Future Kaon Program at CERN

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“Flavour in the era of LHC”

CERN, 09/11/2005
The Present: NA48/2

**Goal**
Measurement of the Dalitz plot asymmetry of the $K^\pm \to 3\pi$ decays

**Method**
- 60 GeV/c Kaon beams produced using $\sim 10^{12}$ protons per pulse @400 GeV/c from SPS
- Decays from $K^+$ and $K^-$ collected simultaneously

**Data taking**
- 2003: $\sim 1.6 \times 10^9 K^\pm \to \pi^+\pi^+\pi^+$, $\sim 4.8 \times 10^7 K^\pm \to \pi^+\pi^0\pi^0$ collected
- 2004

**Data analysis**
- Exploit $K^\pm$ simultaneity and frequent magnets polarity alternations for systematics cancellations

**Results**
(preliminary 2003)
- $A_g = (0.5 \pm 2.4_{\text{stat}} \pm 2.1_{\text{trig}} \pm 2.1_{\text{syst}}) \times 10^{-4}$ $K^\pm \to \pi^+\pi^+\pi^+$
- $A_g = (1.7 \pm 1.7_{\text{stat}} \pm 1.2_{\text{trig}} \pm 1.3_{\text{syst}} \pm 0.2_{\text{ext}}) \times 10^{-4}$ $K^\pm \to \pi^+\pi^0\pi^0$
- ~10 times better precision than previous measurements
- Results consistent with SM predictions: $A_g < 10^{-4}$

**Near future**
- 2004 analysis:
  Same amount of data, more checks on systematics
Observation of a cusp-like effect in the \( \pi^0\pi^0 \) invariant mass at \((2m_{\pi^\pm})^2\) from \(K^\pm \rightarrow \pi^\pm\pi^0\pi^0\) decay

**Interpretation**
- Rescattering \(\pi^+\pi^-\rightarrow \pi^0\pi^0\) in the decay \(K^\pm \rightarrow \pi^\pm\pi^+\pi^- \rightarrow \pi^\pm\pi^0\pi^0\)

**Measurement**
- Determination of the \(\pi\pi\) scattering lengths (amplitudes at threshold)

**Method**
- Fit to the \(m^2(\pi^0\pi^0)\) distribution around the cusp using theoretical models (Cabibbo – Isidori, JHEP03(2005)021)

**Results**
- \((a_0-a_2)m_+ = 0.268 \pm 0.010_{\text{stat}} \pm 0.004_{\text{syst}} \pm 0.013_{\text{ext}}\)
- \(a_2m_+ = -0.041 \pm 0.021_{\text{stat}} \pm 0.014_{\text{syst}}\)

The future: Kaons and CKM matrix

- $K \rightarrow \pi \nu \bar{\nu}$ decay is sensitive to $V_{td}$
- $|V_{td}|$ determination independent on $B^0 - \bar{B}^0$ mixing
- Theoretically the cleanest processes in K and B physics

Standard Model predictions

- $\text{BR}(K^+ \rightarrow \pi^+ \nu \bar{\nu}) \approx (1.6 \times 10^{-5}) |V_{cb}|^4 [\sigma \eta^2 + (\rho_c - \rho)^2] \rightarrow (8.0 \pm 1.1) \times 10^{-11}$
- $\text{BR}(K_L \rightarrow \pi^0 \nu \bar{\nu}) \approx (7.6 \times 10^{-5}) |V_{cb}|^4 \eta^2 \rightarrow (3.0 \pm 0.6) \times 10^{-11}$
Setting the bar for future Kaon experiments

- Measurement of the BR($K^+ \rightarrow \pi^+ \nu \nu$)
- Present (E787/949): \( BR(K^+ \rightarrow \pi^+ \nu \nu) = 1.47^{+1.30}_{-0.89} \times 10^{-10} \)

100 events
Mean: 
E787/949

Current constraint on \( \rho, \eta \) plane

P-326
**P-326 guidance principles**

~80 $K^+ \rightarrow \pi^+ \nu\nu$

Signal acceptance ~10%
K decays ~$10^{13}$

BR($K^+ \rightarrow \pi^+ \nu\nu$) $\sim 8 \times 10^{-11}$

Low level of background

**Kinematics**

\[
m_{\text{miss}}^2 = (P_K - P_\pi)^2
\]

**Vetoes**

- Particle ID $\rightarrow$ RICH
- $\gamma/\mu$ detection $\rightarrow$ CALORIMETERS
- Charged $\rightarrow$ SPECTROMETER

- K decay in flight technique
- Intense proton beam from SPS
- High energy K (75 GeV/c)
- Unseparated secondary beam p/\(\pi/K/e

- Kaon $\rightarrow$ BEAM TRACKER
- Pion $\rightarrow$ SPECTROMETER

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Backgrounds

- **Kinematically constrained**
  - Allows us to define a signal region
  - \( K^+ \rightarrow \pi^+ \pi^0 \) forces us to split it into two parts (Region I and Region II)

- **Not kinematically constrained**
  - Span across the signal region
  - Rejection must rely on vetoes

