mu-e conversion search experiment
COMET at J-PARC

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Outline

• J-PARC Introduction
• COMET at J-PARC
  – Proton/Muon beam at J-PARC
  – Detector
  – Sensitivity and Background
  – (R&D Status)
  – Schedule and Cost
• Summary
J-PARC Introduction

• What is J-PARC (Japan Proton Acceleration Research Complex)?
  – Joint project between JAEA and KEK
  – New and exciting accelerator research facility, using MW-class high power proton beams at both 3 GeV and 30 GeV.
  – Various secondary particle beams
    • neutrons, muons, kaons, neutrinos, etc. produced in proton-nucleus reactions
  – Three major scientific goals using these secondary beams
    • Particle and Nuclear physics
    • Materials and life sciences
    • R&D for nuclear transformation (in Phase 2)
  – The anticipated goal is 1 MW
J-PARC Accelerator

Commissioning Status

Linac

J-PARC Facility (KEK/JAEA)

South to North

Neutrino Beams (to Kamioka)

3 GeV Synchrotron

MR

3 GeV proton

Muons

Neutrons

< 30 GeV proton

Muons

Kaons

Materials and Life Experimental Facility

Hadron Exp. Facility

Bird's eye view in January of 2008
Status of Accelerator

- From 2008 four secondary beams have been obtained exactly on schedule;
  - neutron beams (May, 2008)
  - muon beams (September, 2008)
  - kaon beams (February, 2009)
  - neutrino beams (April, 2009)

\[ \begin{align*}
\text{Linac 181MeV} & \quad \text{Upgrade to 400MeV in 2013} \\
& \quad \text{nEDM measurement proposal} \\
\text{RCS (booster) 3GeV} & \quad \text{120-300 kW operation for Material Life Science Facility} \\
& \quad \text{Particle physics experiments using muon} \\
\text{MR (Main Ring) 30 GeV} & \quad \text{100-150 kW operation with fast extraction for T2K} \\
& \quad \text{10kW operation with slow extraction for 2ndary beam expts}
\end{align*} \]
An Expected Beam Power Curves
defined before the earthquake

PMR (8-bunch@30GeV) = 1.6 x PRCS / MR CYCLE

( ): Beam transfer ratio from RSC to MR

RCS POWER FOR MR

Linac energy upgrade

Earthquake

MR POWER AT 30GeV
(maximum cycle with existing power supply)

0.72MW
J-PARC Damage by Earthquakes

- No damage by Tsunami
- All equipments are standing at where they should be but...
  - Needed to align again
- LINAC/T2K near detector floors were covered by underground water
  - quickly removed when the electricity was recovered
- Many cracks on the wall in tunnels
- Inspection and recovery are in progress
- Plan to provide beam for experiments at the end of this JFY
  - Acceleration test in Dec. 2011!
Revised Beam Power Curves

Operation plan of RCS/MR-FX: made after the earthquake

- Original power upgrade plan of RCS
- 7 month summer/autumn shutdown for installation of ACS, new RFQ and IS.
- 3 month summer shutdown
- Shutdown due to the earthquake
- 200 kW (achieved)
- 145 kW (achieved)

J-PARC Power Expectation [MW]

- RCS power
- MR power

MR Improvements
- New injection kicker, Ring collimator shields, RF (6th fundamental, 2nd higher harmonics)
- Ring collimator upgrade, RF (3rd HH)

JFY
Introduction

mu-e conversion physics
Introduction
Lepton Flavour Violation of Charged Leptons

Neutrino Mixing
(confirmed)

\[ \bar{\nu}_e \quad \bar{\nu}_\mu \quad \bar{\nu}_\tau \]

\[ e \quad \mu \quad \tau \]

Charged Lepton Mixing
(not observed yet)

LFV diagram in Standard Model

\[ \propto (m_\nu / m_W)^4 \]

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

LFV diagram in SUSY

Sensitive to new Physics beyond the Standard Model
What is $\mu$-e Conversion?

