LEPTON NUMBER VIOLATING MUON DECAY AND THE LSND NEUTRINO ANOMALY

K.S. BABU
OKLAHOMA STATE UNIVERSITY

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WITH S. PAKVASA, hep-ph/0204236

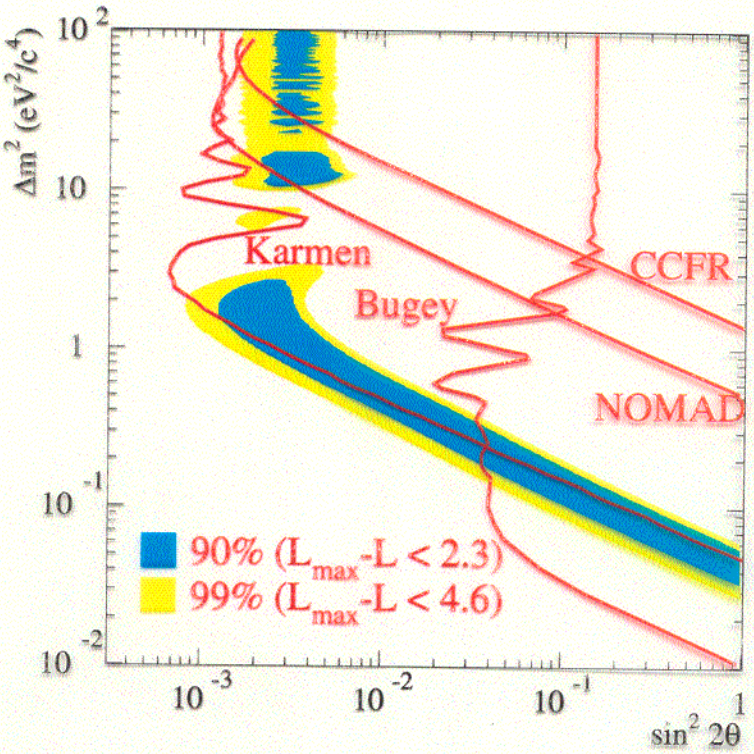


FIG. 27: A $(\sin^2 2\theta, \Delta m^2)$ oscillation parameter fit for the entire data sample, $20 < E_e < 200$ MeV. The fit includes primary $\bar{\nu}_\mu \to \bar{\nu}_e$ oscillations and secondary $\nu_\mu \to \nu_e$ oscillations, as well as all known neutrino backgrounds. The inner and outer regions correspond to 90% and 99% CL allowed regions, while the curves are 90% CL limits from the Bugey reactor experiment, the CCFR experiment at Fermilab, the NOMAD experiment at CERN, and the KARMEN experiment at ISIS.

$$\Delta m^2_{\odot} \approx 5 \cdot 10^{-5}\ eV^2$$

$$\Delta m^2_{atm} \approx 3 \cdot 10^{-3}\ eV^2$$

$$\Delta m^2_{LSND} \approx (0.2\text{-}2)\ eV^2$$

$\Rightarrow$

OSCILLATION LENGTH $\lambda = \frac{4E}{\Delta m^2}$

$$\lambda_{\odot} \sim 200\ km$$

$$\lambda_{atm} \sim 6000\ km$$

$$\lambda_{LSND} \sim 60\ m$$

- NO OVERLAP IN λ
- 3-FLAVOR ν-OSCILLATIONS CANNOT FIT ALL 3 OBSERVATIONS

OPTIONS

1. IGNORE ONE EXPERIMENT (LSND)

2. INTRODUCE A 4TH STERILE NEUTRINO ν_s

   POTENTIAL PROBLEMS:

   - ν_e-ν_s OSCILLATIONS CANNOT FIT SOLAR ν- DATA*
   - ν_μ-ν_s OSCILLATIONS DOES NOT FIT ATMOSPHERIC ν*
   - BIG BANG NUCLEOSYNTHESIS DISFAVORS ν_s
   - LIGHT ν_s DOES NOT ARISE IN SEESAW

