



# Future Constraints on, and from Lepton Universality

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# Potential of Future $\nu$ Experiments

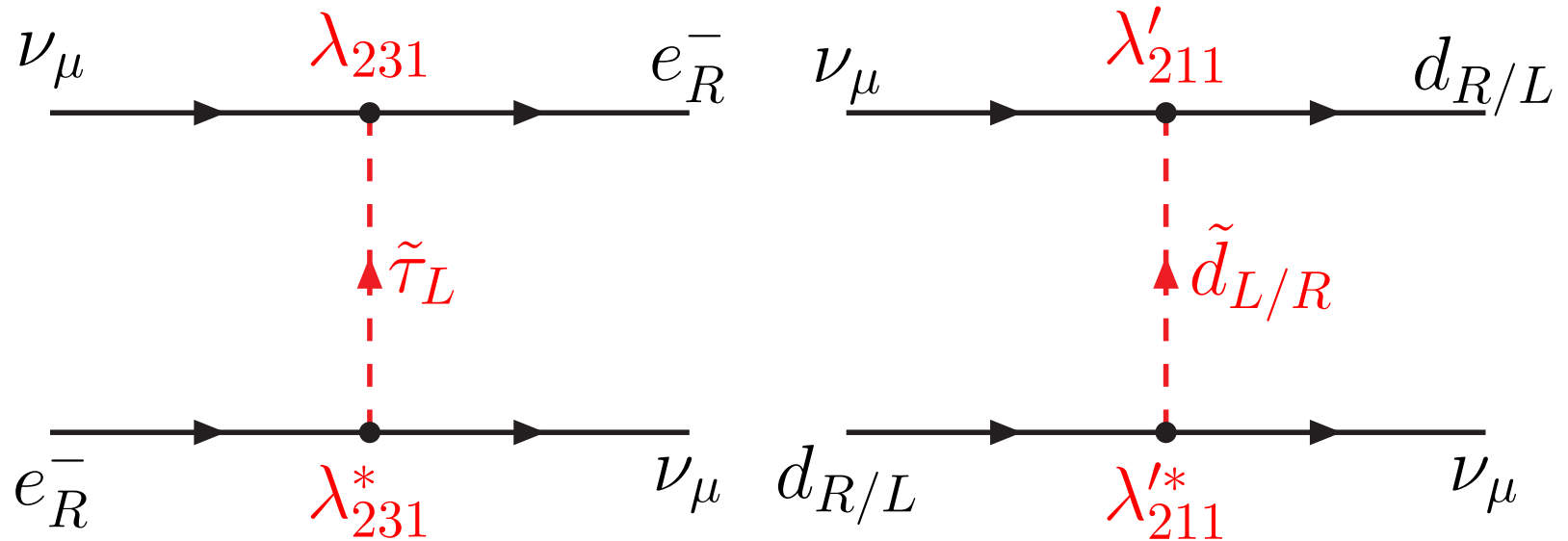
- Future high statistics neutrino experiments will have the **precision** to probe new physics at the **TeV scale**.
  - Fixed target  $\nu$ -scattering experiments, e.g. **NuSOnG**.  
*cf. arXiv:0803.0354 [hep-ph]*
  - Long baseline  $\nu$ -oscillation experiments, e.g. **Fermilab→Hyper-Kamiokande**.  
*cf. arXiv:0707.4545 [hep-ph]*

# Example: R-parity Violation

$$W_{\mathcal{R}} = \frac{1}{2} \lambda_{ijk} \hat{L}_i \hat{L}_j \hat{E}_k + \lambda'_{ijk} \hat{L}_i \hat{Q}_j \hat{D}_k + \frac{1}{2} \lambda''_{ijk} \hat{U}_i \hat{D}_j \hat{D}_k ,$$

	NuSOnG 95%	current 95%
$ \lambda_{231} $	$0.05 \left( \frac{M_{\tilde{\tau}_L}}{100 \text{ GeV}} \right)$	$0.07 \left( \frac{M_{\tilde{e}_R}}{100 \text{ GeV}} \right)$
$ \lambda'_{211} $	$0.05 \left( \frac{M_{\tilde{d}}}{100 \text{ GeV}} \right)$	$0.06 \left( \frac{M_{\tilde{d}_R}}{100 \text{ GeV}} \right)$

