Future Prospects for K Decay Experiments

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BNL
Outline

• What should we be doing?
• Is (American) history any guide?
• The leading opportunities
  – $K^+ \rightarrow \pi^+ \nu \bar{\nu}$
  – $K_L \rightarrow \pi^0 \nu \bar{\nu}$
  – $K_L \rightarrow \pi^0 \ell^+ \ell^-$
• Conclusions
What should we be doing?

• $K_L \rightarrow \pi^0 \nu \bar{\nu}$ & $K^+ \rightarrow \pi^+ \nu \bar{\nu}$
  – NP governed by a single effective operator
  – Determine the IP & modulus of any NP contribution
  – Can be calculated in almost any model
  – Sensitive to high mass scales

• $K_L \rightarrow \pi^0 e^+ e^-$ & $K_L \rightarrow \pi^0 \mu^+ \mu^-$
  – In SM, same information as $K_L \rightarrow \pi^0 \nu \bar{\nu}$
  – NP can contribute to $>1$ operator: richer but harder to interpret
  – Recent developments show these more accessible!

• LFV processes, T-violation, medium rare
• Some pion decays
BNL AGS E949 $K^+ \rightarrow \pi^+ \nu \bar{\nu}$
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FNAL CKM $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ Experiment
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FNAL P940 $K^+ \rightarrow \pi^+ \nu \bar{\nu}$
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KAMI $K_L \rightarrow \pi^0 \nu \bar{\nu}$ at FNAL

KAMI DETECTOR LAYOUT

Magnet

Vacuum Window

Hadron Anti

CsI

Charged Hodoscope

Beam Hole Veto

CsI Anti

Muon Range Stack

Fiber Tracker

Vacuum Veto

Mask Anti
KAMI $K_L \rightarrow \pi^0 \nu \bar{\nu}$ at FNAL
KOPIO $K_L \rightarrow \pi^0 \nu \nu$ at BNL
KOPIO $K_L \rightarrow \pi^0 \nu \bar{\nu}$ at BNL
Experimental considerations for $K^+ \rightarrow \pi^+ \nu \bar{\nu}$

- $BR \sim 8 \times 10^{-11}$
- 3-body decay, only 1 visible
- $\pi^+$ common K decay product
- Backgrounds:
  - $K^+ \rightarrow \mu^+ \nu(\gamma)$
  - $K^+ \rightarrow \pi^+ \pi^0$
  - $K^+ n \rightarrow K^0 p; K_L \rightarrow \pi^+ \ell^- \nu, \ell^- \text{ missed}$
  - $Ke4$
  - Beam (stopped-K configuration)
    - Beam $\pi^+$ mis-ID as $K^+$, then fakes K decay at rest
    - $K^+$ decay in flight
    - 2 beam particles
  - Beam (in-flight)
    - Beam $\pi^+$ mis-ID as $K^+$, then interacts
    - 2 beam particles
Solenoidal detector at the end of a stopped $K^+$ beam
E787/949 Technique

- Incoming 700MeV/c beam $K^+$: identified by Č, WC, scintillator hodoscope (B4). Slowed down by BeO
E787/949 Technique

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- $K^+$ stops & decays at rest in scintillating fiber target – measure delay (2ns)
E787/949 Technique

- Incoming 700MeV/c beam $K^+$: identified by Č, WC, scintillator hodoscope (B4). Slowed down by BeO

- $K^+$ stops & decays at rest in scintillating fiber target – measure delay (2ns)

- Outgoing $\pi^+$: verified by IC, VC, T counter. Momentum measured in UTC, energy & range in RS and target (1T magnetic field parallel to beam)
E787/949 Technique

- Incoming 700MeV/c beam K⁺: identified by Č, WC, scintillator hodoscope (B4). Slowed down by BeO
- K⁺ stops & decays at rest in scintillating fiber target – measure delay (2ns)
- Outgoing π⁺: verified by IC, VC, T counter. Momentum measured in UTC, energy & range in RS and target (1T magnetic field parallel to beam)
- π⁺ stops & decays in RS – detect \( \pi^+ \rightarrow \mu^+ \rightarrow e^+ \) chain
• Incoming 700MeV/c beam K⁺: identified by Č, WC, scintillator hodoscope (B4). Slowed down by BeO

