Results and Future Prospects from NA62 and Other Kaon Experiments

Zuzana Kučerová
Comenius University Bratislava

On behalf of the NA62 Collaboration

01/10/2019
BEAUTY 2019, Ljubljana, Slovenia
## Kaon Physics at NA62

<table>
<thead>
<tr>
<th>Type</th>
<th>Decay mode</th>
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<tr>
<td><strong>Main goal:</strong></td>
<td>$K^+ \rightarrow \pi^+ \nu \bar{\nu}$</td>
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<td><strong>Exotic searches:</strong></td>
<td>$K^+ \rightarrow l^+ N$, $K^+ \rightarrow \pi^+ \pi^0$, $\pi^0 \rightarrow A' \gamma$</td>
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<tr>
<td>Heavy neutral lepton</td>
<td></td>
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<tr>
<td>Dark photon $A'$</td>
<td></td>
</tr>
<tr>
<td>others</td>
<td></td>
</tr>
<tr>
<td><strong>Forbidden decays:</strong></td>
<td>$K^+ \rightarrow \pi^- e^+ e^+$, $K^+ \rightarrow \pi^- \mu^+ \mu^+$, others</td>
</tr>
<tr>
<td><strong>Rare decays:</strong></td>
<td>$K^+ \rightarrow \pi^+ \mu^+ \mu^-$, $K^+ \rightarrow \pi^+ \gamma \gamma$, others</td>
</tr>
</tbody>
</table>
$K^+ \rightarrow \pi^+ \nu\bar{\nu}$ in Standard Model

- FCNC loop process - rare meson decay naturally suppressed by the GIM mech.
- Theoretically very clean (no hadronic uncertainties)
- Sensitive to contributions of physics BSM

**SM prediction**


$$\mathcal{B}_{SM}(K^+ \rightarrow \pi^+ \nu\bar{\nu}) = (8.4 \pm 1.0) \times 10^{-11}$$

- Uncertainty coming mostly from CKM parameters ($\gamma, |V_{cb}|$)
$K^+ \rightarrow \pi^+ \nu \bar{\nu}$ Experimental Status

**E787/E949 (BNL),**
$K^+$ decays at rest

**NA62 (CERN),**
$K^+$ decays in flight

  - $B_{\text{exp.}} = (1.73^{+1.15}_{-1.05}) \times 10^{-10}$

  - $B_{\text{exp.}} < 14 \times 10^{-10}$ @ 95% CL
NA62 Experiment at CERN

**MAIN GOAL:** measure $\mathcal{B}(K^+ \rightarrow \pi^+ \nu \bar{\nu})$ with precision better than 10%
Requirements: $10^{13}K$ decays, Signal acceptance $O(10\%)$, Bckg rejection $O(10^{12})$

Other physics program: LFV/LNV searches, Exotic searches, Rare decays, $\pi^0$ decays

**NA62:**
- 2014: Pilot run
- 2015: Commissioning run
- September 2016: full detector installation completed
- September-October 2016: first physics run
- **May-October 2017:** second physics run
- April-November 2018: third physics run

- ~200 participants, 31 institutes
Beam:
- Primary (SPS) proton beam with momentum 400 GeV/c
- $2 \times 10^{12}$ protons per 3.5s spill
- Beryllium target
- Secondary positive beam with momentum $\sim 75$ GeV/c
- Secondary beam content:
  - $K^+$ (6%), $\pi^+$ (70%), p (24%)
- 2017 Intensity: 450 MHz @ GTK3
- Kaon decay rate $\sim 3$ MHz

Detectors:
- KTAG - Cherenkov det. for $K^+$ tagging
- GTK - beam spectrometer
- Decay region - 60 m long, in vacuum
- STRAW - downstream spectrometer
- CHOD - charged particle hodoscope
- LAV, IRC, SAC - photon veto
- RICH, LKr - Cherenkov detector and calorimeter for PID
- MUV3 - muon veto
Measurement Strategy

Measurement strategy:
- $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ signature: one $K^+$ in the initial state, one $\pi^+$ and missing energy (neutrinos) in the final state
- Two kinematic signal regions
- Blind analysis
- Trigger streams (HW+SW): PNN and Control (minimum bias)

Main background processes:

<table>
<thead>
<tr>
<th>Process</th>
<th>BR</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K^+ \rightarrow \mu^+ \nu (\gamma)$</td>
<td>0.6356</td>
</tr>
<tr>
<td>$K^+ \rightarrow \pi^+ \pi^0 (\gamma)$</td>
<td>0.2067</td>
</tr>
<tr>
<td>$K^+ \rightarrow \pi^+ \pi^+ \pi^–$</td>
<td>0.0558</td>
</tr>
</tbody>
</table>

