New limits on Heavy Neutrinos from NA62

Antonino Sergi
on behalf of the NA62 collaboration

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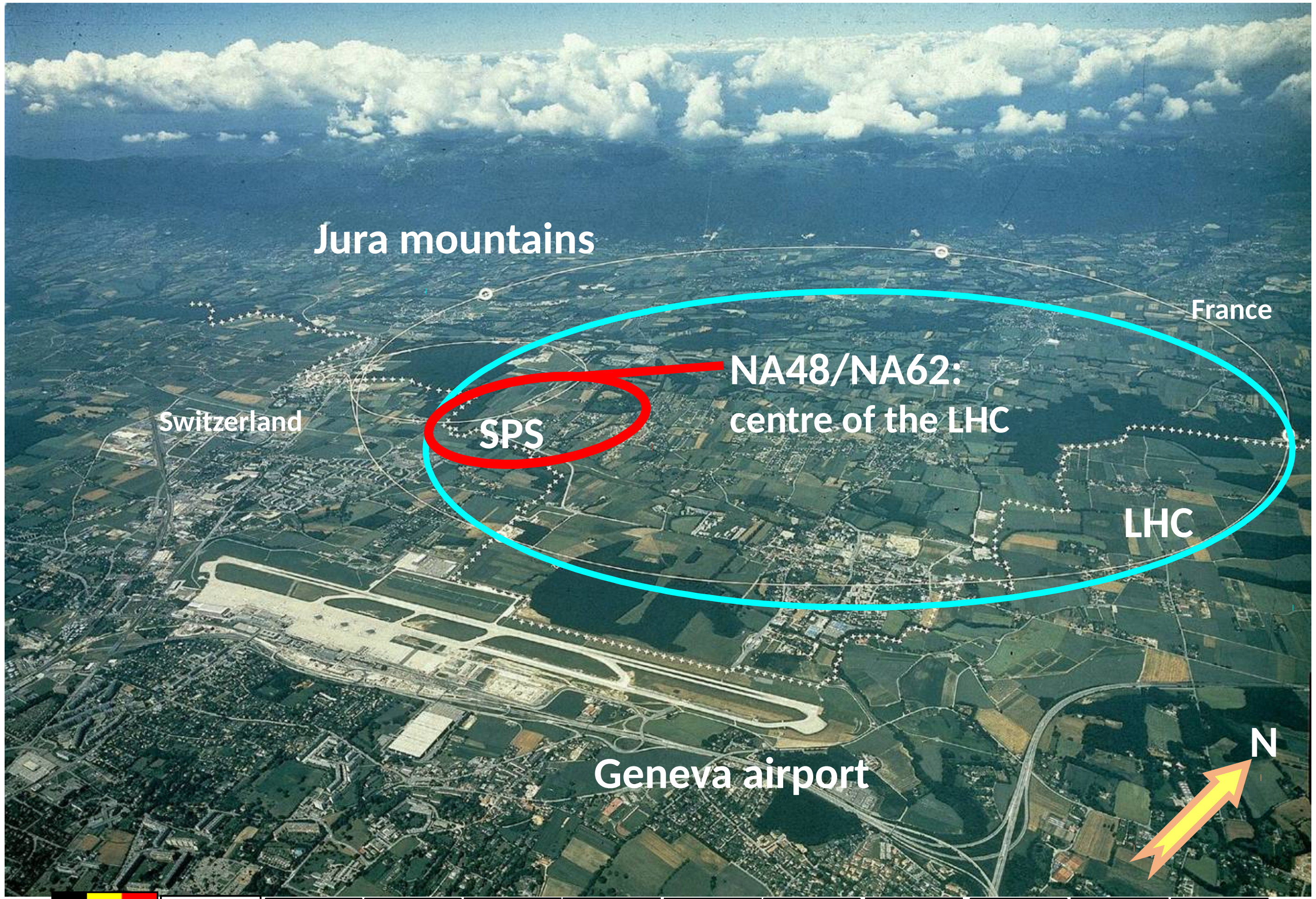
NA62 P326

Kaon Decay Experiments at CERN



Kaon decay in flight experiments.

NA62: ∼200 participants, ∼ 30 institutes

Earlier: NA31

NA48 (discovery of direct CPV)	1997: ε'/ε: K_L+K_S	
	1998: K_L+K_S	
	1999: K_L+K_S	K_S HI
	2000: K_L only	K_S HI
	2001: K_L+K_S	K_S HI
NA48/1	2002: K_S/hyperons	
NA48/2	2003: K^+/K^-	
	2004: K^+/K^-	
NA62 (R_K phase)	2007: $K^\pm_{e2}/K^\pm_{\mu 2}$	tests
	2008: $K^\pm_{e2}/K^\pm_{\mu 2}$	tests
NA62	2014: pilot run	
	2015: commissioning run	
	2016 – : $K^+\to\pi^+\nu\nu$ run	

This talk

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Heavy Neutrino: Motivation

- Observation of neutrino oscillations → massive neutrinos need to be accommodated in SM
- Example of a SM extension: Neutrino Minimal SM (νMSM) [*Asaka et al., PLB 620 (2005) 17*]
  - 3 right-handed neutrinos N_i added to SM, masses: $m_1 \sim 10\,\mathrm{keV}$, $m_{2,3} \sim 1\,\mathrm{GeV}$
  - N_1: dark matter candidate
  - $N_{2,3}$: extra CPV-phases to account for Baryon Asymmetry, produce SM masses via see-saw mech.

