Lepton Flavor Violation in Tau decays

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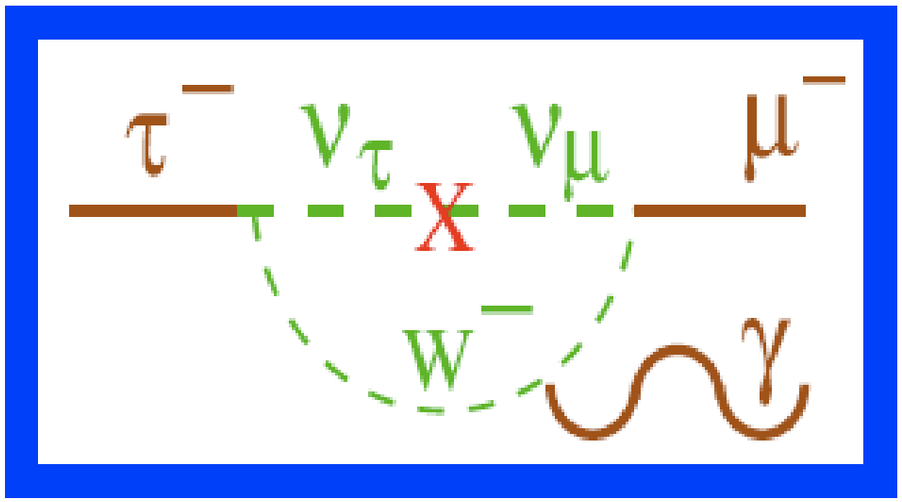
LFV in τ decays

- Lepton flavor violation (LFV)
  - not forbidden by SM gauge symmetry
  - most new models naturally include LFV vertex
- In SM, LF is conserved for zero degenerate ν masses
- Now we have clear indication that ν's have finite mass
  $\Rightarrow$ Lepton Flavor is violated in Nature: but by how much?

- SM extended to include finite ν mass and mixing predicts LFV



$\mathcal{B}(\tau^{\pm} \to \mu^{\pm}\gamma)$ [Lee-Shrock, Phys. Rev. D 16, 1444 (1977)]

$= \frac{3\alpha}{128\pi}\left(\frac{\Delta m^2_{23}}{M^2_W}\right)^2 \sin^2 2\theta_{\rm mix}\mathcal{B}(\tau \to \mu\bar{\nu}_\mu\nu_\tau)$

