Heavy Neutral Lepton Search at NA62

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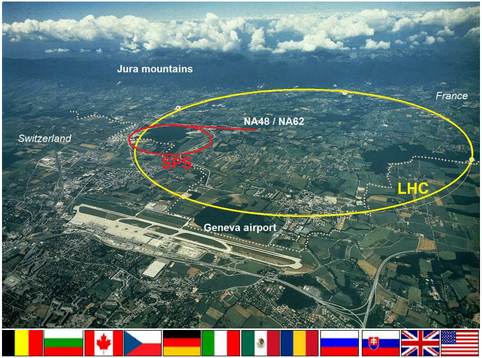
Outline

Kaon Experiments at CERN

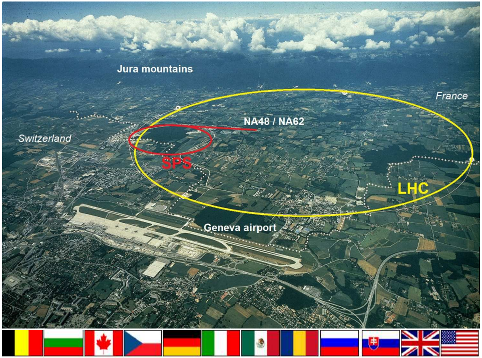


NA62: ~ 200 participants, ~ 30 institutes

- **NA48** (1997-2001): Beam of K_L/K_S
  - Discovery of direct CPV
- **NA48/1** (2002): Beam of K_s/hyperons
- **NA48/2** (2003-2004): Beam of K^+/K^-
  - $K^\pm \to \mu^\pm N, N \to \mu\pi$
- **NA62-R_k** (2007-2008): Beam of K^+/K^-
  - $K^+ \to \mu^+ N$
- **NA62** (Since 2014): Beam of K^+
  2014: pilot run
  2015: Commissioning run
  - $K^+ \to \ell^+ N$

  2016-2018 $K^+ \to \pi^+ \nu \bar{\nu}$

Kaon Experiments at CERN



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Why looking for heavy neutrinos

- Open Theoretical questions:
  1. Neutrino oscillations $\rightarrow$ non-zero neutrino masses
  2. Why neutrinos are lighter than other leptons
  3. Dark Matter $\rightarrow$ no SM particle satisfies DM properties
  4. Baryon asymmetry
  5. ...
- SM extentions: **Neutrino Minimal SM (*νMSM*)** (*Asaka et al., PLB 620 (2005) 17*)
  - 3 right-handed steril neutrinos N_i are added to SM, $m_1 \sim 10$ keV, $m_{2,3} \sim 1$ GeV,
  - N_1 is a Dark Matter candidate
  - $N_{2,3}$ introduce extra CPV phases to account for Baryon Assymmetry and are responsible for SM neutrino masses (see-saw mechanism)

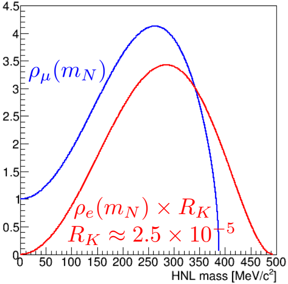
HNL observable via production

If $m_N < M_{K^\pm} - m_{\ell^\pm}$, heavy neutrinos are observable via **production** in K leptonic decay processes ($K^\pm \to \ell^\pm N$)

$$\Gamma(K^\pm \to \ell^\pm N) = \Gamma(K^\pm \to \ell^\pm \nu_\ell)\rho(m_N)|U_{\ell 4}|^2$$

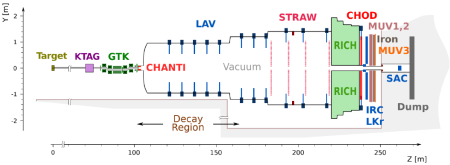
Where:

- $\rho(m_N) \to$ Kinematic factor, phase space and helicity suppression
- $|U_{\ell 4}|^2 \to$ Mixing matrix element



R. Shrock PLB96 (1980) 159

NA62: Beam and Detector



NA62 collaboration, JINST 12 (2017) P05025

Main subdetectors

- Trackers: Si pixel beam tracker(GTK), Straw tubes spectrometer (STRAW)
- Hermetic veto detectors:
  - Photon vetoes: LAV,LKr, IRC, SAC
  - Muon vetoes: MUV
- Particle identification:
  - Beam (kaons): KTAG
  - $\pi/\mu/e$: RICH, LKr, MUV

Main goal

- 10% precision measurement of $BR(K^+ \rightarrow \pi^+\nu\bar{\nu})$ see “J.Engelfried talk”

Beam Parameters

- Beam momentum: 75 $GeV/c(\pm 1\%)$
- Positive Beam: $\sim 6\% K^+$
- nominal intensity 750 MHz

