Invited paper presented at 1983 Annual Meeting of
Division of Particles and Fields
Blacksburg, September 15-17

TRI-PP-83-94
Sep 1983

RECENT RESULTS ON μ, π AND K DECAYS

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INTRODUCTION

I shall review recent results obtained in the study of rare decay modes of muons, pions and kaons. I will have, of course, to limit myself and to establish the logic for doing it. I shall consider only K decays which are giving the same kind of information as the muon or pion decays which I shall review. This, for example, will eliminate the very rich and important field of CP violation which so far has been observed only in the kaon system.

The list of all possible decay modes for the μ and the π is quite extensive but manageable. Going to the K system, the list quadruples and arbitrary selection has to be made.

I will regroup the various decay modes under specific topics:

a) Tests of the electroweak gauge theory. This will include lepton number violating processes, lepton universality and neutrino mixing.

b) Structure of mesons including weak and electromagnetic form factors.

c) Other symmetries.

TESTS OF THE ELECTROWEAK THEORY

Leptons (and quarks) as we know them today come in families of which we have identified 3; the lepton families exhibit striking common properties:

- identical electromagnetic properties
- identical weak interaction
- no strong interaction.

Some features remain mysterious:

- number of families
- absence of family (flavour) changing interactions
- masses of family members.

The Weinberg-Glashow-Salam model (WGS)[1] has incorporated most of these features in "one family" model based on the gauge group $SU(2)_L \times U(1)$. Underlying the model are some fundamental assumptions which eventually will require explanation.

- each family is treated identically (lepton universality)
- the number of families is irrelevant
- the massless neutrino case accounts for the non existence of flavour changing processes
- nothing is said about the masses of family members.

It is important to test these fundamental assumptions and show if they are indeed absolutly satisfied (implying additional symmetries) or only partially true.

FLAVOUR CHANGING INTERACTIONS*

In the standard WGS model with one single Higgs doublet, leptons are identified with a doublet representation for the left handed particles, whereas the right handed particles are put into singlet (the neutrinos are assumed to be purely left handed). The model contains no flavour changing coupling of fermions to neutral gauge bosons nor to the Higgs bosons. Even so, muon-number conservation would not be expected to hold unless the neutrinos are mass-degenerate (or massless). But the present upper limit on the masses of known three generations of neutrinos would imply undetectable rates as shown in Table I.[3] This is due to the fact that the rate is proportional to the square of mass differences square of the neutrino on a scale of the vector boson mass square.

Table I Estimates on flavour violating processes in the standard WGS model with neutrinos at their upper limits

$\Gamma(\mu\to e\gamma)/\Gamma(\mu\to e\nu\bar{\nu}) < 4 \times 10^{-17}$	$\Gamma_{exp} < 1.9 \times 10^{-10}$
$\Gamma(\mu^-+{}^{32}S\to e^-+{}^{32}S)/\Gamma(\mu^-+{}^{32}S\to \text{capture}) < 6 \times 10^{-14}$	$\Gamma_{exp} < 7.9 \times 10^{-11}$
$\Gamma(\mu\to 3e)/\Gamma(\mu\to e\nu\bar{\nu}) \to 3 \times 10^{-17}$	$\Gamma_{exp} < 1.9 \times 10^{-9}$
$\Gamma(K_L\to\mu e)/\Gamma(K_L\to \text{all}) < 5 \times 10^{-16}$	$\Gamma_{exp} < 2 \times 10^{-9}$
$\Gamma(K^+\to\pi^-\mu e)/\Gamma(K^+\to \text{all}) < 6 \times 10^{-18}$	$\Gamma_{exp} < 7 \times 10^{-9}$

For example the rate for the $\mu\to e\gamma$ decay is given in a 2 generation model by

$$B_L(\mu\to e\gamma) = \frac{3\alpha}{32\pi} \sin\theta \cos\theta \frac{m_{\nu_2}^2 - m_{\nu_1}^2}{m_{W_L}^2}$$

where θ is the mixing angle and m_{W_L} the mass of the left-handed W boson. Even assuming maximal mixing the rate would be inaccessible to the experiment.