• K⁺ stops & decays at rest in scintillating fiber target – measure delay (2ns)

• Outgoing π⁺: verified by IC, VC, T counter. Momentum measured in UTC, energy & range in RS and target (1T magnetic field parallel to beam)

• π⁺ stops & decays in RS – detect π⁺→µ⁺→e⁺ chain

• Photons vetoed hermetically in BV-BVL, RS, EC, CO, USPV, DSPV
**E787/949 Analysis Strategy**

**Signal region “the BOX”**

PNN1: $p_\pi > p(K^+\rightarrow\pi^+\pi^0) = 205\text{MeV/c}$

**Background sources**

Identify *a priori.* at least 2 independent cuts to target each background:
- $K^+\rightarrow\pi^+\pi^0$
- muon background ($K^+\rightarrow\mu^+\nu(\gamma),...$)
- Beam background
- etc.

**Analysis Strategy**

- Blind Analysis
- Measure background level with real data
- To avoid bias,
- 1/3 of data ⇒ cut development
- 2/3 of data ⇒ background measurement
- Characterize backgrounds using background functions
- Likelihood Analysis
E787/949 Events

\[ B(K^+ \rightarrow \pi^+ \nu \bar{\nu}) = (1.47^{+1.30}_{-0.89}) \times 10^{-10} \]
Combined E787/949 Result

\[ BR(K^+ \to \pi^+ \nu\bar{\nu}) = (1.47^{+1.30}_{-0.89}) \times 10^{-10} \]

(68% CL interval)

E787 result:

\[ BR(K^+ \to \pi^+ \nu\bar{\nu}) = (1.57^{+1.75}_{-0.82}) \times 10^{-10} \]

<table>
<thead>
<tr>
<th></th>
<th>E787</th>
<th>E949</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stopped K(^+) ((N_K))</td>
<td>(5.9 \times 10^{12})</td>
<td>(1.8 \times 10^{12})</td>
</tr>
<tr>
<td>Total Acceptance</td>
<td>0.0020 ± 0.0002</td>
<td>0.0022 ± 0.0002</td>
</tr>
<tr>
<td>S.E.S.</td>
<td>(0.8 \times 10^{-10})</td>
<td>(2.6 \times 10^{-10})</td>
</tr>
<tr>
<td>Total Background</td>
<td>0.14 ± 0.05</td>
<td>0.30 ± 0.03</td>
</tr>
<tr>
<td>Candidate</td>
<td>E787A</td>
<td>E787C</td>
</tr>
<tr>
<td>(S_i/b_i)</td>
<td>50</td>
<td>7</td>
</tr>
<tr>
<td>(W_i = \frac{S_i}{S_i+b_i})</td>
<td>0.98</td>
<td>0.88</td>
</tr>
</tbody>
</table>
Status & prospects for E949

- E949 detector worked well
- Obtained $\sim2/3$ sensitivity of E787 in 12 weeks (1/3 pnn1+1/3 pnn2)
- Found one new pnn1 candidate
- pnn2 analysis currently in progress – looks promising
- AGS & beamline problems cost a factor $\sim2$ in sensitivity/hour
- DOE cut off experiment after 12 of 60 promised weeks

$E949(02) = \text{combined E787 & E949.}$

$E949$ projection with full running period.
J-PARC $K^+ \rightarrow \pi^+ \nu \overline{\nu}$ LOI

- Stopped $K^+$ experiment
- Builds on E787/949 experience
  - Lower energy separated beam
  - Higher B spectrometer
  - More compact apparatus
  - Better resolution
  - Finer segmentation
  - Improved $\gamma$ veto (crystal barrel)
- Aims for 50 events

- Not an early experiment for J-PARC
  - Needs longer spill than planned
  - beamline
  - place on the floor
  - $ for detector
P326 (NA48/3) $K^+ \rightarrow \pi^+ \nu \bar{\nu}$