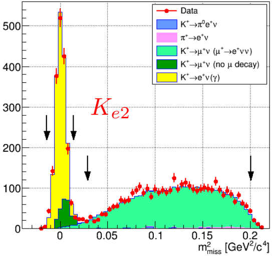
Data taking conditions for 2015

- Minimun bias data: taken at 1% of nominal beam intensity
- Beam tracker not available: kaon momentum estimated as beam average

$K^+ \to \ell^+ N$: selection criteria

Event selection: $K^+ \to e^+ N$ $\quad K^+ \to \mu^+ N$

- single positive charged track in the spectrometer
- KTAG kaon signal
- no activity in photon-vetoes and CHANTI
- decay vertex in the fiducial decay region
- single cluster in LKr, no signal in muon detectors (e^+)
- signal in muon detectors (μ^+)
- E/p and RICH (p<40 GeV/c) to differentiate e^+ from μ^+



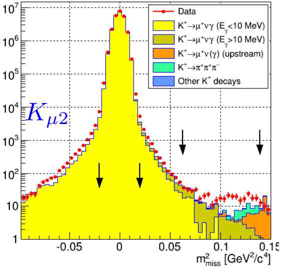
HNL production signal: peaks in $m^2_{miss} = (P_{K^+} - P_{\ell^+})^2$ distributions

SM signal regions:

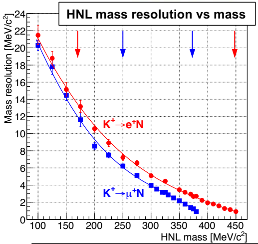
- e^+: $|m^2_{miss}| < 0.014 GeV^2/c^4$
- μ^+: $|m^2_{miss}| < 0.020 GeV^2/c^4$

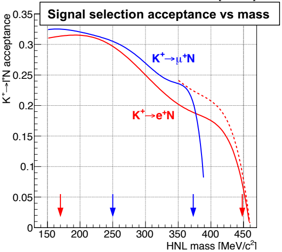
HNL signal regions:

- e^+: $170 < m_{miss} < 448 MeV/c^2$ $(0.029 < |m^2_{miss}| < 0.2 GeV^2/c^4)$
- μ^+: $250 < m_{miss} < 373 MeV/c^2$ $(0.062 < |m^2_{miss}| < 0.14 GeV^2/c^4)$



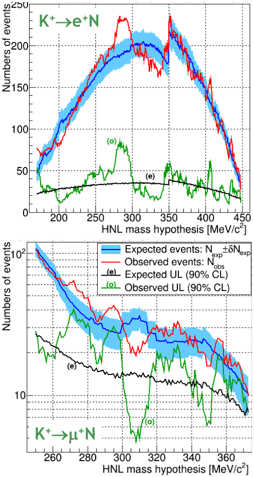
$K^+ \to \ell^+ N$: measurement principle





- $K^+ \to \ell^+ N$ decay rates measured with respect to the normalization SM $K^+ \to \ell^+ \nu$
    - similar topologies and known branching fractions
- HNL signal events N^ℓ_{sig} given by $BR(K^+ \to \ell^+ N)$ assumptions and A^ℓ_N acceptances of the $K^+ \to \ell^+ N$ selections
    - $N^\ell_{sig} = N^\ell_K \cdot BR(K^+ \to \ell^+ N) \cdot A^\ell_N$
- HNL search strategy: scan of $m_{miss} = \sqrt{(P_K - P_{\ell^+})^2}$ distributions
    - $1 MeV/c^2$ step for mass scans in the HNL signal regions
    - search window size for each HNL mass hypothesis given by HNL mass resolution: $|m - m_N| < 1.5\sigma_m$
    - statistical analysis
- HNL detailed MC simulation
    - HNL mass resolution σ_m vs HNL mass
    - selection acceptance vs HNL mass

$K^+ \to \ell^+ N$ search results: limits



Single event sensitivities of $O(10^{-8})$

- $N_{obs} \to$ Number of observed events in each HN mass hypothesis evaluated within $\pm 1.5\sigma_m$, with $1 MeV/c^2$ mass scan step signal window
- $N_{exp} \to$ number of expected Background, evaluated using data for each HNL mass hypothesis with m_{miss} distribution sidebands using polynomial fitting

Statistical significance never exceeds 2.2σ:

$\to$ **No HNL signal observed**

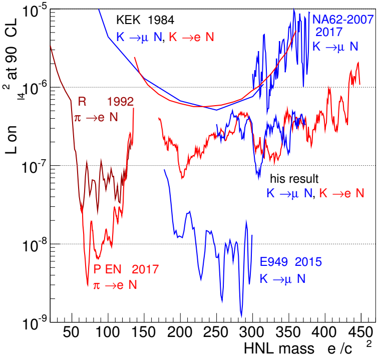
N_{obs}, N_{exp} and δN_{exp} converted into confidence levels assuming Poissonian/Gaussian distributions for both distributions using Rolke-Lopez method to compute **90% CL**