The search for flavour violating processes probes the existence of new interactions and of new particles beyond the standard WGS model.

There are several classes of models in which flavour changing neutral gauge interaction might be considered:

- Horizontal symmetries relating the different generations
- Higgs exchanges with more complex Higgs structure (more than one doublet)
- Extended electroweak theories (technicolour)
- Leptoquark exchange
- Standard model with more generations.

These models have been considered to solve some of the problems of the standard models like

- Calculate the quark mixing angles from their masses;

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*I borrowed liberally from comprehensive reviews by O. Shanker[2].

additional symmetries are then introduced which involve transformation between the fermion families.

- Generate CP violation spontaneously: in these models, either flavour conservation is imposed and CP violation is generated by Higgs exchange with the consequence that the electric dipole moment of the neutron and CP violation parameter are too large, or flavour conservation is violated in which case CP is spontaneously broken in 2 Higgs doublets, with Higgs masses of order TeV.

Left-right symmetric models have been developed to generate CP violation and they have flavour violating interactions as a general feature. Also in the model attempting to generate spontaneously broken symmetries dynamically, the Higgs are replaced by bound states of fermion-antifermion composites and these theories predict rates for flavour violating processes not far from present experimental limits. Horizontal gauge model introduce "horizontal" neutral gauge bosons mediating flavour transitions, leptoquark theories assume that quark and lepton are composite objects and that the generations represent various excitation of the fundamental composites.

Flavour violating interactions appear also in grand unified theories if intermediate mass scales are present between our energies and the grand unification mass. Flavour violation can then be caused by:

a) lepton mixing
b) exotic gauge bosons
c) scalar Higgs coupling.

The present experimental situation is compiled in Table II.

Table II Present experimental status of flavour violation experiments

$\mu \rightarrow e\gamma$		<1.7	10^{-10}	LAMPF(SIN,TRIUMF)[a]
$\mu \rightarrow eee$		<1.9	10^{-9}	Dubna[b]
$\mu \rightarrow e\gamma\gamma$		<8.4	10^{-9}	TRIUMF[c]
$\mu^- Z \rightarrow e^- Z$	S	<7.0	10^{-11}	SIN[d]
	Cu	<1.6	10^{-8}	SREL[e]
	Ti	<2	10^{-11}	TRIUMF[f]
$K_L \rightarrow \mu e$		<2	10^{-9}	P.D. Group[g]
$K^{\mp} \rightarrow \pi^{+} \mu e$		<5	10^{-9}	(note h)
$\pi^{\circ} \rightarrow \mu^{\pm} e^{\mp}$		<7	10^{-8}	(note i)

[a] J.D. Bowman et al., Phys. Rev. D25, 2846 (1982)

[b] S.M. Korenchenko et al., JETP 43, 1 (1976).

[c] G. Azuelos et al., to be published in Phys. Rev. Lett.

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[e] D.A. Bryman et al., Phys. Rev. Lett. 28, 1469 (1972).

[f] M. Blecher et al., paper submitted at this conference.

[g] A.R. Clark et al., Phys. Rev. Lett. 26 1667 (1971), possible error see Particle Data Group (1982).

[h] A.-M. Diamant Berger et al., Phys. Lett. 62B, 485 (1976).

[i] D. Bryman, Phys. Rev. D26, 2538 (1982).

Phenomenologically the interaction violating flavour can be described by a current whose properties can be determined by studying the μ^-e^- conversion on different nuclei.[2] The rate for $\mu\to e$ conversion can be written as

$$\frac{R(\mu^-\to e^-)}{R(\mu^-\to\nu)} = w_G(Z)\left[g_V^{(0)} + g_V^{(1)}\,\frac{Z-N}{3A}\right]^2$$

where $w_G(Z)$ is a nuclear physics factor related to proton, neutron densities and $g^{(0)}$, $g^{(1)}$ are phenomenological coupling constants for the isoscalar and isovector part. Table III presents the limits on the coupling constants obtained from the three most recent experiments.

