Experimental Status of Rare Decays in Charged Leptons and Light Mesons
Experimental Status of Rare Decays in Charged Leptons and Light Mesons

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July 9th, 2012
Melbourne
Outline

• Why Rare Decays?
• Rare Muon Decays
• Rare Tau Decays
• Rare Kaon Decays
• Rare Charm Decays
• Particle Sources (Facilities)
• Summatry

There are not many new results on these subjects in this conference.
This talk does not have talks on CP violation decays.
Due to time limitation, only selected subjects are shown, sorry.
Why Rare Decays?

woodblock prints on “Kabuki” actors by Tsuruya Kokei (1978-2000)
Now, the Standard Model has the Higgs boson
Now, the Standard Model has the Higgs boson.

Congratulations for the discovery of the Higgs.
Now, the Standard Model has the Higgs boson

Congratulation for the discovery of the Higgs.

The Standard Model can explain most of the experimental results. However, there are many undetermined parameters and issues.
Now, the Standard Model has the Higgs boson. 

Congratulations for the discovery of the Higgs.

The Standard Model can explain most of the experimental results. However, there are many undetermined parameters and issues.

The Standard Model is considered to be incomplete. New Physics is needed.
Three Frontiers of Particle Physics

The Energy Frontier
- Origin of Mass
- Matter/Anti-matter Asymmetry
- Neutrino Physics
- Proton Decay

The Cosmic Frontier
- Origin of Universe
- Unification of Forces
- New Physics Beyond the Standard Model

The Intensity Frontier
- Dark Matter
- Dark Energy
Three Frontiers of Particle Physics

To explore new physics at high energy scale
Three Frontiers of Particle Physics

To explore new physics at high energy scale

The Intensity Frontier

use intense beams to observe rare processes and study the particle properties to probe physics beyond the SM.
Three Frontiers of Particle Physics

To explore new physics at high energy scale

The Intensity Frontier

use intense beams to observe rare processes and study the particle properties to probe physics beyond the SM.

Rare Decays
Guideline for Rare Decay Searches

New physics effects may be very small.
Guideline for Rare Decay Searches

New physics effects may be very small.

SM Standard Model

New Physics

NP

SM contribution is dominant.
New physics effects may be very small.

SM \rightarrow NP

SM contribution is highly suppressed.

\[ B \sim \frac{1}{\sqrt{N}} \]
New physics effects may be very small.

**SM** (Standard Model) contribution is dominant.

**SM** + **NP** contribution is highly suppressed.

**SM** + **NP** contribution is forbidden.

\[ B \sim \frac{1}{\sqrt{N}} \]

\[ B \sim \frac{1}{N} \]
Guideline for Rare Decay Searches

New physics effects may be very small.

- SM contribution is dominant.
  \[ B \sim \frac{1}{\sqrt{N}} \]

- SM contribution is highly suppressed.
  \[ B \sim \frac{1}{N} \]

- SM contribution is forbidden.
Example: No SM Contribution in Charged Lepton Flavor Violation (CLFV)
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\[ B(\mu \rightarrow e\gamma) = \frac{3\alpha}{32\pi} \left| \sum_{\ell} (V_{MNS})_{\mu\ell}^* (V_{MNS})_{e\ell} \frac{m_{\nu_{\ell}}}{M_W^2} \right|^2 \]
Example: No SM Contribution in Charged Lepton Flavor Violation (CLFV)

\[ B(\mu \rightarrow e\gamma) = \frac{3\alpha}{32\pi} \left| \sum_l (V_{MNS})_{\mu l}^* (V_{MNS})_{el} \frac{m_{\nu_l}^2}{M_W^2} \right|^2 \]

Note: LFV in SM with massive neutrinos is very tiny! The SM with neutrino masses predicts small event rates for the LFV. The observation of the LFV will be clearly a discovery of physics beyond the SM with non-zero neutrino masses.

