KEK-TH-564
March 1998

Kaon and Muon Decay Phenomenology *

YASUHIRO OKADA
KEK
Oho 1-1, Tsukuba 305, Japan

ABSTRACT

Theoretical aspects of kaon and muon decays are reviewed. In particular, three topics on kaon and muon decays, namely $K \to \pi\nu\bar{\nu}$ processes, T violation in $K^+ \to \pi^0\mu^+\nu$ decay and lepton flavor violation in muon decay are considered. Theoretical backgrounds and possible significance on new physics searches by these processes are discussed.

1. Introduction

Current view of the elementary particle physics is based on SU(3) $\times$ SU(2) $\times$ U(1) gauge theory of quarks and leptons. This theory called the Standard Model (SM) has been intensively studied in various processes. In order to establish the SM and search for physics beyond the SM two directions are considered in experiments of high energy physics. One is to go to higher energy to search for new particles and new interactions and the other is to construct facilities with intense beams and search for rare processes or processes which are forbidden within the SM. Kaon and muon rare processes have been contributing in the latter way. This will continue to be true because there are many future plans including AGS 2000 at BNL, experiments at Fermilab Main Injector and Japan Hadron Facility (JHF). In this talk I would like to cover three topics on kaon and muon decays which are considered to be important in future experiments. Namely, (1)$K_L \to \pi^0\nu\bar{\nu}$ and $K^+ \to \pi^+\nu\bar{\nu}$, (2) T violation in $K^+ \to \pi^0\mu^+\nu$, (3) lepton flavor violation(LFV) in muon decays. I would like to clarify how these processes are important to explore physics beyond the SM.

2. $K \to \pi\nu\bar{\nu}$ and CKM Physics

In the SM various flavor changing neutral current (FCNC) and CP violation processes should be consistently explained by the quark flavor mixing matrix called the Cabibbo-Kobayashi-Maskawa (CKM) matrix. The CKM matrix is parametrized by

* Talk presented at International KEK Workshop on Kaon, Muon, Neutrino Physics and Future, October 31 - November 1, 1997, KEK, Tsukuba, Japan.

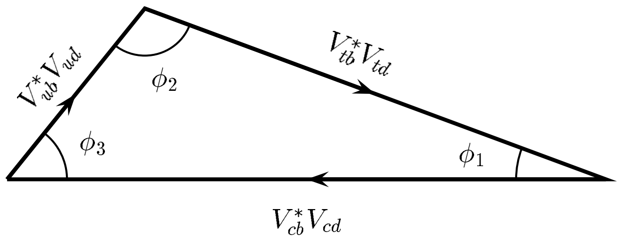

Figure 1: The unitarity triangle.

four independent parameters. In the Wolfenstein parametrization this matrix is given by

$$\left(\begin{array}{ccc} 1-\frac{1}{2}\lambda^2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{1}{2}\lambda^2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{array} \right). \tag{1}$$

The two of the four parameters, λ and A, are already known well. λ corresponds to the Cabibbo mixing and is given by $\lambda = 0.221 \pm 0.002$ and A is determined from the inclusive and exclusive decay of B meson and given by $A = 0.82 \pm 0.06$.[1] The remaining two parameters, ρ and η, have not been well constrained. The main purpose of flavor physics in B and K meson decays is to measure various quantities which depend on the ρ and η and put as many constraints as possible on the unitarity triangle defined in the figure 1. This can be a new window to physics beyond the SM.

Present constraints on the ρ and η parameters are given by three independent measurements, namely charmless b decay for the ratio of the CKM element $|V_{ub}/V_{cb}|$, CP violating mixing parameter in the $K^0 - \bar{K}^0$ system, ϵ_K, and $B_d^0 - \bar{B}^0{}_d$ mixing. Although each of three measurements still contains considerable theoretical ambiguities from hadron physics, it is remarkable that there is an overlapping region of the parameter space as shown in figure 2.

