Recent results from NA48 experiment

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on behalf of NA48 collaboration

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Chiral Perturbation Theory tests

\( \chi PT \) describes low energy processes where QCD is non-perturbative.

It is based on perturbative expansion of momenta and masses:

\[
\frac{p^2}{(4\pi F_\pi)^2}, \frac{m^2}{(4\pi F_\pi)^2} \quad \text{where} \quad (4\pi F_\pi) \sim 1.2 \text{ GeV}
\]

Two experimental tests of the theory will be presented:

- \( K_S \rightarrow \gamma \gamma \)
- \( K_S \rightarrow \pi^0 \gamma \gamma \)

They all have \( \mathcal{O}(p^2) = 0 \) and \( \mathcal{O}(p^4) \) precisely predicted.
The beam
The detector
### NA48 data taking periods

<table>
<thead>
<tr>
<th>Year</th>
<th>Beam type</th>
<th>Physics program</th>
</tr>
</thead>
<tbody>
<tr>
<td>1997</td>
<td>$K_L + K_S$</td>
<td>$\varepsilon'/\varepsilon$</td>
</tr>
<tr>
<td>1998</td>
<td>$K_L + K_S$</td>
<td>$\varepsilon'/\varepsilon$, $K_S$ lifetime, $K_L \rightarrow \pi^0\gamma\gamma$, ...</td>
</tr>
<tr>
<td>1999</td>
<td>$K_L + K_S$</td>
<td>$\varepsilon'/\varepsilon$, $K_L \rightarrow \pi^0\gamma\gamma$, ...</td>
</tr>
<tr>
<td>2000</td>
<td>$K_L$ only</td>
<td>$K^0$ mass, $K_L \rightarrow \gamma\gamma$, $\varepsilon'/\varepsilon$ checks</td>
</tr>
<tr>
<td></td>
<td>$\eta$ run</td>
<td>$\eta$ mass</td>
</tr>
<tr>
<td></td>
<td>$K_S$ high intensity</td>
<td>$K_S \rightarrow \gamma\gamma$, ...</td>
</tr>
<tr>
<td>2001</td>
<td>$K_L + K_S$</td>
<td>$\varepsilon'/\varepsilon$</td>
</tr>
<tr>
<td>2002</td>
<td>$K_S$ high intensity</td>
<td>Hyperon physics, $K_S$ rare decays</td>
</tr>
<tr>
<td>2003</td>
<td>$K^+, K^-$</td>
<td>$CP$ violation in charged Kaons</td>
</tr>
</tbody>
</table>

*No spectrometer*

Recent results from NA48 experiment – p.5/13
The $z_{\text{vertex}}$ reconstruction

$$z_{\text{vertex}} = z_{\text{LKR}} - \frac{1}{m_{K^0}} \sqrt{\sum_{i,j<i} E_i E_j [(x_i - x_j)^2 + (y_i - y_j)^2]}$$

Requirements for Kaon decay vertex reconstruction

- Good cluster energy resolution
- Good impact point resolution

$$\frac{\sigma(E)}{E} = \frac{0.09}{E} \oplus \frac{0.032}{\sqrt{E}} \oplus 0.0042$$

$$\sigma_{x,y} = 1.3 \text{ mm}$$

$$\sigma_t = 300 \text{ ps}$$
$K_S \rightarrow \gamma\gamma$

- $\chi PT$ at $O(p^4)$ predicts $\text{BR} = 2.1 \times 10^{-6}$ (few % error) 
  (D’Ambrosio-Espriu, J.L. Goity)

- Data from 2000 near-target run.

- Main background sources
  - $K_S \rightarrow \pi^0\pi^0$ with two showers in LKR:
    - overestimation of $z_{rec} (> 9$ meters) 
    - decay region $-1 \text{ m} < z_{vertex} < 5 \text{ m}$
  - $K_L \rightarrow \gamma\gamma$ irreducible ($\sim 1.5$ $K_S \rightarrow \gamma\gamma$)
    - $K_L \rightarrow 3\pi^0$ to estimate $K_L$ flux 
    - “far-target” data used to measure $\frac{\Gamma(K_L \rightarrow \gamma\gamma)}{\Gamma(K_L \rightarrow 3\pi^0)}$
Background subtraction

- **Background from $\pi^0\pi^0$** subtracted using MC normalized to the fully reconstructed $\pi^0\pi^0$ events

- $K_L \rightarrow \gamma\gamma$ estimated from the "far-target" run because from PDG

$$\frac{\Gamma(K_L \rightarrow \gamma\gamma)}{\Gamma(K_L \rightarrow 3\pi^0)} = (2.77 \pm 0.08) \times 10^{-3}$$

Not enough precise!

$$\frac{\Gamma(K_L \rightarrow \gamma\gamma)}{\Gamma(K_L \rightarrow 3\pi^0)} = (2.81 \pm 0.01_{\text{stat}} \pm 0.02_{\text{syst}}) \times 10^{-3}$$

Recent results from NA48 experiment – p.8/13
Experiment-theory comparison

- Compatibility with previous measurements.
- NA48/00 differs by 30% from $\mathcal{O}(p^4)$ prediction of $\chi PT \implies$ Indication of a large $\mathcal{O}(p^6)$ contribution.

$$BR(K_S \to \gamma \gamma) = (2.78 \pm 0.06_{sys} \pm 0.03_{stat} \pm 0.02_{ext}) \times 10^{-6}$$
$K_S \rightarrow \pi^0 \gamma \gamma$: theory

- Chiral structure of weak vertex is testable from the distribution of
  
  \[ z_q = \left( \frac{m_{\gamma\gamma}}{m_K} \right)^2 \]


\[ \text{BR}(K_S \rightarrow \pi^0 \gamma \gamma)_{z>0.2} = 3.8 \times 10^{-8} \]

Recent results from NA48 experiment – p.10/13
Data analysis: preliminary

- Data sample from 2000 near-target data
- Normalization to $K_S \rightarrow 2\pi^0$
- Main background contributions
  - $K_S \rightarrow \pi^0\pi^0$, $K_S \rightarrow \pi^0\pi_D^0$: rejected by kinematic cuts
  - $K_L \rightarrow \pi^0\gamma\gamma$: irreducible
  - $\Xi^0 \rightarrow \Lambda\pi^0 \rightarrow n\pi^0\pi^0$
    - $E_\gamma$ asymmetries cuts
    - Estimated using neutron shower profile distribution
  - Beam activity: rejected by time cuts + anticounters
Signal & Background

Preliminary result

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

Not enough statistics to test the chiral structure of the weak vertex.
Two tests of the $\chi$PT performed by the analysis of the data collected by the NA48 experiment have been presented.

The results show that

- The $K_S \rightarrow \gamma\gamma$ can be described only invoking the $O(p^6)$ terms of the theory
- More statistics is needed to prove the chiral structure of the weak vertex in the $K_S \rightarrow \pi^0\gamma\gamma$