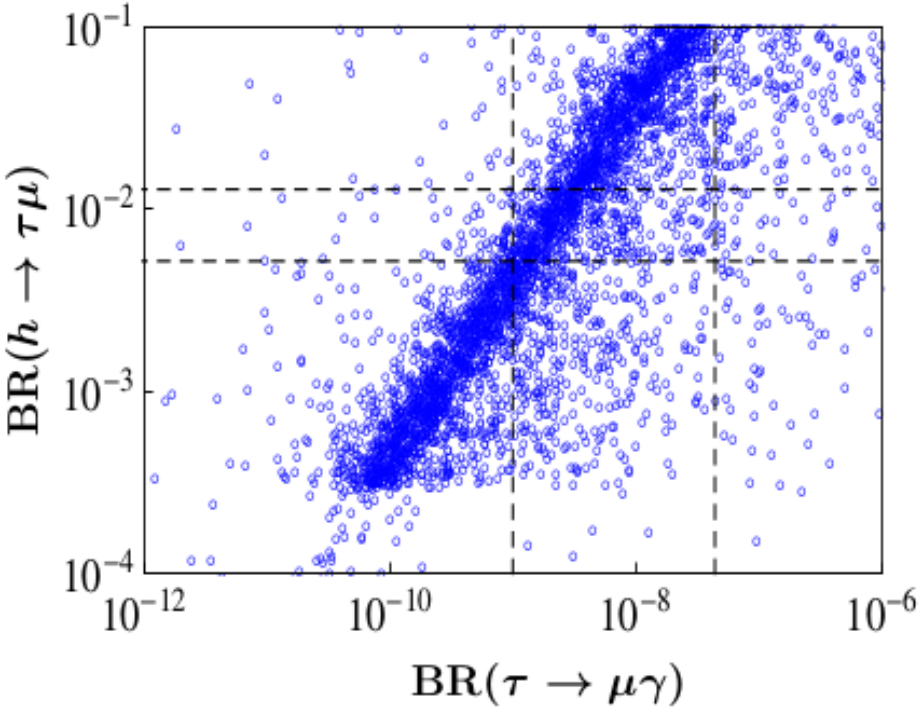


Figure: BR(h → τ μ) as a function of BR(τ → μ γ)
(Aristizabal Sierra and Vicente, 2014)

- horizontal lines are 1σ bands on BR(h → τ μ) (at 90% CL)
- vertical lines are (right) current upper limit BR(τ → μ γ) and (left) Belle II expected sensitivity
- under this model we would expect to find a signature in Belle II

Models predicting $\tau \to l\,\gamma$

model	$Br(\tau \to \mu\gamma)$
mSUGRA + seesaw	10^{-7}
SUSY + SO(10)	10^{-8}
SM + seesaw	10^{-9}
Non-Universal Z'	10^{-9}
SUSY + Higgs	10^{-10}

Table 2: Branching fractions of $\tau \to \mu\,\gamma$, predicted by models of new physics beyond the SM (various sources)

- recall present and future bounds on some LFV processes

LFV Process	Present Bound	Future Sensitivity
$\tau \to e\gamma$	3.3×10^{-8} [9]	$\sim 10^{-8} - 10^{-9}$ [10]
$\tau \to \mu\gamma$	4.4×10^{-8} [9]	$\sim 10^{-8} - 10^{-9}$ [10]

MSSM

- “The source of LFV in the MSSM is the potential misalignment between lepton and slepton mass matrices.” *Brignole, Rossi* (2004).

- Not sure if I need this slide (or others specifically discussing models, since theorists will know these models a lot better than I will, and I don’t actually need to know the specifics)

Current searches

Belle (2007), 535fb^{-1} :

$$BR(\tau \to \mu\gamma) < 4.5 \times 10^{-8}$$

$$BR(\tau \to e\gamma) < 1.2 \times 10^{-7}$$

Babar (2010), 515.5fb^{-1} :

$$BR(\tau \to \mu\gamma) < 4.4 \times 10^{-8}$$

$$BR(\tau \to e\gamma) < 3.3 \times 10^{-8}$$

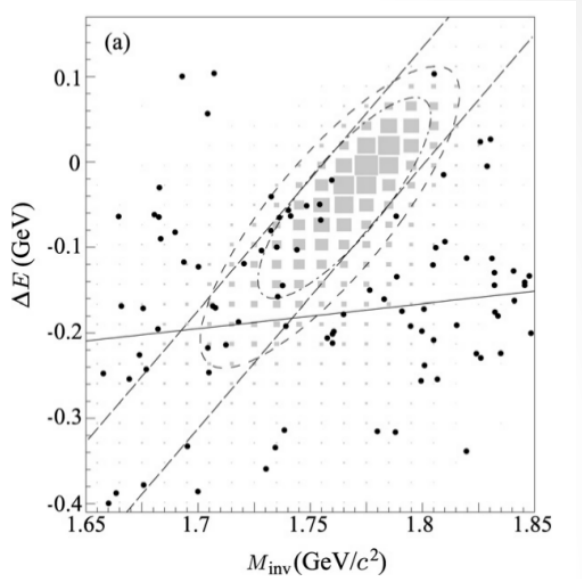


Figure: M_{inv} - ΔE distribution in the search for $\tau \to \mu\gamma$ at Belle (*Hayasaka,* 2008)