1s state in a muonic atom

Neutrino-less muon nuclear capture (= $\mu$-e conversion)

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

muon decay in orbit

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

nuclear muon capture

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

lepton flavors changes by one unit

$$B(\mu^- N \rightarrow e^- N) = \frac{\Gamma(\mu^- N \rightarrow e^- N)}{\Gamma(\mu^- N \rightarrow \nu N')}$$
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 view point 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 \rightarrow e\gamma ) and ( \mu \rightarrow 3e )</td>
<td>Detector performance resolution, high rate</td>
</tr>
<tr>
<td>( \mu - e ) conversion</td>
<td>Beam</td>
</tr>
<tr>
<td></td>
<td>Cosmic</td>
</tr>
<tr>
<td></td>
<td>Beam background</td>
</tr>
</tbody>
</table>

- Improvement of a muon beam is possible, both in purity (no pions) and in intensity (*thanks to muon collider Re3D*). 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
$\mu \rightarrow \gamma \gamma$ and $\mu - e$ conversion
$\mu \rightarrow e\gamma$ and $\mu$-e conversion

- If $\mu \rightarrow e\gamma$ exits, $\mu$-e conv must be
\( \mu \rightarrow e\gamma \) and \( \mu \)-e conversion

- If \( \mu \rightarrow e\gamma \) exits, \( \mu \)-e conv must be
- Even if \( \mu \rightarrow e\gamma \) is not observed, \( \mu \)-e conv may be
  - Loop vs Tree
  - Searches at LHC
µ→eγ and µ-e conversion

- If µ→eγ exits, µ-e conv must be
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What can we learn from cLFV search?

- Mass matrix information of SUSY sleptons
  - How SUSY is breaking?
  - What kind of LFV interactions at GUT scale?

- Off-diagonal components
  - How SUSY is breaking?
  - What kind of LFV interactions at GUT scale?
SUSY-GUT and Seesaw

\[(m^2_L)_{ij} = m^2_0 \delta_{ij}\]  @ Planck mass scale

SUSY-GUT
Yukawa interaction

\[(\Delta m^2_{ij})_{ij} \neq 0\]

SUSY Seesaw Model
Neutrino Yukawa interaction

\[m^2_0 \approx \frac{3m^2_0 + A^2_0}{8\pi^2} h^2 V_{td} V_{ts} \ln \frac{M_{GUT}}{M_{Rs}}\]

CKM matrix

LFV

\[m^2_{\tau} \approx \frac{3m^2_0 + A^2_0}{8\pi^2} h^2 U_{i1} U_{i2} \ln \frac{M_{GUT}}{M_{Rs}}\]

Neutrino oscillation

L.J. Hall, V. Kostelecky, S. Raby, 1986; A. Masiero, F. Borzumati, 1986
cLFV Search and $\nu$ oscillation, $g$-2

Hep-ph/0607263v2 S.Antusch et al
cLFV Search and $\nu$ oscillation, $g$-2

$|\delta_{12}^{LL}| = 10^{-4}$ and $|\delta_{23}^{LL}| = 10^{-2}$

$300 \text{ GeV} \leq M_{\tilde{\ell}} \leq 600 \text{ GeV}$

$200 \text{ GeV} \leq M_2 \leq 1000 \text{ GeV}$

$500 \text{ GeV} \leq \mu \leq 1000 \text{ GeV}$

$10 \leq \tan \beta \leq 50$

$A_U = -1 \text{ TeV}$

$M^*q = 1.5 \text{ TeV}$

and the GUT relations.

B-physics constraints case shown in red

hep-ph/0703035v2 G.Isidori et al
cLFV Search and ν oscillation, g-2

|δ_{12}^{LL}| = 10^{-4} and |δ_{23}^{LL}| = 10^{-2}
300 \text{ GeV} \leq M_{\sim \ell} \leq 600 \text{ GeV}
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Current Bound

This Experiment

~10

0.002

hep-ph/0703035v2 G.Isidori et al
$0\nu\beta\beta$ and $\mu$-$\text{e}$ conversion

- V. Cirigliano et al. PRL 93, 231802 (04)

- $R = B(\mu \rightarrow e)/B(\mu \rightarrow e\gamma)$

- RPV-SUSY
  - $R \gg 10^{-2}$

- LRSM (Left-Right Symmetric Model)
  - $R \sim O(1)$

- Important to measure $R$ to extract $m_{0\nu\beta\beta}$ from $\Gamma_{0\nu\gamma\gamma}$
MEG at PSI Status

- Physics data production started in 2008
- Current published limit $\text{Br}(\mu \rightarrow e\gamma)<2.4 \times 10^{-12}$ (at 90% C.L.) using 2009 and 2010 data
- Further data statistic; 2011 DAQ finished this morning!
- Detector upgrade is under discussion to further sensitivity improvement

