Summary of WG4, Part Two.
Yannis Semertzidis, BNL

Most muon physics experiments are statistics limited.

The prospect of intense muon sources is very exciting!
Intense Muon Physics, Part two

• Lepton Flavor Violation (LFV)

• Muon EDM and g-2

• Precision measurement of muon properties
## Lepton Flavor Violation

**Wednesday July 28**

<table>
<thead>
<tr>
<th>Time</th>
<th>Topic</th>
<th>Speaker</th>
</tr>
</thead>
<tbody>
<tr>
<td>11:30-12:00</td>
<td>A variety of lepton number violating processes related to Majorana nature of neutrino masses</td>
<td>C. S. Lim (Kobe)</td>
</tr>
<tr>
<td>12:00-12:30</td>
<td>Bi-Maximal mixing at the GUT scale and its applications</td>
<td>E. Takasugi (Osaka)</td>
</tr>
<tr>
<td>14:00-14:30</td>
<td>Yukawa matrix and lepton flavor violation</td>
<td>K. Tsumura (Osaka)</td>
</tr>
<tr>
<td>14:30-15:00</td>
<td>Search for lepton flavor violation via the intense high-energy muon beam</td>
<td>S. Kanemura (Osaka)</td>
</tr>
<tr>
<td>15:00-15:30</td>
<td>Exploring neutrino models at high energy scale from various processes</td>
<td>T. Shindo (KEK)</td>
</tr>
</tbody>
</table>

### Muon LFV Experiments

<table>
<thead>
<tr>
<th>Time</th>
<th>Experiment</th>
<th>Speaker</th>
</tr>
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<tbody>
<tr>
<td>15:45-16:15</td>
<td>MEG</td>
<td>M. Grassi (Pisa)</td>
</tr>
<tr>
<td>16:15-16:45</td>
<td>MECO</td>
<td>Y. Semertzidis (BNL)</td>
</tr>
<tr>
<td>16:45-17:15</td>
<td>PRIME</td>
<td>Y. Kuno (Osaka)</td>
</tr>
</tbody>
</table>
### Three Generations…

<table>
<thead>
<tr>
<th></th>
<th>leptons</th>
<th>quarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>G=1</td>
<td>$e$</td>
<td>$\nu_e$</td>
</tr>
<tr>
<td>G=2</td>
<td>$\mu$</td>
<td>$\nu_\mu$</td>
</tr>
<tr>
<td>G=3</td>
<td>$\tau$</td>
<td>$\nu_\tau$</td>
</tr>
</tbody>
</table>

**Neutrino Oscillations:**

\[
Rate \propto \left[ \frac{\Delta m^2}{M_W^2} \right]^2
\]

**Y. Okada:** “Large effects are expected in well motivated SUSY models”

**MECO is searching for the COHERENT conversion of $\mu \rightarrow e$ in the field of a nucleus (Al).**
Supersymmetry Predictions for $\mu \rightarrow e$ Conversion

<table>
<thead>
<tr>
<th>Process</th>
<th>Current Limit</th>
<th>SUSY level</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mu^- N \rightarrow e^- N$</td>
<td>$10^{-12}$</td>
<td>$10^{-15}$</td>
</tr>
<tr>
<td>$\mu^+ \rightarrow e^+ \gamma$</td>
<td>$10^{-11}$</td>
<td>$10^{-13}$</td>
</tr>
<tr>
<td>$\tau \rightarrow \mu \gamma$</td>
<td>$10^{-6}$</td>
<td>$10^{-9}$</td>
</tr>
</tbody>
</table>

Higgs field mixing parameter

$R_{\mu e}$

MEOC single event sensitivity

J. Hisano et al.
History of Lepton Flavor Violation Searches

- $\mu^- N \rightarrow e^- N$
- $\mu^+ \rightarrow e^+ \gamma$
- $\mu^+ \rightarrow e^+ e^+ e^-$

$K^0 \rightarrow \mu^+ e^-$
$K^+ \rightarrow \pi^+ \mu^+ e^-$

MECO Goal

MEGA
E871
SINDRUM2
PSI-MEG Goal

MECO Goal

PRIME
Marco GRASSI (INFN-Pisa)

**Easy signal selection with \( \mu^+ \) at rest**

\[
\begin{align*}
\theta_{e\gamma} &= 180^\circ \\
e^+ &\rightarrow \mu^+ \\
E_{e} &= E_{\gamma} = 52.8 \text{ MeV} \\
T_e &= T_{\gamma}
\end{align*}
\]