# RPV Contribution to $\nu$ -Scattering



# Current Bounds

Current bounds on RPV come from CC lepton universality measurements:

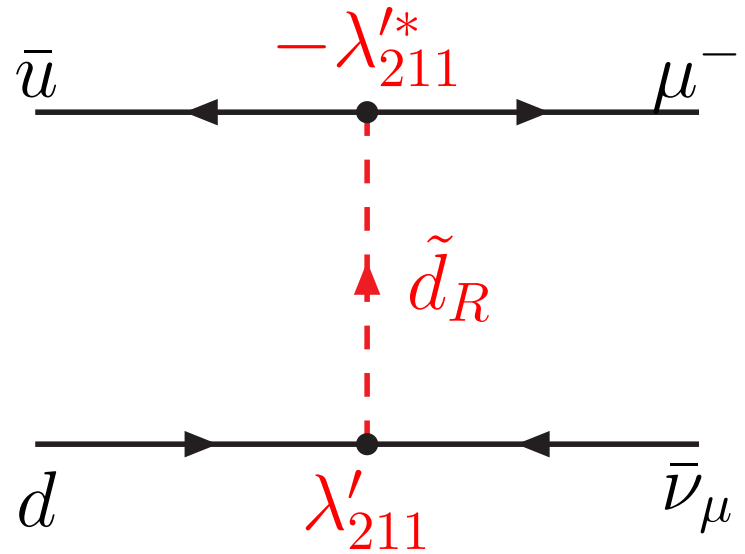
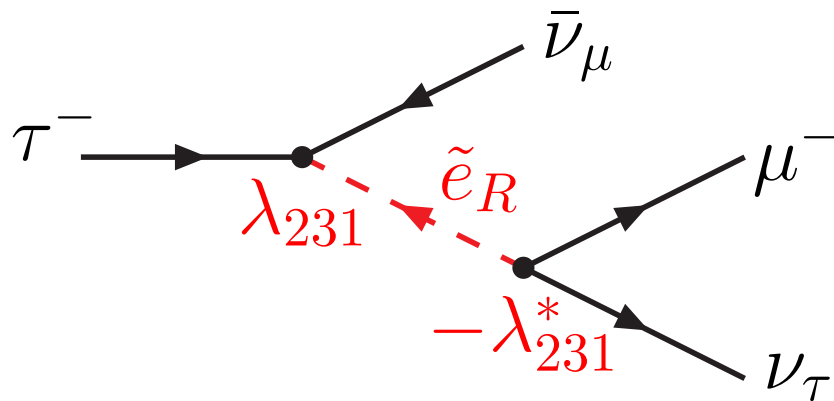
$$R_\tau = \frac{B(\tau \rightarrow e\nu_e\nu_\tau)}{B(\tau \rightarrow \mu\nu_\mu\nu_\tau)} = 1.028 \pm 0.004$$

$$\rightarrow g_\mu/g_e = 1.0021 \pm 0.0016$$

$$R_\pi = \frac{B(\pi \rightarrow e\nu_e)}{B(\pi \rightarrow \mu\nu_\mu)} = (1.231 \pm 0.004) \times 10^{-4}$$

$$\rightarrow g_\mu/g_e = 1.0003 \pm 0.0021$$

# RPV contribution to $\tau$ and $\pi$ decays



# In the Near Future:

Current bounds on CC lepton universality can be expected to be improved dramatically in the near future. In the case of  $\pi$ -decay:

- PIENU@TRIUMF aims to reduce the error on  $R_\pi$  by a factor of 5.
- PEN@PSI aims to reduce the error on  $R_\pi$  by a factor of 6.
- Combined, the error on  $R_\pi$  will be reduced by a factor of 8.

# In the Near Future 2:

$\tau$ -decay:

- Babar aims to reduce the errors on ALL one-prong  $\tau$  branching fractions by factors of 3.
- Belle?

$W$ -decay:

- LEP2 sees  $2\sigma$  difference in  $B(W \rightarrow \tau\nu_\tau)$  vs.  $B(W \rightarrow \mu\nu_\mu), B(W \rightarrow e\nu_e)$ .
- Tevatron Run 2?

