



# Search for heavy neutral lepton production at the NA62 experiment

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# Heavy neutral leptons (HNLs)

HNLs are included in several extensions of the SM

Generic possibility of  $k$  sterile neutrinos mass states:

$$\nu_\alpha = \sum_{i=1}^{3+k} U_{\alpha i} \nu_i \quad (\alpha = e, \mu, \tau)$$

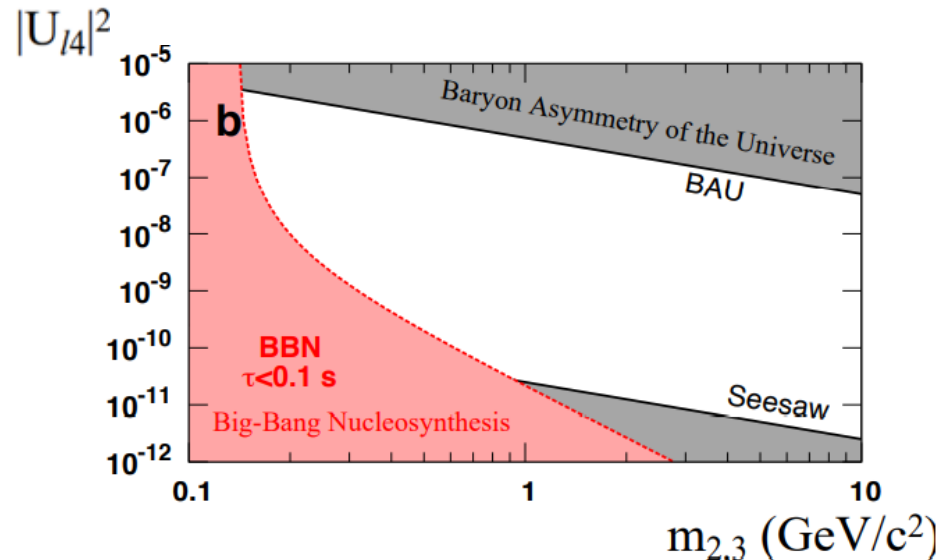
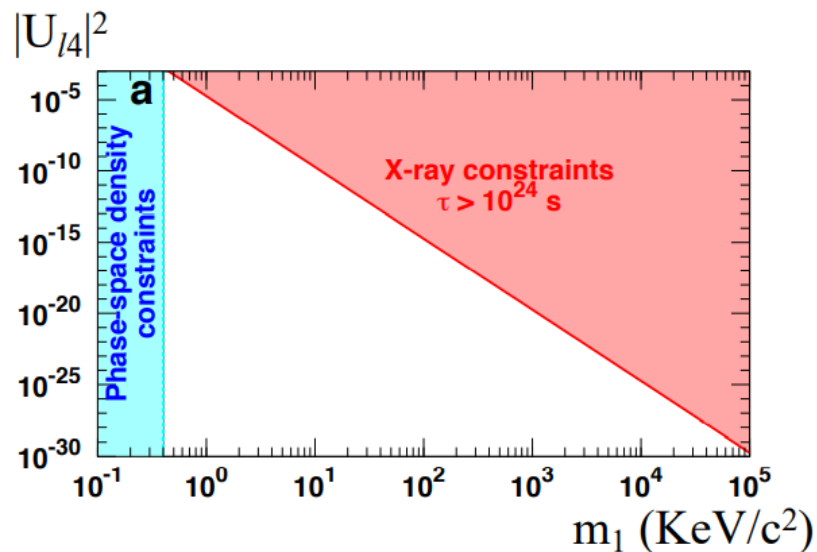
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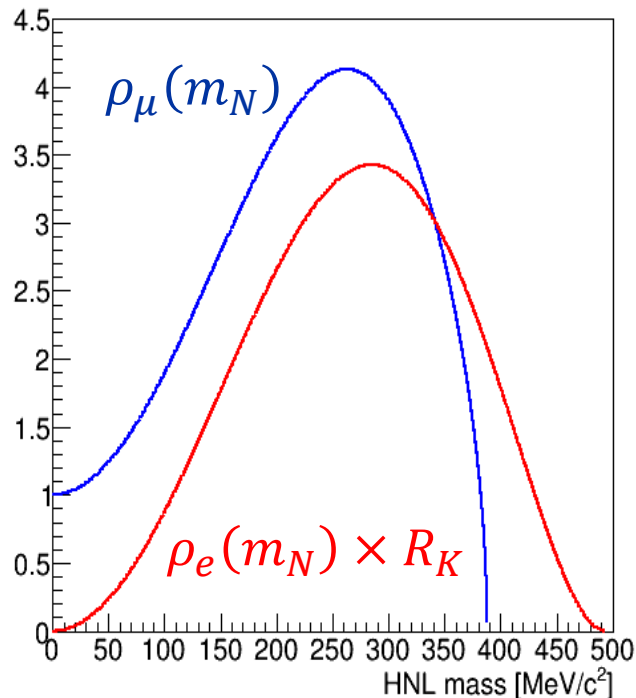
Three HNLs:  $m_1 \sim 10 \text{ keV}/c^2$  (DM candidate),  $m_{2,3} \sim 1 \text{ GeV}/c^2$