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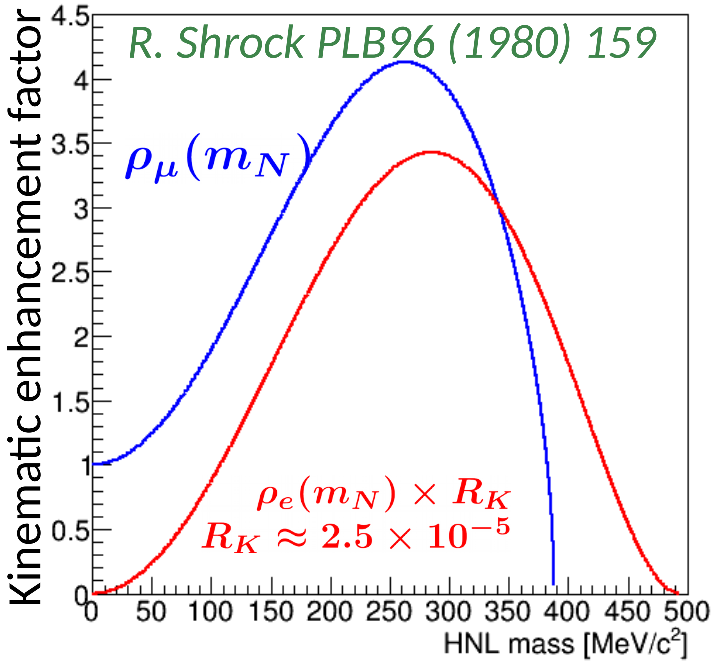
  - $N_{2,3}$: extra CPV-phases to account for Baryon Asymmetry, produce SM masses via see-saw mech.
- If $m_N < m_{K^+}$, heavy neutrinos observable via production in:

$$\Gamma(K^+ \to l^+ N) = \Gamma(K^+ \to l^+ \nu_l)\ \rho_l(m_N)\ |U_{l4}|^2$$



- This talk: search for peaks in $m_{miss}(K_{l2}) = \sqrt{(P_K - P_l)^2}$
  - NA62 2007 data sample: $l = \mu$
  - NA62 2015 data sample: $l = e$
- Other searches look for decays of heavy neutrinos (HN), e.g.

$$N \to \pi^\pm l^\mp\ ,\ N \to \pi^0 \nu,\ \ldots$$

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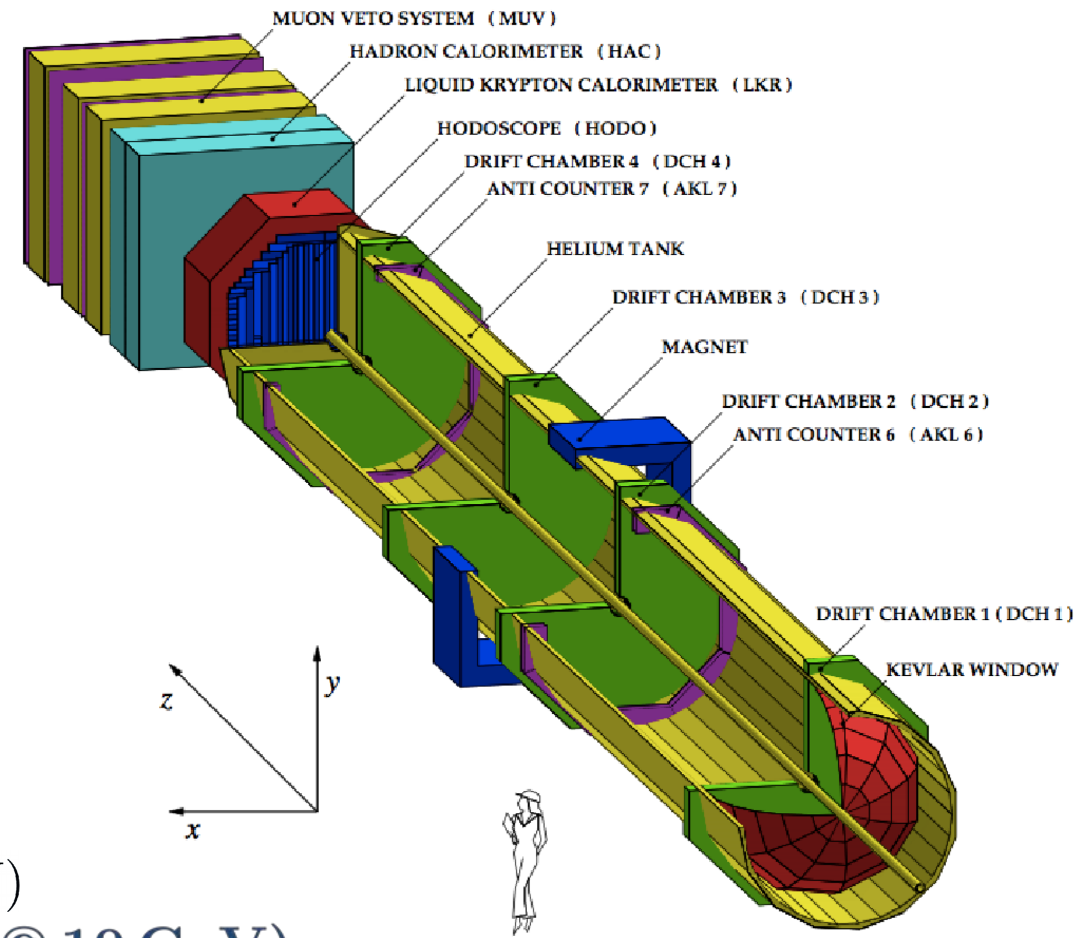
NA62 Experiment in 2007

- Main measurement: $R_K = \Gamma(K_{e2})/\Gamma(K_{\mu 2})$
  Phys. Lett. B 719 (2013) 326
- Beam momentum: (74 ± 2) GeV/c
- Triggers: 1-track $e^{\pm}$, 1-track $\mu^{\pm}$ (scaled down)
- Subdetectors:
  - Magnetic spectrometer (4 DCHs)
    $\sigma_p/p = 0.48\% \oplus 0.009\% \cdot p\ [\mathrm{GeV/c}]$
  - Scintillator hodoscope (HOD)
  - Liquid Krypton EM calorimeter (LKr)
    $\sigma_E/E = (3.2/\sqrt{E} \oplus 9/E + 0.42)\%$ (E in GeV)
    $\sigma_x = \sigma_y = (4.2/\sqrt{E} \oplus 0.6)$ mm (1.5 mm @ 10 GeV)
  - Muon veto system (MUV)



