Lepton Flavor Violation
Muon to Electron Conversion
COMET and PRISM at J-PARC

Yoshitaka Kuno
Osaka University, Japan
July 3rd, 2008
NuFACT2008
Valencia Spain

Lepton Flavor Violation
Outline

- Goal of Particle Physics
  - Big Questions
  - Tools
  - What is the Intensity Frontier
  - Lepton Flavor Violation of Charged Leptons (LFV)
- LFV Physics Motivation with Muons
  - Supersymmetry Models
- LFV Experiments with Muons
  - $\mu \rightarrow e \gamma$ and $\mu - e$ conversion
  - COMET, PRISM and Mu2E
- Neutrino Factory (in terms of LFV)
  - Charged LFV Currents
- Summary

No experimental details are given.
LFV Physics Motivation
Lepton Flavor Violation (LFV) of Charged Leptons

- **LFV of neutrinos** (confirmed)
  - $\nu_e$ ↔ $\nu_\mu$ ↔ $\nu_\tau$
  - $e$ ↔ $\mu$ ↔ $\tau$

- **LFV of charged leptons** (not observed yet)

What is the contribution from neutrino mixing in the Standard Model?

$\propto \left(\frac{m_\nu}{m_W}\right)^4$ $\approx 10^{-26}$

Very Small ($10^{-52}$)

Sensitive to new Physics beyond the Standard Model
Various Models Predict Charged Lepton Mixing.

Sensitivity to Different Muon Conversion Mechanisms

- **Supersymmetry Predictions at $10^{15}$**

- **Compositeness**
  \[ \Lambda_c = 3000 \text{ TeV} \]

- **Heavy Neutrinos**
  \[ |U_{\mu N}^* U_{e N}|^2 = 8 \times 10^{-13} \]

- **Second Higgs doublet**
  \[ g_{H_{\mu e}} = 10^{-4} \times g_{H_{\mu\mu}} \]

- **Leptoquarks**
  \[ M_L = 3000 (\lambda_{\mu d} \lambda_{e d})^{1/2} \text{ TeV/c}^2 \]

- **Heavy $Z'$, Anomalous $Z$ coupling**
  \[ M_{Z'} = 3000 \text{ TeV/c}^2 \]
  \[ B(Z \rightarrow \mu e) < 10^{-17} \]

After W. Marciano
LFV in SUSY Models

Through quantum corrections, LFV could access ultra-heavy particles such as $\nu_R$ ($\sim 10^{12}-10^{14}$ GeV/c²) and GUT that cannot be produced directly by any accelerators.

Features
- The decay rate is not too small, because it is determined by the SUSY mass scale.
- But, it contains the information at $10^{16}$ GeV through the slepton mixing.
- It is in contrast to proton decays or double beta decays which need many particles.

Slepton Mixing

$\tilde{\nu}_\mu \rightarrow e\gamma$

Hagiwara et al: hep-ph/0611102
Slepton Mixing in mSUGRA Models

\( m_i^2 = \begin{pmatrix} m_{11}^2 & m_{12}^2 & m_{13}^2 \\ m_{21}^2 & m_{22}^2 & m_{23}^2 \\ m_{31}^2 & m_{32}^2 & m_{33}^2 \end{pmatrix} \)

\( (m_i^2)_{ij} = m_0^2 \delta_{ij} \) @ M_planck

GUT Yukawa interaction

Neutrino Yukawa interaction

SUSY-GUT Models

\( (m_L^2)_{21} \sim \frac{3m_0^2 + A_0^2}{8\pi^2} h^2 V_{td} V_{ts} \ln \frac{M_{GUT}}{M_{Rs}} \)

CKM matrix

SUSY Seesaw Models

\( (m_L^2)_{21} \sim \frac{3m_0^2 + A_0^2}{8\pi^2} h^2 U_{31} U_{32} \frac{M_{GUT}}{M_{Rs}} \)

