mu-e conversion
COMET at J-PARC

Satoshi MIHARA
KEK, Japan
Outline

• Introduction

• COMET at J-PARC
  – Muon beam at J-PARC
  – Detector
  – Sensitivity and Background
  – R&D Status
  – Schedule and Cost

• Summary
Introduction
Introduction
Lepton Flavour Violation of Charged Leptons

Neutrino Mixing (confirmed) Soon!

$\nu_e \leftrightarrow \nu_\mu \leftrightarrow \nu_\tau$

$\nu_e \leftrightarrow \nu_\mu \leftrightarrow \nu_\tau$

$\nu_e \rightarrow \nu_\mu \rightarrow \nu_\tau$

$\nu_e \rightarrow \nu_\mu \rightarrow \nu_\tau$

Charged Lepton Mixing (not observed yet)

$\mu \leftrightarrow \tau$

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$\mu \leftrightarrow \tau$
What is a $\mu$-e Conversion?

1s state in a muonic atom

Neutrino-less muon nuclear capture

($=\mu$-e conversion)

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

lepton flavors changes by one unit

nuclear muon capture

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

$B(\mu^- N \rightarrow e^- N) = \frac{\Gamma(\mu^- N \rightarrow e^- N)}{\Gamma(\mu^- N \rightarrow \nu N)}$
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>

$$\frac{B(\mu N \rightarrow eN)}{B(\mu \rightarrow e\gamma)} \sim \frac{1}{100}$$
μ-e conversion Signal

- $E_{\mu e} \sim m_\mu - B_\mu$
  - $B_\mu$: binding energy of the 1s muonic atom

- Comparison with $\mu \rightarrow e\gamma$ (and $\mu \rightarrow 3e$) from the viewpoint of experimental technique

<table>
<thead>
<tr>
<th>Background</th>
<th>Challenge</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mu \rightarrow e\gamma$ and $\mu \rightarrow 3e$</td>
<td>Accidental</td>
</tr>
<tr>
<td>$\mu$-e conversion</td>
<td>Beam</td>
</tr>
</tbody>
</table>

- 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.

- Potential to discriminate different models through studying the $Z$ dependence

R. Kitano, M. Koike, Y. Okada

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The SINDRUM-II Experiment (at PSI)

Published Results

\[ B(\mu^- + Au \rightarrow e^- + Au) < 7 \times 10^{-13} \]

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.
The MELC and MECO Proposals

- MELC (Russia) and then MECO (the US)

- To eliminate beam related background, beam pulsing was adopted (with delayed measurement)

- To increase a number of muons available, pion capture with a high solenoidal field was adopted

- For momentum selection, curved solenoid was adopted

The MECO Experiment

at BNL

Cancelled in 2005

→ mu2e @ Fermilab
Mu2E @ Fermilab

Fermilab Accelerators

- The mu2e Experiment at Fermilab.
  - Proposal has been submitted.
  - After the Tevatron shut-down
    - uses the antiproton accumulator ring
    - the debuncher ring to manipulate proton beam bunches
cLFV Search Experiment

- cLFV search is as important as \( \nu \) oscillation measurements to find a clue to understand
  - SUSY-GUT
  - Neutrino See-saw

- MEG result is expected to appear pretty soon

- Need other experiment(s) to confirm it
  - Using “different” physics process (with better sensitivity)!

- COMET (COherent Muon Electron Transitiition) submitted a proposal to J-PARC in 2008
COMET

An Experimental Search For Lepton Flavor Violating

$\mu^- - e^-$ Conversion at Sensitivity of $10^{-16}$
Collaboration as of Oct/2008

D. Bryman
Department of physics and astronomy, University of British Columbia, Vancouver, Canada,
R. Palmer
Department of Physics, Brookhaven National Laboratory, USA,
E. Hungerford
Department of Physics, University of Houston, USA
Y. Iwashita
Institute for Chemical Research, Kyoto University, Kyoto, Japan
V. Kalinnikov, A. Moiseenko, D. Mzhavia, J. Pontecorvo, B. Sabirov, Z. Tsamaiaidze,
and P. Evtukhovitch
JINR, Dubna, Russia
M. Aoki, Y. Arimoto, Md.I. Hossain, T. Itahashi, Y. Kuno, A. Sato, M. Yoshida
Department of Physics, Osaka University, Japan
J. Sato, M. Yamanaka
Department of Physics, Saitama University, Japan
Y. Takubo
Department of Physics, Tohoku University, Japan
Y. Igarashi, S. Ishimoto, S. Mihara, H. Nishiguchi, T. Ogitsu, M. Tomizawa,
A. Yamamoto, and K. Yoshimura
High Energy Accelerator Research Organization (KEK), Japan
T. Numao
TRIUMF, Canada
Overview of the COMET Experiment