In near future, experiments at KEK and SLAC asymmetric B factories as well as HERA and TEVATRON will provide us one angle of the unitarity triangle $\sin 2\phi_1$, through the gold-plated mode $B \to J/\psi K_S$. The experimental uncertainty in each of these experiments are expected to be about 0.1 or smaller for the determination of $\sin 2\phi_1$, and eventually with the LHC-B experiment the precision for the $\sin 2\phi_1$ will be a few % level. There are many proposals to measure other angles of the unitarity triangle.[2] The angle ϕ_2 is determined by time dependent asymmetry of the $B \to \pi\pi, \pi\rho$ mode. The ϕ_3 measurement can be done through $B \to DK$ mode. Because of small branching ratios, the determination of these angles requires more luminosity in the B factory experiments. Another promising way to determine the ρ, η parameter is measurement of the $B_s - \bar{B}_s$ mixing. If we take the ratio of $B_s - \bar{B}_s$ and $B_d - \bar{B}_d$ mixing we get

$$\frac{\Delta M_{B_s}}{\Delta M_{B_d}} = \frac{M_{B_s} B_{B_s} f_{B_s}^2}{M_{B_d} B_{B_d} f_{B_d}^2} \left| \frac{V_{ts}}{V_{td}} \right|^2 \tag{2}$$

and the ratio of the CKM matrix element depends on the parameter $(1-\rho)^2 + \eta^2$. The

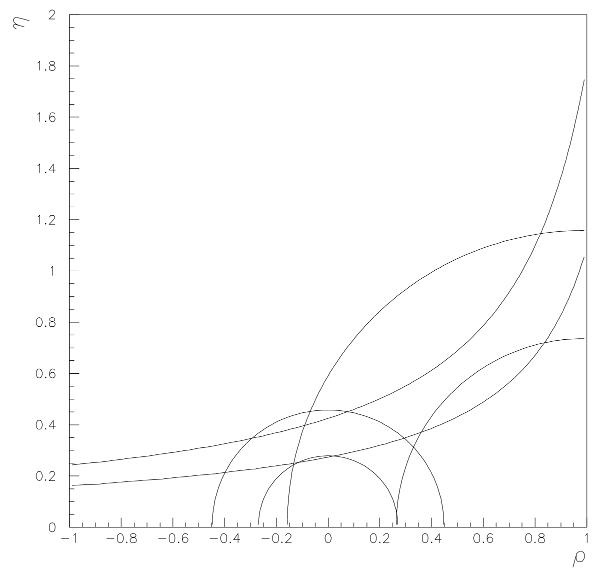

Figure 2: The constraint on ρ and η parameters from $|V_{ub}/V_{cb}|$, ϵ_K and $B_d^0 - \bar{B}^0{}_d$. We take $|V_{ub}/V_{cb}| = 0.08 \pm 0.02$, $B_K = 0.75 \pm 0.15$ and $f_B\sqrt{B_B} = 200 \pm 40$ MeV.

bag parameter B_B and the decay constant f_B should be determined from lattice gauge theory. The error of the lattice determination for $B_B f_B^2$ is supposed to be smaller if we take the ratio between these quantities for B_s^0 and B_d^0 instead of considering $B f_B^2$ itself. In the SM the present allowed region on (ρ, η)space predicts the B_s mixing parameter $x_s \equiv \frac{\Delta M_{B_s}}{\Gamma_{B_s}}$ in the range of $15 \lesssim x_s \lesssim 40$. The HERA-B experiment may be able to measure the B_s mixing in future and eventually the experiment at LHC will be able to cover whole parameter region of x_s.[3]

