Lepton Flavor Violation at BaBar

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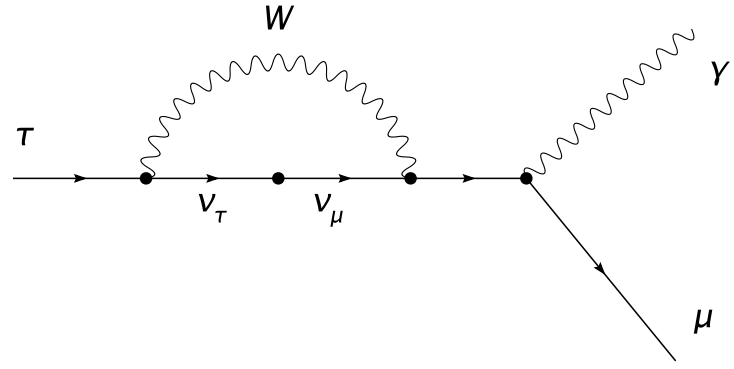
On behalf of the BaBar Collaboration

Lepton Flavor Violation

Lepton Flavor Violation (LFV): non-conservation of number of tau-like, muon-like, or electron-like particles

Conservation of lepton flavor is not associated with any fundamental symmetry of the Standard Model

Neutrino Oscillations: Nature violates lepton flavor symmetry



SM $\tau \to \mu\gamma$ rate is $\mathcal{O}(10^{-54})$

Any observation is a sign of New Physics!

LFV: Experiment

One can make many searches for LFV at Babar:

Talk will focus on decay modes in red

- $\tau \to \ell\gamma$
- $\tau \to \ell\ell\ell$
- $\tau \to \ell hh$
- $\tau \to \ell\, \pi^0/\eta/\eta'$

- $\tau \to \Lambda\pi/K$
- $e^+e^- \to \ell\tau$
- $B \to \ell\tau$

Experimental Limits before B-factories

Channel	limit (90%CL)	experiment
$\mu \to e\gamma$	1.2×10^{-11}	MEGA/LAMPF
$\mu \to eee$	1.0×10^{-12}	SINDRUM
$\tau \to \mu\gamma$	1.1×10^{-6}	CLEO
$\tau \to \mu\mu\mu$	1.9×10^{-6}	CLEO

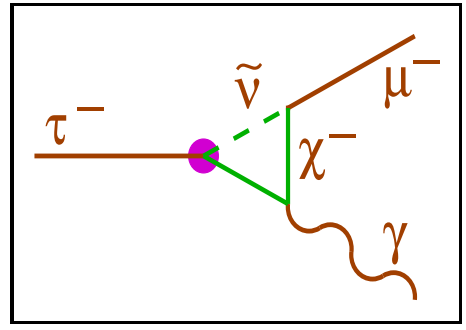
Babar/Belle can achieve limits 1-2 orders of magnitude lower than CLEO in these searches.

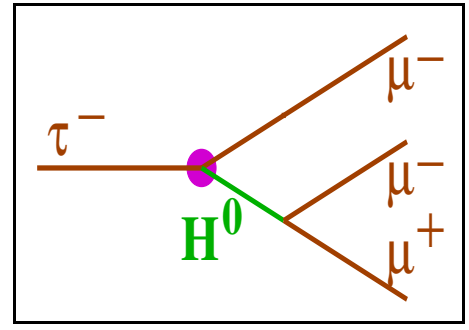
LFV in Tau Decays

Models of new physics often predict LFV in tau decays with rates $10^{-10} - 10^{-7}$.

	$\mathcal{B}(\tau \to \ell\gamma)$	$\mathcal{B}(\tau \to \ell\ell\ell)$
SM+ν-mixing (PRL95(2005)41802,EPJC8(1999)513)	10^{-54}	10^{-14}
SUSY Higgs (PLB549(2002)159, PLB566(2003)217)	10^{-10}	10^{-7}
SM+Heavy Majorana $\nu_{\rm R}$ (PRD66(2002)034008)	10^{-9}	10^{-10}
Non-Universal Z′ (PLB547(2002)252)	10^{-9}	10^{-8}
SUSY SO(10) (NPB649(2003)189, PRD68(2003)033012)	10^{-8}	10^{-10}
mSUGRA+seesaw (EPJC14(2000)319, PRD66(2002)115013)	10^{-7}	10^{-9}

- mass-dependant couplings enhance tau modes
- Neutrinoless 2- and 3-body LFV tau decays have different sensitivities





