$K_S$ and $\Xi^0$ decays in NA48/1

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On behalf of the NA48/1 Experiment
Cambridge, Chicago, CERN, Dubna, Edinburgh
Ferrara, Firenze, Mainz, Northwestern, Perugia, Pisa, Saclay,
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Overview

• The NA48/1 beam line in 2002

• Results from 2000 data

• $K_S \rightarrow \pi^0 e^+ e^-$

• $K_S \rightarrow \pi^0 \mu^+ \mu^-$

• $\Xi^0 \rightarrow \Lambda \gamma$

• Prospects for other analyses and Conclusions
$4 \times 10^{10}$ $K_S$ decays in 89 days
in $40 < E_K < 240$ GeV, $0 < c\tau < 2.5c\tau_{K_S}$
Results from 2000 data

- $BR(K_S \rightarrow \gamma\gamma) = (2.78 \pm 0.06_{stat} \pm 0.04_{syst}) \times 10^{-6}$
  Published

- $BR(K_S \rightarrow \pi^0\gamma\gamma, \frac{m_{\gamma\gamma}}{m_K} > 0.2) = (4.9 \pm 1.6_{stat} \pm 0.9_{syst}) \times 10^{-8}$
  Published

- $K_S \rightarrow \pi^0\pi^0\pi^0$:
  
  $Re(\eta_{000}) = -0.026 \pm 0.010_{stat} \pm 0.005_{syst}$
  
  $Im(\eta_{000}) = -0.034 \pm 0.010_{stat} \pm 0.011_{syst}$

  Preliminary
\[ K_L \rightarrow \pi^0 l^+ l^- \]

- **CP conserving**
  
  NA48 measurement \( BR(K_L \rightarrow \pi^0 \gamma \gamma) \):
  
  \[ BR(K_L \rightarrow \pi^0 e^+ e^-)_{CP\ cons} = 0.47^{+0.22}_{-0.18} \times 10^{-12} \]
  
  [PL B536 229]
  
  \[ BR(K_L \rightarrow \pi^0 \mu^+ \mu^-)_{CP\ cons} \approx 10^{-12} \]

- **direct CP violating**
  
  Proportional to \( \eta \) or \( Im(\lambda_t) \)
  
  \[ Im(\lambda_t) = \eta A^2 \lambda^5 \quad \lambda_t = V_{ts}^* V_{td} \]
  
  \[ BR(K_L \rightarrow \pi^0 l^+ l^-)_{dir} \sim few \times 10^{-12} \]

- **indirect CP violating**
  
  \[ BR(K_L \rightarrow \pi^0 l^+ l^-)_{ind} = |\epsilon|^2 \frac{(\tau_L)}{\tau_S} BR(K_S \rightarrow \pi^0 l^+ l^-) \]

\( BR(K_S \rightarrow \pi^0 l^+ l^-) \) and \( BR(K_L \rightarrow \pi^0 \gamma \gamma) \) determine whether it will be possible to extract \( \eta \) from a measurement of \( BR(K_L \rightarrow \pi^0 l^+ l^-) \)
\[ K_S \rightarrow \pi^0 e^+ e^- \]
$K_S \rightarrow \pi^0 e^+ e^- : \text{Background from } K_S \rightarrow \pi^0 \pi^0_D$

Blind analysis: Control and Signal regions masked

Events with $m_{ee}$ mis-measured: $m_{ee} > m_{\pi^0} \rightarrow m_{ee\gamma\gamma} > m_K$

Apply conservative cut $m_{ee} > 0.165 \text{ GeV}$
$K_S \rightarrow \pi^0 e^+ e^-$: Background from $K_L \rightarrow ee\gamma\gamma$

$\sim 5 \times 10^8$ $K_L$ decay in the $0 < \frac{ct}{c\tau_S} < 2.5$ fiducial region

$\Rightarrow$ 300 $K_L \rightarrow ee\gamma\gamma$ decays ($BR = 6 \times 10^{-7}$)

