The COMET experiment: A search for muon-to-electron conversion at J-PARC

XXXVII-th International Conference on High Energy Physics
2-9/Jul./2014, Valencia

Hajime NISHIGUCHI, KEK
On behalf of the COMET collaboration
CONTENTS

- COMET physics motivation
- COMET overview
- COMET features
- COMET beam
- COMET phase-I
- COMET status & prospects
CONTENTS

- COMET physics motivation
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- COMET features
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Why charged LFV is so attractive?

Why? : Quark/Neutrino Flavour Mixing = ☺ / Charged LFV = ☹?

SM + simple $\nu$ Oscillation

- charged LFV is possible
  - e.g. $\nu_\mu \rightarrow \nu_e$
  - $B(\mu \rightarrow e \gamma) \approx 10^{-50} \text{!!!}$
  - but extremely rare

Beyond SM (SUSY-GUT etc.)

- charged LFV is largely enhanced
  - e.g. $\tilde{\mu} \rightarrow e \gamma$
  - $B(\mu \rightarrow e \gamma) \approx 10^{-15} \sim 10^{-11} \text{!!!}$
  - still rare but observable level

$\alpha_\mu, \chi_0$, $e.G.F.$
Why charged LFV is so attractive?

Why? : Quark/Neutrino Flavour Mixing = ☺ / Charged LFV = ☹ ?

“charged LFV” = “NEW PHYSICS”

TeV-scale New Physics

competitive & complementary to LHC!

\[ B(\mu \rightarrow e\gamma) \approx 10^{-6} !!! \]

\[ B(\mu \rightarrow e\gamma) = 10^{-15} \sim 10^{-11} !!! \]
“μ→eγ” vs. “μN→eN”

- Sensitivity for “photonic” and “non-photonic” processes is different.

<table>
<thead>
<tr>
<th></th>
<th>μ→eγ</th>
<th>μN→eN</th>
</tr>
</thead>
<tbody>
<tr>
<td>photonic (eg. SUSY-base models, etc.)</td>
<td>YES (on-shell)</td>
<td>YES (off-shell)</td>
</tr>
<tr>
<td>non-photonic (eg. Extra-D, Little-Higgs, etc.)</td>
<td>NO</td>
<td>YES !!</td>
</tr>
</tbody>
</table>

eg. SUSY-based case, \( \frac{B(μ→eγ)}{B(μN→eN)} \sim O(100) \) (depends on N)
"μ→eγ" vs. "μN→eN"

<table>
<thead>
<tr>
<th></th>
<th>μ→eγ</th>
<th>μN→eN</th>
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</thead>
<tbody>
<tr>
<td>Dominant B.G.</td>
<td>Accidental</td>
<td>Beam related</td>
</tr>
<tr>
<td>Challenge</td>
<td>Detector Performance</td>
<td>Beam Quality</td>
</tr>
<tr>
<td>Suitable Muon Source</td>
<td>DC Muon Beam</td>
<td>Pulsed Muon Beam</td>
</tr>
<tr>
<td>Beam Intensity</td>
<td>(almost) Limited</td>
<td>No Limitation</td>
</tr>
</tbody>
</table>

μ→eγ: accidental B.G. \(\propto (\text{rate})^2\)

- MEG (and its upgrade) may be the final experiment

μN→eN: Required Beam is recently / finally achievable

- Once we get a required beam, μN→eN experiment might be a next experiment after the MEG.
What is the muon-to-electron conversion?

* 1S state in a muonic atom

- Muon Decay in Orbit (DIO)
  \[ \mu^- \rightarrow e^- \nu_\mu \bar{\nu}_e \]

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

* If \( \mu\)-e Conversion is Occurred ...