- **Proton Beam**
  - \( p \rightarrow \pi \rightarrow \mu \)

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

- **The Detector**
  - Muon Stopping Target
  - Electron Transport
  - Electron Detection
Requirements for the Muon Beam

- Backgrounds
  - Beam Pion Capture
    - $\pi^+ + (A,Z) \rightarrow (A,Z-1)^* \rightarrow \gamma + (A,Z-1)$
    - $\gamma \rightarrow e^+ e^-$
  - Prompt timing $\rightarrow$ good Extinction!
    - $\mu^-$ decay-in-flight, $e^-$ scattering, neutron streaming
- Requirements from the experiment
  - Pulsed
  - High purity
  - Intense and high repetition rate

**Muon Capture (MC)**

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

**Muon Decay in Orbit (MDO)**

$$\mu^- \rightarrow e^- \nu \bar{\nu}$$

**SIGNAL**

$$\mu^- + (A, Z) \rightarrow e^- + (A, Z)$$
Requirements for the Proton Beam

- Proton beam structure for the mu-e conversion search
  - 100nsec bunch width, 1.1μsec bunch-bunch spacing
  - 8GeV to suppress anti-proton background
  - < 10^{11} proton/bunch, limited by the detector performance
  - Repetition rate as high as possible within tolerable CR background
- Extinction
  - Residual protons in between the pulses should be < 10^{-9}

\[
N_{bg} = NP \times R_{ext} \times Y_{\pi}/P \times A_{\pi} \times P_{\gamma} \times A
\]

- NP : total # of protons (~10^{21})
- R_{ext} : Extinction Ratio (10^{-9})
- Y_{\pi}/P : \pi yield per proton (0.015)
- A_{\pi} : \pi acceptance (1.5 x 10^{-6})
- P_{\gamma} : Probability of \gamma from \pi (3.5x10^{-5})
- A : detector acceptance (0.18)

\[BR=10^{-16}, N_{bg} < 0.12 \rightarrow \text{Extinction} < 10^{-9}\]
Proton Acceleration at J-PARC

- Proton acceleration in
  - LINAC
  - Booster (RCS)
  - Main Ring

- Nominal scheme
  - RCS: h=2
  - MR: h=9
    - 8 buckets filled
    - 1 empty bucket, used for kicker excitation

- MR RF cavities are designed for this scheme
  - h=18 optional by removing capacitors on cavities
  - Need long shutdown to change the configuration

8 filled buckets out of 9 buckets
Proton Acceleration for COMET
Proposed Scheme (I)

- RCS: h=2 with one empty bucket
- MR: h=9 with 5 empty buckets
- Bunched slow extraction
  - Slow extraction with RF cavity ON, 210kV

Realization of an empty bucket in RCS by using the chopper in Linac

- Simple solution
  - No need of hardware modification
- Heavier heat load in the scraper
- Possible leakage of chopped beam in empty buckets

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Pion Production Target

- low-E pions
  - for low-E muons to stop
  - Backward extraction
- pion yield is proportional to $T_{\text{proton}}$
  - pion yld is proportional to Beam Power
- High-Z Metal Rod
  - 12-mmØ x 16-cm
  - 3-4 kW on the target
  - Water cooling or Radiation cooling

![Graph showing pion production yields at 3m downstream of the target](Image)
Pion Capture

- 5 T at the target position
  - capture $p_t < 120$ MeV/c
- Radiation Shield
  - < 100 W on SC coil
  - 3-4 kW @ target
  - 35 kW @ W Shield
  - $2 \times 10^{-5}$ W/g @ coil
- Yields
  - $0.05(\pi + \mu)/8$-GeV-proton

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**π-Capture Solenoid**

- Heat-load density: $2 \times 10^{-5}$ W/g behind W shield
- Utilize Al stabilized SC cable to reduce a heat load to the cold mass.
  - 2-layers x 3-cm$^3$ Al SC coil: 10 W
    - $B = 5$T
    - 80 A/mm$^2$
    - Load line ratio: 0.63
  - 12.3 MJ, 12.5 kJ/kg

30 mm x 5 mm
NbTi
1.28 mm diameter
32 strands
NbTi: Cu: Al = 19%: 34%: 46%
density: 4.0 g/cm$^3$

Al-SC: one of world leading expertise of KEK
Guide π’s until decay to μ’s

Suppress high-p particles
- μ’s: $p_\mu < 75$ MeV/c
- e’s: $p_e < 100$ MeV/c
High-p Suppression