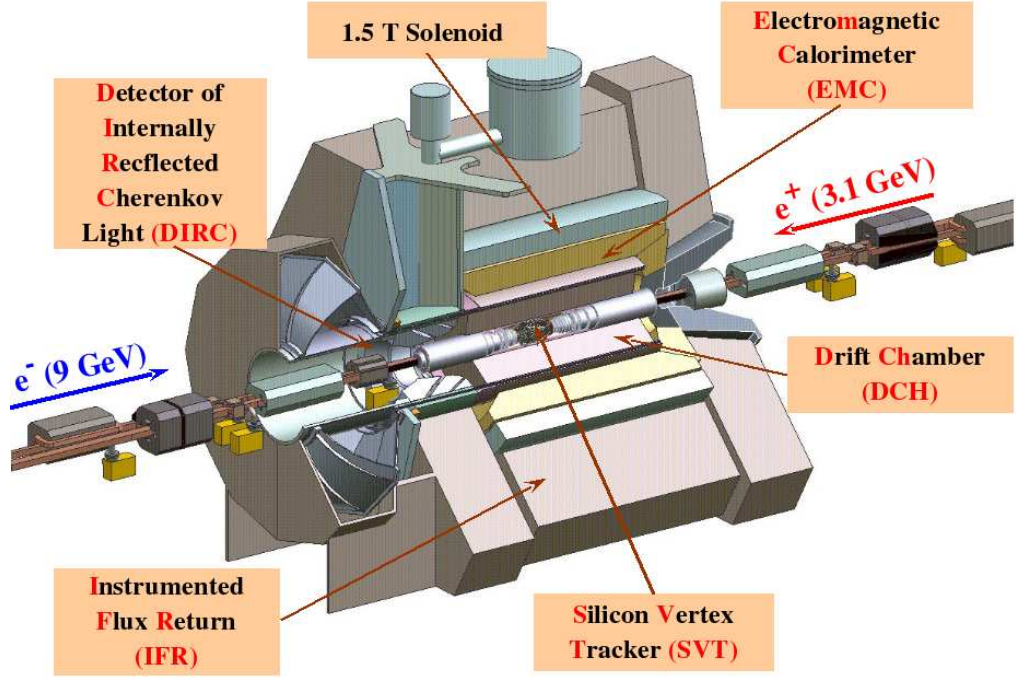
The BaBar Detector

Asymmetric e^+e^- "B Factory" is also a Tau-Charm Factory:

$\sigma(e^+e^- \to B\bar{B}) = 1.05$ nb
$\sigma(e^+e^- \to \tau^+\tau^-) = 0.9$ nb

- 9 GeV electrons
- 3.1 GeV positrons

collisions at 10.58 GeV in CMS



Typical lepton-ID performance
for LFV tau searches (loose criteria)

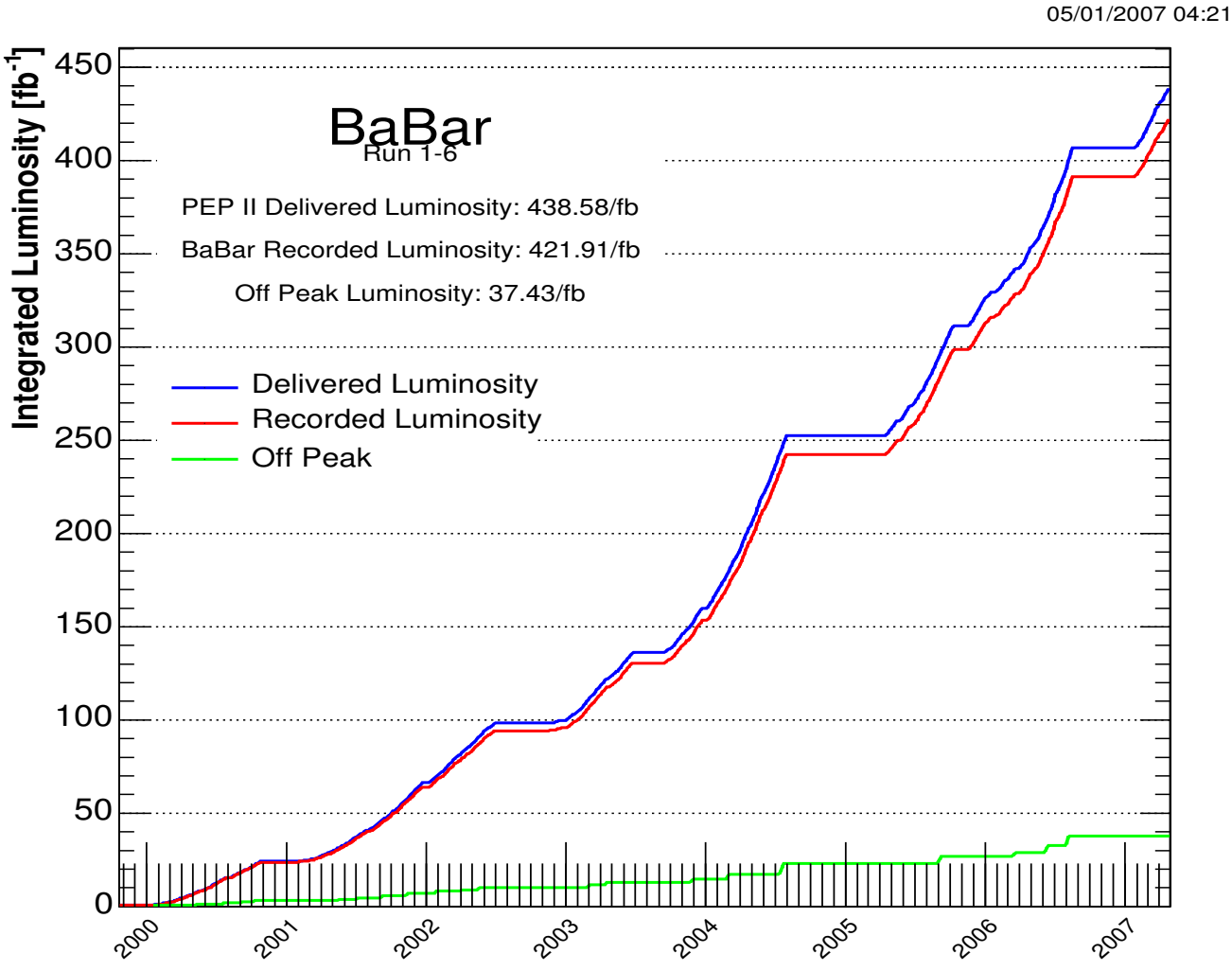
Particle	Efficiency	hadron mis-ID
electron	91%	2.2%
muon	66%	4.8%

PEP-II Luminosity

Integrated luminosity as of 1 May, 2007:

$421.9\ \text{fb}^{-1}$

almost 800M tau decays

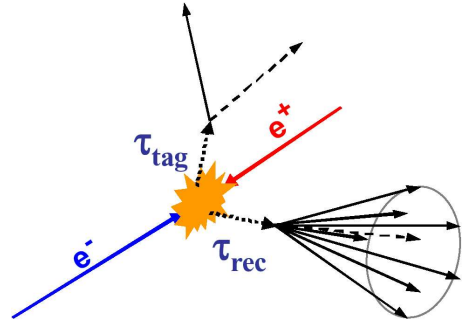


LFV in Tau Decays

Signature of LFV in tau decays: neutrinoless final state

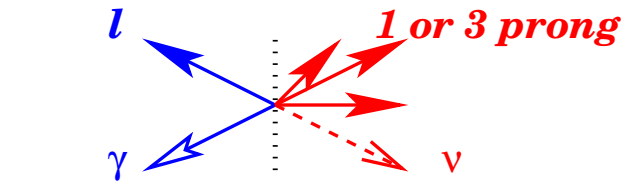
$\Rightarrow$ no missing energy

Clean environment:

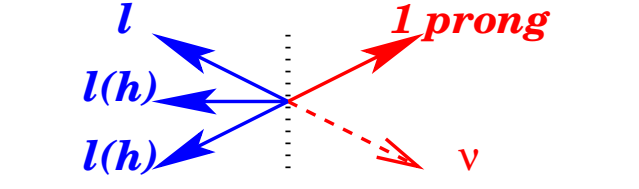


no $B\bar{B}$ background

Search for 1-1, 1-3 charged track topology.



(CM frame)

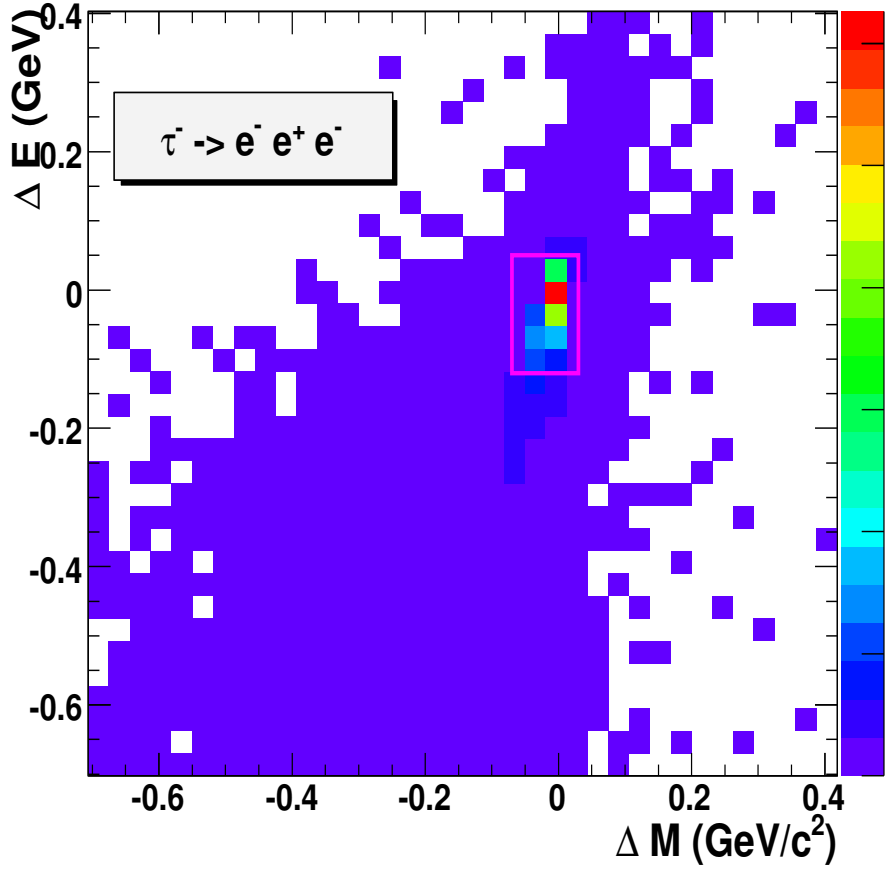


(CM frame)

Signal Characteristics

- Neutrinoless tau decay:
  - $\Delta m = m_{(3-prong)} - m_\tau$
  - $\Delta E = E_{rec}^{CM} - \sqrt{s}/2$
- Smeared by resolution and radiative effects
- Signal Box (SB) optimized for best upper limit
- Compare events in SB to expected background