Proposal submitted to CERN for ~100 events
P326 Technique

• Detection in-flight

• High energy (75 GeV/c) unseparated beam (800 MHz!)
  – Careful design to keep halo to ~7MHz
  – Measure all beam tracks (“Gigatracker”)
  – Differential Cerenkov (“CEDAR”) for K ID

• Redundant measurement of pion momentum
  – Two-stage magnetic spectrometer (straws in vacuum)
  – Require large missing momentum

• Redundant pion I.D.
  – Magnetized hadron calorimeter (“MAMUD” + RICH)

• (Almost) hermetic photon veto system
  – NA48 liquid Krypton calorimeter
  – Small angle charged & neutral vetoes (beam bent out of the way)
  – Wide-angle frame anti’s
π⁺ momentum cut requires a huge momentum mismeasurement to mistake a beam π⁺ for a final state particle (75→35 GeV/c). Also guarantees large missing momentum, e.g., so that there’s plenty of γ energy from K⁺→ π⁺π₀

Assumption of pion mass spreads out K⁺→µ⁺ν peak
0.3% resolution on p_K and 1% resolution on p_π allows >10% acceptance
Plan for P326

- **2005**
  - Gigatracker R&D
  - Vacuum tests
  - Technical design & cost estimate
- **2006**
  - Detector tests in present beam
- **Construction & installation 2007-8**
  - Construct new beamline
  - Construct & install detectors
- **2009-10**
  - Data taking
- **Expect ~80 events with S:B ~ 8:1**
## Stopped vs In-flight K⁺

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<th>P326</th>
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<tbody>
<tr>
<td>beam/spill</td>
<td>25M</td>
<td>2500M</td>
</tr>
<tr>
<td>K⁺/spill</td>
<td>30M</td>
<td>125M</td>
</tr>
<tr>
<td>purity</td>
<td>0.8</td>
<td>0.05</td>
</tr>
<tr>
<td>duty factor</td>
<td>4.1/6.4</td>
<td>4.8/16.8</td>
</tr>
<tr>
<td>inst. beam rate</td>
<td>7.2MHz</td>
<td>800MHz</td>
</tr>
<tr>
<td>‘decay’ factor</td>
<td>26%</td>
<td>10%</td>
</tr>
<tr>
<td>DKs/clock-sec</td>
<td>0.81M</td>
<td>0.74M</td>
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<tr>
<td>DAQ/veto livetime</td>
<td>1/1.7</td>
<td>1/1.7</td>
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<tr>
<td>eff. DK/clock-sec</td>
<td>0.48M</td>
<td>0.44M</td>
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<tr>
<td>acceptance</td>
<td>0.3%</td>
<td>17%</td>
</tr>
<tr>
<td>acc. DK/clock-sec</td>
<td>1400</td>
<td>74000</td>
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How far can stopped exp. be pushed?
How to pursue $K^+ \rightarrow \pi^+ \nu \bar{\nu}$?

- **In-flight has the “appeal of the new”**
  - The only way to get >100 events
  - But requires 11 O.M. leap!
    - Watch out for tails, acceptance losses, the unexpected
- **Stopping experiment very well understood**
  - Technique shown to have sufficient S/B
  - Any further improvements can increase acceptance
    - Note acceptance of 787/949 is ~0.002-0.003
    - Plenty of room for improvement!
    - Trick is to increase the beam rate w/o losing acceptance
  - Could *really know* if 50-100 events possible
    - But so far very little support for such an experiment
The Challenge of $K_L \rightarrow \pi^0 \nu \bar{\nu}$