# Comparison of Babar and Belle:

- Integrated Luminosities:
  - Babar:  $557 \text{ fb}^{-1}$   
(data taking ended April 7, 2008)
  - Belle:  $> 800 \text{ fb}^{-1}$  and growing
- $\tau$  events
  - Babar:  $\sim 500$  million  $\tau$  pairs
  - Belle:  $\sim 700$  million  $\tau$  pairs and growing

If Belle can analyze their data, the improvement will be much better!

# Potential Impact on RPV limits

- Babar

$$|\lambda_{231}| < 0.07 \left( \frac{M_{\tilde{e}_R}}{100 \text{ GeV}} \right) \Rightarrow 0.03 \left( \frac{M_{\tilde{e}_R}}{100 \text{ GeV}} \right)$$

- PIENU+PEN

$$|\lambda'_{211}| < 0.06 \left( \frac{M_{\tilde{d}_R}}{100 \text{ GeV}} \right) \Rightarrow 0.01 \left( \frac{M_{\tilde{d}_R}}{100 \text{ GeV}} \right)$$

Actual bounds could be stronger or weaker depending on whether the measured values are higher or lower than the SM.

# Global Analysis of CC Lepton Universality

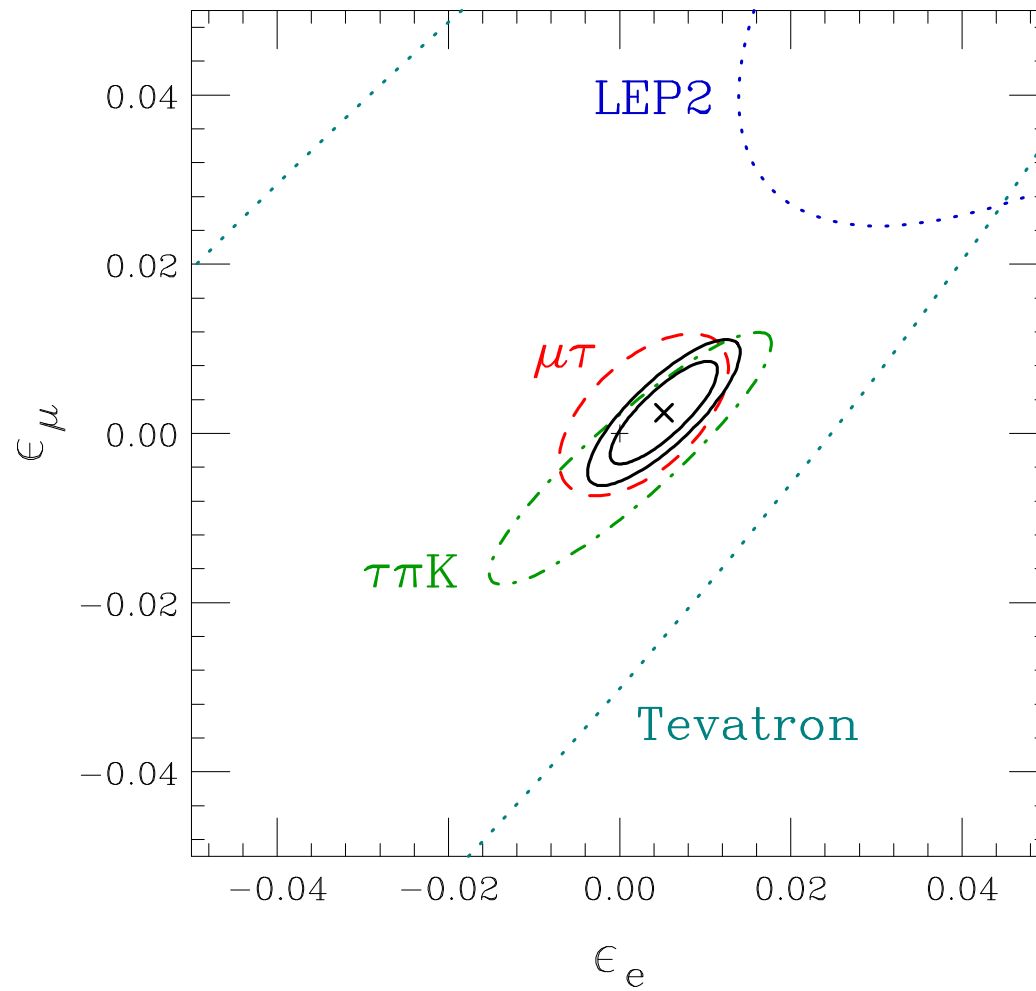
Allow the CC couplings to depend on lepton flavor:

$$\mathcal{L} = \sum_{\ell=e,\mu,\tau} \frac{g_\ell}{\sqrt{2}} W_\mu^+ \bar{\nu}_\ell \gamma^\mu \left( \frac{1 - \gamma_5}{2} \right) \ell^- + \text{h.c.} .$$

Fit all CC particle decay data with the parameters  $\epsilon_\ell$ ,  $\ell = e, \mu, \tau$ .

$$g_\ell = g \left( 1 - \frac{\epsilon_\ell}{2} \right)$$

# Current Status:



# Comment on the Tevatron:

- The Tevatron ellipse is based on:
  - 4 pb<sup>-1</sup> of data from CDF Run 1
  - 18 pb<sup>-1</sup> of data from D0 Run 1
  - 72 pb<sup>-1</sup> of data from CDF Run 2
- Total Integrated Luminosity delivered to each detector was:
  - Run 1: >160 pb<sup>-1</sup>
  - Run 2: ~4000 pb<sup>-1</sup> and growing

# Tevatron Run 2 $W$ Mass & Width Analyses

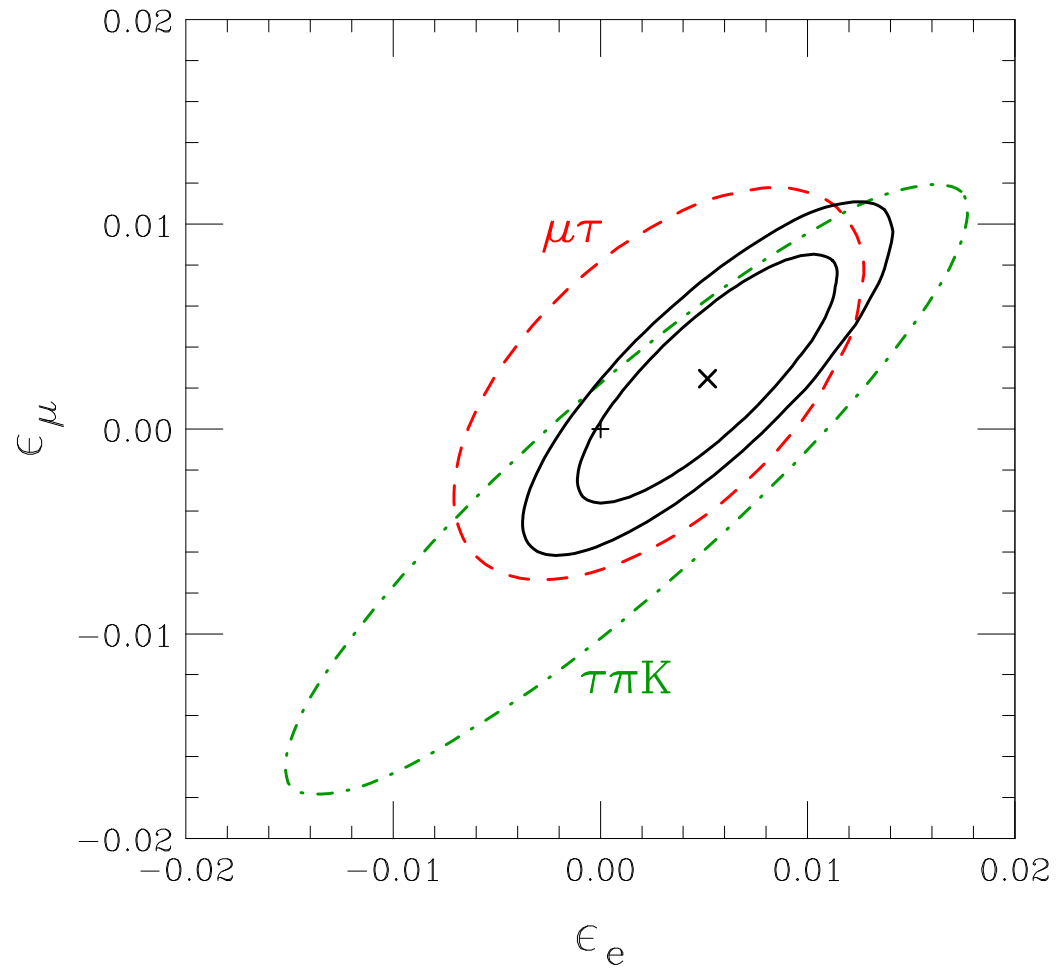
## • CDF

- $\sim 200 \text{ pb}^{-1}$  of data for  $W$  Mass  
63964  $W \rightarrow e\nu$ , 51228  $W \rightarrow \mu\nu$
- $\sim 350 \text{ pb}^{-1}$  of data for  $W$  Width  
230185  $W$  candidates

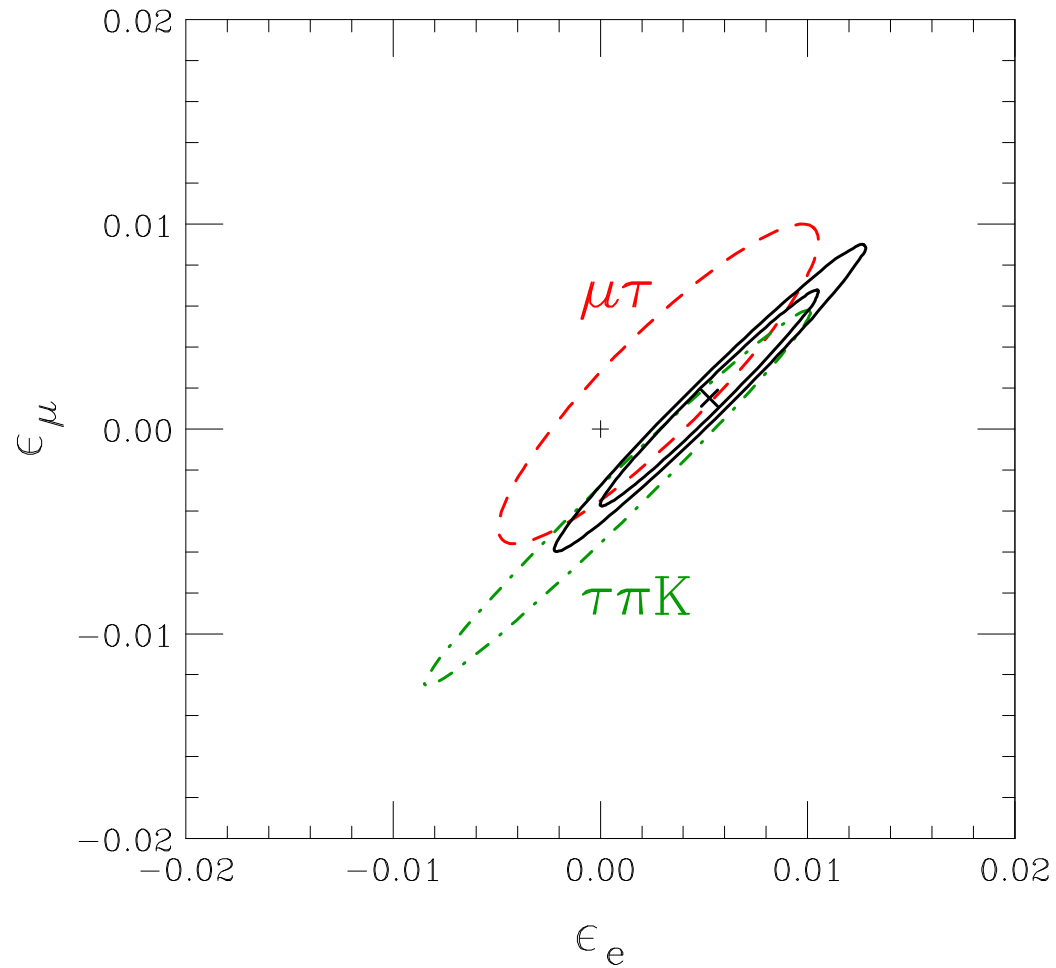
## • D0

- $177 \text{ pb}^{-1}$  of data for  $W$  width  
75910  $W \rightarrow e\nu$  candidates
- $96 \text{ pb}^{-1}$  of data  
62286  $W \rightarrow \mu\nu$  candidates