simulated signal events



Analyses are blinded: data in SB are not counted until analysis is finalized

Backgrounds

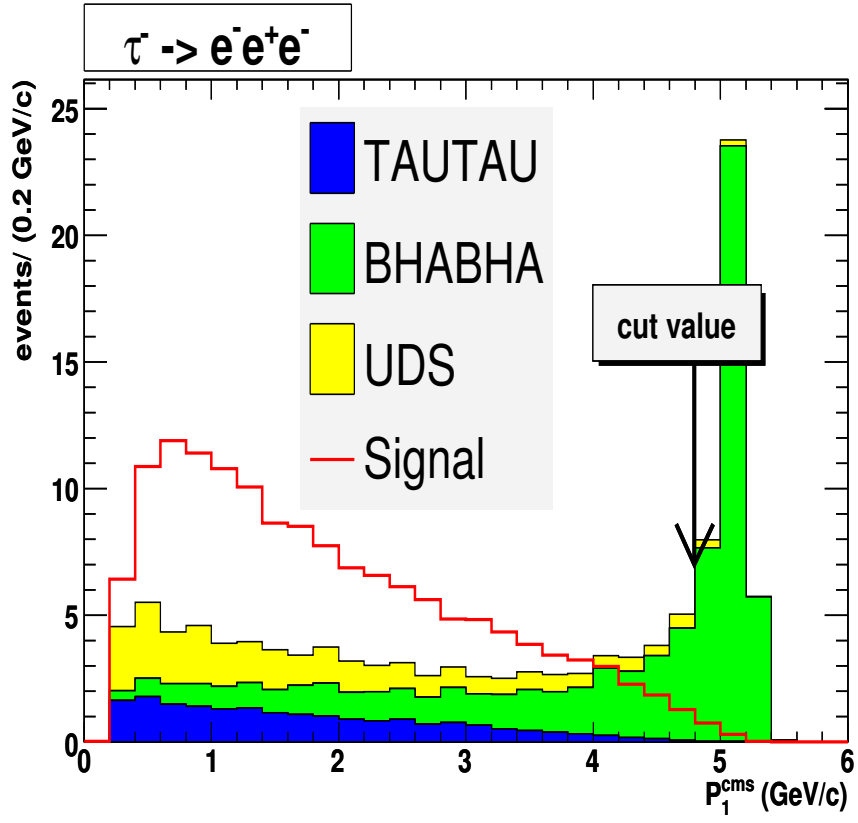
- $\boxed{\tau \to \ell\gamma}$ backgrounds present a problem
  - $\tau \to \ell\nu_\tau\bar{\nu}_\ell\gamma$ irreducible at some level
    $\Rightarrow$ mass/energy resolution is important
  - $e^+e^- \to \mu^+\mu^-\gamma$ is more significant
- $\boxed{\tau \to \ell\ell\ell}$ generally lower backgrounds than $\tau \to \ell\gamma$
  - radiative Bhabha/dimuon events
  - four fermion events (via two-photon production)
  - $q\bar{q}$ events
- $\boxed{\tau \to \ell hh}$ moderate background levels
  - $q\bar{q}$, SM τ pairs

Reject backgrounds with tight particle ID, kinematics.

Backgrounds: $\tau \to \ell\ell\ell, \tau \to \ell hh$

Once events with correct topology are selected, further background suppression is needed:

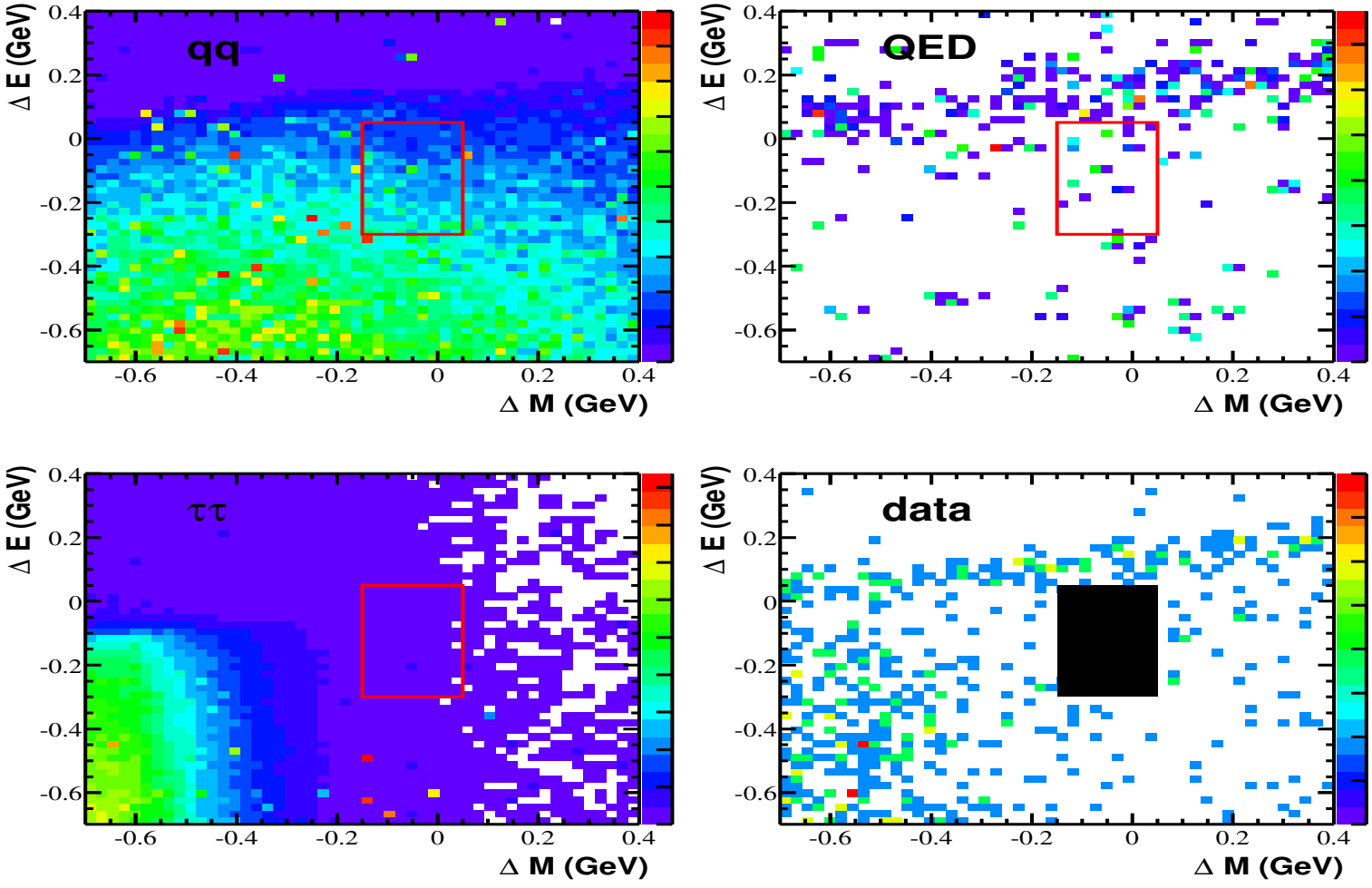
- Rejection of gamma conversions
- Particle Identification (PID)
  - require leptons/hadrons on 3-prong side
- Channel-specific cuts, e.g. 1-prong track momentum $\Longrightarrow$



Bhabha and di-muon backgrounds are modeled with data control samples.

