Search for $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ at NA62

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on behalf of the NA62 Collaboration

* CERN

Presentation Outline:

1 Motivations
2 Search Strategy
3 Results from the 2015 NA62 Run

BEACH 2016, Fairfax, U.S.A.
**Motivations**

**$K^+ \rightarrow \pi^+ \nu \bar{\nu}$: a rare and clean decay**

- **Ultra rare FCNC: $s \rightarrow d$ transition, hard GIM suppression**

![Diagram](image)

- **Theoretically clean (no hadronic uncertainties)**

- **Prediction in SM:** [Buras, 1503.02693]

\[
\mathcal{B}(K^+ \rightarrow \pi^+ \nu \bar{\nu}) = (8.4 \pm 0.3) \times 10^{-11} \left( \frac{|V_{cb}|}{0.0407} \right)^{2.8} \left( \frac{\gamma}{73.2} \right)^{0.74}
\]

\[
= (8.4 \pm 1.0) \times 10^{-11}
\]
Testing the Standard Model

- \( \mathcal{B}(K^+ \rightarrow \pi^+ \nu \bar{\nu}) \) with 10% uncertainties allows to determine \(|V_{td}|\) at 9%

[Buras 0405132]

- With \( \mathcal{B}(K^+ \rightarrow \pi^+ \nu \bar{\nu}) \), \( \mathcal{B}(K_L \rightarrow \pi^0 \nu \bar{\nu}) \) the **CKM unitarity triangle** can be built independently from B observables:
Going Beyond the Standard Model

- Deviation from $B_{SM}$ would **signal new particles** (e.g. vector boson) contributions
- Even more sensitive to NP when using **correlations** with $\mathcal{B}(K_L \rightarrow \pi^0 \nu \bar{\nu})$, $\mathcal{B}(B_s^0 \rightarrow \mu^+ \mu^-)$, $\gamma$, $B_s^0 \rightarrow K(K^*) \mu \mu$, $\epsilon'/\epsilon$
- A key observable for the LHC era

![Graph showing 68% CL contours](image-url)
Motivations

State of the Searches

E949 Measurements

- Stopping kaon technique

\[ \mathcal{B}(K^+ \to \pi^+ \nu \bar{\nu}) = (17.3^{+11.5}_{-10.5}) \times 10^{-11} \]
Motivations

State of the Searches

E949 Measurements

- **Stopping kaon technique**
  
  \[ \mathcal{B}(K^+ \rightarrow \pi^+ \nu \bar{\nu}) = (17.3^{+11.5}_{-10.5}) \times 10^{-11} \]

NA62

- **Decay in flight**
- **Aim to measure \( \mathcal{B} \) with 10% precision**

Mathieu Perrin-Terrin (CERN)  
K\(^{+} \rightarrow \pi^{+} \nu \bar{\nu} \) at NA62  
Saturday, June, 18\(^{\text{nd}} \)
**Search Strategy**

**NA62 Apparatus**

- **HCAL**
- **Guard**
- **Giga**
- **Large Angle Veto**
- **Spectrometer**
- **vacuum**
- **50m 100m 150m 200m 250m**
- **ECAL**
- **Muon**
- **ECAL LKr-IRC-SAC**
- **Veto**
- **Tracker**
- **KTAG**
- **Ring**
- **BEAM**

[Mathieu Perrin-Terrin (CERN)](mailto:mathieu.perrin-terrin@cern.ch)

*K^+ \rightarrow \pi^+ \nu \bar{\nu} at NA62*  
Saturday, June 18th
Secondary Beam from SPS

- 5s spill at 750 MHz
- Composition: \( p \quad 70 \quad \pi^+ \quad 24 \quad K^+ \quad 6\%
- 75 GeV/c with \( \delta p/p = 1\%
- Commissioned
Beam Instrumentation

- **Kaon Tagging** (KTAG, Differential Cerenkov N$_2$ or H$_2$)
- **Kinematics** (GigaTracker- GTK, Silicon hybrid pixels, $\mu$-channel cooling)
- Beam particle **scattering detection** (Guard Ring)
- **Arrival time** measurement
- All commissioned but GTK (not fully efficient)
Decay Region

- 120m long, in **vacuum** (500 m³ at $10^{-6}$ mbar)
- **10% of $K^+$ decay** in the first 65m:

  5MHz of $K^+$ decay, $4.5 \times 10^{12}$/year
Decay Products Instrumentation

- Kinematics (Straw tubes in vacuum)
- Photon Detection (ECAL: LAV, LKr, IRC, SAC)
- $\pi$ and $\mu$ identification (RICH Neon, HCAL and, Muon Veto)
- Arrival time measurement (all + CHOD for charged particles)
- All commissioned
trigger