Table III Limits on coupling constants from μe conversion experiment

Target material	$\mu^-\to e^-$ experimental limit	$g_V^{(0)}$	$g_V^{(1)}$
S	$<7\times10^{-11}$	$<7\times10^{-7}$	-
Cu	$1.6\ 10^{-8}$		$<26\ 10^{-5}$
Mn	$1.8\ 10^{-9}$		$<6\ 10^{-5}$
Ti	$5\ 10^{-11}$		$<1\ 10^{-5}$

What do we learn from the existing limits?:

In horizontal gauge models - one needs to suppress the contribution to K_L-K_S mass difference which is sensitive to the matrix element of F.V. current whereas the rates are proportional to (matrix element)^2. In some models K_L-K_S is suppressed if H gauge bosons are nearly degenerate. Table IV (from Shanker)[2] gives limits on M_H, or δ the mass degeneracy assuming maximum mixing angles. In general the mechanism that suppresses K_L-K_S also suppresses muon number violating processes with 2 flavours ($\mu\to e\gamma$ or $\mu\to eee$) but not always (depending on mixing angle matrix). $\mu^-Z\to e^-Z$ gives the best constraint because of coherent quark effect.

In hypercolour models a suppression mechanism is needed for light scalar particles. Ellis has a separate scalar to give mass to each generation but coloured leptoquark scalars would mediate $K_L\to\mu e$ (presumably also $\mu\to e$). Here the F.V. current has both scalar and vector components which could be tested with μ^-e^- on different elements.

In models where horizontal discrete symmetries have been introduced, flavour violating processes can occur at measurable rates if the Higgs bosons have masses low enough (Pati-Salam models leptoquarks 10^4-10^6 GeV). In general GUTs predict non zero neutrino masses.

Neutrino Mass: Non degenerate neutrino mass implies flavour violation in lepton sectors but for theories which reduce to standard WGS the predicted rates are far from being measurable. See Table I. In theories where more generation would be present with massive ν or new mass scales for the ν (left-right symmetric model) F.V. current could be generated.

Table IV Mass bounds (in TeV) from different processes

Process	Higgs scalars	Pseudoscalar leptoquarks[a] (A)	Pseudoscalar leptoquarks[b] (B)	Vector leptoquarks	Experimental limit
$\frac{\Gamma(\mu \to e\gamma)}{\Gamma(\mu \to all)}$	0.2	–	–	–	1.9×10^{-10}
$\frac{\Gamma(\mu \to ee\bar{e})}{\Gamma(\mu \to all)}$	0.4	–	–	–	1.9×10^{-9}
$\frac{\Gamma(\mu A \to eA)}{\Gamma(\mu A \to \nu A')}$	11	1.5	11	60	7×10^{-11}(for S)
$\frac{\Gamma(K_L \to \mu\bar{e})}{\Gamma(K_L \to all)}$	7	1.8	5	93	2×10^{-9}
$\frac{\Gamma(K_L \to \mu\bar{\mu})}{\Gamma(K_L \to all)}$	4.7	1.2	3.6	62	9×10^{-9}
$\frac{\Gamma(K_L \to e\bar{e})}{\Gamma(K_L \to all)}$	7	1.8	5	95	2×10^{-9}
$\frac{\Gamma(K^+ \to \pi^+\mu\bar{e})}{\Gamma(K^+ \to all)}$	0.7	0.1	0.3	3.5	7×10^{-9}
$\Delta m(K_L-K_S)$	150	–	–	–	3.5×10^{-15} GeV

[a] The average fermion mass was taken to be 1 GeV.

[b] The average fermion mass was taken to be of order $\sqrt{m_\tau m_c} = 7.8$ GeV for uμ couplings and $\sqrt{m_\tau m_b} = 3.1$ GeV for dμ couplings.

Higgs Models: Additional scalar Higgs particles are sometimes introduced to generate CP violation spontaneously or because they appear in GUTs theories when reduced to low energy. In general even if natural flavour conservation is not imposed a priori K_L-K_S mass difference imposes strict limitations on the Higgs masses and μe violation is small. Again if a suppression mechanism affects the K_L-K_S mass difference, then $\mu \to e$ could reach experimental limits. This happens in models where the Higgs masses are almost degenerate. Although this also affects $\mu \to e\gamma$, processes like $\mu \to e$ may have detectable rates.