![Graph showing likelihood distributions as a function of the $\mu \rightarrow e\gamma$ branching ratio for 2009, 2010, and the combined 2009 + 2010 data sample.](image-url)
## Status of Muon cLFV

<table>
<thead>
<tr>
<th>MEGA</th>
<th>SINDRUM II</th>
<th>MEG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Los Alamos</td>
<td>PSI</td>
<td>PSI</td>
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<tr>
<td>$\mu \rightarrow e \gamma$</td>
<td>$\mu$-$e$ conversion</td>
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</table>

### Pulsed $\mu$ beam (28MeV/c)
- $4 \times 10^7 \text{ s}^{-1}$

### (Cont.) $\mu$ beam (52MeV/c)
- $\sim 10^7 \text{ s}^{-1}$

### Cont. $\mu$ beam (28MeV/c)
- $3 \times 10^7 \text{ s}^{-1}$

### DAQ completed in 1995
- PRD 65, 112002
- UL 1.2 $\times 10^{-11}$

### DAQ completed
- EPJ C47 337-346 (2006)
- UL (Au) $7 \times 10^{-13}$

### DAQ in progress
- PRL 107 (2011) 171801
- UL 2.4 $\times 10^{-12}$
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
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⇒ mu2e @ Fermilab
Mu2E @ Fermilab

- The mu2e Experiment at Fermilab.
  - Proposal has been submitted.
    - CD-1 in Spring 2012
  - After the Tevatron shut-down
    - uses the antiproton accumulator ring
    - the debuncher ring to manipulate proton beam bunches
ESME Simulations – Scenario I

Bunching using Barrier saw-tooth rf and 2.5 MHz rf.
Beam is ready for the Mu2e experiment in \( \approx 33 \) ms after the 3rd injection

Saw-tooth rf using Barrier RF
\( t=0.146 \) sec after the 1st injection

Partial bunching with Barrier rf \( T\approx 0.152 \) sec

\( \sim 100\% \) Duty factor

Capture with 2.5MHz rf,
\( t=0.167 \) sec \( V_{rf} \) (2.5MHz) = 170kV

\( t=0.167 \) sec

\( \sigma_{E(RMS)} \approx 35\text{ns}, \quad \text{FW} \approx 147\text{ns} \)

FW= 180 MeV
\( \sigma_{E(RMS)} = 35\text{MeV} \)

Chandra Bhat

C. Bhat and M. Syphers Mu2e Acc WG meeting Mar 9, 2010
cLFV Search Experiment
cLFV Search Experiment

- cLFV search is as important as high-energy frontier experiments (and $\nu$ oscillation measurements) to find a clue to understand
  - SUSY-GUT
  - Neutrino See-saw
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  – Using “different” physics process (with better sensitivity if possible)!
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- COMET (COherent Muon Electron Transition)
  - Submitted a proposal to J-PARC in 2008 and a CDR in 2009,
  - and obtained Stage-1 approval in July 2009
  - TDR in preparation, will be published in 2011
An Experimental Search For Lepton Flavor Violating $\mu^- - e^-$ Conversion at Sensitivity of $10^{-16}$

http://comet.phys.sci.osaka-u.ac.jp:8080/comet

COMET
70 people from 19 institutes (December 2010)

**Imperial College London, UK**
A. Kurup, J. Pasternak, Y. Uchida, P. Dauncey, U. Egede, P. Dornan

**University College London, UK**
M. Wing, M. Lancaster, R. D’Arcy, S. Cook

**University of Glasgow**
P. Soler

**JINR, Dubna, Russia**
V. Kalinnikov, A. Moiseenko, D. Mzhavia, J. Pontecorvo, B. Sabirov, Z. Tsamaiaidze, and P. Evtukhovich

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E. Hungerford, K. Lau

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**Department of Physics and Astronomy, University of British Columbia, Vancouver, Canada**
D. Bryman
Overview of the COMET Experiment
Overview of the COMET Experiment

- **Proton Beam**
  - $p \rightarrow \pi \rightarrow \mu$
  - 8GeV, $\sim 7 \mu$A

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

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

• Backgrounds
  – Beam Pion Capture
    • \( \pi^+ (A,Z) \rightarrow (A,Z-1)^0 \rightarrow \gamma + (A,Z-1) \gamma \rightarrow e^+ e^- \)
    • *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
Requirements for the Beam

