Heavy neutral lepton (HNL) production searches at NA62

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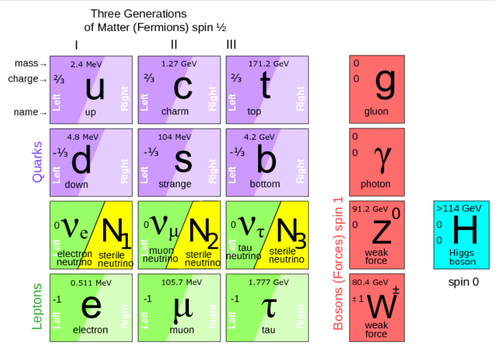
Neutrino Minimal Standard Model

- SM extension accounting for baryon asymmetry of universe (BAU), dark matter (DM), neutrino masses and oscillations
- 3 additional right-handed, singlet, Majorana HNLs (not observed yet)
- N_1 mass O(10 keV/c^2), good DM candidate
- $N_{2,3}$ mass O(1 GeV/c) [2]
- B($K^+ \to 1^+N$) depends on $B_{SM}(K^+ \to 1^+\nu)$, HNL-lepton coupling U^2_{14}, and kinematic factor [2]



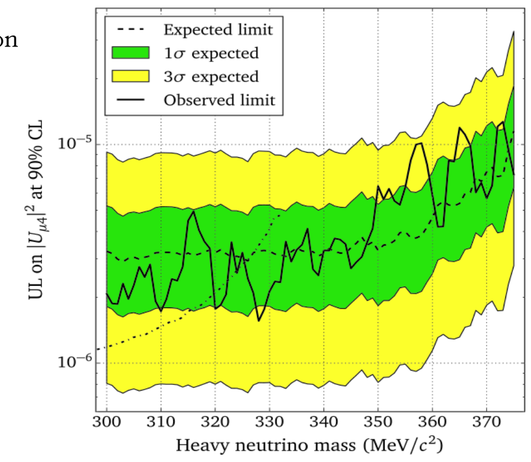
νMSM particle zoology

$$\begin{pmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\end{pmatrix} = \begin{pmatrix}U_{e1} & U_{e2} & U_{e3}\\ U_{\mu1} & U_{\mu2} & U_{\mu3}\\ U_{\tau1} & U_{\tau2} & U_{\tau3}\end{pmatrix}\begin{pmatrix}\nu_1\\ \nu_2\\ \nu_3\end{pmatrix}$$

PMNS mixing matrix between HNL flavour and mass eigenstates

Previous measurements

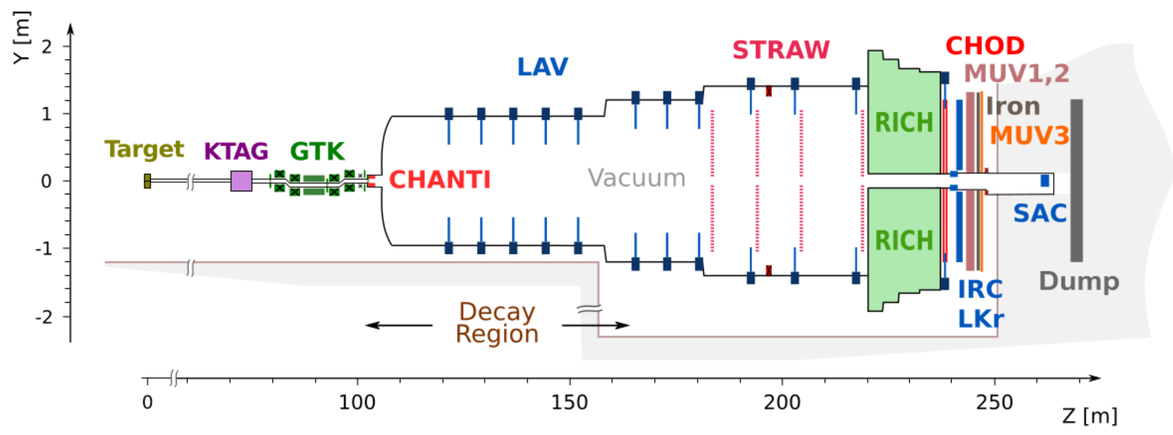
- Production searches:
  - Look for peaks in missing mass distribution
  - Decay-model independent
  - Sensitive to long-lived HNLs
- Previous measurements in $K^+ \to \mu^+N$
- 90% CL upper limits (UL) on HNL-muon coupling U^2_μ:
  - KEK E089 (1982) [3]: (10^{-6}, 10^{-4}) for m_N in (70, 300) MeV/c^2
  - BNL E949 (2015) [4]: (10^{-9}, 10^{-7}) for m_N in (175, 300) MeV/c^2
  - NA62 (2017) [5]: ($2\cdot10^{-6}$, 10^{-5}) for m_N in (300, 375) MeV/c^2