(General conclusion) Flavour violating processes occur naturally in many extensions of WGS and ν oscillations and $\mu \to e$ conversion seem to be the most likely place to look for evidence:

- for ν oscillations one measures the violating amplitude directly,
- for $\mu \to e$ processes the enhancement due to quark coherence effect favour this rate over the others.

For models where both lepton and muon numbers are violated (Majorana neutrino models) $\nu\bar{\nu}$ oscillations are very sensitive, $\mu^- e^+$ and no ν double-beta decay should also have something to say.

A new generation of experiments in the μ system is currently underway. At TRIUMF, we have built a detector system centered around a Time Projection Chamber[4] which has been operating since 1980 and is shown in Fig. 1. Final data taking is in progress. So far we are able to accept 0.5 10^6 stopped μ^- into our target

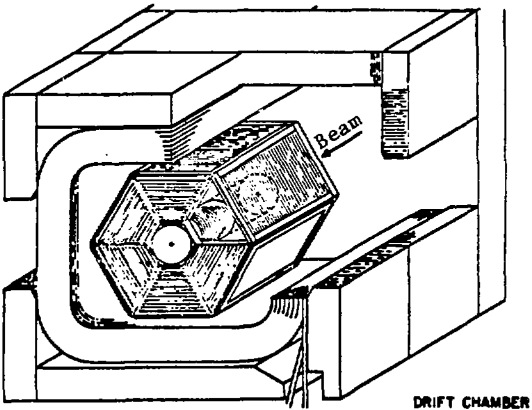

Fig. 1. The TRIUMF TPC detector.

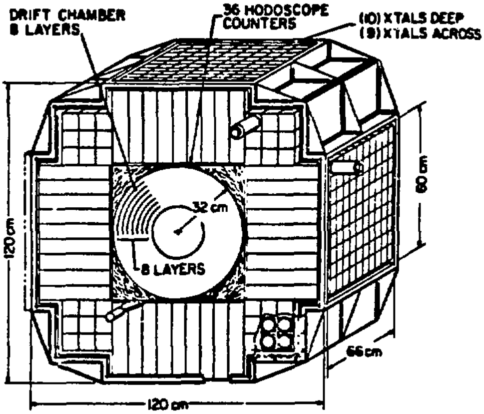

Fig. 2. The LAMPF crystal box detector.

(isotopic titanium) and our overall efficiency is close to 20%. We are expecting to increase the stopping rate by at least a factor of 2 and are confident to reach the predicted limit of 5×10^{-12} within a year of data collection. At LAMPF, a beautiful device called the crystal box[5] is ready to collect data on $\mu^+ \to e^+e^-e^+$, $\mu \to e\gamma\gamma$ and $\mu \to e\gamma$ with a goal of $\sim 10^{-12}$. Figure 2 shows the sodium iodide array in the present configuration. At SIN a spectrometer based on thin wire chambers is being developed to study $\mu^+ \to e^+e^-e^+$.[6]

LEPTON UNIVERSALITY

The V-A structure of the charged weak current and the identity of weak interaction for the different lepton generations has been a cornerstone of the old weak interaction theories and these aspects were incorporated into the Weinberg-Salam model.

In the current × current description of the weak interaction, the matrix element M for the two-body π and K decay is given by

$$M = \frac{iG}{\sqrt{2}} \langle 0 | \{V_\lambda(0) - A_\lambda(0)\} | {}^{\pi}_{K} \rangle \, \bar{u}_{\ell} \gamma_\lambda (1-\gamma_5) v_\nu \ ,$$

the V-A form of the interaction forces the leptons to be emitted in the same state of helicities (due to the pseudoscalar nature of the mesons considered here). Assuming $m_\nu=0$ (left-handed neutrino states only) this forces the charged leptons into the wrong helicity state in the limit $v/c \rightarrow 1$. Therefore the electronic decay is strongly inhibited compared to the muonic mode.

