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Limits on a Lepton Number Violating Process in e^+e^- Collisions*

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ABSTRACT

If a new hypothetical particle induces a lepton number violating process, it could also affect $e^+e^- \rightarrow \mu^+\mu^-$ and $\tau^+\tau^-$ through its t-channel exchange. A fit of the measured cross sections and forward-backward asymmetries at PEP and PETRA yields the 90% CL limits on the coupling of the particle: $G_{e\mu} < 0.119G_F$ and $G_{e\tau} < 0.085G_F$, where G_F is the Fermi coupling constant. These limits exclude certain regions of couplings allowed by other lepton number violation searches.

The search for a lepton number violating process has long been a tradition of particle physics. In recent years the immense interest in models that go beyond the standard model, such as compositeness, technicolor, and lepto-quarks, has intensified interest in the search.[1] The lepton number violating process has been sought in many experiments, such as the search for $\mu^- \rightarrow e^-e^+e^-$, $K^+ \rightarrow \pi^+e^+\mu^-$, and $K_L^0 \rightarrow e^+\mu^-$. If a new hypothetical particle Z' induces one of the lepton number violating processes, it could also affect $e^+e^- \rightarrow \mu^+\mu^-$ and $\tau^+\tau^-$ through its t-channel exchange (Fig. 1). Within this context, we analyze the effect of such a Z' on the cross sections and forward-backward asymmetries and present new limits on the coupling.[2]

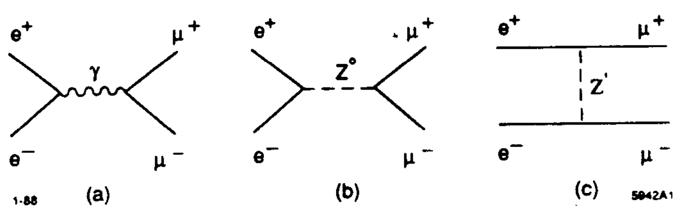

Fig. 1. The production of $\mu^+\mu^-$ through the t-channel exchange of Z' (c), in addition to the γ (a) and Z^0 exchange (b).

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In order to obtain the limits on the coupling, it is necessary to make an assumption on the form of interaction. To facilitate comparison with the limits from other lepton number violating processes, the interaction is assumed to be a four-fermion contact interaction. The limits are extracted by performing a fit on the cross sections and asymmetries measured at PEP and PETRA.[3] The fit takes into account correlations in the systematic errors within each experiment and between different experiments. For a V–A interaction, the limits on the coupling are, in unit of the Fermi coupling,

$$G_{e\mu} < 0.119 G_F \quad \text{and} \quad G_{e\tau} < 0.085 G_F \quad ,$$

at the 90% CL. Assuming that Z' couples to μ and τ with the same strength, these two limits can be combined to give

$$G_{e\ell} < 0.089 G_F \quad .$$

There is no need to restrict Z' to be a V–A interaction. Other possibilities have been investigated as shown in Table I. The limit for a V + A interaction is similar to that for a V–A, however the limit for V or A is about a factor of two less stringent and, for scalar, it is about another factor of two worse. In all cases, limits considerably below G_F are obtained.

Table I. 90% CL upper limits on the coupling of the Z' in unit of G_F, for various forms of interaction.

	V − A	V + A	V or A	Scalar
$G_{e\mu}$	0.119	0.117	0.233	0.231
$G_{e\tau}$	0.085	0.083	0.168	0.601
$G_{e\ell}$	0.089	0.087	0.175	0.218

The limits obtained for a V–A interaction could be compared with those from other lepton number violating processes. We assume that the same particle induces all the lepton number violating processes. The e^+e^- process is similar to the muonium to anti-muonium conversion, $\mu^+e^- \rightarrow \mu^-e^+$. The limit obtained is $G_{e\mu} < 7.5\ G_F$.[4] The e^+e^- limit therefore represents an improvement of about two orders of magnitude.

If Z' couples e to both μ and τ, then it permits the process $\tau^- \rightarrow e^-\mu^\pm e^\mp$. The limit on the branching ratio[5] yields a limit on the product of couplings,

$$(G_{e\mu}G_{e\tau})^{1/2} < 1.4 \times 10^{-2} G_F \quad .$$

Therefore the limit on the product of couplings obtained in this paper is not as stringent. However, the individual limits on $G_{e\mu}$ and $G_{e\tau}$ exclude the regions allowed by the decay search as shown in Fig. 2.

The limits on the exotic decays,[6] $\mu^- \to e^- e^+ e^-$, $K_L^0 \to e^+\mu^-$, and $K^+ \to \pi^+ e^+ \mu^-$, provides very stringent limits on the coupling. Comparison with this limit will be meaningless if Z' has no diagonal coupling or the coupling to quarks is very different from leptons. Again, the limit on $G_{e\mu}$ excludes some of the regions allowed by the searches.

The sensitivity of the e^+e^- search increases as the square of the center-of-mass energy and will therefore continue to improve with higher energy colliders. The search in μ and K decays will eventually be limited by background and beam intensity. Experiments at the TRISTAN e^+e^- collider could reach the sensitivity of the exotic τ decay, which is being limited by the event rate with no prospect for significant improvement in the near future. The sensitivity will be further increased at SLC and LEP if the colliders run at off the Z^0 resonance. In multi-TeV colliders, the sensitivity of the e^+e^- search will reach that in μ and K decays.

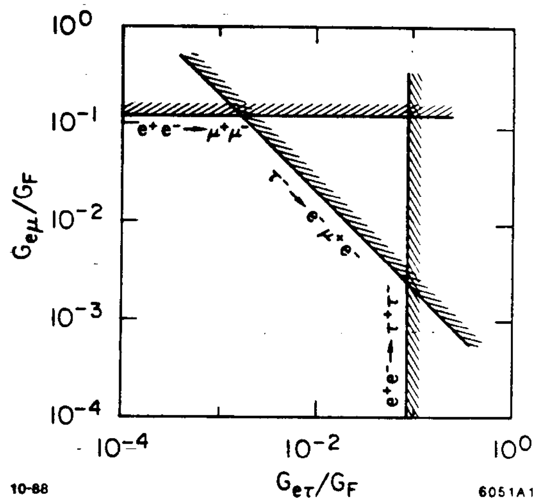

Fig. 2. 90% CL limits on $G_{e\mu}$ and $G_{e\tau}$.

In conclusion, new limits are presented for searching for a lepton number violating process in e^+e^- interactions with large momentum transfer. These limits exclude certain regions of couplings allowed by other lepton number violation searches. Prospect for improvement in the near future is good.

REFERENCES

1. See for example, H. Harari, Fundamental Forces, ed. by D. Frame and K. J. Peach (St. Andrews, 1984), P. 357.

2. This is a condensed version of the paper published by the author in Phys. Lett. **209B** (1988) 95. The differential cross section, including the interferences between different diagrams, can be find in the paper.

3. The measurements used in the fit are those compiled by U. Amaldi *et al.*, Phys. Rev. **D36** (1987) 1385.

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