- Neutrino-less Muon Nuclear Capture
  \[ \mu^- + (A, Z) \rightarrow e^- + (A, Z) \]

* Branching Ratio is Determined as
  \[ B(\mu^- N \rightarrow e^- N) = \frac{\Gamma(\mu^- N \rightarrow e^- N)}{\Gamma(\mu^- N \rightarrow \nu N')} \]
Experimental signature

**Signal**

- $E_e = m_\mu - B_\mu \sim 105\text{MeV}$
- Coherent Process ($Z_{\text{ini}} = Z_{\text{end}}$)

**Signal**: Single Mono-Energetic Electron  
**Sensitivity**: Limited by Beam Quality  
- Wait until Pion decays  
- Pulsed Beam is the BEST

**Backgrounds**

- Radiative Muon Capture
- Radiative Pion Capture
- Electrons from Muon DIF
- Muon Decay in Orbit (DIO)
- Cosmic Rays, etc.
Present best limit on $BR(\mu N \rightarrow eN)$

- SINDRUM-II experiment (1989-1993, PSI)
Present best limit on $\mathcal{B}(\mu N \rightarrow eN)$

- SINDRUM-II experiment (1989-1993, PSI)

DC muon beam with veto counter

Results:
- $\mathcal{B}(\mu^- Ti \rightarrow e^- Ti) < 6.1 \times 10^{-13}$ (1993)
- $\mathcal{B}(\mu^- Au \rightarrow e^- Au) < 7 \times 10^{-13}$ (2000)

Limited by Significant BG Rate
CONTENTS

- COMET physics motivation
- COMET overview
- COMET features
- COMET beam
- COMET phase-I
- COMET status & prospects
Overview

Primary proton beam

Muon transport

Electron detectors and solenoid

Pion capture solenoid

Muon stopping target

Electron transport solenoid
Overview

1. Powerful proton source by J-PARC
2. High-eff π-capture system
3. “C-shape” long/bending π/μ transport
4. High reso electron detector with 2ndary “C-shape” transport

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① powerful proton source at J-PARC
① powerful proton source at J-PARC
1 powerful proton source at J-PARC

- **Linac**: (330m, 400MeV)
- **3GeV Synchrotron (RCS)**: (350m ring, 25Hz, 1MW)
- **30GeV Synchrotron (MR)**: (1600m ring, 0.75MW)
- **Material/Life-Science Facility (MLF)**: (muon source, pulse neutron source)
- **Neutrino Experiment Facility (T2K, towards SK)**
- **Hadron Experiment Facility**

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**Hajime NISHIGUCHI (KEK)**

**The COMET Experiment**

**ICHEP2014 2-9 Jul. 2014, Valencia**
Hadron Experimental Facility (HD) is being modified to be safe, to have more beam lines; High-$p$ beam line & the COMET beam line.

will be realized by putting a Lambertson magnet and extending the experimental hall.
Hadron Experimental Facility (HD) is being modified to be **safe**, to have more beam lines; **High-\(p\)** beam line & the **COMET beam line**.

will be realized by putting a Lambertson magnet and extending the experimental hall.
② High efficiency $\pi$-capture system

- Large muon yield by Large Solid Angle
- Powerful Solenoid
- Surround p target

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

B=5T, R=0.2 \rightarrow P_T=150\text{MeV}/c

- Super-conducting solenoidal magnet
  - 5T
  - 30 cm thick W shield.
- Issue : Heat Load

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Demonstration of high-eff. capture solenoid

400MeV 1μA DC proton beam at Osaka Univ. using 3.5T pion capture solenoid and graphite target → 2000μ’s / 6 pA already achieved.

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Utilize C-shape long/bending magnet to reject background particles.

- Requirements:
  - Long enough for pions to decay to muons (> 20 meters or \(2 \times 10^{-3}\)).
  - High transport efficiency (\(P \approx 40\) MeV/c).
  - Negative charge selection.
  - Low momentum selection (\(P < 75\) MeV/c).

- Straight + curved solenoid transport system is adopted.

Select low-\(p\) muons (& reject high-\(p\) \(\mu\)) using C-shaped “transport” solenoid

Select high-\(p\) e\(^-\) (& reject low-\(p\) BGs.) using C-shaped “transport” solenoid

\(B_{\text{max}} = 3.5\)T

\(B_{\text{max}} = 1\)T
Secondary-bending for detector system

- Torus drift for rejecting low energy DIO electrons.

\[
D(m) = \frac{1}{0.3 \times B(T)} \times \frac{s}{R} \times \frac{P_L^2 + \frac{1}{2}P_T^2}{P_L}
\]

- Rejection Power : \(\sim 10^{-6}\)

- Good Acceptance for signal electrons (w/o including event selection and trigger acceptance)
  - \(\sim 20\%\)
High resolution electron detector

to stop muons

Muon Target Disks

Beam Blocker

DIO Blocker

to detect and identify 100 MeV electrons

Detector Slenoid

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

Beam Collimator

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Electron Detector (Tracker + Calorimeter)

