τ LFV Decays at e^+e^- Colliders

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τ physics – present and future

- Most of what we know about the τ (87 pages in PDG 2012) comes from τ pair samples produced in e^+e^- annihilation
  - Is there more to learn on a Snowmass exercise timescale?
  - If so, it will likely come from the next generation of e^+e^- machines*:
    SuperKEKB (KEK), ~~Super*B*~~ $c-\tau$ (Cabibbo Lab) or $c-\tau$ (Novosibirsk) ,
    Building on results from *BABAR*, Belle, BES III and LHC, these higher luminosity colliders can use τ s to explore the most important outstanding question in lepton physics, in a manner complementary to μ decay/conversion studies:

Is there physics beyond the Standard Model in the charged lepton sector ?

  - Progress requires a very large sample of $\tau^+\tau^-$ decays, either to have sensitivity to rare processes involving New Physics or to improve precision measurements
  - Some measurements are best done near $\tau^+\tau^-$ threshold, others at higher energy

* Note also that an e^--ion collider can contribute to New Physics searches (Deshpande talk)

New τ experimental objectives

Primary objectives

- Search for charged lepton flavor violation and determination of Lorentz structure
- Search for T violation in τ production (EDM) and decay (new CPV phase)
- Search for second class currents
- Measurement of the τ anomalous moment
- Confirm or refute the NuTeV $\sin^2\theta_W$ anomaly

Polarized τs can improve several of these measurements, either by providing sensitive new observables, or by reducing background

Other interesting measurements

- τ mass measurement (PDG): $m_\tau = 1776.82 \pm 0.16$ MeV

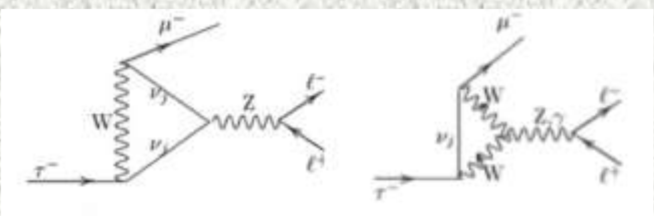
  BES III projects $\Delta m_\tau = (\pm 0.05 \text{ (stat)} \pm 0.06 \text{ (sys)})$ MeV
- Leptonic and hadronic (strange and non-strange) branching fractions
- Lepton universality tests
- Extraction of the CKM element $|V_{us}|$

Lepton Flavor Violation in example models

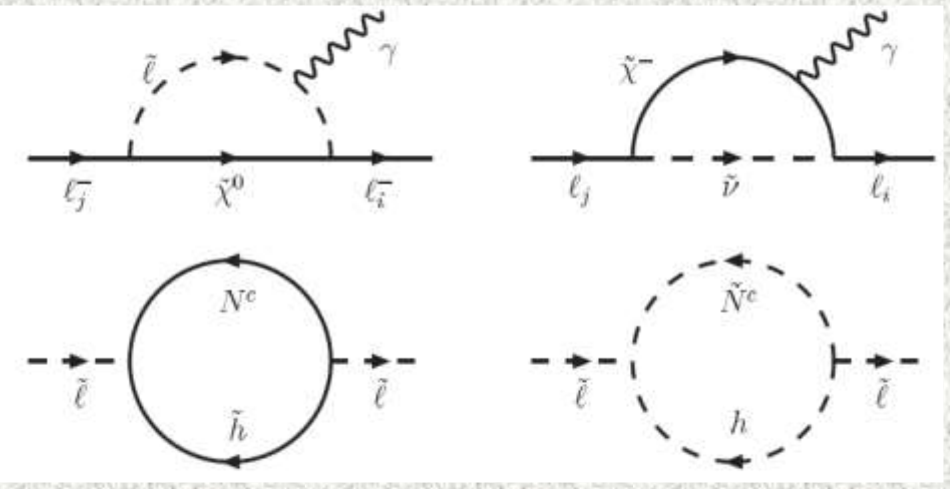
		$\tau \to \mu\gamma$	$\tau \to \ell\ell\ell$
SM + ν mixing	Lee, Shrock, PRD 16 (1977) 1444 Cheng, Li, PRD 45 (1980) 1908	10^{-52}	10^{-14}
SUSY Higgs	Dedes, Ellis, Raidal, PLB 549 (2002) 159 Brignole, Rossi, PLB 566 (2003) 517	10^{-10}	10^{-7}
SM + heavy Maj ν_R	Cvetic, Dib, Kim, Kim , PRD66 (2002) 034008	10^{-9}	10^{-10}
Non-universal Z'	Yue, Zhang, Liu, PLB 547 (2002) 252	10^{-9}	10^{-8}
SUSY SO(10)	Masiero, Vempati, Vives, NPB 649 (2003) 189 Fukuyama, Kikuchi, Okada, PRD 68 (2003) 033012	10^{-8}	10^{-10}
mSUGRA + Seesaw	Ellis, Gomez, Leontaris, Lola, Nanopoulos, EPJ C14 (2002) 319 Ellis, Hisano, Raidal, Shimizu, PRD 66 (2002) 115013	10^{-7}	10^{-9}

Search for charged lepton flavor violation - motivation

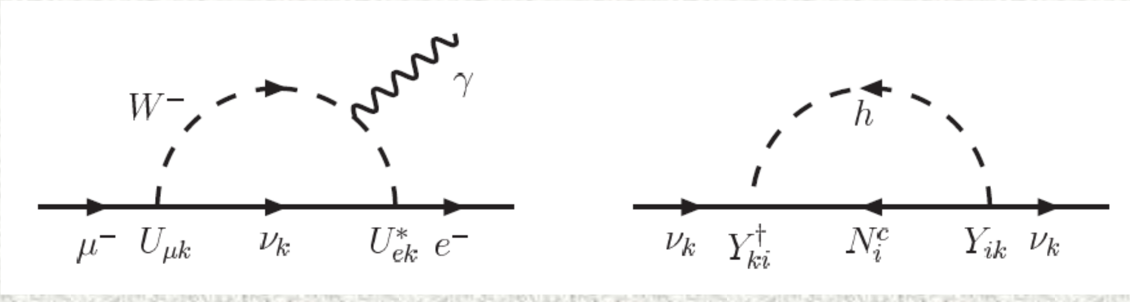
- Neutrino oscillations are *prima facie* evidence for neutral lepton flavor violation
- The obvious next question is whether there is charged lepton flavor violation ?
  - CLFV is too small to measure in the Standard Model, but can reach observable levels in several channels in Standard Model extensions



  - CLFV may appear in
    - $2 \to 1$
    - $3 \to 2$
    - $3 \to 1$ transitions

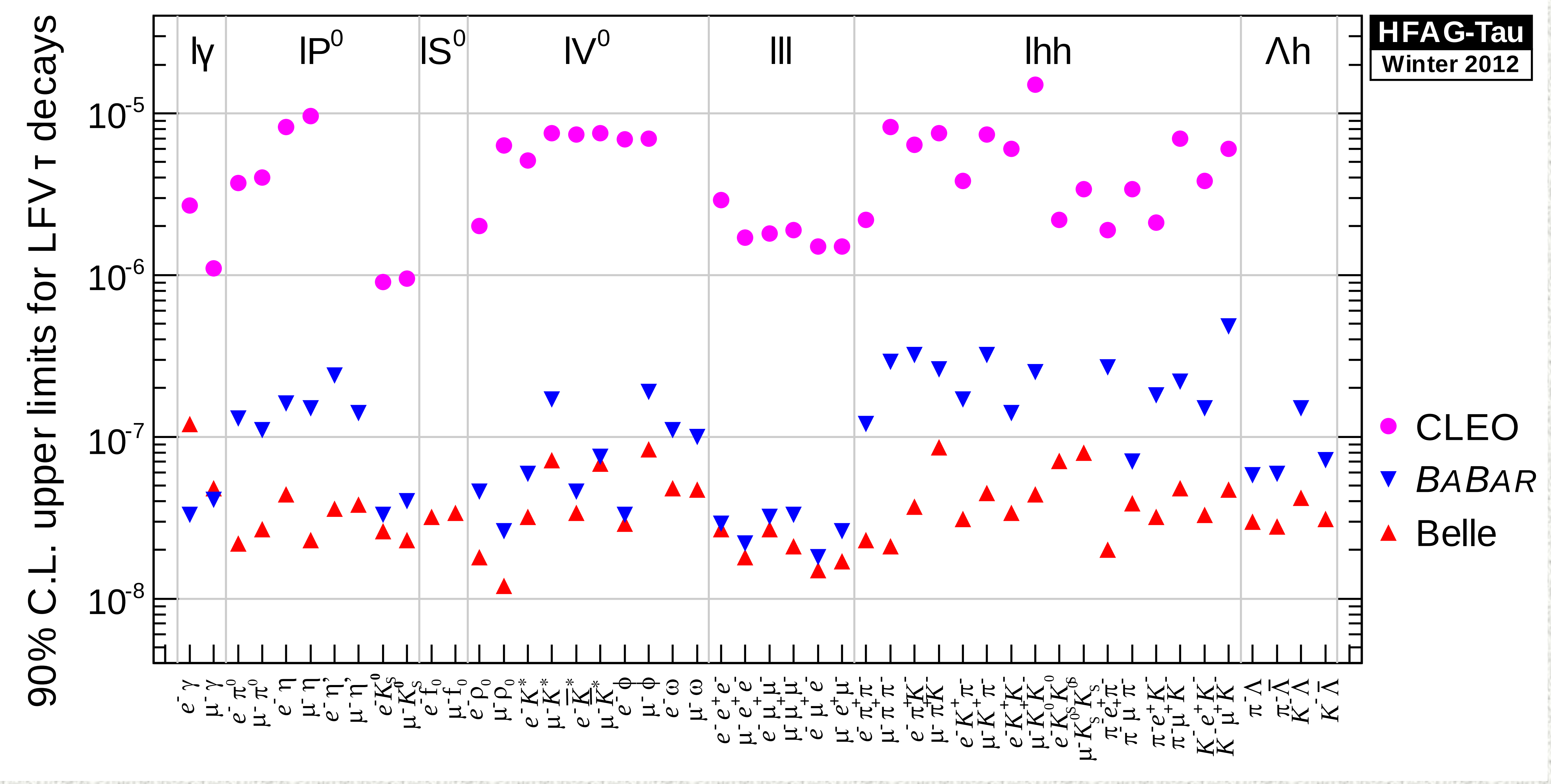


  - μ to e conversion
  - $\mu \to e\gamma$, $\tau \to \mu\gamma$, $\tau \to e\gamma$
  - $\mu \to eee$, $\tau \to 3\ell$
  - $\tau \to h\ell$



  - The sensitivity of particular modes to CLFV couplings is model-dependent
  - Comparison of branching fractions/conversion rate is model-diagnostic

Lepton Flavor Violation in τ decays - current status



Can a Super *B* or τ/c factory improve the sensitivity to the level required to confront relevant models?