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- **Requirements from the experiment**
  - Pulsed
  - High purity
  - Intense and high repetition rate
Requirements for the Proton Beam

- Proton beam structure for the mu-e conversion search
  - 100nsec bunch width, 1.3 (or 1.7) µsec 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 $< 10^{-9}$

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

- $NP$ : total # of protons ($\sim 10^{21}$)
- $R_{\text{ext}}$ : Extinction Ratio ($10^{-9}$)
- $Y_\pi/P$ : $\pi$ yield per proton (0.015)
- $A_\pi$ : $\pi$ acceptance ($1.5 \times 10^{-6}$)
- $P_\gamma$ : Probability of $\gamma$ from $\pi$ ($3.5\times10^{-5}$)
- $A$ : detector acceptance (0.18)

\[
\text{BR}=10^{-16}, \ N_{bg} \sim 0.1 \rightarrow \ Extinction < 10^{-9}
\]
J-PARC Proton Acceleration for COMET

- RCS: $h=2$ with one empty bucket
- MR: $h=8(9)$ with 4(3) empty buckets
- Bunched slow extraction
  - Slow extraction with RF cavity ON

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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Muon/pion production
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
- Target material
  - High-Z Metal Rod like tungsten or gold
    - Water cooling
  - Graphite
    - Helium gas cooling

Target radius optimization
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
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.
  - Cable dimension: 15mm x 4.7mm

<table>
<thead>
<tr>
<th>Length (mm)</th>
<th>Thickness (mm)</th>
<th>$\rho_{\text{Current}}$ (A/mm$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coil 1</td>
<td>1200</td>
<td>90 (6 layers)</td>
</tr>
<tr>
<td>Coil 2</td>
<td>1400</td>
<td>30 (2 layers)</td>
</tr>
<tr>
<td>Coil 3</td>
<td>600</td>
<td>30 (2 layers)</td>
</tr>
<tr>
<td>Coil 4</td>
<td>300</td>
<td>60 (4 layers)</td>
</tr>
</tbody>
</table>

Al-SC: one of world leading expertise of KEK
Muon transport
Muon Transport
Muon Transport

Guide $\pi$'s until decay to $\mu$'s

Suppress high-p particles

- $\mu$'s: $p_{\mu} < 75$ MeV/c
- $e$'s: $p_e < 100$ MeV/c

Beam Blocker

Beam collimator
High-\(p\) Suppression

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

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

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

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

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

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
  - Inner radius of transport magnet cryostat (175 mm)
- Transport Efficiency

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td># of $\mu$ /proton</td>
<td>0.0071</td>
</tr>
<tr>
<td># of stopped muons/proton</td>
<td>0.0035</td>
</tr>
<tr>
<td># of muons with $p &gt; 75$ MeV/c / proton</td>
<td>$10^{-5}$</td>
</tr>
</tbody>
</table>

Dispersion on the muon beam just before the collimator.

Spectra at the end of the beamline
- (top left) total momentum
- (top right) $p_t$ vs $p_L$
- (bottom left) time of flight
- (bottom right) beam profile

75 MeV/c
The COMET Detector
The COMET Detector

to detect and identify 100 MeV electrons.

Detector Section

under a solenoid magnetic field.

Target Section

to stop muons in the muon stopping target

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

Curved Solenoid
Muon Stopping Target

- Light material for delayed measurement (1st choice)
  - Aluminum: $\tau_{\mu^-} = 0.88$ $\mu$s
- Thin disks to minimize electron energy loss in the target
  - $R = 100$ mm, 200$\mu$m, 17 disks, 50 mm spacing
- Graded B field for a good transmission in the downstream curved section.
- Good $\mu$-Stopping efficiency: $\varepsilon = 0.66$
  - Muon rate $1.5 \times 10^{11}$/sec
  - stopped-muon yields: $\sim 0.0023$ $\mu$/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 (w/o including event selection and trigger acceptance)
  - 20%