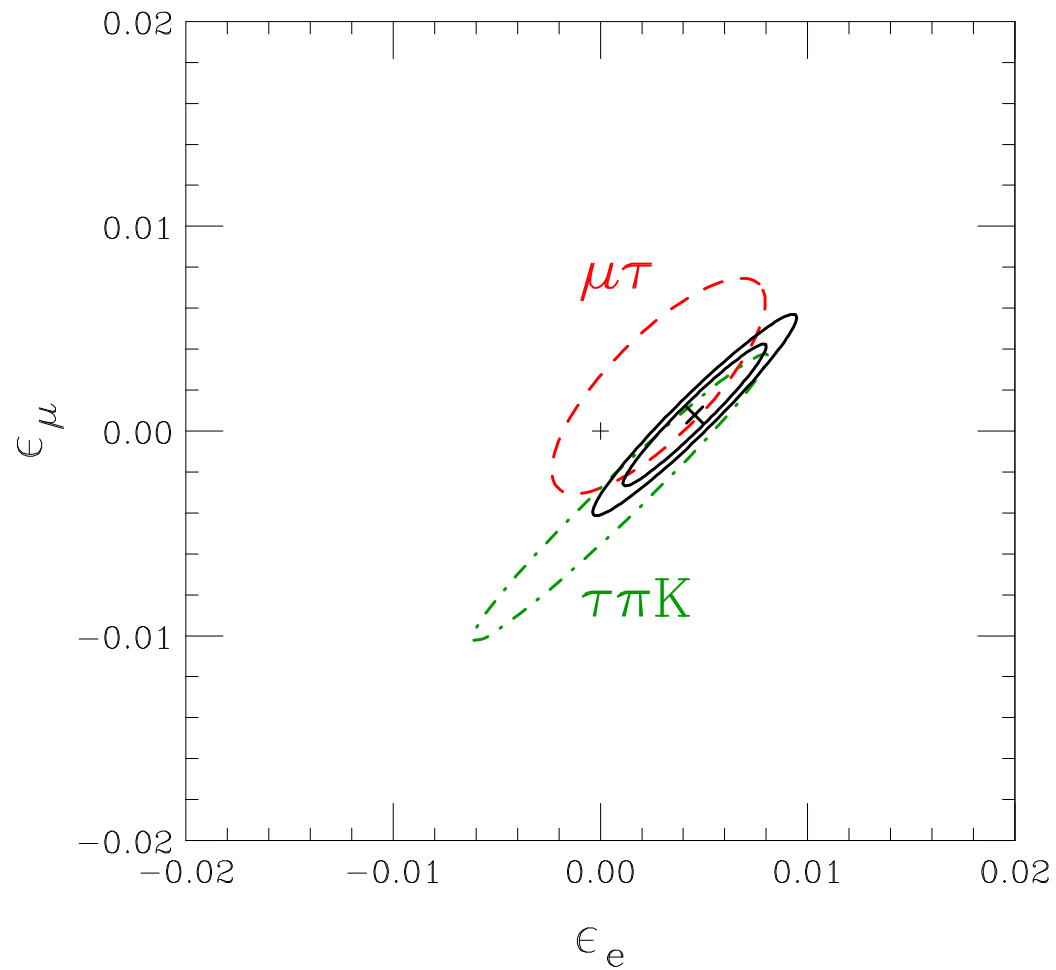
# Blowup of Current Status:



# With improved $\pi$ and $\tau$ branching fractions:



# With improved $\tau$ lifetime:



# Neutrino Mixing with Gauge Singlet States

$$\nu = \nu_{\text{light}} \cos \theta + \nu_{\text{heavy}} \sin \theta$$

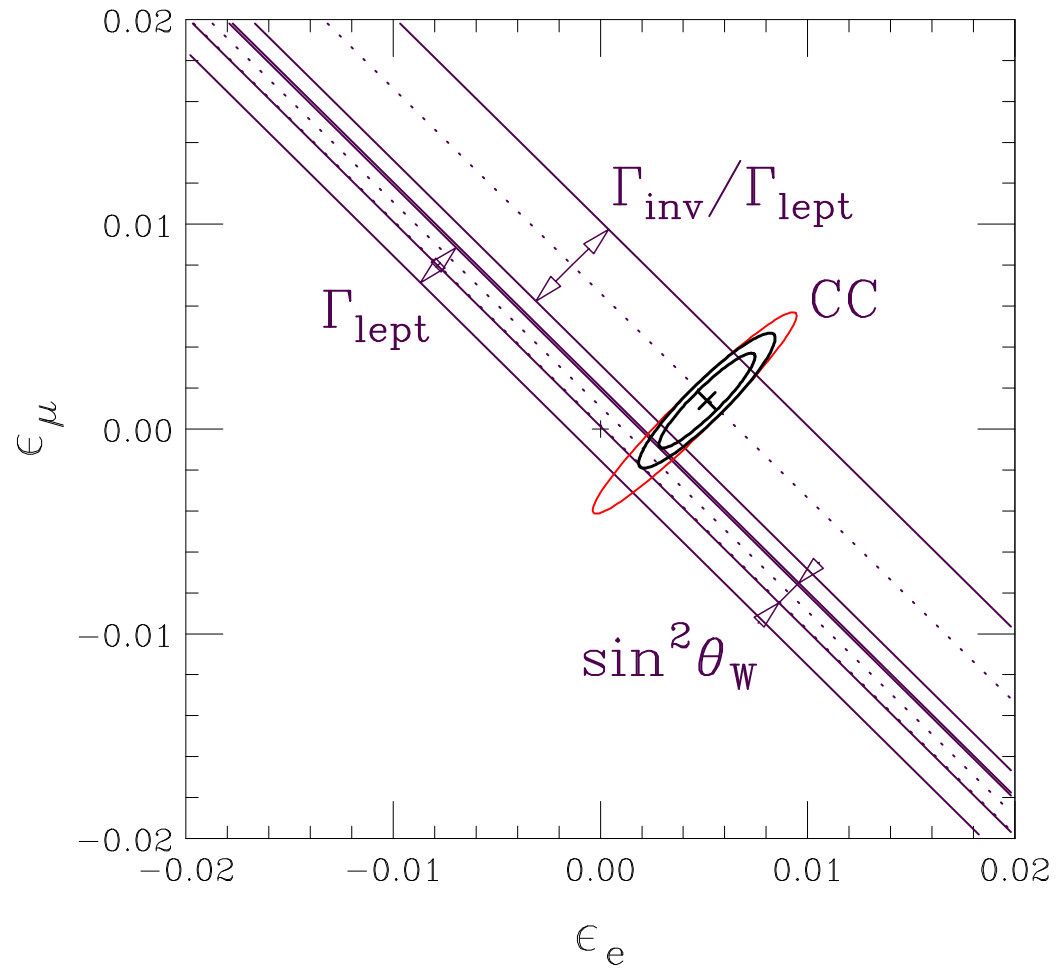
$$\chi = -\nu_{\text{light}} \sin \theta + \nu_{\text{heavy}} \cos \theta$$

$$\begin{aligned} Z\nu\nu &= Z\nu_{\text{light}}\nu_{\text{light}} \cos^2 \theta \\ &\quad + 2Z\nu_{\text{light}}\nu_{\text{heavy}} \sin \theta \cos \theta \\ &\quad + Z\nu_{\text{heavy}}\nu_{\text{heavy}} \sin^2 \theta \end{aligned}$$

$$W\ell\nu = W\ell\nu_{\text{light}} \cos \theta + W\ell\nu_{\text{heavy}} \sin \theta$$