Keystones:
- $\mathcal{O}(100 \text{ ps})$ timing between subdetectors
- $\sim \mathcal{O}(10^3)$ kinematic background suppression
- PID background suppression ($\mu^+$ and $\pi^0$) $> 10^7$

Main kinematic variable:

$m^2_{\text{miss}} = (P_{K^+} - P_{\pi^+})^2$
Signal selection:
- Single track topology
- $K^+$ and $\pi^+$ momentum reconstruction (GTK, STRAW)
- $K^+ - \pi^+$ matching
- $K^+$ decays in the fiducial region
- $\pi^+$ identification ($\epsilon_{\pi^+} \sim 64\%$)
- $\gamma$ rejection
- Multi-track event rejection
- Upstream background suppression
- $15 \text{ GeV} < P_{\pi^+} < 35 \text{ GeV}$
- Signal regions defined by $m_{\text{miss}}^2(\pi^+)$

Reconstructed $m_{\text{miss}}^2$ (assuming $\pi^+$ mass) as a function of the track momentum for control data before PID and $\gamma$ and multi-track rejection. [Phys.Lett.B 791, 156-166(2019)]
Data After Signal Selection (2017 Dataset)

- Validation regions dedicated to background validation
- Signal and validation regions blinded

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Recent Results in Kaon Physics
01/10/2019
Single Event Sensitivity (SES) (2017 Dataset)

\[
N_{\pi\nu\nu}^{\text{exp}} \approx N_{\pi\pi} \epsilon_{\text{trig}} \epsilon_{RV} \frac{A_{\pi\nu\nu}}{A_{\pi\pi}} \frac{B(\pi\nu\nu)}{B(\pi\pi)} \quad \Rightarrow \quad SES = \frac{B(\pi\nu\nu)}{N_{\pi\nu\nu}^{\text{exp}}}
\]

- \(N_{\pi\nu\nu}^{\text{exp}}\) = expected number of \(K^+ \rightarrow \pi^+\nu\bar{\nu}\) events
- \(N_{\pi\pi}\) = Number of \(\pi^+\pi^0\) events from Control sample with \(\pi\nu\nu\)-like selection without \(\gamma\)/multiplicity rejection
- \(\epsilon_{\text{trig}}\) = efficiency of PNN trigger
- \(\epsilon_{RV} = K^+ \rightarrow \pi^+\nu\bar{\nu}\) loss due to \(\gamma\)/multi-track rejection bc of random activity
- \(A_{\pi\nu\nu,\pi\pi}\) = MC acceptances for \(K^+ \rightarrow \pi^+\nu\bar{\nu}\) (\(\sim 3\%\)) and \(K^+ \rightarrow \pi^+\pi^0\) (\(\sim 8.5\%\))
- \(B(\pi\pi)\) = PDG branching ratio for \(K^+ \rightarrow \pi^+\pi^0\)
- \(B(\pi\nu\nu)\) = SM branching ratio for \(K^+ \rightarrow \pi^+\nu\bar{\nu}\)

Ratio of acceptances allows for cancellation of systematic effects
- Computation in bins of \(\pi^+\) momentum and instantaneous beam intensity

Measured single event sensitivity:

\[
SES = (3.89 \pm 0.21) \times 10^{-11} \quad \text{(Preliminary)}
\]

Expected number of \(K^+ \rightarrow \pi^+\nu\bar{\nu}\) events in both signal regions combined:

\[
N_{\pi\nu\nu}^{\text{exp}} = 2.16 \pm 0.12 \pm 0.26_{\text{ext}} \quad \text{(Preliminary)}
\]

External error coming from \(B(\pi\nu\nu)\).
$K^+ \rightarrow \pi^+\pi^0$ Background

$K^+ \rightarrow \pi^+\pi^0$ Control data used to study tails of $m^2_{miss}$ distribution

Expected and observed $K^+ \rightarrow \pi^+\pi^0$ bckg in validation regions after PNN selection

$$N^{exp}_{\pi\pi}(\text{region}) = N(\pi^+\pi^0) \cdot f^{\text{kin}}(\text{region})$$

