
NATIONAL RESEARCH CENTER
"KURCHATOV INSTITUTE"


# New limits on heavy neutrinos from NA62

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NRC «Kurchatov Institute» - IHEP

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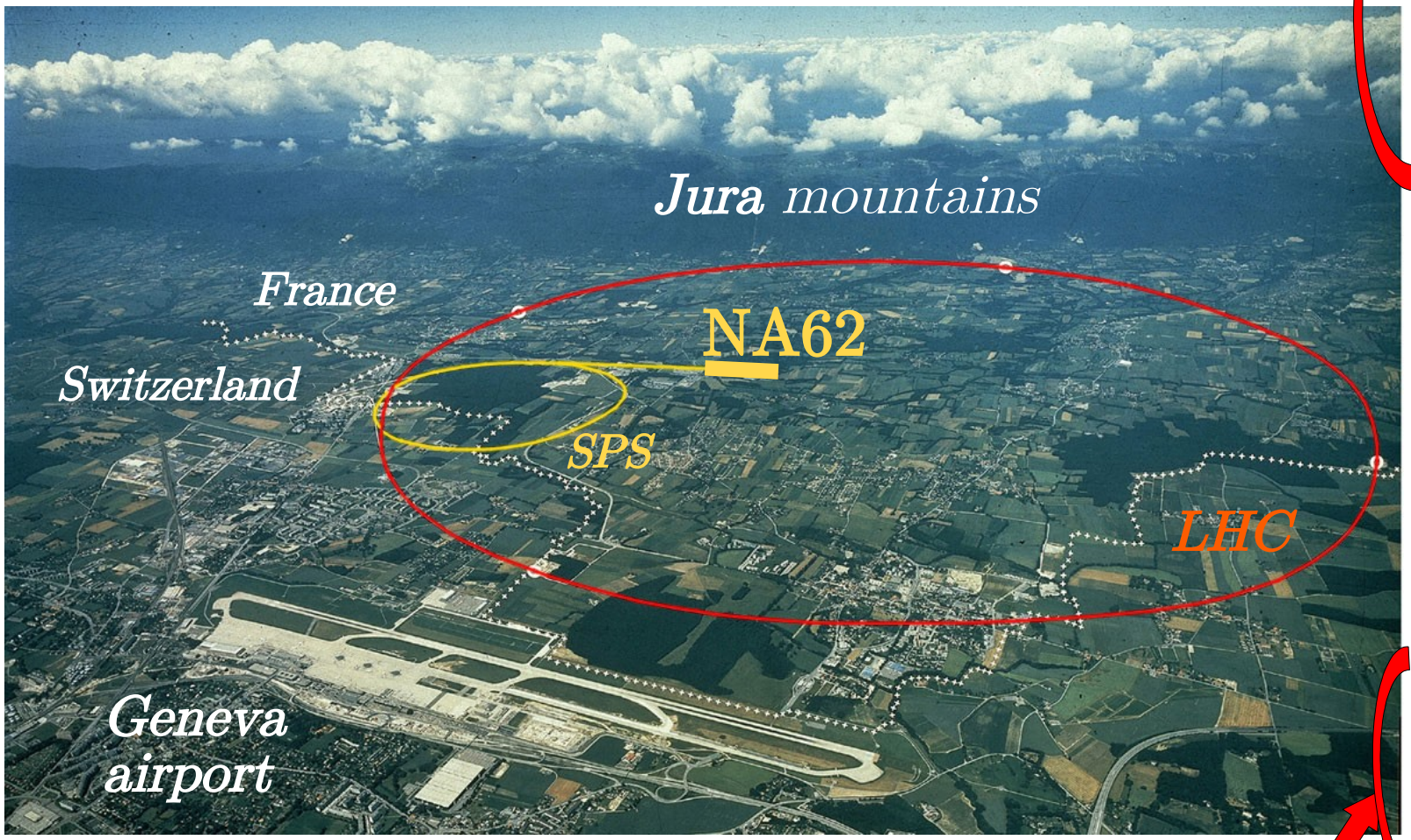
# Kaon decay experiments @ CERN

direct CP violation




**NA31**
1987 - 1989: $K_L/K_S$

**NA48**
1997 - 2001: $K_L/K_S$

**NA48/1**
2002: $K_S$ /hyperons

**NA48/2**
2003-04: $K^+/K^-$

**NA62 - Rk**
2007-08: $K^{\pm}_{e2}$ / $K^{\pm}_{\mu 2}$

**NA62**
2014: pilot run
2015: commissioning run
**2016- : $K^+ \to \pi^+ \nu\bar{\nu}$**

This talk

NA62: ~ 200 participants, 30 institutes from 13 countries

# Heavy neutrinos: Motivation

- **Neutrino oscillations** → massive neutrinos need to be accommodated in SM
- Example of SM extension: **Neutrino Minimal SM (νMSM)**

(T.Asaka, M. Shaposhnikov, Phys.Lett.B620:17-26,2005)

  - 3 right-handed neutrinos added to SM with masses: $m_1 \sim 10$ keV, $m_{2,3} \sim 1$ GeV
  - $N_1$: dark matter candidate
  - $N_{2,3}$: extra CPV-phase to account for Baryon Asymmetry, produce SM masses via see-saw mechanism.