Charged lepton flavor violation

- Charged lepton flavor violation can be large in SUSY GUTs
- The LFV branching fractions are very sensitive to the details of the Yukawa couplings and the mass scale of heavy ν_R

T. Goto et al., Phys.Rev. D77, 095010 (2008)

$$A(\ell_i \to \ell_j \gamma) =$$

$$a[Y_e Y_\nu^\dagger Y_\gamma]_{ij} + b[Y_U^\dagger Y_U Y_D]_{ij}$$

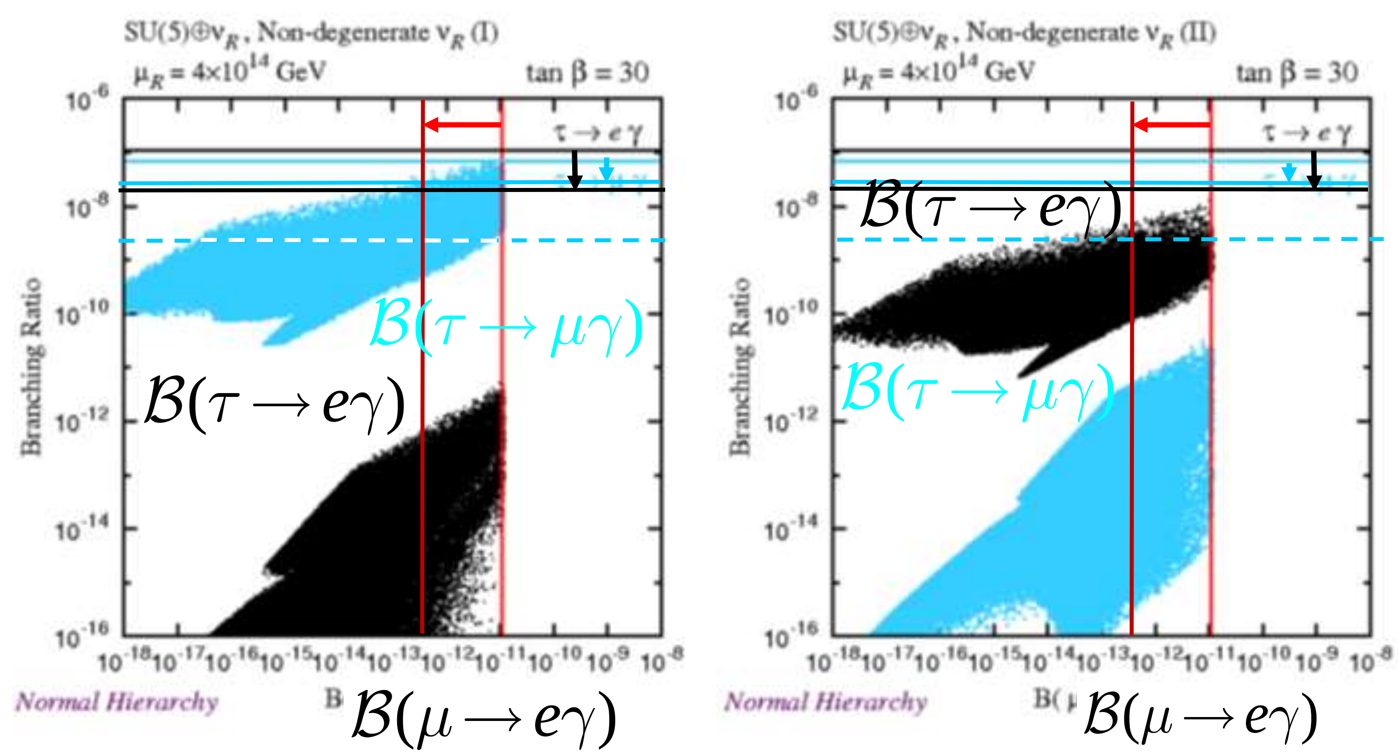
PMNS mixing	CKM mixing
dominant if	dominant if
$M_R > 10^{12}$ GeV	$M_R < 10^{12}$ GeV

$\mathcal{B}(\tau \to \mu\gamma):\mathcal{B}(\tau \to e\gamma):\mathcal{B}(\mu \to e\gamma)$

$[500-10]:1:1$	$10^4:500:1$

$SU(5) \oplus \nu_R$ (non-degenerate)

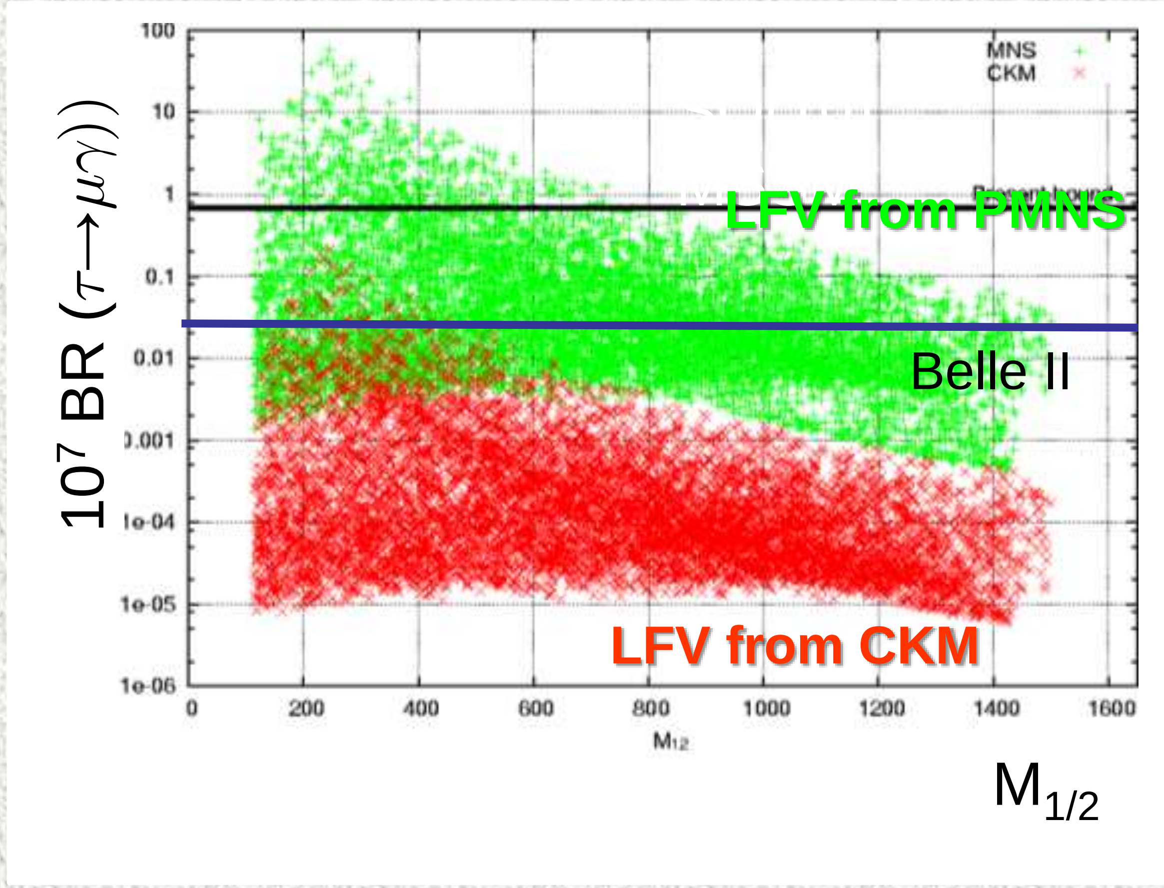
[Goto et al.]



Correlations between $\mathcal{B}(\mu \to e\gamma)$ and $\mathcal{B}(\tau \to \mu\gamma)$, $\mathcal{B}(\tau \to e\gamma)$ in an SU(5) model with right-handed neutrinos, with different structures for the neutrino Yukawa couplings (I and II)

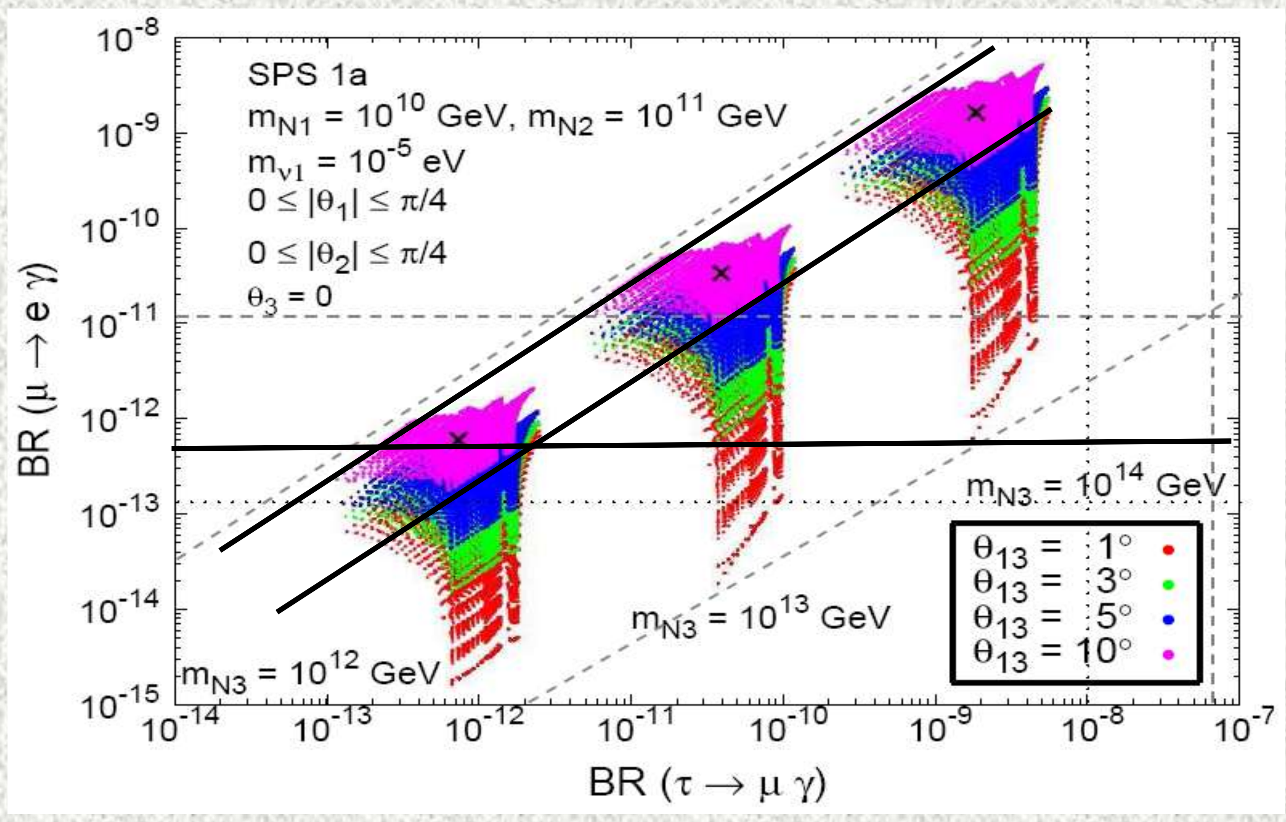
Lepton Flavor Violation in different models