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

\[ D[m] = \frac{1}{0.3 \times B[T]} \times \frac{s}{R} \times \frac{p_t^2 + \frac{1}{2}p_i^2}{p_i} \]

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

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

\[ \delta p/\delta x = 1 \text{ MeV/c/cm} \]

See “Classical Electrodynamics”, J.D.Jackson Ch.12-Sec.4
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>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td># of μ /proton</td>
<td>0.0071</td>
</tr>
<tr>
<td># of stopped muons/proton</td>
<td>0.0018</td>
</tr>
<tr>
<td># of μ of pμ &gt;75 MeV/c /proton</td>
<td>2x10^{-4}</td>
</tr>
</tbody>
</table>
The COMET Detector
The COMET Detector

to detect and identify 100 MeV electrons.

under a solenoid magnetic field.

to stop muons in the muon stopping target

to eliminate low-energy beam particles and to transport only ~100 MeV electrons.
Muon Stopping Target

- Light material for delayed measurement
  - Aluminum: $\tau_{\mu^-} = 0.88 \mu s$
- Thin disks to minimize electron energy loss in the target
  - $R = 100 \text{ mm}, 200 \mu \text{m}^4, 17 \text{ disks}, 50 \text{ mm spacing}$
- Graded B field for a good transmission in the downstream curved section.
- Good $\mu$-Stopping efficiency: $\varepsilon = 0.3$
  - stopped-muon yields: $\sim 0.002 \mu\text{s}/\text{proton}$
Curved Solenoid Spectrometer

- Torus drift for rejecting low energy DIO electrons.
  \[ D[m] = \frac{1}{0.3 \times B[T]} \times \frac{s}{R} \times \frac{p_i^2 + \frac{1}{2}p_t^2}{p_t} \]
  - rejection \(\sim 10^{-6}\): < 10kHz
- Good acceptance for signal electrons
  - 20%
Electron Detectors

- Rate < 10-100 kHz
- Straw-tube tracker to measure electron momentum
  - 5 Planes with 48cm distance, $\sigma_p = 230$ keV/c
  - One plane has 2 views (x and y) with 2 layers per view.
  - A straw tube has 25mm thick, 5 mm diameter.
  - Should work in vacuum and under a magnetic field.
  - 250$\mu$m position resolution.
- Crystal calorimeter for Trigger
  - GSO or PWO
Cosmic Ray Shields

- Both passive and active shields are used
- Passive shields
  - 2 meter of concrete and 0.5 m thick of steel
- Active shields
  - layers of scintillator veto counters (~1% inefficiency)
Signal Sensitivity

$2 \times 10^7$ sec running

- Single event sensitivity

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

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

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<table>
<thead>
<tr>
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<tbody>
<tr>
<td>total protons</td>
<td>$8 \times 10^{20}$</td>
</tr>
<tr>
<td>muon transport efficiency</td>
<td>0.0071</td>
</tr>
<tr>
<td>muon stopping efficiency</td>
<td>0.26</td>
</tr>
<tr>
<td># of stopped muons</td>
<td>$1.5 \times 10^{18}$</td>
</tr>
</tbody>
</table>

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

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

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

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

\[ \alpha (E_{\text{end}} - E_e)^5 \]

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DIO Background

a number of events for $1.1 \times 10^{18}$ stopped muons.
Beam Related Background Rejection

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

<table>
<thead>
<tr>
<th>Component</th>
<th>Requirement</th>
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<tbody>
<tr>
<td>Momentum Selection at the Muon Transport</td>
<td>$p_\mu &lt; 75$ MeV/c</td>
</tr>
<tr>
<td>Electron Energy Cut</td>
<td>$104.0 - 105.2$ MeV uncorrected</td>
</tr>
<tr>
<td>Electron Transverse Momentum Cut</td>
<td>$p_T &gt; 52$ MeV/c</td>
</tr>
<tr>
<td>Timing Cut and Beam Extinction</td>
<td>$10^{-9}$</td>
</tr>
<tr>
<td>Beam Channel Length</td>
<td>(pion decay)</td>
</tr>
</tbody>
</table>

(pion decay)
Radiative Pion Capture
- pion prod. rate: $1 \times 10^{-5}$
- pion survival: $2 \times 10^{-3}$
- $E_p > 104$ MeV with conversion: $6.3 \times 10^{-6}$
- beam extinction: $10^{-9}$
- total is $0.12$ events at $10^{-16}$.