- $B(K_L \rightarrow \pi^0 \nu \bar{\nu}) \sim 3 \times 10^{-11}$, need intense flux of K’s
  - rates inevitably rather high
  - hard to minimize both random vetoing & veto-blindness
- Kinematic signature weak (2 particles undetectable)
- Backgrounds with $\pi^0$ up to $10^{10}$ times larger than signal
- Veto inefficiency on extra particles, both charged particles and photons, must be $\leq 10^{-4}$
- Self-vetoing is a problem
  - shower spreading makes it hard to maximize both signal efficiency and veto power
- Huge flux of neutrons in beam
  - can make $\pi^0$ off residual gas – requires high vacuum
  - halo must be tiny
  - hermeticity requires photon veto in this beam
- Need convincing measurement of background
1\textsuperscript{st} dedicated $K_L \rightarrow \pi^0 \nu \bar{\nu}$ experiment - E391a

- KEK 12 GeV PS
- 4° “pencil” beam
- $<p_K> \sim 2$ GeV/c
- CsI calorimeter
Pencil Beam

5 stages of collimators made of heavy metal (tungsten)
2 stages of sweeping magnets
Thermal neutron absorber
Pb/Be plug for control of $\gamma$/neutron flux
Fine alignment using telescope
GEANT3 M.C. agrees well with the measurements
2\gamma analysis

Data without tight veto
(from Run 1)

\( P_T (\text{GeV/c}) \)

Reconstructed vertex (cm)

\( \pi^0 \text{ produced at CC02} \)

\( \pi^0 \text{ produced at CV (?)} \)

\( K_L \rightarrow \gamma\gamma \)

M.C. for \( K_L \) decays (Without Normalization)

\( K_L \rightarrow \pi^0\pi^0\pi^0 \)

\( K_L \rightarrow \pi^+\pi^-\pi^0 \)

\( K_L \rightarrow \pi^-e^+\nu \)

\( K_L \rightarrow \pi^-\mu^+\nu \)

7 Nov 05  L. Littenberg  Flavour in the ERA of the LHC 36
Veto Optimization
~Main-barrel timing (low E sample)~

upstream

\[ K_i \rightarrow \gamma\gamma \text{ pure sample} \]

\[ \gamma\gamma \text{ B.G.sample} \]

T(down) - T(up), [ns]

early → late

Backsplash → should NOT veto!

1. Real photon hit → should veto.
2. Backsplash → should NOT veto.
E391a Result from 10% of Run I

- No events observed/expected background of $0.03\pm0.01$ events (mainly $K\pi2$)
- $1.14\times10^9 K_L$ decay, 0.0073 acceptance $\Rightarrow$ s.e.s of $1.17\times10^{-7}$
- $B(K_L\rightarrow\pi^0\nu\bar{\nu})<2.86 \times10^{-7}$ @ 90% CL (c.f. $5.9 \times10^{-7}$ from KTeV)

![Graph showing event distribution with all event selection]
Better quality of data (online plots)

Run-I

Run-II

Run-II analysis → Run-III (starting now)
E391a status & prospects

• First physics run Feb-June 2004
  – $2.2 \times 10^{12}$ 12 GeV POT, 50% duty factor
  – $5 \times 10^5$ $K_L$/pulse
  – Detector worked well
  – Nominal s.e.s. $4 \times 10^{-10}$
    • But acceptance $\sim$ 15× lower than in proposal (0.0073)
    – first sight of the enemy
    • Halo neutrons, self-vetoing, etc.
  – Analysis of 10% of data $\Rightarrow B(K_L \rightarrow \pi^0 \nu \bar{\nu}) < 2.86 \times 10^{-7}$

• Run II, Feb-March 2005
  – Many problems fixed, 60% of Run 1

• Run III, Nov-Dec 2005, starting now
JPARC Phase I Beamlines

Fig.1 Hadron Hall Layout Plan

protons

High-\(p\) K0.8/ K1.1 (C-type) K1.1/ K0.8 (S-type) Test line K1.8 BR K1.8
KEK-PS to J-PARC

- $10^{14}$ interacting 30 GeV protons/cycle, $5 \mu$sr beamline @ 16°
- 22MHz $K_L$ @ 20m, $<p_K> = 2.1$ GeV/c, 9%/5m decay
- 4% acceptance
- 23 events in 3 Snowmass years (competition from $\nu$)
- S:B~1:1 (optimization studies in progress)
Step by step at JPARC