3. ANOMALOUS (L-VIOLATING) μ DECAY

$$\mu^+ \to e^+ + \bar{\nu}_e + \bar{\nu}_\iota \qquad \iota = e, \mu, \tau$$

* M. Maltoni et.al, hep-ph/0207157

4. CPT VIOLATION ?

LEPTON NUMBER CONSERVING ANOMALOUS μ-DECAY CANNOT EXPLAIN LSND DATA

Bergmann, Grossman, 99

$$\mu^+ \to e^+ + \bar{\nu}_e + \nu_i \qquad i = e, \mu, \tau$$

BY SU(2) LOWERING OPERATOR, WILL HAVE

$$\mu^+ \to e^+ + e^+ + \ell_i^-$$

$i = e \Rightarrow \quad \mu \to 3e \qquad Br(\mu \to 3e) \lesssim 10^{-12}$

$i = \mu \Rightarrow \quad \mu^+ + e^- \to \mu^- + e^+$

$G_{eff} \lesssim 10^{-3} G_F \Rightarrow \quad Br \lesssim 10^{-6}$

$i = \tau \Rightarrow \quad \tau^- \to \mu^+ + e^- + e^-$

$Br(\tau \to \mu ee) \lesssim 10^{-6}$

SU(2) VIOLATION NOT ENOUGH TO EXPLAIN

LSND: $\quad Br(\mu^+ \to e^+ + \bar{\nu}_e + \nu_i) \approx 0.2\,\%$

L-VIOLATING μ-DECAY

$$\boxed{\mu^+ \to e^+ + \bar{\nu}_e + \bar{\nu}_i} \qquad i = e, \mu, \tau$$

SU(2) ROTATIONS WILL GIVE NO UNWANTED DECAYS

EFFECTIVE OPERATORS

$$O_1 = \frac{1}{\Lambda^5}(\bar{\Psi}_\mu e_R \Phi)(\Psi_e^T C^{-1} \Psi_i \Phi \Phi)$$

$$O_2 = \frac{1}{\Lambda^5}(\bar{\mu}_R \Psi_e \Phi^\dagger)(\Psi_e^T C^{-1} \Psi_i \Phi \Phi)$$

Leung Babu (2000)

$$\Phi = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix} \qquad \Psi_e = \begin{pmatrix} \nu_e \\ e \end{pmatrix}_L$$

$$\langle \Phi \rangle = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ v \end{pmatrix} \Rightarrow$$

$$O_1 \sim \frac{v^3}{\Lambda^5}(\bar{\mu}_L e_R)(\nu_e^T C^{-1} \nu_i)$$

$$O_2 \sim \frac{v^3}{\Lambda^5}(\bar{\mu}_R e_L)(\nu_e^T C^{-1} \nu_i)$$

$$Br(\mu^+ \to e^+ \bar{\nu}_e \bar{\nu}_i) = \left[\frac{v^3}{4\sqrt{2} G_F \Lambda^5} \right]^2$$

$Br = (0.0015 - 0.0025) \Rightarrow$

$$\Lambda \approx (350 - 400)\ \text{GeV}$$

O_1 AND O_2 GIVE RISE TO $\mu^+ \to e^+ \bar{\nu}_e \bar{\nu}_i$ DECAY AND NO OTHER PROCESS

KARMEN LIMIT :-

$$\mathcal{L}_{eff}^{\Delta L=2} = \frac{v^3}{\Lambda^5} (\bar{\mu}_L e_R)(\nu_e^T C^{-1} \nu_i)$$

$\Rightarrow$

MICHEL PARAMETERS :

$\boxed{\rho = 0}$ $\quad \eta = 0 \quad \xi = -\frac{3}{4} \quad \delta = 0$

$$Br(\mu^+ \to e^+ \bar{\nu}_e \bar{\nu}_i)\Big|_{KARMEN} \lesssim (0.0015 - 0.002)$$

(Eitel)

NOT INCONSISTENT WITH LSND

PREDICTIONS

① NO (L/E) DEPENDENCE AT LSND OR SIMILAR EXPERIMENTS

② Mini-BOONE WILL SEE NO OSCILLATION SIGNAL, SINCE NEUTRINOS FROM $\overline{\mu}$ DECAY ARE USED

③ MICHEL PARAMETER $\rho \neq 3/4$

$$\rho = 0.7485$$

CURRENT UNCERTAINTY = ± 0.0026

TWIST EXPERIMENT AT TRIUMF: $\pm 10^{-4}$

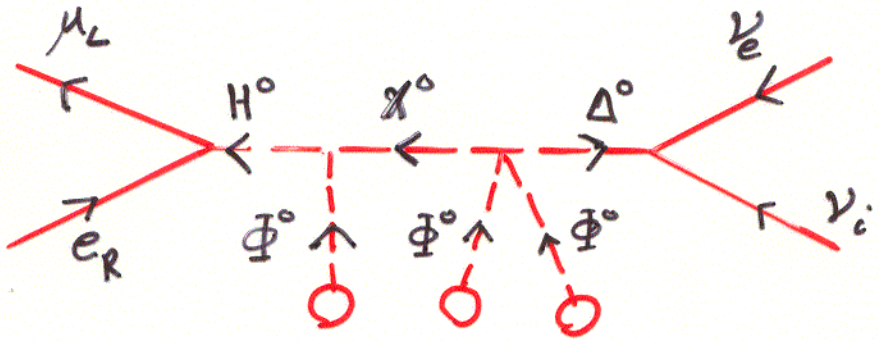
④ NEW SCALAR PARTICLES WITH MASS BELOW $\Lambda \sim 400$ GeV