- $N^{exp}_{\pi\pi}(\text{region}) =$ Expected $K^+ \rightarrow \pi^+\pi^0$ events in signal region after PNN selection
- $N(\pi^+\pi^0) =$ Data in $\pi^+\pi^0$ peak after PNN selection
- $f^{\text{kin}}(\text{region}) =$ Fraction of $K^+ \rightarrow \pi^+\pi^0$ in signal region measured on Control data

By-product: $\mathcal{B}(\pi^0 \rightarrow \text{invisible}) < 4.4 \times 10^{-9}$ 90% CL
Upstream Background

Normal decay of $K^+$:

- $K^+ \rightarrow \pi^+ \nu \bar{\nu}$
- MC projected at collimator

Track from $K^+ \rightarrow \pi^+ \nu \bar{\nu}$

Decay vertex

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Recent Results in Kaon Physics
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**Upstream Background**

**Normal decay of $K^+$:**

$K^+(75 \text{ GeV}) \rightarrow \pi^+ < 35 \text{ GeV}$

**Upstream Background:**

- $K^+$ decays/interacts in the achromat
- Secondary $\pi^+$ downstream
- Beam elements block additional particles
- $\pi^+$ scattering in Straw Chamber 1
- Pileup beam particle tagged as $K^+$

**Sketches from G. Ruggiero**
Upstream Background

Normal decay of $K^+$:

$K^+ (75 \text{ GeV})$ decays/interacts in the achromat.

Secondary $\pi^+$ downstream.

Beam elements block additional particles.

$\pi^+$ scattering in Straw Chamber 1.

Pileup beam particle tagged as $K^+$.

Upstream bckg:

- $K^+$ decays/interacts in the achromat.
- Secondary $\pi^+$ downstream.
- Beam elements block additional particles.
- $\pi^+$ scattering in Straw Chamber 1.
- Pileup beam particle tagged as $K^+$.
Background Summary (2017 Dataset)

Expected number of events in both signal regions combined (Preliminary):

<table>
<thead>
<tr>
<th>Process</th>
<th>Expected events</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K^+ \rightarrow \pi^+ \nu \bar{\nu}$ (SM)</td>
<td>$2.16 \pm 0.12_{\text{stat}} \pm 0.26_{\text{ext}}$</td>
</tr>
<tr>
<td>$K^+ \rightarrow \pi^+ \pi^0 (\gamma)$ IB</td>
<td>$0.29 \pm 0.03_{\text{stat}} \pm 0.03_{\text{syst}}$</td>
</tr>
<tr>
<td>$K^+ \rightarrow \mu^+ \nu_{\mu} (\gamma)$ IB</td>
<td>$0.11 \pm 0.02_{\text{stat}} \pm 0.03_{\text{syst}}$</td>
</tr>
<tr>
<td>$K^+ \rightarrow \mu^+ \nu_{\mu} (\mu^+ \rightarrow e^+ \text{decay})$</td>
<td>$0.04 \pm 0.02_{\text{syst}}$</td>
</tr>
<tr>
<td>$K^+ \rightarrow \pi^+ \pi^- e^+ \nu_e$</td>
<td>$0.12 \pm 0.05_{\text{stat}} \pm 0.03_{\text{syst}}$</td>
</tr>
<tr>
<td>$K^+ \rightarrow \pi^+ \pi^- \pi^+$</td>
<td>$0.02 \pm 0.02_{\text{syst}}$</td>
</tr>
<tr>
<td>$K^+ \rightarrow \pi^+ \gamma \gamma$</td>
<td>$0.005 \pm 0.005_{\text{syst}}$</td>
</tr>
<tr>
<td>$K^+ \rightarrow l^+ \pi^0 \nu_l$</td>
<td>negligible</td>
</tr>
<tr>
<td>Upstream background</td>
<td>$0.9 \pm 0.2_{\text{stat}} \pm 0.2_{\text{syst}}$</td>
</tr>
<tr>
<td>Total background</td>
<td>$1.5 \pm 0.2_{\text{stat}} \pm 0.2_{\text{syst}}$</td>
</tr>
</tbody>
</table>

$K^+ \rightarrow \pi^+ \pi^0 (\gamma)$, $K^+ \rightarrow \mu^+ \nu (\gamma)$, $K^+ \rightarrow \pi^+ \pi^- \pi^+$ and upstream backgrounds estimated from Control data and validated using the validation regions. Other backgrounds estimated from the MC simulations validated on data.
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Recent Results in Kaon Physics

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Box Opened
2 events observed in signal region

NA62 Preliminary

\( m_{\text{miss}}^2 \) vs \( \pi^+ \) momentum

\( \text{SM } K^+ \rightarrow \pi^+ \nu \bar{\nu} \)

