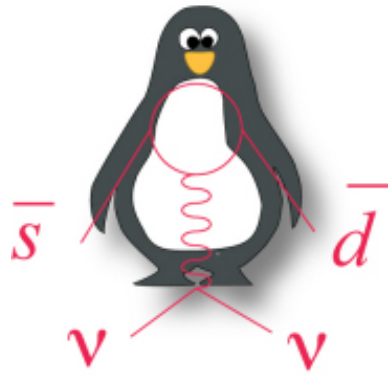

Physics Beyond Standard Model with Kaons from NA62

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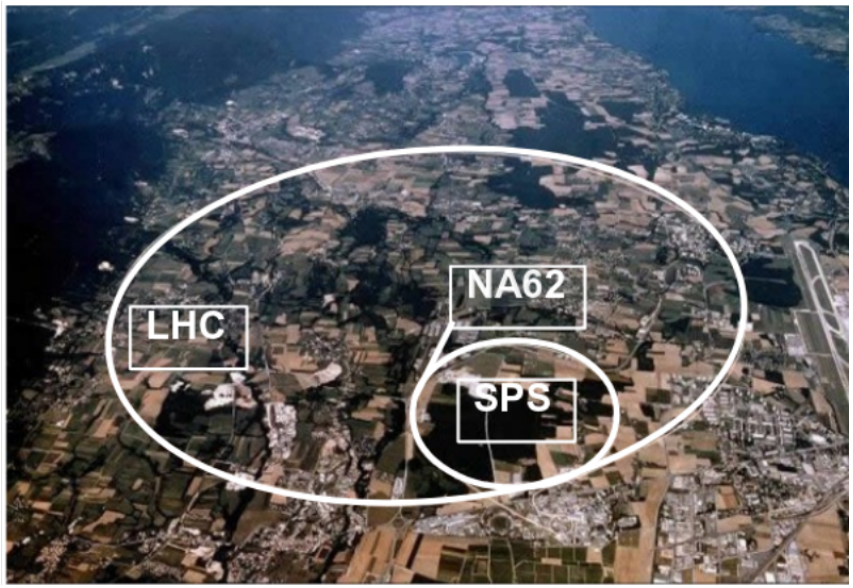
IFIN-HH, Romania
for the NA62 Collaboration

ICNFP, August 2019

Outline



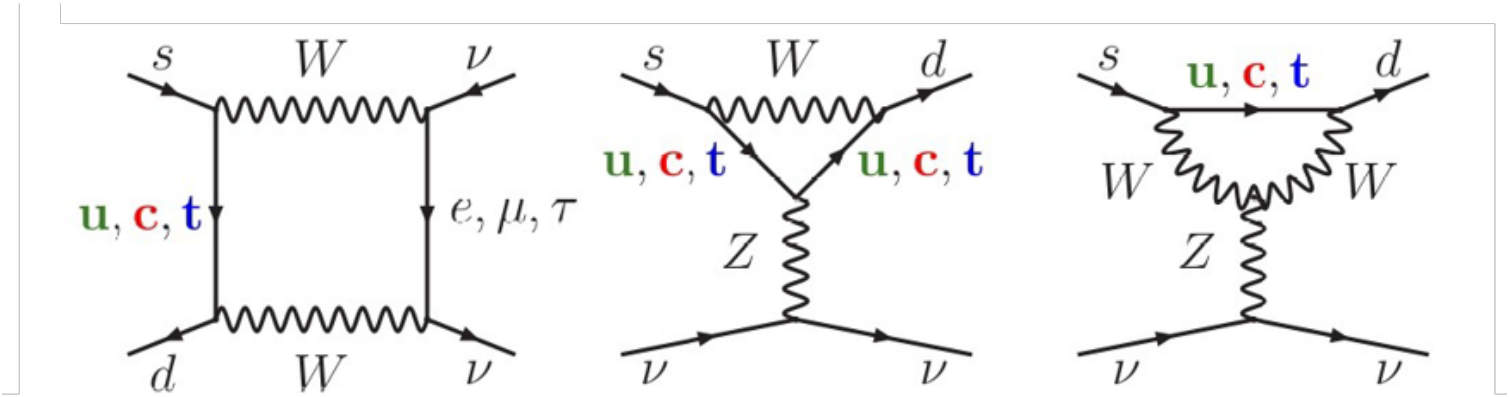
- $\sim$ 200 participants from 27 institutes: Birmingham, Bratislava, Bristol, Bucharest, CERN, Dubna, Fairfax, Ferrara, Florence, Frascati, Glasgow, Lancaster, Liverpool, Louvain, Mainz, Moscow, Naples, Perugia, Pisa, Prague, Protvino, Rome I, Rome II, San Luis Potosi, TRIUMF, Turin, Vancouver

