Reach of Future Kaon Efforts

Tadashi Nomura
(Kyoto U)
The Standard Model

- KAON inspired SM ideas in history
  - CPV in K decay → KM theory, 3 generations

- And now..
Role of Kaon efforts in future

• Explore physics beyond SM
  – Find discrepancy from SM

• Explore the flavor structure beyond SM
  – Find feature depending on flavors

COMMON TO
Flavor physics in next generation
Golden Modes: $K \rightarrow \pi \nu \nu$

- Rare decays, $O(10^{-11})$
- Process via loop diagrams
  - “Top”-loop dominant in terms of SM
  - New particles can contribute in the loop
  - New flavor-violation can occur in the loop
Golden Modes : $K \rightarrow \pi \nu \nu$

- Extremely small theoretical uncertainty
  - <2% for neutral mode : $K_L \rightarrow \pi^0 \nu \nu$
  - <5% for charged mode : $K^+ \rightarrow \pi^+ \nu \nu$

- Many room to be contributed from BSM and not yet to be constrained
Mescia’s talk on 6 May

Excluded area
Grossman-Nir bound
CPV observables at comparison: large room left due to the $A^u$ terms

small impact on $\varepsilon_K$ & $\sin\beta$, complementarity to LHCb/SuperB

$A_{CP}(B_d \to \psi K)$

$\varepsilon_K$

$B(\bar{K}_L \to \pi^0\nu\bar{\nu})$

Isidori, F. M., Paradisi, T., Trine, S., Smith (06)
Comparison with SM

- Once we achieve 10% measurements of $K \rightarrow \pi \nu \nu$...

May find discrepancy
Current Achievements in Experiment
Current Situation - $K^+$

- BNL-E787/949
  - 3 candidates observed

$K^+ \to \pi^+ \nu \nu$

$BR = (1.5^{+1.3}_{-0.9}) \times 10^{-10}$

$BR_{SM} = 8.2 \times 10^{-11}$
Constraints in $\rho$-$\eta$ plane (by now)

- By $K^+ \rightarrow \pi^+ \nu \bar{\nu}$
  - Based on 3 candidate events

$\Rightarrow$ Clearly, we want to get more statistics.
Current Situation - $K_L$

- KEK E391a
  - No events observed

$K_L \rightarrow \pi^0\nu\nu$

$BR < 6.7 \times 10^{-8}$

$BR_{SM} = 2.8 \times 10^{-11}$

I realize we didn’t announce our results at any conference…

Let me present more for E391a
KEK-E391a: Introduction

• Dedicated to $K_L \rightarrow \pi^0 \nu \nu$
  – With 12GeV KEK-PS, intensity of $2 \times 10^{12}$ protons per pulse
  – 3 run periods in 2004-05
    • one not-clean run (Run1)
    • two clean runs (Run2 and 3)
  – Run2 result was announced last December

arXiv:0712.4164 (will appear in PRL soon)
KEK E391a: Strategy

Signal = 2\(\gamma\) + nothing

1. require 2 photons
   - Hermetic veto system

2. measure the photon energies and positions

3. reconstruct the decay vertex
   on the beamline assuming \(M_{2\gamma} = M_{\pi 0}\)

4. require missing \(P_T\) and the vertex in the fiducial region
   - “Pencil” beam line
   to improve \(P_T\) resolution
   - 8cm diameter @ 16m from the target
KEK E391a: Detector
- Decay region
  - High vacuum: $10^{-5}$ Pa
    - to suppress the background from interactions with residual gas

- Detector components
  - Set in the vacuum: 0.1 Pa
    - separating the decay region from the detector region with "membrane": 0.2mmth film
KEK E391a : Fight against BG

- Kaon BG
  - $K_L \rightarrow 2\pi^0$, with $2\gamma$ escaping detection
- Halo neutron BG
  - Interact with detectors placed near the beam
  - Produce $\pi^0, \eta$

Dominant in E391a
KEK E391a : Control BG

- **Kaon BG**
  Verify photon veto using $4\gamma$ data ("$2\pi^0$" and "$3\pi^0+2\gamma$ missing")

- **Halo neutron BG**
  Verify neutron interaction using special run data
  (reconstruction tail / $\eta$ production cross section)
KEK E391a : Sensitivity

• BG well controlled

<table>
<thead>
<tr>
<th>Background source</th>
<th>Estimated number of BG</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K^0_L \rightarrow \pi^0\pi^0$</td>
<td>0.11 ± 0.09</td>
</tr>
<tr>
<td>CC02</td>
<td>0.16 ± 0.05</td>
</tr>
<tr>
<td>CV</td>
<td>0.08 ± 0.04</td>
</tr>
<tr>
<td>CV-(\eta)</td>
<td>0.06 ± 0.02</td>
</tr>
<tr>
<td>total</td>
<td>0.41 ± 0.11</td>
</tr>
</tbody>
</table>

\{ Neutron-induced \}

• $N(K_L \text{ decays}) = 5.1 \times 10^9$, ACC=0.67%

⇒ S.E.S = 2.9 \times 10^{-8}
KEK E391a : Result

- Open the box and no event inside

⇒ Set upper limit

\[ BR < 6.7 \times 10^{-8} \]

E391a has another dataset with similar statistics and it is now on analysis.
Kaon on the menu in Japan
J-PARC is coming

- High intensity proton synchrotron being constructed in Japan

= J-PARC [Japan Proton Accelerator Research Complex]

- High power (0.75MW in phase 1), ~x100 of KEK-PS
- 30 GeV Main Ring
- Start MR commissioning in 2008 (this month!!)
Prioritized due to limited budget
1\textsuperscript{st} : K1.8BR in 2008
2\textsuperscript{nd} : K1.8 & KL in 2009
**Step 1**