Branching ratios of $K^+ \to \pi^+\nu\bar{\nu}$ and $K_L \to \pi^0\nu\bar{\nu}$ are also important to determine the ρ and η parameters. Advantages of these processes are theoretical cleanness: The form factors are determined from the $K^+ \to \pi^0 e^+\nu$ decay. Also the perturbative QCD corrections are calculated up to the next-to-leading order and remaining theoretical ambiguities are estimated to be less than 10% for $K^+ \to \pi^+\nu\bar{\nu}$ and a few % for $K_L \to \pi^0\nu\bar{\nu}$.[4] The long distance contributions are considered to be small. In the SM these two processes are induced by Z-penguin and W-box diagrams. The branching ratio are given by $Br(K^+ \to \pi^+\nu\bar{\nu}) \simeq 4.2 \times 10^{-11}(\eta^2 + (1.4 - \rho)^2)$, $Br(K_L \to \pi^0\nu\bar{\nu}) \simeq 1.8 \times 10^{-10}\eta^2$. The experiment at BNL reported one candidate event for $K^+ \to \pi^+\nu\bar{\nu}$ and they obtain $Br(K^+ \to \pi^+\nu\bar{\nu}) = 4.2^{+9.7}_{-3.5} \times 10^{-10}$.[5] Although the central value is a few times higher this results are consistent with the SM prediction. The present upper bound for $Br(K_L \to \pi^0\nu\bar{\nu})$ is 1.8×10^{-6} from the KTeV experiment[6] which is still 5 orders of magnitudes above the expected region. Future plans for dedicated experiments are considered for this process.[7]

Let us discuss how new physics effects can be explored by above observables in B and K physics. In this respect it is important to improve various measurements in both B and K physics. One way to look for new physics effects is to try to determine the ρ and η parameters by each observable assuming the SM. New physics effects may appear as inconsistency of the parameter determinations. We may first observe the time-dependent asymmetry of the $B \to J/\Psi K_S$ mode and use it as an input parameter. Then we can determine ρ and η with one more input parameter which can be provided by CP asymmetry of B decay from other modes ($B \to \pi\pi, \pi\rho$, $B \to DK$), ΔM_{B_s} / ΔM_{B_d} and the branching ratios for $K \to \pi\nu\bar{\nu}$. If the ρ and η values determined by these observables do not coincide we can get an important clue to new physics from a pattern of the deviation from the SM among these observables.

One such example is given by the minimal supersymmetric (SUSY) standard model based on supergravity theory. In SUSY model flavor physics is affected by loop diagrams of SUSY particles as well as the charged Higgs boson and FCNC processes such as ϵ_K, ΔM_B, $Br(K \to \pi\nu\bar{\nu})$ receive new contributions. Also the CP asymmetry in B decay may be affected by a new phase of the $B_d^0 - \bar{B}_d^0$ mixing amplitude. In the context of the minimal supergravity model, however, we can show that loop contributions to various FCNC amplitudes associated with SUSY particles and the charged Higgs boson depend on essentially the same CKM parameters as the SM contribution. Thus SUSY contributions can change magnitudes of FCNC amplitudes, but do not introduce new phases in the $B_d^0 - \bar{B}_d^0$ mixing amplitude. We have calculated in details the ϵ_K and ΔM_B in the this model.[8] We can also deduce $K^+ \to \pi^+\nu\bar{\nu}$ or $K_L \to \pi^0\nu\bar{\nu}$ branching ratio for the SUSY model from the calculation of $Br(b \to s\nu\bar{\nu})$ [9] because these quantities are practically the same in the minimal supergravity model if normalized by the SM prediction. We see that the ϵ_K and ΔM_B are enhanced up to 20% in the minimal supergravity model compared to the SM values whereas the branching ratio for $K^+ \to \pi^+\nu\bar{\nu}$ are suppressed up to 5%. One the other hand the ρ and η values determined from the CP asymmetry in B decay and $\Delta M_{B_S}/\Delta M_{B_d}$ are not affected by the SUSY contributions. If we relax the strict universality condition for the SUSY breaking terms for Higgs fields and squark fields the deviations from the SM can be twice as large as above.[10] In this model, therefore, we may see difference of (ρ, η)values determined from (1) ϵ_K, ΔM_B, (2) $Br(K^+ \to \pi^+\nu\bar{\nu})$, $Br(K_L \to \pi^+\nu\bar{\nu})$ and (3) CP asymmetries in $B \to \pi\pi$ and $B \to DK$ models and $\Delta M_{B_S}/\Delta M_{B_d}$. This example suggests importance of measuring the $Br(K^+ \to \pi^+\nu\bar{\nu})$ or $Br(K_L \to \pi^0\nu\bar{\nu})$ at the level of 10% in order to be competitive to other measurements