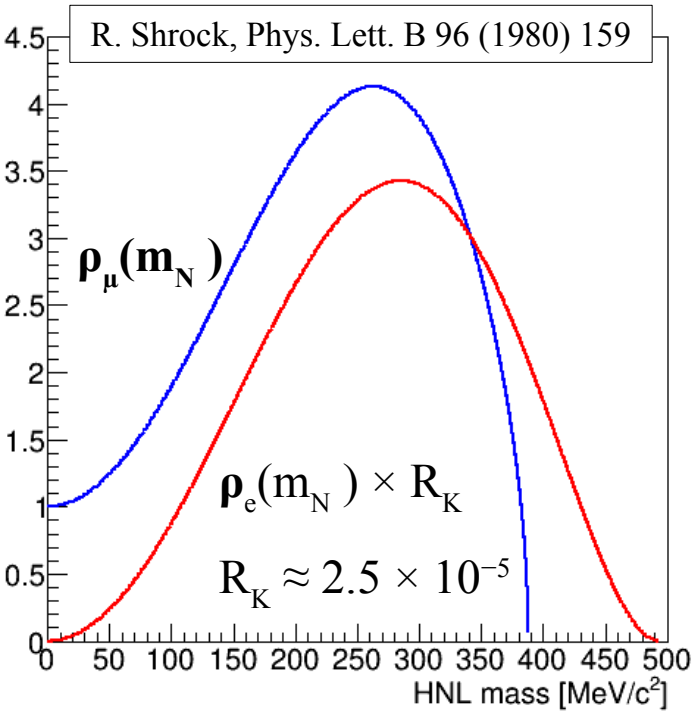
- If $\mathbf{m_N < m_{K+} - m_{l+}}$ ,

→ heavy neutrinos could be observed in kaon decays:

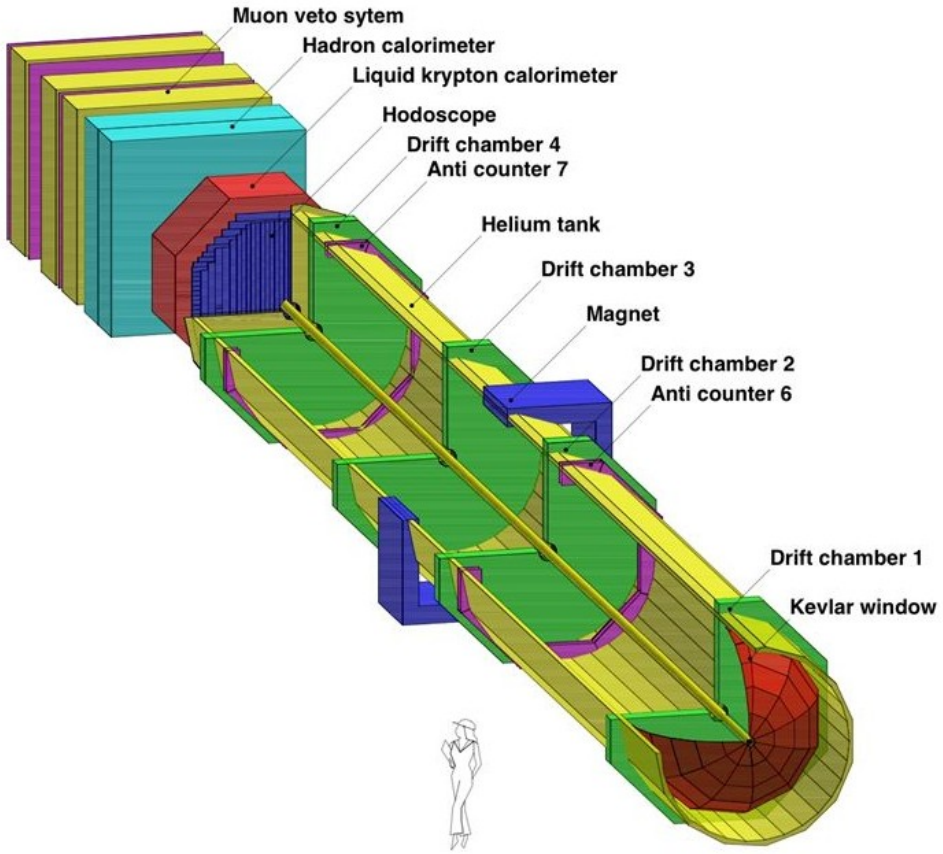
$$\Gamma(K^+ \to l^+ N) = \Gamma(K^+ \to l^+ \nu_l)\, \rho_l(m_N)\, |U_{l4}|^2$$

**Kinematic enhancement factor** **Mixing matrix element**

- **This talk:** search for peaks in $m_{miss}(K_{l2}) = \sqrt{(P_K - P_l)^2}$
  - **2007 data: $K_{\mu 2}$**
  - **2015 data: $K_{e2}$**