- Rate < 800 kHz
- **Straw-tube tracker to measure electron mom.**
  - 5 planes with 48cm spacing
  - $\sigma_p < 200$ keV/c
    - 4 planes / super-layer
    - 5mm diam. straw-tube with 20 or 12 $\mu$m thick
  - **should be operational in vacuum**
  - <200$\mu$m spacial resolution

- **Crystal calorimeter for trigger (ECAL)**
  - GSO or LYSO crystal will be chosen soon
COMET Collaboration (129 collaborators from 11 countries, 28 institutes)

| Japan | UK | Russia | China | Canada | Malaysia | Vietnam | France | Philippines | USA | Italy |
|-------|-----|--------|-------|------|----------|---------|--------|-------------|-----|------|--------|

The COMET Collaboration

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A pulsed proton beam is needed to reject beam-related prompt BG

Time structure required to be:

- Pulse separation ~1μs or more (muonic atom lifetime)
- Narrow pulse width ~ 100ns

Pulsed beam from slow extraction.

fill every other rf buckets and make slow extraction
spill length ~ 0.7-3 sec

good to be shorter for cosmic-ray backgrounds.

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Extinction measurement at J-PARC

- Extinction = 
  "# of residual proton" / "# of main proton", should be < 10^{-10} !!!

- Should be realized with the COMET operation mode;
  - 8GeV (56kW), bunched slow extraction

- Abort monitor
  - dynamic R ~ 10^{12} counts
- Direct measurement
  - 2010-Dec., @ FX abort line
  - Result:
    Ext. <~ O(-7)

- Beam counter at secondary beam line
- Direct measurement
  - 2010-Oct., @ SX
  - Result:
    Ext. < 5.4\times10^{-7}
- Consistent with measurement at abort.
Extinction improvement

- **Miss kick injection method**: Special Thanks to J-PARC Accelerator group
- Fail injection in purpose for the empty bucket

Obtained best extinction = $O(10^{-12})$ !!
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Staging approach

Pion Capture Section
A section to capture pions with a large solid angle under a high solenoidal magnetic field by superconducting magnet.

Pion-Decay and Muon-Transport Section
A section to collect muons from decay of pions under a solenoidal magnetic field.

Detector Section
A detector to search for muon-to-electron conversion processes.
Staging approach

**(phase-I)**

- Protons
- Production Target
- Stopping Target
- Pions
- Muons

**full COMET (phase-II)**

- Pion Capture Section
  - A section to capture pions with a large solid angle under a high solenoidal magnetic field by superconducting magnets.
- Detector Section
  - A detector to search for muon-to-electron conversion processes.
- Pion-Decay and Muon-Transport Section
  - A section to collect muons from decay of pions under a solenoidal magnetic field.
Goal of COMET phase-I

① Background Study for the full COMET (phase-II)

direct measurement of potential background sources for the full COMET experiment by using the actual COMET beam line

② Search for μ-e Conversion

a search for μ-e Conversion at the intermediate sensitivity which would be 100-times better than the present limit (SINDRUM-II)
Background measurement

- Measure almost all particles
- Same detector technology for phase-II
  - SC spectrometer solenoid
  - Straw Tube Transverse Tracker
  - Crystal Calorimeter
- Particle ID with $dE/dx$ and $E/p$

**CHAPTER 4. MUON BEAM**

Momentum, $p$ (MeV/c)

<table>
<thead>
<tr>
<th>$p$ (MeV/c)</th>
<th>Count</th>
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<tbody>
<tr>
<td>0</td>
<td>50</td>
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<tr>
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<tr>
<td>1400</td>
<td>1450</td>
</tr>
</tbody>
</table>

**Figure 4.15:** Momentum distribution of the different types of particles at the end of the first $90^\circ$ bend for a correction dipole field of 0.018T.

**Figure 4.16:** Arrival time distributions of various beam particles for the case of a correction dipole field of 0.018 T.