**Single Event Sensitivity**

\[ BR_{\text{acc}} \propto R_\mu^2 \times \Delta E_e \times \Delta E_\gamma^2 \times \Delta \theta_{e\gamma}^2 \times \Delta t_{e\gamma} \approx 3 \times 10^{-14} \]

**Background**

\[ BR (\mu \rightarrow e\gamma) \approx 1 \times 10^{-13} \]

**Upper Limit at 90\% CL**

\[ BR (\mu \rightarrow e\gamma) \approx 1 \times 10^{-13} \]

**Discovery**

4 events (\( P = 2 \times 10^{-3} \)) correspond \( BR = 2 \times 10^{-13} \)
Yannis SEMERTZIDIS (BNL)

MECO at BNL

Muon Stopping Target
Superconducting Transport Solenoid (2.5 T – 2.1 T)
Production Solenoid (5.0 T – 2.5 T)
Production Target

Straw Tracker
Crystal Calorimeter
Superconducting Detector Solenoid
Collimators

Funding approved starting in FY05
Complete the final design june 06
Start magnet channel building dec 07
Acceptance testing dec 08

Discovery: 5 events for $10^{-16}$

Proton Beam 40TP/s
PRISM/PRIME

PRISM is a dedicated muon source of high intensity, narrow energy width, and high purity $10^{11}$-$10^{12} \mu/s$.

The PRISM-FFAG ring construction has started at Osaka University (5 years).

PRIME is to search for mu-e conversion at a sensitivity of $10^{-18}$ with PRISM.

LoI’s have been submitted to J-PARC and positively evaluated.

The project is open for new collaborators.
Lepton Flavor Violation

Many theoretical models beyond the Standard Model predict LFV, and some of them LNV.

The expected branching ratios span a few orders of magnitude near the present experimental limits.

The comparison among the processes constitutes a tool to single out the right model.

\textit{MEG (}$$\mu \rightarrow e\gamma$$\text{), MECO and PRIME (}$$\mu$$-e conversion\text{) are under construction or design. They will provide results in a few year, with a great discovery potential.}
# Muon g-2 and EDM

**Friday July 30**

<table>
<thead>
<tr>
<th>Time</th>
<th>Topic</th>
<th>Speaker</th>
</tr>
</thead>
<tbody>
<tr>
<td>14:00-14:25</td>
<td>Muon g-2 experiment</td>
<td>J. Miller (Boston)</td>
</tr>
<tr>
<td>14:25-14:55</td>
<td>Hadronic contribution to muon g-2</td>
<td>K. Hagiwara (KEK)</td>
</tr>
<tr>
<td>14:55-15:30</td>
<td>EDMs in the SUSY GUTs</td>
<td>J. Hisano (Tokyo)</td>
</tr>
<tr>
<td>15:45-16:10</td>
<td>Muon EDM experiment</td>
<td>J. Miller (Boston)</td>
</tr>
</tbody>
</table>
\[ \Delta a_\mu(ee) = (23.9 \pm 9.9) \times 10^{-10} \quad 2.4 \text{ s.d.} \]

\[ \Delta a_\mu(\tau) = (7.6 \pm 8.9) \times 10^{-10} \quad 0.9 \text{ s.d.} \]
\[ \Delta a_\mu(ee) = (23.9 \pm 9.9) \times 10^{-10} \quad 2.4 \text{ s.d.} \]

Difference between 2 and 3 s.d.! Need to run again…
New proposal to BNL for a factor >2 improvement in total error
\[ \Delta a_\mu (ee) = (23.9 \pm 9.9) \times 10^{-10} \quad 2.4 \text{ s.d.} \]

LOI to J-PARC for a factor >10 improvement in total error
K. Hagiwara (KEK): A further factor of 2 to 3 improvement in theory error is possible...
SUSY Dark Matter