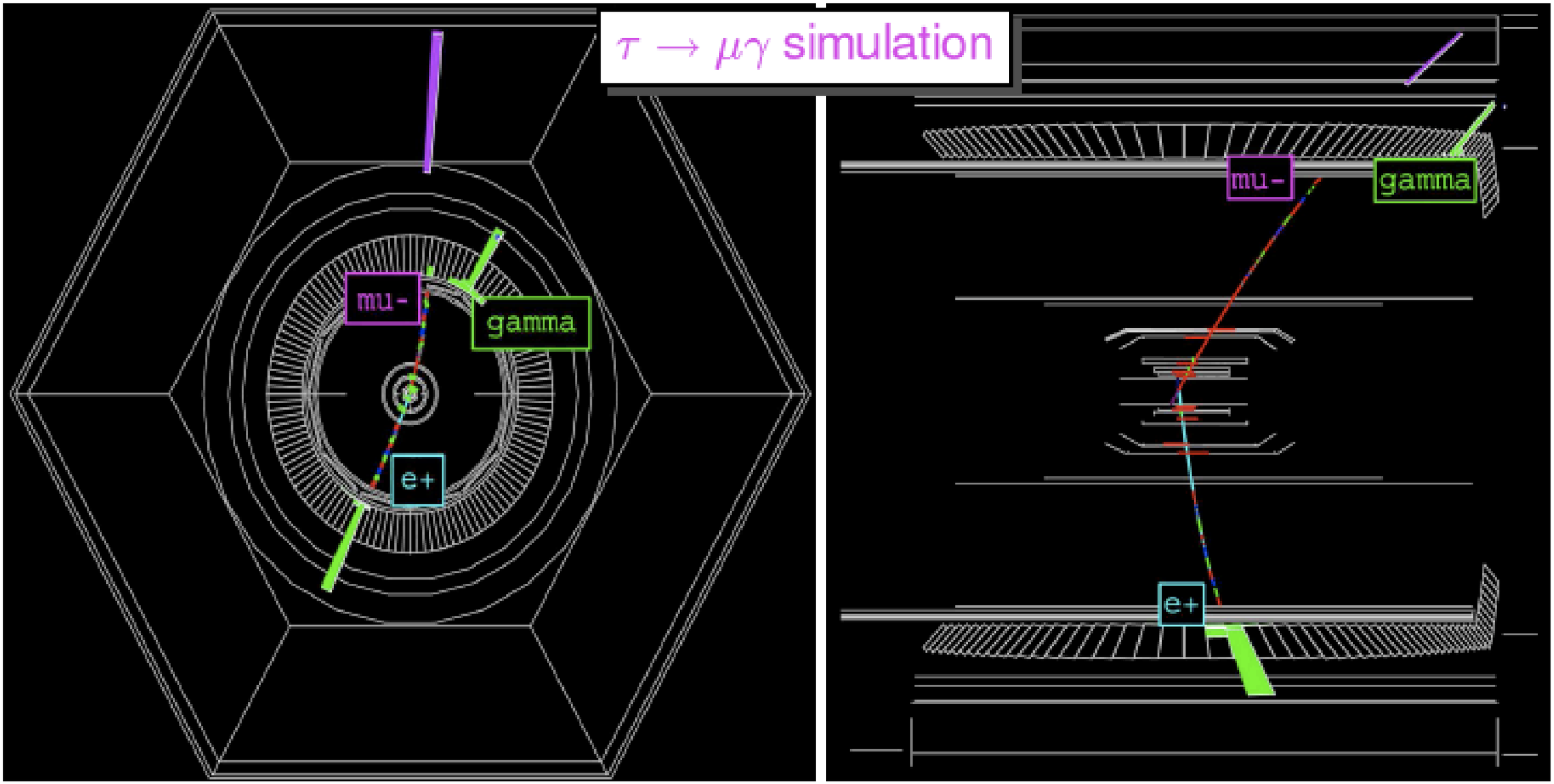
With $\Delta \sim 10^{-3}\,\mathrm{eV}^2$, $M_W \sim \mathcal{O}(10^{11})\,\mathrm{eV}$

$\approx \mathcal{O}(10^{-54})$ ($\theta_{\rm mix}$: max)

... many orders below experimental sensitivity!

If we saw ...

- (Energy, Mass)$_{\tau-\text{daughters}} \sim (\frac{\sqrt{s}}{2}, m_\tau)$ (upto resolution & radiation)



...unambiguous signature of new physics!