Neutrino oscillation
SUSY Predictions for LFV with Muons

- **SU(5) SUSY GUT**
- **SUSY Seesaw Model**

---

**Left Diagram:**
- $f_t (M) = 2.4$
- $\mu > 0$
- $M_1 = 50 \text{GeV}$
- $R(\mu \to e; T_i)$
- $m_{\tilde{c}_R}$

**Right Diagram:**
- $\mu \to \gamma$ in the MSSMRN with the MSW large angle solution
- $M_s = 130 \text{GeV}$, $m_{\nu_e} = 170 \text{GeV}$, $m_{\nu_\tau} = 0.07 \text{eV}$, $m_{\nu_\mu} = 0.004 \text{eV}$
- $\tan \beta = 3$, $\tan \beta = 10$, $\tan \beta = 30$

- MEG, COMET, super-MEG
- PRISM

---

**SU(5) SUSY GUT**

**SUSY Seesaw Model**
Complementarity to LHC (mSUGRA)

- In mSUGRA, some of the parameter regions, where LHC does not have sensitivity to SUSY, can be explored by LFV.
- Bench mark points
  - coannihilation strip
    - LHC covers and LFV does.
  - A-pole funnels
    - LHC partially covers and LFV does cover.
- Focus point
  - LHC does not cover and LFV does cover.
Short Summary of Motivation: LFV, Energy Frontier and SUSY

- In SUSY models, charged lepton mixing is sensitive to slepton mixing.
- LHC would have potentials to see SUSY particles. However, at LHC nor even ILC, slepton mixing would be hard to study in such a high precision as proposed here.

- Slepton mixing is sensitive to either (or both) Grand Unified Theories (SUSY-GUT models) or neutrino seesaw mechanism (SUSY-Seesaw models).
- If LFV sensitivity is extremely high, it might be sensitive to multi-TeV SUSY which LHC cannot reach, in particular SUSY models.
LFV Experiments
Searches in the Past

- A long history of the LFV search, which started from the experiment with cosmic rays by Pontecorvo et al. in 1947. They believed the muon is an excited state of the electron, and went to the ground state by emitting a photon.
- Since then, the upper limits have been improved by two orders of magnitude with muons that are created by accelerators.
# Present Limits and Expectations in Future

<table>
<thead>
<tr>
<th>process</th>
<th>present limit</th>
<th>near future</th>
<th>comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mu\rightarrow e\gamma$</td>
<td>$1.2 \times 10^{-11}$</td>
<td>$10^{-13}$</td>
<td>MEG at PSI</td>
</tr>
<tr>
<td>$\mu\rightarrow eee$</td>
<td>$1.0 \times 10^{-12}$</td>
<td>$10^{-13} - 10^{-14}$</td>
<td>?</td>
</tr>
<tr>
<td>$\mu N\rightarrow eN$ (in Tl)</td>
<td>$4.3 \times 10^{-12}$</td>
<td>$10^{-18}$</td>
<td>PRISM</td>
</tr>
<tr>
<td>$\mu N\rightarrow eN$ (in Al)</td>
<td>none</td>
<td>$10^{-16}$</td>
<td>COMET and Mu2e</td>
</tr>
<tr>
<td>$\tau\rightarrow e\gamma$</td>
<td>$1.1 \times 10^{-7}$</td>
<td>$10^{-8} - 10^{-9}$</td>
<td>super B factory</td>
</tr>
<tr>
<td>$\tau\rightarrow eee$</td>
<td>$2.7 \times 10^{-7}$</td>
<td>$10^{-8} - 10^{-9}$</td>
<td>super B factory</td>
</tr>
<tr>
<td>$\tau\rightarrow \mu\gamma$</td>
<td>$6.8 \times 10^{-8}$</td>
<td>$10^{-8} - 10^{-9}$</td>
<td>super B factory</td>
</tr>
<tr>
<td>$\tau\rightarrow \mu\mu\mu$</td>
<td>$2 \times 10^{-7}$</td>
<td>$10^{-8} - 10^{-9}$</td>
<td>super B factory</td>
</tr>
</tbody>
</table>
What is a Muon to Electron Conversion?