3. T Violation in $K^+ \to \pi^0\mu^+\nu$ decay

In the three body decay with initial or final polarization we can define a triple vector correlation which is a T odd quantity. Assuming CPT invariance this is another way to look for CP violation. In the $K^+ \to \pi^0\mu^+\nu$ decay the transverse muon polarization is a signal of T violation. The previous limit on this quantities is $P_\perp(K^+ \to \pi^0\mu^+\nu) = (-3.1 \pm 5.3) \times 10^{-3}$.[11] There is an on-going experiment at KEK aiming to improve the limit by one order of magnitude. In the SM the contribution induced from Kobayashi-Maskawa phase is negligible and the T odd asymmetry induced by the final state interaction which mimics the T violation is estimated to be $0(10^{-6})$.[12] Thus this process provides an interesting window to look for new sources of CP violation in such models as multi-Higgs doublet model(MHDM)[13] and SUSY models.[14]

In the MHDM without tree-level FCNC we can introduce new CP violating phases in the charged Higgs mass matrix if the number of Higgs doublets is more than three. The coupling with charged Higgs boson and quarks is written as

$$\mathcal{L} = (2\sqrt{2}G_F)^{\frac{1}{2}} \sum_{i=1}^{2} \{\alpha_i \bar{u}_L V M_D d_R H_i^+ + \beta_i \bar{u_R} M_U V d_L H_i^+ + \gamma_i \bar{\nu}_L M_E e_R H_i^+\} + h.c., \qquad (3)$$

where M_D, M_U, M_E are diagonal mass matrixes and V is the CKM matrix. $\alpha_i, \beta_i, \gamma_i$ are new complex coupling constants associated to the charged Higgs interactions. There are several relations among these coupling constants from the unitarity of the charged Higgs boson mixing matrix. Using these relations we can show that the number of the physical phases is $\frac{(n-2)(n-1)}{2}$ for n-Higgs doublet model.

The transverse muon polarization in the $K^+ \to \pi^0\mu^+\nu$ decay is induced from the interference between the W-boson and the charged Higgs boson exchange diagrams. These diagrams generate operators of $\bar{s}_L\gamma^\mu u_L \bar{\nu}_L \gamma_\mu \mu_L$ and $\gamma\alpha^* \bar{s}_R u_L \bar{\nu}_L \mu_R$, respectively. The polarization is therefore proportional to $Im(\gamma\alpha^*)$. If we assume that only the lightest charged Higgs boson's contribution is dominant, we get

$$P_\perp(K^+ \to \pi^0\mu^+\nu) \simeq -0.2\frac{m_K^2}{m_H^2} Im(\gamma_1\alpha_1^*), \qquad (4)$$

where α_1, γ_1 stand for the coupling constant for the lightest charged Higgs boson. The most severe constraint on this combination of coupling constants come from the tauonic B decay which is given by $|Im(\gamma\alpha^*)| \lesssim 0.2(\frac{m_H}{GeV})^2$.[15] This leads to the bound on the transverse muon polarization as $|P_\perp(K^+ \to \pi^0\mu^+\nu)| \lesssim 1\times 10^{-2}$,which is about the same as the present experimental bound. This means that non-zero value of the transverse polarization may be observable at the on-going experiment and if not the improved bound puts the strongest constraint on this combination of the coupling constants.

The transverse muon polarization in the $K^+ \to \mu^+\nu\gamma$ process is also a signal of T violation. Although the branching ratio is smaller, this process can be measured in the same on-going KEK experiment. The effect of final state interaction is estimated to be $0(10^{-3})$ [16] so that this effect has to be subtracted properly in future experiments. It is interesting to see correlation between two transverse polarizations. In the MHDM, we obtain

$$P_\perp(K^+ \to \mu^+\nu\gamma) \simeq -0.1\frac{m_K^2}{m_H^2} Im(\gamma_1\alpha_1^*), \qquad (5)$$

if we use various phenomenological constraints on α, β, γ coupling constants.[17] Therefore if these polarizations are observed in near future, two polarizations should be in the same sign.