BR(\mu \rightarrow e\gamma) \ll O(10^{-54})
Observation of CLFV would indicate a clear signal of physics beyond the SM with massive neutrinos.

\[ B(\mu \to e\gamma) = \frac{3\alpha}{32\pi} \left| \sum_l (V_{MNS})_{\mu l}^* (V_{MNS})_{el} \frac{m_{\nu l}^2}{M_W^2} \right|^2 \]

Example: No SM Contribution in Charged Lepton Flavor Violation (CLFV)

\[ \text{BR} \sim O(10^{-54}) \]
Example: Sensitivity to Energy Scale of NP
Example: Sensitivity to Energy Scale of NP

A. de Gouvea’s effective interaction for μ-e conversion

\[
L_{\text{CLFV}} = \frac{1}{1 + \kappa} \frac{m_\mu}{\Lambda^2} \bar{\mu} \sigma^{\mu\nu} e_L F_{\mu\nu} + \frac{\kappa}{1 + \kappa} \frac{1}{\Lambda^2} (\bar{\mu} L \gamma^\mu e_L)(\bar{q}_L \gamma_\mu q_L)
\]

\(\Lambda\): energy scale of new physics

\[
B(\mu \rightarrow e\gamma) < 2.4 \times 10^{-12}
\]

\[
B(\mu N \rightarrow eN) < 7 \times 10^{-13}
\]
Example: Sensitivity to Energy Scale of NP

A. de Gouvea’s effective interaction for $\mu$-$e$ conversion

$$L_{\text{CLFV}} = \frac{1}{1 + \kappa} \frac{m_\mu}{\Lambda^2} \bar{\mu}_R \sigma^{\mu\nu} e_L F_{\mu\nu}$$

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$$+ \frac{\kappa}{1 + \frac{1}{\Lambda^2}} (\bar{\mu}_L \gamma^\mu e_L) (\bar{q}_L \gamma_\mu q_L)$$

$\Lambda$: energy scale of new physics

$O(10^3)$GeV

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Example: Sensitivity to Energy Scale of NP

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\(\Lambda\): energy scale of new physics

With loop suppression
Example: Sensitivity to Energy Scale of NP

A. de Gouvea's effective interaction for \( \mu\)–\( e \) conversion

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\( \Lambda \): energy scale of new physics

\( O(1) \text{TeV} \)

With loop suppression
Example: Sensitivity to Energy Scale of NP

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\[ L_{\text{CLFV}} = \frac{1}{1 + \kappa} \frac{m_\mu}{\Lambda^2} \bar{\mu}_R \sigma^{\mu\nu} e_L F_{\mu\nu} \]

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\( \Lambda \): energy scale of new physics

O(1)TeV

With loop suppression

Flavor mixing couplings gives additional reduction on the \( \Lambda \) reach.
Example: Sensitivity to Energy Scale of NP Loop contribution in SUSY models
Example: Sensitivity to Energy Scale of NP
Loop contribution in SUSY models

For loop diagrams,

$$\text{BR}(\mu \rightarrow e\gamma) = 1 \times 10^{-11} \times \left( \frac{2\text{TeV}}{\Lambda} \right)^4 \left( \frac{\theta_{\mu e}}{10^{-2}} \right)^2 \quad y = \frac{g^2}{16\pi^2} \theta_{\mu e}$$

> sensitive to TeV energy scale with reasonable mixing
Example: Sensitivity to Energy Scale of NP
Loop contribution in SUSY models

For loop diagrams,

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\[ y = \frac{g^2}{16\pi^2} \theta_{\mu e} \]

> sensitive to TeV energy scale with reasonable mixing

example diagram for SUSY (~TeV)

Physics at about $10^{16}$ GeV

SUSY-GUT model

SUSY neutrino seesaw model

\[ (m^2_{L})_{21} \sim \frac{3m^2_0 + A^2_0}{8\pi^2} h^2 V_{td} V_{ts} \ln \frac{M_{GUT}}{M_{R_s}} \]

\[ (m^2_{L})_{21} \sim \frac{3m^2_0 + A^2_0}{8\pi^2} h^2 U_{31} U_{32} \ln \frac{M_{GUT}}{M_{R}} \]

slepton mixing (from RGE)

\[ \tilde{W} \rightarrow \tilde{\mu} \bar{\nu}_e \]

\[ \text{muon g-2} \]

example: large extra dimension

\[ \text{example: SUSY} \]

\[ \text{example: new physics scale} \]

Is the LFV searches sensitive to TeV scale physics?