SO(10) GUT



Calibbi, Faccia, Masiero and Vempati

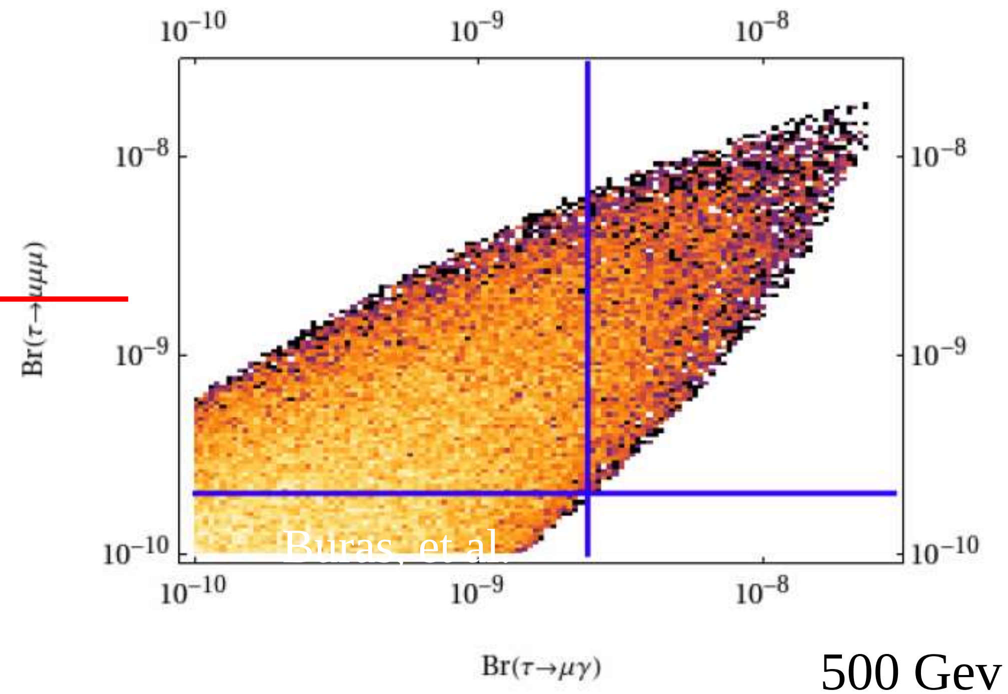
Impact of θ_{13} in a SUSY seesaw model



Antusch, Arganda, Herrero and Teixeira

LFV branching fraction ratios are model discriminators

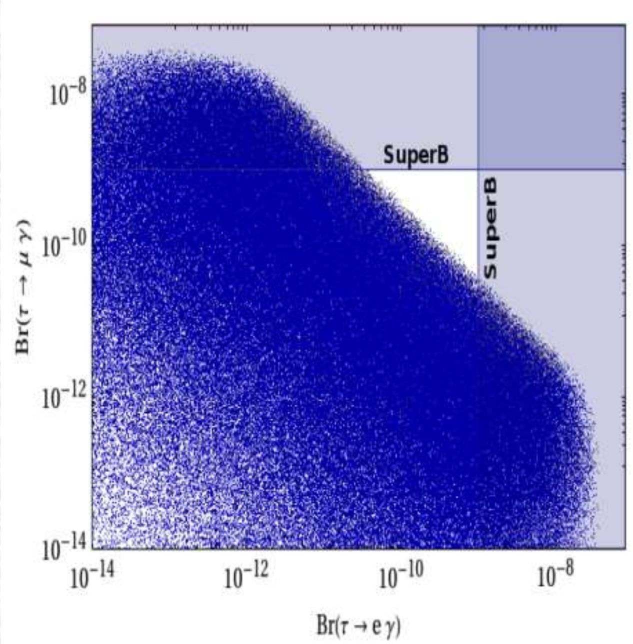
ratio	LHT	MSSM (dipole)	MSSM (Higgs)
$\frac{Br(\mu^-\to e^-e^+e^-)}{Br(\mu\to e\gamma)}$	$0.02\ldots1$	$\sim 6\cdot10^{-3}$	$\sim 6\cdot10^{-3}$
$\frac{Br(\tau^-\to e^-e^+e^-)}{Br(\tau\to e\gamma)}$	$0.04\ldots0.4$	$\sim 1\cdot10^{-2}$	$\sim 1\cdot10^{-2}$
$\frac{Br(\tau^-\to \mu^-\mu^+\mu^-)}{Br(\tau\to \mu\gamma)}$	$0.04\ldots0.4$	$\sim 2\cdot10^{-3}$	$0.06\ldots0.1$
$\frac{Br(\tau^-\to e^-\mu^+\mu^-)}{Br(\tau\to e\gamma)}$	$0.04\ldots0.3$	$\sim 2\cdot10^{-3}$	$0.02\ldots0.04$
$\frac{Br(\tau^-\to \mu^-e^+e^-)}{Br(\tau\to \mu\gamma)}$	$0.04\ldots0.3$	$\sim 1\cdot10^{-2}$	$\sim 1\cdot10^{-2}$
$\frac{Br(\tau^-\to e^-e^+e^-)}{Br(\tau^-\to e^-\mu^+\mu^-)}$	$0.8\ldots2.0$	~ 5	$0.3\ldots0.5$
$\frac{Br(\tau^-\to \mu^-\mu^+\mu^-)}{Br(\tau^-\to \mu^-e^+e^-)}$	$0.7\ldots1.6$	~ 0.2	$5\ldots10$
$\frac{R(\mu\mathrm{Ti}\to e\mathrm{Ti})}{Br(\mu\to e\gamma)}$	$10^{-3}\ldots10^{2}$	$\sim 5\cdot10^{-3}$	$0.08\ldots0.15$



There are correlations in the $\tau \to \mu\gamma$ and $\ell\ell\ell$ branching fractions

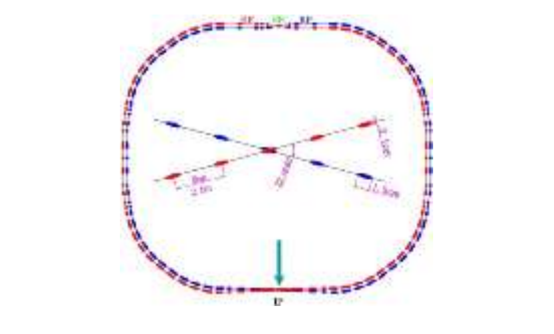
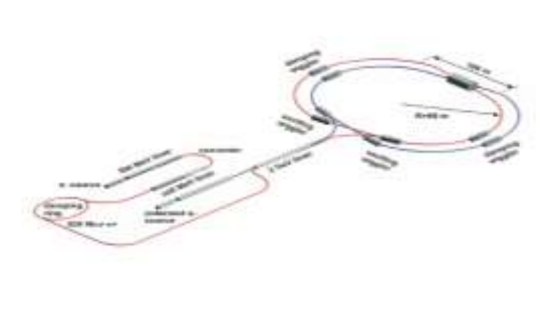
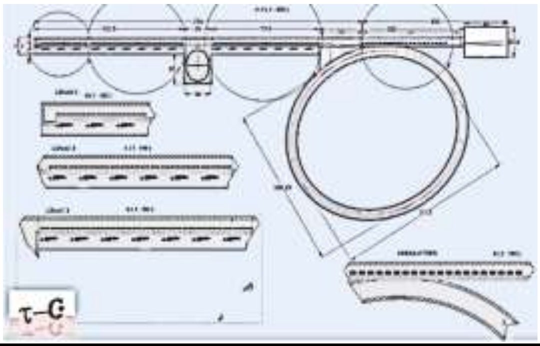
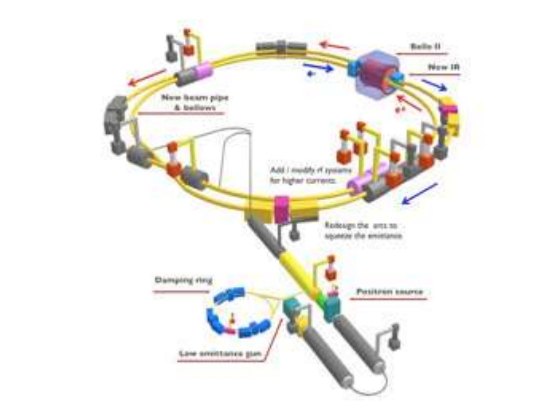
Blanke, Buras, Duling, Recksiegel & Tarantino, Acta Phys. Polon. B41, 657 (2010)

$\mathcal{B}(\tau\to\mu\gamma)$ *vs.* $\mathcal{B}(\tau\to e\gamma)$ in a general fourth generation scenario (Buras)



$\mathcal{B}(\tau\to\mu\gamma)$ *vs.* $\mathcal{B}(\tau\to e\gamma)$ are anticorrelated.
Seeing both modes would be evidence against a fourth generation

e^+e^- flavor factories

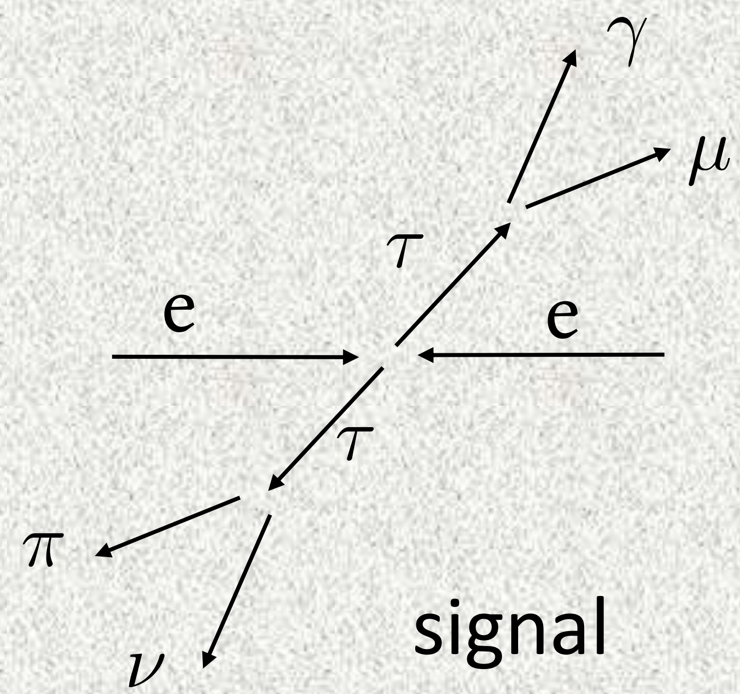
e^+e^- collider	**CM Energy**	**Luminosity ($cm^{-2}s^{-1}$)**	**Circumference (m)**	**e^- polarization**	
BEPC II @IHEP Symmetric 1 – 2.3 GeV	$c-\tau$ $\psi(nS)$	10^{33} @ 3.7	238	No	
$c-\tau$ Factory @BNP Symmetric 1 – 2.5 GeV	$c-\tau$ $\psi(nS)$	6×10^{34} @ 2 1×10^{35} @ 5	765	Yes	
$\tau-$ c Factory @Cabibbo Lab Symmetric ~ 1 - 2.5GeV	$c-\tau$ $\psi(nS)$	10^{35} @ 3.77	362	Yes	
SuperKEKB @KEK Asymmetric 7×4 GeV	$\Upsilon(nS)$	2 - 8 $\times 10^{35}$ @ 10.58	3016	No	

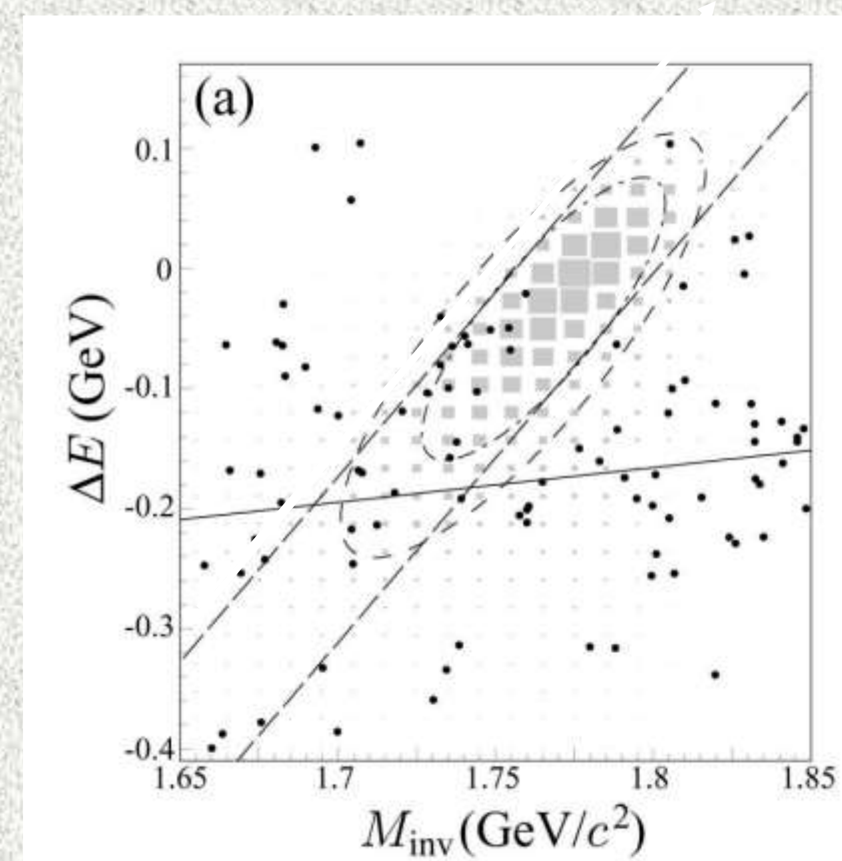
Search for $\tau \to \mu\gamma$ at SuperKEKB

