Status of the NA62 Experiment

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Introduction

- NA62: kaon experiment at CERN SPS
  - Main goal: precise measurement of $\text{BR}(K^+ \to \pi^+\nu\bar{\nu})$
  - Broader physics program: LFV / LNV in $K^+$ decays, hidden sector particles searches.

- NA62 is taking data. Approved until LS2
- Proposed runs after LS2 under discussion*

*see P.Petrov and M. Moulson talks on Saturday
Kaon @ CERN - SPS

‘97-’01 NA48: $\varepsilon'/\varepsilon$

’02 NA48/1: $K_s$ rare decays

’03-’04 NA48/2: $K^\pm$ CP violation, semileptonic, low energy QCD

’07-’08 NA62: Lepton universality (using the NA48 apparatus)

’14 - NA62: $K^+ \rightarrow \pi^+ \nu \bar{\nu}$
  • Installation complete
  • Runs from 2014
  • Detector commissioning
  • Data quality studies
The $K \to \pi \nu \bar{\nu}$ decays: a theoretical clean environment

- FCNC loop processes: $s \to d$ coupling and highest CKM suppression

  \[
  \begin{align*}
  \text{BR}(K^+ \to \pi^+ \nu \bar{\nu}) &= (8.39 \pm 0.30) \cdot 10^{-11} \left( \frac{|V_{cb}|}{0.0407} \right)^2 \left( \frac{\gamma}{73.2^\circ} \right)^{0.74} = (8.4 \pm 1.0) \cdot 10^{-11} \\
  \text{BR}(K_L \to \pi^0 \nu \bar{\nu}) &= (3.36 \pm 0.05) \cdot 10^{-11} \left( \frac{|V_{ub}|}{0.00388} \right)^2 \left( \frac{|V_{cb}|}{0.0407} \right)^2 \left( \frac{\sin \gamma}{\sin 73.2^\circ} \right)^2 = (3.4 \pm 0.6) \cdot 10^{-11}
  \end{align*}
  \]

- Very clean theoretically: Short distance contribution. No hadronic uncertainties.


- Experiments:
  \[
  \begin{align*}
  \text{BR}(K^+ \to \pi^+ \nu \bar{\nu}) &= (17.3^{+11.5}_{-10.5}) \times 10^{-11} \quad \text{Phys. Rev. D 77, 052003 (2008), Phys. Rev. D 79, 092004 (2009)} \\
  \text{BR}(K_L \to \pi^0 \nu \bar{\nu}) &< 2.6 \times 10^{-8} \quad \text{(90\% C.L.)} \quad \text{Phys. Rev. D 81, 072004 (2010)}
  \end{align*}
  \]
$K \to \pi \nu \bar{\nu}$ NP Sensitivity

- **Simplified Z, Z’ models** [Buras, Buttazzo, Knegjens, JHEP 1511 (2015) 166]
- **Littlest Higgs with T-parity** [Blanke, Buras, Recksiegel, EPJ C76 (2016) no.4 182]
- **Custodial Randall-Sundrum** [Blanke, Buras, Duling, Gemmler, Gori, JHEP 0903 (2009) 108]

- **Constraints from existing measurements** (correlations model dependent):
  - Kaon mixing and CPV, CKM fit, K,B rare meson decays, NP limits from direct searches

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**Z’ model**

**Randall - Sundrum**

**Littlest Higgs**
The NA62 Experiment for $K^+ \rightarrow \pi^+ \nu \bar{\nu}$

Primary goal:

10% precision $\text{BR}(K^+ \rightarrow \pi^+ \nu \bar{\nu})$

Requirements:

Statistics: $O(100)$ events

$K$ decays $10^{13}$, Signal acceptance $\sim 10\%$

Systematics: $<10\%$ precision background measurement

$>10^{12}$ background rejection ($<20\%$ background)

Technique:

$K$ Decay – in – flight
**NA62 Layout**

**Detectors for Secondary Beam**
- Kaon ID (KTAG)
- Beam Tracker
- Beam guard ring (CHANTI)

**SPS proton**
- 400 GeV
- $10^{12}$ p/s
- 3.5 s spill

**Secondary Beam**
- $75 \text{ GeV}/c$, $\Delta p/p \sim 1\%$
- X,Y Divergence $< 100 \mu \text{rad}$
- K(6%), $\pi$ (70%), p (23%)
- Total rate: 750 MHz
- Beam size: $6.0 \times 2.7 \text{ cm}^2$

