Lepton Flavor Violating (LFV) τ decays into leptons and hadrons

Presented on behalf of the BaBar collaboration
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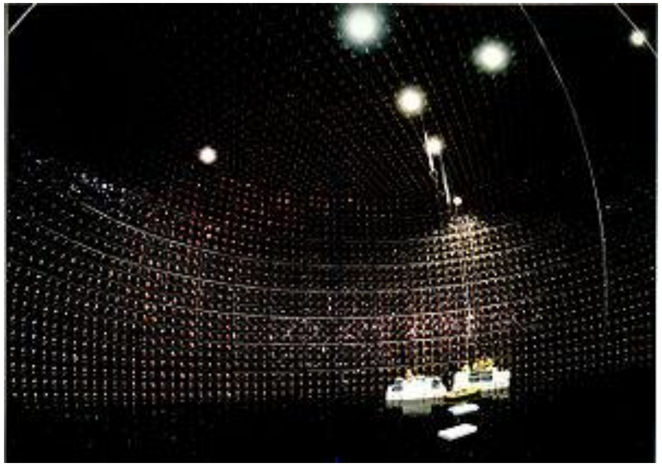
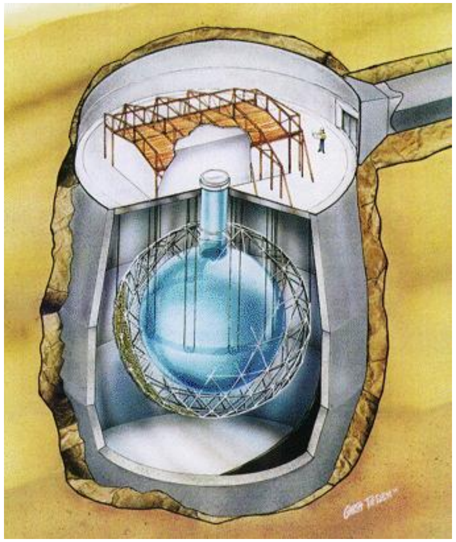
Lepton Flavor Violation

- Lepton flavor would be conserved in the SM if neutrinos were massless.
- Super K observed neutrino oscillation between $\nu_\mu \rightarrow \nu_\tau$, which was closely followed by observation of neutrino oscillation at SNO lab of $\nu_e \rightarrow \nu_\mu$.
- Neutrino oscillation implies that neutrinos have mass, and so LFV was observed.