Goal: Measure $BR(K^+ \to \pi^+ \nu\bar{\nu})$ with at least 10% precision

NA62 Timeline

- 2008: Approval
- 2009-2014: R&D and installation
- 2015: Commissioning
- 2016-2018: Run 1
- 2021-2023: Future Runs

$K^+ \to \pi^+ \nu\bar{\nu}$ in SM



- FCNC process forbidden at tree level
- High CKM suppression
- Short distance contribution dominates → very clean theoretically
- Hadronic matrix element extracted from $BR(K^+ \to \pi^0 e^+ \nu)$

Theoretical prediction:

$$BR(K^+ \to \pi^+ \nu\bar{\nu}) = (8.4 \pm 1.0) \times 10^{-11}$$
$$BR(K_L \to \pi^0 \nu\bar{\nu}) = (3.4 \pm 0.6) \times 10^{-11}$$

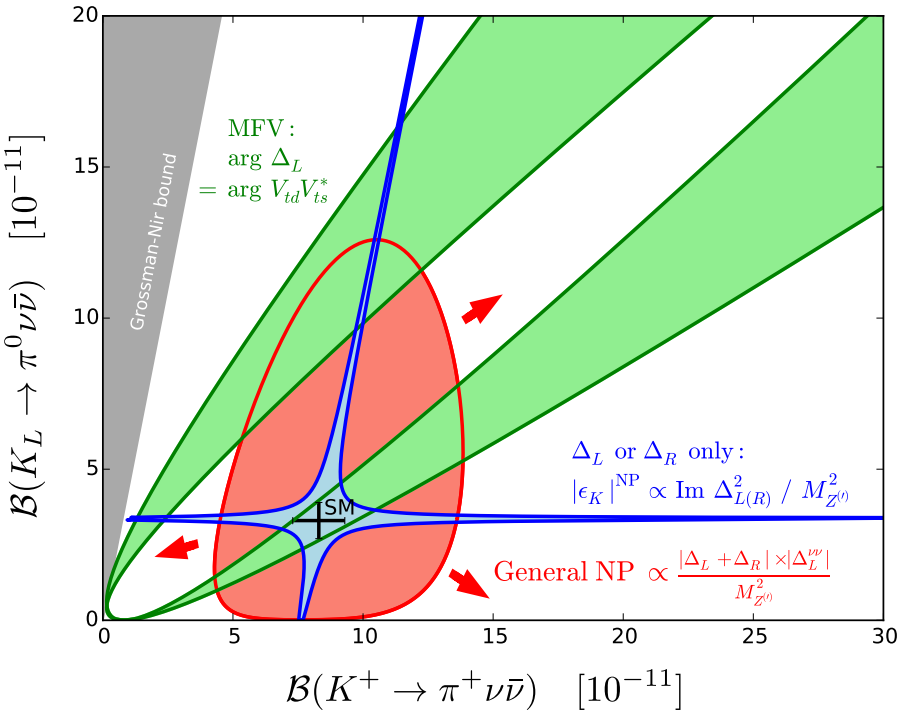
Experiment:

$$BR(K^+ \to \pi^+ \nu\bar{\nu}) < \left(17.3^{+11.5}_{-10.5}\right) \times 10^{-11}$$
$$BR(K_L \to \pi^0 \nu\bar{\nu}) < (2.6) \times 10^{-8} (@90\% CL)$$

$K^+ \to \pi^+ \nu\bar{\nu}$ for New Physics

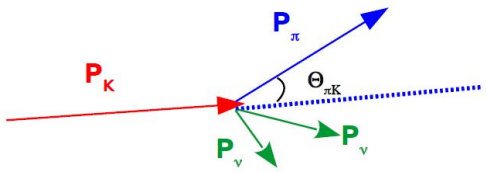
Measurements of $BR(K^+ \to \pi^+ \nu\bar{\nu})$ and $BR(K_L \to \pi^0 e^+ \nu)$ can reveal NP scenarios in many ways

- Custodial Randall-Sundrum
- Simplified Z,Z' models
- Littlest Higgs with T-parity
- Models with MFV