Expected and observed UL (at 90% CL) from NA62 2007 data-taking [4]

HNL production searches at NA62

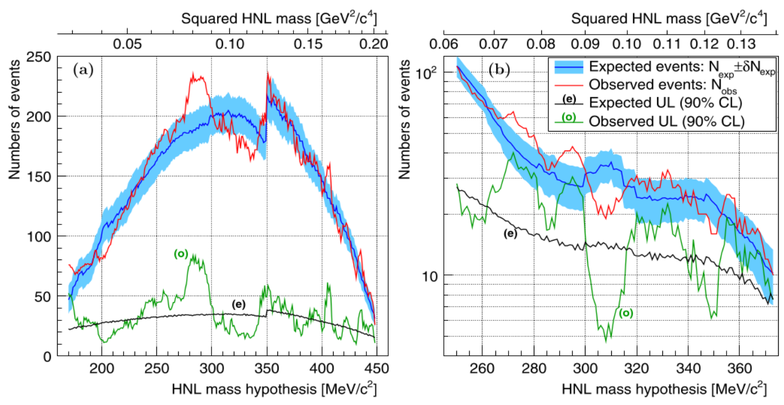
- Fixed-target experiment at CERN SPS:
  - SPS 400 GeV/c p beam onto Be target → 75 GeV/c K^+
  - In-flight K^+ decays in 60 m long fiducial volume (FV)
  - Data taking (2015-2018) with possibility to extend beyond 2021
  - Measure B($K^+ \to \pi^+\nu\bar{\nu}$) with 20% precision to study CKM matrix element V_{td}
  - Perform hidden sector searches in presence of K^+ beam (axions, dark photons, HNLs)
- Minimum bias run (2015) [1]:
  - Data collected during $1.2\cdot10^4$ SPS spills (about 3 s effective spill)
  - 0.4% - 1.3% of nominal beam intensity ($3.3\cdot10^{12}$ protons on target per spill)
- HNL production searches in kaon decays [1]:
  - Kaons tagged with upstream Cherenkov detector (70 ps time resolution)
  - Lepton tracks reconstructed in downstream spectrometer (130 μm spatial resolution)
  - Particle ID with downstream Cherenkov detector, spectrometer and calorimeters



NA62 schematic layout. HNL signal topology is visible

Event selection

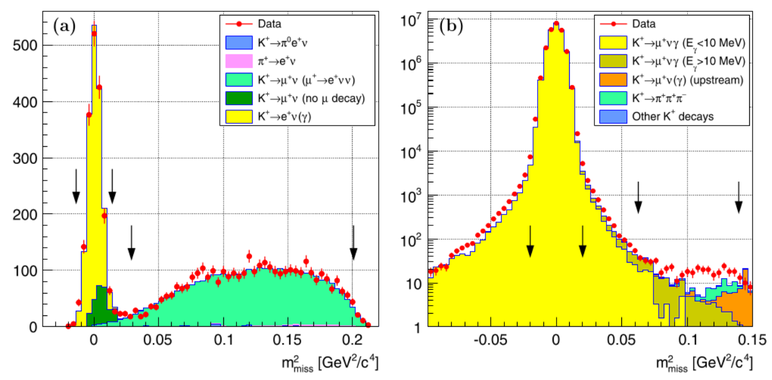
- One positive track with momentum in (5, 70) GeV/c, in time with kaon
- No extra activity in photon veto systems
- Positrons and muons identified through energy-momentum ratio [1]