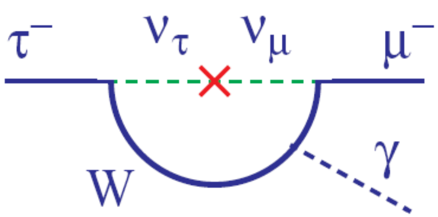
Super K Detector



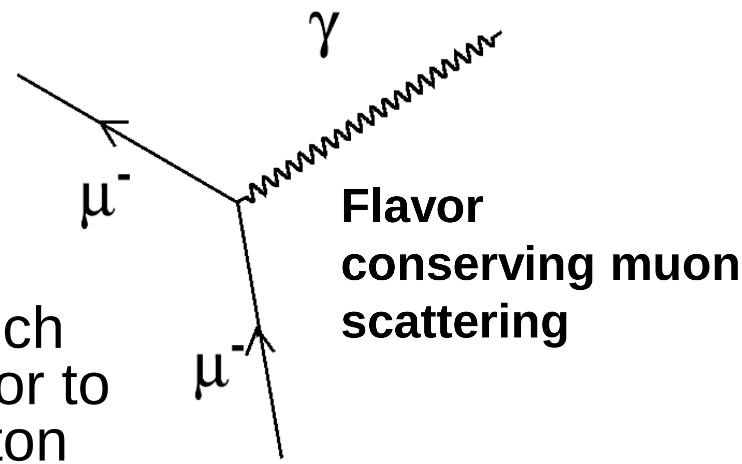
SNO Detector

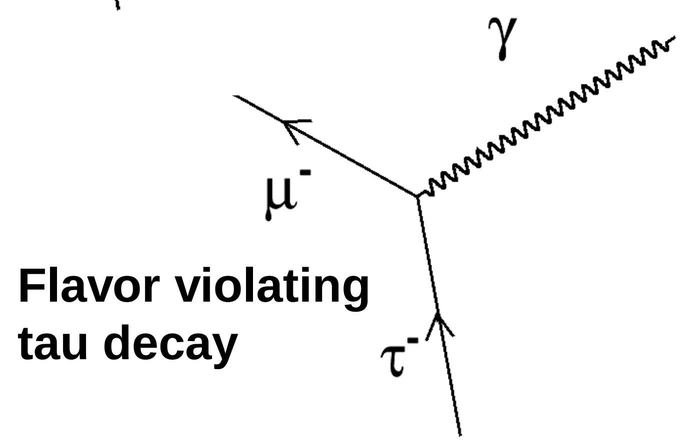
Lepton Flavor Violation

- Decays such as $\mu \to e\gamma$ or $\tau \to e\gamma$ would be a sign of LFV.
- One can draw loop diagrams which oscillate a neutrino from one flavor to another and hence conserve lepton flavor at each vertex.



$B \sim 10^{-55}$

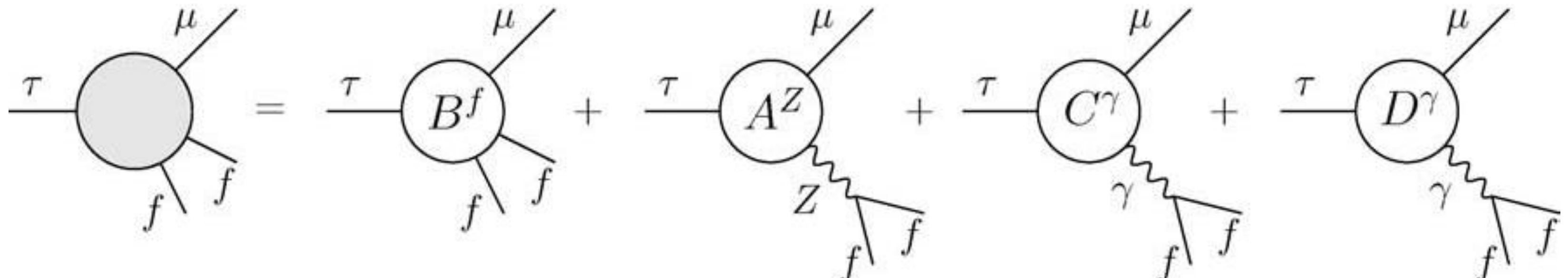




- These rates are far below current experimental sensitivity and so measuring an LFV decay is a sign of new physics.

Beyond the Standard Model

- Rates can be calculated in extensions to the Standard Model.
- Predicted rates are very sensitive to parameters; regions sensitive to current experiments have not all been ruled out.