Total momentum vs $y$ for $\mu$ at monitor45

Total momentum vs $y$ for $\mu$ at monitor21: before the collimator

Total momentum for $s$ (MeV/c) vs $y$ for $\mu$ (MeV/c)
Search for $\mu^{-}N \rightarrow e^{-}N$ by the COMET phase-I

Dedicated CDC-type tracker $\rightarrow$ a large bore CDC in a 1T solenoidal magnet
- all stereo-wire base
- helium-based low mass gas
- with a combination of trig. hodoscope (Cherenkov radiator + plastic scinti.)
8 GeV, 3.2 kW proton beam is assumed

- 2.5 \times 10^{12} \text{ protons/sec}
- 10^{-9} \text{ of extinction is supposed}
- 90 \text{ days (7 \times 10^6 \text{ sec}) running time}
- Expected single event sensitivity

\[ \mathcal{B}(\mu^- + Al \rightarrow e^- + Al) = \frac{1}{N_{\mu}^{\text{stop}} \cdot f_{\text{cap}} \cdot A_{\mu-e}} \]

\[ \mathcal{B}(\mu + Al \rightarrow e + Al) = 3.1 \times 10^{-15} \]

Upper limit at 90% C.L.

\[ \mathcal{B}(\mu + Al \rightarrow e + Al) < 7.0 \times 10^{-15} \]

\textit{cf.} present limit < 7 \times 10^{-13} (SINDRUM-II)
<table>
<thead>
<tr>
<th></th>
<th>COMET-Phase-I</th>
<th>COMET-Phase-II</th>
</tr>
</thead>
<tbody>
<tr>
<td>experiment starts (*)</td>
<td>in ~2016</td>
<td>in ~2019</td>
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<tr>
<td>beam intensity</td>
<td>3.2kW (8GeV)</td>
<td>56kW (8GeV)</td>
</tr>
<tr>
<td>running time</td>
<td>7.8 x 10^6 (sec)</td>
<td>2.0 x 10^7 (sec)</td>
</tr>
<tr>
<td># of protons</td>
<td>1.5 x 10^(19)</td>
<td>8.5 x 10^(20)</td>
</tr>
<tr>
<td># of muon stops</td>
<td>9.4 x 10^(15)</td>
<td>2.0 x 10^(18)</td>
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<tr>
<td>muon rate</td>
<td>5.8 x 10^9</td>
<td>1.0 x 10^(11)</td>
</tr>
<tr>
<td># of muon stops / proton</td>
<td>0.0023</td>
<td>0.0023</td>
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<tr>
<td># of BG</td>
<td>0.02</td>
<td>0.3</td>
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<tr>
<td>S.E.S.</td>
<td>3.1 x 10^(-15)</td>
<td>2.6 x 10^(-17)</td>
</tr>
<tr>
<td>U.L. (90%CL.)</td>
<td>7.0 x 10^(-15)</td>
<td>6.0 x 10^(-17)</td>
</tr>
</tbody>
</table>

* including the engineering run
CONTENTS

- COMET physics motivation
- COMET overview
- COMET features
- COMET beam
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- COMET status & prospects
Facility Construction

Construction of the COMET building is in progress.

- Everything on schedule, will be completed at the end of JFY2014.
- At the moment, piling is in progress and almost close to the end.
- Underground structure construction is starting.
In addition to beam-line construction, SC magnet construction was already started. (SC conductor production is ongoing.)
In addition to beam-line construction, SC magnet construction was already started. (SC conductor production is ongoing.)
Detector R&D

All sub-detector system; CDC / Straw-ECAL, design finalization is in progress and close to the end. Currently, final prototyping for each sub-detector is ongoing to complete all the R&D.

- **CDC**: final construction prototype
  - decision on the cell configuration and gas mixture, estimate aging effects, etc.

- **Straw**: "1-to-1 scale" prototype
  - assembly study, decision on straw specification, etc.

- **ECAL**: test-beam prototype
  - decision on crystal choice, FE study, etc.
CDC prototyping

Schedule of CDC prototype

<table>
<thead>
<tr>
<th>Year</th>
<th>2013</th>
<th>2014</th>
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<tbody>
<tr>
<td>Month</td>
<td>10</td>
<td>11</td>
</tr>
<tr>
<td>Construction/Wiring</td>
<td></td>
<td></td>
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<tr>
<td>Beam test @Osaka</td>
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<td></td>
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<tr>
<td>Cosmic-ray test @Osaka</td>
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<tr>
<td>Cosmic-ray test @KEK</td>
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<tr>
<td>Beam test @Tohoku</td>
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</tbody>
</table>