1s state in a muonic atom

Neutrino-less muon nuclear capture (=μ-e conversion)

\[ \mu^- + (A, Z) \rightarrow e^- + (A, Z) \]

lepton flavors changes by one unit.

\[ B(\mu^- N \rightarrow e^- N) = \frac{\Gamma(\mu^- N \rightarrow e^- N)}{\Gamma(\mu^- N \rightarrow \nu N')} \]

nuclear muon capture

\[ \mu^- + (A, Z) \rightarrow \nu_\mu + (A, Z - 1) \]


\[ \mu^- + (A,Z) \rightarrow e^- + (A,Z) \]

**Signal**
- single mono-energetic electron
- coherent process (the same initial and final nucleus)

\[ m_\mu - B_\mu \sim 105 \text{ MeV} \]

\[ \propto Z^5 \]

**Backgrounds**
- Muon decay in orbit
  - Endpoint comes to the signal region

\[ \propto (\Delta E)^5 \]
- Radiative muon capture
- Radiative pion capture
  - pulsed beam required
  - wait until pions decay.
- Electrons from muon decays in flight
- Cosmic rays
- and many others
Comparison between $\mu \rightarrow e \gamma$ and $\mu$-e Conversion (Physics sensitivity)

Photonic and non-photonic (SUSY) diagrams

<table>
<thead>
<tr>
<th></th>
<th>Photonic</th>
<th>Non-photonic</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mu \rightarrow e \gamma$</td>
<td>yes (on-shell)</td>
<td>no</td>
</tr>
<tr>
<td>$\mu$-e conversion</td>
<td>yes (off-shell)</td>
<td>yes</td>
</tr>
</tbody>
</table>

$B(\mu N \rightarrow e N) / B(\mu \rightarrow e \gamma) \sim \frac{1}{100}$

$M_N = 10^{14}$ GeV
$\tan \beta = 60$

$\mu > 0$
$\mu < 0$
Comparison between $\mu \rightarrow e \gamma$ and $\mu$-e Conversion (Experimental)

<table>
<thead>
<tr>
<th></th>
<th>background</th>
<th>challenge</th>
<th>beam intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mu \rightarrow e \gamma$</td>
<td>accidentals</td>
<td>detector resolution</td>
<td>limited</td>
</tr>
<tr>
<td>$\mu$-e conversion</td>
<td>beam</td>
<td>beam background</td>
<td>no limitation</td>
</tr>
</tbody>
</table>

- $\mu \rightarrow e \gamma$ : Accidental background is given by $(rate)^2$. The detector resolutions have to be improved, but they (in particular, photon) would be hard to go beyond MEG from present technology. The ultimate sensitivity would be about $10^{-14}$ (with about $10^8$/sec) unless the detector resolution is radically improved.
- $\mu$-e conversion : Improvement of a muon beam can be possible, both in purity (no pions) and in intensity (thanks to muon collider R&D). A higher beam intensity can be taken because of no accidentals.

$\mu$-e conversion might be a next step.
The SINDRUM-II Experiment (at PSI)

SINDRUM-II used a continuous muon beam from the PSI cyclotron. To eliminate beam related background from a beam, a beam veto counter was placed. But, it could not work at a high rate.

**Published Results**

\[ B(\mu^- + Au \rightarrow e^- + Au) < 7 \times 10^{-13} \]
Potential Improvements for Next Generation $\mu$-e Conversion Experiments

- **Reduction of beam-related backgrounds**
  Beam pulsing is needed and the measurement during beam pulses is made. Pulse separation should be about 1 $\mu$sec.

- **High muon beam intensity**
  Pion capture and muon transport by superconducting solenoids would provide high beam intensity.

- **Narrow beam energy spread**
  A thinner muon stopping target is needed to improve the energy resolution of electron detection. And therefore the beam energy spread should be narrow.

- **Reduction of pions in a muon beam**
  A muon beam line should be sufficient long to eliminate pions in a muon beam.
High-sensitivity Measurements

• The latest developments in accelerator and detector technology make possible promising new scientific opportunities through measurement of rare processes. Incisive experiments, complementary to experiments at the LHC, would probe the Terascale and possibly much higher energies.

• The panel recommends pursuing the muon-to-electron conversion experiment, subject to approval by the Fermilab PAC, under all budget scenarios considered by the panel.