# NA62–$R_K$: apparatus in 2007




**Main measurement:** $R_K = \Gamma(K_{e2}) / \Gamma(K_{\mu 2})$

Phys. Lett. B 719 (2013) 326

**Beam:** $K^{\pm}$ (74 ± 2) GeV/c

**Triggers:** 1 track $e^{\pm}$, 1 track $\mu^{\pm}$ (downscaled)

**Spectrometer:**

$$\sigma_p/p = 0.48\% + 0.009\% \cdot p \text{ [GeV/c]}$$

**Scintillator hodoscope (HOD)**

**Liquid Krypton EM calorimeter (Lkr)**

Energy resolution: stochastic term 3.2%

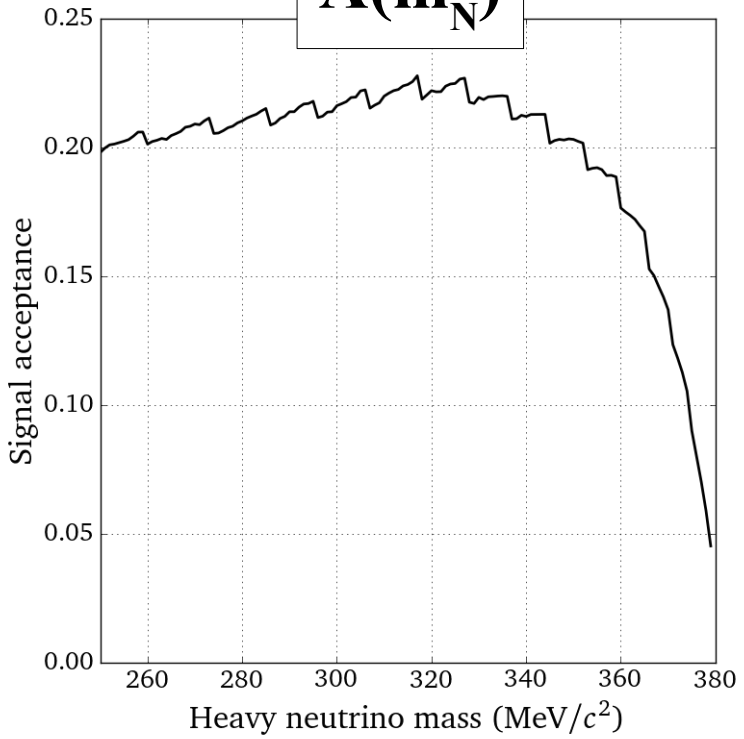
Spatial resolution: $(4.2\%/\sqrt{E} + 0.6)$ mm

**Muon Veto (MUV)**

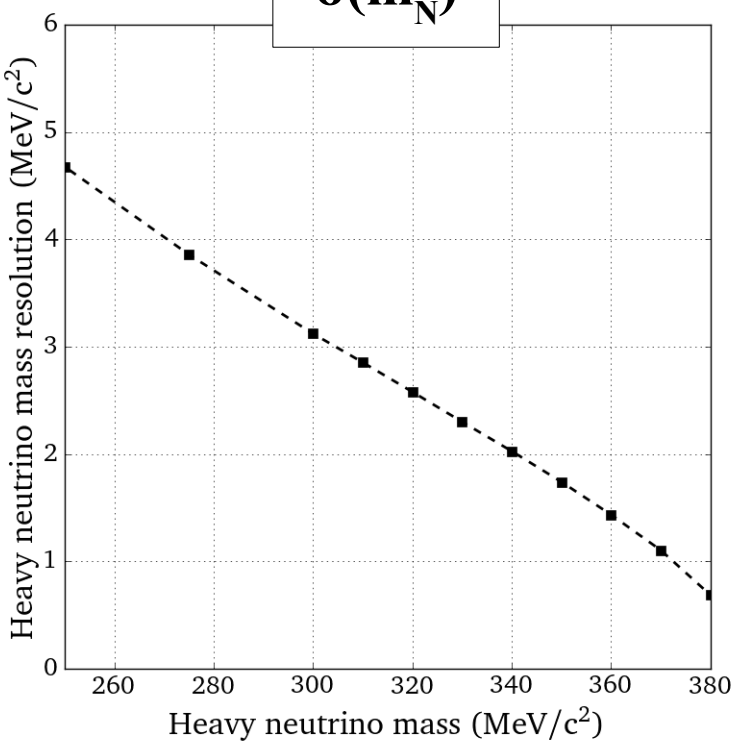
# NA62–$R_K$: data sample in 2007

- Kaon decays in fiducial volume: ~ **60 x $10^6$**
- Heavy neutrino (HN) MC simulation
  - Acceptance vs HN mass: **$A(m_N)$**
  - Missing mass resolution vs HN mass: **$\sigma(m_N)$**