Backgrounds: $\tau \to \ell\ell\ell, \ell hh$

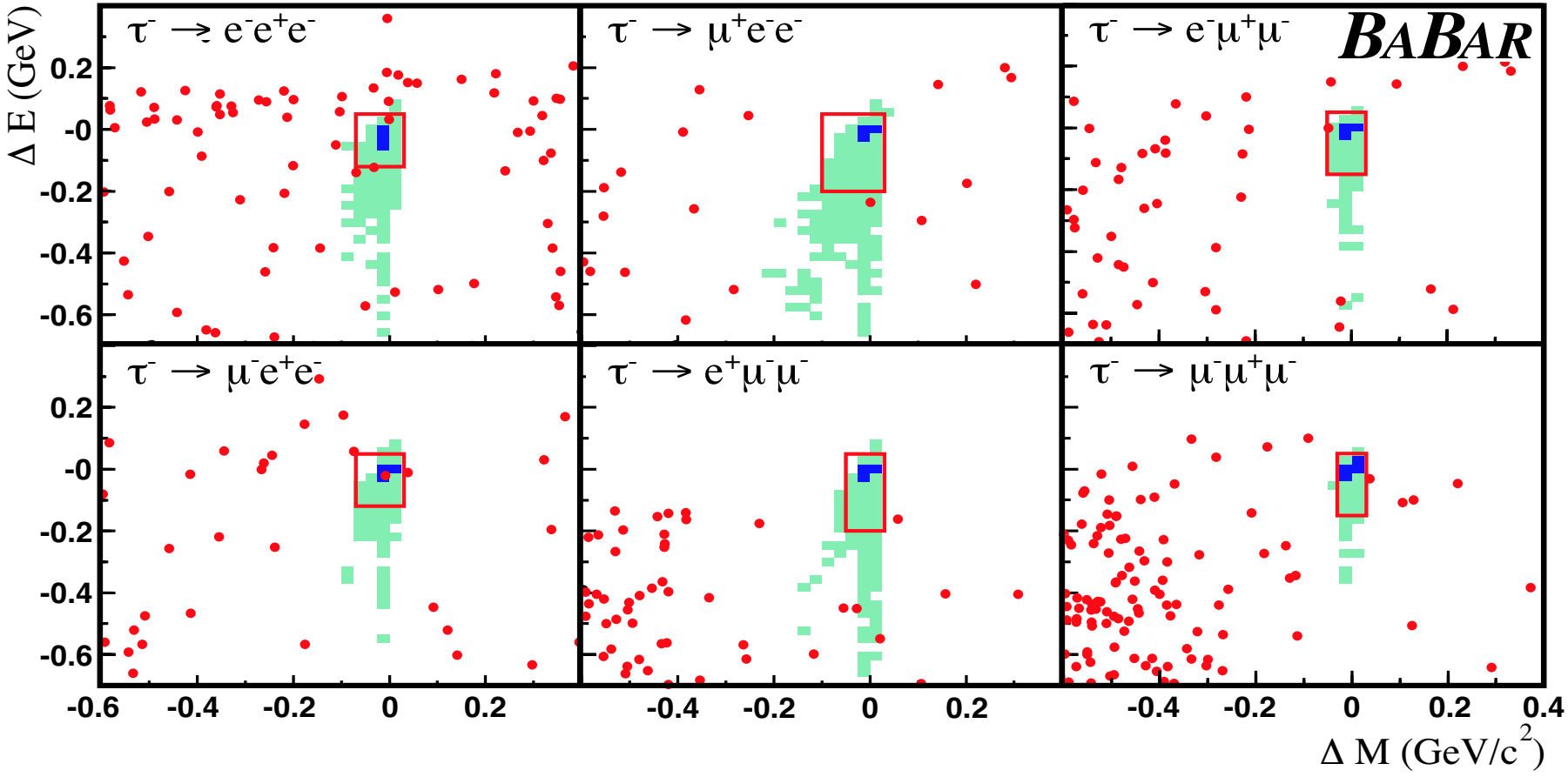
Final background estimate: shape from MC/control, rate from data sidebands.