60-MeV/c DIO electrons

105-MeV/c \( \mu \)-e electron

Transmission Efficiency graph

Electron Total Energy (MeV) vs. Transmission Efficiency
Electron Detectors

• Rate < 800 kHz
• Straw-tube tracker to measure electron momentum
  – 5 Planes with 48 cm distance, $\sigma_p = 230$ keV/c
    • One plane has 2 views (x and y) with 2 layers per view.
    • A straw tube has 25 mm thick, 5 mm diameter.
  – should work in vacuum and under a magnetic field.
  – <500µm position resolution.
• Crystal calorimeter for Trigger
  – GSO, PWO, LYSO, or new crystals …
Experimental Space
A possible layout

- Discussion in the task force
  - Target and beam dump outside the hall
  - Share the upstream proton transport line with the high p beam line
  - External extinction device in the switch yard
Experimental Space
A possible layout

- Discussion in the task force
  - Target and beam dump outside the hall
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  - External extinction device in the switch yard
Signal Sensitivity
2x10^7 sec running

- 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 2.0x10^{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 0.031.

<table>
<thead>
<tr>
<th>total protons</th>
<th>8.5x10^{20}</th>
</tr>
</thead>
<tbody>
<tr>
<td>muon yield per proton</td>
<td>0.0035</td>
</tr>
<tr>
<td>muon stopping efficiency</td>
<td>0.66</td>
</tr>
<tr>
<td># of stopped muons</td>
<td>2.0x10^{18}</td>
</tr>
</tbody>
</table>

Single event sensitivity

2.6 \times 10^{-17}

90% C.L. upper limit

6.0 \times 10^{-17}
## Background Estimation Summary

<table>
<thead>
<tr>
<th>Background</th>
<th>Events</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiative Pion Capture</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td>Beam Electrons</td>
<td>&lt;0.1</td>
<td>MC stat limited</td>
</tr>
<tr>
<td>Muon Decay in Flight</td>
<td>&lt;0.0002</td>
<td></td>
</tr>
<tr>
<td>Pion Decay in Flight</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>Neutron Induced</td>
<td>0.024</td>
<td>For high E_n</td>
</tr>
<tr>
<td>Delayed-Pion Radiative Capture</td>
<td>0.002</td>
<td></td>
</tr>
<tr>
<td>Anti-proton Induced</td>
<td>0.007</td>
<td>For 8 GeV p</td>
</tr>
<tr>
<td>Muon Decay in Orbit</td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td>Radiative Muon Capture</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>Muon Capture with n Emission</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>Muon Capture with Charged Part. Emission</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>Cosmic-Ray Muons</td>
<td>0.002</td>
<td></td>
</tr>
<tr>
<td>Electrons from Cosmic-Ray Muons</td>
<td>0.002</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>0.34</td>
<td></td>
</tr>
</tbody>
</table>

Assuming proton beam extinction < $10^{-9}$
R&D Status
R&D Status

• Straw-tube tracker
  – Done by Osaka group for MECO
  – being continued at KEK

• Crystal calorimeter

• Transport Solenoid

• Extinction Measurement
  • Device R&D
    • Gas Cherenkov + Gated PMT
  • Extinction measurement at J-PARC MR
R&D Status

SC Magnet & Detector

Al stabilized conductor

Crystal development

Neutron irradiation at a research reactor

Straw-tube tracker
Slow Extraction R&D

- Measure the time structure of the primary proton beam
- Secondary beam at K1.1BR
- 800MeV/c, pion dominant, 200k/spill
- Primary Beam Condition
  - h=9, 3 filled and 6 empty
  - 30GeV
- Bunched Slow Extraction
- Bunch ID using MR Flat Top and RF signals
- Read out
  - Measure secondary beam (~100k sample/spill) for tens of minutes and get $10^8$ samples
Extinction Measurement Result

- Normal beam injection to MR
- Integration over 20 minutes
- Extinction level at $(5.4 \pm 0.6) \times 10^{-7}$
Schedule and Construction Cost

Funding starting

<table>
<thead>
<tr>
<th>Year</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st</td>
<td>design &amp; order of SC wires</td>
</tr>
<tr>
<td>2nd</td>
<td></td>
</tr>
<tr>
<td>3rd</td>
<td></td>
</tr>
<tr>
<td>4th</td>
<td></td>
</tr>
<tr>
<td>5th</td>
<td>engineering run</td>
</tr>
<tr>
<td>6th</td>
<td>physics run</td>
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</table>