• The intermediate budget scenario would allow in addition pursuing significant participation in one overseas next-generation B factory.

• The more favorable funding scenario, scenario C, would allow for pursuing a program in rare K decay experiments at Fermilab as well.
J-PARC at Tokai, Japan

- Material & Life Science Facility
- Hadron Experimental Facility
- Accelerator-Driven Transmutation Experimental Facility
- Linac (350m)
- 3GeV Synchrotron (25Hz, 1MW)
- Neutrino Facility
- 50GeV Synchrotron (0.75MW)
COMET (COherent Muon to Electron Transition) in Japan

$B(\mu^- + Al \rightarrow e^- + Al) < 10^{-16}$

Proton Beam

The Muon Source
- Proton Target
- Pion Capture
- Muon Transport

The Detector
- Muon Stopping Target
- Electron Transport
- Electron Detection

proposed to
J-PARC
PI: Y. Kuno
A pulsed proton beam is needed to reject beam-related prompt background.
- Detection will be made between pulses (delayed measurement).
- Time structure required for proton beams.
- Pulse separation is ~ 1 μsec or more (muon lifetime).
- Narrow pulse width (<100 nsec)

Pulsed beam from slow extraction.
- fill every other rf buckets with protons and make slow extraction with keeping bunches
- spill length (flat top) ~ 0.7 sec
  - good to be shorter for cosmic-ray backgrounds.
Proton Beam (2) - 2 SSC years

- Proton Extinction:
  - (delayed)/(prompt)<10^{-9}
  - Test done at BNL-AGS gave 10^{-7} (shown below).
  - Extra extinction devices are needed.

- Required Protons:
  - 8 x 10^{20} protons of 8 GeV in total for a single event sensitivity of about 0.3 x 10^{-16}.
  - For 2 x 10^7 sec running, 4 x 10^{13} protons /sec (= 7 μA).
  - A total beam power is 56 kW, which is about 1/8 of the J-PARC full beam power of 450 kW (30 GeV x 15μA).

Test of Extinction at BNL-AGS
Pion Capture

- A large muon yield can be achieved by large solid angle pion capture by a high solenoid field, which is produced by solenoid magnets surrounding the proton target.

\[ P_T(GeV/c) = 0.3 \times B(T) \times \left( \frac{R(m)}{2} \right) \]

- B=5T,R=0.2m, P_T=150MeV/c.

- Superconducting Solenoid Magnet for pion capture
  - 15 cm radius bore
  - a 5 tesla solenoidal field
  - 30 cm thick tungsten radiation shield
  - heat load from radiation
  - a large stored energy
Muon Transport Beamline

- Muons are transported from the capture section to the detector by the muon transport beamline.
- Requirements:
  - long enough for pions to decay to muons (> 20 meters ≈ 2x10^{-3}).
  - high transport efficiency (P_μ~40 MeV/c)
  - negative charge selection
  - low momentum selection (P_μ<75 MeV/c)
- Straight + curved solenoid transport system is adopted.
Charged Particle Trajectory in Curved Solenoids

• A center of helical trajectory of charged particles in a curved solenoidal field is drifted by

\[ D = \frac{p}{qB} \theta_{bend} \frac{1}{2} \left( \cos \theta + \frac{1}{\cos \theta} \right) \]

- \( D \): drift distance
- \( B \): Solenoid field
- \( \theta_{bend} \): Bending angle of the solenoid channel
- \( p \): Momentum of the particle
- \( q \): Charge of the particle
- \( \theta \): \( \text{atan}(P_T/P_L) \)

• This effect can be used for charge and momentum selection.