- “Step by step” approach, learning as they go
- Different beam angles, lengths
- Larger detector
- Eventual goal – few 100 evts

<table>
<thead>
<tr>
<th>Tgt ∆ z-det</th>
<th>Beam size</th>
<th>K_L flux (MHz)</th>
<th>Decay prob</th>
<th>Decay rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>16° 20m</td>
<td>10cm</td>
<td>27MHz</td>
<td>25%</td>
<td>6.8MHz</td>
</tr>
<tr>
<td>5° 50m</td>
<td>10cm</td>
<td>63MHz</td>
<td>11%</td>
<td>6.9MHz</td>
</tr>
<tr>
<td>8° 70m</td>
<td>15cm</td>
<td>28MHz</td>
<td>14%</td>
<td>3.9MHz</td>
</tr>
</tbody>
</table>

16° case

Signal: $\pi^0 p_T$

$K_L \rightarrow \pi^0 \pi^0$ bckgnd
\[ K_L \rightarrow \pi^0 \nu \bar{\nu} \] Experiment

Diagram showing the experimental setup for the \( K_L \rightarrow \pi^0 \nu \bar{\nu} \) experiment, with labeled sections for production (prod.), target (tgt), veto, calorimeter (calor.), and beam veto.
$K_L \rightarrow \pi^0 \nu \bar{\nu}$ Experiment
$K_L \rightarrow \pi^0 \nu \bar{\nu}$ Experiment
In the $K_L$ CoM

- Bckgnd mainly in discrete areas
- Obvious for $K_L \rightarrow \pi^0\pi^0$ “even”
- But even “odd” case not ubiquitous

- $K\pi3$ infests slightly different area

- Even after all bckgrnds accounted for, still some clear space for signal
- Can get factor 50-100
In the $K_LCoM$

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In the $K_L$ CoM

- Bckgnd mainly in discrete areas
  - Obvious for $K_L \rightarrow \pi^0 \pi^0$
  - But even "odd" case not ubiquitous
  - $K \pi^3$ infests slightly different area
  - Even after all backgrounds accounted for, still some clear space for signal
  - Can get factor 50-100
KOPIO Technique

- High intensity micro-bunched beam from the AGS
- Measure everything! (energy, position, angle, time)
- Eliminate extra charged particles or photons
  - KOPIO: $\pi^0$ inefficiency $< 10^{-8}$
- Suppress backgrounds
  - Predict backgrounds from data: dual cuts
  - Use “blind” analysis techniques
  - Test predictions “outside the box”
- Weight candidate events with S/N likelihood function
Is KOPIO completely dead?

- AGS E926 is certainly completely dead
- But we asked whether Fermilab might be interested
  - Would use 8 GeV proton beam from Booster
  - Answer - not immediately, but maybe later
  - Agreed to have accelerator physicists help
  - Some studies were done …. 
First Surprise

- Useful K flux not much impacted!

Large loss in forward dirn.

Small loss at KOPIO-type $\angle$
How to get the protons

Send 8 GeV protons from the Booster to the Accumulator (need new line)

Momentum stack Booster batches in Accumulator and debunch. Then microbunch at 26MHz on extraction (need slow extraction system, beam-line, etc.)
Dave McGinnis’ Scenarios

- NUMI and 4/23 batches to KOPIO
  - Accelerator cost not including slow extraction ~10-12 M$
  - Constraints
    - Cycle time – 1.5 Seconds
    - C.O.D 6 mm
    - Loss 550W
    - Booster Notching - 3 / 84 bunches
      - Improvement comes because notching is not needed for momentum stacking KOPIO beam
  - NUMI – 12 batches @ 4.8e12 protons/batch
  - KOPIO – 4.6e16protons/hr

- NUMI and 8/23 batches to KOPIO
  - Constraints
    - Cycle time – 1.5 Seconds
    - C.O.D 6 mm
    - Loss 600 W
    - Booster Notching - 2.4 / 84 bunches
      - Improvement comes because notching is not needed for momentum stacking KOPIO beam
  - NUMI – 12 batches @ 4.8e12 protons/batch
  - KOPIO – 9.2e16protons/hr
Second Surprise

