New N448 Results

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on behalf of the N448 COLLABORATION:

June 29, 2002

BECCH 2002

Scuola Normale Superiore and INFN - Pisa

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the N448 Experiment at CERN

New results from
Conclusions

Present ($K_\beta$ and future ($K_{\beta'}$))

\[ M_0 \leftarrow s \]
\[ K \leftarrow s \]

KS Lifetime

New Result from 2001 data and conclusions

Data-taking and analysis highlights

Introduction and experimental approach

Re($\beta$ / $\beta'$)
\[(f \leftarrow 0 K) A \neq (f \leftarrow 0 K) A\]

Does direct CP violation in the decay processes exist in nature?

CP violation, restricted to the $K$ system.

Indirect CP violation can be accommodated in a superweak scenario for

\[\text{Indirect CP violation}\]

\[\text{Indirect CP violation } \varepsilon = \left| \frac{2.27 \pm 0.01}{10^{-3}} \right| \]

\[K^0 \rightarrow K^+ + \varepsilon K^0\]

\[\varepsilon = -1\] (CP)

\[\varepsilon = +1\] (CP)

\[K^0 \rightarrow K^+ + \varepsilon K^0\]

\[K^0 \rightarrow K^+ + \varepsilon K^0\]

\[\varepsilon = -1\] (CP)

\[\varepsilon = +1\] (CP)

Eigenstates $\langle K^0, Y^0 \rangle$ are not pure CP eigenstates $\langle K^0, Y^0 \rangle$.

CP violation in the neutral $K$ system is dominated by state mixing: mass
\[
\frac{3/3}{3} \approx 1 - 6 \text{ Re } \left( \frac{-v + v \leftrightarrow S K}{-v + v \leftrightarrow T K} \right) = R
\]

The experimental observable is the double ratio:

**Direct CP violation**

\[
\left[ \langle 0^0 \rightarrow \eta \rangle \right] \exp \left( \frac{0 V}{\varepsilon V} \right) \text{ Im} \left( \frac{\zeta}{\zeta} \right) \approx \beta
\]

\[
\beta \beta - 3 \approx \frac{(0^0 \rightarrow \eta \leftrightarrow S K) V}{(0^0 \rightarrow \eta \leftrightarrow T K) V} \equiv 0 \mu \quad \beta + 3 \approx \frac{(-v + v \leftrightarrow S K) V}{(-v + v \leftrightarrow T K) V} \equiv -\mu
\]

Strong phases \( \phi_0^0, \phi_2 \) interfere:

\[ K \rightarrow \pi^+ \pi^+ \pi^0 \text{ decay: } \text{two amplitudes } A^0, A^2 \text{ (final state isospin } I = 0, 2) \]

\[ K \rightarrow \eta \eta \rightarrow \pi^+ \pi^- \eta^0 \text{ with interactions needed.} \]

Interference of two decay amplitudes with different final state (strong...
Recent news from lattice QCD computations:

Very difficult (non-perturbative) problem. 
\[ \text{Re} \approx -10^{-4} \text{ to } +30 \cdot 10^{-4} \text{ with errors } \pm 5 \text{ to } 10^{-4} \]

Typical theoretical predictions/postdictions:

\[ \mathcal{O} \leftrightarrow \mathcal{P} \text{ Penguin diagrams} \]

Direct CP violation

\[ \mathcal{K}_{0} \] / oscillations

through mixing

Indirect CP violation

\[ \mathcal{K}_{0} \] / oscillations

through mixing

Standard Model predictions
Finally, NA48/CEPT results for precise measurement

Direct CP violation firmly established

Current world average:

$\sqrt{\chi^2} / \text{ndf} = 5.7 / 3$ (17.3 ± 1.7) x 10$^{-4}$

KTeV (FNAL)

No effect

$7.4 \pm 5.9 \times 10^{-4}$ (ET31)

NA48 (CERN)

3.5$\sigma$ effect

$23.0 \pm 6.5 \times 10^{-4}$ (NA31)

New generation of experiments after inconclusive results in the early 90s:

Experimental measurements of Re(e^3/3)
2001: $1.5 \times 10^9$ million $K_L$ with different beam conditions

2000-2001: Drift chambers repaired

2000: Only neutral data (cross-checks + high intensity $K_S$ runs)

November 1999: Beam tube implosion drifted chambers damaged

Efficiency: Result published in 2001

Further improvements in trigger and DAG, higher data-taking

1999: $2 \times 10^9$ million $K_L$

Several improvements (trigger, DAG, calorimeter)