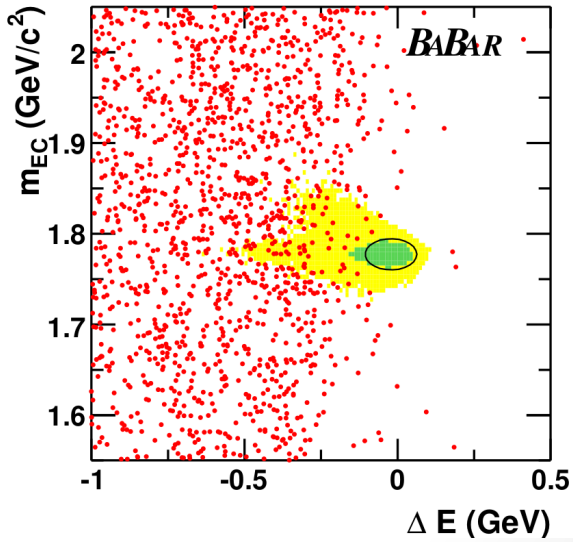


Figure: M_{bc} - ΔE distribution in the search for $\tau \to \mu\gamma$ at Babar(*Babar Collaboration,* 2010)

Future searches

Belle II, $5\,ab^{-1}$:

$$BR(\tau \to \mu\gamma) < 1.5 \times 10^{-8}$$

$$BR(\tau \to e\gamma) < 3.9 \times 10^{-8}$$

Belle II, $50\,ab^{-1}$:

$$BR(\tau \to \mu\gamma) < 4.7 \times 10^{-9}$$

$$BR(\tau \to e\gamma) < 1.2 \times 10^{-8}$$

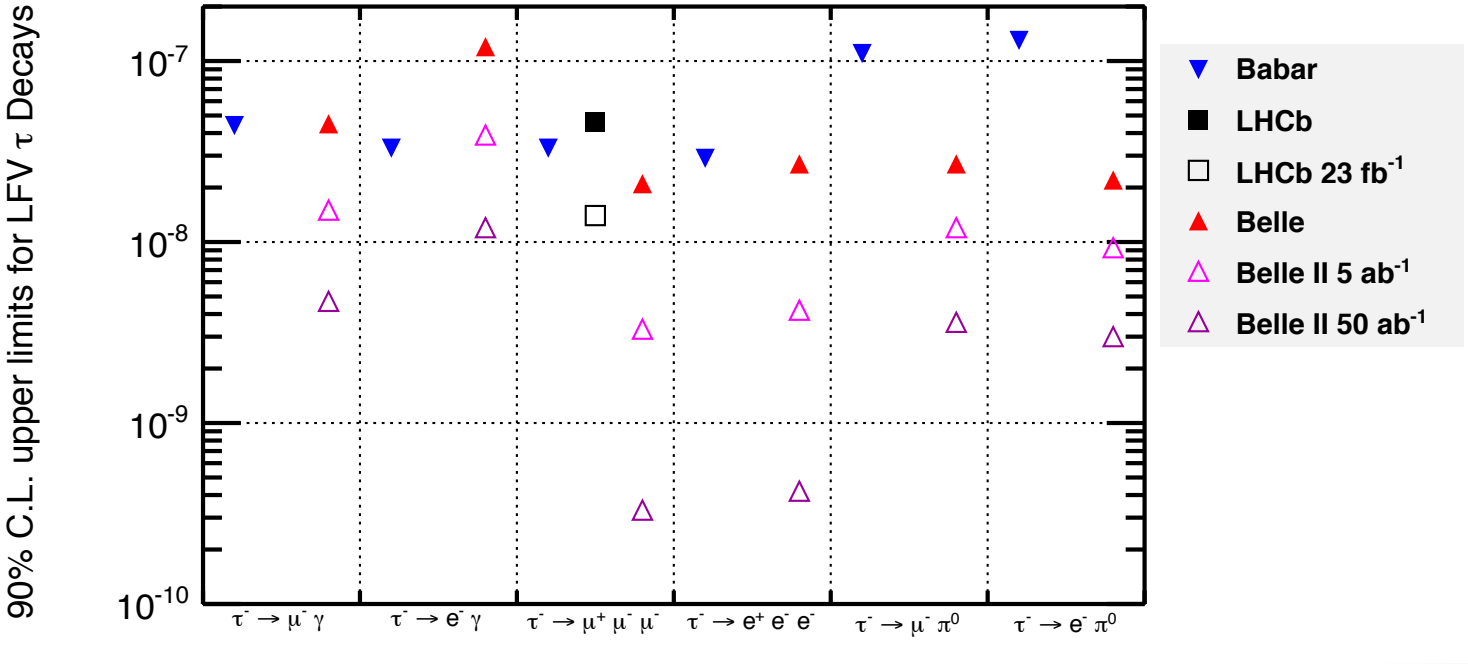


Figure: Current and future sensitivities on tau LFV branching fractions (*Urquijo*, 2016)