Astrophysical and cosmological constraints on  $m_k$



# HNL production in K decays

Master formula:  $BR(P^+ \rightarrow l^+ N) = BR(P^+ \rightarrow l^+ \nu) \times \rho_l(m_N) \times |U_{l4}|^2$



$$R_K = \Gamma(K^+ \rightarrow e^+ \nu) / \Gamma(K^+ \rightarrow \mu^+ \nu) \sim 2.5 \times 10^{-5}$$

$$\underbrace{\rho_l(m_N)}_{O(1)} = \frac{[(x+y) - (x-y)^2]}{[x(1-x)^2]} \times \sqrt{\lambda(1, x, y)}$$

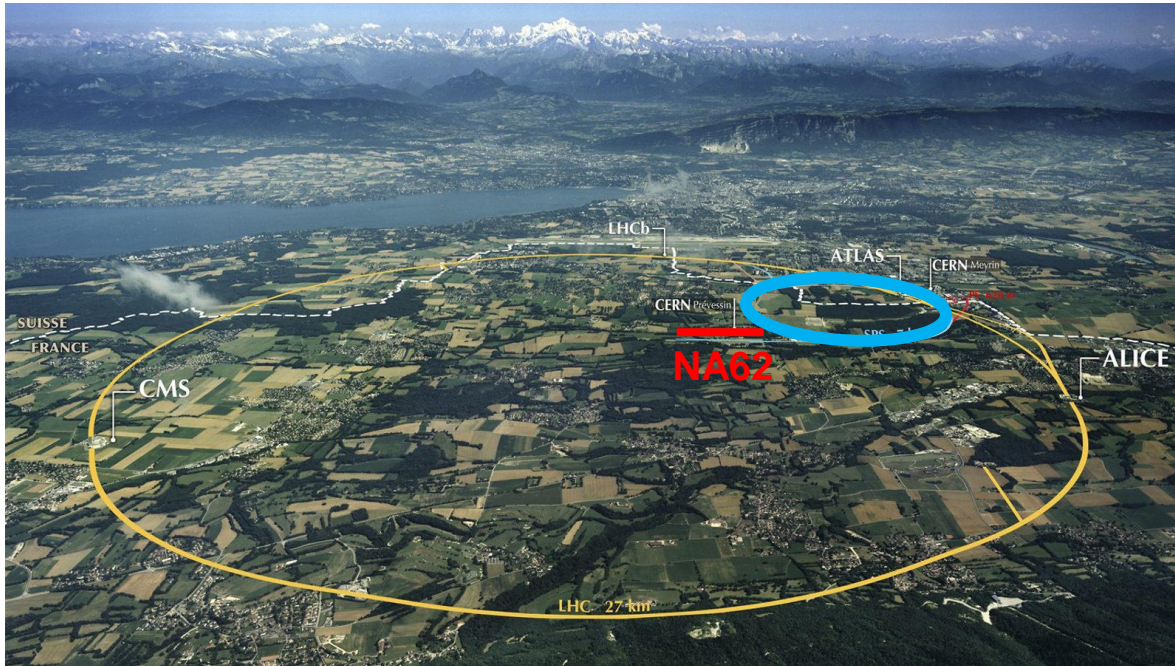
$x = (m_l/m_p)^2, y = (m_N/m_p)^2, \lambda(a, b, c) = a^2 + b^2 + c^2 - 2(ab + bc + ac)$