1 Oku JPY ~ 0.953 M Euro

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost (Oku JPY)</th>
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<tbody>
<tr>
<td>Proton beam line</td>
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</tr>
<tr>
<td>Proton beam line magnets</td>
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<tr>
<td>Proton beam dump</td>
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<tr>
<td>Radiation shielding for a proton beam line</td>
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<tr>
<td>Superconducting Solenoid</td>
<td>35.7</td>
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<tr>
<td>Detector</td>
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<tr>
<td>Electron tracker</td>
<td>2.1</td>
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<tr>
<td>Electron calorimeter</td>
<td>2.3</td>
</tr>
<tr>
<td>Cosmic ray shield</td>
<td>3</td>
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<tr>
<td>DAQ system</td>
<td>0.5</td>
</tr>
<tr>
<td>Infrastructure</td>
<td></td>
</tr>
<tr>
<td>Refrigeration</td>
<td>4.7</td>
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<tr>
<td>Pion production system and tungsten shielding</td>
<td>2.3</td>
</tr>
<tr>
<td>Civil construction</td>
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<tr>
<td>Extension of the NP experimental hall</td>
<td>3</td>
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<tr>
<td>Total</td>
<td>75</td>
</tr>
<tr>
<td>Total (with 20% contingency)</td>
<td>90</td>
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</tbody>
</table>
Schedule

Budget request to realize;
Construction starts in 2014
Engineering run in 2018

<table>
<thead>
<tr>
<th>Component</th>
<th>2012</th>
<th>2014</th>
<th>2016</th>
<th>2018</th>
<th>2020</th>
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<tbody>
<tr>
<td>Accelerator</td>
<td></td>
<td></td>
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<tr>
<td>Proton Beam line</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pion Capture</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Muon Transport</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Detector</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Infrastructure</td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Run</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- R&D, Preparation
- Construction
- Installation
- Engineering Run
- Physics Run
Yet Another Mu-e conversion Search at J-PARC
DeeMe
µ-e electrons may directly come from a production target.

- An electron analogue of the surface muon.
- Experiment could be very simple, quick and low-cost.

→ DeeMe
DeeMe Overview

- Proton beam from RCS
- Pion production target as a muon stopping target
- Replace the current graphite target with a SiC target
- Si has larger muonic-nuclear capture rate
- Beam line as an electron spectrometer
- Secondary beam-line kicker to remove prompt BG
- Only delayed electrons enter the spectrometer
- S.E.S. $1.5 \times 10^{-14}$ for $2 \times 10^7$ sec DAQ

![Diagram showing experimental setup and beam paths]
DeeMe Overview

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3GeV Proton
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
Backup
Target Material

- $f_c$: Fraction of the atomic capture of muon to the atom of interest
  - single-element material: $f_c = 1$
  - composite material: proportional to $Z$ (Fermi-Teller $Z$ law)
    - Silica-carbide $\text{Si:C}=7:3$

- $f_{MC}$: muonic nuclear-capture rate
  - $(1-f_{MC}) = f_{\text{free-decay}}$ --- useless muons: large $f_{MC}$ is better

- On the other hand, $\tau_\mu \gg 300 \text{ nsec}$ (light $Z$) to avoid the prompt background

Engineering point of view:
- good thermal shock resistance
- high melting point
- good radiation resistance

<table>
<thead>
<tr>
<th>target material</th>
<th>$f_c \times f_{MC}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Graphite</td>
<td>0.08</td>
</tr>
<tr>
<td>Silica-carbide (SiC)</td>
<td>0.46</td>
</tr>
</tbody>
</table>
High-frequency Chopper

Materials and Life Science Experimental Facility

Hadron Beam Facility

Nuclear Transmutation

Linac (330m)

3 GeV Synchrotron (25 Hz, 1MW)

50 GeV Synchrotron (0.75 MW)

Neutrino to Kamiokande

J-PARC = Japan Proton Accelerator Research Complex
High-frequency Chopper
Additional Extinction Means

• AC-dipole
• @ primary beamline
• $f_{\text{extinction}} \sim 1/100$
• collaboration with mu2e

• Bunch Cleaner
  • in MR
  • tested at AGS for MECO
Background

- Event signature
  - $P_e = 105$ MeV/c
  - $T_e > \sim \mu$sec

- Any particle production $1 \mu$sec later than the prompt proton timing?
  - Only decay product of $\mu$
    - Michel electron $P_e < 55$ MeV/c

- If any off-timing proton exists, that can be BG
  - Extinction $< 10^{-14}$