• This drift can be compensated by an auxiliary field parallel to the drift direction given by

\[ B_{\text{comp}} = \frac{p}{qr} \frac{1}{2} \left( \cos \theta + \frac{1}{\cos \theta} \right) \]

- \( p \): Momentum of the particle
- \( q \): Charge of the particle
- \( r \): Major radius of the solenoid
- \( \theta \): \( \text{atan}(P_T/P_L) \)

Tilt angle=1.43 deg.
Transport Solenoid Design
Spectra at the End of the Muon Transport

- Preliminary beamline design
  - main magnetic field
  - compensation field
  - radius of magnets (200 mm)

- Transport Efficiency

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td># of muons /proton</td>
<td>0.0071</td>
</tr>
<tr>
<td># of stopped muons</td>
<td>0.0018</td>
</tr>
<tr>
<td># of muons of $p_{\mu} &gt; 75$ MeV/c /proton</td>
<td>$2 \times 10^{-4}$</td>
</tr>
</tbody>
</table>
Detector Components

- a muon stopping target, curved solenoid, tracking chambers, and a calorimeter/trigger and cosmic-ray shields.

- a muon stopping target, to stop muons in the muon stopping target.

- Curved Solenoid, under a solenoid magnetic field, to detect and identify 100 MeV electrons.

- to detect and identify 100 MeV electrons.

- to eliminate low-energy beam particles and to transport only ~100 MeV electrons.
Transmission of the Electron Transport

- Electron Transport System Parameters (preliminary)
  - Radius : 50 cm
  - Magnetic field : 1 Tesla
  - Bending angle : 180 degrees
- Geometrical Acceptance
  - Solid angle at the target : 0.73
    - mirror effect at a graded field
  - Transport efficiency : 0.44
  - Total : 0.32
- Suppression of electrons from decay in orbit.
  - about $10^{-8}$ suppression
  - about 1000 tracks / sec for $10^{11}$ stopping muons.
Electron Detection (preliminary)

Straw-tube Trackers to measure electron momentum.
- should work in vacuum and under a magnetic field.
- A straw tube has 25\(\mu\)m thick, 5 mm diameter.
- One plane has 2 views (x and y) with 2 layers per view.
- Five planes are placed with 48 cm distance.
- 250\(\mu\)m position resolution.

Under a solenoidal magnetic field of 1 Tesla.

In vacuum to reduce multiple scattering.

Electron calorimeter to measure electron energy and make triggers.
- Candidate are GSO or PbWO2.
- APD readout (no PMT).
The signal acceptance is given by the geometrical and the analysis (cut) acceptance.

**Signal Acceptance**

<table>
<thead>
<tr>
<th>Items</th>
<th>Acceptance</th>
</tr>
</thead>
<tbody>
<tr>
<td>geometrical</td>
<td></td>
</tr>
<tr>
<td>solid angle at target</td>
<td>0.73</td>
</tr>
<tr>
<td>transport efficiency</td>
<td>0.44</td>
</tr>
<tr>
<td>analysis</td>
<td></td>
</tr>
<tr>
<td>$p_t &gt; 52$ MeV/c cut</td>
<td>0.67</td>
</tr>
<tr>
<td>chi2 cut</td>
<td>0.86</td>
</tr>
<tr>
<td>energy cut</td>
<td>0.56</td>
</tr>
<tr>
<td>time window cut</td>
<td>0.38</td>
</tr>
<tr>
<td>total</td>
<td>0.04</td>
</tr>
</tbody>
</table>

Signal energy window (104.0-105.2 MeV in uncorrected energy scale)
Signal Sensitivity (preliminary) - 2 SSC years

- Single event sensitivity

\[ B(\mu^- + Al \rightarrow e^- + Al) \sim \frac{1}{N_\mu \cdot f_{\text{cap}} \cdot A_e}, \]

- \( N_\mu \) is a number of stopping muons in the muon stopping target. It is \( 1.5 \times 10^{18} \) muons.
- \( f_{\text{cap}} \) is a fraction of muon capture, which is 0.6 for aluminum.
- \( A_e \) is the detector acceptance, which is 0.04.