Prototype Chamber

- Wiring
  - All stereo layers
  - #/sense layers: 9 [18]
  - Square cell: 1.6cm x 1.6cm
  - Length: 60cm [150cm]
  - Azimuthal angle: 30deg [360deg]
  - Sense wire
    - Tungsten/Au
    - Diameter: 30 μm [25 μm]
    - Tension: 50g [50g]
    - Total: 199 [4986]
  - Field wire
    - Aluminium
    - Diameter: 126 μm [80 μm]
    - Tension: 80g [70g]
    - Total: 602 [14562]

- Done at Belle2 CDC clean room @KEK
- Complete in one week (Nov. 2013)

Cosmic-ray test @ Osaka Univ.

- He: iC4H10 (90:10), 1900V

- Big cell (3 x π cm²)

- KLOE’s results with cosmic-ray test at B=0.6T

- NIM A 488 (2002) 51-73

- drift distance (cm)

- spatial resolution (μm)

- Sum
- Primary (Np = 15.23 cm)
- Diffusion (2D/V = 1.9e-04 cm, N = 1.81)
- Extrapol (79 μm, fixed)

- σr = √150² - 80² = 130 μm
Straw R&D by the 1-to-1 size prototype

assembly studies

FE in manifold

"1-to-1 scale" prototype
ECAL R&D by the test-beam experiment

Event Sample (105 MeV/c runs)

7x7 LYSO Array

Beam Define Counters
Trigger counters
Crystals
Preamps

LYSO is clearer than GSO.
(Amp. gain 1/4 in LYSO runs to compensate light yield difference.)
### General Schedule for Phase-I and Phase-II

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<td><strong>COMET phase-II</strong></td>
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**COMET Phase-I**
- 2016~
- S.E.S. ~ $3 \times 10^{-15}$
- for $7.8 \times 10^6$ sec
- with 3.2kW proton beam

**COMET Phase-II**
- 2019~
- S.E.S. ~ $3 \times 10^{-17}$
- for $2 \times 10^7$ sec
- with 56kW proton beam
Schedule for Phase-I (Facility)

<table>
<thead>
<tr>
<th>JFY</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
<th>2016</th>
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<tbody>
<tr>
<td>COMET building design</td>
<td></td>
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</tr>
<tr>
<td>construction</td>
<td></td>
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<tr>
<td>Solenoid magnet</td>
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<tr>
<td>SC wire</td>
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<tr>
<td>Capture magnet</td>
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<tr>
<td>Transport magnet</td>
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<tr>
<td>Cryogenic system</td>
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<tr>
<td>Magnet system test</td>
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<tr>
<td>Radiation shield</td>
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<td>Beam dump</td>
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<tr>
<td>Pion target</td>
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<tr>
<td>Design &amp; test construction</td>
<td></td>
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</table>

### JFY2013
- Design of the building & beam line
- Design of SC solenoid and start of construction
- Production of SC wires
- Design of pion production target

### JFY2014
- Completion of the building
- Construction of SC solenoid magnet
- Start magnet and radiation shielding & dump
- Transport solenoid
- Start preparation of cryogenic system
- Tests of the production target

### JFY2015
- Construction of SC solenoid magnet
- Preparation of cryogenic system
- Construction of pion production target

### JFY2016
- Installation of the capture solenoid
- Completion of the cryogenic system
- Tests of whole magnet system
- Installation of the target
- Ready to accept the 8GeV beam.

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*Hajime NISHIGUCHI (KEK)*

*The COMET Experiment*

*ICHEP2014 2-9 Jul./2014, Valencia*
### Schedule for Phase-I (Detector)

<table>
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<tbody>
<tr>
<td>CDC</td>
<td>Prototype construction</td>
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<td>Endplate construction</td>
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<td>Inner &amp; outer wall construction</td>
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<td>Wire stringing &amp; assembly</td>
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<td>Readout electronics</td>
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<td>Gas system construction</td>
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<td>Cosmic test</td>
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<td>CDC trigger</td>
<td>Counter construction</td>
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<td>Detector</td>
<td>Design</td>
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<td>Solenoid</td>
<td>Superconductor fabrication</td>
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<td>Coil winding</td>
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<td>Cryostat construction</td>
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<td>Iron yoke production</td>
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<td>Power supply</td>
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<td>Collimator</td>
<td>Design</td>
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<td>Power supply</td>
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<td>Muon Target</td>
<td>Construction</td>
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- Straw Chamber: straw construction, ROESTI prototype, ROESTI production, vacuum chamber, gas system construction
- ECAL: crystal construction, ROESTI prototype, ROESTI production, assembly
- Cosmic Veto: counter construction, SIPM production, installation
- Muon Target: construction, trigger prototype, trigger production, DAQ development
- DAQ: beam measurement, construction
- X-ray detector: procurement, construction
- Experiment: Transportation, Installation, Engineering run, Physics run