Following Ellis, Olive, Santoso, Spanos.
Plot by K. Olive
SUSY Dark Matter

Following Ellis, Olive, Santoso, Spanos. Plot by K. Olive.
SUSY: EDM, MDM and Transition Moments (LFV) are in Same Matrix
Expected Muon EDM Value from $a_\mu$

$$L_{DM} = \frac{1}{2} \left[ D \bar{\mu} \sigma^{\alpha \beta} \frac{1 + \gamma_5}{2} + D^* \bar{\mu} \sigma^{\alpha \beta} \frac{1 - \gamma_5}{2} \right] \mu F_{\alpha \beta},$$

where $\sigma^{\alpha \beta} = \frac{1}{2} \left[ \gamma^\alpha, \gamma^\beta \right]$ and

$$a_\mu \frac{e}{2m_\mu} = \Re D,$$

$$d_\mu = \Im D,$$

$$D^{SUSY} = \left| D^{SUSY} \right| e^{i\phi_{CP}}$$

$$d_\mu = 2 \times 10^{-22} \text{ e} \cdot \text{cm} \frac{a^{SUSY}_\mu}{25 \times 10^{-10} \tan(\phi_{CP})}$$
Baryon-AntiBaryon asymmetry in Universe...

Conclusions

• $d_\mu \approx 10^{-24} \text{ e} \cdot \text{cm}$ (and $d_{\text{deuteron}} < 10^{-27} \text{ e} \cdot \text{cm}$) have exceptional physics reach

• Deuteron proposal to BNL PAC being prepared now- most systematic problems for muons will be solved in developing this experiment. Begins 4 years after funding, runs for two years.

• Techniques perfected for deuteron will carry over to the muon case in the future

• J-PARC has the potential to provide the needed muon flux (LOI’s submitted for Muon EDM and PRISM II)

• At $10^{-24} \text{ e} \cdot \text{cm}$ muon EDM is statistics limited- with planned increases in flux could go to $10^{-26} \text{ e} \cdot \text{cm}$ or better
CEDMs in SUSY SU(5) GUT with right-handed neutrinos

For $m_0 = 500 GeV$, $a_0 = 0$ $m_g = 500 GeV$, $\tan \beta = 10$ (JH, Kakizaki, Nagai, Shimizu)

Here, diagonal right-handed neutrino mass matrix is assumed, and then parameters in neutrino sector are given by oscillation data.

EDMs in SUSY GUTs
J. Hisano (ICRR, Univ. of Tokyo)
### Precision measurement of muon properties

**Tuesday July 27**

<table>
<thead>
<tr>
<th>Time</th>
<th>Description</th>
<th>Speaker</th>
</tr>
</thead>
<tbody>
<tr>
<td>11:30-12:00</td>
<td>Measurement of the transverse e^+ polarization from the decay of polarized mu^+ and its implications on G_F and TRI (time reversal invariance)</td>
<td>W. Fetscher (ETH Zurich)</td>
</tr>
<tr>
<td>12:00-12:30</td>
<td>Muon lifetime measurement with pulsed muon beam</td>
<td>D. Tomono (KEK)</td>
</tr>
<tr>
<td>14:00-14:35</td>
<td>muLAN (muon lifetime) and muon capture</td>
<td>F. Gray (Berkeley)</td>
</tr>
</tbody>
</table>
Measurement of the transverse $e^+$ polarization from the decay of polarized $\mu^+$ and its implications on $G_F$ and TRI (time reversal invariance)

W. Fetscher (ETH Zurich)

Improvement of TRI limit by 10
Muon lifetime measurement with pulsed muon beam

\[
\Delta \alpha / \alpha \sim 0.045 \text{ ppm} \quad \Delta G_F / G_F \sim 9 \text{ ppm} \quad \Delta M_Z / M_Z \sim 22 \text{ ppm}
\]

muon life time

pulsed muon method to allow
\(~10000\) muon stops in a time window
muLAn (muon lifetime) and muon capture

F. Gray (Berkeley)

muon lifetime
to more than $10^{12}$ statistics ($\Delta G_F < 0.5$ ppm)

<table>
<thead>
<tr>
<th>Spatial separation</th>
<th>Bunched muons</th>
</tr>
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<tbody>
<tr>
<td>FAST</td>
<td>$\mu$Lan</td>
</tr>
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</table>

muon capture

$g_p$ (weak probe of strong interaction physics)
protiumu gas (0.01 LHD) and TPC
Summary of WG4, Part Two.

NuFact04 WG4 - Intense Muon Physics

• Most muon physics experiments are currently statistics limited.

• LFV, Muon g-2, EDMs, and Muon Decay Parameter Experiments are very exciting.

• The discovery potential is great!
SUSY Dark Matter

Following Ellis, Olive, Santoso, Spanos.
Plot by K. Olive