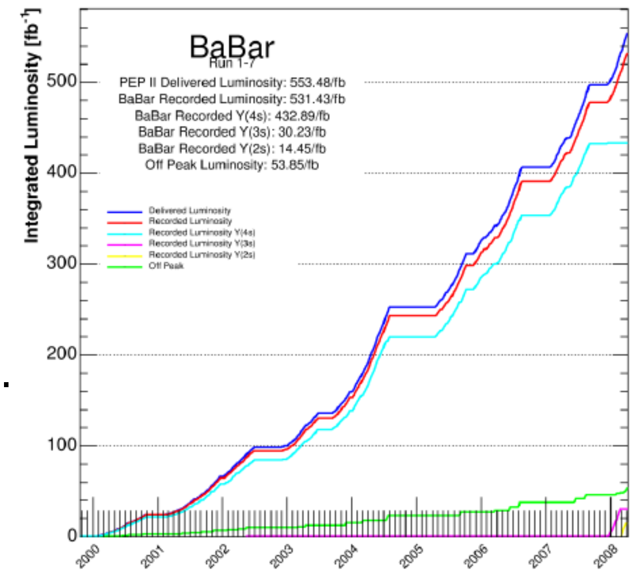


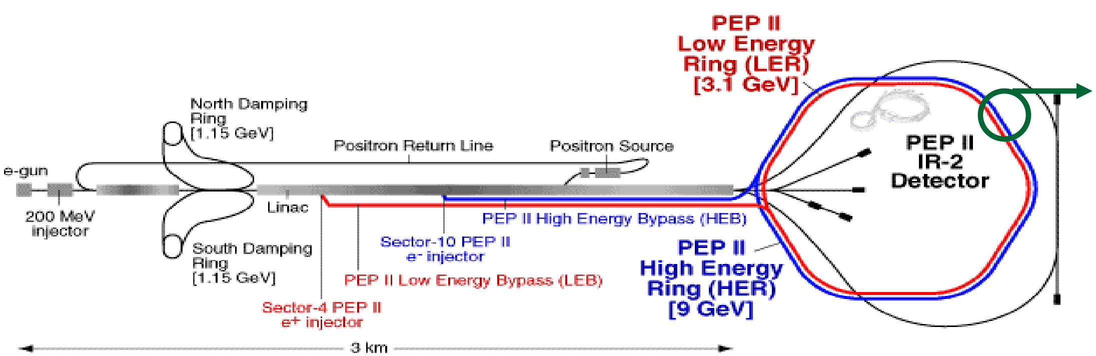
MSSM: A. Brignole and A. Rossi, Nucl. Phys. B 701, 3

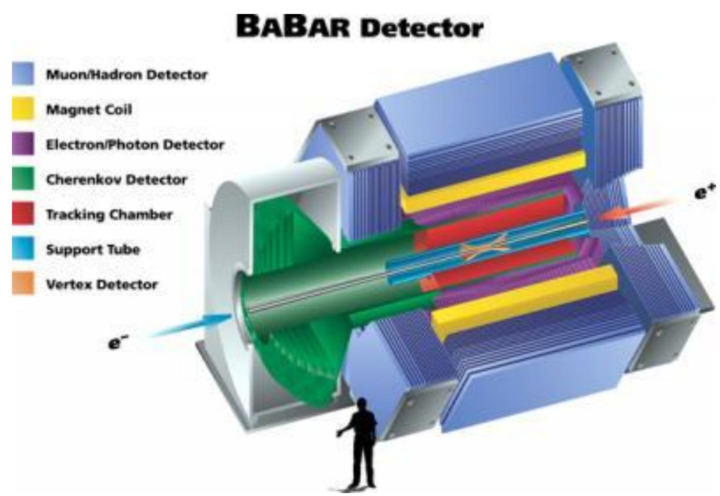
SM Extensions with heavy singlet Dirac neutrions: A.Ilkovac, Phys. Rev. D 62, 03601
R-parity violating SUSY: J.P. Saha and A. Kundu, Phys. Rev. D 66, 054021
MSSM-seesaw: E. Arganda, J.M. Herrero, J. Portoles, JHEP 0806, 079

BaBar at PEPII

- Accelerates electrons and positrons
- The τ-pair production cross-section at BaBar is: $\sigma_{\tau\tau}$= 0.92nb
- Majority of data acquired at the Υ(4S).
- Asymmetric energy electrons and positrons are used.
- PEP-II rings store electrons and positrons, that later collide at the BaBar detector