$K^+ \rightarrow l^+ N$  decays:

- HNL production is enhanced kinematically wrt SM decays (except near kinematic endpoints)
- Helicity suppression relaxed in the  $K \rightarrow eN$  case: factor  $O(10^5)$  enhancement

# The NA62 experiment at CERN

- Fixed target experiment
- Kaon decays in flight
- **Main goal:** measurement of  $\text{BR}(K^+ \rightarrow \pi^+ \nu \bar{\nu})$  at 10% precision level



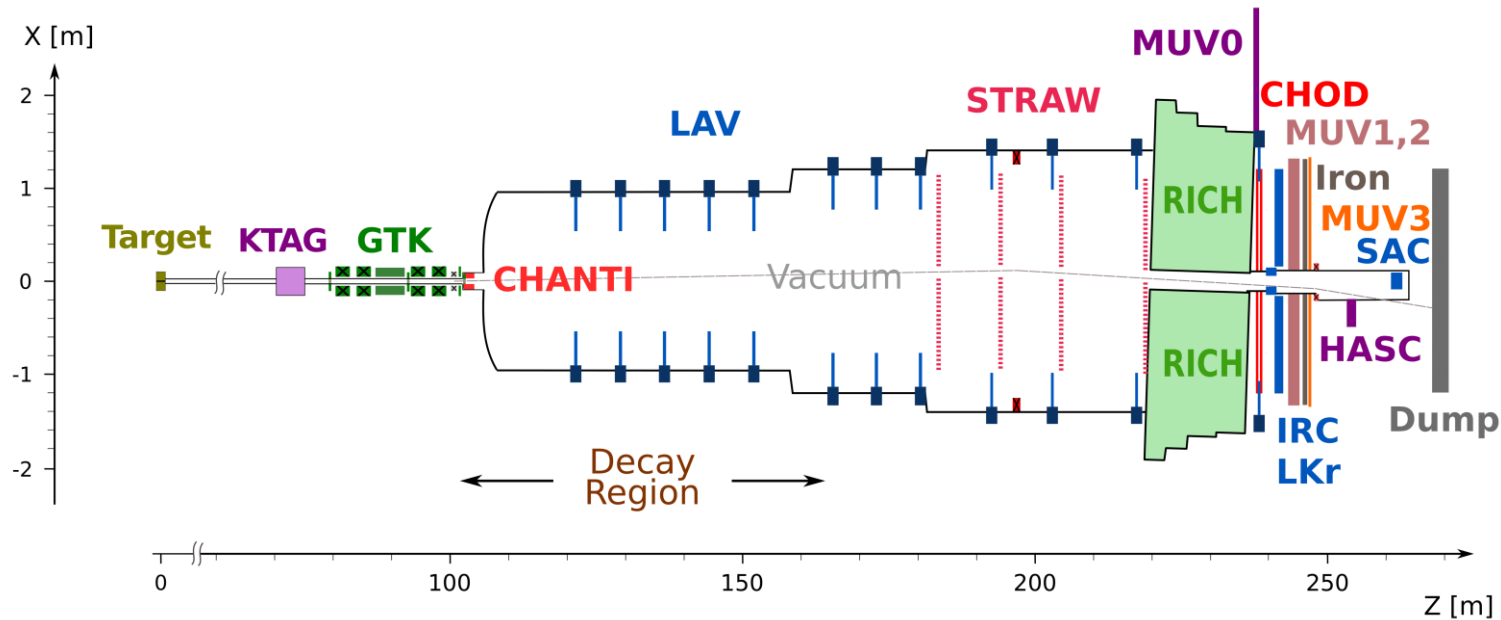
Primary beam of protons from SPS (400 GeV)

Secondary beam of hadrons (75 GeV/c, 800 MHz)

- Pions (70%)
- Protons (23%)
- Kaons (6%)
- Muons (0.7%)

$2.2 \times 10^{18} POT$  collected in Run1 (2016-2018), data taking will restart in 2021

# NA62 schematic layout



## Keystones:

- $O(100 \text{ ps})$  timing between sub-detectors
- $O(10^4)$  kinematic background rejection
- $> 10^7$  muon suppression
- $> 10^7 \pi^0$  suppression