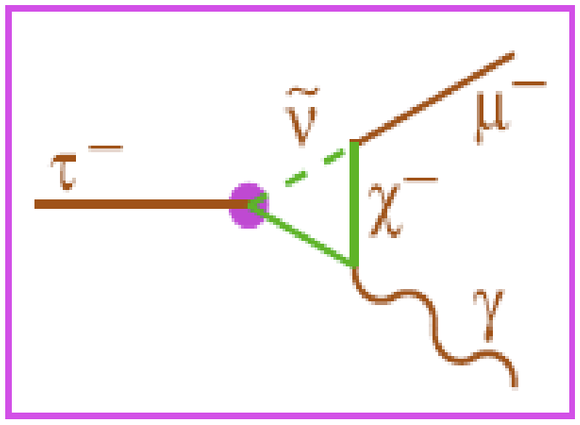
LFV in τ decays

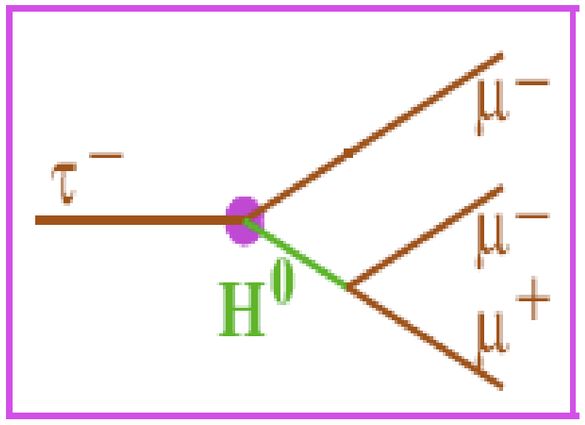
- Some models predict LFV upto existing experimental bounds

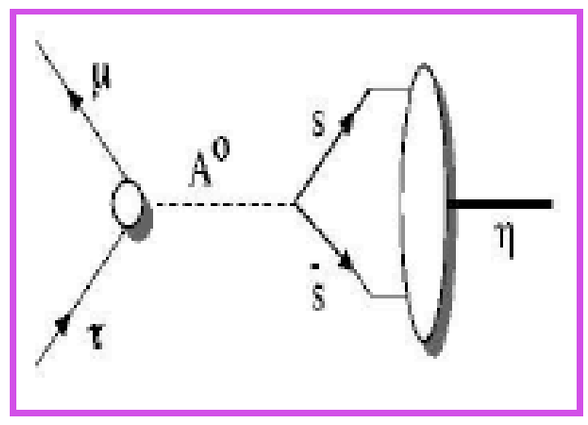
	$\mathcal{B}(\tau \to \ell\gamma)$	$\mathcal{B}(\tau \to \ell\ell\ell)$
SM+ν-mixing (PRL95(2005)41802,EPJC8(1999)513)	10^{-54}	10^{-14}
SUSY Higgs (PLB549(2002)159, PLB566(2003)217)	10^{-10}	10^{-7}
SM+Heavy Majorana ν_R (PRD66(2002)034008)	10^{-9}	10^{-10}
Non-Universal Z′ (PLB547(2002)252)	10^{-9}	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}

MSSM+seesaw (PRD66 (2002) 057301) $\mathcal{B}(\tau \to \mu\gamma) : \mathcal{B}(\tau \to \mu\mu\mu) : \mathcal{B}(\tau \to \mu\eta) = 1.5 : 1 : 8.4$

Illustrations:



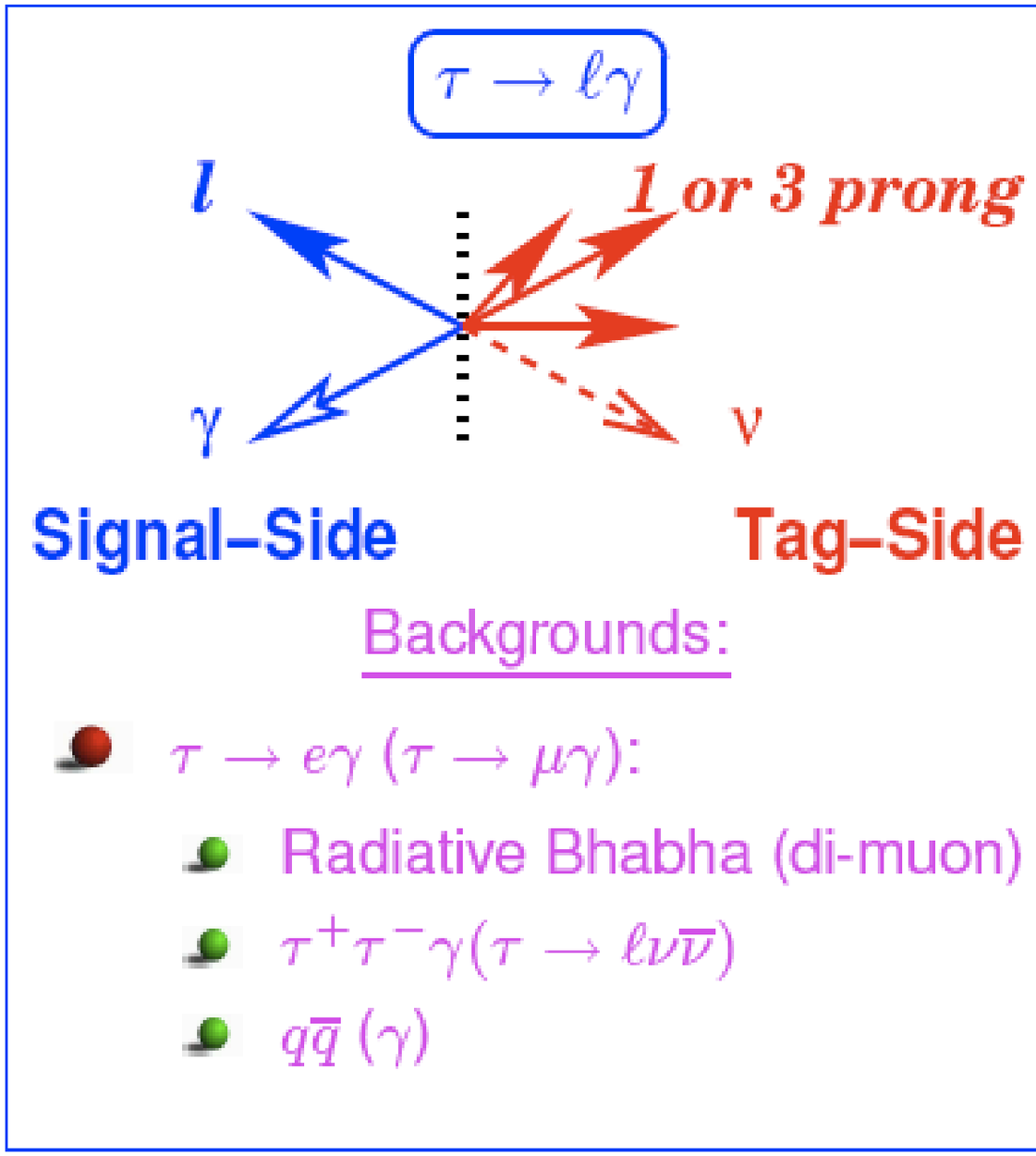




☞ Search for $\tau \to \ell\gamma/\pi^0/\eta/\eta', \tau \to \ell\ell\ell, \tau \to \ell hh' \; (\ell = e, \mu; h = \pi, K)$