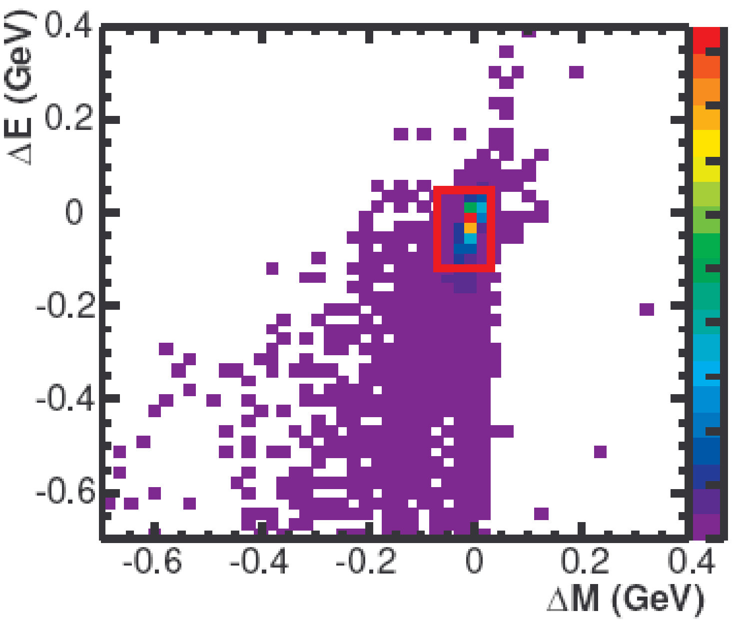




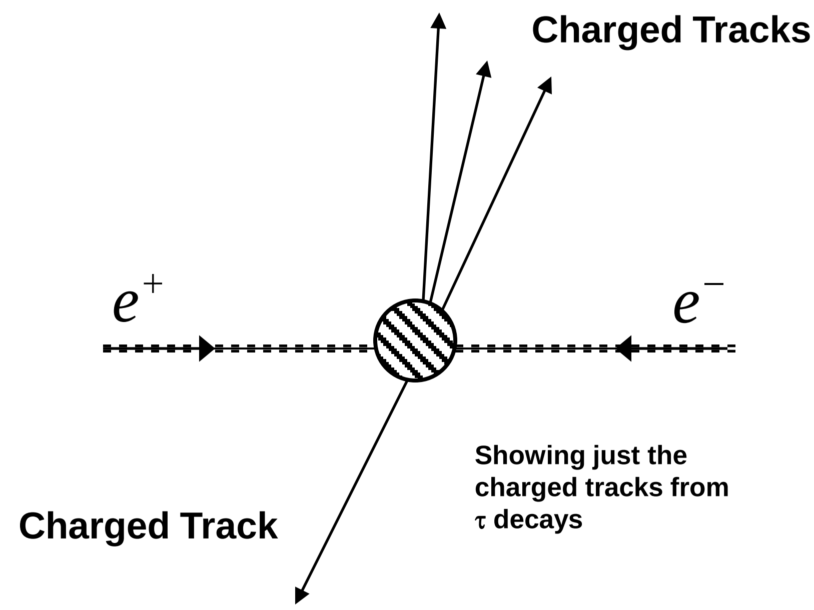


General Selections

- Selections are applied to:
  - Energy and Momenta of the tag and signal side particles.
  - Spatial arrangement of the event in the detector.



General schematic of an event in the c.m. frame



$$\Delta m = m_{Reco} - m_{\tau}$$

$$\Delta E = E_{Reco} - E_{beam}$$

$\tau^- \to \ell^- K^0_s$ (ℓ = e or μ)

- Estimates on this branching fraction are not well understood.
  [Phys. Rev. D 66, 054021 (2002)]
  [Phys. Rev. D 62, 036010 (2000)]
- This decay has not been excluded from the current level of sensitivities offered at the B factories.
- Previous limits were set by Belle at:

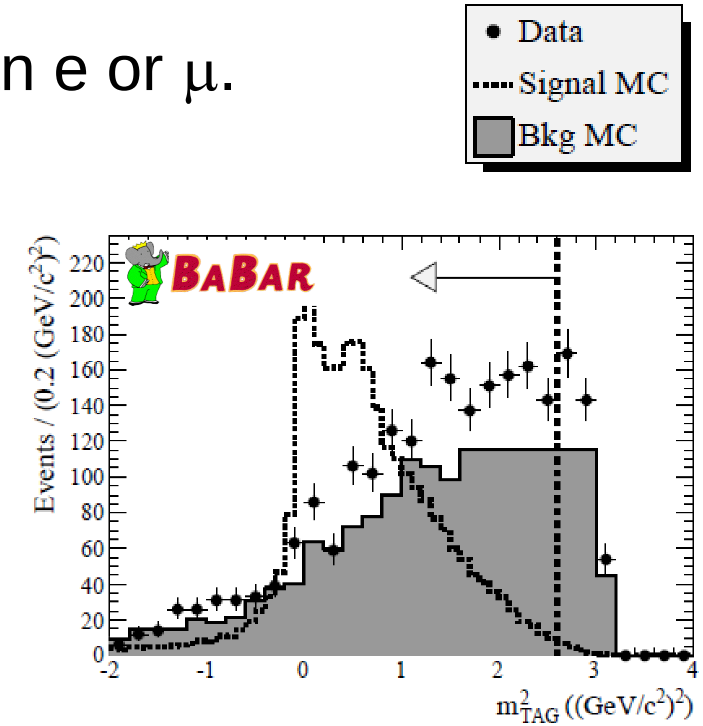
$$B(\tau^- \to e^- K_s^0) < 5.6 \times 10^{-8} \quad @90\%CL$$

$$B(\tau^- \to \mu^- K_s^0) < 4.9 \times 10^{-8} \quad @90\%CL$$

Belle: Phys. Lett. B 639, 159 (2006)

Specific selection for $\tau^- \to \ell^- K^0_s$

- K0s candidates are reconstructed from two oppositely charged tracks where the π mass is assumed for both.
- The reconstructed K0s mass is required to be within:
  $$0.482 < M_{K^0_s} < 0.514 \ \ \mathrm{GeV/c^2}$$
- Additional track is required to be an e or μ.
- Cut on the defined tag side mass:
  $$m^2_{Tag} = (\hat{p}_{tag} - \hat{p}_\nu)^2 < 2.6 \ \ (\mathrm{GeV/c^2})^2$$