For loop diagrams, > sensitive to TeV energy scale with reasonable mixing

\[ \frac{g^2}{16\pi^2} \theta_{\mu e} \]

\[ h^2 V_{td} V_{ts} \ln \frac{M_{GUT}}{M_{R_s}} \]

\[ h^2 U_{31} U_{32} \ln \frac{M_{GUT}}{M_{R}} \]
CLFV and Neutrino Mass Generation from Y. Okada-san’s slide (2010)
CLFV and Neutrino Mass Generation

If two scales are well separated, LFVs are suppressed.

\[ \text{CLFV} \sim O(10^{-54}) \]

In supersymmetric models, large LFV signals are expected even if two scales are separated.

If two scales are close, large LFVs are expected.

Neutrino mass from loop
Triplet Higgs for neutrino mass
Left-right symmetric model
Rare Decays are indirect searches,
**The pattern of measurement:**

- ★★★ large effects
- ★★ visible but small effects
- ★ unobservable effects

is characteristic, often uniquely so, of a particular model.

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These are a subset of a subset listed by Buras and Girrbach
MFV, CMFV, 2HDM_{MFV}, LHT, SM4, SUSY flavor. SO(10) – GUT,
SSU(5)_{HN}, FBMSSM, RHMFV, L-R, RS₀, gauge flavor, ...........
Rare Muon Decays
Various BSM models predict sizable muon CLFV, as well as tau CLFV.

**CLFV Predictions**

### SUSY model

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### Little Higgs model

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**extra dimension model**
CLFV Predictions

Various BSM models predict sizable muon CLFV, as well as tau CLFV.

SUSY model

little Higgs model

extra dimension model
What is $\mu \to e\gamma$?

- **Event Signature**
  - $E_e = m_\mu/2, E_\gamma = m_\mu/2$ ($=52.8$ MeV)
  - angle $\theta_{\mu e}=180$ degrees (back-to-back)
  - time coincidence

- **Backgrounds**
  - prompt physics backgrounds
    - radiative muon decay $\mu \to e\nu\nu\gamma$ when two neutrinos carry very small energies.
  - accidental backgrounds
    - positron in $\mu \to e\nu\nu$
    - photon in $\mu \to e\nu\nu\gamma$ or photon from $e^+e^-$ annihilation in flight.
MEG Experiment

3x10^7 μ/s @ PSI, Switzerland

Special gradient magnetic field
Sweeps out high rate e+ quickly
Constant bending radius of e+

Ultra thin material
Precise e+ tracking

Precise e+ timing
Plastic scintillator + PMTs

2.7 ton of liquid xenon
Homogeneous detector
Good time, position, energy resolution

Waveform digitizer for all detectors
MEG Result (2009+2010)

from H. Nishiguchi’s talk [829]
MEG Result (2009+2010)

from H. Nishiguchi's talk [829]
MEG Results (2011)

Signal box is not opened yet....

from H. Nishiguchi’s talk [829]

\[ N_{\text{sig}} = -0.3^{+6.0}_{-2.5} \]

\[ N_{\text{acc}} = 951^{+25}_{-25} \]

\[ N_{\text{RMD}} = 18^{+27}_{-24} \]

Expected Sensitivity

\[ \sim 1 \times 10^{-12} \]

(2011 data only)
What is Muon to Electron Conversion?

1s state in a muonic atom

\[ \mu^- \rightarrow e^- \nu \bar{\nu} \]

Nucleus
electron of 100 MeV

Event Signature:
a single mono-energetic

Backgrounds:
(1) physics backgrounds
   ex. muon decay in orbit (DIO)
(2) beam-related backgrounds
   ex. radiative pion capture,
   muon decay in flight,
(3) cosmic rays, false tracking

\[ \mu^- + (A, Z) \rightarrow e^- + (A, Z) \]
**μ-e conversion:**
COMET (E21) at J-PARC

**8GeV proton beam**

**5T pion capture solenoid**

**3T muon transport (curved solenoids)**

**Muon stopping target**

**Electron transport**

**Electron tracker and calorimeter**

**Experimental Goal of COMET**

- $B(\mu^- + Al \rightarrow e^- + Al) = 2.6 \times 10^{-17}$
- $B(\mu^- + Al \rightarrow e^- + Al) < 6 \times 10^{-17}$ (90% C.L.)