Belle, PLB66, 16 (2008), 535 fb^{-1}

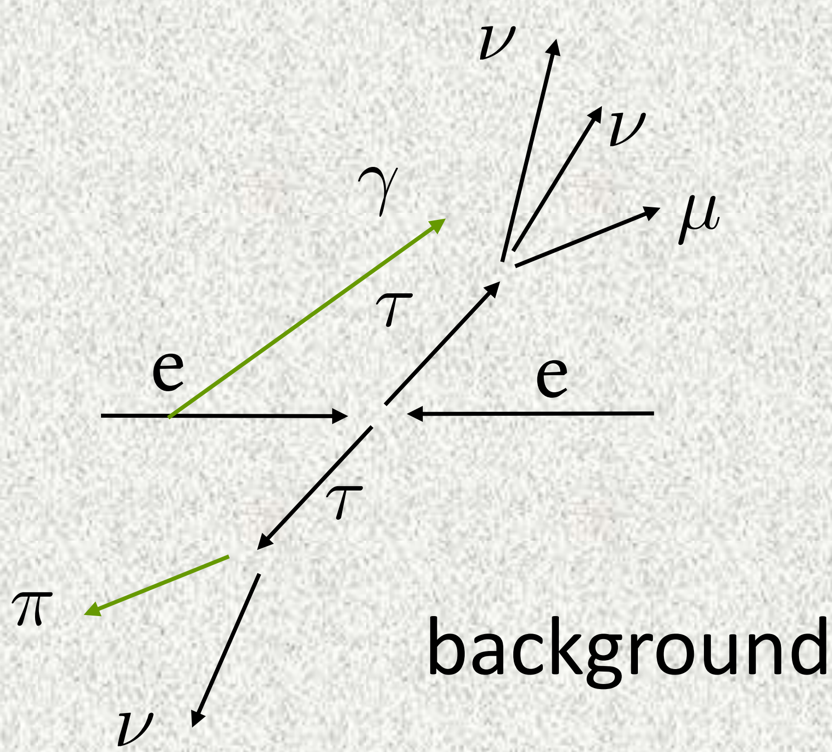
kinematic variables
for signal isolation:
$\Delta E = E^{CM}(\mu\gamma) - E^{CM}(\text{beam})$
$M_{inv} = m(\mu\gamma)$

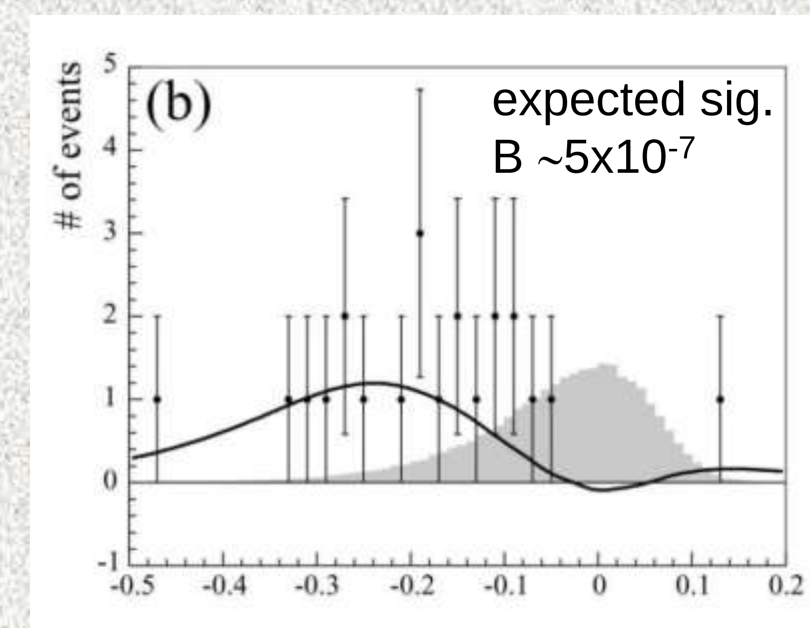
main background from
$e^+e^- \to \tau(\mu\nu\nu)\ \tau(\pi\nu)\ \gamma_{ISR}$





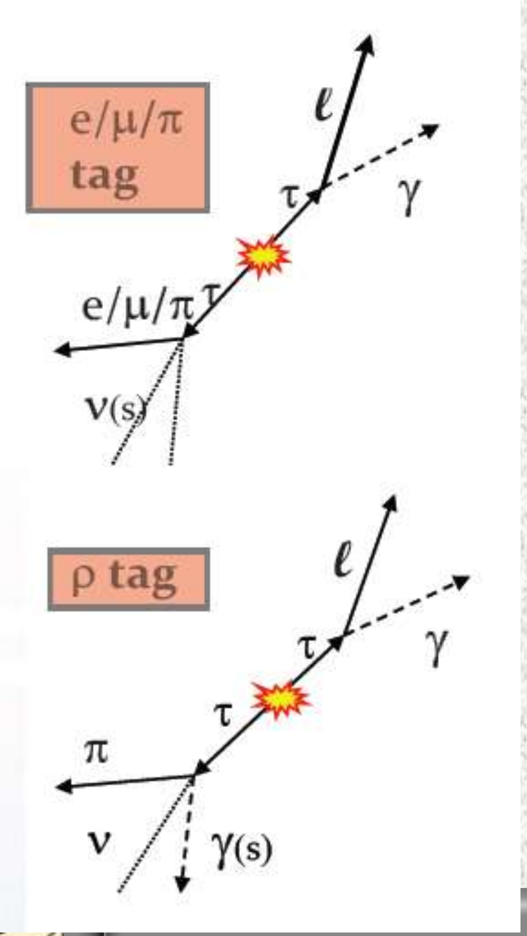
$Br^{UL} \sim 1/\sqrt{\mathcal{L}}$
polarized beam(s) can
help in reducing this
background
(assuming SM couplings!)

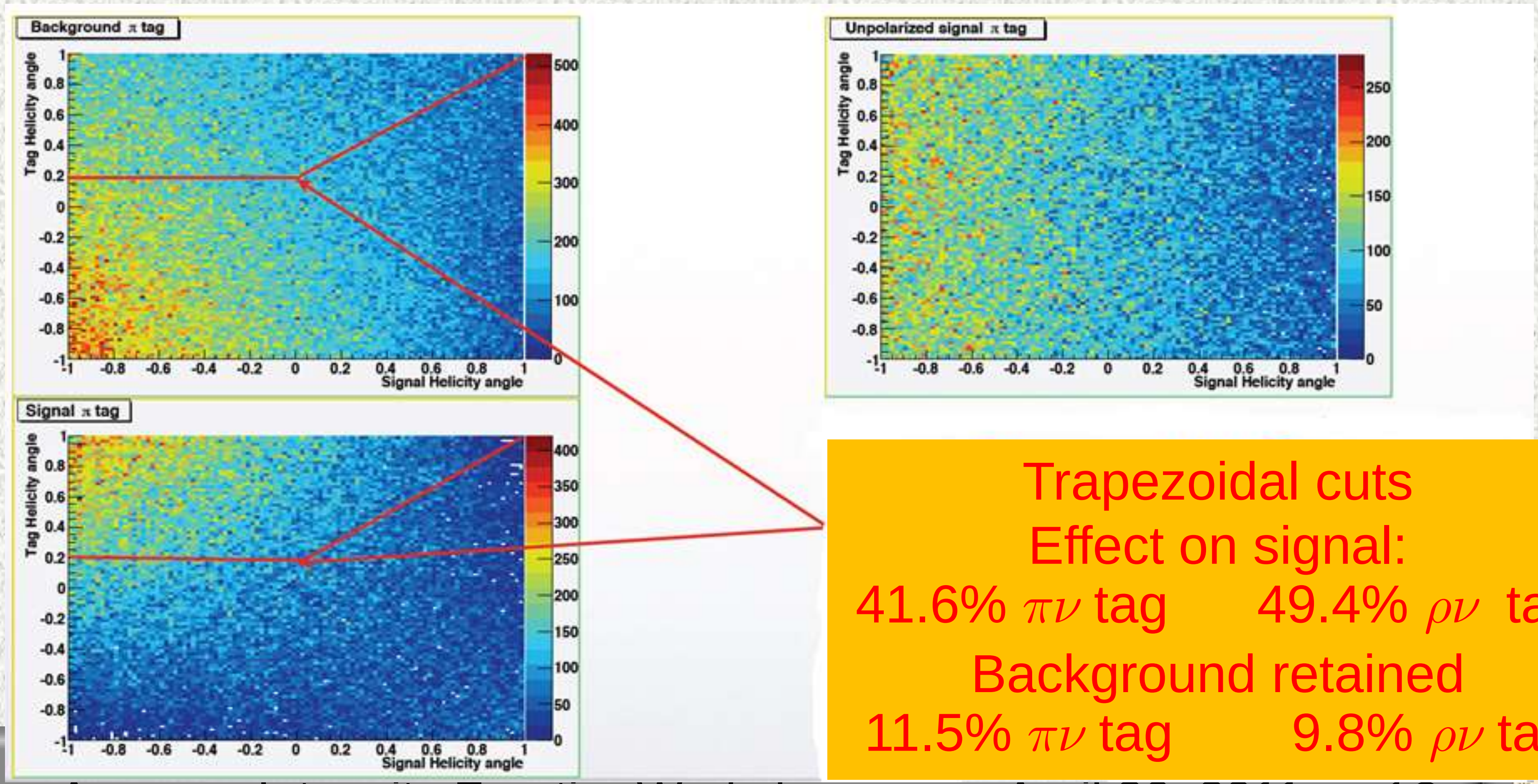




Sensitivity of $\tau \rightarrow \mu\gamma$ decay searches

- $\tau \rightarrow \mu\gamma$ searches suffer from irreducible backgrounds:
  Thus sensitivity improves as $1/\sqrt{\int L\,dt}$
  $e^+e^- \rightarrow \tau^+\tau^-\gamma$ backgrounds are reduced by a hadronic tag, leaving $\tau^- \rightarrow \mu^-\bar{\nu}_\mu\nu_\tau$ as the main background
- A polarized electron beam can reduce this background by exploiting the correlation between the ν direction in hadronic tag and the helicity of the polarized τ, leading to an improvement in sensitivity of a factor of ~2.6

