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

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The NA62 Experiment

Fixed Target Experiment
Located at the North Area of CERN
75 GeV/c Secondary Hadron Beam
Carry on the tradition of Kaon experiments at CERN - SPS
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Theoretical Motivation

FCNC loop process, highly suppressed, theoretically very clean


$$Br_{SM}(K^+ \to \pi^+ \nu \bar{\nu}) = (8.4 \pm 1.0) \times 10^{-11}$$

Previous Measurement (only 7 events) [BNL E787/E949: PRL101 (2008) 191802]

$$Br_{Exp}(K^+ \to \pi^+ \nu \bar{\nu}) = (17.3 \pm 11.5_{10.5}) \times 10^{-11}$$
Theoretical Motivation

FCNC loop process, highly suppressed, theoretically very clean

Well calculated inside the Standard Model \[ A.J. \text{Buras et al., JHEP 1511 (2015) 033} \]

\[
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Br_{Exp}(K^+ \rightarrow \pi^+ \nu \bar{\nu}) = (17.3 \pm ^{11.5}_{10.5}) \times 10^{-11}
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Any deviation from the SM prediction is a hint of new physics
Theoretical Motivation

FCNC loop process, highly suppressed, theoretically very clean

Well calculated inside the Standard Model

\[ B_r(#$K$&$\rightarrow$\pi$\&\nu\bar{\nu}$) = (17.3 ± 11.5$^{+0.5}_{-10.5}$) \times 10^{-11} \]

Expected 10% precision by NA62

Previous Measurement (only 7 events) [BNL E787/E949: PRL101 (2008) 191802]

Any deviation from the SM prediction is a hint of new physics
The NA62 Strategy and Apparatus

SPS Protons
400 GeV
$10^{12}$ protons/s
3.5 s spill

Beryllium Target

Secondary Beam
75 GeV,
$\Delta p/p \approx 1\%$
K (6%), p (23%), π (70%)
750 MHz

Kaon Decays
$\approx 5$ MHz
$4.5 \times 10^{12}$ per year
$10^{-6}$ mbar vacuum
The NA62 Strategy and Apparatus

Signal:
✓ One beam $K^+$
✓ One $\pi^+$
✓ Nothing else

Background:
✗ Beam activity
✗ Other $K^+$ decays

➢ Precise kinematic reconstruction
➢ Hermetic Photon Detection
➢ Efficient PID for pion/muon discrimination

$M_{\text{miss}} = (P_{K^+} - P_{\pi^+})^2$
The NA62 Strategy and Apparatus

Signal:
- One beam $K^+$
- One $\pi^+$
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Background:
- Beam activity
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- Precise kinematic reconstruction
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\[
M_{\text{miss}} = (P_{K^+} - P_{\pi^+})^2
\]
The NA62 Strategy and Apparatus

Kaon Tagging – CEDAR
45 MHz rate
time: 100 ps

Kaon Tracking – GTK
momentum: $dp/p < 0.4\%$
direction: $\approx 0.016$ mrad

Spectrometer – STRAW
momentum: $dp/p < 0.33\%$
direction: $\approx 10$ mrad
extracted vertex: $\approx 1$ mm
The NA62 Strategy and Apparatus

**Signal:**
- ✓ One beam $K^+$
- ✓ One $\pi^+$
- ✓ Nothing else

**Background:**
- ✗ Beam activity
- ✗ Other $K^+$ decays

**Sample of $K^+\rightarrow\pi^+\pi^+\pi^-$**

- NA62 PRELIMINARY
- Kaon track
- Kaon Timing $\sim 100$ ps
- Pion Timing $\sim 150$ ps
- Random beam track

**Sample of $K^+\rightarrow\pi^+\pi^+\pi^-$**

- NA62 PRELIMINARY
- Kaon track
- Spatial Matching $\sim 1.5$ mm
- Random beam track
The NA62 Strategy and Apparatus

Signal:
✓ One beam $K^+$
✓ One $\pi^+$
✓ Nothing else

Mis-Tagging probability $\approx 1.7\%$

Background:
× Beam activity
× Other $K^+$ decays

Kaon Timing $\sim 100$ ps
Pion Timing $\sim 150$ ps

Spatial Matching $\sim 1.5$ mm

Random beam track
The NA62 Strategy and Apparatus

Signal:
✓ One beam $K^+$
✓ One $\pi^+$
✓ Nothing else

Background:
× Beam activity
× Other $K^+$ decays

Kinematics cut on a 3D space:
- Squared Missing Mass STRAW – GTK
- Squared Missing Mass RICH – GTK
- Squared Missing Mass STRAW – Nominal
The NA62 Strategy and Apparatus