- 10^{11} muon stops/sec for 56 kW proton beam power.
- C-shape muon beam line and C-shape electron transport followed by electron detection system.
- Stage-1 approved in 2009.
- Aim to start in 2020.

Electron transport with curved solenoid would make momentum and charge selection.
µ-e conversion:
COMET Phase-I

• COMET Phase-I (LOI) aims ....
• BG studies for Phase-II
• intermediate sensitivity
  • SE sensitivity $\sim 3 \times 10^{-15}$ for $10^6$ s (12 days) with 3 kW proton beam power (with $5 \times 10^9$ stopped µ/s).
• Aim to start in 2016.

from YK poster presentation

Cylindrical DC
Cylindrical drift chamber
μ-e conversion : Mu2e at Fermilab

B(\(\mu^- + Al \rightarrow e^- + Al\)) \(= 5 \times 10^{-17}\) (S.E.)

B(\(\mu^- + Al \rightarrow e^- + Al\)) \(< 10^{-16}\) (90%C.L.)

- Reincarnation of MECO at BNL.
- Antiproton buncher ring is used to produce a pulsed proton beam.
- Approved in 2009, and CD0 in 2009, and CD1 review underway.
- Data taking starts in about 2019.
Tau Rare Decays

tau CP violation not included.
The remaining mode are $\tau \to \mu \gamma$ and $e\gamma$!

Previously, a 545 fb$^{-1}$ data subsample was analyzed.

- 980 fb$^{-1}$ data (about $10^9$ taus) at Belle
- Signal box is still blinded, but $<5 \times 10^{-8}$ level is expected.
Results

- Preliminary upper limits 95 (90)% C.L. extracted using the CLs method

\[ \mathcal{B}(\tau^- \rightarrow \mu^+ \mu^- \mu^-) < 7.8 (6.3) \times 10^{-8} \]


\[ \mathcal{B}(\tau^- \rightarrow \mu^+ \mu^- \mu^-) < 2.1 \times 10^{-8} \text{ at 90% C.L.} \]

---

> Mathieu Perrin-Terrin

CPPM

Rare decays to purely leptonic final states at LHCb

July 6th, 2012 17 / 18
Kaon Rare Decays
B(K⁺→eν)/B(K⁺→μν) at NA48/2-NA62

\[ R_K^{SM} = \frac{\Gamma(K^+ \to e^+ \nu)}{\Gamma(K^+ \to \mu^+ \nu)} = \frac{(m_e^2/m_\mu^2)m_K^2 - m_e^2}{m_K^2 - m_\mu^2} \times (1 + \delta R_K^{rad}) \]

\[ = (2.477 \pm 0.001) \times 10^{-5} \]

beyond SM:
2HDM → presence of extra charged Higgs introduces LFV at one-loop level

\[ R_K^{LFV} = R_K^{SM} \left[ 1 + (m_K/m_\mu^\pm)^4 \times (m_\tau /m_e)^2 |\Delta_{13}|^2 \times \tan^6 \beta \right] \]


MSSM: 1% effect

[Girrbach, Nierste, arXiv: 1202.4906]

\[ R_K = (2.488 \pm 0.007_{\text{stat}} \pm 0.007_{\text{syst}}) \times 10^{5} \]

= (2.488 ± 0.010) \times 10^{5}

• in-flight K⁺ decays
• excellent test of μ-e universality
• hadronic uncertainty is canceled in ratio.
• good μ/e separation below 30 GeV/c