\( \text{data} \)

\( 0 \)

\( -0.1 \)

\( 10 \)

\( 15 \)

\( 20 \)

\( 25 \)

\( 30 \)

\( 35 \)

\( 40 \)

\( -0.05 \)

\( 0 \)

\( 0.05 \)

\( 0.1 \)

NA62 Preliminary

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Recent Results in Kaon Physics

01/10/2019
Preliminary Results from the 2016+2017 Datasets

<table>
<thead>
<tr>
<th>Single event sensitivity</th>
<th>$(0.346 \pm 0.017) \times 10^{-10}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expected number of background events</td>
<td>$1.65 \pm 0.31$</td>
</tr>
<tr>
<td>Observed number of events</td>
<td>3</td>
</tr>
</tbody>
</table>

**Observed upper limits:**

- $B(K^+ \to \pi^+ \nu \bar{\nu}) < 1.85 \times 10^{-10}$ \(\text{@} 90\% \text{ CL} \) (Preliminary)
- $B(K^+ \to \pi^+ \nu \bar{\nu}) < 2.44 \times 10^{-10}$ \(\text{@} 95\% \text{ CL} \) (Preliminary)

**Grossman-Nir limit:** $B(K_L \to \pi^0 \nu \bar{\nu}) < 8.14 \times 10^{-10}$ \(\text{@} 90\% \text{ CL} \) (Preliminary)
Forbidden Decays (LNV) at NA62

- Study of $K^+ \rightarrow \pi^- \mu^+ \mu^+$ and $K^+ \rightarrow \pi^- e^+ e^+$ ($\Delta L_I = 2$)
- Processes in BSM with massive Majorana neutrinos $U$
- Signal selection using $|M(\pi^- l/l^+ l^+) - M(K^+)|$ and PID
  → improvement by factor 2-3 wrt previous result:
  - $\mathcal{B}(K^+ \rightarrow \pi^- e^+ e^+) < 2.2 \times 10^{-10}$ @ 90% CL
  - $\mathcal{B}(K^+ \rightarrow \pi^- \mu^+ \mu^+) < 4.2 \times 10^{-11}$ @ 90% CL
Hidden Sector Searches: Heavy Neutral Leptons (HNL)

- Study of $K^+ \rightarrow l^+ N (l = e, \mu) – production search$
- $\nu$MSM – mixing of three massive sterile neutrinos (HNL) with the three ordinary active neutrinos – fermion portal to a hidden sector
- Kinematic variable: squared missing mass $m^2_{\text{miss}} = (P_K - P_l)^2$
- Signal: a spike above continuous missing mass spectrum
- Mass scan in the range of 141–462 (220–383) MeV/$c^2$ in the $e^+$ ($\mu^+$) case

- Preliminary 2016+2017 results → new upper limit on mixing parameter $|U_{l4}|^2$ [Goudzovski, KAON 2019]
- Improvement by less than a factor of 2 with full dataset (2016-2018)
- Intention to collect data in beam-dump mode in 2021-2023 for HNL decay (and other) searches

![Graph showing upper limits on mixing parameter $|U_{l4}|^2$](image)
Hidden Sector Searches: Dark Photon \( A' \)

- Search for dark photon using \( K^+ \rightarrow \pi^+\pi^0, \pi^0 \rightarrow A'\gamma \), decay chain with \( A' \) decaying to invisibles – vector portal to a hidden sector
- SM extension – new vector field \( A' \) mixing with the SM \( \gamma \)
- Signal signature: \( \pi^0 \) decay, one \( \gamma \) and missing energy, no additional activity
- Kinematic variable: squared missing mass \( m_{\text{miss}}^2 = (P_K - P_{\pi^+} - P_{\gamma})^2 \)
- Signal: a spike above continuous missing mass spectrum
- Mass scan in range 30–130 MeV/c\(^2\) of \( M_{A'} \)
- 2016 results \( \rightarrow \) no statistically significant excess identified \( \rightarrow \) **new upper limit on \( \epsilon^2 \) coupling of \( A' \) to \( \gamma \)** [JHEP 05 (2019) 182]
- Expected \( \sim 100\times \) more statistics from full 2016–2018 dataset

![Graphs showing mass scan and coupling limits](image)
Prospects for NA62

All physics analyses ongoing (2017 and/or 2018 datasets):
- 2018 $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ dataset
  - Analysis ongoing
  - $2 \times$ more data than in 2017
  - Optimization studies to increase signal efficiency
  - New collimator installed – increased signal acceptance