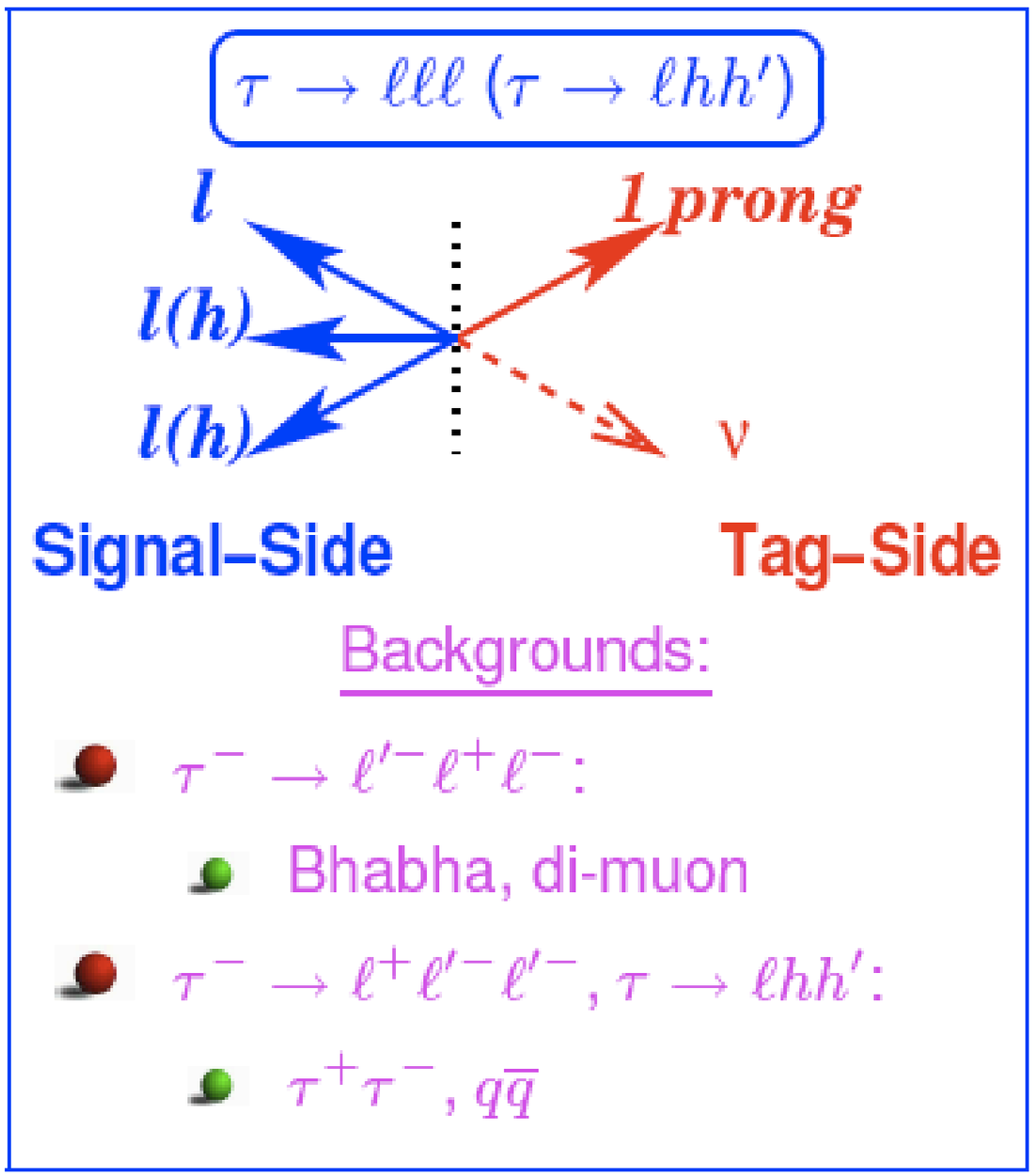
$e^+e^- \rightarrow \tau^+\tau^-$ (Clean Environment)

- Divide τ-pair event $\perp$ to thrust axis (CM frame) in 2 hemispheres



Backgrounds:

- $\tau \rightarrow e\gamma\ (\tau \rightarrow \mu\gamma)$:
  - Radiative Bhabha (di-muon)
  - $\tau^+\tau^-\gamma(\tau \rightarrow \ell\nu\overline{\nu})$
  - $q\overline{q}\ (\gamma)$



Backgrounds:

- $\tau^- \rightarrow \ell'^-\ell^+\ell^-$:
  - Bhabha, di-muon
- $\tau^- \rightarrow \ell^+\ell'^-\ell'^-, \tau \rightarrow \ell hh'$:
  - $\tau^+\tau^-, q\overline{q}$

No signal found ...

Upper Limit: $B^{90}_{\rm UL} = N^{90}_{\rm UL}/(N_\tau \times \varepsilon)$

- ε: *high statistics signal MC simulated for different Data-taking periods*

$\varepsilon =$ **Trigger . Reco . Topology . PID . Cuts . Signal–Box**

90% 70% 70% 50% 50% 50%

Cumulative:

90% 63% 44% 22% 11% ~5%

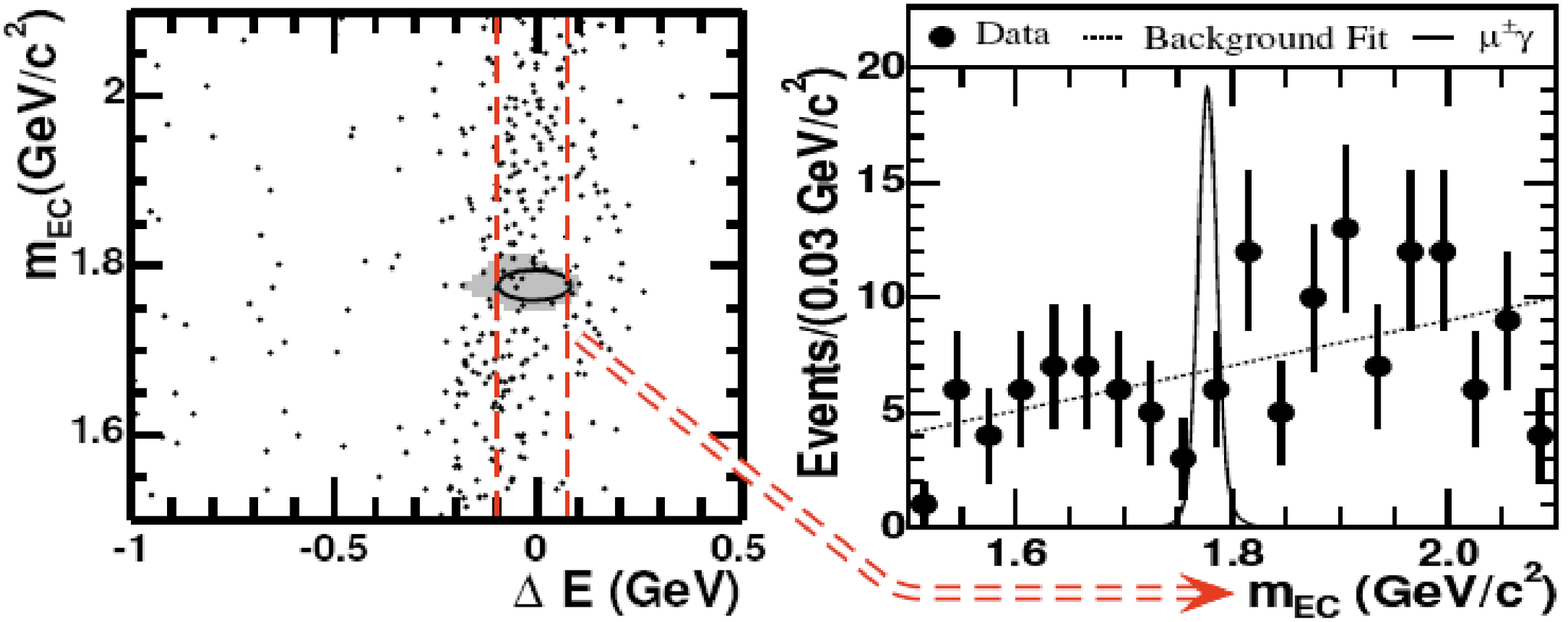
- $\sigma_{\tau^+\tau^-}(10.6\,\mathrm{GeV}) \sim 0.9\ nb$, $\mathcal{L} \sim 339\ fb^{-1}$ (BABAR *Summer 2006*)
  $\Rightarrow N_\tau = 2 \times \mathcal{L} \times \sigma_{\tau^+\tau^-} \sim 6.0 \times 10^8$
- $N^{90}_{\rm UL}$: *90% C.L. Upper Limit for* $(N_{\rm obs}, N_{\rm bkg})$ *from Data*
- *Naive Sensitivity :* $N^{90}_{\rm UL} = 2.3 \times \sqrt{N_{\rm bkg}}$, $N_{\rm bkg} \sim \mathcal{O}(1) \Rightarrow B^{90}_{\rm UL} \sim \mathcal{O}(10^{-7})$

