Status of the $K_L \to \pi^0 \nu\nu$ Experiment at J-PARC

Tadashi Nomura
(KEK)

- Introduction
- KOTO experiment
- Analysis status of 2013 run
- Prospect
CP violating rare decay $K_L \to \pi^0\nu\nu$

* Flavor changing neutral current, occurring via loop diagrams
* Dominated by t-quark loop
* Theoretically clean

* A probe to explore beyond the Standard Model
  - New heavy particle in loop can contribute

Possible BSM effects
- SM diagrams
- Possible NP diagrams ($s \to dZ$) from PRD76.074027

THDM: two-Higgs-doublet model
MSSM: minimal-supersymmetric SM
mUED: minimal universal extra dimension
LHT: littlest Higgs model with T parity
Numbers for $\text{Br}(K_L \rightarrow \pi^0 \nu \nu)$

* Standard Model Prediction
  - $\text{Br}(\text{SM}) = 2.4 \times 10^{-11}$ [intrinsic uncertainty $\sim 2\%$]

* Experimental limit
  - $\text{Br}(K_L \rightarrow \pi^0 \nu \nu) < 2.6 \times 10^{-8}$ (KEK E391a)

* Grossman-Nir (G-N) limit [limit from $\text{Br}(K^+ \rightarrow \pi^+ \nu \nu)$]
  - $K_L$ and $K^+$ see the same $s \rightarrow d$ transition amplitude ($A_{s \rightarrow d}$)
  - $K_L \propto K^0 - K^0 \Rightarrow \text{Br}(K_L) \propto (\text{Im}(A_{s \rightarrow d}))^2 \iff \text{Br}(K^+) \propto |A_{s \rightarrow d}|^2$
  - $\text{Br}(K^+ \rightarrow \pi^+ \nu \nu) = (1.7 \pm 1.1) \times 10^{-10}$ (BNL-E949)
  - $\Rightarrow \text{Br}(K_L \rightarrow \pi^0 \nu \nu) < 1.5 \times 10^{-9}$
Grossman-Nir Limit by $K^+ \to K_L$ decay Isospin rotation

Standard Model

http://www.lnf.infn.it/wg/vus/content/Krare.html
Grossman-Nir Limit by $K^+$ decay → $K_L$ decay Isospin rotation

Standard Model

http://www.lnf.infn.it/wg/vus/content/Krare.html
KOTO stands for “K0 at Tokai”

J-PARC E14/KOTO experiment: $K_L \rightarrow \pi^0 \nu\nu$ measurement

* Goal = observation of few SM events
**Principle of experiment**

* Signature of $K_L \rightarrow \pi^0 \nu \nu = 2\gamma + \text{nothing}
  - Calorimeter + Hermetic veto detectors
KOTO detector

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Photo of the vacuum tank and 3D image inside
Principle of experiment

* Reconstruction
  - Assuming $2\gamma$ come from $\pi^0$,
    - Calculate Z vertex
    - Calculate $\pi^0$ transverse momentum

\[
\cos \theta = 1 - \frac{M^2_{\pi^0}}{2E_1 E_2}
\]

\(\pi^0\) 
ZOtx 
A narrow $K_L$ beam is the key.
Timeline of KOTO

- Closing vacuum chamber (2012 Dec)
- Charged Veto installation (2012 June)
- FB installation (2012 Nov)
- Main Barrel installation (2012 Dec)

- CsI calorimeter stacking finished (2011 Feb)
- Beamline construction finished (2009 Aug)
- KL→eμ event display
- 1st physics run 2013 May

- NCC installation (2012 Nov)
- 2013 Jan engineering run
- 2013 May
- 1st physics run
- 2013 June
- Beamline construction finished (2009 Aug)
Goal of KOTO first-step run

* J-PARC beam power for slow extraction is not high enough yet.
  - <50kW in early stage, and will increase year by year.
    (While design power >>100kW)

➡ We thus set a first milestone of reaching the G-N limit sensitivity.

➡ We thus ran in the first run period without some new detectors, after considering achievable background level.
Missing detectors in first phase

Inner Barrel Photon Veto:
for improvement of photon detection efficiency in barrel region

A half of In-beam Photon Veto (BHPV)
Run in 2013

Until terminated due to the accident in J-PARC hadron hall

* January: Engineering run in vacuum
  - 11kW × 1.5 days + 15kW × 6.5 days

* March and April: Tuning for physics run
  - 15kW × (5 days)

* May: Physics run
  - 24 kW, ~100 hours

![Graph showing accumulated P.O.T.](image)
Analysis path

- Understanding of the detector performance

- Analysis of normalization modes
  \((K_L \rightarrow 3\pi^0, 2\pi^0, 2\gamma)\)
  - Being done in parallel with above and below

- Analysis of \(K_L \rightarrow \pi^0\nu\nu\) mode
CsI EM calorimeter

Demonstration using $K_L \rightarrow 3\pi^0$

(6\gamma in calorimeter)
VETO detector response

4γ analysis ($K_L \rightarrow 2\pi^0$) before cuts

Deposit E in Main Barrel
Understanding of VETO rejection

Reproducibility in 4γ analysis after veto cuts

$M_{2\pi^0}$

Data/MC/10 MeV/c

# of events/10 MeV/c

mass [MeV/c²]

$Z$ decay

Data/MC/100 mm

# of events/100 mm

$z$ [mm]
Analysis status of May 2013 run

* Detector performance is well understood.

* Now analyzing $K_L \rightarrow \pi^0\nu\nu$ mode
  - With blind analysis for “signal box”
  - Estimating the number of backgrounds from other $K_L$ decays and neutron interactions.

* Will announce the result from the 100-hour physics run soon.
Summary and prospect

* KOTO experiment, $K_L \rightarrow \pi^0 \nu\nu$ study at J-PARC, took first physics data in May 2013 for 100 hours. ⇒ The result is coming soon.

KOTO will restart from early 2015, and will cross the G-N limit by summer 2015

  • Renovation of the J-PARC hadron hall for safety will continue until fall of this year.

We plan to install remaining missing detectors in summer 2015, and will go further in sensitivity.
Extras
Understanding detector performance

With high statistics $K_L \rightarrow 3\pi^0$ in January Run

$M_{3\pi^0}$

Data

$K_L \rightarrow 3\pi^0$ MC

Other $K_L$ MC

Reconstructed $K_\pi$ mass [MeV/c^2]
Understanding detector performance
With high statistics $K_L \rightarrow 3\pi^0$ in January Engineering Run
Inner Barrel Photon Veto

* Add $5X_0$ to $13.5X_0$ of current Main Barrel
  ■ 25 layers of Pb/scint. sandwich $\times$ 32 modules
  ■ Suppress inefficiency due to punch through by $1/50$
* Plan to install in summer 2015
Accident at J-PARC Hadron Hall on May 23, 2013

* Malfunction of a magnet for slow extraction caused a very short beam to the hall.
  - In usual (as of May 2013): $3 \times 10^{13}$ protons/2 sec.
  - On accident: $\sim 2 \times 10^{13}$ protons/5 msec.

* This made a damage on the common Au target.

* A part of radioactivities from the damaged target was leaked to the hall and the outside of the hall.

Improvement for safety (target system, air tightness, monitoring) is on-going.