# $K^+ \rightarrow l^+ N$ : signal selection

Two different trigger streams:  $K_{\pi\nu\nu}$  for  $e^+$  mode, minimum bias (downscaled by 400) for  $\mu^+$  mode

Selection steps:

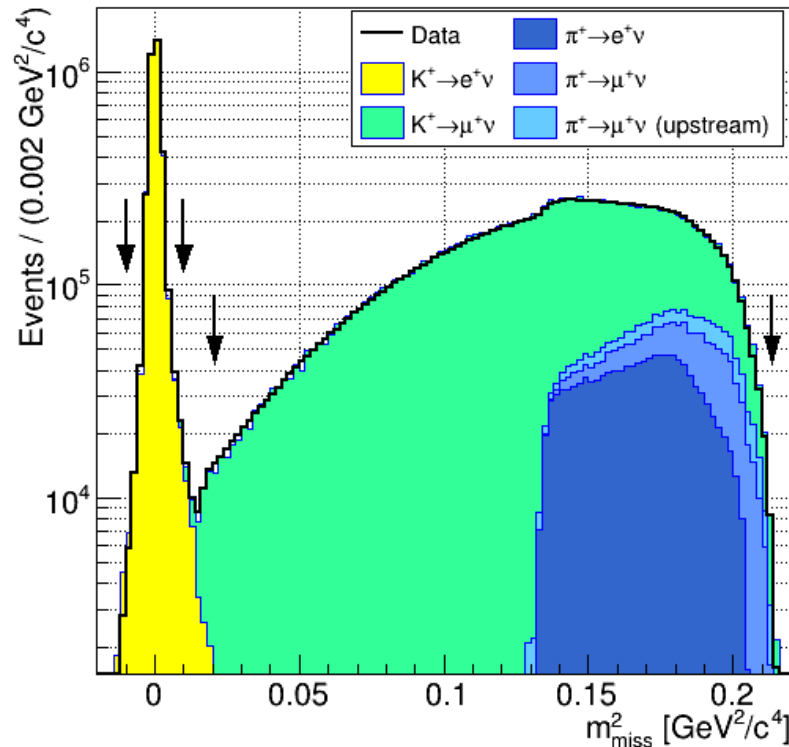
- Good downstream track reconstructed by the STRAW spectrometer,
- Lepton momentum requirements:  $5 < p_e < 30 \text{ GeV}/c$ ,  $5 < p_\mu < 70 \text{ GeV}/c$
- Track in acceptance of LKr and MUV3
- Upstream track identified by KTAG and GTK matched with the downstream lepton
- Lepton PID using RICH and MUV3 ( $\mu^+$  mode only)

# $K^+ \rightarrow l^+ N$ : final samples

$$m_{miss}^2 = (P_K - P_l)^\alpha (P_K - P_l)_\alpha$$

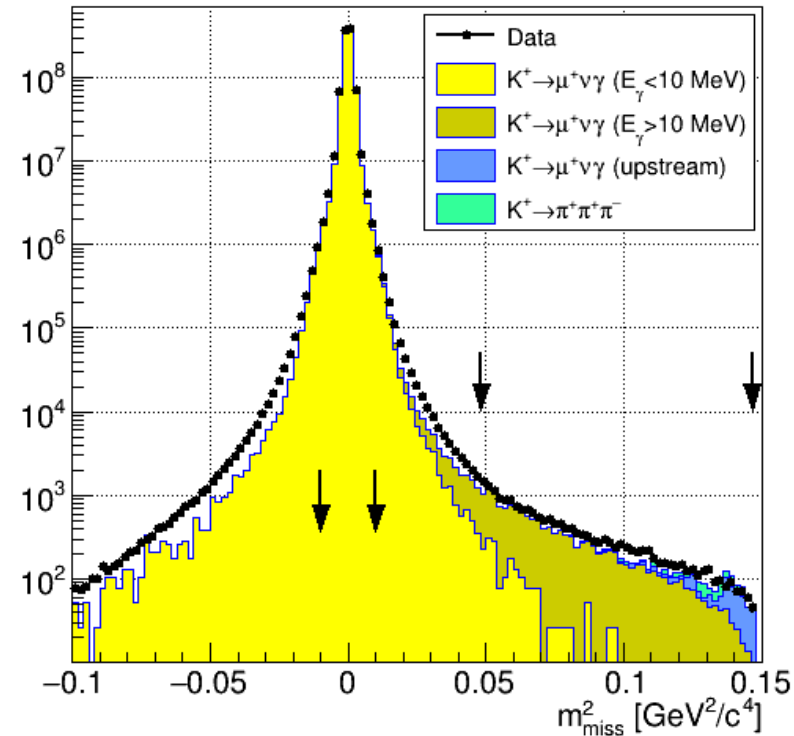
HNL signal: spike over the continuous mass spectrum