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**Both Facility / Detector will be ready for 8GeV proton in 2016.**

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Hajime NISHIGUCHI (KEK)  The COMET Experiment  ICHEP2014  2-9/Jul./2014, Valencia
The COMET is a search experiment for $\mu\cdot N \rightarrow e\cdot N$ at J-PARC with an excellent sensitivity of $O(-17)$ which is four orders of magnitudes better than the present limit. The COMET experiment employs the staged approach: In Phase-I, ‘beam measurement’ and ‘$\mu\cdot N \rightarrow e\cdot N$ search with an intermediate sensitivity’. Phase-II = ‘Full COMET sensitivity’ Funding for COMET Phase-I beam-line is secured and fully supported by KEK/J-PARC as a first priority project for the facility upgrade. We’re ready for the COMET Experiment phase-I. Thank you !!!
appendices
History of muon LFV search experiment

- Long Tradition on the $\mu \rightarrow e\gamma$ / $\mu N \rightarrow eN$ Search Experiment
- Started right after the muon discovery
- $\mu \rightarrow e\gamma$ has already entered the predicted region!!
- $\mu N \rightarrow eN$ is sitting at just in front of the predicted region!!
- NOW VERY VERY ATTRACTIVE !!!!!
Linac Chopper at J-PARC

Two Cavities

Beam dumps 0-deg 30-deg 90-deg 100-deg
1st stage: Until Jul., 2007 0.6 kW 0.1 kW N/A N/A
2nd stage: From Sep., 2007 0.6 kW 5.4 kW 0.6 kW 2 kW

Front-end IS + LEBT + RFQ + MEBT
Proton beam at J-PARC

RCS (3 GeV, h=2)
MR (30 GeV, h=9)

【Normal Operation】

RCS (3 GeV, h=2)
MR (30 GeV, h=9)

【COMET Operation】

Hajime NISHIGUCHI (KEK)
The COMET Experiment
ICHEP2014 2-9 Jul./2014, Valencia
Miss-kick method

- Miss kick injection method; Special Thanks to J-PARC Accelerator group

- By shifting the kicker timing 598ns forward/backward, residual protons are originally not injected into MR.

- Completely empty bucket should be realized!
Miss-kick Demonstration

Miss-kick methode was successfully demonstrated

This was done w/o acceleration...
Front-end Electronics R&D

* Own Front-end electronics is under development

* **ROESTI** : ReadOut Electronics for Straw Tube Instrument

  * power consumption
  * # of feedthrough
  * space limitation
  * pile-up elimination (WF)
  * picking up a small charge / timing resolution, etc.

* Pre-amplification→Pulse shaping, discrimination is done by ASD and Waveform digitization is done by DRS4, controlled by FPGA-based local bus control system on the board.

Hajime NISHIGUCHI (KEK)

The COMET Experiment

ICHEP2014 2-9 Jul./2014, Valencia
ROESTI prototype

* Two prototypings were done, and ver.3 is under development which will be the final prototype.
Funding for Phase-I

Almost secured...

Proton beam-line supplemental-budget-JFY2012

Detector (CDC+trig.+elec.) + Solenoid Grant-in-Aid JFY2013-17
Detector (Straw+ECAL+elec.)

Partially secured by another Grant-in-Aid. Remaining cost would be covered by efforts from other countries, eg. UK, JINR, etc.