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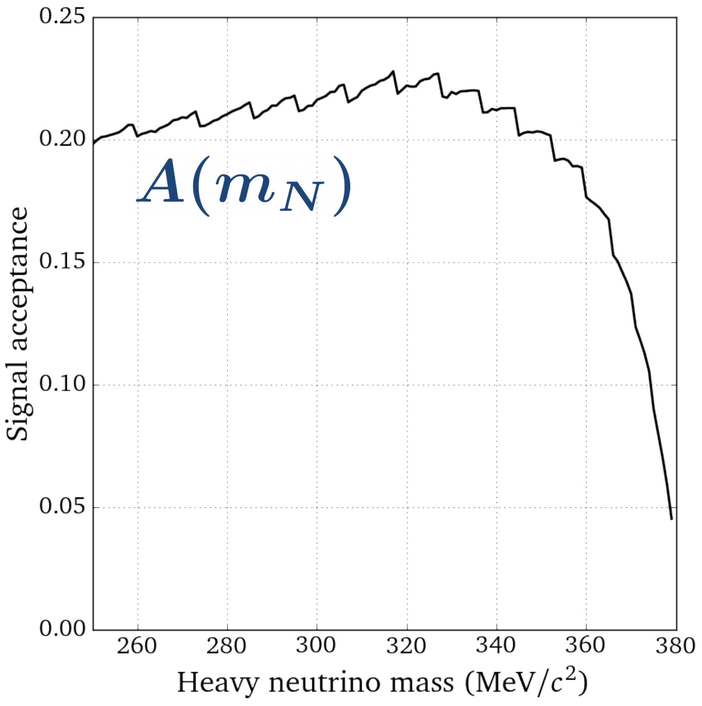
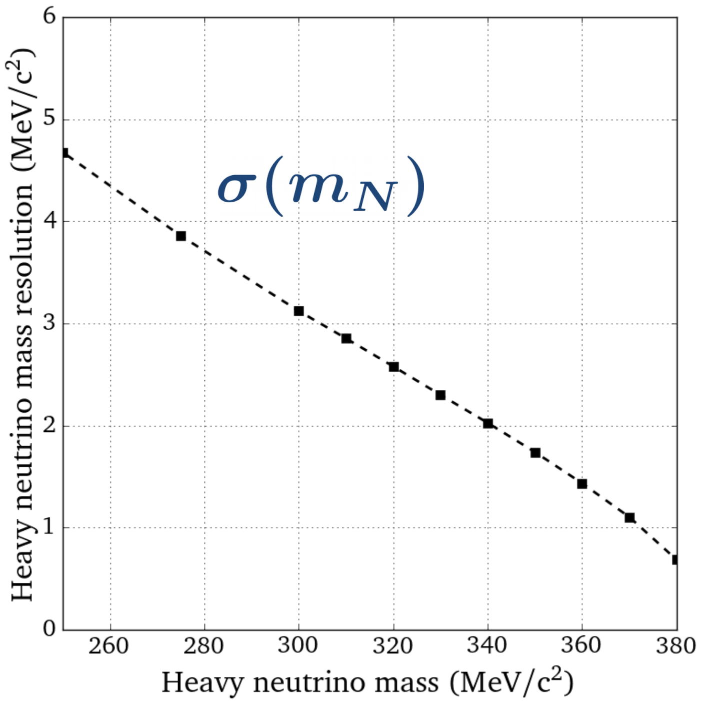
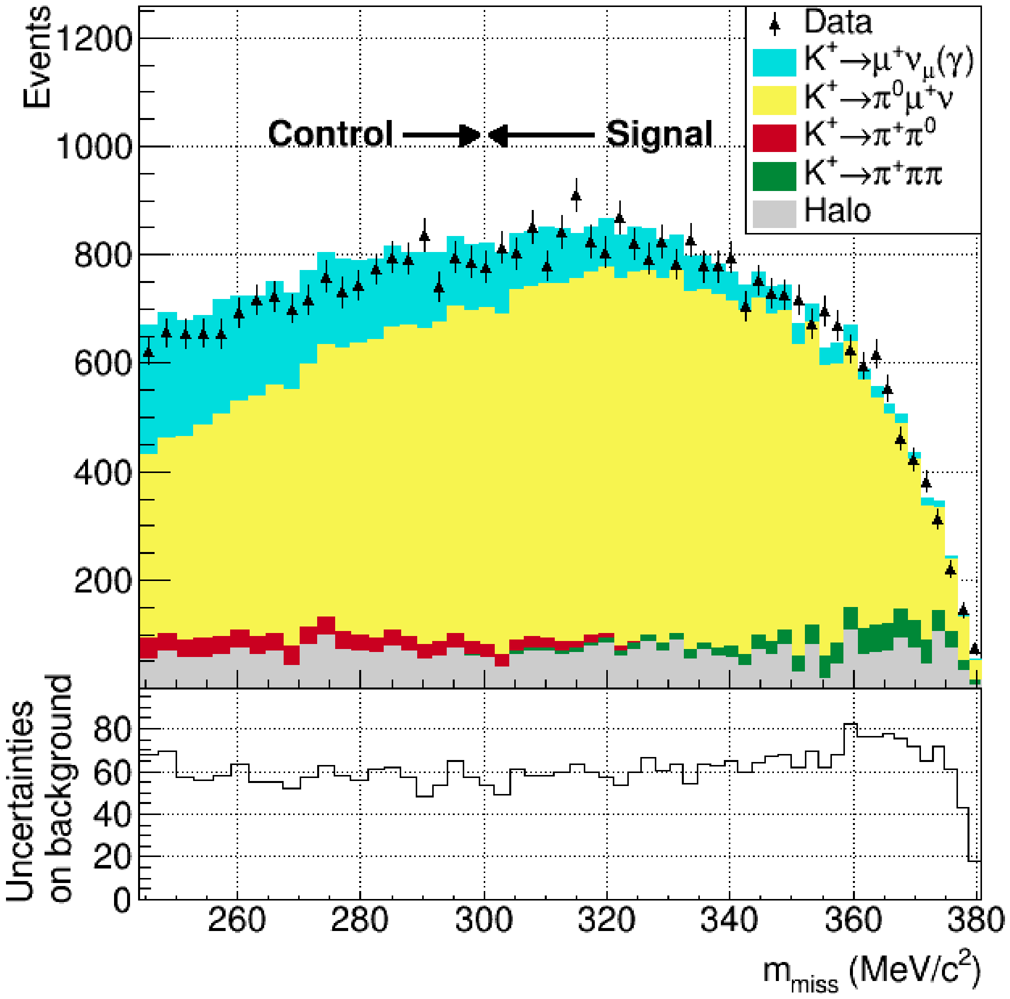
NA62 Experiment in 2007