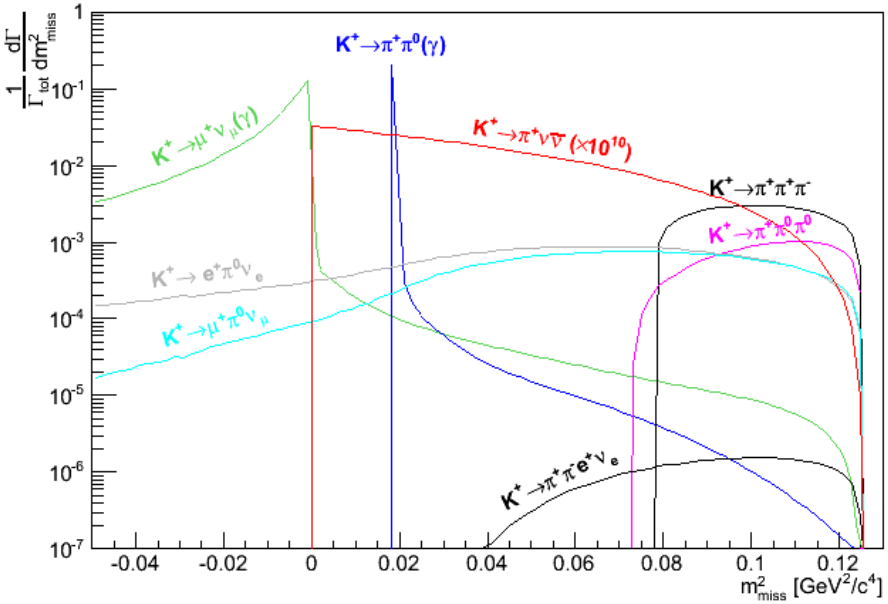


Strategy

- Decay in flight technique:
  $m^2_{miss} = (p_K - p_\pi)^2$

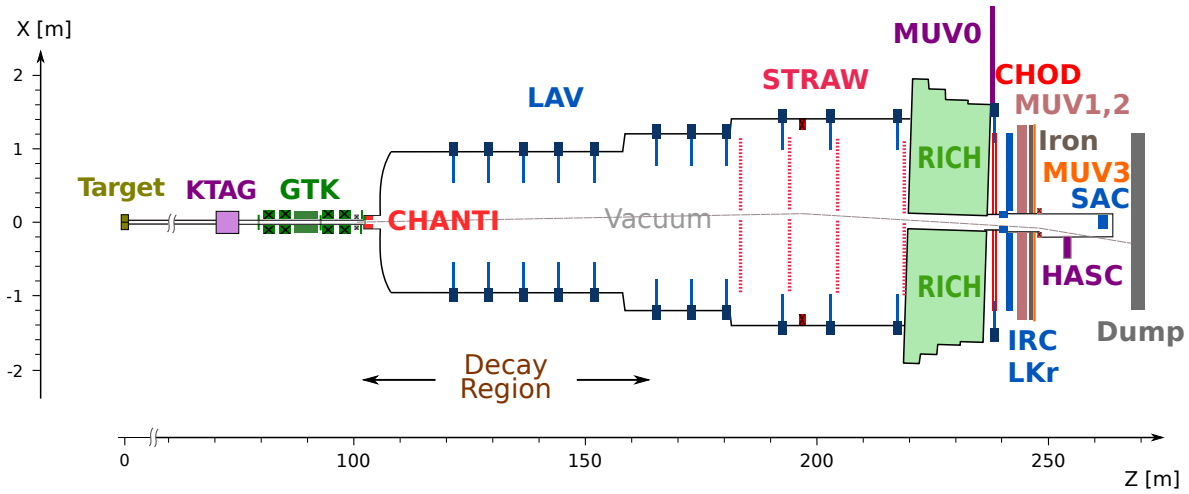


- Signal signature: 1 beam track and one charged track downstream
- Sources of background: main K^+ decay modes and beam activity
- 2 signal regions
- $15 < p_{\pi^+} < 35 GeV/c$



Process	Branching Ratio
$K^+ \to \mu^+ \nu_\mu$	63.56%
$K^+ \to \pi^+ \pi^0$	20.66%
$K^+ \to \pi^+ \pi^+ \pi^-$	5.58%