**Kaon Decay**
- $\sim 5 \text{ MHz}$
- $4.5 \times 10^{12}/year$
- 60 m length
- $10^{-6}$ mbar vacuum

**Detectors for decay products**
- Charged particle tracking
- Charged particle time stamping
- Photon detection
- Particle ID
The Apparatus
Present Status

Beam line, detectors, trigger and DAQ fully commissioned

NA62 data taking periods
- 2014: detector commissioning
- 2015: trigger commissioning, detector quality studies, beam line commissioning up to nominal intensity
- 2016: high level trigger commissioning (done), full beam tracker commissioning (done), physics (on-going)

Data samples for analysis:
- 2015:
  - Low intensity data with minimum bias trigger for detector quality studies (this talk)
- 2016:
  - $\pi\nu\nu$ data (up to 30% of nominal intensity)
  - not – $\pi\nu\nu$ data (up to 30% of nominal intensity)
\( K^+ \rightarrow \pi^+ \nu \bar{\nu} \) Analysis Principles

- **Signal**

  \[
  K_K \rightarrow p_\pi \theta_{\pi K} \rightarrow p_\nu \theta_{\nu K} 
  \]

- **Background:** \( K^+ \) decay modes; beam activity

- **Kinematics:** \( m_{\text{miss}}^2 = (P_K - P_{\pi^+})^2 \)

- **Experimental principles:**
  1. Precise kinematic reconstruction
  2. PID: \( K \) upstream, \( e/\mu/\pi \) downstream
  3. Hermetic \( \gamma \) detection
  4. Sub-ns timing

- **Key analysis requirements**
  1. 2 signal regions in \( m_{\text{miss}}^2 \)
  2. \( 15 < P_\pi < 35 \text{ GeV}/c \)
  3. 65 m long decay region
Expected Performances and Sensitivity

**Required background suppression**

<table>
<thead>
<tr>
<th>Component</th>
<th>Suppression</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kinematics</td>
<td>$O(10^4-10^5)$</td>
</tr>
<tr>
<td>Charged Particle ID</td>
<td>$O(10^7)$</td>
</tr>
<tr>
<td>$\gamma$ detection</td>
<td>$O(10^8)$</td>
</tr>
<tr>
<td>Timing</td>
<td>$O(10^2)$</td>
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</tbody>
</table>

**Sensitivity**

<table>
<thead>
<tr>
<th>Decay</th>
<th>ev/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K^+ \rightarrow \pi^+\nu\nu$ [SM] (flux $4.5 \times 10^{12}$)</td>
<td>45</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>3 tracks 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>&lt; 1</td>
</tr>
<tr>
<td><strong>Total background</strong></td>
<td>&lt; 10</td>
</tr>
</tbody>
</table>
Signal Topology and Kaon ID

One – track selection (OTS)
- Single downstream track topology
- Downstream track matching energy in calorimeters
- Beam track matching the downstream track

Kaon ID
- Beam track matching a K signal in Kaon ID
- Decay vertex in the fiducial region (65 m).

Time resolutions:
- Kaon ID < 100 ps
- Beam track < 200 ps
- Downstream track < 200 ps
- Calorimeters 1-2 ns
Tracking Techniques: Si - pixel tracker (beam); Straw tube tracker in vacuum (downstream)

Goal: $O(10^4 \div 10^5)$ suppression factor of the main kaon decay modes

$P_{\pi^+} < 35 \text{ GeV/c}$: best $K^+ \to \mu^+ \nu$ suppression.

Kinematics studied on $K^+ \to \pi^+ \pi^0$ selected using LKr calorimeter.

Resolutions close to the design.

$O(10^3)$ kinematic suppression factor measured.
Beam Tracker (GigaTracker)

- 3 Si pixel stations on the beam
- $300 \times 300 \, \mu m^2$ pixels, $\sim54000$ pixels
- Cooling using microchannel technique
- On-sensor TDC readout chip
- $X/X_0 < 0.5\%$ / station
- Commissioned in 2015-2016
- Measured performances match the design
- $\sigma(t_{beam\, track}) \leq 200 \, ps$

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$75 \, GeV/c$ beam

Collimator

$2^{nd}$ achromat

13.2 m

9.6 m

60 mm

GTK1

GTK2

GTK3

CHANTI

2016 data

Missing chip

Hit Map of GTK 3

 GTK1 2015

rms 239 ps

$t_{hit} - t_{KTAG} [\, ns]$
Downstream Particle Identification

- **Technique:** RICH and calorimeters
- **Goal:** $O(10^7)$ $\mu/\pi$ separation to suppress mainly $K^+ \rightarrow \mu^+ \nu$
- $15 < P_{\pi^+} < 35$ GeV/c: best $\mu/\pi$ separation in RICH
- Pure samples of pions and muons selected using kinematics
- RICH: $O(10^2)$ $\pi/\mu$ separation, 80% (90%) $\pi^+$ efficiency in 2015 (2016)
- Calorimeters: $(10^4 \div 10^6)$ $\mu$ suppression, (90% $\div$ 40%) $\pi^+$ efficiency in 2015 using a cut analysis. Room for improvements.
**Technique:** EM calorimeters exploiting correlations between $\gamma s'$ from $\pi^0$.