2001 data with $K_L$ beam used to estimate background

(10 $\times$ number of $K_L$ decays in 2002 data)

Extrapolate from low $m_{\gamma\gamma}$ region to signal region

$\rightarrow$ Background 0.075 events in signal region
\[ K_S \rightarrow \pi^0 e^+ e^- : \text{Background from fragments of two decays} \]

\[ \Delta t = \text{time between fragments} \]

Control region: \( 3 < \Delta t < 50 \text{ ns} \)

Signal region: \( \Delta t < 3 \text{ ns} \)

Dominated by

\[
(\pi^\pm e^\mp \nu) + (\pi^0 \pi^0(\pi^0))
\]

confirmed relaxing E/p cut

Extrapolate from out-of-time control region to in-time signal region
First observation of $K_S \rightarrow \pi^0 e^+ e^-$

7 events found in the signal region with a background $0.15^{+0.05}_{-0.04}$ → presence of signal well established
$K_S \rightarrow \pi^0 e^+ e^-$ branching ratio

$$BR(K_S \rightarrow \pi^0 e^+ e^-)(m_{ee}>0.165 \text{ GeV}) =$$

$$(3.0^{+1.5}_{-1.2}(stat) \pm 0.2(syst)) \times 10^{-9}$$

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$K_S \rightarrow \pi^0 \mu^+ \mu^-$
$K_S \to \pi^0 \mu^+ \mu^- : \text{Background from } K_L \to \pi^+ \pi^- \pi^0$

Potential background from pion decay in flight
Studied using Monte Carlo, with $\tau/\tau_S$ cut removed

$\approx 22 \times 2002$ statistics generated, no MC events found in signal region
\[ K_S \rightarrow \pi^0 \mu^+ \mu^- : \text{Background from } K_L \rightarrow \mu^+ \mu^- \gamma \gamma \]

- \( K_L \rightarrow \mu^+ \mu^- \gamma \gamma \) branching ratio is much smaller \((10^{-9})\) than in \( K_S \rightarrow \pi^0 e^+ e^- \) channel \((6 \times 10^{-7})\)

- Impossible to use 2001 data because of unsuitable trigger

- Studied with Monte Carlo \(\rightarrow\) acceptance \(= 5 \times 10^{-3}\)

- Mainly suppressed by the pion mass cut

0.04 \(\pm\) 0.04 events expected in signal region
$K_S \rightarrow \pi^0 \mu^+ \mu^- :$ Background from fragments of two decays

Dominated by:

- $K_L \rightarrow \pi^\pm \mu^\pm \nu + K_S \rightarrow \pi^0(\pi^0), m_{\mu\mu} < 0.3$ GeV
- $K_S \rightarrow \pi^+ \pi^- + K_S \rightarrow \pi^0(\pi^0), 0.30 < m_{\mu\mu} < 0.36$ GeV

Control region: $-115 < |\Delta t| < -3$ ns , $3 < |\Delta t| < 60$ ns
First observation of $K_S \rightarrow \pi^0 \mu^+ \mu^-$

Presence of signal well established:

6 events found with a background $0.22^{+0.19}_{-0.12}$
$K_S \rightarrow \pi^0 \mu^+ \mu^- \text{ Branching ratio}$

$$BR(K_S \rightarrow \pi^0 \mu^+ \mu^-) = (2.9^{+1.5}_{-1.2}(stat) \pm 0.2(syst)) \times 10^{-9}$$

Submitted to Physics Letter B
Implication of results

Assuming vector interaction and a unit form factor:
\[ BR(K_S \rightarrow \pi^0 e^+ e^-) = (5.8^{+2.8}_{-2.3}(\text{stat}) \pm 0.3(\text{syst}) \pm 0.8(\text{theor})) \times 10^{-9} \]

\[ BR(K_S \rightarrow \pi^0 l^+ l^-) \propto |W(z)|^2 \quad W(z) \sim (a_s + b_s \frac{m_{ll}^2}{m_K^2}) \]