**$A(m_N)$**



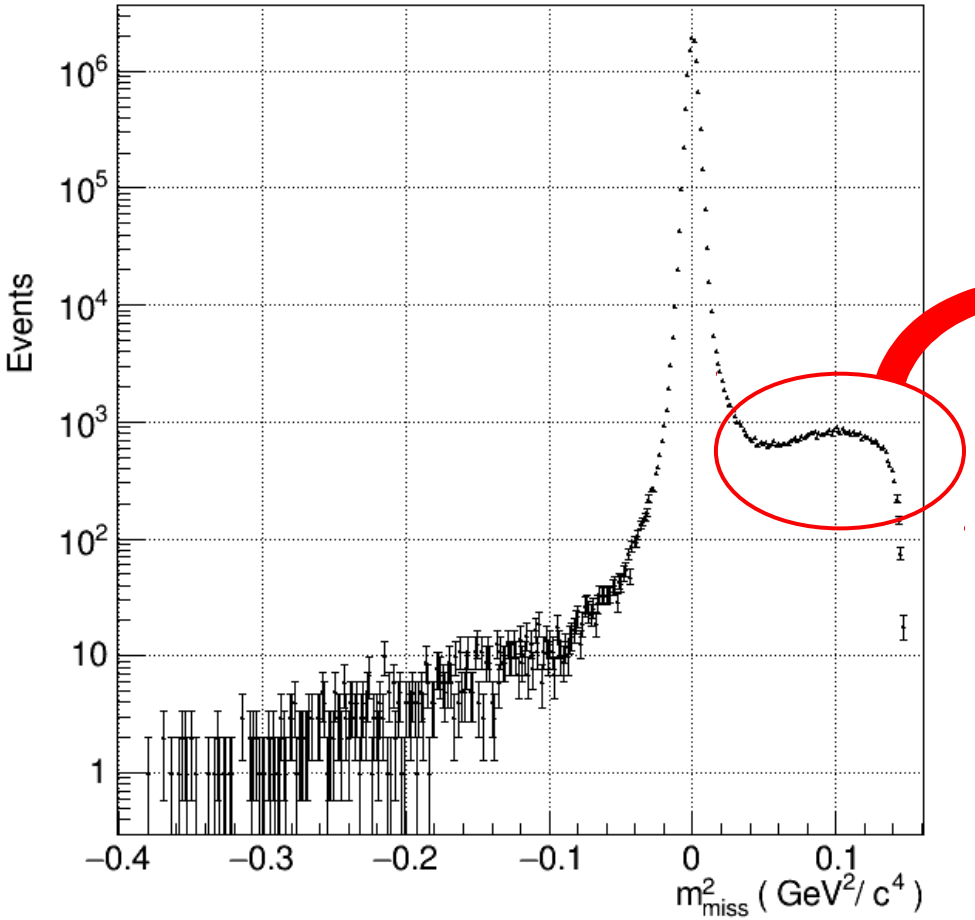

**$\sigma(m_N)$**

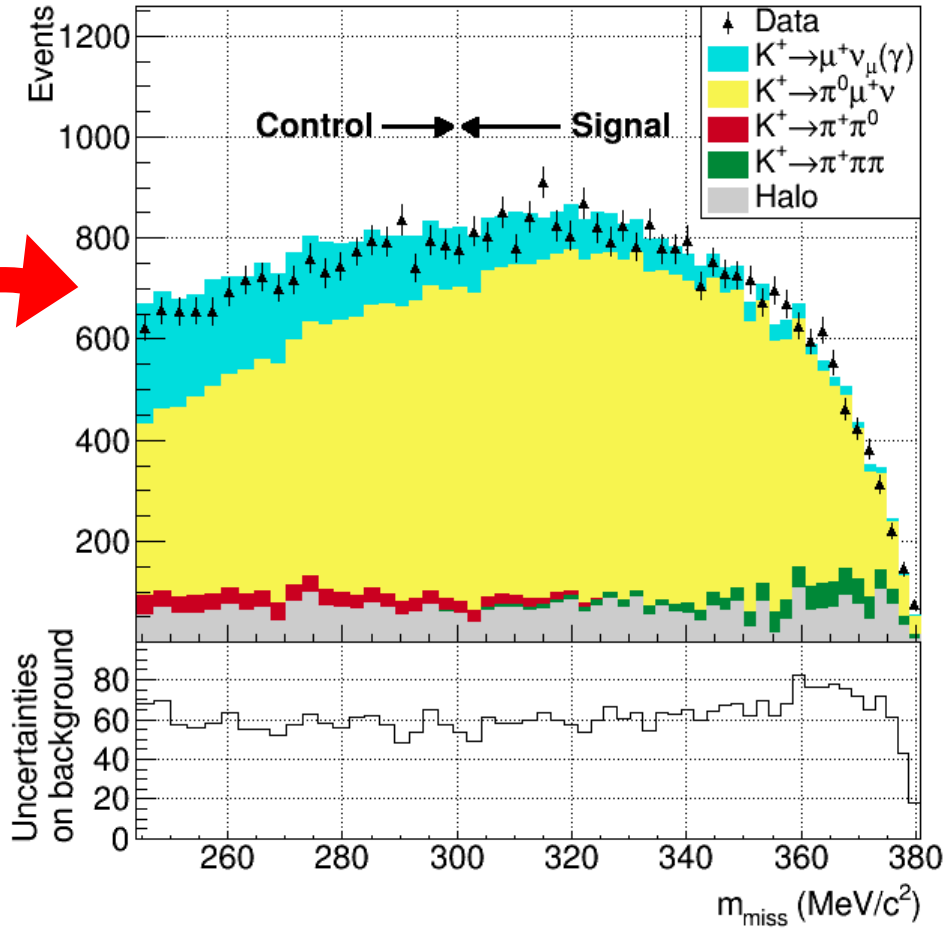


# NA62–$R_K$: data sample in 2007

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

Signal region: (300 , 375) MeV/c$^2$

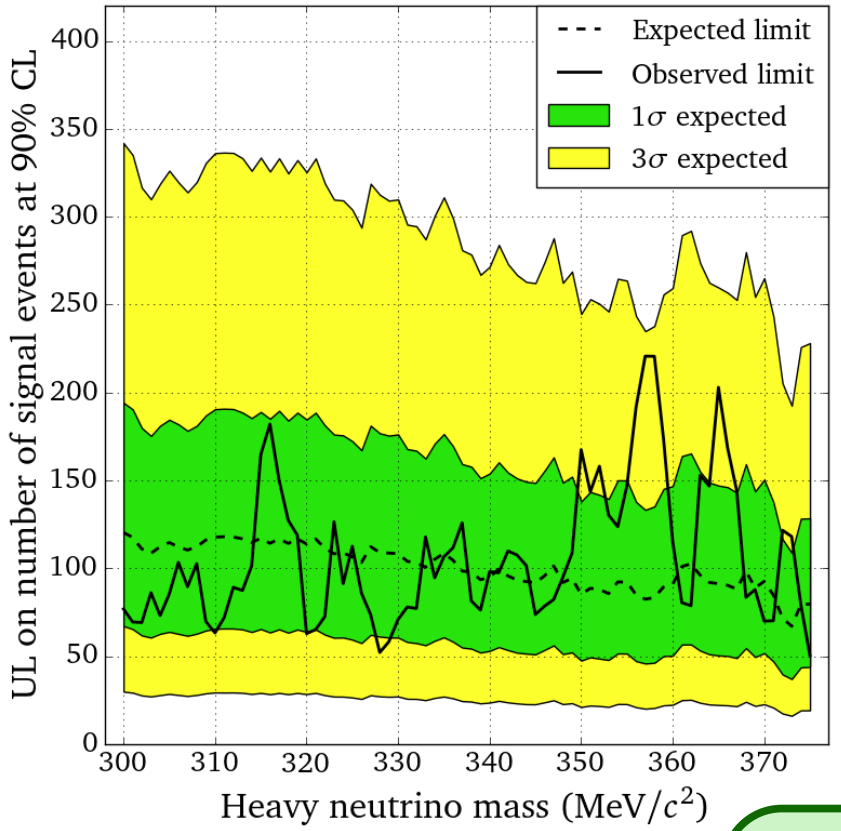


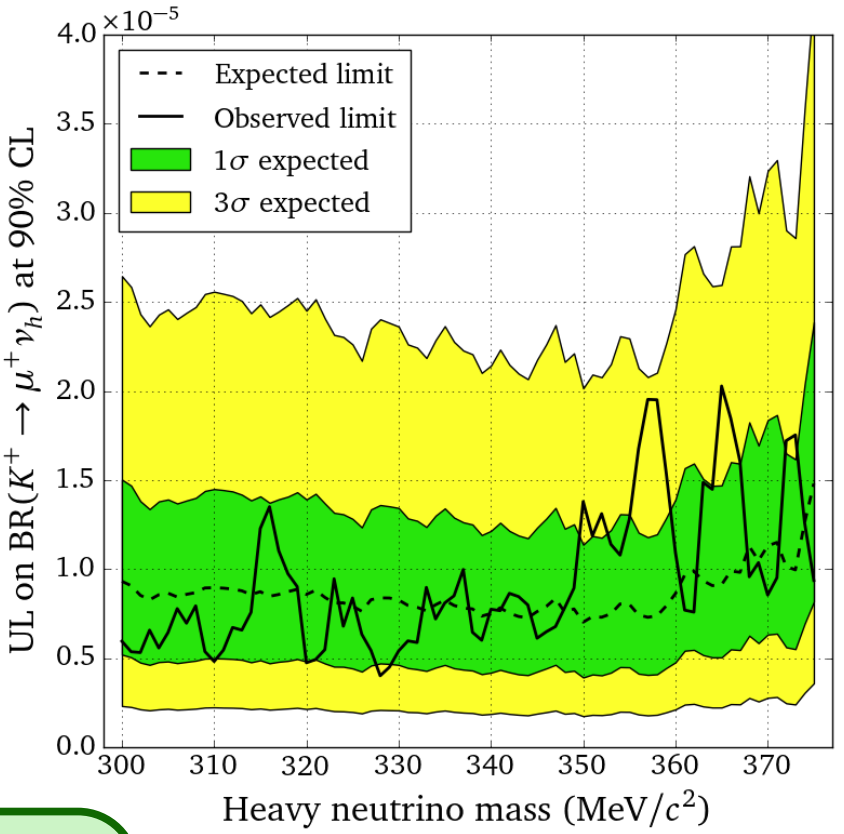