Expected and observed number of events: $K^+ \to e^+N$ (left) and $K^+ \to \mu^+N$ (right) [2]

Data-MonteCarlo comparison

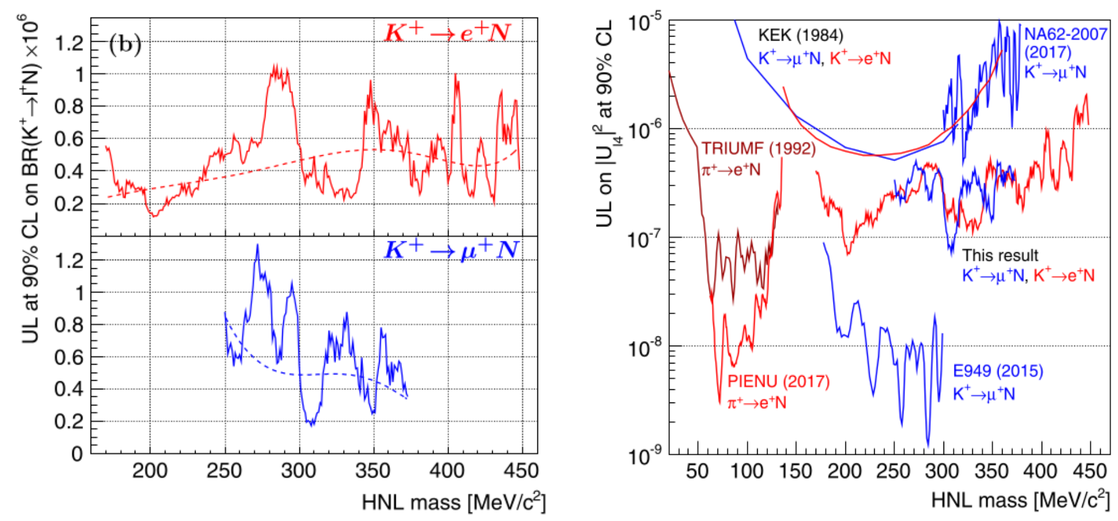
- Squared missing mass: $m^2_{miss} = (P_K - P_1)^2$ (SM $K^+ \to 1^+\nu$ peak at $m^2_{miss} = 0$)
- HNL signal regions:
  - $170 < m_{miss} < 448$ MeV/c^2 for $K^+ \to e^+N$ and $250 < m_{miss} < 373$ MeV/c^2 for $K^+ \to \mu^+N$ [1]



Squared missing mass distributions for data and simulated events passing the e^+ (left) and μ^+ (right) selections [2]

Technique, results and future prospects

- Mass scans performed in HNL signal regions with step size of 1 MeV/c^2
- For each HNL mass hypothesis, background evaluated from sidebands of data m_{miss} distribution
- No statistically significant HNL production signal observed
- UL on B($K^+ \to 1^+N$) established for each HNL mass hypothesis
- UL on coupling computed from UL on BR
- UL on $|U^2_e|$ in (10^{-7}, 10^{-6}) for m_N in (170, 448) MeV/c^2 and on $|U^2_\mu|$ in (10^{-7}, 10^{-6}) for m_N in (250, 373) MeV/c^2 [1]
- Results improve world existing limits on HNL production searches on $|U^2_e|$ (over whole mass range) and on $|U^2_\mu|$ (for masses above 300 MeV/c^2)
- 2016-2018 data collected by NA62 much larger than 2015 sample
- Opportunity to further improve existing limits on $|U^2_e|$ and $|U^2_\mu|$



Squared missing mass distributions for data and simulated events passing the e^+ (left) and μ^+ (right) selections [2]

[2] JHEP0710:015 (2007) [3] Physical Review D 91, 052001 (2015) [4] Physical Review Letters 49, 18 (1982)
[5] Physics Letters B 772, 712—718 (2017)

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