Muon Decay in Flight
- $p_\mu > 77$ MeV/c: $2 \times 10^{-4}$/proton
- muon decay prob.: $3 \times 10^{-2}$
- $E_\mu > 104$ MeV & $p_\mu > 52$ MeV/c: $< 10^{-8}$
- beam extinction: $10^{-9}$
- total is $0.02$ events at $10^{-16}$.

Pion Decay in Flight
- $\pi \rightarrow e^+\nu$ branching ratio: $10^{-4}$
- $p_\pi > 60$ MeV/c to make $E_e > 104$ MeV: $5 \times 10^{-6}$/proton
- $E_e > 104$ MeV & $p_\pi > 52$ MeV/c: $5 \times 10^{-6}$
- beam extinction: $10^{-9}$
- total is $0.001$ events at $10^{-16}$.

Beam Electrons
- $p_e > 100$ MeV/c: $10^{-8}$/proton
- scat. prob.: $10^{-5}$
- beam extinction: $10^{-9}$
- total is $0.08$ events at $10^{-16}$.

Neutron induced
- neutrons through beamline.
- $E_n > 100$ MeV: $3 \times 10^{-7}$/proton
- $E_e > 100$ MeV: $10^{-7}$
- beam extinction: $10^{-9}$
- total is $0.024$ events at $10^{-16}$.

Antiproton induced
- eliminate high-energy antiprotons by curved solenoid.
- absorb low-energy antiprotons by 120 μm beryllium foil placed in the middle of beamline.
- eliminate backgrounds from antiproton annihilation above.
- total is $0.007$ events at $10^{-16}$.

Cosmic ray Background
- eliminate by passive and active shields.
- $10^{-4}$ veto inefficiency assumed.
- total is $0.04$ events for $2 \times 10^7$ sec (a duty factor 0.2)
## Background Rejection Summary

<table>
<thead>
<tr>
<th>Backgrounds</th>
<th>Events</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Muon decay in orbit</td>
<td>0.05</td>
<td>230 keV/c resolution</td>
</tr>
<tr>
<td>Radiative muon capture</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>Muon capture with neutron emission</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>Muon capture with charged particle emission</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>(2) Radiative pion capture*</td>
<td>0.12</td>
<td>prompt</td>
</tr>
<tr>
<td>Radiative pion capture</td>
<td>0.002</td>
<td>late arriving pions</td>
</tr>
<tr>
<td>Muon decay in flight*</td>
<td>&lt;0.02</td>
<td></td>
</tr>
<tr>
<td>(2) Pion decay in flight*</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>Beam electrons*</td>
<td>0.08</td>
<td></td>
</tr>
<tr>
<td>Neutron induced*</td>
<td>0.024</td>
<td>for high energy neutrons</td>
</tr>
<tr>
<td>Antiproton induced</td>
<td>0.007</td>
<td>for 8 GeV protons</td>
</tr>
<tr>
<td>(3) Cosmic-ray induced</td>
<td>0.10</td>
<td>$10^{-4}$ veto &amp; $2 \times 10^7$ sec run</td>
</tr>
<tr>
<td>Pattern recognition errors</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>0.4</td>
<td></td>
</tr>
</tbody>
</table>

BG with asterisk needs beam extinction.
R&D Status
R&D Status

- Straw-tube tracker
  - Done by Osaka group for MECO

- Crystal calorimeter

- Transport Solenoid

- Extinction Measuring Device R&D
  - Gas Cherenkov + Gated PMT

- Extinction measurement at J-PARC MR
Straw-tube Tracker R&D

- **Seamless type tube (I.S.T.)**
  - Thickness: 25 μm
  - Diameter: 5mm
  - Material: polyimide+carbon
  - Resistance: 6MΩ/sq

- **Prototype Straw-tube chamber**

Beam test using 2.0GeV/c pion beam in 2002
Calorimeter R&D

- GSO crystal for PET use
  - Stack in 3D
  - Light loss across the connection
- Agreement btw data & MC
- Need further study
  - Stacking method
  - Readout
  - Radiation hardness?
Transport Solenoid Design
Extinction Measuring Device

- Monitor extinction level online by using a Gas Cherenkov detector with gating PMTs
  - Blind to proton beam core, active only in between proton pulses

Aiming at
- Repetition ~1MHz
- On/off ratio <10^{-6}
- Long-term operation

![Graph of Gas Scintillation Yields]

![Diagram of detector circuit]

280V, 10kHz, fall t ~100nsec
Extinction Measurement using Secondary Beam

- Measure secondary particle time structure relative to a reference signal from the MR
  - MR RF signal in the experimental area
  - Beam line hodoscope counters at the K1.8BR line
    - Support by E15/E17 group
  - MR operation with empty buckets
  - Bunched slow extraction