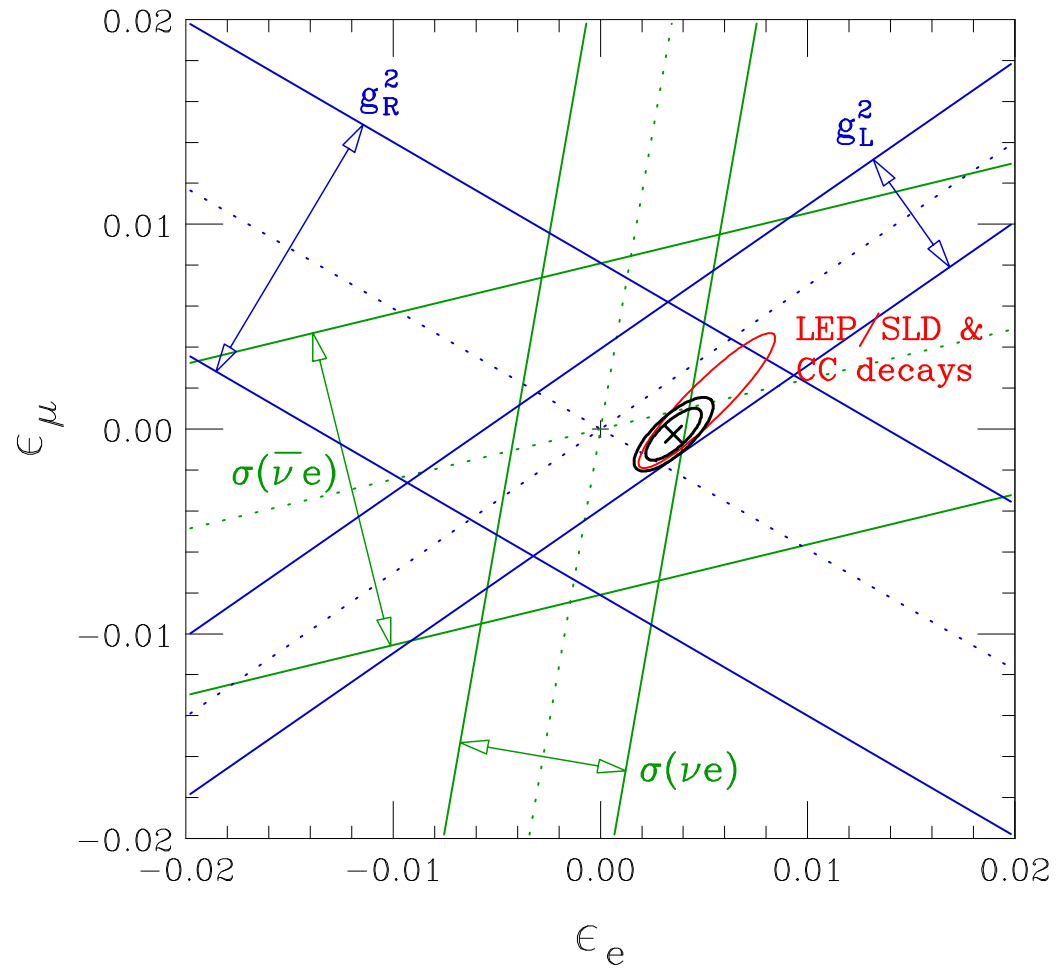
$$Z\nu_{\ell}\nu_{\ell} (1 - \epsilon_{\ell}) \quad W\ell\nu_{\ell} \left(1 - \frac{\epsilon_{\ell}}{2}\right)$$

# With LEP/SLD data:



Fit with  $S$ ,  $T$ ,  $\epsilon_e$ , and  $\epsilon_\mu$ .

# Potential Impact of NuSO<sub>n</sub>G:



Fit with  $S$ ,  $T$ ,  $\epsilon_e$ , and  $\epsilon_\mu$ .

# Conclusions:

- Bounds on CC Lepton Universality can be expected to be improved dramatically in the near future by new data (PIENU, PEN) and the analysis of already existing ones (Babar, Belle, Tevatron).
- Such improvements will place strong constraints on certain types of New Physics which will be difficult to beat even with future high statistics  $\nu$  experiments. (e.g. certain R-parity violating couplings)

# Conclusions continued:

- When combined with future high statistics  $\nu$  experiments, they can yield very stringent bounds on other types of New Physics. (e.g. neutrino mixing with heavy gauge singlet states)
- When are the Belle and Tevatron Run 2 analyses coming out?