# Heavy neutrino search in 2007 data

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

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




$$\frac{1}{N_K \cdot A(m_{N4})}$$



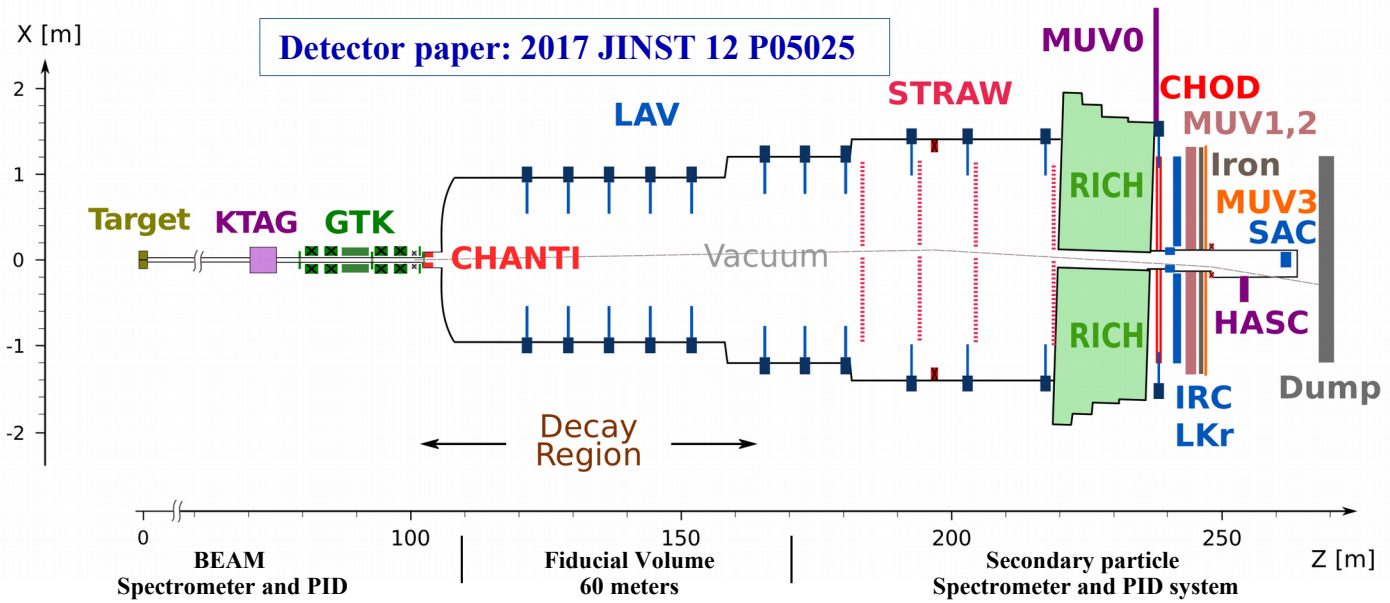

No HN signal observed with > 3σ significance

# NA62 Detector

- **Physics Goal:** Measuring Br($K^+ \to \pi^+ \nu\bar{\nu}$) with 10% precision

**More details in Silvia's talk:**
Search for $K^+ \to \pi^+ \nu\bar{\nu}$ at NA62

- **Kaon decay in flight technique**
- **Experimental setup:** 270 meters long
- **Primary beam:** 400 GeV/c protons from SPS
  $10^{12}$ protons /spill
  3.5 s spill
- **Secondary beam:**
  75 GeV/c (dp/p ~ 1%)
  750 MHz rate
  6% $K^+$