Results: $\tau \to \ell\ell\ell$

Luminosity: 91.5 fb^{-1}

PRL92(2004)121801



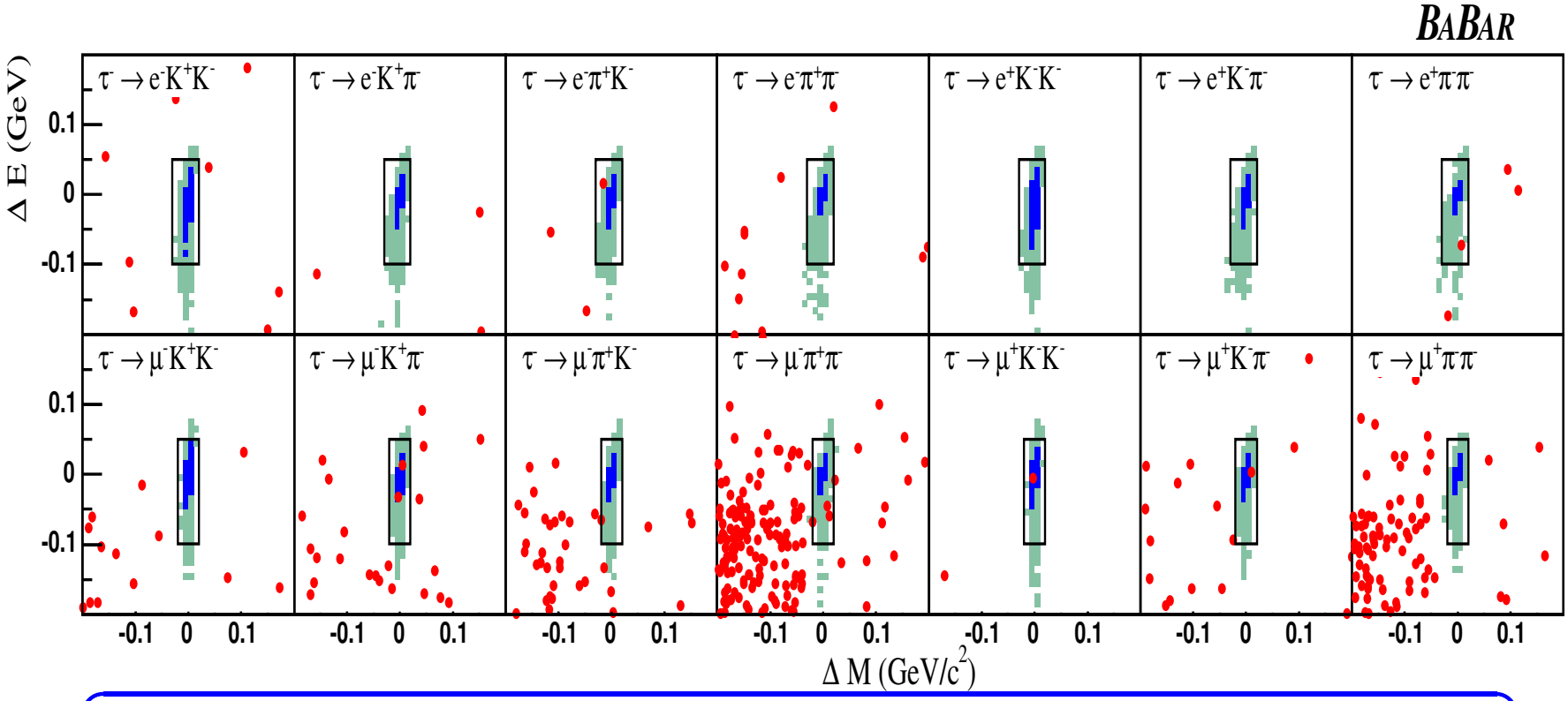
N_{bkg}/channel = $(0.2 - 1.5)$, Total expected = 3.4, Observed = 3

Results: $\tau \to \ell hh$

Luminosity: 221.4 fb^{-1}

PRL95(2005)191801

- Lepton Flavor violating modes: $\tau^- \to \ell^- h^+ h'^-$
- Lepton Number violating modes: $\tau^- \to \ell^+ h^- h'^-$



N_{bkg}/channel = $(0.1 - 3.0)$, Total expected = 11.3, Observed = 10

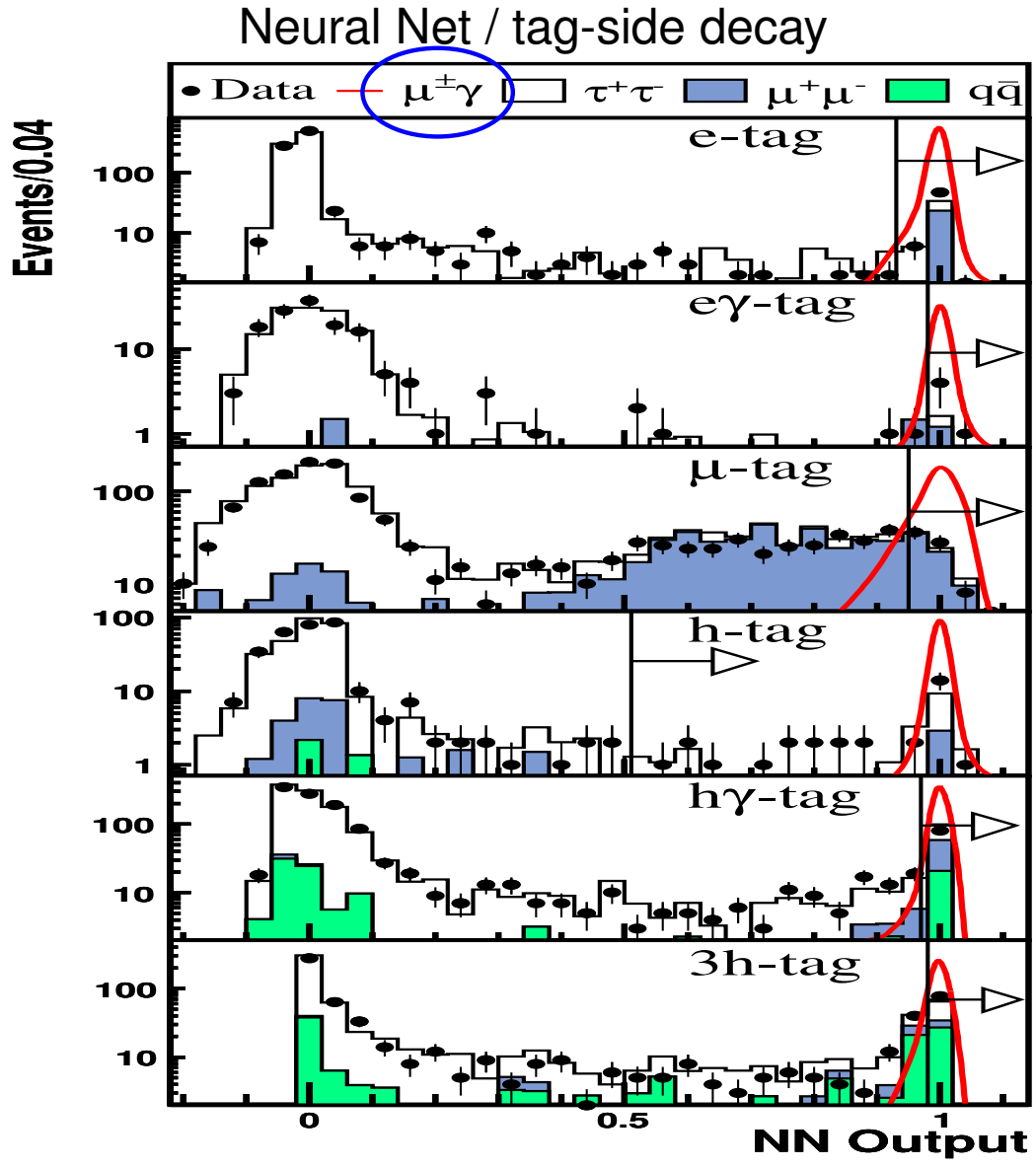
Background Suppression: $\tau \to \ell\gamma$