- Kaon decays in fiducial volume: $N_K \sim 6 \times 10^7$
- Heavy neutrino (HN) MC simulation
  - ➢ Acceptance vs. HN mass: $A(m_N)$
  - ➢ Missing mass resolution vs. HN mass: $\sigma(m_N)$





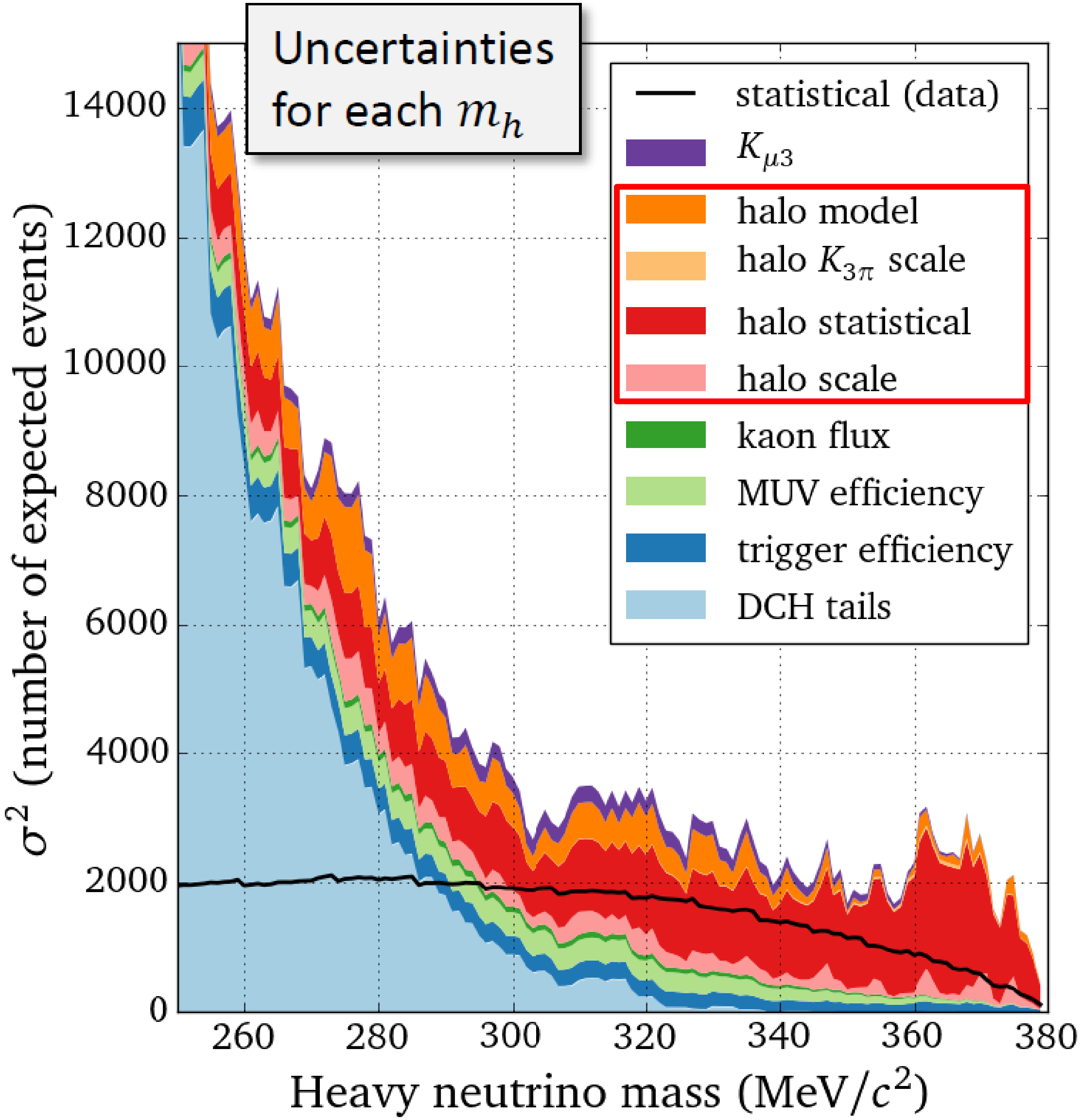
Missing mass: $m_{miss} = \sqrt{(P_K - P_\mu)^2}$



Signal region: $m_{miss} \in (300, 375)\ \mathrm{MeV}/c^2$

Uncertainties

- Kaon decays
  - ➢Below 1 %
  - ➢Dominated by $K_{\mu 3}$
- Dominant systematic uncertainty in the signal region is from halo muons
  - ➢Generated along the beamline
  - ➢Extensively studied to reduce their contribution in the signal region
  - ➢Residual contribution modeled with K- and Kless data samples