92% of total background

8% of total background
P-326 Layout

Located in the same hall of NA48

5×10^{-7} mbar
### Beam Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>NA48/2</th>
<th>P-326</th>
</tr>
</thead>
<tbody>
<tr>
<td>( P_K ) (GeV/c) ((\Delta P_K/P_K))</td>
<td>5.7%</td>
<td>6.0%</td>
</tr>
<tr>
<td>Fraction of K</td>
<td>400</td>
<td>400</td>
</tr>
<tr>
<td>Beam acceptance ((\mu)str)</td>
<td>0.4</td>
<td>16</td>
</tr>
<tr>
<td>Area (@beam tracker)</td>
<td>0.40 cm²</td>
<td>16 cm²</td>
</tr>
<tr>
<td>Rate (MHz)</td>
<td>18</td>
<td>800</td>
</tr>
<tr>
<td>( K ) decay/year (60m volume)</td>
<td>10¹¹</td>
<td>4.8×10¹²</td>
</tr>
</tbody>
</table>

### Primary Beam

- \( Pp \) (GeV/c): NA48/2 = 400, P-326 = 400
- \( p/pulse \) \(10^{12}\): NA48/2 = 1, P-326 = 3
- Duty cycle (s): NA48/2 = 4.8/16.8, P-326 = 4.8/16.8
- Eff. n pulses/year: NA48/2 = 3×10⁵, P-326 = 3×10⁵

### Decay Rates

- K⁺ decay rate: ~11 MHz
- K⁻ decay rate: (60m volume) 10¹¹

### Diagram Details

- **Dipoles (1ˢᵗ achromat)**
- **Dipoles (2ⁿᵈ achromat)**
- **Collimators**
- **Scaper**
- **CEDAR**
- **Gigatracker**
- **Quadrupoles**
- **Muon sweeping**

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Beam tracker: Gigatracker

- Si pixel stations across the 2nd achromat: size 36 mm (X) x 48 mm (Y)
- Rate: 800 MHz (charged particles) ~ 50 MHz/cm²

- Low $X/X_0$ not to spoil the beam
- 300 μm sensor + 100 μm chip

- Good space resolution not to spoil the downstream tracker performances
- 300 x 300 μm pixels
- $\sigma(P_K)/P_K \sim 0.4\%$
- $\sigma(\theta_K) \sim 16 \mu$rad

- $\sigma(t) \sim 200$ ps (per station)
- Complex readout chip bump-bonded on the sensor (0.25 or 0.13 μm CMOS technology)

- Time coincidence with the downstream track to select the right K track

Dependence of S/B for $K \rightarrow \pi^+\pi^0$ vs $\sigma(t)$ of the beam track
**Downstream tracker**

- 6 chambers with 4 double layers of straw tubes each (⌀ 9.6 mm)
- Rate: ~45 KHz per tube (max 0.5 MHz) (μ+π)

- **Low X/X₀**
  - Operate in high vacuum
  - $X/X₀ \sim 0.1\%$ per view

- **Good space resolution**
  - 130 μm / hit
  - $\sigma(P)/P = 0.23\% \oplus 0.005\%P$
  - $\sigma(\theta) \sim 50 \div 20$ μrad

- **Redundant momentum measurement**
  - 2 magnets: 270 and 360 MeV $P_{\text{kick}}$

- **Veto for charged negative particles up to 60 GeV/c**
  - 5 cm radius beam holes displaced in the bending plane according to the 75 GeV/c beam path

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09-Nov-05

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Kinematics reconstruction

Two almost independent measurements of the downstream track momentum

$m^2_{\text{miss}}$ resolution $\sim 1.1 \times 10^{-3}$ GeV$^2$/c$^4$
main contribution from $\Theta_{\pi K}$ measurement
Particle ID: RICH

- pion / muon separation
- Velocity spectrometer

18 m Ne @ 1.0 atm

- Threshold: 12 GeV/c for $\pi$
- $3\sigma$ separation for $P < 35$ GeV/c

RICH as particle ID

RICH as velocity spectrometer
Large angle: 13 ANTIs (10 < acceptance < 50 mrad), lead-scintillators
Medium angle: NA48 LKr (1 < acceptance < 10 mrad), homogenous calorimeter
Small angle: IRC1,2 SAC (acceptance < 1 mrad)
**Photon Vetoes**

- **ANTI**: Rate $\sim4\text{ MHz} (\mu)+\sim0.5\text{ MHz} (\gamma)$ (OR of 13 ANTI’s)

<table>
<thead>
<tr>
<th>$E_{\gamma} \text{ GeV}$</th>
<th>Ineff.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$&lt; 0.05$</td>
<td>1</td>
</tr>
<tr>
<td>$0.05,1$</td>
<td>$10^{-4}$</td>
</tr>
<tr>
<td>$&gt;1$</td>
<td>$10^{-5}$</td>
</tr>
</tbody>
</table>

- **LKr**: Rate $\sim7\text{ MHz} (\mu) + \sim4\text{ MHz} (\gamma) + \sim3\text{ MHz} (\pi)$

