Results from $K_s$ and neutral hyperons decays from NA48/1

Mara Martini, Ferrara University, Italy

New trends in high energy physics
May 24-31, 2003 – Alushta, Crimea, Ukraine

On behalf of the NA48 Collaboration
Plan of the presentation

- Introduction
- Results on rare decays and ChPT tests
  - Precision measurement of $K_{S,L} \rightarrow \gamma\gamma$ decays
  - Precision measurement of $K_L \rightarrow \pi^0\gamma\gamma$ decay
  - First observation of $K_S \rightarrow \pi^0\gamma\gamma$ decay
- Results on hyperons ($\Xi^0$, $\Lambda$) decays
- Outlook and Summary
Chiral Perturbation Theory

- **ChPT** is the effective field theory of the Standard Model at low energy (E < 1 GeV region of non-perturbative QCD)

- Chiral symmetry of the QCD Lagrangian is spontaneously broken
  
  ⇒ degree of freedom of the theory are eight pseudoscalar Goldstone bosons (π, η, K)

- Processes described in perturbative expansion of momenta and masses

- Higher order boson loops are divergent, but compensated by counter-terms with (empirically determined) effective couplings

- **Rare kaon decays** eg., $K_{L,S} \rightarrow \pi^0 \gamma \gamma$, $K_{L,S} \rightarrow \gamma \gamma$ are the ideal tool to probe ChPT ($m_K \sim 0.5$ GeV)
**NA48/1**

**Unique opportunity:**
- Use NA48 detectors with modified beam line and upgraded read-out systems
- More than 50 times the $K_S$ world statistics, improved collimator technique

**NA48**

**History:**
- **Proposal**
  - December 1999
  - $3 \times 10^{10} K_S$ (120 SPS days)
- **Phase I:** approved March 2000
  - 45 day in 2000 SPS run
  - Final states only with $\gamma$
- **Phase II:** approved November 2000
  - Data taken in 2002

28/5/2003

Mara Martini
NA48 Detector

Kaon decays
~ 90 m upstream
Performance of the Specrometer

- **HV = 2200 V** (Ar-Ethane 50-50)
  1. 2300 V during $\varepsilon'/\varepsilon$ era
  2. 2250 V during 2001 Ks tests

- $\pi^+\pi^-$ mass resolution worsens from 2.5 to 3.1 MeV/$c^2$

- Good enough for rare decays
- Stable during the run
Liquid Krypton Calorimeter

10 m$^3$ of Lkr (13212 cells)
1.25 m depth (27 X$_0$)

$\sigma (E)/E = 3.2\%/\sqrt{E} \oplus 9\%/E \oplus 0.42\%$
Liquid Krypton Calorimeter

\[ D = \sqrt{\sum E_i E_j \times \frac{r_{ij}^2}{M_K}} \quad m_{ij} = \sqrt{E_i E_j r_{ij}^2 / D} \]

- LKr calorimeter resolutions:
  - energy \( \lesssim 1\% \) for \( >25 \) GeV photons
  - position \( \lesssim 1 \) mm for \( >25 \) GeV photons
  - time \( \sim 0.22 \) ns/\( \pi^0 \pi^0 \)

28/5/2003  Mara Martini
Run 2001

- 89 days of run, improved readout ⇒ 50 K events/burst
- Data taken at high intensity ($5 \times 10^{10}$ ppp) from July 18 onward

$$N_{K_S} = \frac{\text{Downscale} \times N_{\pi^0 \pi^0}}{\text{Acceptance} \times \text{BR}(K_S \rightarrow \pi^0 \pi^0)} \approx 4.4 \times 10^{10}$$

$SES(5\%\text{ acceptance}) \approx 4.5 \times 10^{-10}$
$\text{K}_S \rightarrow \gamma\gamma \quad \text{decay}$

- Decays into neutral final states: $O(p^2) = 0$

- $O(p^4)$ unambiguously predicted by ChPT loop diagram to better than 5% without counter terms