Assuming Vector Meson Dominance: \[ b_s/a_s = m_K^2/m_\rho^2 = 0.4 \]
D’Ambrosio, Ecker, Isidori, Portoles JHEP08 (1998) 004

\[ BR(K_S \rightarrow \pi^0 e^+ e^-) = 5.2 \times 10^{-9}|a_s|^2 \Rightarrow |a_s| = 1.06^{+0.26}_{-0.21} \pm 0.07 \]
\[ BR(K_S \rightarrow \pi^0 \mu^+ \mu^-) = 1.2 \times 10^{-9}|a_s|^2 \Rightarrow |a_s| = 1.54^{+0.40}_{-0.32} \pm 0.06 \]
**Determination of $a_s$ and $b_s$**

Combining both $K_S \rightarrow \pi^0 l^+ l^-$ results in a log-likelihood fit:

![Graph showing contours in $a_s$ vs $b_s$ plane with $b_s/a_s=0.4$ line]

**Curves compatible with each other and VMD**

Statistics too low to determine $b_s$
Implications for $K_L \rightarrow \pi^0 l^+ l^-$ CPV

Global fit for $\text{Im} \lambda_t$

Construct. interf.
\[ \Xi^0 \rightarrow \Lambda \gamma \]
$\Xi^0 \rightarrow \Lambda\gamma$ decay asymmetry

1999 High Intensity $K_S$ run (48 h of data taking):
730 $\Xi^0 \rightarrow \Lambda\gamma$ events with background of 58.2 ± 7.8 events

The asymmetry was measured using the angle $\Theta_\Lambda$ between the $\Xi_0$ and the out-going proton (coming from the decay $\Lambda \rightarrow p\pi^-$) in the $\Lambda$ rest frame.

The MC and the technique were first tested measuring the decay asymmetry in the decay $\Xi^0 \rightarrow \Lambda\pi^0$.
$\Xi^0 \rightarrow \Lambda\gamma$ decay asymmetry (cont.)

Data were compared with an isotropic MC distribution:

\[ \alpha(\Xi^0 \rightarrow \Lambda\gamma) = -0.78 \pm 0.18_{\text{stat}} \pm 0.06_{\text{syst}} \]

Effect of background on the asymmetry was measured in the mass sidebands

The main systematic uncertainty comes from background subtraction

First clear evidence for negative asymmetry
$\Xi^0 \rightarrow \Lambda \gamma$ branching ratio

$BR(\Xi^0 \rightarrow \Lambda \gamma) = (1.16 \pm 0.05_{stat} \pm 0.06_{syst}) \times 10^{-3}$

The systematic uncertainty is dominated by the error on the asymmetry measurement
$\Xi^0$ radiative decays

Much larger statistical sample from 2002 data is currently under analysis:
First clear evidence for the muon channel

Trigger inefficiency causes main systematic uncertainty  
⇒ Final cuts chosen to minimise overall uncertainty
Conclusions

- Main goal of NA48/1 reached:
  - First observation of $K_S \rightarrow \pi^0 e^+ e^-$, Published
  - First observation of $K_S \rightarrow \pi^0 \mu^+ \mu^-$, Submitted

- Clear signal from $\Xi^0$ decays

- Branching ratio and asymmetry $\Xi^0 \rightarrow \Lambda \gamma$, 99 data, Published

- Many analyses in progress, both $K_S$ and $\Xi^0$
  $(K_S \rightarrow \pi^+ \pi^- \pi^0, K_S \rightarrow \pi e \nu,$  
  $\Xi^0 \rightarrow \Lambda \gamma, \Xi^0 \rightarrow \Sigma^+ l^- \nu, \Xi^0 \rightarrow \Lambda e^+ e^-, \text{ limit on } \Xi^0 \rightarrow p \pi, \Xi^0 \text{ lifetime}$)