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<tr>
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<th>( R_K \times 10^5 )</th>
<th>precision</th>
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<tr>
<td>PDG 2008</td>
<td>2.447 ± 0.109</td>
<td>4.5 %</td>
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<tr>
<td>PDG 2010</td>
<td>2.493 ± 0.031</td>
<td>1.3 %</td>
</tr>
<tr>
<td>now</td>
<td>2.488 ± 0.009</td>
<td>0.4 %</td>
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<tr>
<td>SM</td>
<td>2.477 ± 0.001</td>
<td>0.04 %</td>
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**K→πγγ at NA48/2-NA62**

from V. Kekelidze’s talk [152]

- **in-flight K⁺ decays**
- **test of chiral perturbation theory up to O(P₆)**

**ChPT O(p₆) combined BR fit:** $\text{BR} = (1.01 \pm 0.06) \times 10^{-6}$

**PDG (= BNL E787):** $\text{BR} = (1.10 \pm 0.32) \times 10^{-6}$
$K^+ \rightarrow \pi^+ \nu\bar{\nu}$ and $K_L \rightarrow \pi^0 \nu\bar{\nu}$ decays

- Golden modes of rare K decays (FCNC)

\[
B_{SM}(K^+ \rightarrow \pi^+ \nu\bar{\nu}) = (7.2 \pm 0.8) \times 10^{-11}
\]
\[
B_{SM}(K_L^0 \rightarrow \pi^0 \nu\bar{\nu}) = (2.8 \pm 0.4) \times 10^{-11}
\]

E787/E949 Final: 7 events observed

\[
B(K^+ \rightarrow \pi^+ \nu\bar{\nu}) = 17.3^{+11.5}_{-10.5} \times 10^{-11}
\]
K⁺ → π⁺νν : NA62 at CERN

The NA62 detector for K⁺ → π⁺νν

- SPS primary protons @ 400GeV/c
- 75GeV/c unseparated hadron beam (p/π/K), (δp/p ~1%)
- 750MHz → 50MHz kaons (6%) → 6MHz decays
- 4.8×10¹² kaon decays per year

NA62 timeline:
- first technical run in autumn 2012 including many parts of the experiment
- 2013: complete detector installation
- 2014-?: data taking with full detector (driven by CERN accelerator schedule)

• 10% in BR with ~100 events

[152] V. Kekelidze’s talk
K$^+ \rightarrow \pi^+ \nu\nu$ : ORKA at FNAL

ORKA: a 4th generation detector

- Expect $\times 100$ sensitivity relative to BNL experiment: $\times 10$ from beam and $\times 10$ from detector

- 5% in BR with ~1000 events in 5 years
- 53 M USD
Charm Rare Decays

charm CP violation not included.
$D^0 \to \mu^+ \mu^-$

- $D^0 \to \mu^+ \mu^-$ is FCNC process, highly suppressed in the SM ($\sim 10^{-13}$), but could be enhanced by NP.
- SM short distance contribution $\sim 10^{-18}$
- SM long distance contribution
- Two photon contribution

Present best published upper limit $\Rightarrow$ Belle: $1.4 \times 10^{-7}$ @90% C.L.

An intriguing new result from Babar (arXiv:1206.5419v1): $[0.6, 8.1] \times 10^{-7}$ @90% C.L.

Theory: FCNC < short distance contribution: $10^{-18}$ in SM, can be enhanced by e.g. RPV SUSY.

< long distance contributions:
- Single particle contribution $< 10^{-18}$
- Two photon contribution

Present best UL on $D^0 \to \gamma \gamma$ is from Babar: $2.2 \times 10^{-6}$ @90% C.L. Phys.Rev. D85 (2012091107)

So the UL to the two-photon contribution to $BR(D^0 \to \mu \mu)$ is $6 \times 10^{-11}$ @90% C.L.
$D^0 \rightarrow \mu^+\mu^-$

**LHCb**

$B(D^0 \rightarrow \mu^+\mu^-) < 1.3 \times 10^{-8}$ at 95 (90)% CL

Preliminary (LHCb-CONF 2012-005)

0.9 fb$^{-1}$ data

**CMS**

$B(D^0 \rightarrow \mu^+\mu^-) \leq 5.4 \times 10^{-7}$ (90% CL).