$K^+ \to \ell^+ N$ search results: limits on $|U_{\ell 4}|$

$K^+ \to e^+ N$ NA62-2015

Limit improved in a large mass range at the level of 10^{-7}

- $K^+ \to \mu^+ N$ $250 \leq m_N \leq 373\ Mev/c^2$
- $K^+ \to e^+ N$ $170 \leq m_N \leq 448\ Mev/c^2$



NA62 Collaboration, Phys.Lett.B778 (2018) 137

HNL prospects with total data sample

2016 - 2018 data set

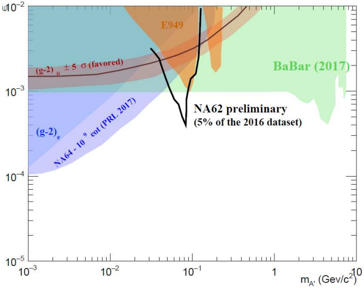
- Beam Tracker (GTK) in operation
  - Factor ~ 2 improvement in mass resolution
  - Factor ~ 3 lower background in $K^+ \to e^+ N$
  - Lower background from upstream decays in $K^+ \to \mu^+ N$
- Larger data set

Sensitivity better than 10^{-8} for $|U_{\mu 4}|^2$ and $|U_{e4}|^2$

Larger data sets already collected. Analysis in progress

Beyond-Standard Model Particles

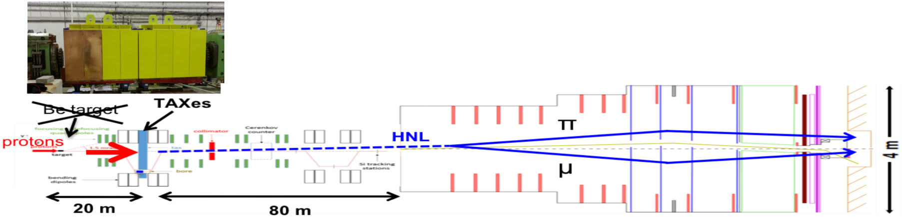
- Dark Photon
  - Multiple limits assuming decays into SM particles, including $K^{\pm} \to \pi^{\pm}\pi^{0}$, $\pi^{0} \to \gamma A'$, $A' \to e^{+}e^{-}$ from NA48/2 *Phys.Lett. B746 (2015) 178*
  - NA62: search for $K^{+} \to \pi^{+}\pi^{0}$, $\pi^{0} \to \gamma A'$, $A' \to invisible$



- Forbidden K^{+} decay searches

  Goal: Improve over most existing limits
  - Search for the LNV decay $K^{+} \to \pi^{-}\mu^{+}\mu^{+}$
  - Search for the LNV decay $K^{+} \to \pi^{-}e^{+}e^{+}$
  - Search for the LNV/LFV decay $K^{+} \to \pi e \mu$, including $\pi^{+}\pi^{0}$ with $\pi^{0} \to \mu e$
  - Searches for $K^{+} \to \mu^{-}\nu e^{+}e^{+}$ and $K^{+} \to e^{-}\nu\mu^{+}\mu^{+}$
  - searches for $\Delta S = \Delta Q$ violating decays $K^{+} \to \pi^{+}\pi^{+}e^{-}\nu$ and $K^{+} \to \pi^{+}\pi^{+}\mu^{-}\nu$

NA62 dump mode operation



- TAXes (2 collimators): sliding copper and iron collimators, $2 \times 10.7\lambda_I$ thick, higher Z than Be target, closer to the decay region → DUMP
- Easy to switch between K^+ beam and proton dump mode with TAXes
- Short dedicated runs in dump-mode with special low-bandwidth triggers
- Preliminary studies of background, rates and topologies have been performed: rejection power down to zero bkg at $\sim 4 \times 10^{15}$ POT for fully reconstructed di-muon final states
- **HNL** and Axion-like particles

Summary

- NA62 searches for HNL production in K^+ decays were presented:

  No heavy neutrino signal observed

  NA62 Collaboration, Phys.Lett.B778 (2018) 137

  - $N_K \sim 4 \times 10^8$ kaon decays in the fiducial volume
  - Set limits on $|U_{l4}|^2$

- NA62 physics run in progress up to 2018: a large sample of K^+ data in being collected

  - Main goal of measuring $BR(K^+ \to \pi^+ \nu \bar{\nu})$ with 10% accuracy
  - Broad program of rare decay measurements, hidden sector particles and LF/LN violation