Common inputs:

- event missing mass
- highest tag-side p
- missing P_t
- tag-side m_ν^2

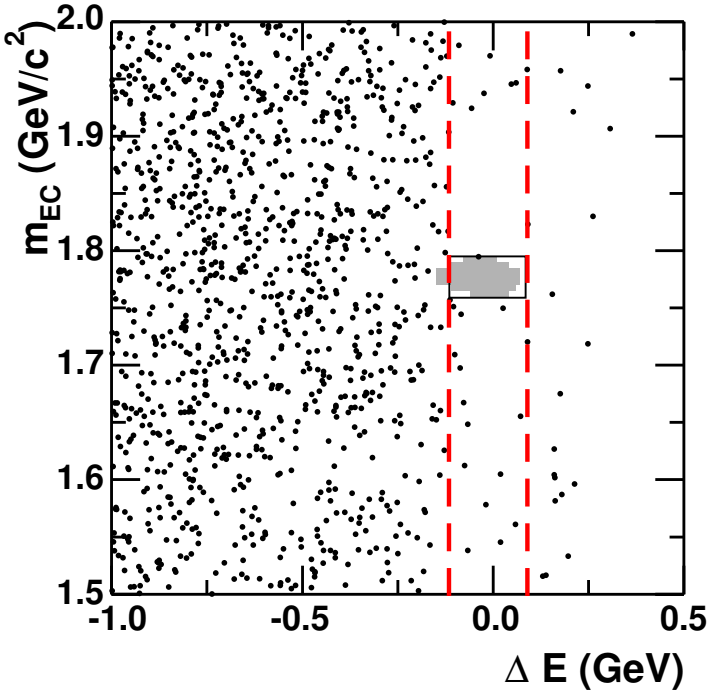
Tune by tagged mode:

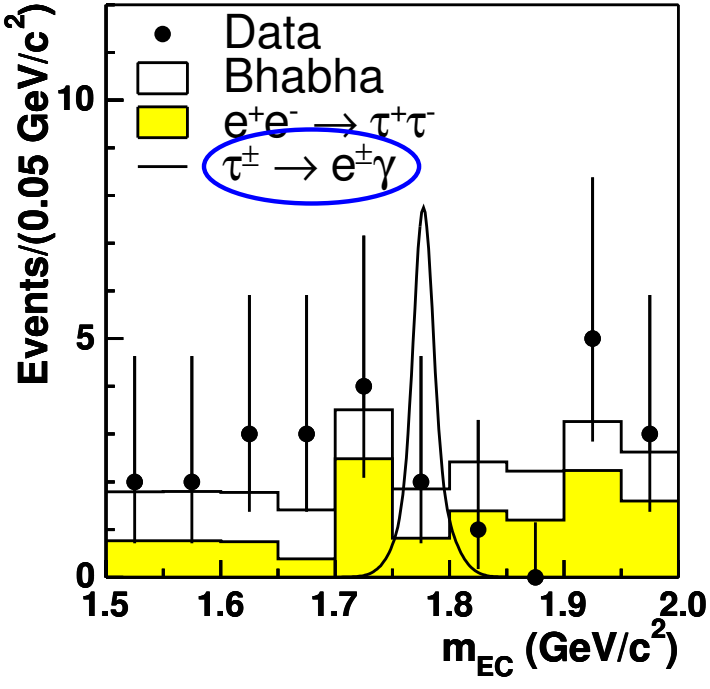
- electron
- electron gamma
- muon
- hadron
- hadron gamma
- 3-prong



Results: $\tau \to \ell\gamma$

$\tau \to \ell\gamma$: Background rate from m_{ec} PDF in $\pm 2\sigma$ band in ΔE





Beam-energy constrained mass ($m_{\rm EC}$) provides better resolution than $m_{\rm rec}$