$\tau \to \ell\gamma$

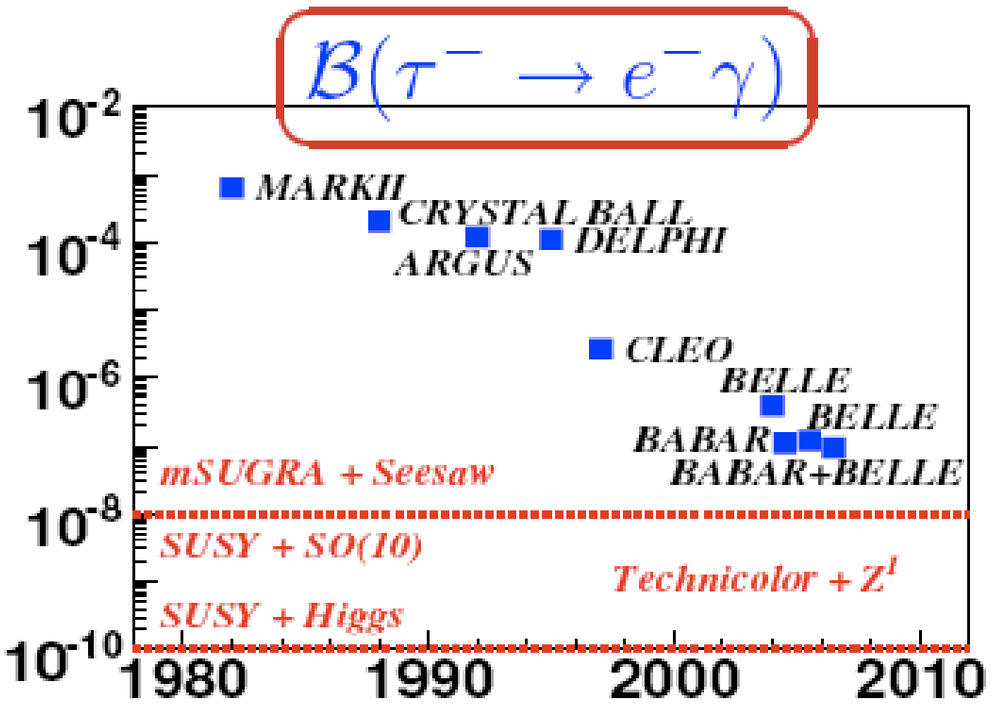
$\tau^- \to$	$\mu^-\gamma$	$e^-\gamma$
ε (%)	7.4	4.7

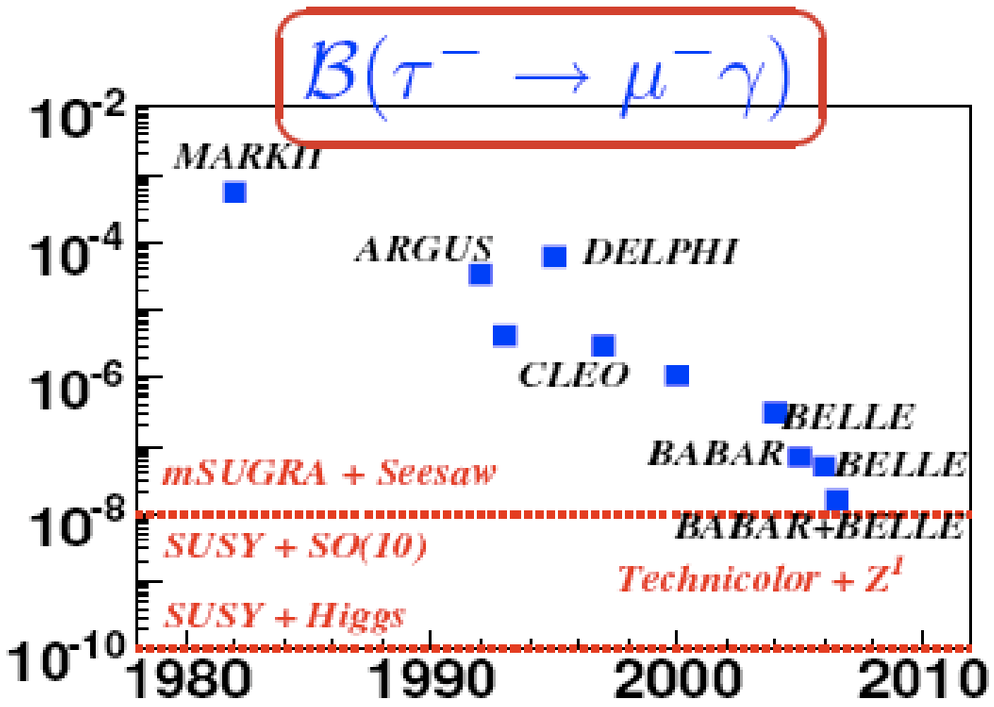
- $\tau^\pm \to \ell^\pm\gamma$: Background rate from PDF($m_{\rm EC}$) in $\pm 2\sigma$ band in ΔE