1998: $1 \times 10^9$ million $K_L$

Result published in 1999

1997: $0.5 \times 10^9$ million $K_L$

1990: Proposal
<table>
<thead>
<tr>
<th>Year</th>
<th>K_L Beam Intensity</th>
<th>K_S Beam Intensity</th>
<th>Duty Cycle</th>
<th>Spill Length (Effective)</th>
<th>SPS Cycle Time</th>
<th>Proton Momentum</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>( \approx 7 \cdot 10^7 ) ppd</td>
<td>( \approx 2.4 \cdot 10^{12} ) ppd</td>
<td>0.31 5.2 s (3.6 s) 16.8 s 400 GeV/c</td>
<td>( \approx 4 \cdot 10^7 ) ppd</td>
<td>( \approx 1.5 \cdot 10^{12} ) ppd</td>
<td>( 0.17 ) 2.4 s (1.7 s) 14.4 s 450 GeV/c</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Good K_L Events / 100 ms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time within burst(s)</td>
</tr>
</tbody>
</table>

The 2001 run had a better instantaneous intensity and a lower SPS duty cycle, and a lower instantaneous intensity. The 1999 run had a better instantaneous intensity.
The N448 Present Approach

\[
\frac{3/3 \text{Re}(\zeta)}{1 - 6 \text{Re}(\zeta)} \approx \frac{(-\nu + \nu \leftarrow S)_{KL} N}{(-\nu + \nu \leftarrow S)_{KL} N} / \frac{(-\nu + \nu \leftarrow S)_{KL} N}{(-\nu + \nu \leftarrow S)_{KL} N} = R
\]
production target.

Ks are distinguished from KL by tagging the protons upstream of their decay region.
Neutral beams always pass through vacuum.

- Neutral beams always pass through vacuum.
- Neutrinos and muons are detected by anti-counter arrangements.
- They measure their time of flight from the neutrino to detect $\nu^0$ events.
- Krypton calorimeter and quasi-homogeneous liquid hydrogen calorimeter perform event time measurement.
- Scintillator hodoscope for $\nu^+$, $\nu^-$ events.
- Magnetic spectrometer for $\nu^+$, $\nu^-$ events.
Rebuilt drift chambers performed.

\[
\frac{[\%][p/p]}{0.0909 \oplus 0.005 \% \sim 0.0909 p/(d)} \Delta \\
\text{Space point resolution} \approx 95.7 \mu \text{m} \\
\text{Plane efficiency} > 99.5 \% \\
(265 \text{ MeV/c} \ p_T \text{ kick}) \\
2 \times 2 \text{ drift chambers + magnet}
resolution \approx 0.9 \text{ MeV}/c^2

Pair photons to get best \( \pi^0 \) mass

scale

Longitudinal decay position energy

\[ \frac{1}{4} \sqrt{\frac{m}{E}} = 2 - \frac{1}{4} K \Phi D \leftrightarrow E = (\gamma K x^0 + E \Phi) \]

mass constraint

\( \Phi(x) \approx 3.2\% \) after (after) corrections

uniformity before (after) corrections

Better than 1 mm space resolution

Better than 250 ps time resolution

Try, fast initial current readout

Quasi-homogeneous Liquid Krypton Calorimeter,
tures 2001 because of strong beam struc-

First 200 ms of burst not used in

tensity differences

minimize effect of $K^*_S-K^L$ beam in-

ity ratio constant

Reweight $K^S$ to keep $K^S/K^L$ inter-

chamber hit multiplicities) and apply them off-line to all events

Record dead time conditions during simultaneous data-taking

minimize effect of $K^*_S-K^L$ acceptance differences

Apply lifetime weighting to $K^L$

Insensitive to $K^*_S-K^L$ energy spectra differences

Measure $R$ in kaon energy bins (5 GeV wide)

Data Analysis
Price: 35% increase in statistical error

Acceptance correction cancels weighted \( K_L \) vertex distribution for \( K_S \) and same longitudinal decay

\[
\frac{\text{weighted } K_L}{\text{weighted } K_S} = \frac{\frac{1}{2} (\frac{1}{2} K_L + \frac{1}{2} K_S)}{\frac{1}{2} (\frac{1}{2} K_L + \frac{1}{2} K_S)} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{1}{2} = \frac{1}{2} \frac{
factor 1/6 to get effect on $e^\gamma$.