GAUGE MODELS

$$O_1 = \frac{1}{\Lambda^5}\left(\bar{\psi}_\mu e_R \Phi\right)\left(\psi_e^T C^{-1} \psi_i \Phi \Phi\right)$$

$$\mathcal{L} = h_{\mu e}\,\bar{\psi}_\mu e_R H + f_{ei}\,\psi_e^T C^{-1}\psi_i \Delta + M_0 H^\dagger \chi \Phi + \lambda' \Delta \chi \Phi^\dagger \Phi^\dagger + \text{h.c.}$$

$\Delta(3,1)$, $\chi(3,0)$, $H(2,1/2)$



$$G_{eff} = \frac{h_{\mu e} f_{ei} \lambda' M_0 v^3}{(m^2_{\chi^\circ} m^2_{H^\circ} m^2_{\Delta^\circ})}$$

$$Br(\mu^+ \to e^+ \bar{\nu}_e \bar{\nu}_i) = \frac{|h_{\mu e} f_{ei}|^2 |K_{12} K_{32}^*|^2}{32\, M_1^4 G_F^2}$$

$$M_1 \lesssim 442\ \text{GeV}$$

OTHER LEPTON NUMBER VIOLATIND DECAYS

$$\mu^+ \to e^+ + \bar{\nu}_e + \bar{\nu}_i$$

$\boxed{i = e} \Rightarrow$ $(L_e + 3L_\mu)$ AND L_τ UNBROKEN

(EXCEPT BY SMALL ν- MASSES)

Z_3 SUBGROUP OF L_e ALSO UNBROKEN

THESE SYMMETRIES PREVENT RARE DECAYS SUCH AS $\mu \to 3e$, $\tau \to \mu ee$

$\boxed{i = \mu} \Rightarrow$ L_μ, L_τ AND Z_2 SUBGROUP OF L_e UNBROKEN

$\boxed{i = \tau} \Rightarrow$ $(L_e + 2L_\mu)$, $(L_\mu + L_\tau)$ AND Z_2 OF L_e UNBROKEN

$\Rightarrow$ MECHANISM SAFE FROM RARE PROCESSES

NO LARGE ν- MASS INDUCED SINCE SCALARS CARRY UNBROKEN LEPTON NUMBERS

OTHER PREDICTIONS

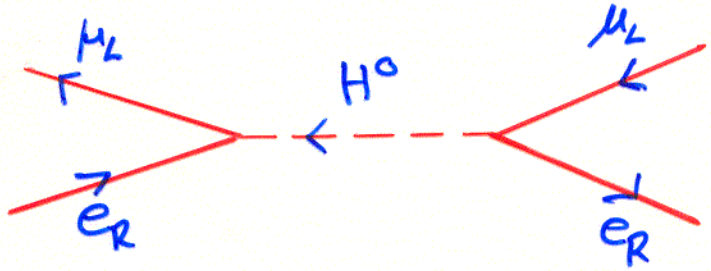
① RADIATIVE CORRECTION TO μ DECAY:

$$G_\mu = \frac{\pi\alpha}{\sqrt{2}\, M_W^2 \left(1 - \frac{M_W^2}{M_Z^2}\right)(1-\Delta r)}$$

$$\Delta r = \Delta r_{SM} + 0.001$$

CURRENT UNCERTAINTY IN $\Delta r \approx \pm 0.002$

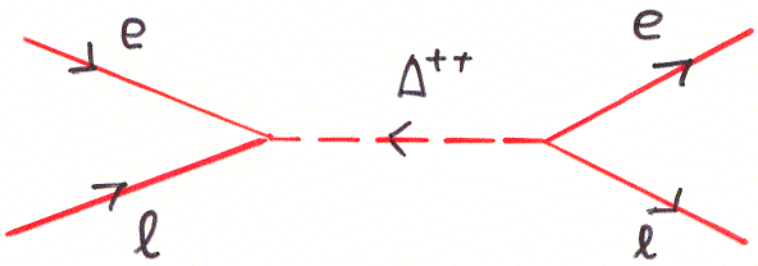
② $e^+ e^- \to \mu^+ \mu^-$



$$\mathcal{L}_{eff} = -\frac{|h_{\mu e}|^2}{2 m_{H^0}^2} (\bar{\mu}_L \gamma_\mu \mu_L)(\bar{e}_R \gamma^\mu e_R)$$