- Digital Trigger
- L0 commissioned, L1,2 partially
- Minimum bias data taken at low beam intensity
- Samples at half and full intensity taken with a calorimeter trigger
Search Strategy

\[ K^+ \rightarrow \pi^+ \nu \bar{\nu} \] Analysis Strategy

**Background Sources**
- \( K^+ \) decay incorrectly reconstructed
- Beam activity

**Key Analysis Elements**
- **Main variable** \( m_{\text{miss}}^2 = |p_K - p_\pi|^2 \)
- **Signal selection**
  - \( m_{\text{miss}}^2 \) in regions I and II,
  - vertex in fiducial region (65m)
  - \( p_\pi \in [15,35] \) GeV/c
- Background controlled with
  - Kinematics
  - \( K \) and \( e/\mu/\pi \) PID
  - Hermetic \( \gamma \) detection
  - Timing

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## Analysis Sensitivity (MC)

<table>
<thead>
<tr>
<th>Decay</th>
<th>event/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K^+ \rightarrow \pi^+ \nu \bar{\nu}$ (SM)</td>
<td>45</td>
</tr>
<tr>
<td>Total Background</td>
<td>10</td>
</tr>
<tr>
<td>$K^+ \rightarrow \pi^+ \pi^0$</td>
<td>5</td>
</tr>
<tr>
<td>$K^+ \rightarrow \mu^+ \nu$</td>
<td>1</td>
</tr>
<tr>
<td>$K^+ \rightarrow \pi^+ \pi^+ \pi^-$</td>
<td>&lt;1</td>
</tr>
<tr>
<td>$K^+ \rightarrow \pi^+ \pi^- e^+ \nu +$ other 3 track decays</td>
<td>&lt;1</td>
</tr>
<tr>
<td>$K^+ \rightarrow \pi^+ \pi^0 \gamma^{IB}$</td>
<td>1.5</td>
</tr>
<tr>
<td>$K^+ \rightarrow \mu^+ \nu \gamma^{IB}$</td>
<td>0.5</td>
</tr>
<tr>
<td>$K^+ \rightarrow \pi^0 e^+ (\mu^+ \nu +$ others</td>
<td>negligible</td>
</tr>
</tbody>
</table>

Mathieu Perrin-Terrin (CERN) $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ at NA62 Saturday, June, 18\textsuperscript{nd}
Minimum Bias Sample and Timing

Candidate Selection

- Single downstream track
- Energy deposits in calorimeters
- Beam track: Kaon
- Vertex in fiducial region
Minimum Bias Sample and Timing

Candidate Selection

- Single downstream track
- Energy deposits in calorimeters
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\( K^+ \rightarrow \pi^+ \nu \bar{\nu} \) at NA62
Candidate Selection

- Single downstream track
- Energy deposits in calorimeters
- Beam track: NOT Kaon

Timing

- Kaon ID $\leq 100$ ps
- Beam Track $\leq 200$ ps
- Downstream Track $\leq 200$ ps
- Calorimeters $\simeq 1$-2 ns
Kinematics in view of 2015 Data

- $15 \leq p_\pi \leq 35 \text{ GeV/c}$ to suppress $K^+ \rightarrow \mu^+ \nu$
- $K^+ \rightarrow \pi^+ \pi^0$ selected using LKr
- Resolution close to design
- Background rejection aimed: $10^4 - 10^5$, measured: $10^3$
Results from the 2015 NA62 Run

Kinematics in view of 2015 Data

- $15 \leq p_\pi \leq 35$ GeV/c to suppress $K^+\rightarrow \mu^+\nu$
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- Resolution close to design
- Background rejection aimed: $10^4 - 10^5$, measured: $10^3$
PID in view of 2015 Data

- Goal: $10^7$ muon rejection to reduce $K^+ \rightarrow \mu^+ \nu$
- $15 \leq p_\pi \leq 35 \text{ GeV/c}$: best RICH performance
- Pure sample of pion and muon selected using kinematics
- RICH: $10^2 \mu^+$ rejection for 80% $\pi^+$ efficiency
- Calorimeter: $10^4 - 10^6 \mu^+$ rejection for 90-40% $\pi^+$ efficiency (cut)
Goal: $10^8$ rejection on $\pi^0$ from $K^+ \rightarrow \pi^+ \pi^0$

$15 \leq p_{\pi} \leq 35 \text{ GeV/c}$
$\rightarrow E_{\pi^0} > 40 \text{ GeV}$

$\theta_{\text{LAV}} \in [50, 8.5]$, $\theta_{\text{LKr}} \in [8.5, 1]$, $\theta_{\text{IRC}, \text{SAC}} \leq 1$

Measured with 2015 data selecting $K^+ \rightarrow \pi^+ \pi^0$ using kinematics

Results limited by statistics
Conclusions and Prospects

- $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ is a key channel to search for NP
- NA62 aims to measure its branching ratio with a 10% precision
- Data taking has started
- Low intensity data taken in 2015 shows:
  - *timing* performance close to design
  - $m_\mu^2$ *resolution* close to design
  - Background rejection promising
  - $\pi/\mu$ separation from *RICH* close to design
  - Separation from *calorimeters* promising
  - $\pi^0$ rejection promising (limited by statistics)
- More data are being taken at the moment