WARNING: All corrections/uncertainties are quoted on $R$.

Evaluate residual effects from accidental-induced event losses

- Compute residual $K_S - K_L$ acceptance differences
- Evaluate effects due to non-linearities, energy scale
- Identify $\nu_\mu + \nu_\tau$ and $\nu_0\nu_\tau$ and subtract residual backgrounds
- Tag $K_S$ and $K_L$ decays and correct for misidentification

Measure small second order differential effects

At first order, almost all effects cancel in $R$.  

Data Analysis - II
(corrected for mistagging)
\begin{align*}
\frac{{\%}}{\%} (8.115 \pm 0.010) \text{ was } 9.497 \pm 0.008 \text{ in } 98-99.
\end{align*}

\begin{align*}
\text{Rate } \approx 30 \text{ MHz, a priori } &\nu^+ + \nu^- - \nu^+ + \nu^- \\
\text{mislabeled as } K_L (\alpha_{KL}) \text{ accidental proton coincidence with } K_L. \\
\end{align*}

\begin{align*}
\frac{\%}{\%} (1.023 \pm 0.014) \cdot 10^{-4} \text{: tails in time measurement }
\end{align*}

\begin{align*}
\text{Vertex position: }
\end{align*}

\begin{align*}
\text{Direct measurement possible for }
\nu^+ + \nu^- \text{ and } \nu^+ \nu^- \text{ dangerous only if different for }
\text{ possible mistakes.}
\end{align*}

\begin{align*}
K^L &\not\leftrightarrow 2 \text{ ns } K_L \leftarrow \nu^+ \\
K_S &\not\leftrightarrow 2 \text{ ns } K_L \leftarrow \nu^+. \\
\end{align*}

Use difference of event time and

\begin{align*}
K^L - K_L \text{ tagging
}
\end{align*}
\[
V_R = \pm 5.3 \cdot 10^{-4}
\]

Total uncertainty on energy scale:

- Can also check non-linearity and uniformity of energy response

Agreement checks neutral energy scale

- Compare to known target
- Use \( \gamma \) decays to reconstruct decay position
- Produce \( \gamma \) and in with known LKr

Special runs with \( \gamma \) beam to two thin targets
Intermezzo: \( \Xi^0 \) (and \( \Lambda^0 \)) mass measurements

\( M_{\Xi^0} = 547.843 \pm 0.030 \text{ stat} \pm 0.041 \text{ syst} \text{GeV/c}^2 \)

\( M_{\Lambda^0} = 497.625 \pm 0.001 \text{ stat} \pm 0.031 \text{ syst} \text{MeV/c}^2 \)

\( \mathcal{L} = 4.2 \times \text{stat} (0.1\%) \) from PDG on

- Check using \( kL \rightarrow \Xi^0 \)
- Non-linearities sensitivity
- Symmetric decays: reduced scale
- Independent of energy
- Constraint on \( m_{\Xi^0} \) from mass vertex from \( \Xi^0 \) beam (from year 2000 background free; no \( K^0 \)
- Use \( \Xi^0 \rightarrow \Xi^0 \) decays

With \( \Xi^0 \) used to check energy scale

\( M_{\Xi^0} \) of shift (0.1\%) from PDG on

\( \Xi^0 \rightarrow \Xi^0 \) decays
Simulation - GEANT based spectrometer
- Comparison of fast MC vs. beam positions and shapes
  - Sys. Error: $\pm 4.0 \times 10^{-4}$
  - MC stat. Error: $\pm 3.3 \times 10^{-4}$
  - Acceptance correction

Acceptance correction

MC R weighting

MC R no weighting

$AVR \sim 2 \times 10^{-10}$

$AVR = 2.19 \times 10^{-10}$
\[
\begin{align*}
\text{Illumination difference: } & \Delta V_R \propto 10^{-4} (3 \mp 0) = \sqrt{V_R} \propto 10^{-4} (3 \mp 0) \\
\text{Intensity difference: } & \Delta V_R = \sqrt{V_R} \propto 10^{-4} (1 \mp 0) = \sqrt{V_R} \propto 10^{-4} (1 \mp 0)
\end{align*}
\]

Uncertainty on R:

Overlay beam-monitor events to data and MC events

Measure KL and KS intensities on (200 ns - 15 ls) time scales with

in a similar way

Lifetime weighting KL and KS events illuminate the detector

activity, within 1% (checked in data)