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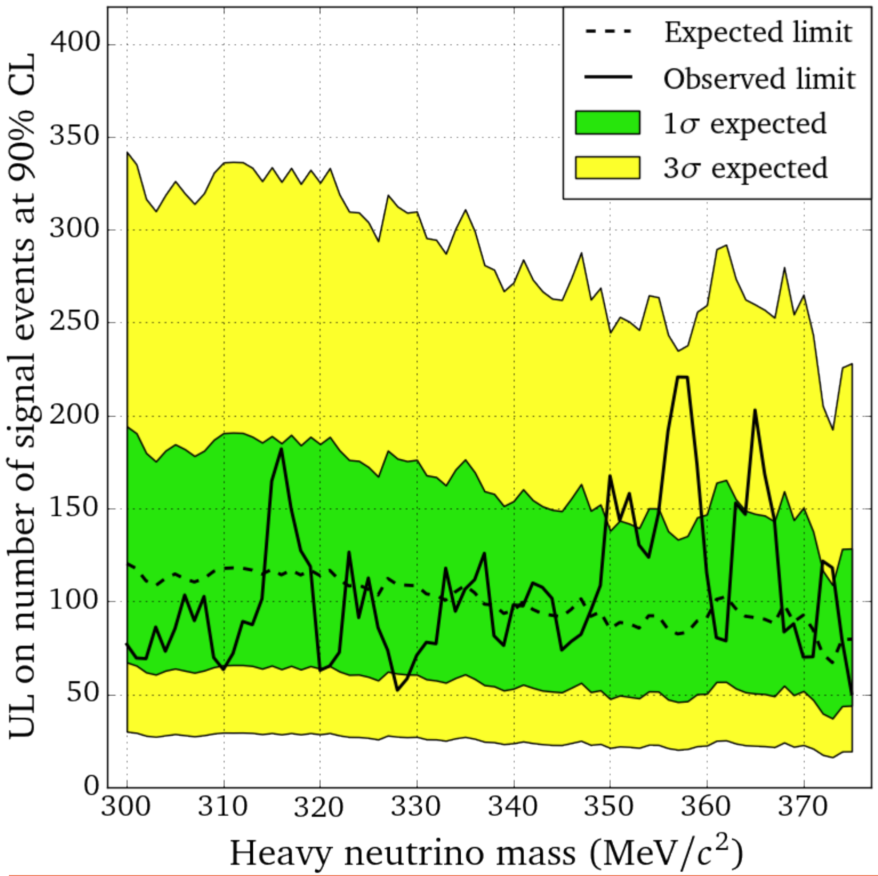
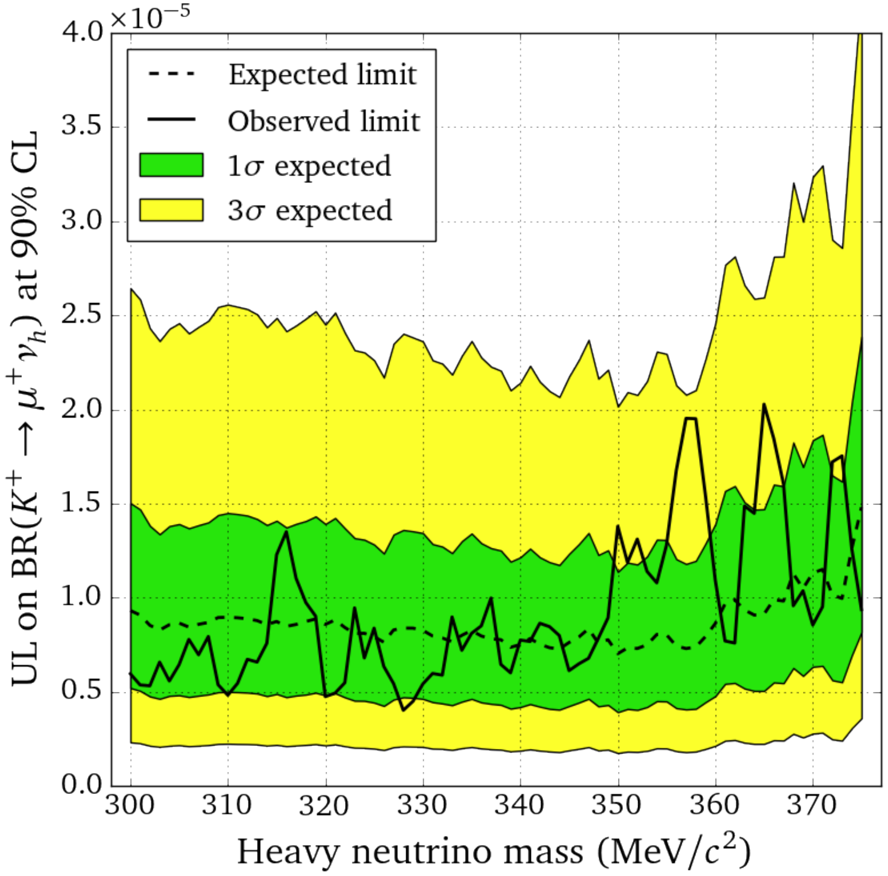
Heavy Neutrino Search in 2007 Data

Rolke-Lopez method used to find upper limits on number of signal events

- Heavy neutrino mass step: $1\,\mathrm{MeV}/c^2$
- Search window size defined by HN mass resolution



$$\xrightarrow{\dfrac{1}{N_K \cdot A(m_N)}}$$



No HN signal observed with >3σ significance

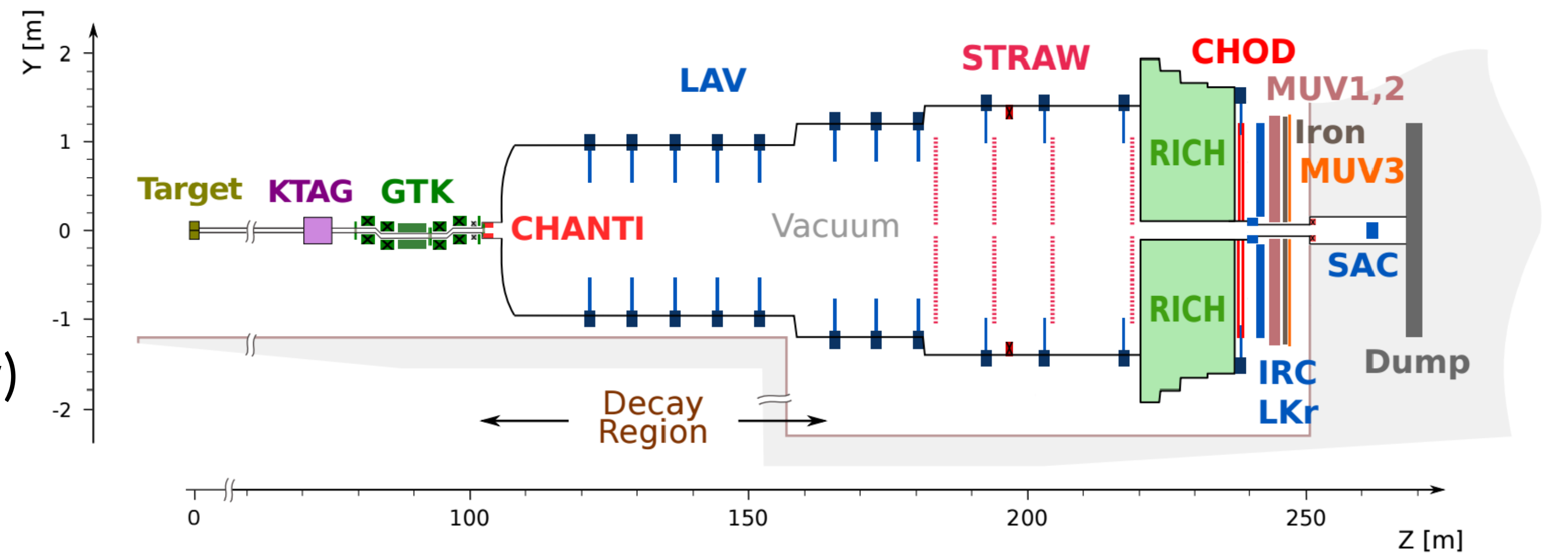
NA62 Experiment in 2015

- Main goal, 10% precision measurement of:

$$\mathcal{B}(K^+ \to \pi^+ \nu \bar{\nu})$$

- Beam momentum: 75 GeV/c (±1%)
- Subdetectors:
  - Tracking: kaon (GTK), π/μ/e (Straw)
  - Hermetic veto detectors:
    - Photons (LAV, LKr, SAC, IRC)
    - Muons (MUV)
  - Particle identification
    - Kaon in the beam (KTAG)
    - π/μ/e (RICH, LKr, MUV)

NA62 collaboration, JINST 12 (2017) P05025



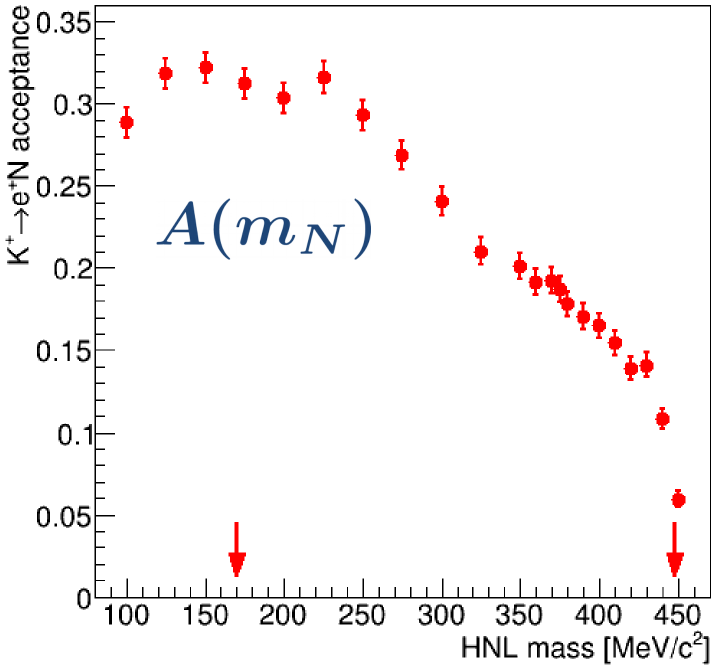
Data taking conditions in 2015:

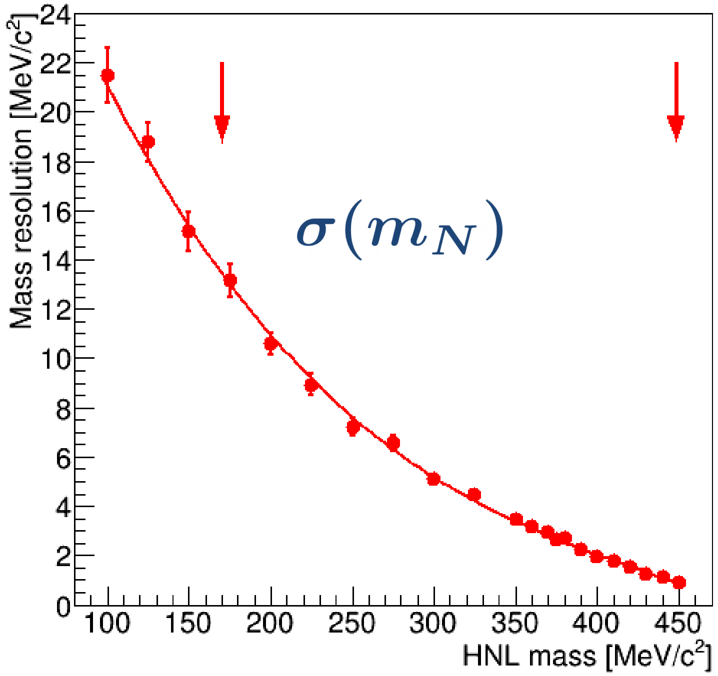
- Minimum bias at 1% of design beam intensity
- Beam tracker not available; kaon momentum estimated as beam average