<table>
<thead>
<tr>
<th>Tungsten target &amp; beam line optimization</th>
<th>→ improvement of x2.7</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th></th>
<th>8x10^{20}</th>
<th>0.0071</th>
<th>0.26</th>
</tr>
</thead>
<tbody>
<tr>
<td>total protons</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>muon transport efficiency</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>muon stopping efficiency</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td># of stopped muons</td>
<td>1.5x10^{18}</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[{\cal B}(\mu^- + Al \rightarrow e^- + Al) = \frac{1}{1.5 \times 10^{18} \times 0.6 \times 0.04} = 2.8 \times 10^{-17}\]

\[{\cal B}(\mu^- + Al \rightarrow e^- + Al) < 5 \times 10^{-17} \quad (90\% \text{ C.L.})\]
Potential Background Events

- Background rejection is the most important in searches for rare decays.
- Types of backgrounds for $\mu^- + N \rightarrow e^- + N$ are,

| Intrinsic backgrounds | originate from muons stopping in the muon stopping target. | •muon decay in orbit  
|                       |                                                        | •radiative muon capture  
|                       |                                                        | •muon capture with particle emission |
| Beam-related backgrounds | caused by beam particles, such as electrons, pions, muons, and anti-protons in a beam | •radiative pion capture  
|                           |                                                        | •muon decay in flight  
|                           |                                                        | •pion decay in flight  
|                           |                                                        | •beam electrons  
|                           |                                                        | •neutron induced  
|                           |                                                        | •antiproton induced |
| Other backgrounds | caused by cosmic rays | •cosmic-ray induced  
|                   |                                                         | •pattern recognition error |
Intrinsic Background (from muons)

- Muon Decay in Orbit
  - Electron spectrum from muon decay in orbit
  - Response function of the spectrometer included.
  - 0.05 events in the signal region of 104.0 - 105.2 MeV (uncorrected).

- Radiative Muon Capture with Photon Conversion
  \[ \mu^- + Al \rightarrow \nu_\mu + Mg + \gamma \]
  - Max photon energy 102.5 MeV
  - < 0.001 events

- Muon Capture with Neutron Emission
- Muon Capture with Charged Particle Emission
  - <0.001 events for both.

Energy spectrum of electrons from decays in orbit in a muonic atom of aluminum, as a function of electron energy. The vertical axis shows the effective branching ratio of \( \mu \)-e conversion.

\[ DIO/MUC \propto (E_{end} - E_e)^5 \]
DIO Background

a number of events for 1.1 x10^{18} stopped muons.
Beam Related Background Rejection

Rejection of beam related (prompt) backgrounds can be done by a combination of the following components.

- **Momentum Selection at the Muon Transport**
  \[ p_\mu < 75 \text{ MeV/c} \]

- **Electron Energy Cut**
  \[ 104.0 - 105.2 \text{ MeV uncorrected} \]

- **Electron Transverse Momentum Cut**
  \[ p_T > 52 \text{ MeV/c} \]

- **Timing Cut and Beam Extinction**
  \[ 10^{-9} \]

- **Beam Channel Length**
  \( \text{(pion decay)} \)
# Background Rejection Summary (Preliminary)

<table>
<thead>
<tr>
<th>Backgrounds</th>
<th>Events</th>
<th>Comments</th>
</tr>
</thead>
</table>
| **(1)**  
Muon decay in orbit  
Radiative muon capture  
Muon capture with neutron emission  
Muon capture with charged particle emission | 0.05  
<0.001  
<0.001  
<0.001 | 230 keV resolution |
| **(2)**  
Radiative pion capture*  
Radiative pion capture  
Muon decay in flight*  
Pion decay in flight*  
Beam electrons*  
Neutron induced*  
Antiproton induced | 0.12  
0.002  
<0.02  
<0.001  
0.08  
0.024  
0.007 | prompt  
late arriving pions  
for high energy neutrons  
for 8 GeV protons |
| **(3)**  
Cosmic-ray induced  
Pattern recognition errors | 0.10  
<0.001 | 10^-4 veto & 2x10^7 sec run |
| **Total** | 0.4 | BG with asterisk needs beam extinction. |
The proposed COMET experiment would use an 8 GeV primary proton beam from the J-PARC main ring to produce pions. Muons (<75 MeV/c) from low energy pion decay would then be transported in a curved solenoid system to an aluminum stopping target. Mono-energetic electrons (105 MeV) from mu-e conversion events would then be transported in another curved solenoid system to a combined tracking plus calorimeter detector. This unique design has excellent rejection of background with an overall signal efficiency of 4%. Background rejection should be highly effective and the estimated background is at the 0.4 event level for the full proposed data run.