Simultaneous beams KL and KS events see the same

\( \Delta (KL - KS) : \text{intensity difference: small by design} \) %

\( \Delta (KL - KS) : \text{intensity difference: small by design} \)

\( \Delta (KL - KS) : \text{intensity difference: small by design} \)

Residual effects: \( \Delta R \approx \sqrt{V_R} \Delta (| KL - KS |) \)

Accidental activity \( \Rightarrow \) event losses, Cancel at first order in R.
<table>
<thead>
<tr>
<th>Total</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>KS in-time activity</td>
<td>0</td>
</tr>
<tr>
<td>Accidental activity (illumination)</td>
<td>0.0</td>
</tr>
<tr>
<td>Accidental activity (intensity)</td>
<td>0.3</td>
</tr>
<tr>
<td>$+$ $-$ trigger</td>
<td>1.1</td>
</tr>
<tr>
<td>Acceptance</td>
<td>3.6</td>
</tr>
<tr>
<td>AKS inefficiency</td>
<td>5.2</td>
</tr>
<tr>
<td>AKS scale</td>
<td>5.3</td>
</tr>
<tr>
<td>Accelerating tagging</td>
<td>2.2</td>
</tr>
<tr>
<td>Tagging inefficiency</td>
<td>3.4</td>
</tr>
<tr>
<td>Beam scattering</td>
<td>6.9</td>
</tr>
<tr>
<td>$+$ $-$ background</td>
<td>3.0</td>
</tr>
<tr>
<td>$+$ $-$ background</td>
<td>2.0</td>
</tr>
<tr>
<td>$+$ $-$ background</td>
<td>2.0</td>
</tr>
<tr>
<td>$+$ $-$ background</td>
<td>2.0</td>
</tr>
<tr>
<td>$+$ $-$ background</td>
<td>2.0</td>
</tr>
<tr>
<td>$+$ $-$ background</td>
<td>1.42</td>
</tr>
<tr>
<td>$+$ $-$ background</td>
<td>16.9</td>
</tr>
<tr>
<td>$+$ $-$ background</td>
<td>3.0</td>
</tr>
<tr>
<td>Correction</td>
<td>2001</td>
</tr>
<tr>
<td>Corrections and statistical or systematic uncertainties (units = 10$^{-4}$) on R:</td>
<td></td>
</tr>
</tbody>
</table>
In systematic error $\pm 0.00065$ due to statistics of the control samples.

$$R = 0.99181 \pm 0.00147 \text{ stat} \pm 0.00110 \text{ syst}$$
New NA48 Results

M. Soszi

Systematic checks

R stability against cut variations

<table>
<thead>
<tr>
<th>Cut Criteria</th>
<th>Diagram Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceptance</td>
<td>R - R standard (1.04)</td>
</tr>
<tr>
<td>Acceptance</td>
<td>R - R standard (1.04)</td>
</tr>
<tr>
<td>Tagging</td>
<td>R - R standard (1.04)</td>
</tr>
<tr>
<td>Energy scale</td>
<td>R - R standard (1.04)</td>
</tr>
<tr>
<td>Neutral back.</td>
<td>R - R standard (1.04)</td>
</tr>
<tr>
<td>Charged back.</td>
<td>R - R standard (1.04)</td>
</tr>
<tr>
<td>Beam halo</td>
<td>R - R standard (1.04)</td>
</tr>
</tbody>
</table>

- Estimated systematic for correction under test
- Estimated systematic for correction under test
- Estimated systematic for correction under test
- Estimated systematic for correction under test
- Estimated systematic for correction under test
- Estimated systematic for correction under test
- Estimated systematic for correction under test
- Estimated systematic for correction under test

- Total syst. error
- Total syst. error
- Total syst. error
- Total syst. error
- Total syst. error
- Total syst. error
- Total syst. error
- Total syst. error

- no mom. asym. cut
- mom. asym. cut 0.2 cm
- track radius < 20 cm
- track radius < 20 cm
- no Ks/Kl intensity weighting
- no extra clusters in p+p
- reject DCH-ovfl > 350 ns
- reject DCH-ovfl > 234 ns
- accept MBX dead time
- accept QX dead time
- tagging window ± 1.5 ns
- tagging window ± 2.5 ns
- P©T2 < 1.5 x 10^{-4}
- P©T2 < 3.0 x 10^{-4}
- D_M < 2 s
- D_M < 4 s
- C_g < 7 cm
- C_g < 11.5 cm
Paper ready for publication
2001 result in agreement with previous ones
6.7 o away from 0 (was 5.9 o)

\[
\left(14.7 \pm 2.2 \right) \times 10^{-4} = 3.3/\epsilon^3
\]