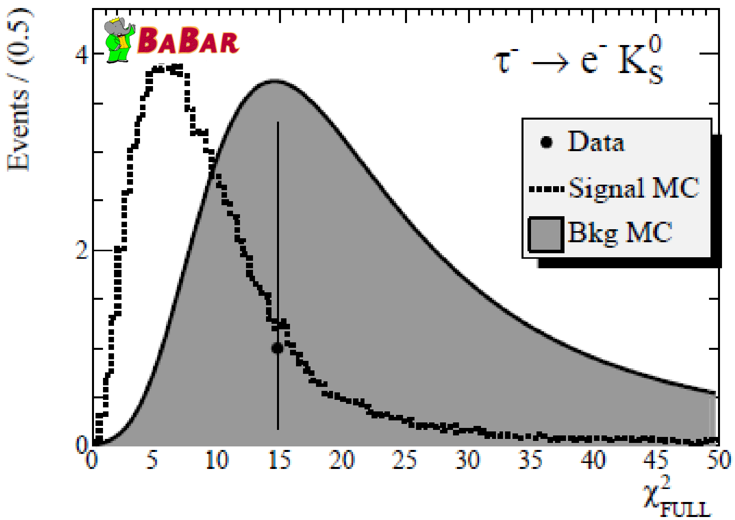


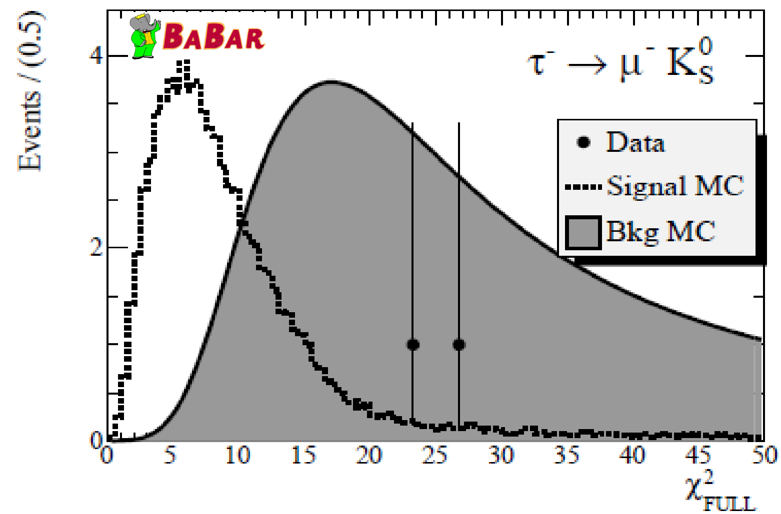
Using missing momentum as neutrinos momentum.

- Signal region boundary set at:
  $$\Delta M_\tau \ \text{within} \ 0 \pm 0.35 \ \ \mathrm{GeV/c^2}$$
  $$\Delta E_\tau \ \text{within} \ 0 \pm 0.40 \ \ \mathrm{GeV/c^2}$$

Measuring $\tau^- \rightarrow \ell^- K^0_s$

- Utilize discriminating variable X^2_{full} , which is the X^2 of geometrical and kinematical fit for the whole decay tree, and additional constraint: $\Delta M = 0 \quad \Delta E = 0$





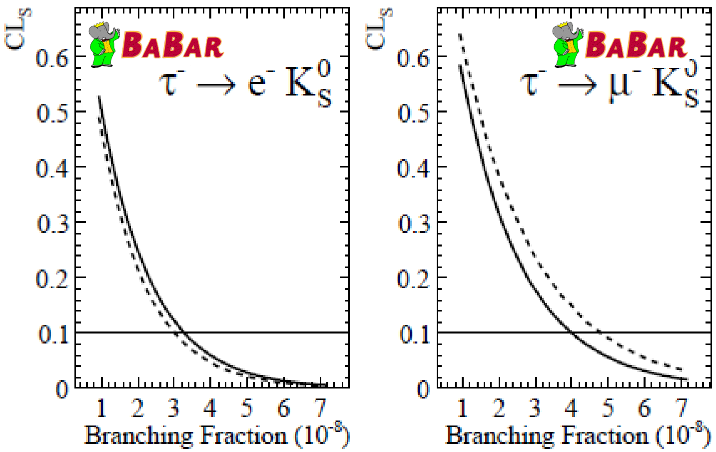
- No excess above background is found using the counting method
- Use CLs method, which is optimal for small statistics, to determine the limit. **T. Junk, Nucl. Instrum. Meth. A 434, 435 1999**