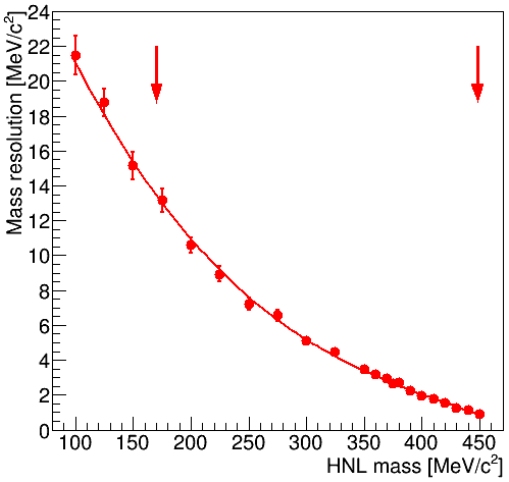


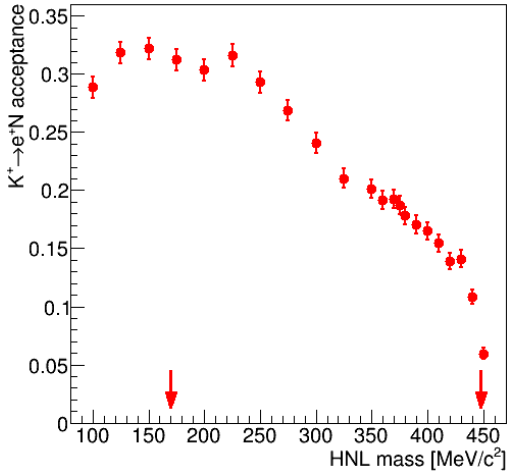
# NA62 2015 data: single-track sample

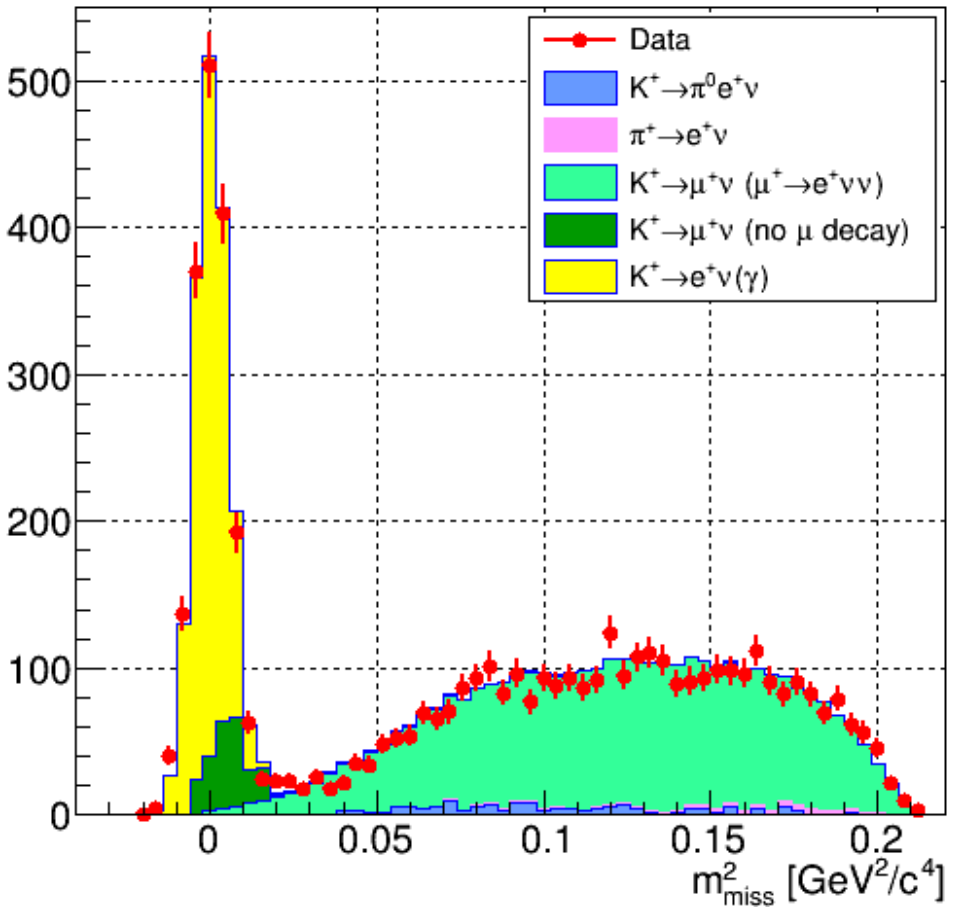
- Search for $\mathbf{K^+ \to e^+ N}$ performed in Missing Mass : $M_{miss} = \sqrt{(P_K - P_e)^2}$
- **Signal region** $M_{miss}$ ϵ **(170-448)** MeV/c$^2$
- **Minimum bias data** @ 1% nominal intensity
- No beam tracker -> average momentum using $K^+ \to \pi^+\pi^+\pi^-$
- $\mathbf{N_K = (3.01 \pm 0.11) \times 10^8}$ **in fiducial volume**