Combining with 97+98+99 result (15.3 \pm 2.6) \times 10^{-4}

\[
\left(13.7 \pm 3.1 \right) \times 10^{-4} = 3.3/\epsilon^3
\]

From 2001 data:

\[ \text{Re}(\epsilon^3) \]
Experimental values of $\text{Re}(e^\gamma/e)$

- $\chi^2/\text{ndf} = 6.2/3$
- Naive average: $\text{Re}(e^\gamma/e) = (16.6 \pm 1.6) \cdot 10^{-4}$
- Average: $(16.7 \pm 2.3) \cdot 10^{-4}$
SM can stretch to accommodate experimental value

Most predictions below $10 \cdot 10^{-4}$
1.7 o shift from PDG average (preprint hep-ex/020508)
Systematics dominated by fit method and beam geometry uncertainties

\[ t_s = (0.89598 \pm 0.0048^{\text{stat}} \pm 0.0043^{\text{sys}} \pm 0.0027^\text{MC stat}) \times 10^{-10} \]

<table>
<thead>
<tr>
<th>543.5/573</th>
<th>551.0/573</th>
<th>601.2/573</th>
<th>628.2/573</th>
<th>699.1/573</th>
<th>999.8/573</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.89635 \pm 0.00167</td>
<td>0.89606 \pm 0.00247</td>
<td>0.89578 \pm 0.00100</td>
<td>0.89578 \pm 0.00072</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[ \chi^2 / \text{dof} \rightarrow 1.5 \text{ at } t_s \]

- Use \( t_s \) to measure acceptance
- \( \chi^2 \) of two measurements (\( \nu^+ \) and \( \nu^- \)) averaged
- Decay region: \( 0.5 < t_s < 3.5 \) to avoid resolution biases
- Use the same samples as in the \( \Re(e^+e^-) \) analysis of 1998-1999

Ks Lifetime
\[ \text{NA48: } \frac{1}{\tau(K_S^0)} = 0.89598 \pm 0.00048 \pm 0.0051 \cdot 10^{-10} \text{ s} \]
No CP-violating asymmetry is expected in $K_S$ decay.

\[
\begin{align*}
\text{(a)} & \quad g_\pi + e^+ + e^- \\
\text{(b)} & \quad g_\pi + e^+ + e^- \\
\text{(c)} & \quad g_\pi + e^+ + e^- \\
\text{(d)} & \quad g_\pi + e^+ + e^-
\end{align*}
\]

$\text{Heiligcr, Sphagel - PR D48, 4145 (1998)}$

decay planes in the CM system: $\phi(4145)$

$\text{KS'} K_L \rightarrow \pi^+ \pi^- e^+ e^-$

$\text{Physics}$
\[\text{KL asymmetry: } A_L(\phi) = \frac{1}{1.3 \pm 2.7 \pm 1.6} \cdot 10^{-7}\]

\[\text{BR}(\text{KL} \rightarrow \mu^+\mu^- e^+e^-) = (3.1 \pm 0.3 \pm 0.2) \cdot 10^{-7}\]

\[\text{No KS asymmetry: } A_S(\phi) = \frac{1}{4.3 \pm 1.4 \pm 0.2 \pm 0.3} \cdot 10^{-5}\]

\[\text{BR}(\text{KS} \rightarrow \mu^+\mu^- e^+e^-) = (25.2 \pm 2.6)\%\]

\[\text{Asymmetry after acceptance correction} = (13.9 \pm 2.7)\%\]

1998+1999 data (921 KS events, 1337 KL events):
$\text{BR}(K_L \rightarrow \mu^- \nu \mu^+ \nu) = (1.68 \pm 0.07 \pm 0.08) \times 10^{-6}$

$\Lambda_{\text{TeV}}$ results: $\Lambda = -0.72 \pm 0.05 \pm 0.06$

$\Lambda_\nu$ contribution leads to $C$-P conserving component to $K_L \rightarrow \mu^- \nu \mu^+ \nu$.

$\Lambda_\nu$ determined experimentally.

VMC sensitive to tail at low $m_{\nu\nu}$.

With $\Lambda_\nu$ contribution parametrized by $\Lambda$, $\Lambda_{\text{TeV}}$.