On the other hand if the weak current contains a V+A term, then the leptons could be emitted in the same helicity state and the rate of the electronic mode would be comparable to the muonic mode. The ratio of the electronic to muonic decay rate is then given by

$$R = \frac{Me\nu}{M\mu\nu} = \left(\frac{m_e}{m_\mu}\right)^2 \left(\frac{m_M^2-m_e^2}{m_M^2-m_\mu^2}\right)^2 \left(\frac{f_M^e}{f_M^\mu}\right)^2 \delta \qquad \text{in V-A}$$

$$R = \left(\frac{m_M^2-m_e^2}{m_M^2-m_\mu^2}\right)^2 \left(\frac{f_M^e}{f_M^\mu}\right)^2 \delta \qquad \text{in V+A}$$

The experimental values obtained in the early '60s showing a very small branching ratio were the best support for the V-A hypothesis. the term δ refers to radiative corrections contributions. These terms calculated in 1958 by Berman and Kinoshita,[7] depend on m_ℓ and were recently recalculated within the framework of the gauge theories by Goldman and Wilson[8] with the remarkable result that the pre-gauge theory estimates were correct to order $(G\, m^2{}_\ell)$.

Strong interaction effects were also investigated by Goldman and Wilson[8] using a modified static quark model for the pion and for the π decay were shown to be at the level of 0.3%.

$$R = 1.239 \pm 0.001\ 10^{-4} \qquad (1)$$

is the predicted value of the branching ratio where the error is mainly a reflection of the uncertainties in the strong interaction effects. For the K$e\nu$ decay the structure dependent effects are much larger and consequently the $\pi e\nu$ branching ratio offers the best test of lepton universality.

A recent experiment was carried out at TRIUMF[9] using a large NaI spectrometer to detect the positron from $\pi e\nu$ and from the decaying μ from $\pi\mu\nu$ (the set-up is shown in Fig. 3 - it is based on the technique developed by Di Capua[10]). In this experiment 50,000 $\pi e\nu$ events were recorded (see Fig. 4) and the quoted errors are essentially dominated by the systematic effects, a list of which is presented in Table V. The branching ratio R was found to be

$$R = 1.218 \pm 0.014\ 10^{-4}\ .$$

Comparing with Eq. (1) we concluded that

$$\frac{f_\pi^e}{f_\pi^\mu} = 0.9939 \pm 0.0057$$

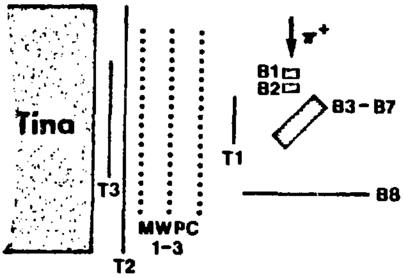

Fig. 3. πeν experimental set-up for the TRIUMF experiment.

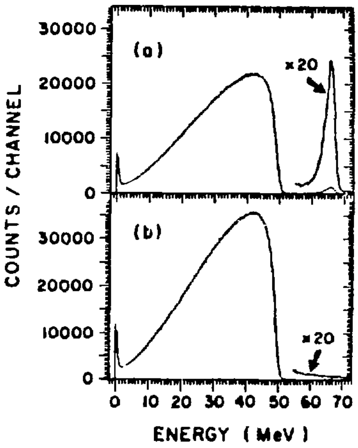

Fig. 4. Positron energy spectrum from the TRIUMF experiment on πeν.

Table V Multiplicative corrections to π→eν branching ratio

π→eν tail	1.0147 ± 0.0075
Low-energy μ→eνν	0.9982 ± 0.0005
Multiple Coulomb scattering	0.9988 ± 0.0040
Positron annihilation	0.9959 ± 0.0010
μ^+ losses from target	1.0002 ± 0.0010
Bin 1 and Bin 2 equality	0.9989 ± 0.0004
Pulse pile-up efficiency	0.9931 ± 0.0029
Bin separation t_s	1.0000 ± 0.0000
Pion lifetime	1.0000 ± 0.0009
Other	1.0004 ± 0.0020

confirming that e-μ universality within the context of the WSG model holds to 0.6%.