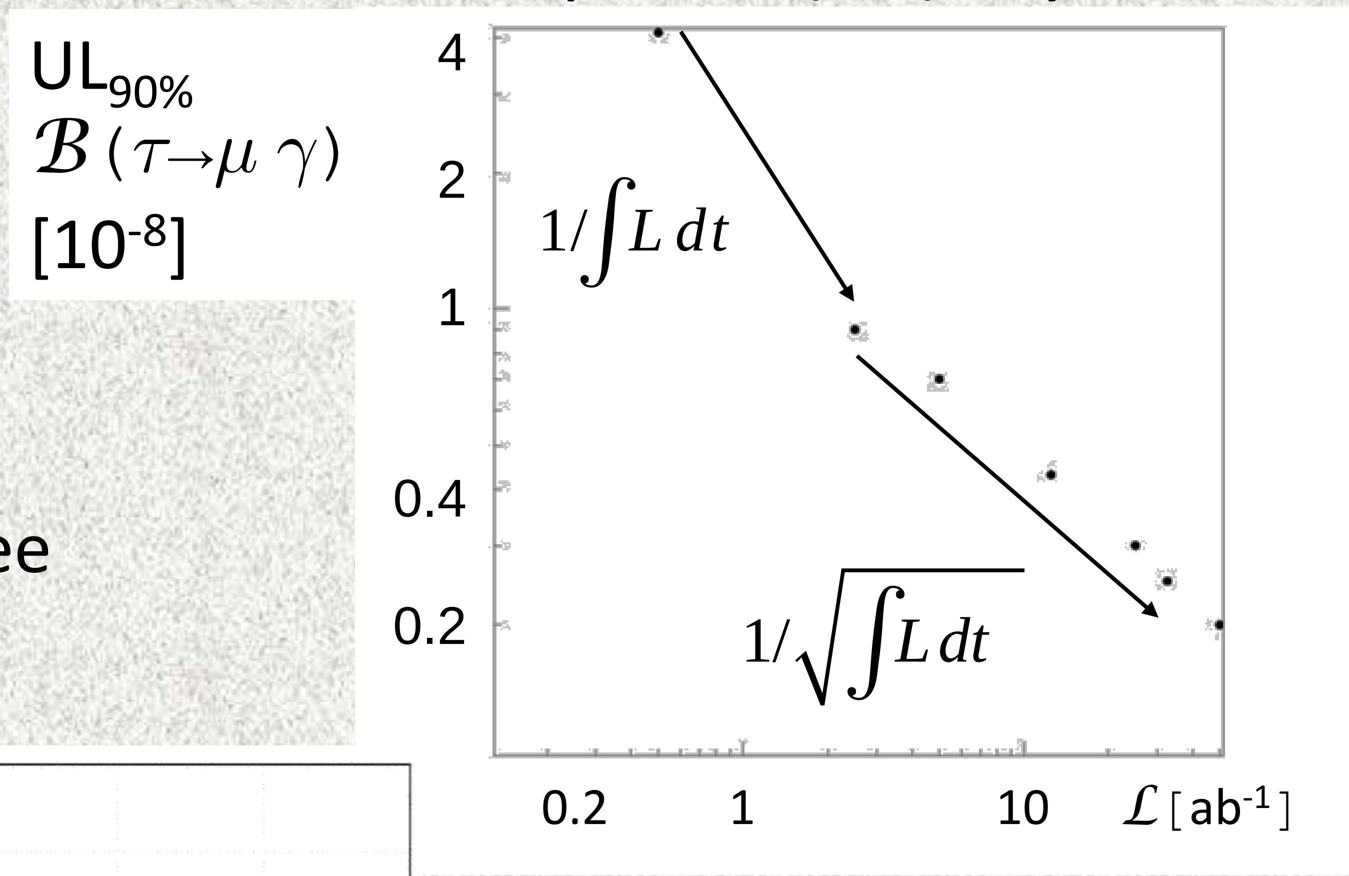




Trapezoidal cuts
Effect on signal:
41.6% $\pi\nu$ tag 49.4% $\rho\nu$ tag
Background retained
11.5% $\pi\nu$ tag 9.8% $\rho\nu$ tag

Search for $\tau\to\mu\gamma$ at SuperKEKB

simplified (1D) toy MC



w/o polarization:

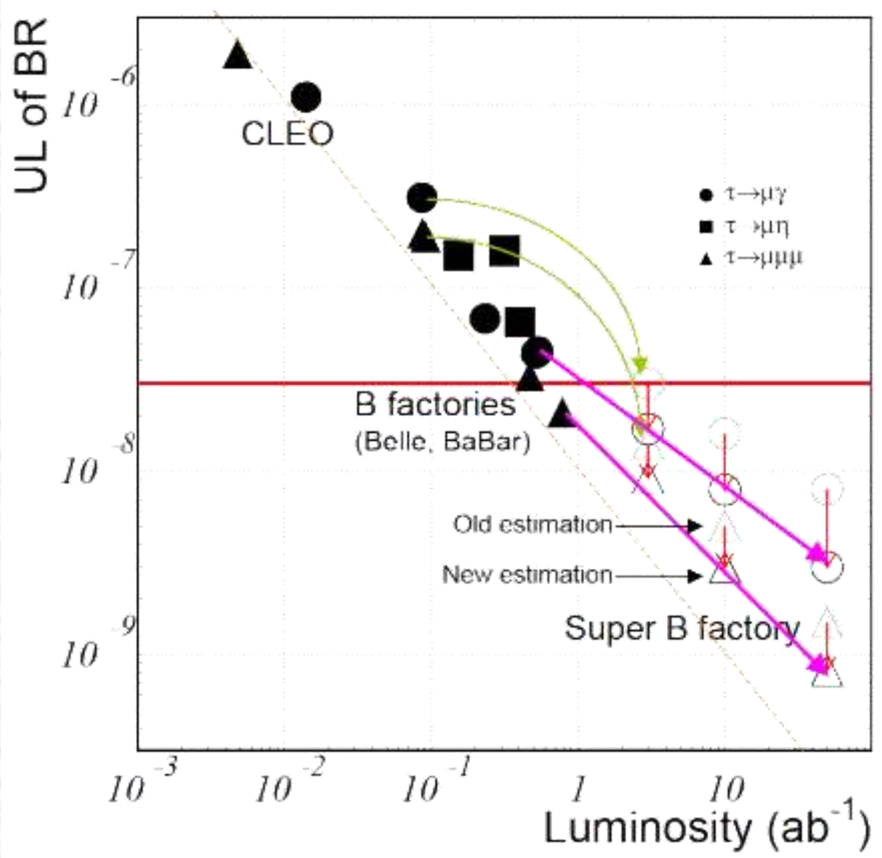
UL$_{90\%}$($\mathcal{B}(\tau\to\mu\gamma)$) ~3x10^{-9} @ 50 ab^{-1}

decays τ 3ℓ, ℓh^0 are background-free

UL$_{90\%}$($\mathcal{B}(\tau\to\mu\gamma)$) ~ $\propto 1/\mathcal{L}$ to ~10 ab^{-1}

$\mathcal{B}(\tau\to\mu\gamma) < 4.4\cdot10^{-8}$

Belle, PLB66, 16 (2008), 535 fb^{-1}

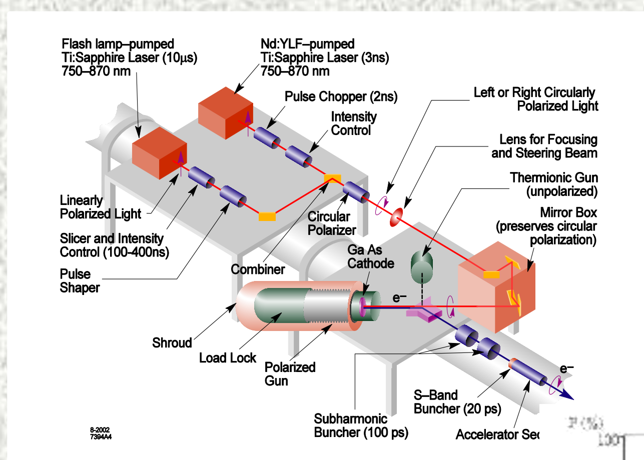


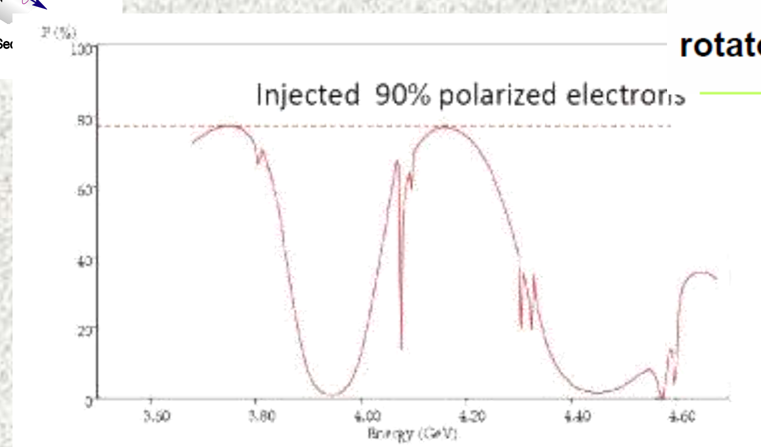
Updated expected sensitivities on τ LFV decays

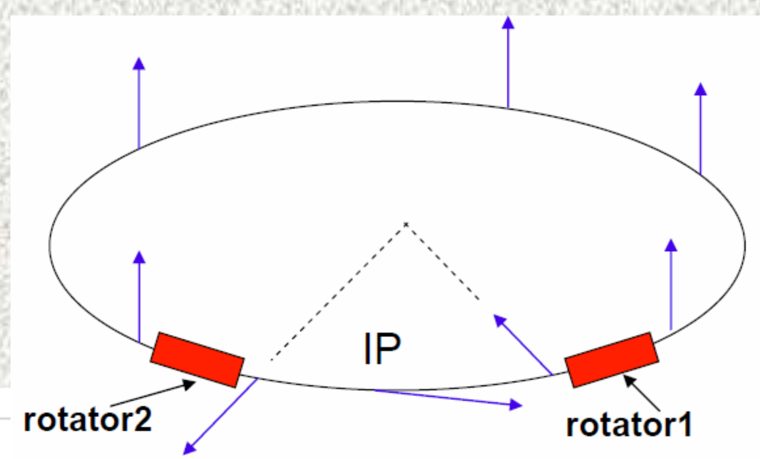
K. Inami, PANIC 2011

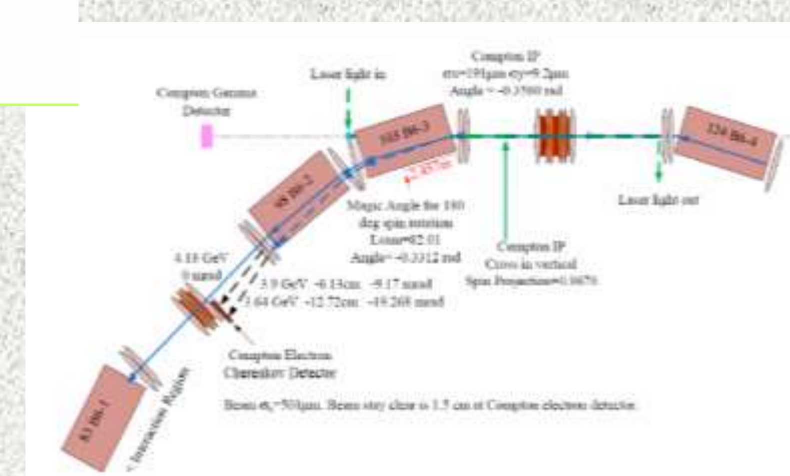
τ polarization requires e^- and/or e^+ beam polarization

- It is quite practical to provide a longitudinally polarized electron beam in a high-luminosity e^+e^- collider, providing certain conditions are met
- Producing a polarized positron beam is much more difficult, but is not necessary to produce longitudinally polarized τ s
- Requirements
  - A polarized electron gun: the existing SLAC gun (90% polarization)
  - A machine lattice that avoids depolarizing resonances at the required energies
  - A means of rotating the polarization between longitudinal and transverse (*e.g.* SC solenoids)
  - A means of monitoring/measuring the longitudinal polarization









τ Polarization – dependence on e^+, e^- polarization

- Longitudinal polarization of beams

$$w_{e^-} = \frac{N_{e^-\rightarrow} - N_{e^-\leftarrow}}{N_{e^-}} \qquad w_{e^+} = \frac{N_{e^+\rightarrow} - N_{e^+\leftarrow}}{N_{e^+}}$$