There are many models which induce transverse muon polarization at the observable level in future experiments. One interesting example is the SUSY model discussed by G.-H. Wu and J.N. Ng.[14] In this case a complex coupling constant between the charged Higgs boson and strange and up quarks can be induced through scalar quark and gluino loops. Although this is a loop effect it is possible to find a parameter region where the induced transverse polarization for $K^+ \to \pi^0\mu^+\nu$ is $0(10^{-3})$ if we allow large flavor mixing coupling in squawk-quark-gluino vertices and take a large value for the ratio of two vacuum expectation values($\tan\beta$). Also the correlation between $P_\perp(K^+ \to \pi^0\mu^+\nu)$ and $P_\perp(K^+ \to \gamma\mu^+\nu)$ is opposite in sign if the transverse polarization is induced by this loop effect.[18] It is therefore useful to search for transverse muon polarization in both processes in order to investigate nature of new CP violation interactions.

4. Lepton flavor violation in muon decay

In the minimal SM, electron, muon and tau lepton numbers are separately conserved and there is no lepton flavor violation (LFV). This property is associated with the fact that we cannot write gauge-invariant and renormalizable interactions with LFV within the SM. If we introduce extra fields or interactions we can easily break conservation of separate lepton numbers. Although there are many experimental searches for LFV in τ, Z^0 and K decays, muon rare decays put particularly strong constraints. Experimental upper bounds quoted in PDG 96 are 4.9×10^{-11} for the $\mu^+ \to e^+\gamma$branching ratio, 1.0×10^{-12} for the $\mu^+ \to e^+e^+e^-$branching ratio and 4.3×10^{-12} for the $\mu^- - e^-$ conversion rate in T_i atoms normalized to the muon capture rate.[1] For the $\mu^+ \to e^+\gamma$ process the MEGA experiment at Los Alamos National Laboratory is analysing data and aiming to improve the branching ratio by one order of magnitude. The $\mu^- - e^-$ conversion experiment is also continued at Paul Scherrer Institute to search for this process at the level of $O(10^{-14})$.

Among various models which predict sizable LFV, SUSY models attract much attention recently. In particular it has been pointed out that SUSY GUT models can induce LFV at the level close to the present experimental bounds. In some cases a part of the SUSY parameter space is already excluded by the LFV processes, especially in SO(10) SUSY GUT model. [19,20]

Unlike the minimal SM, the SUSY SM does not necessarily conserve the lepton number separately for each generation. This is because that the mass matrices for scalar partner of leptons, *i.e.* sleptons, can be a new source of flavor mixing in addition to the Yukawa coupling constants. Although these mass terms conserve total lepton number, they do not have to conserve lepton number for each generation separately. Since the scalar mass terms are determined by SUSY breaking terms the LFV depends on how SUSY is broken spontaneously at the energy scale higher than the electroweak scale. In fact if we allow arbitrary flavor mixing in the slepton sector, too large LFV is often induced. A similar problem occurs in the squark sector where the $K^0 - \bar{K}^0$ mixing becomes too large unless some suppression mechanism is implemented. In the minimal supergravity model these flavor problems can be avoided because SUSY breaking masses for all scalar fields are assumed to be universal at the Planck scale. LFV processes is therefore forbidden in this model if there is no LFV interaction between the Planck and electroweak scales. On the other hand LFV processes are induced through renormalization effects on slepton mass matrices if some LFV interaction is present below the Planck scale.