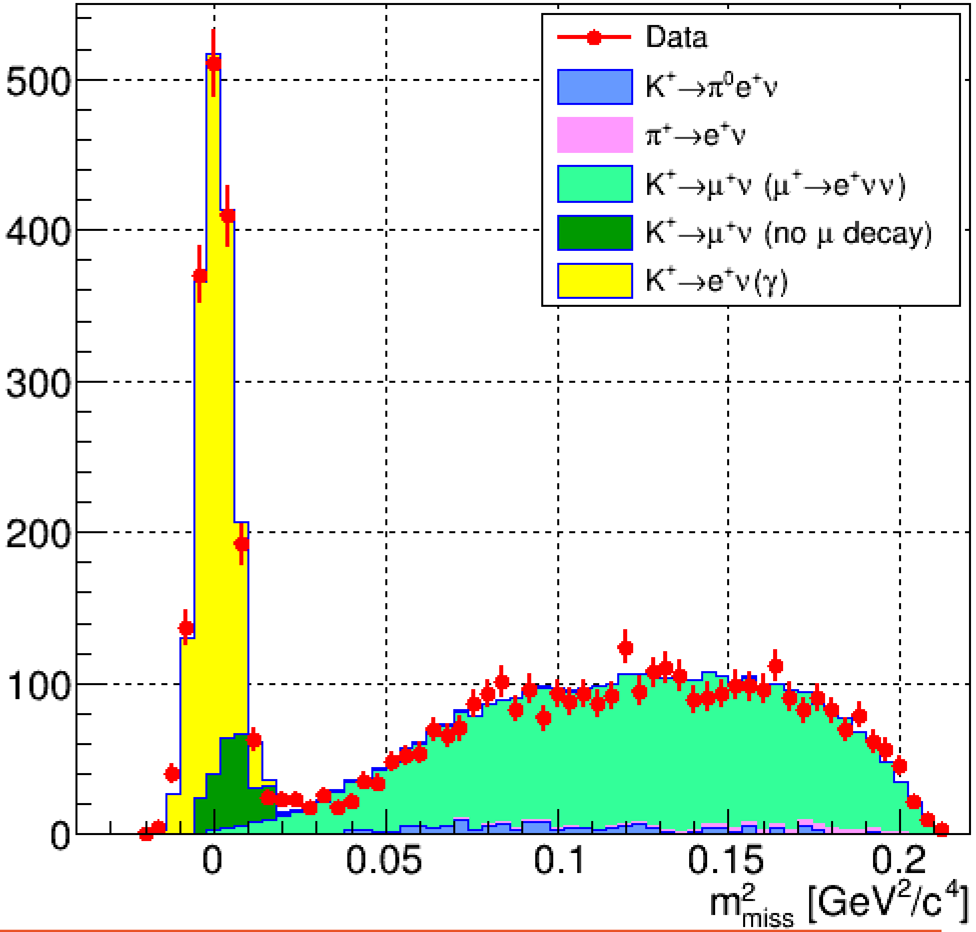
Data Sample in 2015

- Kaon decays in fiducial volume: $N_K = (3.01 \pm 0.11) \times 10^8$
- Heavy neutrino (HN) MC simulation
  - ➢ Acceptance vs. HN mass: $A(m_N)$
  - ➢ Missing mass resolution vs. HN mass: $\sigma(m_N)$

Squared missing mass: $m^2_{miss} = (P_K - P_e)^2$







Signal region: $m_{miss} \in (170, 448)\ \mathrm{MeV}/c^2$

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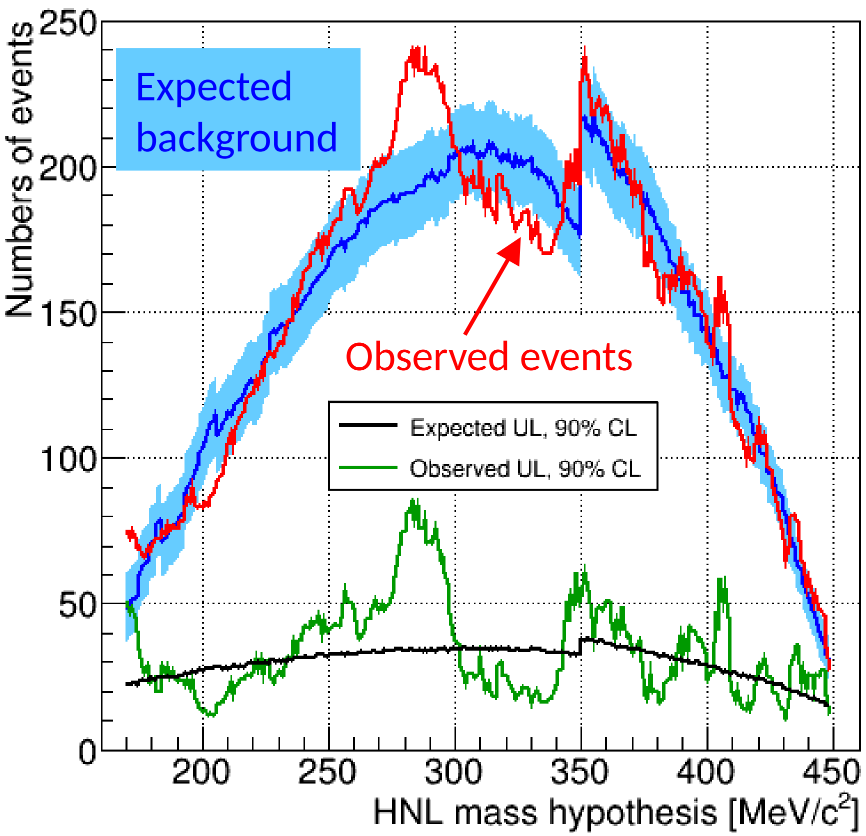
Heavy Neutrino Search in 2015 Data

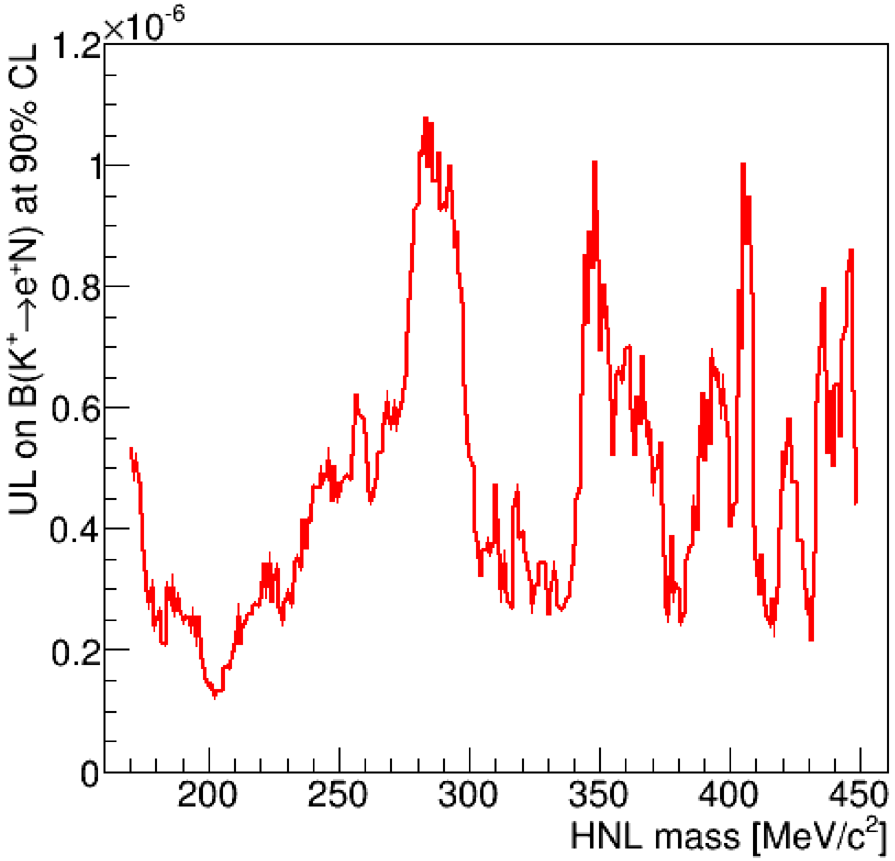
Rolke-Lopez method used to find upper limits on number of signal events