Hajime NISHIGUCHI (KEK)

The COMET Experiment

ICHEP2014 2-9 Jul./2014, Valencia
# Background list for Phase-I

<table>
<thead>
<tr>
<th><strong>Intrinsic physics backgrounds</strong></th>
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</thead>
</table>
| 1 | Muon decay in orbit (DIO) | \( \mu^- + A \rightarrow \nu_\mu + A' + \gamma \),  
followed by \( \gamma \rightarrow e^- + e^+ \) |
| 2 | Radiative muon capture (external) | \( \mu^- + A \rightarrow \nu_\mu + A' + \gamma \),  
followed by \( \gamma \rightarrow e^- + e^+ \) |
| 3 | Radiative muon capture (internal) | \( \mu^- + A \rightarrow \nu_\mu + e^+ + e^- + A' \),  
and neutrons produce \( e^- \) |
| 4 | Neutron emission after | \( \mu^- + A \rightarrow \nu_\mu + A' + n \),  
followed by charged particles produce \( e^- \) |
| 5 | Charged particle emission | \( \mu^- + A \rightarrow \nu_\mu + A' + p \) (or \( d \) or \( \alpha \)), |
|  | after muon capture | |

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<thead>
<tr>
<th><strong>Beam related prompt/delayed backgrounds</strong></th>
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</table>
| 6 | Radiative pion capture (external) | \( \pi^- + A \rightarrow \gamma + A' \),  
\( \gamma \rightarrow e^- + e^+ \) |
| 7 | Radiative pion capture (internal) | \( \pi^- + A \rightarrow e^+ + e^- + A' \) |
| 8 | Beam electrons | \( e^- \) scattering off a muon stopping target |
| 9 | Muon decay in flight | \( \mu^- \) decays in flight to produce \( e^- \) |
| 10 | Pion decay in flight | \( \pi^- \) decays in flight to produce \( e^- \) |
| 11 | Neutron induced backgrounds | neutrons hit material to produce \( e^- \) |
| 12 | \( \bar{p} \) induced backgrounds | \( \bar{p} \) hits material to produce \( e^- \) |

<table>
<thead>
<tr>
<th><strong>Other backgrounds</strong></th>
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<tbody>
<tr>
<td>14</td>
<td>Cosmic-ray induced backgrounds</td>
</tr>
<tr>
<td>15</td>
<td>Room neutron induced backgrounds</td>
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<tr>
<td>16</td>
<td>False tracking</td>
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# Background estimation for Phase-I

<table>
<thead>
<tr>
<th>Type</th>
<th>Background</th>
<th>Estimated events</th>
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<tbody>
<tr>
<td>Physics</td>
<td>Muon decay in orbit</td>
<td>0.01</td>
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<tr>
<td>Physics</td>
<td>Radiative muon capture</td>
<td>$5.6 \times 10^{-4}$</td>
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<tr>
<td>Physics</td>
<td>Neutron emission after muon capture</td>
<td>$&lt; 0.001$</td>
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<tr>
<td>Physics</td>
<td>Charged particle emission after muon capture</td>
<td>$&lt; 0.001$</td>
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<tr>
<td>Prompt Beam</td>
<td>Beam electrons (prompt)</td>
<td>$7.1 \times 10^{-4}$</td>
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<tr>
<td>Prompt Beam</td>
<td>Muon decay in flight (prompt)</td>
<td>$\leq 1.7 \times 10^{-4}$</td>
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<tr>
<td>Prompt Beam</td>
<td>Pion decay in flight (prompt)</td>
<td>$\leq 2.0 \times 10^{-3}$</td>
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<tr>
<td>Prompt Beam</td>
<td>Other beam particles</td>
<td>$\leq 2.4 \times 10^{-6}$</td>
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<tr>
<td>Prompt Beam</td>
<td>Radiative pion capture(prompt)</td>
<td>$4.24 \times 10^{-4}$</td>
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<tr>
<td>Delayed Beam</td>
<td>Beam electrons (delayed)</td>
<td>$\sim 0$</td>
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<tr>
<td>Delayed Beam</td>
<td>Muon decay in flight (delayed)</td>
<td>$\sim 0$</td>
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<tr>
<td>Delayed Beam</td>
<td>Pion decay in flight (delayed)</td>
<td>$\sim 0$</td>
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<tr>
<td>Delayed Beam</td>
<td>Radiative pion capture (delayed)</td>
<td>$\sim 0$</td>
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<tr>
<td>Delayed Beam</td>
<td>Anti-proton induced backgrounds</td>
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<tr>
<td>Others</td>
<td>Electrons from cosmic ray muons</td>
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<tr>
<td>Total</td>
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