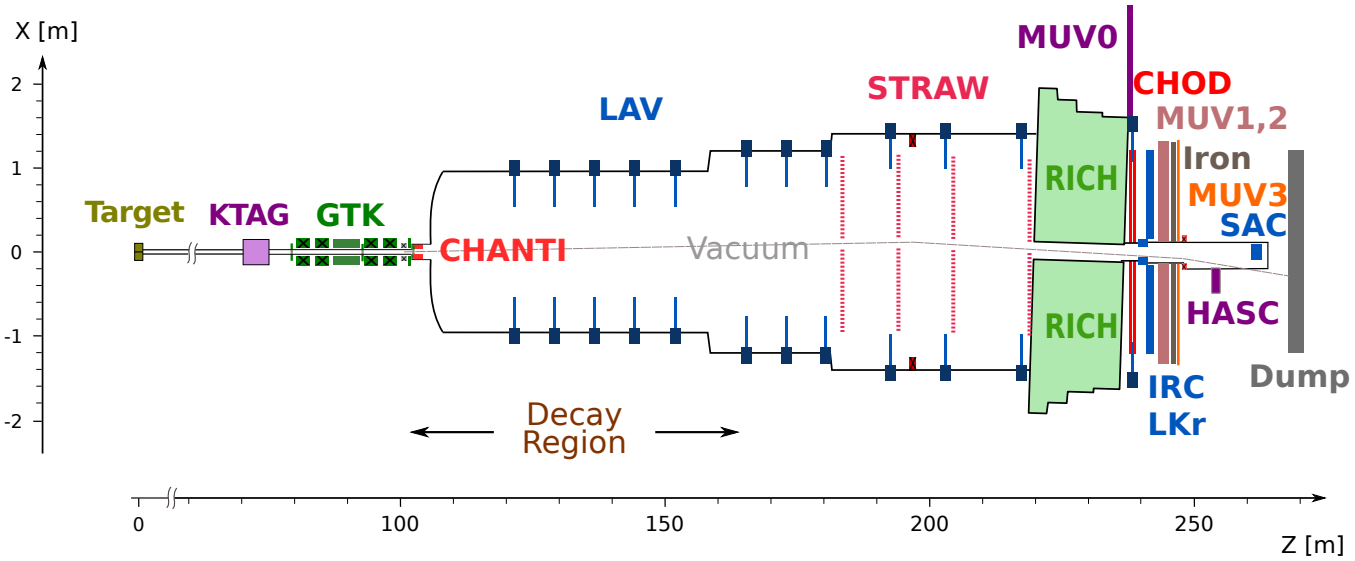
The NA62 detector



Requirements:

- $\sim$ 100ps timing between sub-detectors
- $> 10^7$ muon suppression
- $> 10^7 \pi^0$ suppression
- $\sim 10^4$ kinematic suppression of background

The NA62 detector



Primary Beam:

- 400 GeV/c protons
- 2×10^{12} p/spill
- 3.5 s spill

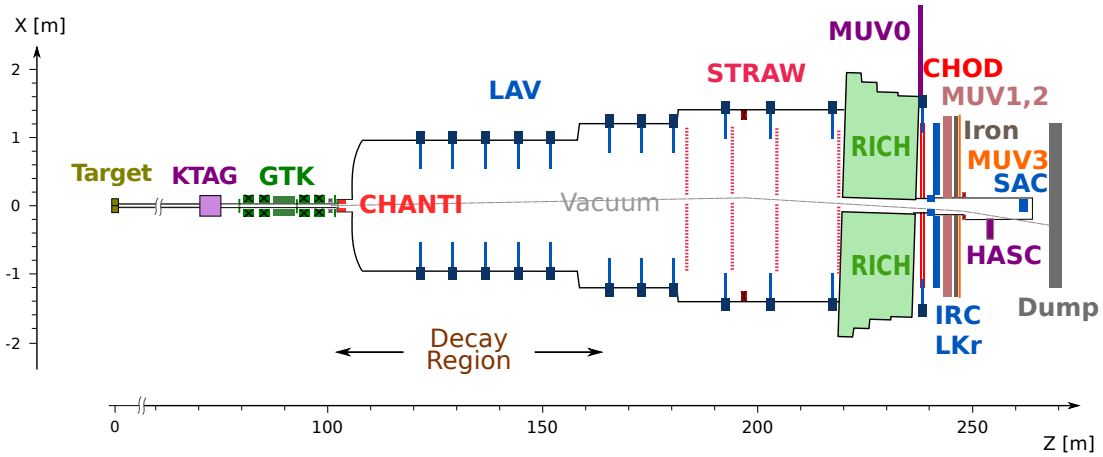
Secondary Beam

- 75GeV/c momentum
- $6\%K^+, 70\%\pi^+, 24\%p$

Decay region:

- 75m fiducial region
- $\sim$5 MHz decay rate
- Vaccuum $\sim 10^{-6}$ mbar

The NA62 detector



Upstream detectors:

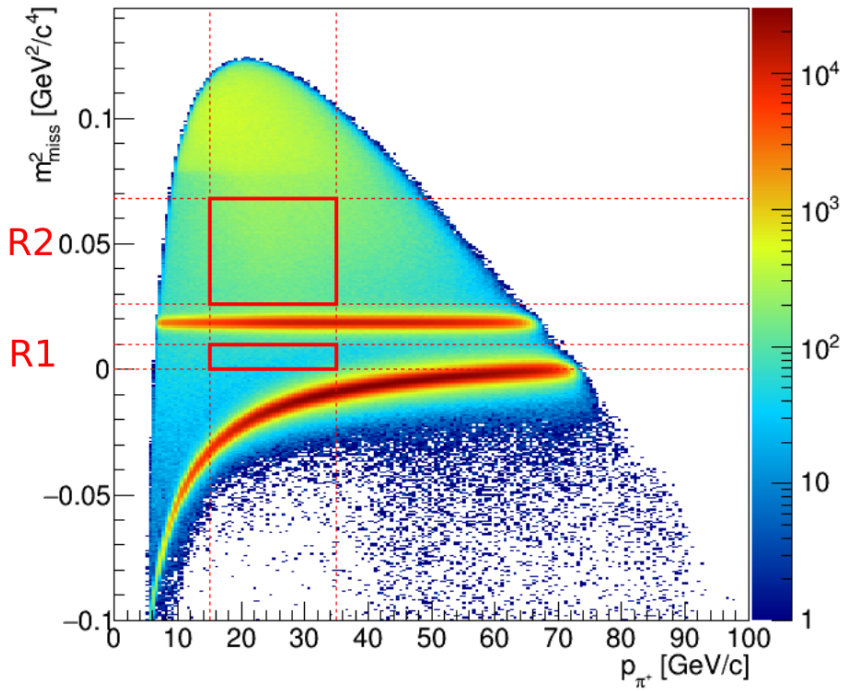
- KTAG: K^+ ID
- GTK: beam tracker
- CHANTI: Anti-counter for inelastic beam-gtk3 interactions