$\tau \to \mu\gamma$



Last 25 years ...





Channel	BABAR		BELLE		BABAR & BELLE	
	$B^{90}_{\rm UL}$ (10^{-8})	$\mathcal{L}$ (fb^{-1})	$B^{90}_{\rm UL}$ (10^{-8})	$\mathcal{L}$ (fb^{-1})	$B^{90}_{\rm UL}$ (10^{-8})	$\mathcal{L}$ (fb^{-1})
$\tau^\pm \to e^\pm\gamma$	11	232.2	12	535.0	9.4	767.2
$\tau^\pm \to \mu^\pm\gamma$	6.8	232.2	4.5	535.0	1.6	767.2
$\tau^\pm \to e^\pm\pi^0$	13	339.0	8.0	401.0	4.4	740.0
$\tau^\pm \to \mu^\pm\pi^0$	11	339.0	12	401.0	5.8	740.0
$\tau^\pm \to e^\pm\eta$	16	339.0	9.2	401.0	4.5	740.0
$\tau^\pm \to \mu^\pm\eta$	15	339.0	6.5	401.0	5.1	740.0
$\tau^\pm \to e^\pm\eta'$	24	339.0	16	401.0	9.0	740.0
$\tau^\pm \to \mu^\pm\eta'$	14	339.0	13	401.0	5.3	740.0

Projections to 75 ab^{-1} Luminosity

$$B^{90}_{\rm UL} = N^{90}_{\rm UL}/(N_\tau \times \varepsilon)$$

	$\tau \to \ell\ell\ell\,(\tau \to \ell hh')$	$\tau \to \ell\gamma$
	Background free search	*Background limited search*
$N^{90}_{\rm UL}$	$2.3 \times \sqrt{N_{\rm obs}} \sim \mathcal{O}(1)$	$\sqrt{\mathcal{L}}$
$B^{90}_{\rm UL}$	$\propto 1/\mathcal{L}$	$\propto 1/\sqrt{\mathcal{L}}$

- $\tau^\pm \to \mu^\pm\gamma$ *search:*

  Baseline: $B^{90}_{\rm UL} \sim 1.2 \times 10^{-7}$ *(BaBar expected @ 232.2 fb*$^{-1}$*)*

- *Super B-Factory:*

  $B^{90}_{\rm UL} <$ *O (10*$^{-10}$*) / O (10*$^{-9}$*) no/with Background*

Expected Upper Limits

Super B-Factory: Expected 90% CL upper limits on LFV τ decays with 75 ab^{-1} assuming no signal is found and reducible backgrounds are small ($\sim \mathcal{O}(1)$ events) and the irreducible backgrounds scale as $1/\mathcal{L}$.

75 ab^{-1}	BR 90%CL UL ($x10^{-9}$)
$\tau \to \mu\gamma$	2
$\tau \to e\gamma$	2
$\tau \to \mu\mu\mu$	0.2
$\tau \to eee$	0.2
$\tau \to \mu\eta$	0.4
$\tau \to e\eta$	0.7
$\tau \to \ell K^0_S$	0.2