NA62 After 2021 (LHC Run 3):
- Plans to modify the beamline setup in order to strongly suppress upstream background
- Add 4$^{th}$ GTK station to reduce $K^+ - \pi^+$ mistagging probability
- Plans for new vetoes in the beamline to detect extra particles
- Plans for data-taking:
  - $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ at nominal beam intensity
  - Rare decays + Exotics
  - NA62++:
    - Beam dump experiment (closed TAX) with $10^{18}$ POT
    - Decays of exotic particles
    - New ANTI0 detector under construction to veto muons produced in the TAX
    - Studies to increase proton beam intensity by 20-50% above nominal
KAoN Facility (2026 Onwards)

NA62 has initiated feasibility study for running at considerably higher intensity...

- Physics goals:
  - NA62×4 – improve precision on $K^+ \rightarrow \pi^+ \nu \bar{\nu}$
  - KLEVER – measure $B(K_L \rightarrow \pi^0 \nu \bar{\nu})$, complementary to NA62 and KOTO
  - 4× higher intensity in $K^+$ mode, 6× higher intensity in $K_L$ mode
    - Challenging for tracking and beam detectors ($K^+$ mode)
    - Challenging for calorimetry and photon detection ($K_L$ mode)
  - Large commonality in terms of upgrades required (hardware, readout)
Search for new physics with CP-violating (and highly suppressed FCNC) process $K_L \rightarrow \pi^0 \nu \bar{\nu}$

SM prediction for branching ratio is $\mathcal{B}_{SM} = (3.0 \pm 0.3) \times 10^{-11}$

~50 people from 16 institutes

First physics run in 2013

2015 dataset:

- Results published in Physical Review Letters [PRL.122.021802 (2019)]
- Measured SES: $(1.30 \pm 0.01_{\text{stat}} \pm 0.14_{\text{syst}}) \times 10^{-9}$
- Expected number of background events in the signal region: $0.42 \pm 0.18$
- No signal candidate events were observed
- New upper limit for $\mathcal{B}(K_L \rightarrow \pi^0 \nu \bar{\nu}) \leq 3.0 \times 10^{-9}$ at 90% C.L.
  $\rightarrow$ 10x improvement wrt prev. limit from KEK E391a [Phys.Rev.D 81, 072004, 2010]

Current status of 2016-2018 data analysis presented at KAON 2019

Future – major upgrades planned for KOTO Step-2 [Nomura, KAON 2019]
\[ K_L \rightarrow \pi^0 \nu \bar{\nu} \] at KOTO, J-PARC Center, Japan

- 30 GeV/c proton beam hitting a gold target
- Secondary neutral beam (neutrons, photons, \( K_L \)) produced at an angle and transported to the decay region via neutral beamline
- Peak \( K_L \) momentum 1.4 GeV/c
- Calorimeter and hermetic veto counters for neutral and charged particles around decay region in vacuum

**Signature:** two photons + missing energy

**Main sources of background:** charged

\[ (K_L \rightarrow \pi^\pm e^\pm \nu, \ K_L \rightarrow \pi^\pm \mu^\pm \nu, \ K_L \rightarrow \pi^+ \pi^- \pi^0, \ K_L \rightarrow \pi^+ \pi^-), \text{neutral} \ \ (K_L \rightarrow \pi^0 \pi^0 \pi^0, \ K_L \rightarrow \gamma \gamma, \ K_L \rightarrow \pi^0 \pi^0) \]

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**Diagram:**

- Proton beam
- Au target
- CsI calorimeter (reconstruct \( \pi^0 \) from 2\( \gamma \))
- \( K_L \) beam
- Hermetic veto detectors
- Beam plug
- Sweeping magnet
- Primary Proton
- Target
- Collimator
- Photon absorber
- Cooling block

**Additional details:**

- \( 30 \text{ GeV/c proton} \)
- Collimator + sweeping magnet
- \( K_L \) pencil beam
- pencil beam (\( K_L, n, \gamma \))
- \( \nu \bar{\nu} \) (undetectable)
- \( \pi^0 \rightarrow 2\gamma \)
2016–2018 dataset:
- 1.4× more statistics
- New veto counters
- Current status presented at KAON 2019 →

[Shinohara, KAON 2019]:
- Measured SES = $6.9 \times 10^{-10}$
- Expected number of background events in the signal region: $0.05 \pm 0.02$
- 4 events found in signal region
Stay tuned...