In the K system the best results are given by the Heidelberg-CERN collaboration[11] in a stopped K^+ experiment carried on at the CERN PS. Part of the CERN set-up is shown in Fig. 5. 404 events from Keν were observed (Fig. 6); above 240 MeV/c the branching ratio R_K was found to be

$$R_K = 2.51 \pm 0.15\ 10^{-5}$$

whereas the theoretical value predicted for pure axial vector interaction and μ-e universality $R_{theo} = 2.57 \times 10^{-5}$.

$$\left(\frac{f_K^e}{f_K^\mu}\right)^2 = \frac{R_K}{R_{theo}} = 0.977 \pm 0.06\ .$$

The error in this case is dominated by the statistical uncertainties.

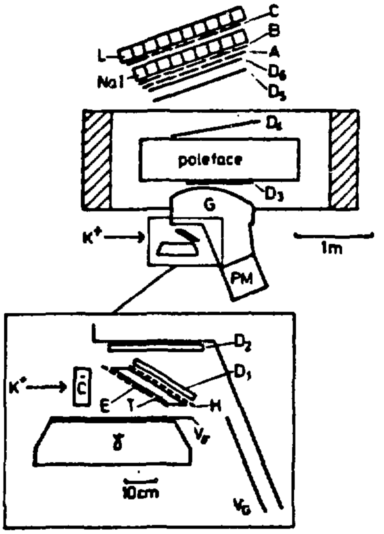

Fig. 5. K→eν experimental set-up from the CERN-Heidelberg collaboration.[8]

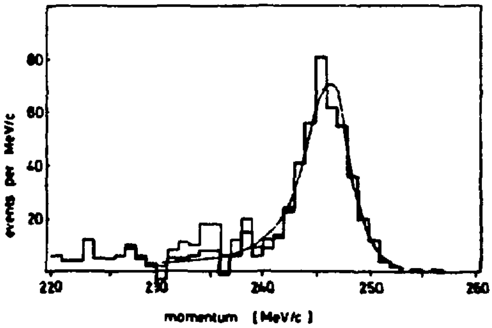

Fig. 6. Positron energy spectrum recorded in the CERN-Heidelberg Keν experiment.

A new π→eν proposal at TRIUMF[12] has been accepted, which will try to reduce the error from the tail of the line shape distribution to the level of 0.1% using a tagging technique for the πeν events.

Alternatively these results can place stringent limitations on models which incorporate violation of lepton universality. The branching ratio obtained severely restricts the amount of pseudoscalar coupling that can be tolerated

$$f_P < (0.0061 \pm 0.0057)\ f_\pi m_e$$

(f_P is the pseudoscalar coupling constant).

As discussed by Shanker[13] this severely restricted several models which lead to pseudoscalar currents:

- charged Higgs bosons	>0.4 TeV
- pseudoscalar leptoquarks	>0.5 TeV
- vector leptoquarks (Pati-Salam)	>85 TeV
- exotic particles in supersymmetric theories	

The branching ratio M→eν/M→μν can also be modified by non-zero neutrino masses. This has been extensively discussed by Shrock.[14]

LIMITS ON NEUTRINO MIXING

The two-body decays of pseudoscalar mesons offer a unique tool to search for evidence of massive neutrino and to set limits on possible mixing parameters.

The argument is based on the fact that the rate for $M \to \ell_\alpha \nu_\alpha$ is proportional to a kinematical factor ρ which is the product of a phase space factor $v^{1/2}$ (monotonically decreasing when m_{ν_α} increases) and an helicity factor f_m (increasing when m_{ν_α} increases).

The effect is most dramatic for the electronic decays because the helicity factor is of order 10^{-4}–10^{-5} for massless (left handed) neutrinos rising to ~1 for massive neutrinos. Figures 7 and 8 show the variation of the kinematical factor for the π and K decays.

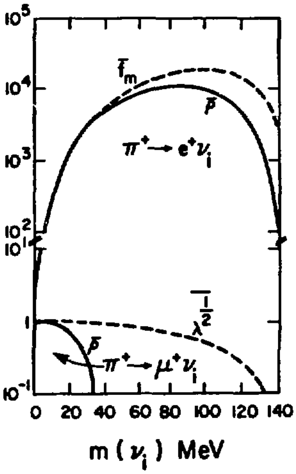

Fig. 7. Kinematical factor for pion two-body decays.