My search

- key backgrounds for $\tau \rightarrow \mu\, \gamma$:
  - $\tau \rightarrow \mu\, \nu\, \nu$
  - $\tau \rightarrow \pi\, \nu$ (π misidentified as μ)
  - $e\, e \rightarrow \mu\, \mu\, \gamma$
- approx 1.5 million signal ($\tau \rightarrow \mu\, \gamma$) MC events produced
- approx 3500 million generic (tau-pair) MC events produced by the Belle II Collaboration
- 24 selection criteria added (based on previous Belle search)
- cuts made to suppress various backgrounds

My search

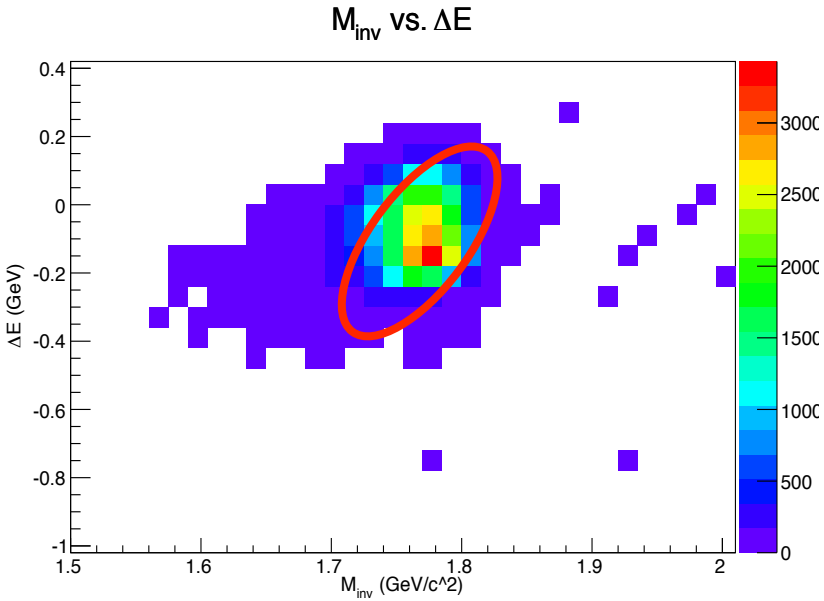
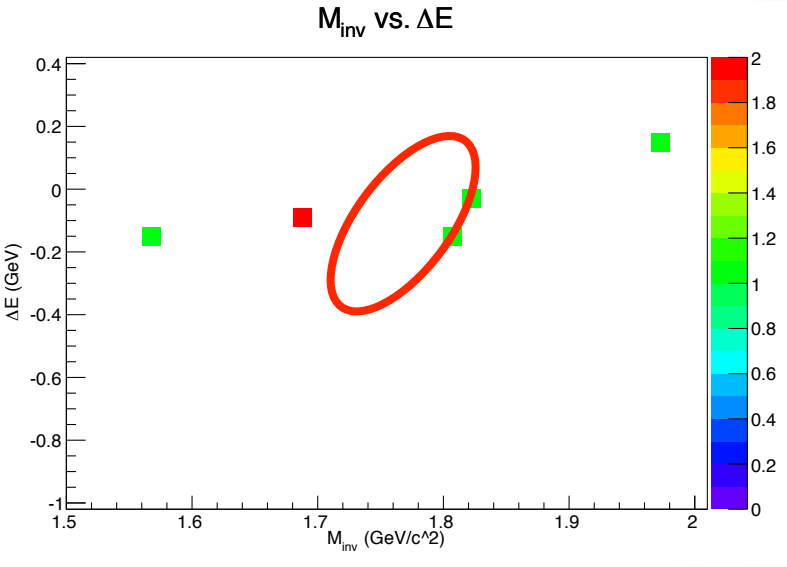


Figure: M_{inv} - ΔE distribution for signal MC ($\tau \rightarrow \mu\,\gamma$) after selection cuts (59,265 events out of 1,632,596)

Efficiency: ~ 3.6%

Figure: M_{inv} - ΔE distribution for background MC after selection cuts (6 events out of 5,938,869)



Efficiency: ~ 1×10^{-4}%

Summary

- LFV is an exciting place to search for new physics
- neutrino masses?
- determining a value of BR($\tau \to l\,\gamma$) can exclude certain models
- negligible SM background means an observation would be an unambiguous signature of NP
- analysis framework is being set up for Belle II data analyses

- my next steps?