- Resulting τ polarization is

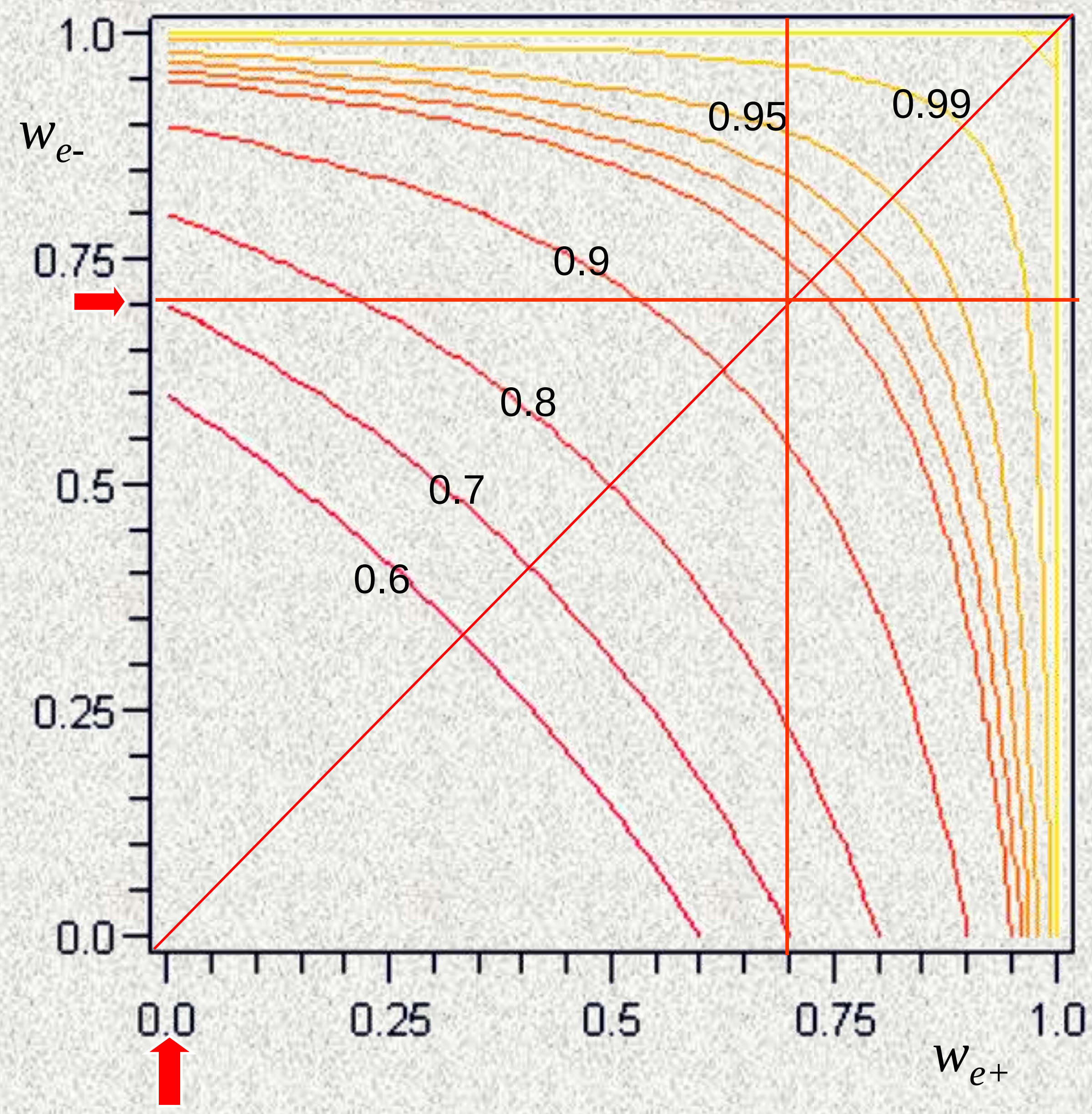
$$P = \frac{w_{e^-} + w_{e^+}}{1 + w_{e^-} w_{e^+}}$$

- Platonic ideal

$$w_{e^-} = 0.9,\ w_{e^+} = 0.9:\ \ P = 0.994$$
$$w_{e^-} = 0.9,\ w_{e^+} = 0:\ \ P = 0.9$$

- Practical realization

$$w_{e^-} = 0.7,\ w_{e^+} = 0:\ \ P = 0.7$$
$$w_{e^-} = 0.8,\ w_{e^+} = 0.4:\ \ P = 0.92$$



Y.S. Tsai, Phys Rev D55, 3172 (1995)

Sensitivity of $\tau \to \mu\gamma$ searches at B and τ/c factories

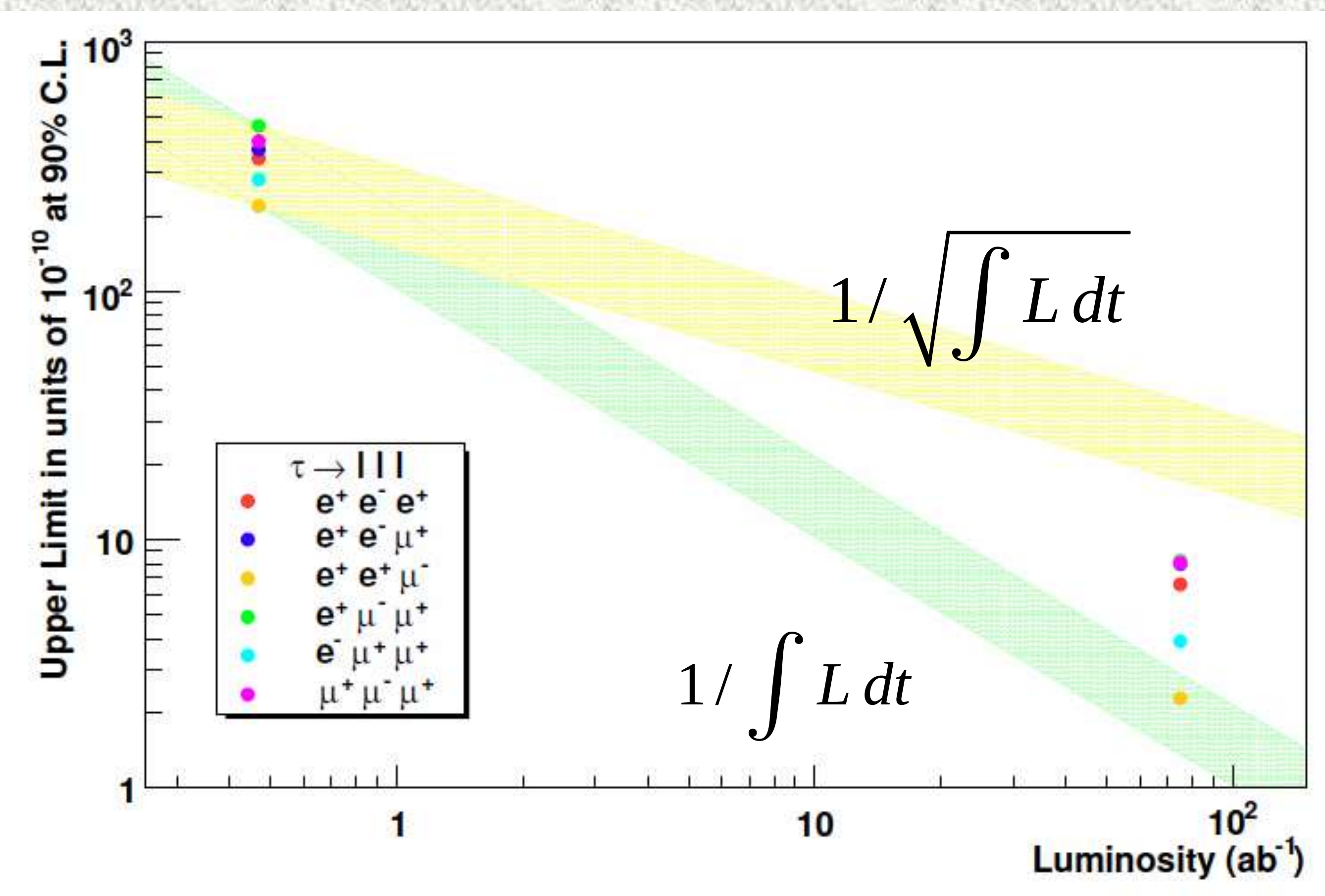
- How does sensitivity compare?
  - Assume running on resonance (not optimal for background rejection)
    - $\tau^+\tau^-$ production cross section ~1/*s* : KORALB: σ(3.77)/σ(10.58) = 2.8/0.92 = 3.05
    - Peak luminosity: SuperKEKB: 2 - 8 x10^{35} ; Super τ/c: 10^{35}
    - Integrated luminosity by 2023 : SuperKEKB: 50 ab^{-1}; Super τ/c: 10 ab^{-1}
  - Since there are irreducible backgrounds, *e.g.*, $e^+e^- \to \tau^+\tau^-\gamma$, sensitivity improves as $1/\sqrt{\int L\,dt}$
    - e^- polarization at τ/c reduces background by a factor of at least two, as at Super*B*|SuperKEKB, assuming SM-type couplings for New Physics

Collider	$\int L\,dt$	e^- polarization	$\tau^+\tau^-$ pairs	90 % CL limit
τ/c @ 3.686, 3.77, 4.17*	10	Y	3.2 x 10^{10}	10^{-9}
SuperKEKB @ $\Upsilon(4S)$	50	N	5 x 10^{10}	~3 x 10^{-9}

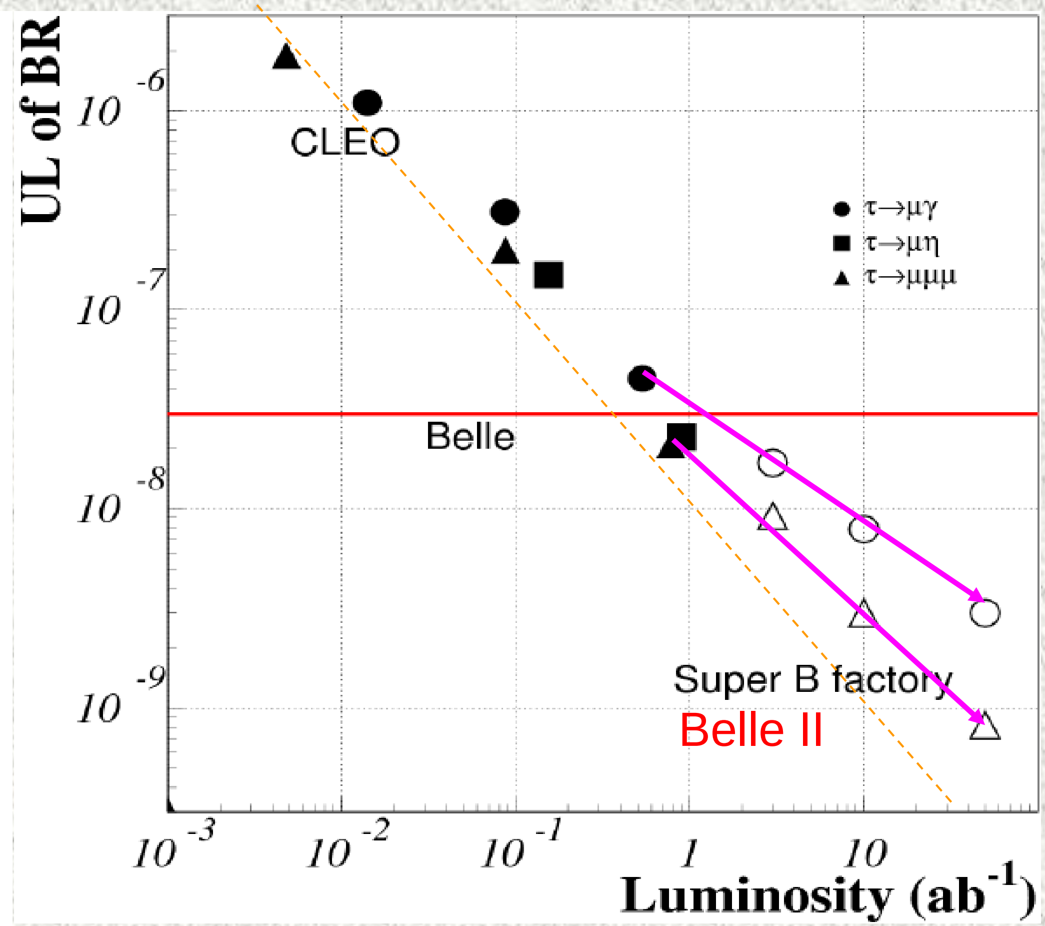
*A.V. Bobrov and A.F. Bondar, Nucl. Phys. **B225**, 195 (2012)