**Goal:** O($10^8$) rejection $\pi^0$ from $K^+\rightarrow\pi^+\pi^0$

$P_{\pi^+} < 35$ GeV/c $\rightarrow E_{\pi^0} > 40$ GeV

Measured on data using $K^+\rightarrow\pi^+\pi^0$ selected kinematically

2015 measurement statistically and background limited
Summary from data quality studies

1) Time resolution
   - Close to the design

2) Kinematics
   - Resolution close to the design.
   - Prospects to reach the designed signal – background separation.

3) Pion – muon ID
   - Separation with RICH close to expectations.
   - Study of the separation with calorimeters on going. Results from simple cut analysis promising.

4) Photon veto:
   - $O(10^6)\pi^0$ rejection already obtained. Statistically limited. 2016 already enough to address the $10^8$ rejection level (analysis on - going).
Broader NA62 Physics Program

- **LFV with Kaons:**
  - $K^+ \rightarrow \pi^+ \mu^\pm e^\mp$, $K^+ \rightarrow \pi^- \mu^+ e^+$, $K^+ \rightarrow \pi^- l^+ l^+$

- **$\pi^0$ decays rare and forbidden/LFV, dark photon production:**
  - $\pi^0 \rightarrow$ invisible, $\pi^0 \rightarrow 3/4 \gamma$, $\pi^0 \rightarrow ee$, $\pi^0 \rightarrow \mu e$, $\pi^0 \rightarrow U\gamma$

- **Heavy neutral lepton production searches in K decays:**
  - $K^+ \rightarrow l^+ \nu_h$ (already under analysis with 2015 data), $K^+ \rightarrow l^+ X$

- **Dark sector particles searches:**
  - Long living dark photon decaying in $l^+ l^-$ and produced by $\pi^0 / \eta / \eta' / \Phi / \varphi / \omega$ decays
  - Long living heavy neutral lepton decaying in $\pi e$, $\pi \mu$
  - Long living axion-like decaying in $\gamma \gamma$ produced in a beam-dump configuration
A glance to the on-going 2016 run

Stable data taking since beginning of August at 20 – 30 % of nominal intensity
L0 $\pi^+\pi^0$ trigger: hits in RICH & CHOD, $\not{\mu}$ons, E(LKr) < 20 GeV
L1 $\pi^+\pi^0$ trigger: KTAG, LAV, Straw (P < 50 GeV/c)
Data type (simultaneously): $\pi^+\pi^0$ (no downscaling), di-lepton, minimum bias
Average rate at L0 (25% of nominal beam intensity): 500 KHz
Average rate after L1 (25% of nominal beam intensity): 60 KHz
On – line $\pi^+\pi^0$ reduction factor ($\pi^+\pi^0$ trigger): 6 (room for improvements ×2 at least)
On – line muon reduction factor ($\pi^+\pi^0$ trigger): O(100)
Data collected so far: $\pi^+\pi^0$ sensitivity below $10^{-9}$ (assuming O(10%) signal acceptance)
$K^+ \rightarrow \pi^+ \nu \bar{\nu}$ program until LS2

End 2016: reach the SM sensitivity for $K^+ \rightarrow \pi^+ \nu \bar{\nu}$

End 2017: improve (by much) the present status of the art (BNL measurement).

End 2018: reach the 10% precision.

Broader physics program until LS2 (see P.Petrov talk on Saturday)

LFV / LNV decays, heavy neutrinos, $\pi^0$ rare decays, ...

as many decay modes as possible to take simultaneously with $\pi \nu \nu$

Broader physics program beyond LS2 (see P.Petrov talk on Saturday)

LFV / LNV decays, heavy neutrinos, $\pi^0$ rare decays, hidden sector particles searches
Conclusions

- The NA62 experiment is running in stable conditions.
- Data quality studies:
  - Physics sensitivity for $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ measurement in line with the design.
- Analysis of the 2016 data on – going.
- $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ program to get the 10% design precision under way.
- Broader physics program for short/medium term plan established.