$$N_K = (3.52 \pm 0.02) \times 10^{12}$$



$e^+$  mode

$$N_K = (4.29 \pm 0.02) \times 10^9$$



$\mu^+$  mode

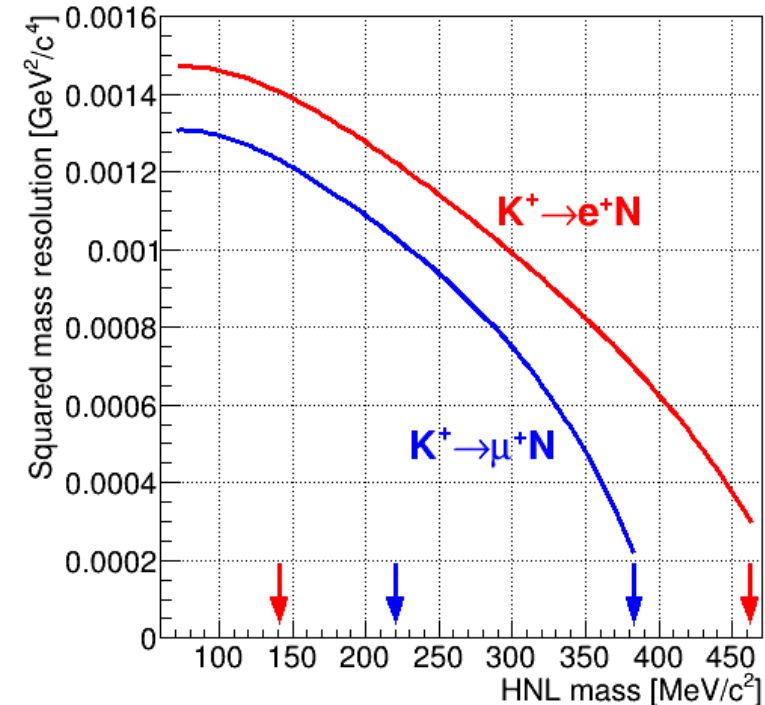
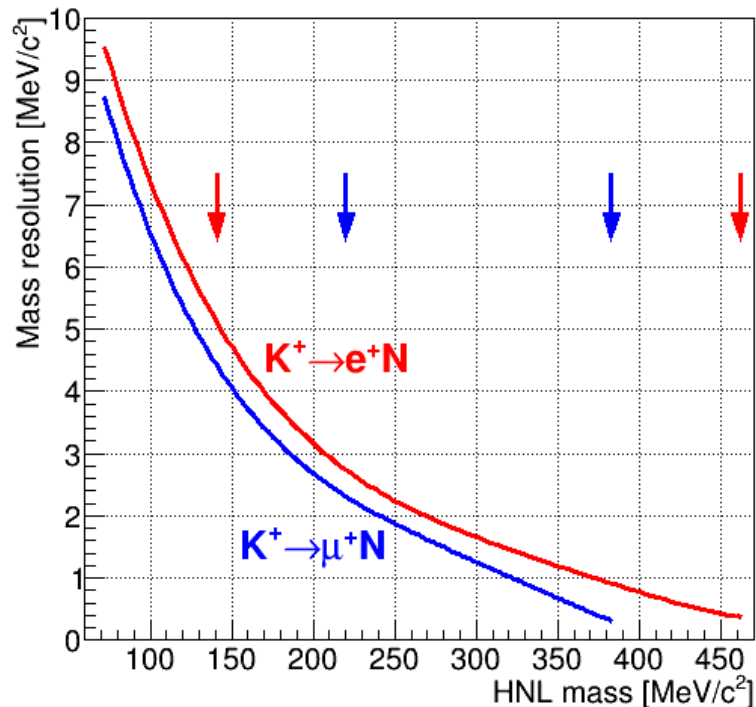