From Mc Ginnis’ Summary:

- To run NUMI and KOPIO at 4.6e16 protons/hour:
  - Decrease the closed orbit distortion by 40% from present
  - Decrease the notching loss by 43% from present
  - Increase the permitted loss in the Booster tunnel by 20% from present
  - KOPIO spill length 82% of cycle

KOPIO is VERY sensitive to duty factor (67% @ AGS)

Inst. K rate a little lower than at AGS

Bottom line - Sensitivity/hour = 93% of AGS
Third Surprise

• When E926 (KOPIO) proposed, asked for 3000 hours per year for three years.
  – That was thought aggressive but possible in the “AGS-2000” era

• When RSVP plan finally set, we were given 6240 hours over three years
  – But not all at 100 TP, equivalent was 5684 hours

• Fermilab seems to assume ~6000 hours/year
Discovering/Constraining New Physics

Equivalent Standard Model Events

KOPIO Run Duration (Hours @ 100TP/pulse)

Discovery Region (5σ)

BR/BR_{SM}

Grossman-Nir Limit from E949

4th generation
SUSY w/R (LFV)
Extra vector quarks

Enhanced Z-Penguins
MSSM

Z'
Technicolor
MFV

Isosinglet d quark

Extra dimensions

Standard Model

1st yr
2nd yr
3rd yr

Discovery Region (5σ)
Discovering/Constraining New Physics at FNAL

Equivalent Standard Model Events

BR/BR_{SM}

KOPIO Run Duration (Hours @ 100TP/pulse)

4th generation
SUSY w/R (LFV)
Extra vector quarks

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Standard Model
Extra dimensions

Grossman-Nir Limit from E949

Discovery Region (5σ)

Discovery Region (5σ)

1st yr
2nd yr
How many $K$’s needed to see $K_L \rightarrow \pi^0 \mu^+ \mu^-$?

From thesis of M. Sadamoto Osaka, 1999 (KTeV)

The number of $K_L$ necessary to see $K_L \rightarrow \pi^0 \mu^+ \mu^-$

In order to discover the $K_L \rightarrow \pi^0 \mu^+ \mu^-$ decay, the number of the signal events must be significant by more than $3\sigma$ above the background. In this section, we will assume that all the background sources are well understood and that the number of the background events is large enough so that the fluctuation can be treated as a Gaussian. This assumption leads to the following relation:

$$N_S > 3\sqrt{N_S + N_{BG}}$$

$$N_S = \#K_L \times Br(K_L \rightarrow \pi^0 \mu^+ \mu^-) \times \epsilon_{\pi \mu^+ \mu^-}$$

$$N_{BG} = \#K_L \times Prob_{BG}$$

where $N_S$ is the number of observed $K_L \rightarrow \pi^0 \mu^+ \mu^-$, $\#K_L$ is the number of $K_L$ decays, $N_{BG}$ is the number of observed background events, $\epsilon_{\pi \mu^+ \mu^-}$ is the detector acceptance for $K_L \rightarrow \pi^0 \mu^+ \mu^-$, and $Prob_{BG}$ is the probability of a $K_L$ to generate a background event, respectively. (If we use the same condition as in KTeV experiment, we can assume $\epsilon_{\pi \mu^+ \mu^-} = 0.05$, $Prob_{BG} = 3.3 \times 10^{-12}$.)

Let us assume the following predicted numbers as described in Chapter 1,

$$Br(K_L \rightarrow \pi^0 \mu^+ \mu^-)_{CP\_conserve} = 4.4 \times 10^{-12}$$

$$Br(K_L \rightarrow \pi^0 \mu^+ \mu^-)_{indirect} = 2.0 \times 10^{-13}.$$
How many K’s needed?