With the beam and detection system proposed for COMET, the branching ratio sensitivity for a mu-e conversion signal would be 6.4x10^{-17} at 90% CL for 2x10^7 sec of running (or 8x10^{20} protons on target). This sensitivity is almost five orders of magnitude better than the current best published limit of 4.3x10^{-12} by the SINDRUM-II experiment at PSI. The MEG experiment at PSI is expected to have new results on mu to e+gamma over the next several years. The sensitivity goal for MEG is 10^{-13}. This rate is equivalent to a mu-e conversion rate of about 5x10^{-16} if photon mediation is the dominant process. Thus, the proposed COMET experiment would have ten times better sensitivity than MEG in reach for LFV via photon mediation. If MEG observes the mu to e+gamma decay, then COMET can not only confirm LFV but also give essential information on the sign and magnitude of non-photonic processes. If MEG does not observe mu to e+gamma decay, then COMET will open up an important new window for LFV.

The PAC is impressed with the physics capabilities of the proposed COMET experiment and believes that this experiment could become one of the flagship experiments in the J-PARC program. On the other hand, this is a very difficult experiment and will demand large resources from the collaboration and the laboratory. A detailed assessment by the PAC and Laboratory of the feasibility for making such a precise measurement will need a more detailed design and simulation of the experiment. For these reasons, the PAC asks for more information to be provided over the next several meetings on the design, capability, and schedule for the experiment. This information and answers to the questions posed below should be given in an addendum to the proposal and presentations should be given at the next meeting if possible. Preliminary interactions should...
Possible Layout at the NP Hall
Long Future Prospects:
From COMET to PRISM

COMET

• without a muon storage ring.
• with a slowly-extracted pulsed proton beam.
• doable at the J-PARC NP Hall.
• regarded as the first phase / MECO type
• Early realization

PRISM

• with a muon storage ring.
• with a fast-extracted pulsed proton beam.
• need a new beamline and experimental hall.
• regarded as the second phase.
• Ultimate search

\[ B(\mu^- + Al \rightarrow e^- + Al) < 10^{-16} \]

\[ B(\mu^- + Ti \rightarrow e^- + Ti) < 10^{-18} \]
mSUGRA with right-handed neutrinos will be improved by a factor of 10,000.

will be improved by a factor of 1,000,000.

Sensitivity Goal

\[ B(\mu^- + Al \rightarrow e^- + Al) < 10^{-16} \]

\[ B(\mu^- + Ti \rightarrow e^- + Ti) < 10^{-18} \]

B(\mu^- e; Al)

Current Exp. Bound on $\mu \rightarrow e$; Ti (SINDRUM II)

MEG ($\mu \rightarrow e\gamma$)

This Experiment ($\mu \rightarrow e$; Al)

PRISM phase-2

Branching Ratios ($\mu \rightarrow e\gamma$)

Branching Ratios ($\mu \rightarrow e$; Ti)
R&D on the PRISM Muon Storage (FFAG) Ring at Osaka University

PRISM-FFAG (6 sectors) in RCNP, Osaka

Ready to demo. phase rotation
Roadmap of Particle Physics based on muons

Based on common technologies

Muon Factory
- muon LFV,
- muon g-2,
- muon EDM
- muon application

Neutrino Factory
- Energy frontier
- Muon Collider
- 2~4 TeV

Neutrino Factory
- Proton Driver
- Hg Target Capture Drift Buncher
- Bunch Rotation Cooling
- Acceleration Linac
- 0.2 – 0.9 GeV

Muon Collider
- 16 GeV/c Proton Accelerator
- π Production Target
- Muon Cooling Channel
- 1.5 x 10^{12} muons/year

Detector
- Stoped π
- Neutrinos from muon storage rings
- Intense High-Energy Muon & Neutrino Beams
- Higgs, "H, WW..."
Summary

TOE (Superstring)

Grand Unification

Neutrino Seesaw Model

Leptogenesis

Muon Lepton Flavor Violation

RGE

$10^{16}$GeV

$10^{19}$GeV

$10^2$GeV
End of My Slides