# Mass resolution

Selection for each HNL mass hypothesis includes a «mass window» condition:

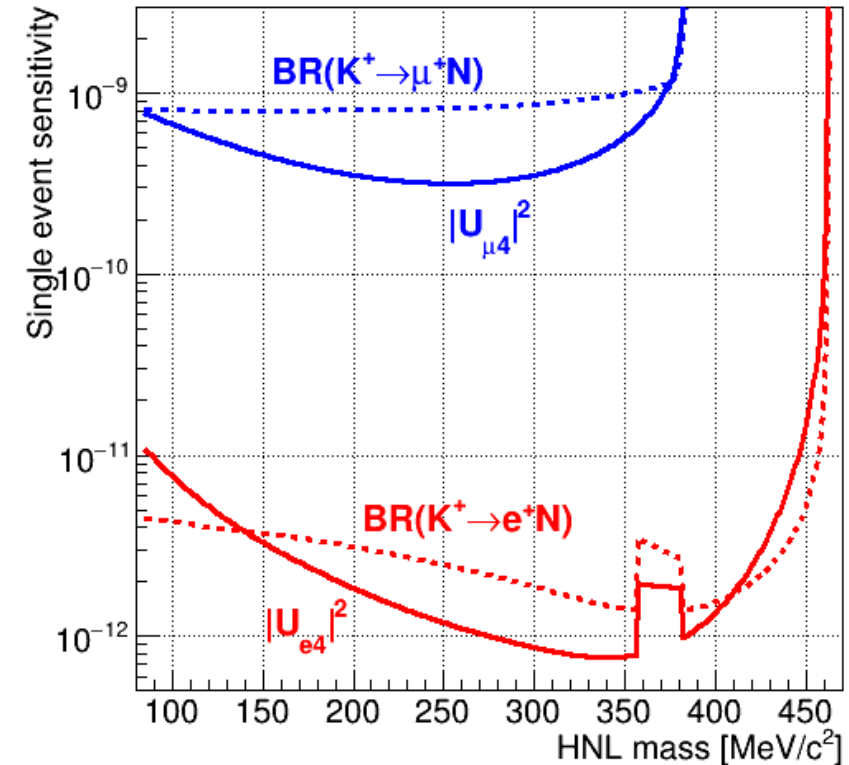
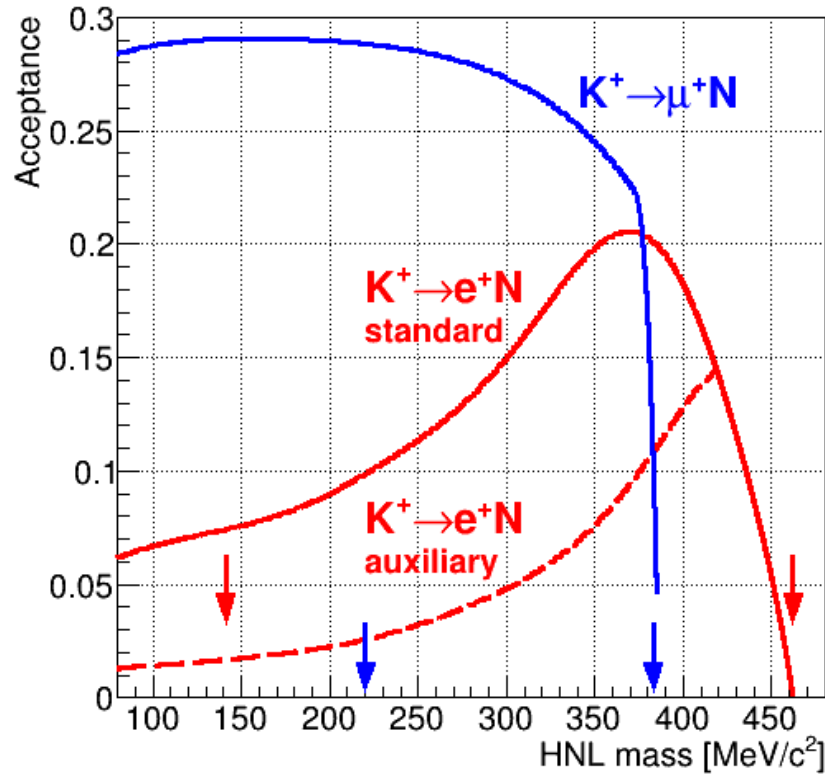
$$|m - m_{HNL}| < 1.6 \sigma_m$$