Luminosity: 232.2 fb^{-1}

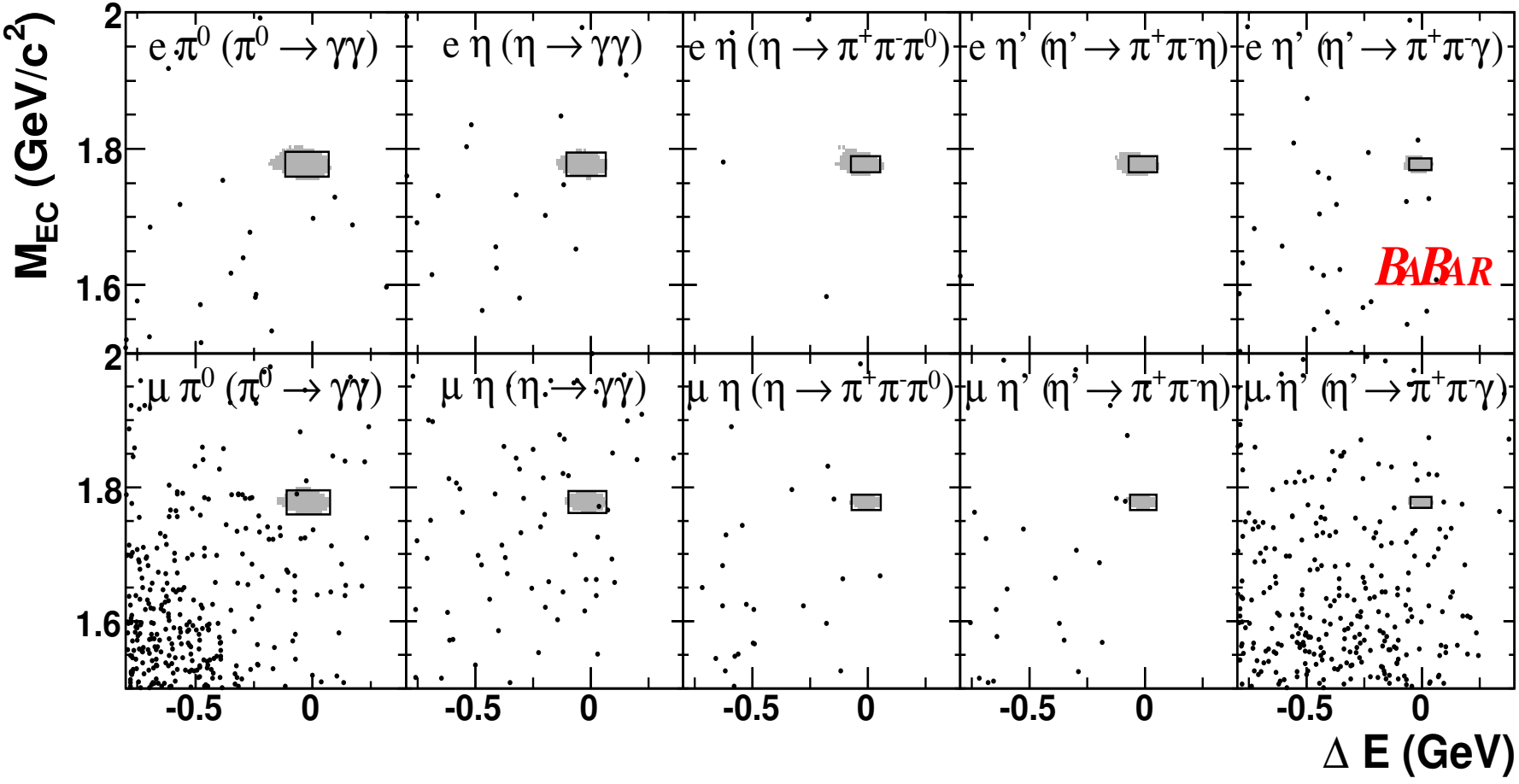
$\tau \to e\gamma$: N_{bkgd} expected: 1.9, observed: 1 PRL96(2006)41801

$\tau \to \mu\gamma$: N_{bkgd} expected: 6.2, observed: 4 PRL95(2005)41802

Results: $\tau \to \ell\pi^0/\eta/\eta'$

Luminosity: 339.0 fb^{-1}

PRL98(2007)061803



N_{bkg}/channel = $(0.1 - 1.3)$, Total expected = 3.1, Observed = 2

Summary of results

Channel	BABAR		BELLE	
	B^{90}_{UL} (10^{-7})	$\mathcal{L}$ (fb^{-1})	B^{90}_{UL} (10^{-7})	$\mathcal{L}$ (fb^{-1})
$\tau \to e\gamma$	1.1	232.2	1.2	535.0
	PRL96(2006)41801		ICHEP06: hep-ex/0609049	
$\tau \to \mu\gamma$	0.7	232.2	0.5	535.0
	PRL95(2005)41802		ICHEP06: hep-ex/0609049	
$\tau \to \ell\,\pi^0/\eta/\eta'$	(1.1-1.6)	339.0	(0.8-1.2)	401.0
	PRL98(2007)061803		hep-ex/0703009	
$\tau \to \ell\ell\ell$	(1-3)	91.5	(2-4)	87.1
	PRL92(2004)121801		PLB589(2004)103	
$\tau \to \ell hh$	(1-5)	221.4	(2-8)	158.0
	PRL95(2005)191801		PLB640(2006)138	

All results are frequentist limits at 90% C.L.

Summary and Outlook

- B-factories are also τ factories.
- Babar dataset is expected to double by Fall 2008.
- Possible to combine Babar and Belle results:

  (S. Banerjee, Tau06, hep-ex/0702017)
  - $\mathcal{B}(\tau \to \mu\gamma)_{(Babar+Belle)} < 1.6 \times 10^{-8}$
- Some searches, $\tau \to \ell\ell\ell$ e.g., are not background limited:
  - upper limit on N_{sig} is $\mathcal{O}(1) \Rightarrow \mathcal{B}^{UL}(\tau \to \ell\ell\ell)$ goes like $1/\mathcal{L}$
  - for 400 fb^{-1}, expect limits around $(2-6) \times 10^{-8}$
  - SUSY+Higgs: $\mathcal{B}(\tau \to 3\mu)$ as high as 10^{-8}

    (A.Brignole, A.Rossi, PLB566(2003)217)
  - Non universal Z′ (Technicolor): $\mathcal{B}(\tau \to \ell\ell\ell) < 10^{-8} \Rightarrow m_{Z'} < 1.2$ TeV

    (C.Yue, Y.Zhang, PLB547(2002)252)
- LF violating decays provide an interesting probe to search for and constrain New Physics.