Results for $\tau^- \to \ell^- K^0_s$

- Using the likelihood ratio of where L(S+B) is the likelihood of finding signal in a signal + background hypothesis and L(B) is the likelihood of finding observed events in background only.

$$Q = \frac{L(S+B)}{L(B)}$$

- BF are determined from plots of $CL_S = CL_{S+B}/CL_B$ at the 90% level.



Datset = 469fb^{-1}

$$BF(\tau^- \to e^- K^0_S) < 3.3\times10^{-8}$$

$$BF(\tau^- \to \mu^- K^0_S) < 4.0\times10^{-8}$$

Phys.Rev.D79:012004,2009

$\tau^- \to \ell^- V^0$ (ℓ = e or μ)

- V^0 is reconstructed from:
- Experimental precision is sensitive to some theoretical predictions involving new physics models.

$$\phi \to K^+K^-$$
$$\rho \to \pi^+\pi^-$$
$$K^* \to K^+\pi^-$$
$$\overline{K}^* \to K^-\pi^+$$

- Using Data Sample of 451fb^{-1}, which corresponds to:

$$N_{\tau\tau} = (4.15 \pm 0.03) \times 10^8$$

- Background and efficiency modeled with Monte Carlo studies.

Selection $\tau^- \rightarrow \ell^- V^0$ (ℓ = e or μ)

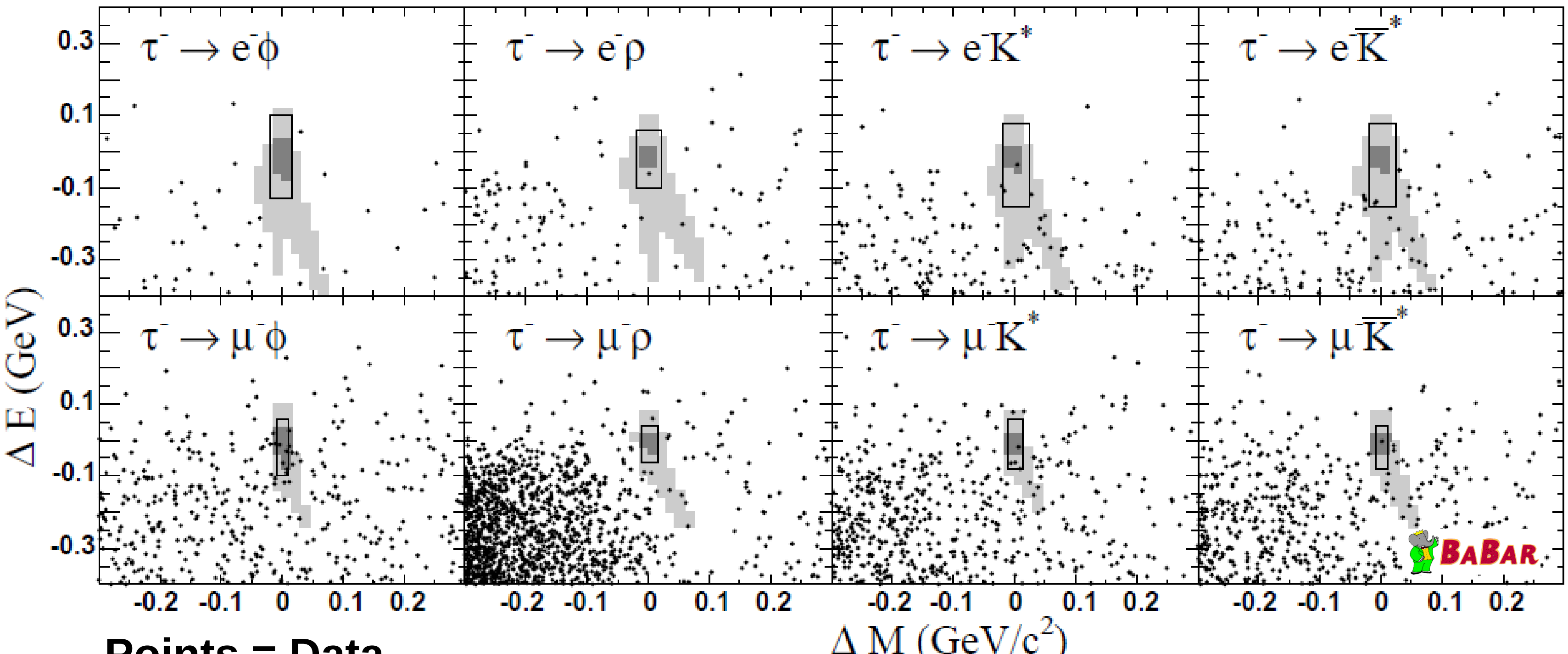
- Selection is tuned for each of the 8 possible channels.