- Old NA48 measurement of $\text{K}_S \rightarrow \gamma\gamma$ branching ratio based on 2 days of test-run in 1999 with high intensity $\text{K}_S$:

  $$(2.6 \pm 0.4) \times 10^{-6} \quad (\text{PLB} 493 \ 2000, \ 29)$$

  not yet conclusive about possible $O(p^6)$ contributions

28/5/2003

Mara Martini
**KS → γγ** measurement

⇒ Data from 2000 near-target run, normalized to KS→π^0 π^0 decay rate

⇒ Principal background sources:

\[ \text{KS→π}^0 \text{ π}^0 \] with only 2 showers in the LKr calorimeter:

→ Reconstructed vertex moves downstream due to missing energy

→ choose decays in the \(-1m < z_{\text{vertex}} < 5m\) wrt collimator exit.

\[ \text{KL→γγ} \] Irrducible: \(N(\text{KL→γγ}) / N(\text{KS→γγ}) \sim 1.5\) in decay volume

→ Use \(\text{KL→π}^0 \text{ π}^0 \text{ π}^0\) to estimate the \(\text{KL}\) flux

→ use 2000 far-target run to measure \(\Gamma(\text{KL→γγ}) / \Gamma(\text{KL→π}^0 \text{ π}^0 \text{ π}^0)\)

\[ \Gamma(\text{KL→γγ}) / \Gamma(\text{KL→π}^0 \text{ π}^0 \text{ π}^0) = (2.81 ± 0.01_{\text{stat}} ± 0.02_{\text{syst}}) \times 10^{-3} \]

This result has an accuracy 4 times better than the current PDG value:

\((2.77 ± 0.08) \times 10^{-3}\)

28/5/2003

Mara Martini
$K_S \rightarrow \gamma\gamma$ measurement

- Background from $\pi^0\pi^0$ subtracted using MC normalized to the flux obtained from fully reconstructed $\pi^0\pi^0$ events $\Rightarrow$ Background : $(0.8 \pm 0.2)\%$

- Binned maximum likelihood fits to measure $\Gamma(K_L \rightarrow \gamma\gamma) / \Gamma(K_L \rightarrow \pi^0\pi^0\pi^0)$ and the $K_S \rightarrow \gamma\gamma$ branching ratio in 10 kaon energy and 6 vertex position bins

$$\text{BR} \left( K_S \rightarrow \gamma\gamma \right) = (2.78 \pm 0.06_{\text{stat}} \pm 0.03_{\text{syst}} \pm 0.02_{\text{ext}}) \times 10^{-6}$$

The new result has an accuracy better than 3% and differs by 30% from $O(p^4)$ prediction of ChPT.

Indication of a large $O(p^6)$ contribution.

Compatible with previous measurements.
$K_L \rightarrow \pi^0 \gamma \gamma$ decay

- Only 1/3 of the measured $K_L \rightarrow \pi^0 \gamma \gamma$ rate is predicted by $O(p^4)$.

- The rate can be reproduced at $O(p^6)$ including vector mesons exchange. The VMD contribution is parametrised by $a_V$, which has to be experimentally determined.
\( K_L \rightarrow \pi^0 \gamma \gamma \) measurement

- The \( a_v \) can be extracted from the tail \( m_{\gamma\gamma} < 2 m_{\pi^0} \)

- The \( a_v \) contribution leads to a CP conserving component to \( K_L \rightarrow \pi^0 e^+ e^- \):

\[
\text{BR}(K_L \rightarrow \pi^0 e^+ e^-)_{\text{CPC}} = 1.24 \times 10^{-12} \quad \text{for} \quad a_v = -0.7
\]

D’Ambrosio, Portoles NP B492 417

- The VMD mechanism could enhance the state \( J=2 \) for the two photons

  - sizeable CP conserving contribution for \( K_L \rightarrow \pi^0 e^+ e^- \)

\[ K_L \rightarrow K_2^+ + e^- K_1^- \quad \text{CP}=1 \]

The CP conserving contribution \( J=0 \) state is elicity-suppressed

28/5/2003 Mara Martini
**K\textsubscript{L} \rightarrow \pi^0\gamma\gamma** measurement

Rare process without a clear signature and a very high background

Data from 1998 and 1999 $\varepsilon'/\varepsilon$ runs.