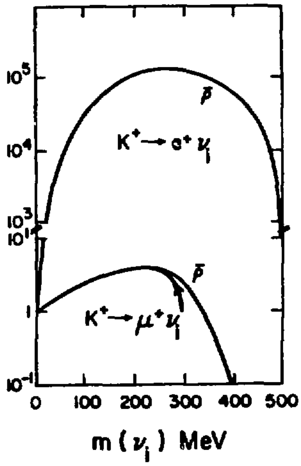

Fig. 8. Kinematical factor for positive kaon two-body decays.

Since in general the neutrino mass eigenstates ν_i would be distinct from the weak eigenstate ν_a ($a=e,\mu,\tau$ ...), these states are related through a unitary transformation

$$\nu_a = U_{ai} \nu_i$$

where U_{ai} is nearly diagonal.

Taking $\pi e \nu$ as an example, the decay must be considered as an incoherent sum of decay modes

$$\pi^+ \rightarrow e^+ \nu_i \ .$$

This leads to peaks in the π decay spectrum whose energy is related to m_{ν_i}.

We have searched for extra peaks in our 30 K data sample of $\pi e \nu$ events.[15] No peaks of statistical significance were found outside the main πe peak. Figure 9 shows the corresponding limits set on the mixing matrix elements $|U_{ei}|^2$.

A similar analysis can be performed on existing $K e \nu$ data. The helicity suppression factor is even larger for this case and although the data is statistically very limited one can extract a bound of $\sim 10^{-5}$ for $|U_{ei}|^2$ in a different ν mass region.

The same study can be performed on the muonic decay mode and recent results have been obtained on $\pi \rightarrow \mu \nu$ and $K \rightarrow \mu \nu$ shown in Fig. 10 extracted from Ref. 16. Constraints on mixing angles for the

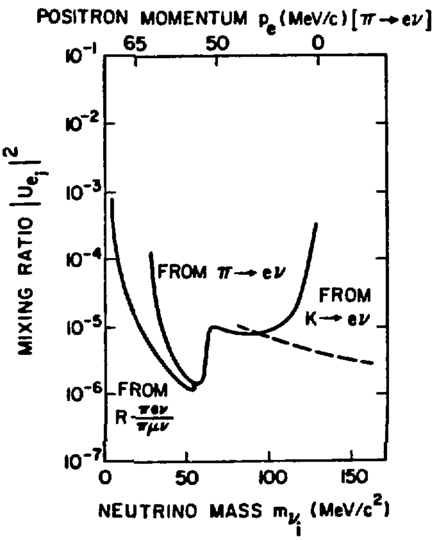

Fig. 9. Limits on $|U_{ei}|^2$ mixing matrix element.

neutrinos can also be derived from the branching ratio measurement $M\rightarrow e\nu_i/M\rightarrow\mu\nu_i$ although the interpretation is subject to uncertainties because the deviation observed could be due to other effects as discussed previously. Here we note the complementarity of the information obtained from π and K decays:

- for $|U_{ei}|^2$, π decay covers the mass range 0 to 130 MeV while K decay covers 130-180 MeV
- for $|U_{\mu i}|^2$ π decay covers 5-30 MeV while K decay gives information in the range 70-310 MeV.

The branching ratio $\pi e\nu/\pi\mu\nu$ gives a limit for $|U_{\mu i}|^2$ in the region 30-70 MeV.

NUMBER OF GENERATION

A very interesting possibility is offered by the decay mode $K\rightarrow\pi^+\nu\nu$. In a free quark model calculation by Inami and Lim,[17] the rate is calculated to be suppressed by the GIM mechanism nearly completely. QCD corrections are very small. The branching ratio is proportional to the number of generations and depends also on the mixing angles and t-quark mass. A value $>10^{-9}$ would imply more generations than we presently know.

The best experiment so far was performed at KEK[18] and set an upper limit for the branching ratio of 1.7×10^{-7}, still 2 orders of magnitude off the theoretical predictions. New proposals[19] based on 4π solid angle detectors are proposing to reach the 10^{-10} region.