- Count the number of secondary particles as a function of time
  - Particle identification
    - TOF
  - Integration for \( \sim 10^3 \) seconds supposing 1MHz counting rate

Delayed reference signals  Counter signal
Extinction Measurement

- Utilize beam monitor in the abort line
- Single bunch operation of the MR
  - Look at the empty bucket before the filled one
  - Detector that can count the number of protons

- Two layers of 2mm scintillator hodoscopes
  - Support by thin carbon fiber plates
  - Read by Multi-anode PMT through optical fibers
  - Operated in the beam line vacuum
Schedule and Construction Cost

Funding starting

<table>
<thead>
<tr>
<th>Year</th>
<th>Activity</th>
<th>Cost (MJPY)</th>
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</thead>
<tbody>
<tr>
<td>1st</td>
<td>design &amp; order of SC wires</td>
<td>130</td>
</tr>
<tr>
<td>2nd</td>
<td></td>
<td>230</td>
</tr>
<tr>
<td>3rd</td>
<td></td>
<td>190</td>
</tr>
<tr>
<td>4th</td>
<td>engineering run</td>
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</tr>
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<td>5th</td>
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<td>6th</td>
<td>physics run</td>
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<tr>
<td></td>
<td>Superconducting Solenoid</td>
<td>2,420</td>
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<tr>
<td></td>
<td>Pion Capture Solenoid</td>
<td>(870)</td>
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<tr>
<td></td>
<td>Curved Muon Transport Solenoid</td>
<td>(380)</td>
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<td></td>
<td>Muon-Stopping Target Solenoid</td>
<td>(330)</td>
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<td></td>
<td>Curved Solenoid Spectrometer</td>
<td>(370)</td>
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<td>Detector Solenoid</td>
<td>(290)</td>
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<td></td>
<td>SC Solenoid Extension (20 m)</td>
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<td></td>
<td>Tracking Detector</td>
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<td>Electron Calorimeter</td>
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<td></td>
<td>Cosmic Ray Shield</td>
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<td></td>
<td>Data Acquisition and Trigger</td>
<td>50</td>
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<td></td>
<td>Installation and Integration</td>
<td>200</td>
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<td></td>
<td><strong>Total</strong></td>
<td><strong>4,440</strong></td>
</tr>
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</table>

100 JPY = 1.23 CHF as of 15/Nov/2008
Summary

- New experiment (COMET) to search for mu-e conversion at J-PARC

- COMET aims at achieving a sensitivity of $10^{-16}$
  - High-intensity, high-purity pulsed proton beam at J-PARC
  - Curved solenoid muon transport/spectrometer to suppress backgrounds efficiently

- R&D work in progress
  - Detector
  - Magnet
  - Proton beam
    - Beam structure
    - Extinction

Do Join COMET Now!

17/Nov/2008
Backup
High-frequency Chopper

<table>
<thead>
<tr>
<th>Beam dumps</th>
<th>0-deg</th>
<th>30-deg</th>
<th>90-deg</th>
<th>100-deg</th>
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<tbody>
<tr>
<td>1st stage:</td>
<td>Until Jul., 2007</td>
<td>0.6 kW</td>
<td>0.1 kW</td>
<td>N/A</td>
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<td>2nd stage:</td>
<td>From Sep., 2007</td>
<td>0.6 kW</td>
<td>5.4 kW</td>
<td>0.6 kW</td>
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</tbody>
</table>

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RCS Bunch Structure

Ring bunch structure in RCS
Circulating frequency ~ 0.5 MHz

Chop!

Micro-bunch structure
324 MHz

Intermediate-bunch structure
~1 MHz

Macro-bunch structure
25 Hz

RCS

RFQ

Bunch structure

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Proposed Scheme (II) & (III)

- Space charge tune shift is half of (1)
- Longitudinal emittance is twice of (1)
- NO EMPTY BUCKET IN RCS
- NO EMPTY BUCKET BOTH IN RCS AND MR
- RCS RF system needs minor modification (low level RF)

- NO EMPTY BUCKET BOTH IN RCS AND MR
- Space charge tune shift is half of (1)
- LARGE MODIFICATION OF MR RF SYSTEM IS NECESSARY
- Long bunch
Design of Muon Transport Beamline

(preliminary)

Solenoid field

Compensation field

Inner radius

17/Nov/2008

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Additional Extinction Means

- AC-dipole
- @ primary beamline
- $f_{\text{extinction}} \sim 1/100$
- collaboration with µ2e

- Bunch Cleaner
  - in MR
  - tested at AGS for MECO