- **Normalization channel:** $K\textsubscript{L} \rightarrow \pi^0\pi^0 \Rightarrow$ systematic effects cancel

- **Background sources:**
  - $K\textsubscript{L} \rightarrow \pi^0\pi^0$ with badly reconstructed showers; $m_{\pi^0}$ mass cut; residual background evaluated from the tagged $K\textsubscript{S} \rightarrow \pi^0\pi^0$ events $(0.16 \pm 0.08)\%$
  - $K\textsubscript{L} \rightarrow \pi^0\pi^0\pi^0$ with missing or overlapping showers; shower width cut and vertex position cut assuming all events background; residual background evaluated from a MC sample of $3 \times 10^9$ events $(2.74 \pm 0.42)\%$
  - pile-up events e.g. two decays occurring within 3 ns; quantified from the tails of the $R_{\text{cog}}$ distribution from good $\pi^0\pi^0$ events $(0.32 \pm 0.21)\%$
$K_L \rightarrow \pi^0 \gamma \gamma$ measurement

\sim 2500$ candidates in signal region $0.132 < m_{12} < 0.138$

$m_{\pi\pi}$ for the $\pi^0$ candidates

$m_{\gamma\gamma}$ for the two non-$\pi^0$ photons

$$a_v = -0.46 \pm 0.03_{\text{stat}} \pm 0.04_{\text{syst}}$$

$$\text{BR}(K_L \rightarrow \pi^0 \gamma \gamma) = (1.36 \pm 0.03_{\text{stat}} \pm 0.03_{\text{syst}} \pm 0.03_{\text{norm}}) \times 10^{-6}$$
$K_L \rightarrow \pi^0 \gamma \gamma$ measurement

$\Rightarrow$ Implies negligible CP conserving amplitude in $K_L \rightarrow \pi^0 e^+ e^-$

$m_{3\Delta} \in [30-110]$, $m_{3\Delta} \in [160-240]$, $m_{3\Delta} \in [240-260]$

KTeV results (PRL 83 (99) 917):

$\alpha_v = -0.72 \pm 0.05_{stat} \pm 0.06_{syst}$

$BR(K_L \rightarrow \pi^0 \gamma \gamma) = (1.68 \pm 0.07_{stat} \pm 0.08_{syst}) \times 10^{-6}$
\( \text{K}_{S} \rightarrow \pi^{0}\gamma\gamma \) measurement

- Up to now unobserved: NA48 placed recently the best limit to \( \text{BR}(\text{K}_{S} \rightarrow \pi^{0}\gamma\gamma) \) \( z_{q} > 0.2 \) < \( 3.3 \times 10^{-7} \) at 90\% CL from 1999 test-run data.


\[
\text{BR}(\text{K}_{S} \rightarrow \pi^{0}\gamma\gamma) \ z_{q} > 0.2 = 3.8 \times 10^{-8}
\]

- Momentum dependence of the weak vertex

Chiral structure of the weak vertex is testable from shape of the \( z_{q} = (m_{34}/m_{K})^{2} \) distribution
$K_S \rightarrow \pi^0 \gamma \gamma$ measurement

PRELIMINARY

2000 near-target data
Normalized to $K_S \rightarrow \pi^0 \pi^0$ decays

$(31.0 \pm 5.6)$ evts in signal region

<table>
<thead>
<tr>
<th>Background &amp; Systematics</th>
<th>Estimated events</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam activity $K_S \rightarrow \pi^0 \pi^0_D$</td>
<td>$7.4 \pm 2.4$</td>
</tr>
<tr>
<td>$K_L \rightarrow \pi^0 \gamma \gamma$</td>
<td>$2.4 \pm 1.2$</td>
</tr>
<tr>
<td>Acceptance</td>
<td>$3.8 \pm 0.0$ $\pm 0.7$</td>
</tr>
<tr>
<td></td>
<td>$13.6 \pm 2.8$</td>
</tr>
</tbody>
</table>

$\text{BR } (K_S \rightarrow \pi^0 \gamma \gamma )_{zq>0.2} = (4.9 \pm 1.6_{\text{stat}} \pm 0.8_{\text{syst}}) \times 10^{-8}$
$K_S \rightarrow \pi^0 \gamma \gamma$ measurement