Resolution is crucial to resolve possible HNL mass splitting



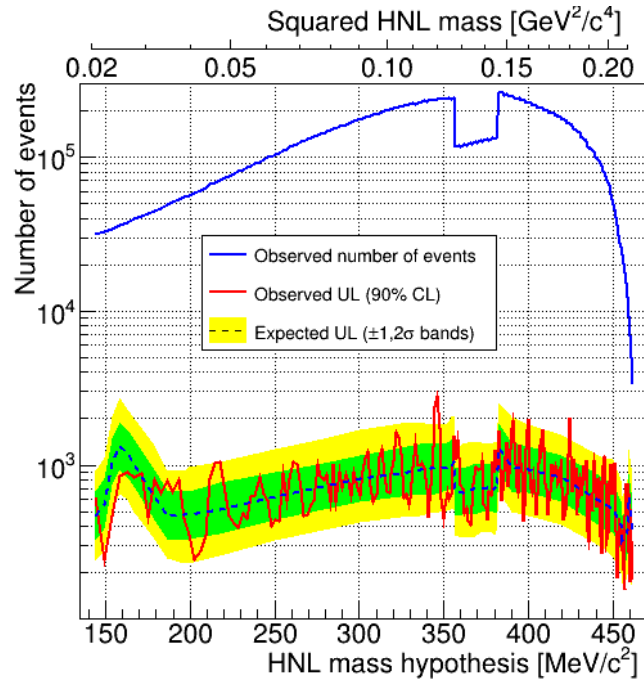
# Acceptance and SES

Definitions:  $BR_{SES} = 1/(N_K \times A)$ ,  $|U_{l4}|_{SES}^2 = BR_{SES}/[BR(K^+ \rightarrow l^+ \nu) \times \rho_l(m_N)]$

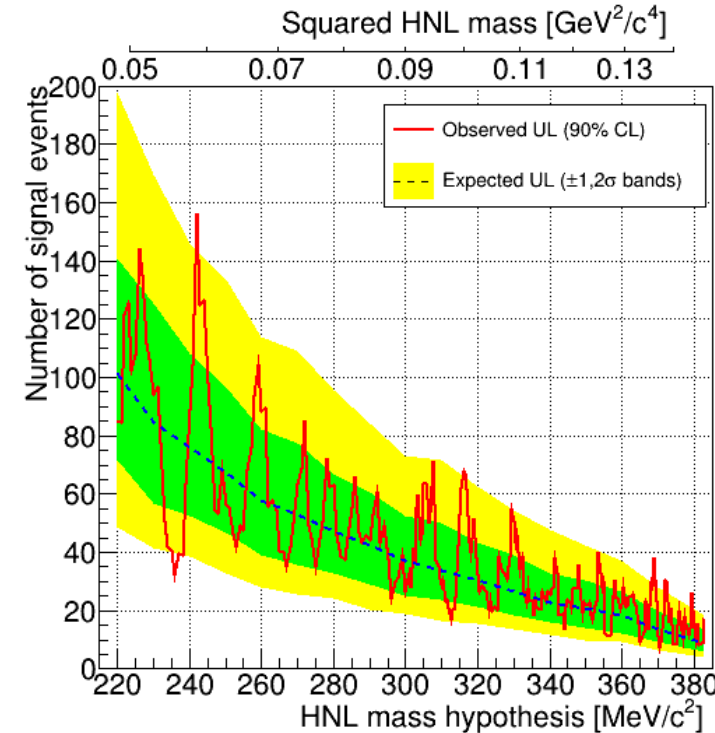


Auxiliary  $K_{eN}$  selection ( $p_e < 20$  GeV/c): smoother background near the  $\pi_{e2}$  threshold