Event in signal region = 23, predicted BG = 23

**BELLE**

Belle $< 1.4 \times 10^{-7}$

PRD, 81 091102

best published result
Search for $D^0 \rightarrow \ell^\mp \ell'^\pm$ Submitted to PRD: arXiv 1206.5419

- No statistically significant excess over the background
- Observed 1 event for $D^0 \rightarrow e^+e^-$ with expected bkg $1.0 \pm 0.5$
- Observed 2 events for $D^0 \rightarrow e^\pm \mu^\mp$ with expected bkg $1.4 \pm 0.3$
- Observed 8 events for $D^0 \rightarrow \mu^+\mu^-$ with expected bkg $3.9 \pm 0.6$

- Set Upper Limit on the Branching Fraction at 90% CL:
  - $D^0 \rightarrow e^+e^- < 1.7 \times 10^{-7}$ (best electron channel)
  - $D^0 \rightarrow e^\mp \mu^\pm < 3.3 \times 10^{-7}$
  - $D^0 \rightarrow \mu^+\mu^- = [0.6, 8.1] \times 10^{-7}$

- LHCb: $D^0 \rightarrow \mu^+\mu^- < 1.3 \times 10^{-8}$ at 95% CL (LHCb-CONF-2012-005)
**D_s \rightarrow \mu \nu and D_s \rightarrow \tau \nu at Belle**

**Belle Preliminary (913 fb^{-1})**

- **Signal:** True D, Background
- **Combinatorial Background**

\[ \mathcal{B}(D_s^+ \rightarrow \mu^+ \nu_\mu) = (0.528 \pm 0.028 \text{(stat.)} \pm 0.019 \text{(syst.)})\% \]
- **PDG value:** (0.590 \pm 0.033)\%

**PDG value:** (5.43 \pm 0.31)\%

**Motivation for studying D_s \rightarrow l^+ l^- \nu \nu:**
- Clean mode for SM calculation
- Determine f_{D_s} D_s to compare with theoretical prediction
- Sensitive to new physics

**\tau decay mode:**

<table>
<thead>
<tr>
<th>\tau \rightarrow l^+ l^- \nu \nu</th>
<th>\tau \rightarrow l^+ l^- \nu \nu</th>
<th>\tau \rightarrow l^+ l^- \nu \nu</th>
</tr>
</thead>
<tbody>
<tr>
<td>e\nu\nu</td>
<td>5.37 \pm 0.33 \pm 0.35</td>
<td>5.88 \pm 0.37 \pm 0.34</td>
</tr>
<tr>
<td>\mu\nu\nu</td>
<td>5.96 \pm 0.42 \pm 0.45</td>
<td>5.70 \pm 0.21 \pm 0.31</td>
</tr>
</tbody>
</table>

Combination: 5.70 \pm 0.21 \pm 0.31

**Experiments & Theory agree within 2 \sigma**

**Sensitively to NP**

**Compared with f_{D_s} theoretical prediction:**

<table>
<thead>
<tr>
<th>CLEO-c</th>
<th>BaBar</th>
<th>Belle Preliminary</th>
</tr>
</thead>
<tbody>
<tr>
<td>\text{CLEO-c}</td>
<td>\text{BaBar}</td>
<td>\text{Belle Preliminary}</td>
</tr>
<tr>
<td>D_s^+ \rightarrow \mu^+ \nu_\mu</td>
<td>D_s^+ \rightarrow \tau^+ \nu_\tau</td>
<td></td>
</tr>
</tbody>
</table>

**Experimental W.A.:** 257.2 \pm 4.5 MeV

**Lattice (HPQCD):** 248.0 \pm 2.5 MeV

**K.Hayasaka (KMI, Nagoya Univ.)** for the Belle collaboration
Particle Sources (Facility)
Towards Higher Energy Scale for NP in Rare Decays
Towards Higher Energy Scale for NP in Rare Decays

\[ R \sim \frac{1}{\Lambda^4} \]

\( \Lambda \): energy scale of new physics
Towards Higher Energy Scale for NP in Rare Decays

\[ R \sim \frac{1}{\Lambda^4} \]

\( \Lambda \): energy scale of new physics

Can we improve the \( \Lambda \) reach by an order of magnitude?