Sensitivity of $\tau \to \ell\ell\ell$ decay searches

- Current branching fraction limits, typically in the several x 10^{-8} range, don't have measurable backgrounds. Is this the case with 100 × the data?
- It is difficult to do a realistic Monte Carlo simulation of potential backgrounds at a Super *B* Factory. Preparations for such simulations are underway
- The no-background regime improves as $1/\int L\,dt$
- If there are background events, the improvement is $1/\sqrt{\int L\,dt}$



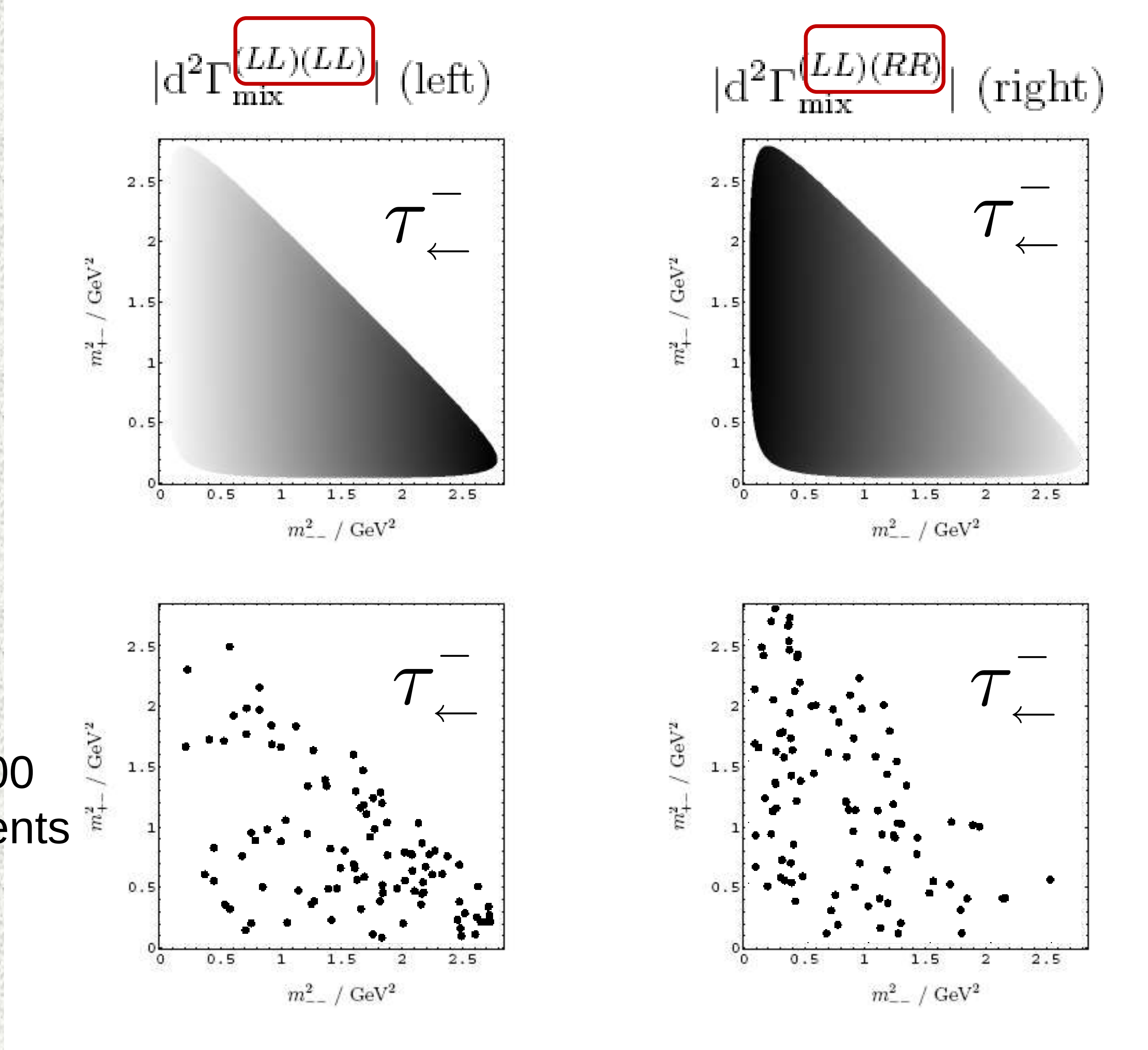
Super*B*



Belle II

Polarized τ s can probe the chiral structure of LFV

- Should $\tau \rightarrow \ell\ell\ell$ events be observed, it is possible to study the Lorentz structure of the coupling using the Dalitz plot

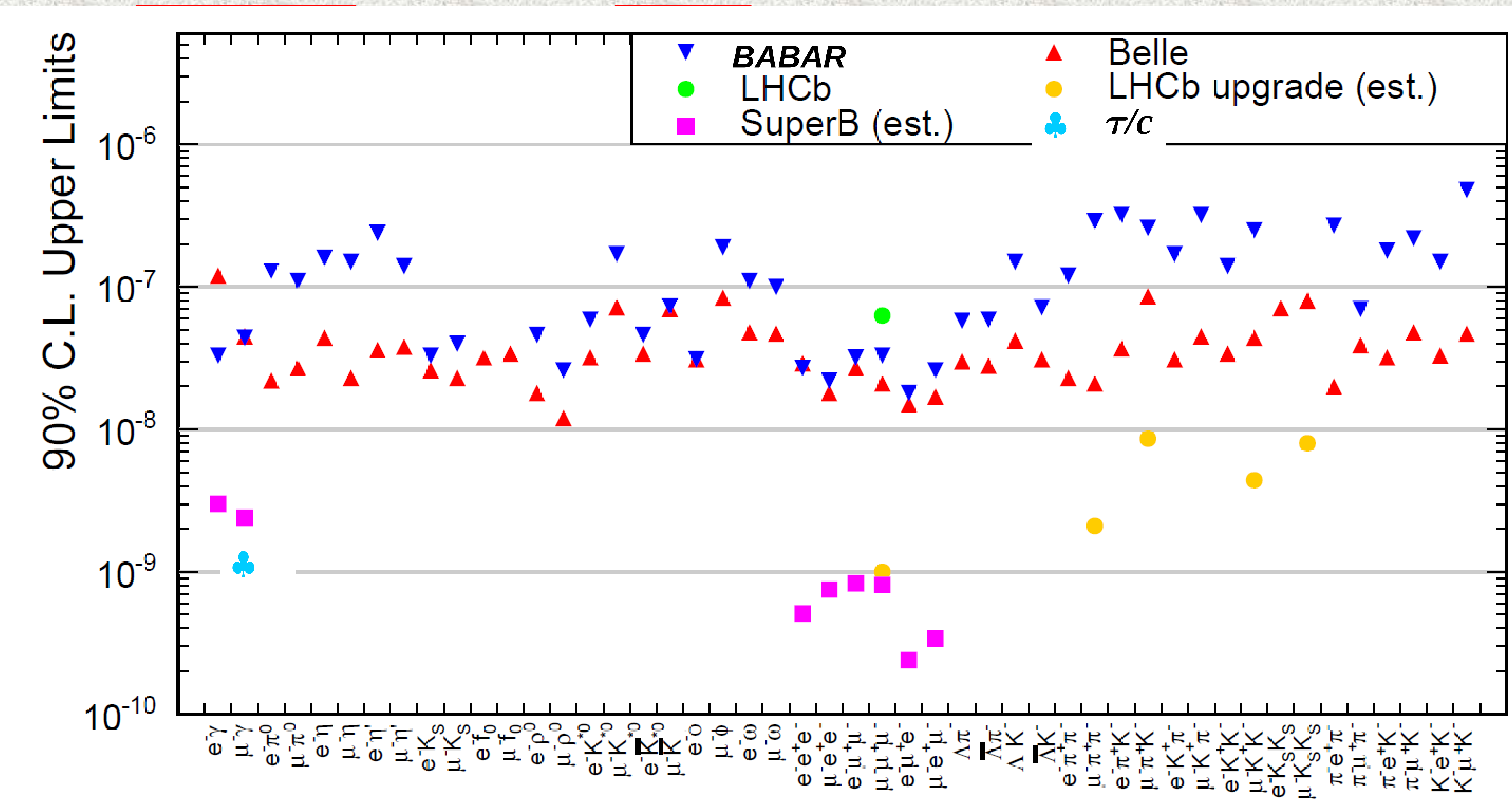


100 events

Flipping the helicity of the polarized electron beam allows us to determine the chiral structure of dimension 6 four fermion lepton flavor-violating interactions

Dassinger, Feldmann, Mannel, and Turczyk, JHEP 0710, 039, 2007
A. Matsuzaki, A.I Sanda, Phys.Rev. D77, 073003, 2008

Super e^+e^- factory sensitivity directly confronts New Physics models of CLFV



CPV in τ decay

Unpolarized τ s

- Measure asymmetries in decay rates of tagged tau decays with two or more hadrons

$$\mathcal{B}(\tau^- \to \pi^-\pi^0\nu_\tau) \neq \mathcal{B}(\tau^+ \to \pi^+\pi^0\bar{\nu}_\tau) \quad \text{CLEO}$$

$$\mathcal{B}(\tau^- \to K^-\pi^0\nu_\tau) \neq \mathcal{B}(\tau^+ \to K^+\pi^0\bar{\nu}_\tau) \quad \text{CLEO}$$

$$\mathcal{B}(\tau^- \to \pi^\pm\pi^\mp\pi^-\nu_\tau) \neq \mathcal{B}(\tau^+ \to \pi^\pm\pi^\mp\pi^+\bar{\nu}_\tau) \quad \textit{Belle}$$

$$\mathcal{B}(\tau^- \to K_S^0\pi^-(\geq 0\pi^0)\nu_\tau) \neq \mathcal{B}(\tau^+ \to K_S^0\pi^+(\geq 0\pi^0)\bar{\nu}_\tau) \quad \textit{BABAR}$$

- The $\tau^- \to K_S^0\pi^-(\geq 0\pi^0)\nu_\tau)$ mode is interesting for two reasons:
  1) Due to the K_S^0 it has an SM *CP* asymmetry of (0.36 ± 0.01)%
  2) *BABAR* has measured an asymmetry of opposite sign: (-0.45 ± 0.24 ± 0.11)% 3σ from the Standard Model

Interpretation of any observed *CP*V requires understanding of inelastic final state interactions

- Measure *CP* or *T*-violating correlations in $\tau^+\tau^-$ decays

Polarized τ s – new more sensitive observables

- Search for *T*-odd rotationally invariant products, *e.g.* $w_{e^-} \cdot p_{\pi^+} \times p_{\pi^0}$
  in τ^+ and τ^- decays such as $\tau^- \to K_S^0\pi^0\nu_\tau,\ K^-\pi^0\nu_\tau, K^-\pi^+\pi^-\nu_\tau, \pi^-\pi^0\nu_\tau, \pi^-\pi^+\pi^-\nu_\tau$

The sensitivity of a τ/c factory with 10 ab^{-1} should approach 2×10^{-5} in the $\tau^- \to K^-\pi^0\nu_\tau$ mode

- Search for *T*-odd correlation between τ polarization and μ polarization in $\tau^- \to \mu^-\bar{\nu}_\mu\nu_\tau$ decay