**Signal:**
- One beam $K^+$
- One $\pi^+$
- Nothing else

**Background:**
- Beam activity
- Other $K^+$ decays

**Kinematics cut on a 3D space:**
- Squared Missing Mass STRAW – GTK
- Squared Missing Mass RICH – GTK
- Squared Missing Mass STRAW – Nominal

\[ \varepsilon (K^+\rightarrow\pi^+\pi^0) \approx 6 \cdot 10^{-4} \]
\[ \varepsilon (K^+\rightarrow\mu^+\nu) \approx 3 \cdot 10^{-4} \]
The NA62 Strategy and Apparatus

**Signal:**
- ✓ One beam $K^+$
- ✓ One $\pi^+$
- ✓ Nothing else

**Precise kinematic reconstruction**

**Background:**
- x Beam activity
- x Other $K^+$ decays

- Hermetic Photon Detection

- Efficient PID for pion/muon discrimination
The NA62 Strategy and Apparatus

Small Angle – IRC, SAC
coverage: < 1 mrad

Large Angle – LAV
coverage: 8.5 – 50 mrad
time: ≈ 1 ns

EM Calorimeter – LKr
coverage: 1 – 8.5 mrad
time: ≈ 300 ps
resolution: \( \frac{\sigma_E}{E} (20 \text{ GeV}) < 1\% \)
The NA62 Strategy and Apparatus

**Signal:**
- ✓ One beam $K^+$
- ✓ One $\pi^+$
- ✓ Nothing else

**Background:**
- × Beam activity
- × Other $K^+$ decays

![Graph of Control Trigger (D=400)](image1)

![Graph of Physics Trigger](image2)
The NA62 Strategy and Apparatus

**Signal:**
- ✓ One beam $K^+$
- ✓ One $\pi^+$
- ✓ Nothing else

**Background:**
- x Beam activity
- x Other $K^+$ decays

$\varepsilon_{\pi^0} = \left( 1.2 \pm 0.2 \right) \cdot 10^{-7}$
The NA62 Strategy and Apparatus

**Signal:**
- One beam $K^+$
- One $\pi^+$
- Nothing else

**Background:**
- Beam activity
- Other $K^+$ decays

- Precise kinematic reconstruction
- Hermetic Photon Detection
- Efficient PID for pion/muon discrimination
The NA62 Strategy and Apparatus

RICH

time: < 100 ps
muon rejection: 100

Calorimeters – LKr, HAC
Hadronic Shower Reconstruction
muon rejection: $10^5$

Fast Muon Veto

time: ≈ 300 ps
The NA62 Strategy and Apparatus

Signal:
- ✓ One beam $K^+$
- ✓ One $\pi^+$
- ✓ Nothing else

PID with Calorimeters (MVA):
$$\varepsilon_{\pi^+} = 80\% \text{ with } \varepsilon_{\mu^+} \sim 10^{-5}$$

PID with RICH:
$$\varepsilon_{\pi^+} \approx 80\% \text{ with } \varepsilon_{\mu^+} \sim 10^{-2}$$
( Momentum dependent )

Background:
- ✗ Beam activity
- ✗ Other $K^+$ decays
Signal:
- One beam $K^+$
- One $\pi^+$
- Nothing else

Background:
- Beam activity
- Other $K^+$ decays

PID with Calorimeters (MVA):
- $\varepsilon_{\pi^+} = 80\%$ with $\varepsilon_{\mu^+} \sim 10^{-5}$

PID with RICH:
- $\varepsilon_{\pi^+} \approx 80\%$ with $\varepsilon_{\mu^+} \sim 10^{-2}$
  (Momentum dependent)

Muon Rejection $\approx 10^7$
5% of 2016 data sample analyzed

Expected $K^+ \rightarrow \pi^+ \nu \bar{\nu} \approx 0.064$
- Normalization: $K^+ \rightarrow \pi^+ \pi^0$

Expected Background $< 0.057$
- $K^+ \rightarrow \pi^+ \pi^0 \approx 0.024$
- $K^+ \rightarrow \mu^+ \nu \approx 0.011$
- $K^+ \rightarrow 3\pi \approx 0.017$
- Beam $< 0.005$

Standard Model Sensitivity reachable with 2016 data

Analysis optimization on going!
Conclusion

NA62 is one of the main player in the search of new physics beyond the standard model through the measurement of the golden channel $K^+ \rightarrow \pi^+ \nu\bar{\nu}$.

The commissioning phase of the experiment finished on September 2016 and is now collecting physics data until 2018.

SM sensitivity is already achievable with 2016 data.

Analysis optimization still on going.
NA62 is one of the main player in the search of new physics beyond the standard model thought the measurement of the golden channel $K^+ \rightarrow \pi^+ \nu \bar{\nu}$

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