In the SU(5) SUSY GUT model the LFV mass term for the right-handed slepton is induced through renormalization effects between the Planck and GUT scales. Above the GUT scale the right-handed slepton mass terms receive a loop correction from the top Yukawa coupling constant because the right-handed slepton is included in the **10** dimensional representation of SU(5) and the top Yukawa coupling is in the form of $\mathbf{10} \cdot \mathbf{10} \cdot \mathbf{H(5)}$ where $\mathbf{H(5)}$ represents the **5** dimensional representation Higgs field. Due to this renormalization effect the third generation right-handed slepton, *i.e.* the right-handed stau becomes lighter than other two right-handed sleptons and the slepton mass matrix is no longer proportional to a unit matrix. Thus this matrix cannot be diagonalized simultaneously with the lepton mass matrix. In the paper by Barbieri and Hall it is pointed out that the induced $\mu \to e\gamma$ branching ratio can be close to the present experimental upper bound mainly due to the effect of large top Yukawa coupling constant[19]. Precise value of the branching ratio depends on various SUSY parameters as well as assumption on Yukawa coupling constants at the GUT scale. According to the recent detailed calculation in this model, the $\mu \to e\gamma$ branching ratio can be as large as 10^{-13} especially for large values of $\tan\beta$ if we make a simple assumption that Yukawa coupling constant are solely given by $\mathbf{10} \cdot \mathbf{10} \cdot \mathbf{H}(\mathbf{5})$ and $\mathbf{10} \cdot \bar{\mathbf{5}} \cdot \mathbf{H}(\bar{\mathbf{5}})$ couplings at the GUT scale.[21]

In the SO(10) model dominant contribution to the LFV amplitude is given by diagrams proportional to tau-lepton mass in the slepton internal line. Compared to the SU(5) case the branching ratio can be enhanced by $(\frac{m_\tau}{m_\mu})^2$ and therefore a large part of SUSY parameter space is already excluded by the $\mu \to e\gamma$ process.[20] In this model we can derive approximate relations among rates of $\mu^+ \to e^+\gamma$, $\mu^- - e^-$ conversion and $\mu^+ \to e^+e^+e^-$ processes. Namely,

$$\frac{\sigma(\mu T_i \to eT_i)}{\sigma(\mu T_i \to capture)} \simeq \frac{1}{200} Br(\mu^+ \to e^+\gamma), \quad (6)$$

$$Br(\mu^+ \to e^+e^+e^-) \simeq \frac{1}{150} Br(\mu^+ \to e^+\gamma) \quad (7)$$

hold. Although the $\mu^- - e^-$ conversion and $\mu^+ \to e^+e^+e^-$ processes depend on four-fermion operators in addition to the photon penguin operator, only the latter one receives enhanced contributions from the above mentioned diagram.

Large LFV may be induced in the SUSY model with small neutrino mass induced by see-saw mechanism.[22] In this case the Yukawa coupling constant for right-handed neutrino superfield and Majorana mass terms for right-handed neutrinos can be new sources of LFV and if the Yukawa coupling constant is large enough the left-handed slepton mass terms receive generation dependent corrections. If we use the see-saw relation for the neutrino mass as $m_\nu \sim \frac{m_D^2}{M_N}$ where m_D is the Dirac mass and M_N is the Majorana mass for right-handed neutrino, the Yukawa coupling constant becomes as large as the top Yukawa coupling constant for $M_N \sim 10^{13}$ GeV and $m_\nu \sim 1$ eV. Since the $\mu \to e\gamma$ branching ratio strongly depends on unknown parameters such as the right-handed Majorana mass scale and mixing matrix elements the prediction for the branching ratio is more ambiguous in this model, but it is interesting to see that in large fraction of parameter space LFV effects are large enough to be observed in near-future experiments. This is contrasted to the see-saw neutrino model without SUSY where the branching ratio for $\mu \to e\gamma$ etc. are too small for experiments in near future although evidence of LFV may be obtained through neutrino oscillation experiments.

Let us finally comment on usefulness of muon polarization in search for LFV. A highly polarized muon beam is available in μ^+ decay experiments. Muons from π^+ decay stopped near the surface of the pion production target is 100% polarized opposite to the muon momentum and this muon is called surface muon.

The first obvious merit of polarized muons in $\mu^+ \to e^+\gamma$ is that we can distinguish $\mu^+ \to e^+_R\gamma$ and $\mu^+ \to e^+_L\gamma$ by the angular distribution of the decay products with respect to the muon polarization direction. For example, the positron from the $\mu^+ \to e^+_R\gamma$ decay follows the $(1 - P\cos\theta)$ distribution where θ is the angle between the polarization direction and the positron momentum and P is the the muon polarization. In the previous examples the SU(5) SUSY GUT predicts $\mu^+ \to e^+_L\gamma$ because LFV is induced only in the right-handed slepton sector. On the other hand the SO(10) SUSY GUT generates almost equal number of $\mu^+ \to e^+_L\gamma$ and $\mu^+ \to e^+_R\gamma$ so that the positron has a flat angular distribution. If the LFV is induced by the right-handed neutrino Yukawa coupling constant, only $\mu^+ \to e^+_R\gamma$ should be observed.