Similarly the decay $\pi^\circ\rightarrow\nu\nu$ would help in determining the nature of the neutrino as it cannot proceed via massless Weyl neutrinos. Observation of the decay $\pi^\circ\rightarrow\nu\nu$ would imply Majorana neutrino or massive neutrino.[20] The decay is also allowed in various extensions of the WSG model (multiple Higgs doublets, anomalous couplings, massive neutrinos). A tagged π° beam can be produced via the $K^+\rightarrow\pi^+\pi^\circ$ decay and it might be feasible to search for branching ratios in the 10^{-9} range where Z exchange mechanisms are expected to contribute for given ν masses.[21]

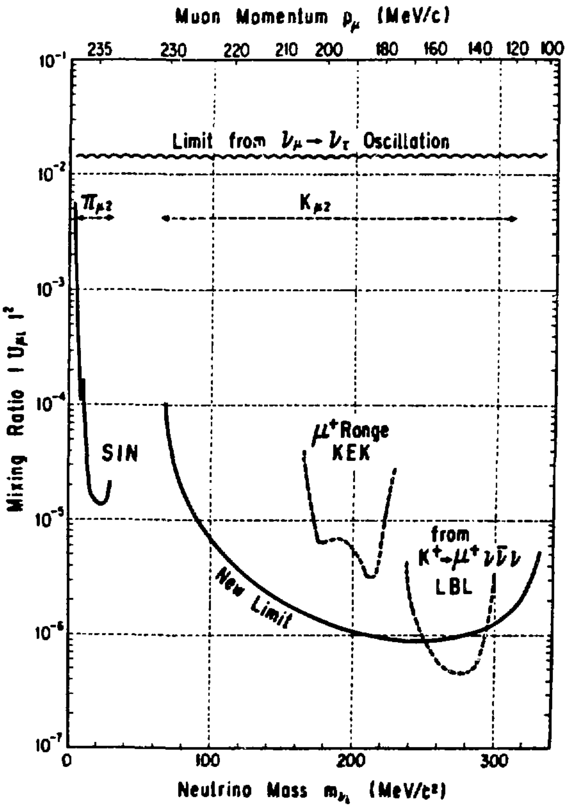

Fig. 10. Limits on $|U_{\mu i}|^2$ mixing matrix element.

WEAK FORM FACTORS OF CHARGED MESONS

We mentioned already that structure dependent effects were more important in the K system than in the π system allowing a better test of μ-e universality in the $M \rightarrow e\nu / M \rightarrow \mu\nu$ branching ratio measurement. The corresponding K decays have large contributions from strong interaction effects.

A by-product of these experiments is the detection of the radiative partner to these decays, $K \rightarrow e\nu_e\gamma$, $\pi \rightarrow e\nu_e\gamma$. The rate for these branches are generally calculated by treating the weak and electromagnetic coupling in first order while the effects of strong interaction are absorbed in 2 form factors (within the context of the V-A theory).

The amplitude for the decay is the sum of two terms M_B and M_S, where M_B is referring to the bremsstrahlung processes while M_S is the structure dependent amplitude. The interference term between these two processes is negligible in both cases. The structure dependent contribution can be further decomposed within the framework of the V-A theory into a vector and axial vector component.

In the π radiative decay the vector form factor can be obtained via CVC from the π° lifetime and the experiment is aimed at measuring γ_π the ratio of the axial to vector form factor. A recent experiment[22] collected 211 events and established the possible value for $|\gamma|$. $|\gamma| = 0.15$ and -2. Although more sensitive to the strong interaction effects, the corresponding measurement in the K system[23] does not provide better information because of the scarcity of events (51 ± 3) and the corresponding limits on γ_k are $-1.8 < \gamma_k < -0.54$. New experiments in progress at the meson facilities are hoping to collect one order of magnitude or so more events.

CONCLUSIONS

Rare decays of μ, π, k provide complimentary information on several aspects of weak interaction models and it is remarkable that present k experiments are competing at the same level as high flux meson experiments done at all three meson facilities. We should hope that the venue of future k factories will prove to be fruitful in pushing further our scrutiny of accepted dogma.

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