At $O(d_6)$, including vector meson exchange, can reproduce the rate.

Theory: $\text{BR} \sim 0.6 \times 10^{-6}$.

Finite at one loop $P_T \chi_{\mu \nu}$ prediction is $1/3$ of extl.
\[ 132 > m_{\tau} > 138 \text{ MeV/c} \]

Using 1998 + 1999 data, \( \approx 2500 \) candidates in the signal region

- Events with out-of-time cluster: \( 0.32 \pm 0.21 \)%
-PILE-up events: evaluated from tails of \( \text{ROOT} \) distribution and normalized MC sample: \( 2.74 \pm 0.42 \)%
- With missing or overlapping showers: evaluated from \( K_L \) with bad fit reconstruction showers evaluated from \( K_S \) tails: \( 0.16 \pm 0.08 \)%

Background sources:

- Cancelation to \( K_L \) \( 0.07 \): most of the systematic uncertainties
- Rare process with a clear signature but a very high background

\[ K_L \leftarrow x_{0} \text{ Data} \]
Systematics dominated by acceptance and background (hep-ex/0205010). Implies negligible CP-conserving amplitude in $K_L \rightarrow \pi^0 e^+ e^-$. Keeping only non-ambiguous events: Using fitted value of $\alpha_Y$ and all events: $\alpha_Y = -0.46 \pm 0.03_{\text{stat}} \pm 0.04_{\text{sys}}$. $BR(K_L \rightarrow \pi^0 \gamma) = (1.36 \pm 0.03_{\text{stat}} \pm 0.03_{\text{sys}}) \times 10^{-6}$.
Rare hyperon decays

Search for CPV in K^0 \to \pi^+ \pi^- and K_S \to \pi^+ \pi^- \pi^0

Aim at \(3 \cdot 10^{-10}\) SE for K_S \to \pi^+ \pi^- \pi^0

Presently running (80 days scheduled)

Limit on \(\text{BR}(K_S \to \pi^+ \pi^-) > 1.4 \cdot 10^{-7}\) (90% CL)

\(2.78 \pm 0.06\) sig. \(\pm 0.02\) MC sig. \(\pm 0.04\) syst.

Measurement of \(\text{BR}(K_S \to \pi^+ \pi^-)\)

\(40 \text{ h run in 1999}\)

No K_L beam, high-intensity \(\times\) several hundred (K_S beam).

N448/1 is a high-sensitivity search for rare K_S decays.
Expect 60_0^0 \approx 0.007 \, \text{(stat)} \, \text{with} \, 10^6 K^\pm \text{events}

- breaking mechanism
- extract size of quark condensate \langle 0|\bar{b}b|0 \rangle \text{ to understand chiral symmetry}
- Study low-energy \pi+\pi- interaction in \pi^+\pi^-\pi^0\pi^- decays to

\begin{align*}
\partial A > 2 \cdot 10^{-4} \\
\text{with more than } 2 \cdot 10^6 K^\pm \text{ decays/yr, N448/2 can}
\end{align*}

Experiment: \( A^\delta \underset{\text{exp}}{=} A^\delta \underset{\text{th}}{=} \text{range:} \)

\begin{align*}
&\frac{\partial^8 + \partial^6}{\partial^8 - \partial^6} \equiv \partial A \\
&\delta \langle \alpha \rangle + \partial \langle \alpha \rangle + \delta \langle \eta \rangle + n \delta + 1 \propto \| (\alpha, \eta) \|
\end{align*}

\text{and } K^\pm \text{ decays}

- Measurement of odd-pion Dalitz plot slope asymmetry in K^+K^- decays
- Measurement of direct CP violation in K^+ decays

Simultaneous, collinear, momentum-selected K^+ beams (60 GeV/c \pm 5%)

N448/2 is an approved experiment scheduled for 2003, for the
Conclusions

The kaon system, central in the development of particle physics, is still delivering exciting results!

- Active program for measurement of rare $K_S$ decays and CP violation in $K^0 \to \pi^0 \nu \bar{\nu}$ decays
- New measurements of $K_S$ lifetime, $K^0_S$ and in masses
- New measurements of $K^0_L$ and $K^0_S$ tests of $CPT$ invariance

Direct CP violation in $K^0_S$ system:

$$4.8 \pm 0.7 \times 10^{-6}$$

New NA48 result on direct CP violation from 4 years of data taking:

$$3.7 \div 2.2 \times 10^{-4}$$