Downstream detectors:

- STRAW: momentum spectrometer
- CHOD: Scintillator hodoscopes
- LKr; MUV1,2: calorimeters
- RICH counter for π, μ, e ID
- LAV, SAC, IRC: Photon vetoes
- MUV3: muon veto

Analysis Strategy

- **Selection**:
  - 1 particle final state topology
  - π identification
  - multi-track rejection
  - photon rejection

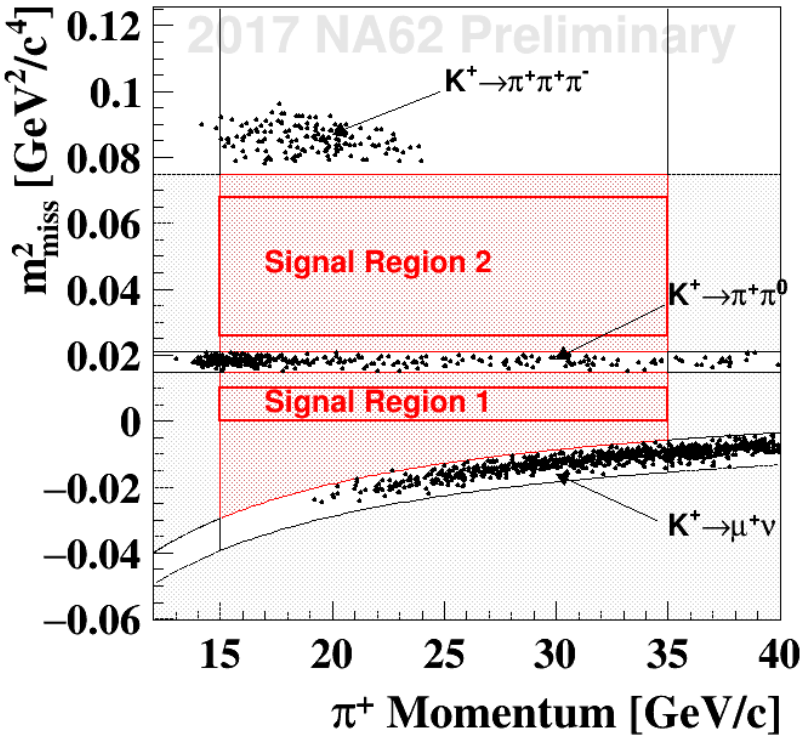


The 2017 dataset

Key features:

- $N_k \sim 10^{12}$, 10 times the 2016 data
- Single Event Sensitivity, $SES = (0.34 \pm 0.04) \times 10^{-10}$
- $N_{expected}(K \to \pi\nu\bar{\nu}) = 2.5 \pm 0.4$