Statistic insufficient to test the chiral structure of the weak vertex
Hyperons

\[ \Xi^- (ssd) \quad \Xi^0 (ssu) \]

\[ \Sigma^- (sdd) \quad \Sigma^0 (sdu) \quad \Sigma^+ (suu) \]

\[ n (ddu) \quad \Lambda (sdu) \quad p (duu) \]

\[ Y = B + S \]

\[ I_3 \]
Hyperon Semi-leptonic decays

The W probes the weak structure of the hyperon

Rich phenomenology: BR, Angular correlations

Same as the neutron (just replace d ⇔ s)
# Hyperon Semi-Leptonic Decay Rates

<table>
<thead>
<tr>
<th>Decay</th>
<th>BR</th>
<th>Events</th>
<th>two-body</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Lambda \rightarrow p e^- \nu$</td>
<td>$8.32 \times 10^{-4}$</td>
<td>20 k</td>
<td>Y</td>
</tr>
<tr>
<td>$\Sigma^- \rightarrow n e^- \nu$</td>
<td>$1.02 \times 10^{-3}$</td>
<td>4.1 k</td>
<td>Y</td>
</tr>
<tr>
<td>$\Sigma^- \rightarrow \Lambda e^- \nu$</td>
<td>$5.73 \times 10^{-5}$</td>
<td>1.8 k</td>
<td>N</td>
</tr>
<tr>
<td>$\Sigma^+ \rightarrow \Lambda e^+ \nu$</td>
<td>$2.0 \times 10^{-5}$</td>
<td>21</td>
<td>N</td>
</tr>
<tr>
<td>$\Xi^- \rightarrow \Lambda e^- \nu$</td>
<td>$5.63 \times 10^{-4}$</td>
<td>2868</td>
<td>N</td>
</tr>
<tr>
<td>$\Xi^- \rightarrow \Sigma^0 e^- \nu$</td>
<td>$8.7 \times 10^{-5}$</td>
<td>154</td>
<td>N</td>
</tr>
<tr>
<td>$\Xi^0 \rightarrow \Sigma^+ e^- \nu$</td>
<td>$2.71 \times 10^{-4}$</td>
<td>176</td>
<td>N</td>
</tr>
<tr>
<td>$\Xi^- \rightarrow \Xi^0 e^- \nu$</td>
<td>$\lesssim 2.3 \times 10^{-3}$</td>
<td>0</td>
<td>N</td>
</tr>
</tbody>
</table>
**Ξ⁰ beta decays:** \( \Xi^0 \rightarrow \Sigma l \nu \)

- **\( \Xi^0 \rightarrow \Sigma^+ e^- \nu \)**
  - Invariant \((p^- \pi^0)\) mass
  - 9280 rec. \(\Sigma^+\) in signal region

- **\( \Xi^0 \rightarrow \Sigma^+ \mu^- \nu \)**
  - \( \Xi^0 \rightarrow \Sigma^+ \mu^- \nu \)

---

**Study of the rate and of the form-factors to extract \( V_{us} \)**

- Run 2002 not optimized for hyperons
- \( \Xi^0 \rightarrow \Sigma e \nu \) clean sample: Signal/Back \( \sim 40 \), \( \sim 9000 \) events after cuts
  - Too early to predict precision on BR and form factor

Currently published sample (KTeV)

- BR 176 events
- FF 487 events

- \( \Xi^0 \rightarrow \Sigma \mu \nu \) first experimental evidence

28/5/2003

Mara Martini
Summary

- Precise measurement of $K_S \rightarrow \gamma\gamma$ decay indicates a significant $O(p^6)$ contribution and provides an input for higher loop calculations of ChPT.

- Precise measurement of $K_L \rightarrow \pi^0\gamma\gamma$ suggests a small vector meson contribution and a small CPC component in the $K_L \rightarrow \pi^0e^+e^-$

- Decay $K_S \rightarrow \pi^0\gamma\gamma$ was observed for the first time with BR in agreement with ChPT

- Interesting results on Hyperon semileptonic and radiative decays are coming soon.

- NA48 present activity: NA48/2
2003 run: NA48/2

New project called NA48/2 with simultaneous and high intensity charged kaon beams.

Main topics:

- Search of direct CP violation by measuring slope asymmetry in $K^\pm \rightarrow 3\pi$ decays
- $K^\pm e4$ decays
- $K^\pm 13$ decays
- Rare $K^\pm$ decays

Run time:
Expected $\approx 3 \times 10^{11} K^\pm$ decays