- Start with “modified E391a detector”
- Aim to touch the SM sensitivity
  - $K_L$ yield $\sim x40$ of KEK-E391a
  - Run period $\sim x10$ of KEK-E391a
    - 30 days of Run2 $\Rightarrow$ 3 snowmass years
  - Reduce acceptance loss $\sim x3$
    - Upgraded detectors
E14 Beam-line

- Common target to other experiments
- 16 degree production angle
- New beam-line configuration
  - Based on experience in E391a, newly designed and much improved

Note: These are not optimum but compromise with boundary condition

⇒ There is a room to be improved in future step.
E14 Detector Upgrade
Pick up the calorimeter upgrade

- Wonderful KTeV CsI calorimeter is coming
  - Longer (30cm → 50cm) and finer segmented (7cm-sq. → 2.5cm-sq.)
  - Better resolution (energy / position)
  - Better shower shape analysis

- Newly developed readout
  - 125MHz FADC
  - Cockcroft-Walton base for PMT
KTeV calorimeter

Grad students work hard...

Will finish transferring in this year

As of the end of April

5-9 May 2008

FPCP08 in Taiwan, T. Nomura (Kyoto)
J-PARC E14 Sensitivity

• ~3 SM events in 3 snowmass years

• Signal-to-BG ratio ~ 1.5
  • Dominant BG : $K_L \rightarrow 2\pi^0$
  • Neutron BG well suppressed by
    - Softer beam
    - Optimize detectors near the beam
J-PARC E14 Timeline

- 2007  Stage 2 approval by PAC
- 2008  Preparing detector upgrade
- 2009  Construction of KL beam-line
- 2010  Beam-line survey
- 2011  Engineering run
- 2010  Physics run
Kaon on the menu at CERN
$K^+ \rightarrow \pi^+ \nu \nu$ at CERN-SPS : NA62

- $K^+$ decay in flight (cf. stopped $K^+$ in BNL-B787/949)
- Existing beam-line + modification
- Existing detector (NA48) + modification
- 80 events in 2 years
- S/N $\sim$ 10
  - Key for BG rejection
    - Kinematical constraint
    - Veto
    - PID
NA62 Key Detectors

Photon veto

PID

$P_K : \text{Si } \mu$-pixels

$P_\pi$
CERN NA62 Timeline

- 2008  TDR submission
- 2008  Full approval (Hope!)
- 2008  Detector R&D
- 2009- Design finalizing
- 2012- Data taking
And more at CERN...

In upgrade of CERN proton complex
Kaon opportunity at FNAL
As a part of Project X

Opportunities with Project X

**Physics**
- Neutrino
- ILC
- Muon
- Kaon
- Charm
- antiproton

**Technology**
- Muon Collider
- Neutrino Factory

Project X for Kaon = 8GeV ILC-like Linac + Recycler
Ideas for $K \rightarrow \pi \nu \nu$

- $K^+ \rightarrow \pi^+ \nu \nu$
  - Like BNL-E787/949
    - Stopped $K^+$
  - Compact and higher B field

- $K_L \rightarrow \pi^0 \nu \nu$
  - KOPIO-like experiment
    - KL-TOF
    - Measure $\gamma$ direction
Just a start of discussion, but...

<table>
<thead>
<tr>
<th>Facility</th>
<th>Duty Factor</th>
<th>Clock hours</th>
<th>Beam hours</th>
<th>Projected # of $K \rightarrow \pi\nu\bar{\nu}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>CERN-SPS (450 GeV)</td>
<td>30%</td>
<td>1420</td>
<td>405</td>
<td>40 (charged)</td>
</tr>
<tr>
<td>Booster Stretcher (8GeV, 16kW)</td>
<td>90%</td>
<td>5550</td>
<td>5000</td>
<td>40 (charged)</td>
</tr>
<tr>
<td>Tevatron-Stretcher (120 GeV)</td>
<td>90%</td>
<td>5550</td>
<td>5000</td>
<td>200 (charged)</td>
</tr>
<tr>
<td>ProjectX Stretcher (8GeV, 200kW)</td>
<td>90%</td>
<td>5550</td>
<td>5000</td>
<td>250 (charged)</td>
</tr>
<tr>
<td>JPARC-I (30 GeV)</td>
<td>21%</td>
<td>2780</td>
<td>580</td>
<td>~1 (neutral)</td>
</tr>
<tr>
<td>BNL AGS (24 GeV)</td>
<td>50%</td>
<td>1200</td>
<td>600</td>
<td>20 (neutral)</td>
</tr>
<tr>
<td>JPARC-II (30 GeV)</td>
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Summary

• Kaon program still can play important roles in flavor physics
  – Explore beyond the SM
  – Explore flavor dynamics beyond the SM

• Experiments for golden mode $K \rightarrow \pi \nu \nu$ are planned and in preparation
  • Japan (E14), CERN (NA62), FNAL, …
Summary – cont’d

- $K_L \rightarrow \pi^0 \nu\nu$
  - Observation in 5 years: $O(1)$ SM events
    - J-PARC E14
  - 10% measurement in 10 years: $O(100)$ events
    - J-PARC Phase-2, FNAL Project-X, CERN Step-3

- $K^+ \rightarrow \pi^+ \nu\nu$
  - 10% measurement in 5 years: $O(100)$ events
    - CERN NA62, FNAL Project-X
Final Message

KAON efforts proceed step by step toward BSM exploration early next decade.

Thank you for your attention.