Figure of Merit for *CP*V: τ/charm and Super*B*

- FOM for measuring *CP*V in τ decay (Tsai):

  Magnitude of the *z* component of τ polarization averaged over the cross section:

$$\mathrm{FOM} = \mathcal{L} \times (w_{e^-} + w_{e^+}) \times \sqrt{1-a^2}\, a^2 (1+2a), \text{ where } a = 2m_\tau / \sqrt{s}$$

- For equal (e^-) longitudinal polarization

Collider	$\mathcal{L}$	FOM/FOM τ/c
τ/c @ $\psi(3770)$	10^{35}	1
~~Super~~*B* @ $\Upsilon(4S)$	10^{36}	1.9

τ magnetic moment and EDM

$$\left\langle \tau(p_-)\bar{\tau}(p_+)\left|J^{\mu}(0)\right|0\right\rangle = e\bar{u}(p_-)\left[\gamma^{\mu}F_1 + \frac{iF_2 + F_3\gamma_5}{2m_\tau}\sigma^{\mu\nu}q_\nu + \left(q^2\gamma^{\mu} - q^{\mu}\not{q}\right)\gamma_5 F_A\right]v(p_+)$$

magnetic moment $a_\tau = F_2(0)$ $\qquad d_\tau = \frac{e}{2m_\tau}$ EDM

τ magnetic moment

The best current bound on the τ anomalous moment $a_\tau = (g-2)/2$ is indirect, derived from the LEP2 measurement of the total cross section for

$$e^+e^- \to e^+e^-\tau^+\tau^-: \quad -0.052 < a_\tau < 0.013 \text{ @ } 95\% \text{ CL}$$

This is well above the SM prediction: $a_\tau^{SM} = 1177.21(5)\times10^{-6}$

- Nonetheless, the limit provides a model-independent bound on New Physics contributions: $-0.007 < a_\tau^{NP} < 0.005$ @ 95 % CL
- The measurement can be done in $e^+e^- \to \tau^+\tau^-$ with unpolarized beams
  - The real part of the form factor needs the measurement of correlations of the τ decay products of both polarized τ s
- An e^+e^- collider with a polarized electron beam has the sensitivity to improve this measurement by three orders of magnitude

τ $\mathrm{Re}(F_2)$ with a polarized beam

- A polarized electron beam provides a sensitive new way of measuring F_2 by measuring the transverse and longitudinal polarizations of the outgoing s

$$A_T^{\pm} = \frac{\sigma_R^{\pm} \mid P_e - \sigma_L^{\pm} \mid P_e}{\sigma} = \mp \alpha_{\pm} \frac{3\pi}{8(3-\beta^2)\gamma}\left[|F_1|^2 + (2-\beta^2)\gamma^2 \,\mathrm{Re}\;\; F_2 \;\; \right]$$

$$A_L^{\pm} = \frac{\sigma_{\mathrm{FB}}^{\pm}(+) \mid P_e - \sigma_{\mathrm{FB}}^{\pm}(-) \mid P_e}{\sigma} = \mp \alpha_{\pm} \frac{3}{4(3-\beta^2)}\left[|F_1|^2 + 2\,\mathrm{Re}\{F_2\} \right]$$

$$\mathrm{Re}\;\; F_2(s) \;= \mp \frac{8(3-\beta^2)}{3\pi\gamma\beta^2} \frac{1}{\alpha_{\pm}} \left(A_T^{\pm} - \frac{\pi}{2\gamma} A_L^{\pm} \right)$$

- Combining channels, the sensitivity is of the order of $10^{-5} - 10^{-6}$, which allows measurement of the magnetic moment form factor $F_2(M_{i}^{2}) = (2.65 - 2.45\,\mathrm{i}) \times 10^{-4}$ (SM value) to a precision of a few per cent.

	15 ab^{-1}		75 ab^{-1}	
	Re{F_2}	Im{F_2}	Re{F_2}	Im{F_2}
Super *B* Factory at *Y*(4S) unpolarized beams	1.1×10^{-5}	7.8×10^{-6}	4.7×10^{-6}	3.5×10^{-6}
Super *B* Factory at *Y*(4S) polarized e^- beam	3.7×10^{-6}	7.8×10^{-6}	1.7×10^{-6}	3.5×10^{-6}

Systematic error with polarized beam is an order of magnitude below this statistical error

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Not yet studied with polarized τ/c

τ EDM

- New Physics sensitivity for a τ EDM is boosted by ~ $m_\tau / m_e = 3.5 \times 10^3$
  - Some predictions in the 10^{-19} range (SM < 10^{-34} e cm)
  - Can be done with unpolarized beams

$$-0.22\, e \text{ cm} < \text{Re}\{d_\tau^\gamma\} \times 10^{16} < 0.45\, e \text{ cm} @ 95\%\ CL \quad \text{Belle}$$

- Polarized τ s provide a new, more sensitive *CP*-odd *T*-odd observable:

$$A_N^{CP} = \frac{1}{2}\left(A_N^+ + A_N^-\right) = \alpha_h \frac{3\pi\gamma\beta}{8(3-\beta^2)} \frac{2m_\tau}{e} \text{Re}\left(d_\tau^\gamma\right)$$

where the azimuthal asymmetry for the two polarizations is

$$A_N^{\mp} = \frac{\sigma_L^{\mp} - \sigma_R^{\mp}}{\sigma} = \alpha_{\mp} \frac{3\pi\gamma\beta}{8(3-\beta^2)} \frac{2m_\tau}{e} \text{Re}\left(d_\tau^\gamma\right)$$

This allows the use of single τ polarization observables, thereby improving sensitivity

Sensitivity estimate for ~~Super*B*~~ (Bernabéu *et al.)* :

$$\left|\text{Re}\{d_\tau^\gamma\}\right| \le 7.2 \times 10^{-20}\, e \text{ cm for } 75 \text{ ab}^{-1} @ 95\% \text{ CL using } \tau^- \to \pi^- \bar{\nu}_\tau,\ \rho^- \bar{\nu}_\tau \text{ decay modes}$$

Belle II: $\sigma\left(\text{Re}\{d_\tau^\gamma\}\right) \sim 3 \times 10^{-19}\, e$ cm for 50 ab^{-1} using $\tau^- \to \pi^- \bar{\nu}_\tau,\ \rho^- \bar{\nu}_\tau$ decay modes

Either estimate brings the sensitivity into the regime of New Physics predictions

Running of $\sin^2\theta_W$ – the NuTeV anomaly

- The NuTev measurement of $\sin^2\theta_W^{eff}$ does not show the expected running behavior
- A measurement of $A_{LR} = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R}\frac{1}{P_e} \propto \sin^2\theta_W^{eff}$ with a polarized electron beam can resolve this question with high precision at 10 (4) GeV
- Use $e^+e^- \to \mu^+\mu^-$ to achieve a precision of

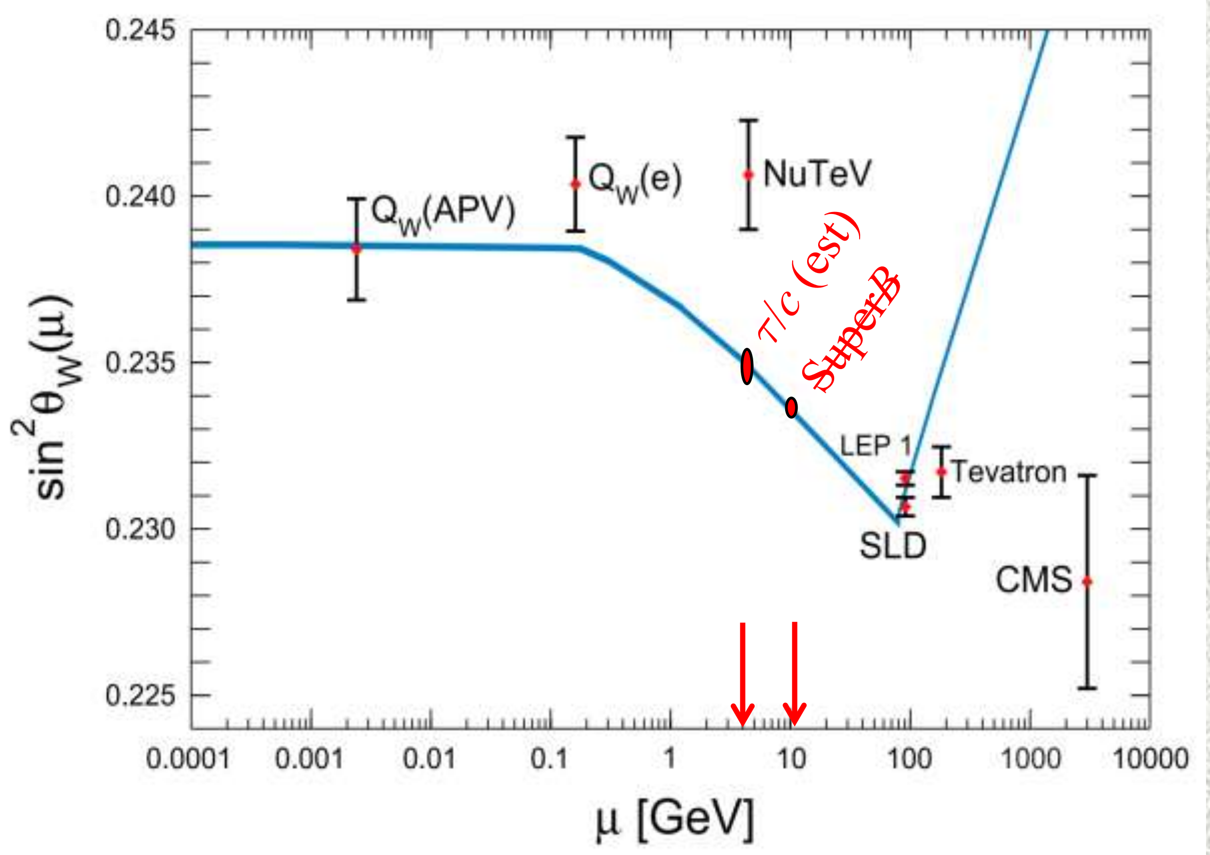
$$\sigma\ A_{LR} = 5\times10^{-6}$$

$$\Rightarrow \sigma\ \sin^2\theta_W^{eff} = 0.00018 \ @\ Y(4S)(\text{stat})$$

Compare to SLD A_{LR}: $\sigma\ \sin^2\theta_W^{eff} = 0.00026\ @\ Z^0$

Therefore must control systematics on beam polarization to ~0.5%

This is feasible with a laser Compton polarimeter or by measuring the forward-backward symmetry $A_{FB} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B}$ in τ production with $\pi\nu_\tau$ decays



- Then compare to A_{LR} in $e^+e^- \to \tau^+\tau^-$ for the most precise test of lepton universality
- Can also measure A^b_{LR} in B^+B^- and $B^0\bar{B}^0$ production, and with a polarized beam at the $\psi(3770)$, A^c_{LR}

Conclusions

- High statistics studies of τ production and decay, particularly at the new generation of e^+e^- colliders in the τ/c (at Tor Vergata and Novosibirsk) and Υ region (SuperKEKB), are uniquely sensitive to the effects of physics beyond the Standard Model in the flavor sector.
  - The search for charged lepton flavor violation is perhaps foremost among them
    - Provides meaningful discrimination between BSM models
    - Certain measurements are best done near threshold, other are best done at higher energy
- τ/c at Tor Vergata and Novosibirsk have longitudinally polarized electron beams, which enhance or enable several interesting searches for New Physics in the lepton sector
  - *CP* violation searches in τ decay
  - Search for a τ EDM in production
  - Measurement of the τ magnetic moment
  - Tests of *CPT* (not discussed here)
- Many other improvements on existing measurements are feasible
  - τ mass measurement
  - Leptonic and hadronic (strange and non-strange) branching fractions
  - Lepton universality tests
  - Extraction of the CKM element $|V_{us}|$