More results from Kaon experiments coming soon...

For more Kaon related searches see presentations at KAON 2019 [KAON 2019, Perugia]
- Intensity:
  - 2016: 40% of nominal
  - 2017: 55% of nominal
  - 2018: 65% of nominal

- Kaon decays:
  - 2017: $2 \times 10^{12}$ $K^+$ decays
  - 2016+2017+2018: $6 \times 10^{12}$ $K^+$ decays

- 2017 signal acceptance: 1.34% (including random veto, trigger and total detector efficiency)

- Rolke-Lopez 68% confidence interval: $\mathcal{B}(K^+ \rightarrow \pi^+ \nu\bar{\nu}) = (0.47^{+0.72}_{-0.47}) \times 10^{-10}$ (for comparison with BNL)
Recent Results in Kaon Physics

Date

Protons on target

* Including periods of beam off

𝐏𝐫𝐨𝐭𝐨𝐧𝐬𝐨𝐧𝐭𝐚𝐫𝐠𝐞𝐭

2014-15 (16) Pilot run, Commissioning runs

2016 Physics run (45 days*)

2017 Physics run (160 days*)

2018 Physics run (217 days*)
π⁰ rejection and search for π⁰ → invisible

A-priori evaluation of π⁰ rejection in K⁺ → π⁺π⁰ (0.015 < m_{miss}^2 < 0.021 GeV²/c⁴)

- Same selection, and trigger stream as K⁺ → π⁺ν̅ν, about 1/3 of the data used for πνν
- Single-γ detection efficiency from data minimum-bias K⁺ → π⁺π⁰ (Tag & Probe)
- π⁰ rejection evaluated from convolution with MC K⁺ → π⁺π⁰(γ)
- Validation: side-bands with expected rejection O(10⁻⁷) where π⁰ → invisible excluded
- π⁰ rejection expected: \((2.8^{+5.0}_{-2.1}) \times 10^{-9}\) (π⁺ momentum 25-40 GeV/c)

Result

- BR(π⁰ → invisible) normalized to π⁰ → γγ
- Background expected: \(10^{+22}_{-8}\) (K⁺ → π⁺π⁰)
- Events observed: 12

BR(π⁰ → invisible) < 4.4 \times 10^{-9} @ 90% CL

UL 60 times stronger than past measurement
Backup

Background Validation

\( K^+ \rightarrow \pi^+\pi^0 \) background expected and observed in control regions (CR1 + CR2) after \( \pi\nu\nu \) selection

\( K^+ \rightarrow \mu^+\nu \) background expected and observed in control region (CR) after \( \pi\nu\nu \) selection

23/10/2019 Giuseppe Ruggiero - Kaon 2019
**πνν Single Event Sensitivity**

\[ \epsilon_{RV} \text{ measured on } K^+ \rightarrow \mu^+ \nu \text{ data} \]

- Intensity measured event-by-event using Gigatracker time sidebands

\[ \langle \epsilon_{RV} \rangle_{2017} = 0.638 \pm 0.014 \]

\[ \epsilon_{\text{trigger}} \text{ measured on data} \]

- \( \pi^+ \) momentum [15,20] GeV/c

Statistical uncertainty

Stat+systematic uncertainty

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Recent Results in Kaon Physics

10/09/2019

Giuseppe Ruggiero - Kaon 2019
\[ \pi\nu\nu \text{ S.E.S.: Results} \]

- Integrated over beam intensity and $\pi^+$ momentum

\[ S.E.S. = (0.389 \pm 0.021) \times 10^{-10} \]

\[ N_{\pi\nu\nu}^{exp} = 2.16 \pm 0.12 \pm 0.26_{ext} \]

- Error budget (S.E.S.)

<table>
<thead>
<tr>
<th>Source</th>
<th>Uncertainty $\times 10^{-10}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>L0 trigger</td>
<td>$\pm 0.015$</td>
</tr>
<tr>
<td>Acceptance</td>
<td>$\pm 0.012$</td>
</tr>
<tr>
<td>Random veto</td>
<td>$\pm 0.008$</td>
</tr>
<tr>
<td>L1 trigger</td>
<td>$\pm 0.003$</td>
</tr>
<tr>
<td>Normalization background</td>
<td>negligible</td>
</tr>
</tbody>
</table>

- External error on $N_{\pi\nu\nu}^{exp}$ from $Br(\pi\nu\nu) = (0.84 \pm 0.10) \times 10^{-10}$