  M_{hh} = Invariant mass of two hadrons in 3-prong hemisphere.
  $M_{1\text{-}pr}$ = Invariant mass of one prong hemisphere.
  P^T_{miss} = Missing transverse momentum in the event.
  P^T_{cms} = Scalar sum of all transverse momentum in the event.
  n^γ_{1pr} = number of photons in one prong hemisphere
  n^γ_{3pr} = number of photons in three prong hemisphere

- All selection criteria is optimized to provide smallest expected upper limit on the branching fraction in the background only hypothesis

Signal Box $\tau^{-} \rightarrow \ell^{-} V^{0}$ (ℓ = e or μ)

- Signal box boundaries are also optimized for smallest limit in the background only hypothesis.



Points = Data

Dark Shade = 50% of selected signal Monte Carlo

Light Shade = 90% of selected signal Monte Carlo

Results $\tau^- \to \ell^- V^0$ (ℓ = e or μ)

- Efficiency (ε) determined from LFV tau decay Monte Carlo.
  N_{bkg} is number of background events determined from data sidebands.
  N_{obs} is number of observed data events in the signal box.
  N^{90}_{UL} is the observed upper limit at 90% CL on number of signal events.
  B^{90}_{exp} is the mean upper limit expected in the background only hypothesis.
  $B^{90}_{UL} = N^{90}_{UL}/(2\varepsilon N_{\tau\tau})$ is the observed 90% CL Upper limit on the BF.

Mode	ε[%]	$N_{\rm bgd}$	$N_{\rm obs}$	$N^{90}_{\rm UL}$	$\mathcal{B}^{90}_{\rm exp}$	10^{-8} $\mathcal{B}^{90}_{\rm UL}$
$e\phi$	6.43 ± 0.16	0.68 ± 0.12	0	1.8	5.0	3.1
$\mu\phi$	5.18 ± 0.27	2.76 ± 0.16	6	8.7	8.2	19
$e\rho$	7.31 ± 0.18	1.32 ± 0.17	1	3.1	4.9	4.6
$\mu\rho$	4.52 ± 0.41	2.04 ± 0.19	0	1.1	8.9	2.6
eK^*	8.00 ± 0.19	1.65 ± 0.23	2	4.3	4.8	5.9
μK^*	4.57 ± 0.36	1.79 ± 0.21	4	7.1	8.5	17
$e\overline{K}^*$	7.76 ± 0.18	2.76 ± 0.28	2	3.2	5.4	4.6
$\mu\overline{K}^*$	4.11 ± 0.32	1.72 ± 0.17	1	2.7	9.3	7.3

Phys.Rev.Lett.103:021801,2009

Summary

- No evidence for a statistically significant LFV signal.
- New high precision limits have been set on the $\tau^- \to \ell^- K^0_s$ and decays $\tau^- \to \ell^- V^0$.

  Phys.Rev.D79:012004,2009 **Phys.Rev.Lett.103:021801,2009**
- These results can be used to restrict some of the theoretical phase space on new physics models.

The CLs Method

- Particularly useful for studies involving small statistics.
- Confidence levels have been shown to be more conservative than direct summation.
- Method relies on definition of test statistic "X" which discriminates signal-like outcomes from background-like outcomes.

$$CL_{s+b} = P_{s+b}(X \leq X_{obs}) \qquad CL_b = P_b(X \leq X_{obs})$$

$$X_i = \frac{e^{-(s_i+b_i)}(s_i+b_i)^{d_i}}{d_i!} \Big/ \frac{e^{-b_i} b_i^{d_i}}{d_i!}$$

T. Junk, Nucl. Instrum. Meth. A 434, 435 1999