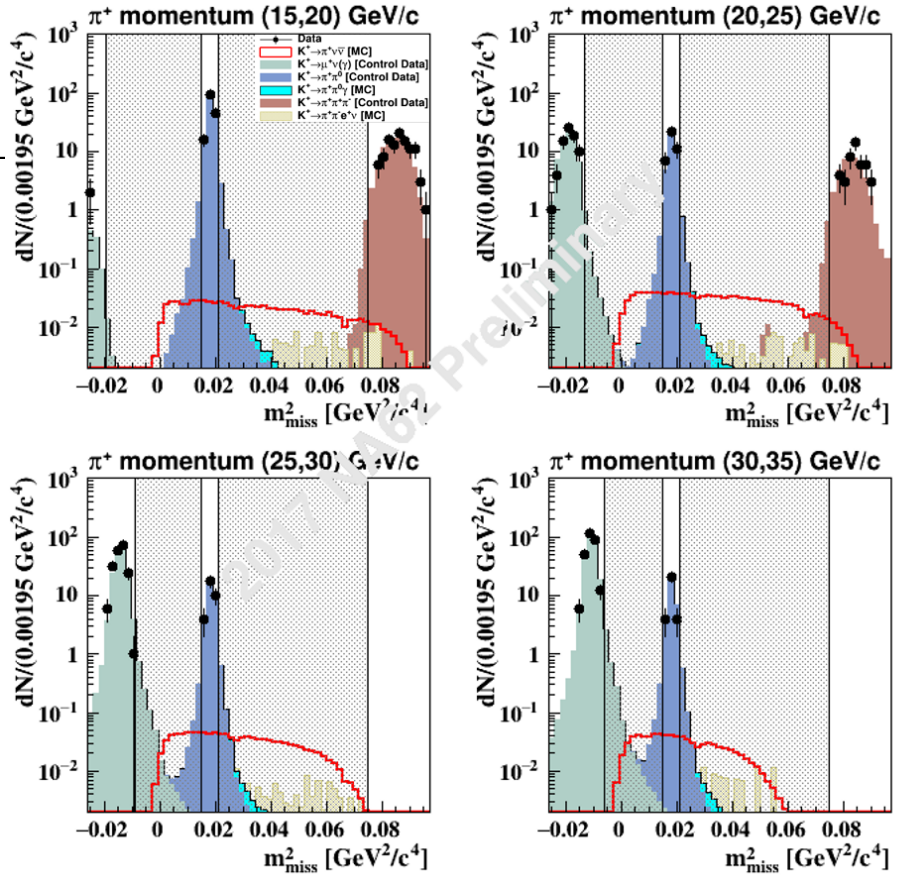
- Blind analysis: Signal and Control Regions blinded until completion of analysis
- 2016-like selection, but with improvements:
  - Better LKr reconstruction
  - Better pileup treatment
  - Improved π^0 rejection



Background studies

Process	Expected events
$K^+ \to \pi^+\pi^0(\gamma)IB$	$0.35 \pm 0.02_{stat} \pm 0.03_{syst}$
$K^+ \to \mu^+\nu(\gamma)IB$	$0.16 \pm 0.01_{stat} \pm 0.05_{syst}$
$K^+ \to \pi^+\pi^- e+\nu$	$0.22 \pm 0.08_{stat}$
$K^+ \to \pi^+\pi^+\pi^-$	$0.015 \pm 0.008_{stat} \pm 0.015_{syst}$
$K^+ \to \pi^+\gamma\gamma$	$0.005 \pm 0.005_{syst}$
$K^+ \to l^+\pi^0\nu_l$	$0.012 \pm 0.012_{syst}$
Upstream Bkg	On-going

- Shape changes with π^+ momentum

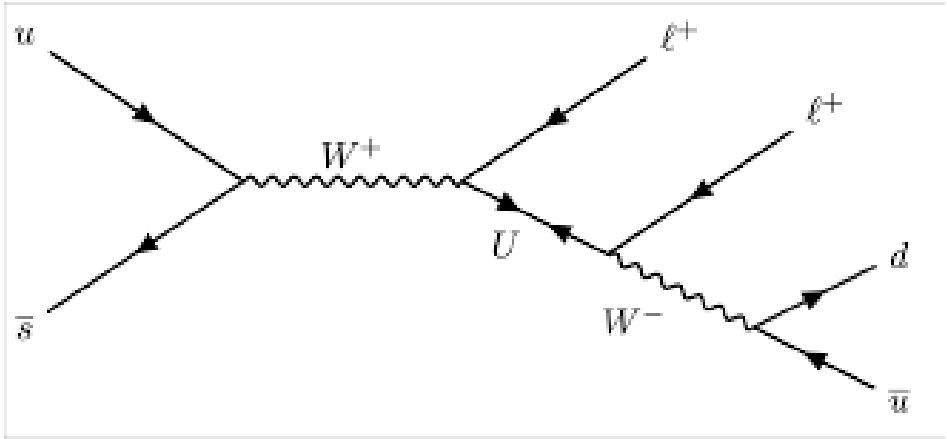


BSM physics program of NA62

- Rare kaon decays
- LNV/LFV in kaon decays [this talk]
- Exotic searches: [M. Mirra Talk]
  - HNL searches
  - Dark Photon
  - ALPs

LFV/LNV

- Conservation of lepton number is not a fundamental symmetry of the Standard model
- LNV,LFV predicted in BSM models
- $K^+ \to \pi^- l^+ l^+$ can happen via Majorana Neutrinos U:



LNV/LFV searches at NA62

- Dataset: 3 months of continuous data-taking in 2017
- Blind analysis strategy
- LNV modes measured wrt SM modes with opposite sign leptons
- Trigger description:

Trigger Name	Description	Use in LNV/LFV search
Di-Muon	3 tracks with 2 μ candidates (MUV3)	SM: $K^+ \to \pi^+\mu^+\mu^-$ & LNV: $K^+ \to \pi^-\mu^+\mu^+$
Multi-Track e	3 tracks with 20GeV energy deposit in LKr	SM: $K^+ \to \pi^+e^+e^-$ & LNV: $K^+ \to \pi^-e^+e^+$
Multi-Track	Minimum bias 3-track trigger	Control samples for bkg. studies

Previous Experiments:

$$BR(K^+ \to \pi^- e^+ e^+) < 6.4 \times 10^{-10} \ @\ 90\% CL$$

$$BR(K^+ \to \pi^- \mu^+ \mu^+) < 8.6 \times 10^{-11} \ @\ 90\% CL$$

SM for comparison

$$BR(K^+ \to \pi^+ e^+ e^-) = (3.00 \pm 0.09) \times 10^{-7}$$

$$BR(K^+ \to \pi^+ \mu^+ \mu^-) = (9.4 \pm 0.6) \times 10^{-8}$$

$K^+ \to \pi^- \mu^+ \mu^+$

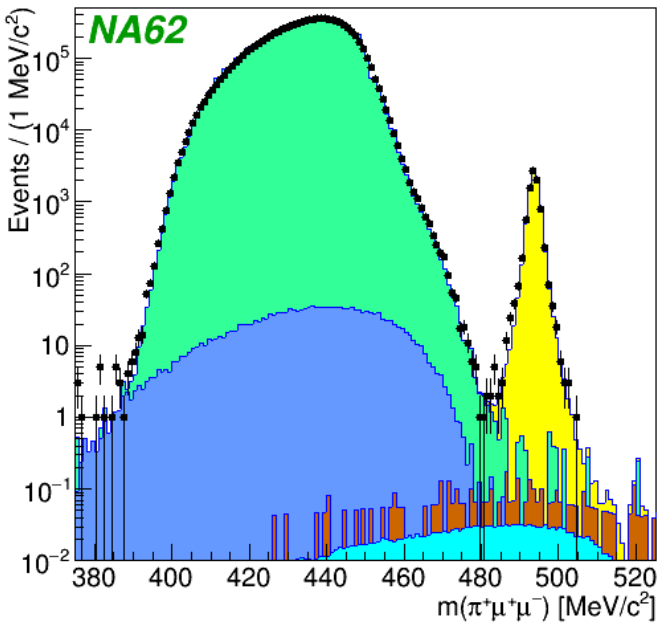
- Number of Kaon decays in sample: $N_K = (7.94 \pm 0.23) \times 10^{11}$
- Signal acceptance: 9.81%
- $SES = (1.28 \pm 0.04) \times 10^{-11}$
- Background:

Process	Expected bkg.
$K^+ \to \pi^+\pi^+\pi^-$	0.70 ± 0.40
$K^+ \to \pi^+\mu^+\mu^-$	0.08 ± 0.02
$K^+ \to \pi^+\pi^-\mu^+\nu$	0.05 ± 0.05
$K^+ \to \pi^+\pi^- e^+\nu$	0.07 ± 0.05
$K^+ \to \mu^+\nu\mu^+\mu^-$	0.01 ± 0.01
Total	0.91 ± 0.41

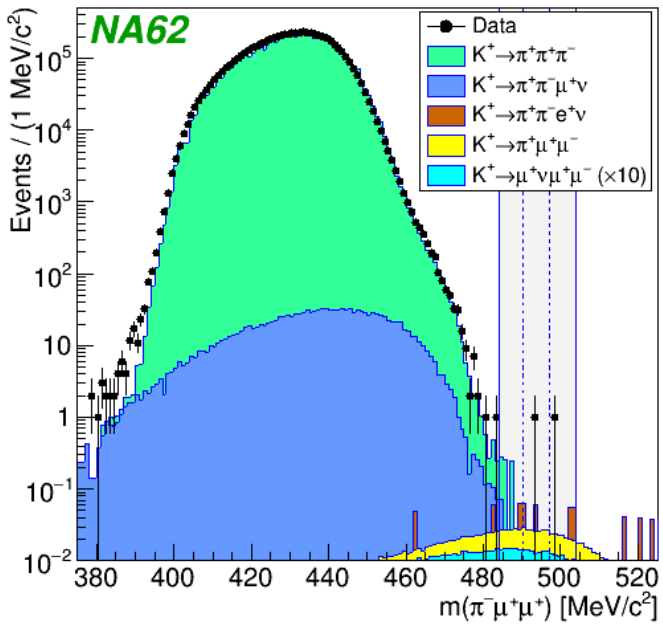
$K^+ \to \pi^- \mu^+ \mu^+$

- Expected bkg. in the blinded region: 0.91 ± 0.41
- One candidate observed in the signal region
- $BR(K^+ \to \pi^- \mu^+ \mu^+) < 4.2 \times 10^{-11}$ @ 90%CL