<table>
<thead>
<tr>
<th>$E_{\gamma} \text{ GeV}$</th>
<th>Ineff.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$&lt; 1$</td>
<td>1</td>
</tr>
<tr>
<td>$1,3$</td>
<td>$10^{-4}$</td>
</tr>
<tr>
<td>$3,5$</td>
<td>$10^{-4},10^{-5}$</td>
</tr>
<tr>
<td>$&gt;5$</td>
<td>$10^{-5}$</td>
</tr>
</tbody>
</table>
Muon Veto (MAMUD)

- Sampling calorimeter + Magnet for beam deflection
- Rate: $\sim 7 \text{ MHz} (\mu) + \sim 3 \text{ MHz} (\pi)$

- $\mu$ rejection $\sim 10^{-5}$

- Sensitivity to the MIPs
- e.m. & hadronic shower detection

- Deflect the beam out from the SAC
- Coils providing 5 Tm field integral in the beam region

1 Section = 18/19 Iron Planes : 20 $X$, 2$\lambda_y$, 8 Sections in total

Magnetic field on iron surface

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Other detectors

- **Cerenkov on the beam (CEDAR)**
  - Keep the beam background under control
  - Provide an a posteriori check at the analysis level

- **Fast Hodoscope**
  - Provide timing of the event (high resolution $\sigma(t) < 100$ ps)
  - Trigger for charged particles

**Cedar N(He) versus W(H$_2$) Comparison**

- Cedar-N, He
- Cedar-W, H$_2$

**Efficiency [%] vs. Diaphragm aperture [mm]**

- $\pi^-$, 7-fold
- $K^-$, 7-fold

Propose to use the Multi-gap Glass RPC (ALICE-TOF technology)

*Prototype is under study*
Analysis: signal acceptance

Simulation of the P-326 apparatus

- Region I and II
- Momentum range: $15 < P_\pi < 35$ GeV/c
  - Against muons
  - RICH operational reasons
  - Plenty of energy in photon vetoes

Acceptance (60 m fiducial volume):

- Region I: 4%
- Region II: 13%
- Total: 17%

To be reduced because of losses due dead time, reconstruction inefficiencies...

Acceptance ~ 10% is achievable
## Analysis: background rejection

<table>
<thead>
<tr>
<th>Events/year</th>
<th>Total</th>
<th>Region I</th>
<th>Region II</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Signal</strong> ((\text{acc}=17%))</td>
<td>65</td>
<td>16</td>
<td>49</td>
</tr>
<tr>
<td>(K^+ \rightarrow \pi^+\pi^0)</td>
<td>2.7</td>
<td>1.7</td>
<td>1.0</td>
</tr>
<tr>
<td>(K^+ \rightarrow \mu^+\nu)</td>
<td>1.2</td>
<td>1.1</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>(K^+ \rightarrow e^+\pi^+\pi^-\nu)</td>
<td>~2</td>
<td>negligible</td>
<td>~2</td>
</tr>
<tr>
<td>Other 3 – track decays</td>
<td>~1</td>
<td>negligible</td>
<td>~1</td>
</tr>
<tr>
<td>(K^+ \rightarrow \pi^+\pi^0\gamma)</td>
<td>1.3</td>
<td>negligible</td>
<td>1.3</td>
</tr>
<tr>
<td>(K^+ \rightarrow \mu^+\nu\gamma)</td>
<td>0.5</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>(K^+ \rightarrow e^+(\mu^+)\pi^0\nu), others</td>
<td>negligible</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td><strong>Total bckg.</strong></td>
<td>9</td>
<td>3.0</td>
<td>6</td>
</tr>
</tbody>
</table>

**S/B ~ 8** (Region I ~5, Region II ~9)
Other Physics Opportunities

- P-326 Kaon Flux ~100 times NA48/2 Kaon Flux

- Other physics opportunities can be addressed:
  - Cusp – like effects:
    - $K^+ \rightarrow \pi^0\pi^0e^+\nu$
  - Lepton – flavour violation:
    - $K_{e2}/K_{\mu2}, K^+ \rightarrow \pi^+\mu^+e^-, K^+ \rightarrow \pi^+\mu^+e^+$
  - Search for new low mass particles:
    - $K^+ \rightarrow \pi^+\pi^0X$
    - $K^+ \rightarrow \pi^+\pi^0P$ (*pseudoscalar sGoldstino*)
  - Improve greatly on rare radiative kaon decays
Conclusions

- Excellent NA48/2 results about \( K^\pm \to 3\pi \) have been presented.

- **Near future:** test of the CKM matrix using rare Kaon decays

- **P-326 experiment:** measurement of \(|V_{td}|\) with a ~10% of accuracy, from the \( K^+ \to \pi^+\nu\bar{\nu} \) decay

- **We propose an experiment** able to reach a ~10\(^{-12}\) sensitivity per event at an existing machine and employing the infrastructures of an existing experiment.  [CERN-SPSC-P-326, 11/06/2005]