# Upper limits on $BR(K^+ \rightarrow l^+ N)$ , 90% CL



$e^+$  mode



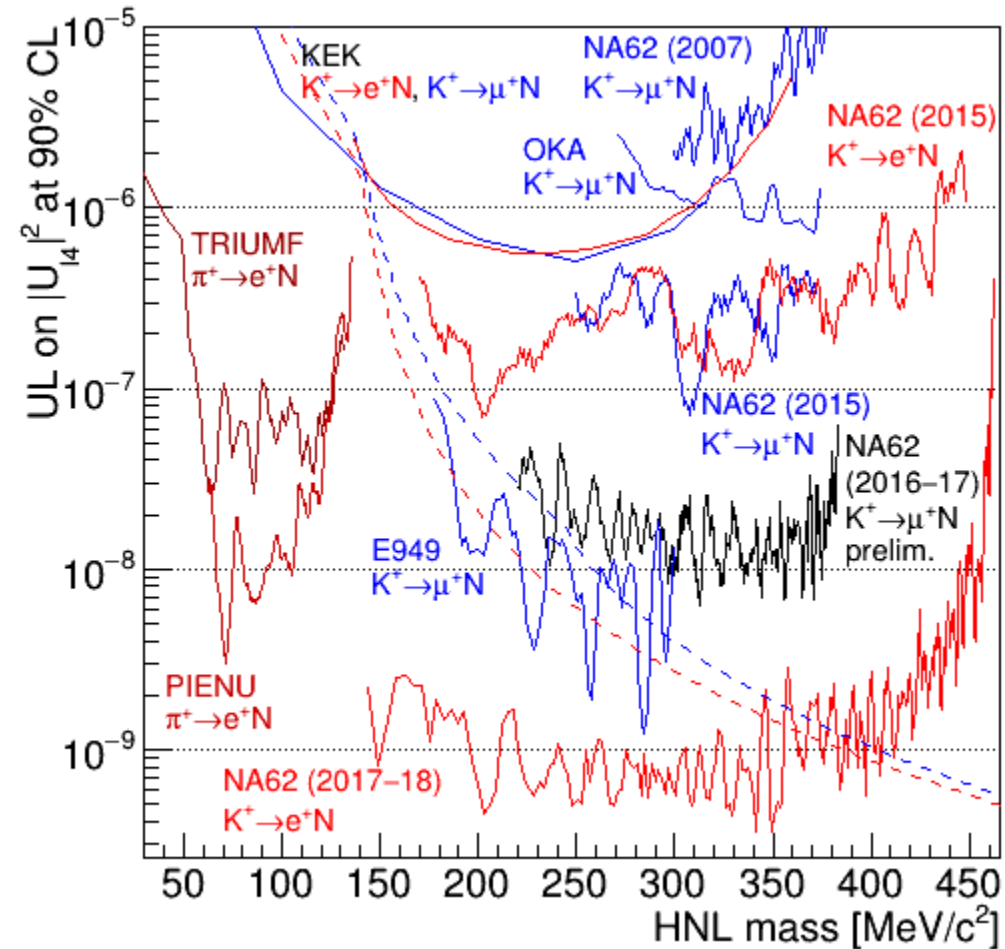
$\mu^+$  mode

In the  $e^+$  mode local significance: 3.6

Taking into account look-elsewhere effect, global significance: 2.2

# HNL summary

- Full Run1 dataset for  $|U_{e4}|^2$ , 1/3 of the full dataset for  $|U_{\mu4}|^2$
- Improvements up to two order of magnitudes
- For  $|U_{e4}|^2$ , BBN-allowed range excluded up to  $340 \text{ MeV}/c^2$
- For  $|U_{\mu4}|^2$ , approached E949 sensitivity and extended search to  $383 \text{ MeV}/c^2$



# Conclusions

- **NA62 collected  $\sim 6 \times 10^{12}$  kaon decays in Run 1**
- **HNL production searches:**
  - $O(10^{-9})$  limit on  $|U_{e4}|^2$  with full Run1 dataset, [PLB 807 (2020) 135599]
  - $O(10^{-8})$  limit on  $|U_{\mu4}|^2$  with 1/3 of Run1 dataset, preliminary
- **For  $|U_{e4}|^2$ , BBN-allowed range excluded up to  $340 \text{ MeV}/c^2$**
- **For  $|U_{\mu4}|^2$ , expected improvements of the sensitivity with larger dataset**



# Spares

# Comparison with HNL decay searches