must have at least \( 10^4 \) times the number of parent particles in rare decays.
Super KEKB and SuperB Factories (for taus and charms)

Super KEKB LHC aim at
10 ab\(^{-1}\) by 2018
50 ab\(^{-1}\) by 2022

SuperB site view
aim at
75 ab\(^{-1}\) for 5 years

LHC luminosity upgrade
Proton Accelerators (for muons and kaons)
Improvement of Particle Collection Efficiency from Y. Hino’s talk [634]
Improvement of Particle Collection Efficiency

MuSIC@Osaka-U

RCNP cyclotron 400 MeV, 1μA

from Y. Hino’s talk [634]
Improvement of Particle Collection Efficiency

MuSIC@Osaka-U

RCNP cyclotron 400 MeV, 1µA

Measurements on June 21, 2011 (26 pA)

MuSIC muon yields
\( \mu^+ : 3 \times 10^8 / s \) for 400W
\( \mu^- : 1 \times 10^8 / s \) for 400W

cf. \( 10^8 / s \) for 1MW @ PSI

Req. of \( x10^3 \) achieved...
Improvement of Particle Collection Efficiency

MuSIC@Osaka-U

RCNP cyclotron 400 MeV, 1µA

Improvement of $\sim 10^3$ has been demonstrated.

Measurements on June 21, 2011 (26 pA)

MuSIC muon yields

$\mu^+$: $3 \times 10^8$/s for 400W

$\mu^-$: $1 \times 10^8$/s for 400W

cf. $10^8$/s for 1MW @ PSI

Req. of $x10^3$ achieved...

from Y. Hino’s talk [634]
Summary
Summary

• Searches for rare decays of charged leptons (muons and taus) and light mesons (kaons and charms) are quite active.
• Rare decays have potential of great discoveries of new physics beyond the SM at high energy scale.
• Search for rare decays would be complementary to the high energy frontier.
Backup
How to Validate Neutrino Seesaw Mechanism? SUSY-Seesaw?

Neutrino Seesaw Mechanism

- $\nu_L$: left-handed neutrino
- $\nu_R$: right-handed neutrino
- Light
- Heavy
How to Validate Neutrino Seesaw Mechanism? SUSY-Seesaw?

1. Majorana Nature of Neutrinos

Neutrinoless Double Beta Decays

Neutrinoless double beta decays address whether neutrinos are Majorana-type or not?
How to Validate Neutrino Seesaw Mechanism? SUSY-Seesaw?

1. Majorana Nature of Neutrinos
   - Neutrinoless Double Beta Decays
     Neutrinoless double beta decays address whether neutrinos are Majorana-type or not?

2. Heavy Partner of Neutrinos
   - CLFV
     Search for CLFV is sensitive to the energy scale of heavy right-handed neutrinos in the neutrino seesaw models.
Mu3e at PSI (LOI)

- thin silicon pixel detectors (<50µm thick) with high position resolution
  - high voltage monolithic active pixel (HVMAPS)
  - three (two) cylinders with double layers
- SciFi hodoscopes with high timing resolution.
- Stage-I (2014-2017)
  - $B \sim 10^{-15}$ with $2 \times 10^8$ µ/s at πE5
- Stage-2 (2018-)
  - $B < 10^{-16}$ with $2 \times 10^9$ µ/s at new muon source

**HVMAPS**

- First MAPS designs were such that ionisation charges were collected mainly through the drift fields. Since then, they have been significantly improved.
- Use the High Voltage MAPS (HV-MAPS) design with pixel electronics combinations through timing and extra readout chips, which downgrade the track reconstruction performances.
- Use a high voltage commercial process (I.Peric, P. Fischer et al., NIM A 582 (2007) 876 (ZITI Mannheim, Uni Heidelberg)).
- Can be thinned down to <50µm or less, depending on the complexity and vertical size.
- Need excellent resolutions to get rid of backgrounds.
- Low power consumption (average about 150 mW/cm²).
- Add a scintillating fiber timing detector.
- 100 ps resolution on average one electron.
- The proposed experiment aims for a sensitivity of $B \sim 10^{-15}$.