Polarized muons are also useful to suppress background processes for the $\mu^+ \to e^+\gamma$ search.[23] In this experiment the experimental sensitivity is limited by appearance of the background processes. There are two major background processes. The first one is physics background process which is a tail of radiative muon decay. If neutrino pair carries out only little energy in the $\mu^+ \to e^+\nu\bar{\nu}\gamma$ process, we cannot distinguish this from the signal process. The second background process is an accidental background process where detections of 52 MeV positron and 52 MeV photon from different muon decays coincide within time and angular resolutions for selection of signals. The source of the 52 MeV positron is the ordinary $\mu^+ \to e^+\nu\bar{\nu}$ decay whereas the 52 MeV photon mainly comes from a tail of the radiative muon decay. We calculated the angular distribution of the final positron and photon and showed that polarized muons are useful for suppression of both background processes. For the physics background it can be shown that the positron follows approximately $(1 + P\cos\theta)$ distribution if we take into account finite energy resolution of photon and positron detectors. The physics background is therefore suppressed for the $\mu^+ \to e^+_R\gamma$ search if the polarized muon is used. For the accidental background both positrons and photons turn out to follow $(1 + P\cos\theta)$ distribution. Thus background suppression works independently of the signal distribution. If we use 97% polarized muons we can expect to reduce the accidental background by one order of magnitude. This looks promising for search of $\mu^+ \to e^+\gamma$ at the level of 10^{-14} branching ratio.

The third example of the merit of polarized muon decays is that we can measure T and CP violation in the $\mu^+ \to e^+e^+e^-$ decay.[24] Since we can take a triple vector correlation for three body decays of polarized particles, T odd asymmetry can be defined in $\mu^+ \to e^+e^+e^-$ decay. We calculated that T odd asymmetry in SU(5) SUSY GUT and showed that the asymmetry can be as large as 20% if we include CP violating phases in SUSY soft breaking terms.[25] If LFV is discovered in the $\mu^+ \to e^+\gamma$ or $\mu^+ \to e^+e^+e^-$ processes measurement of T odd asymmetry will become an important next target which could provide us information on CP nature of LFV interactions.

5. Conclusions

I have reviewed three topics on kaon and muon decays: (1) $K_L \to \pi^0\nu\bar{\nu}$ and $K^+ \to \pi^+\nu\bar{\nu}$, (2) T violation in $K^+ \to \pi^0\mu^+\nu$, (3) LFV in muon decays. These precesses can be new windows to physics beyond the SM. Measurement of the branching ratio of $K_L \to \pi^0\nu\bar{\nu}$ and/or $K^+ \to \pi^+\nu\bar{\nu}$ at the 10% level will provide us an important clue for new physics if we combine with other observables related to the CKM matrix in B decays. We can obtain information of new CP sources in MHDM and SUSY models from the measurement of transverse muon polarization in $K^+ \to \pi^0\mu^+\nu$. The correlation with transverse muon polarization in $K^+ \to \mu^+ \nu \gamma$ is useful to distinguish various models. Finally we showed that LFV processes such as $\mu^+ \to e^+ \gamma$, $\mu^+ \to e^+ e^+ e^-$ and $\mu^- - e^-$ conversion in atoms can occur at the rate as large as the present experimental upper bounds in SUSY GUT and the SUSY model with right-handed neutrino. If observed, these processes can give us information on LFV interaction at very high energy scale. These experiments therefore may provide us the first hint for the physics beyond the SM in facilities with an intense proton beam such as JHF.