**MC simulation**

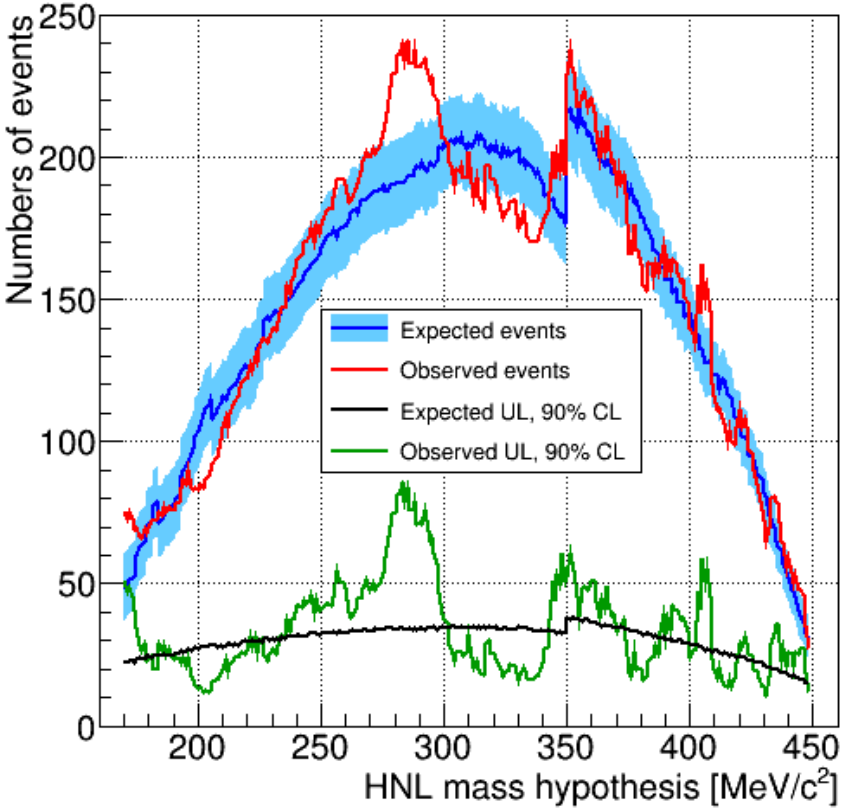
- Acceptance vs. HN mass: A($m_{N4}$ )
- $M_{miss}$ resolution vs. HN mass: σ($m_{N4}$)



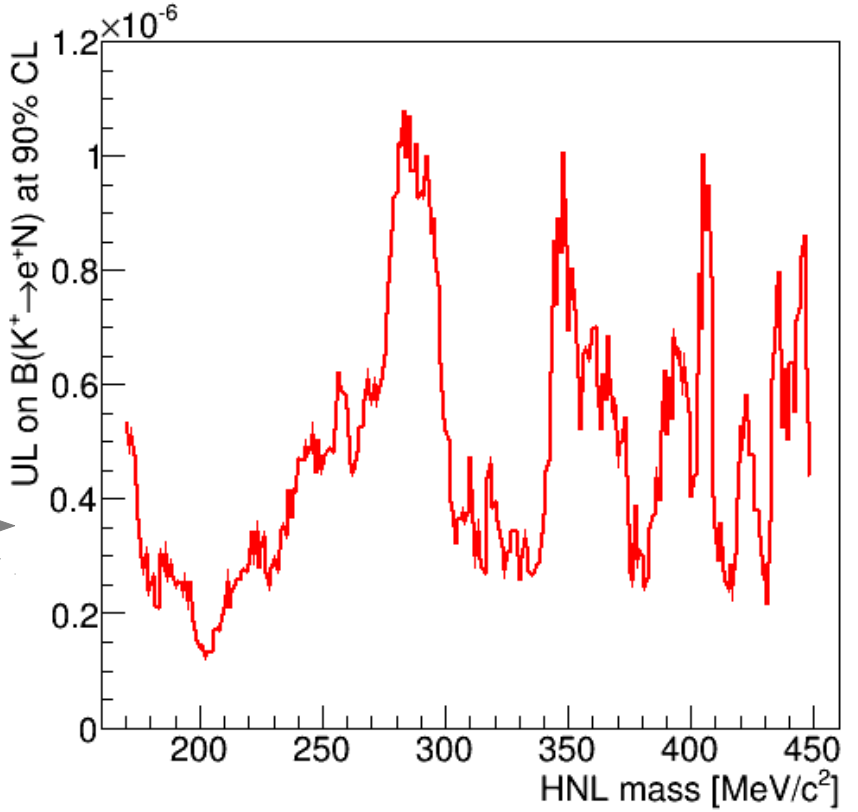



# ULs on $N_{sig}$ and $Br(K^+ \to e^+ N)$




$$\frac{1}{N_K \cdot A(m_{N4})}$$




- Rolke-Lopez method used to determine UL on $N_{sig}$.
- **Heavy neutrino mass step: 1 MeV/c²**
- Search window chosen to be $\pm 1.5\sigma(m_{N4})$
- Statistical significance never exceeds 3σ: **No signal observed**

# Summary

- **NA62 searches for heavy neutrino production in charged kaon decays were presented**
  → No heavy neutrino signal observed

- **Analysis of NA62 2007 data** (Phys.Lett. B772 (2017) 712):
  → About 60 x $10^6$ $K^+$ decays in the fiducial volume
  → Improves limits on $|U_{\mu h}|^2$ at the $10^{-5}$ level
  for $300 < m_{N4} < 375$ MeV/$c^2$

- **Analysis of NA62 2015 data (paper in preparation):**
  → About 300 x $10^6$ $K^+$ decays in the FV
  → New limits on $|U_{eh}|^2$ reaching $10^{-6} - 10^{-7}$
  for $170 < m_{N4} < 448$ MeV/$c^2$

- **Future prospects:**
  → Major analysis improvements with NA62 2016 high intensity data set (fully working beam tracker)