SM



LNV



- SM channel : $BR(K^+ \to \pi^+ \mu^+ \mu^-) = (9.4 \pm 0.6) \times 10^{-8}$

$K^+ \to \pi^- e^+ e^+$

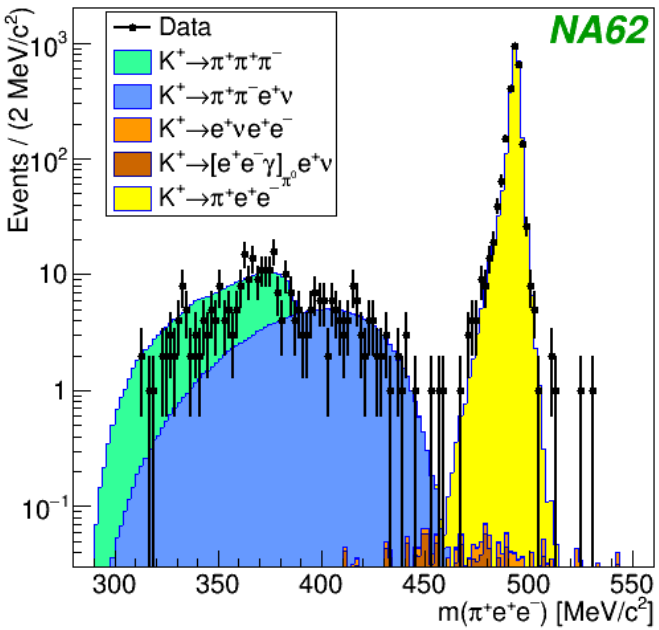
- Number of Kaon decays in sample: $N_K = (2.14 \pm 0.07) \times 10^{11}$
- Signal acceptance: 4.98%
- $SES = (0.94 \pm 0.03) \times 10^{-10}$
- Background:

Process	Expected bkg.
$K^+ \to e^+ \nu e^+ e^-$	0.12 ± 0.02
$K^+ \to (e^+ e^- \gamma)_{\pi^0} e^+ \nu$	0.04 ± 0.01
Total	0.16 ± 0.03

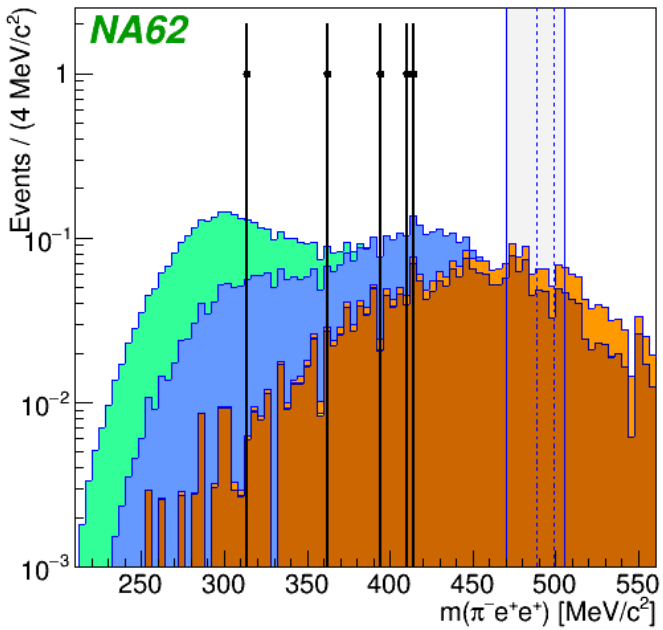
$K^+ \to \pi^- e^+ e^+$

- Expected bkg. in the blinded region: 0.16 ± 0.03
- No candidate in signal region
- $BR(K^+ \to \pi^- e^+ e^+) < 1.1 \times 10^{-10}$ @ 90% CL

SM



LNV



- SM channel : $BR(K^+ \to \pi^+ e^+ e^-) = (3.00 \pm 0.09) \times 10^{-7}$

Summary and prospects

- $K^+ \to \pi\nu\nu$ update on analysis of the 2017 dataset
  - Nb. of Kaon decays: $N_K = (1.3 \pm 0.1) \times 10^{12}$
  - $SES = (3.4 \pm 0.4) \times 10^{-11}$
  - Expected signal: 2.5 ± 0.4 SM events
  - Total bkg. (Upstream not included): 0.76 ± 0.10
  - Final result on 2017 expected later this year

- LFV/LNV [**PLB 797 134794 (2019)**]
  - $BR(K^+ \to \pi^- \mu^+ \mu^+) < 4.2 \times 10^{-11}$ @ 90%CL
  - $BR(K^+ \to \pi^- e^+ e^+) < 1.1 \times 10^{-10}$ @ 90% CL

  Factor 2-3 improvement over previous results! [BNL-E865, NA48/2]

Thank you for your attention!