6. References

1. Particle Data Group, R.M. Barnett *et al.*, *Phys. Rev.* **D54**, (1996) 1.
2. For a review see, for example, Y. Nir and H.R. Quinn, *Ann. Rev. Nucl. Part. Sci.* **42**, 211 (1992); A.J. Buras and R. Fleischer, hep-ph/9704376.
3. ATLAS Technical Proposal (1994).
4. G. Buchalla, A. Buras and M.E. Lautenbacher, *Rev. Mod. Phys.* **68**, (1996) 1125.
5. S. Adler *et al.*, *Phys. Rev. Lett.* **79**, (1997) 2204.
6. K. Arisaka's talk in this workshop.
7. T. Inagaki *et al.*, KEK proposal, (June 1996); I-H. Chiang *et al.* BNL proposal, (September 1996); KAMI Collaboration, E. Cheu *et al.*, hep-ex/9709026.
8. T. Goto, T. Nihei and Y. Okada, *Phys. Rev.* **D 53**, (1996) 5233; *Erratum, ibid.* **D54**, (1996) 5904.
9. T. Goto, Y. Okada, Y. Shimizu and M. Tanaka, *Phys. Rev.* **D 55**, (1997) 4273.
10. T. Goto, Y. Okada, and Y. Shimizu, in preparation.
11. S.R. Blatt *et al. Phys. Rev.* **D 27**, (1983) 1056.
12. A.R. Zhitnitskii, *Yad. Fiz.***6** (1980) 1024 [*Sov. J. Nucl.Phys.* **31**, (1980) 529].
13. H.Y. Cheng, *Phys. Rev.* **D 26**, (1982) 143; M. Leurer, *Phys. Rev. Lett.* **62**, (1989) 1967; P. Castoldi, J.-M. Frére, and G.L. Kane,*Phys. Rev.* **D 39**, (1989) 2633; R. Garisto and G. Kane, *Phys. Rev.* **D 44**, (1991) 2038; G. Bélanger and C.Q. Geng,*Phys. Rev.* **D 44**, (1991) 2789.
14. G.-H. Wu and J.N.Ng, *Phys. Lett.* **B 392**, (1997) 93.
15. Y. Grossman and Z. Ligeti, *Phys. Lett.* **B 332**, (1994) 373; *Phys. Lett.* **B 347**, (1995) 399;Y. Grossman, H.E. Haber and Y. Nir, *Phys. Lett.* **B 357**, (1995) 630.
16. C.Q. Geng, *Nucl. Phys.*B (Proc. Suppl.)**37A** (1994) 59.
17. M. Kobayashi, T.-T. Lin and Y. Okada, *Prog. Theor. Phys.* **95**, (1996) 361.
18. G.-H. Wu and J.N.Ng, *Phys. Rev.* **D 55**, (1997) 2806.
19. R. Barbieri and L.J. Hall, *Phys. Lett.* **B 338**, (1994) 212.
20. R. Barbieri, L.J. Hall and A. Strumia, *Nucl. Phys.* **B 445**, (1995) 219.
21. J. Hisano, T. Moroi, K. Tobe and M. Yamaguchi, *Phys. Lett.* **B 391**, (1997) 341; *Erratum, ibid.* **B 397**, (1997) 357.
22. F. Borzumati and A. Masiero, *Phys. Rev. Lett.* **57**, (1986) 961; J. Hisano, T. Moroi, K. Tobe, M. Yamaguchi and T. Yanagida, *Phys. Lett.* **B 357**, (1995) 579; J. Hisano, T. Moroi, K. Tobe and M. Yamaguchi, *Phys. Rev.* **D 53**, (1996) 2442; D. Nomura, J. Hisano, and T. Yanagida, KEK-TH-548, hep-ph/9711348.
23. Y. Kuno and Y. Okada,*Phys. Rev. Lett.* **77**, (1996) 434; Y. Kuno, A. Maki and Y. Okada,*Phys. Rev.* **D 55**, (1997) 2517.
24. S.B. Treiman, F. Wilczek and A. Zee, *Phys. Rev.* **D 16**, (1977) 152.
25. Y. Okada, K. Okumura and Y. Shimizu, KEK-TH-535, hep-ph/9708446.