$$\frac{m_{H^0}}{|h_{\mu e}|} \geq 379 \text{ GeV} \qquad (L3)$$

③ $e^+e^- \to \ell^+\ell^-$

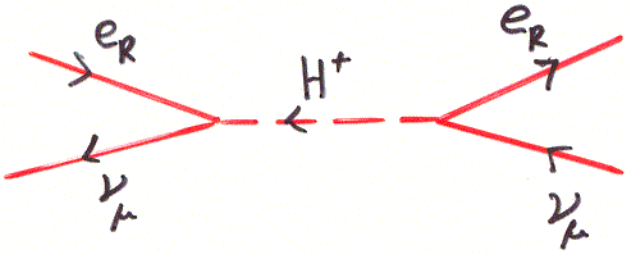


$$\mathcal{L}_{eff} = \frac{|f_{ei}|^2}{2 m^2_{\Delta^{++}}} (\bar{e}_L \gamma_\mu e_L)(\bar{\ell}_{iL} \gamma^\mu \ell_{iL})$$

$$\frac{m_{\Delta^{++}}}{|f_{ee}|} \gtrsim 758 \text{ GeV} \; ; \quad \frac{m_{\Delta^{++}}}{|f_{e\mu}|} \gtrsim 1456 \text{ GeV}$$

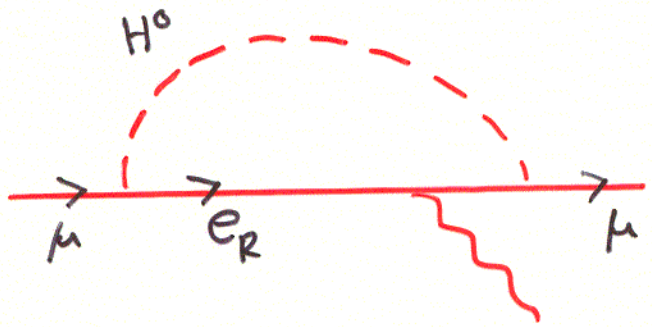
$$\frac{m_{\Delta^{++}}}{|f_{e\tau}|} \gtrsim 778 \text{ GeV} \qquad \text{(L3)}$$

④ $e^+e^- \to \nu\nu\gamma$



$$\frac{m_{H^+}}{|h_{\mu e}|} \gtrsim 375 \text{ GeV}$$

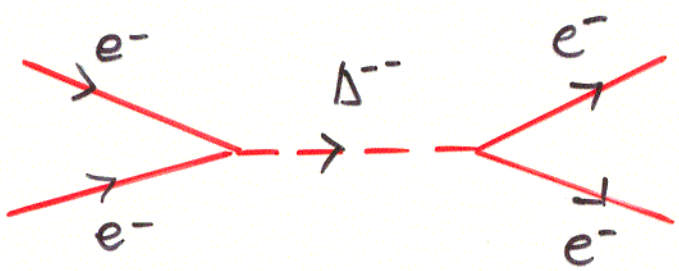
(5) g-2 OF MUON



$$\delta a_\mu \simeq \frac{|h_{\mu e}|^2}{24\pi^2}\frac{m_\mu^2}{m_{H^0}^2} \simeq (47\times 10^{-10})|h_{\mu e}|^2\left(\frac{100\,GeV}{m_{H^0}}\right)^2$$

(6) $e^- + e^- \to e^- + e^-$

RESONANT PRODUCTION OF Δ^{--} AT A LINEAR COLLIDER



SUMMARY

- L-VIOLATING μ DECAY $\mu^+ \to e^+ + \bar{\nu}_e + \bar{\nu}_i$
  CAN CONSISTENTLY EXPLAIN LSND DATA
- SMOKING GUN SIGNALS:

  NO $\frac{L}{E}$ DEPENDENCE

  NULL RESULT AT Mini-BOONE

  NEW SCALAR WITH MASS $\lesssim 450$ GeV

  MICHEL PARAMETER $\rho = 0.7485$