- Heavy neutrino mass step: $1\,\mathrm{MeV}/c^2$
- Search window size for each mass hypothesis: $\pm 1.5\,\sigma(m_N)$



$$\frac{1}{N_K \cdot A(m_N)}$$

No HN signal observed with >3σ significance



Upper Limits on $|U_{l4}|^2$

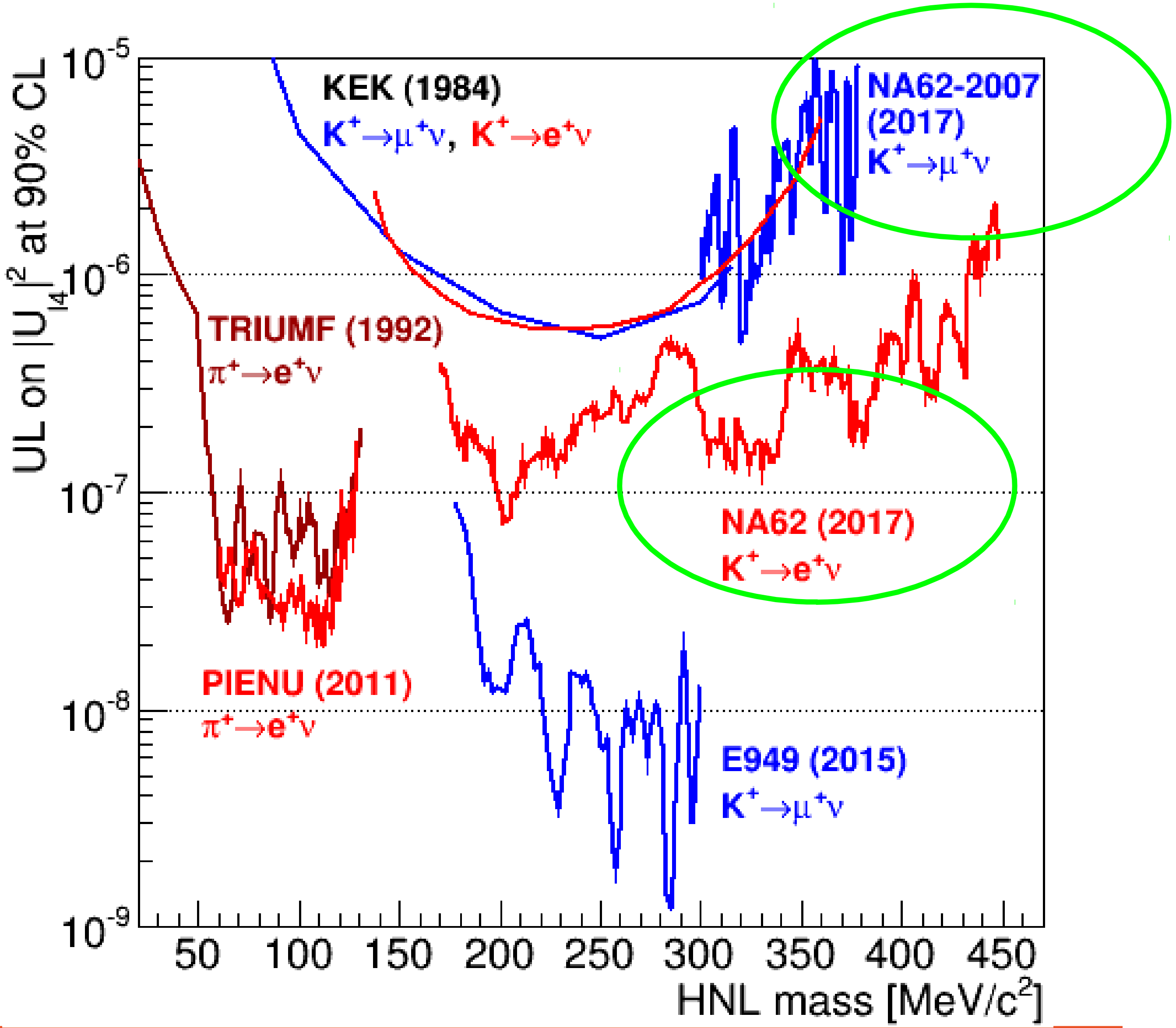
$$|U_{l4}|^2 = \frac{\mathcal{B}(K^+ \to l^+ N)}{\mathcal{B}(K^+ \to l^+ \nu_l)\ \rho_l(m_N)}$$

- NA62 2007 data analysis:
  - Extends the mass range for upper limits on $|U_{\mu 4}|^2$
  - Most stringent limit in

    $m_N \in (300, 375)\ \mathrm{MeV}/c^2$

- NA62 2015 data analysis:
  - Reaches $10^{-6} - 10^{-7}$ limits on $|U_{e4}|^2$ in the range

    $m_N \in (170, 448)\ \mathrm{MeV}/c^2$



Summary and Outlook

- NA62 searches for heavy neutrino production in charged kaon decays were presented
  - No heavy neutrino signal observed
- Analysis of NA62 2007 data (PLB 772 (2017) 712):
  - About 60 million K^+ decays in the fiducial volume
  - Improves limits on $|U_{\mu4}|^2$ for $m_N \in (300, 375)\ \mathrm{MeV}/c^2$
- Analysis of NA62 2015 data (paper in preparation):
  - About 300 million K^+ decays in the fiducial volume
  - New limits on $|U_{e4}|^2$ reaching 10^{-6}—10^{-7} for $m_N \in (170, 448)\ \mathrm{MeV}/c^2$
- Future prospects:
  - Major analysis improvements with NA62 2016 high intensity data set, e.g. fully working beam tracker

Limits from heavy neutrino **production** searches