If we regard the indirect CP violating and CP conserving contributions as background, we can calculate the number of $K_L$ decays required to detect the direct CP violation. At this time, we can assume $Prob_{bg} = 7.9 \times 10^{-12}$. For confirming the direct CP violating $K_L \rightarrow \pi^0 \mu^+\mu^-$ with the branching ratio of $1.0 \times 10^{-12}$, we need more than $1.4 \times 10^{15} K_L$ decays.

Fermilab is planning KAMI experiment which is the next generation of KTeV experiment. KAMI plans to observe $5.6 \times 10^{13}$ kaon decays for searching the direct CP violating phenomena. However, it is still a factor of 10 lower than the sensitivity to detect $K_L \rightarrow \pi^0 \mu^+\mu^-$.  

• In 1999, thought it would require two further generations of experiments to see $K_L \rightarrow \pi^0 \mu^+\mu^-$ at 3$\sigma$ ($K_L \rightarrow \pi^0 e^+e^-$ similar)  
• Also, most people thought in terms of measuring SM $\eta$, so high precision needed  
• Situation today is completely different
New Situation for $K_L \rightarrow \pi^0 \ell^+ \ell^-$

- Now that NA48 observed $K_S \rightarrow \pi^0 \ell^+ \ell^-$ at higher end of expectation
- & arguments for constructive interference between mixing & direct CP-violating components strong as ever
- SM expectation for $K_L \rightarrow \pi^0 \ell^+ \ell^-$ rather large:
  - $B(K_L \rightarrow \pi^0 e^+ e^-) = (4 \pm 1) \times 10^{-11}$
  - $B(K_L \rightarrow \pi^0 \mu^+ \mu^-) = (1.5 \pm 0.3) \times 10^{-11}$
- Compare with $K_L \rightarrow \gamma \gamma \ell^+ \ell^-$ background (worst one):

<table>
<thead>
<tr>
<th></th>
<th>$K_L \rightarrow \pi^0 e^+ e^-$ (‘99)</th>
<th>$K_L \rightarrow \pi^0 \mu^+ \mu^-$ (‘97)</th>
</tr>
</thead>
<tbody>
<tr>
<td>KTeV s.e.s..</td>
<td>$10.4 \times 10^{-11}$</td>
<td>$7.5 \times 10^{-11}$</td>
</tr>
<tr>
<td>$K_L \rightarrow \gamma \gamma \ell^+ \ell^-$ evts</td>
<td>0.99</td>
<td>0.37</td>
</tr>
<tr>
<td>$B(K_L \rightarrow \gamma \gamma \ell^+ \ell^-)_{\text{effective}}$</td>
<td>$10.3 \times 10^{-11}$</td>
<td>$2.8 \times 10^{-11}$</td>
</tr>
<tr>
<td>S:B</td>
<td>1:2.5</td>
<td>1:1.9</td>
</tr>
</tbody>
</table>
Motivation for $K_L \rightarrow \pi^0 \ell^+ \ell^-$

Add to this, now we are interested in bigger game than $\text{Im}\lambda_t$.

*E.g.*, from Isidori, *et al.*, hep-ph/0404127

- Take KaMI as example of a next-generation experiment with sensitivity to $K_L \rightarrow \pi^0 \mu^+\mu^-$. In 3 years, KaMI would have reached a s.e.s of $4 \times 10^{-13}$.

- In the example above, would collect $110 \pm 13$ signal events (with 70 events of background) compared with a SM expectation of 37 events.

- Similar sensitivity experiment possible for $K_L \rightarrow \pi^0 e^+e^-$
Conclusions

• K experiments extinct in US
  – State of the art in 4 of the 5 most interesting decays
  – Some data analysis continuing
  – Experiments could be mounted at FNAL (KOPIO?)
  – But K experiments seem low on DOE priority list
• Continuing K→πνν̅ program in Japan
• K⁺→π⁺νν̅ proposal at CERN
• Could use a KOPIO-type K_L→π⁰νν̅ experiment
  – or at least one with photon pointing.
• K_L→π⁰ℓ⁺ℓ⁻ experiment(s) now seem very worthwhile
  – Could be done!
  – But no proposals yet