Recent results from

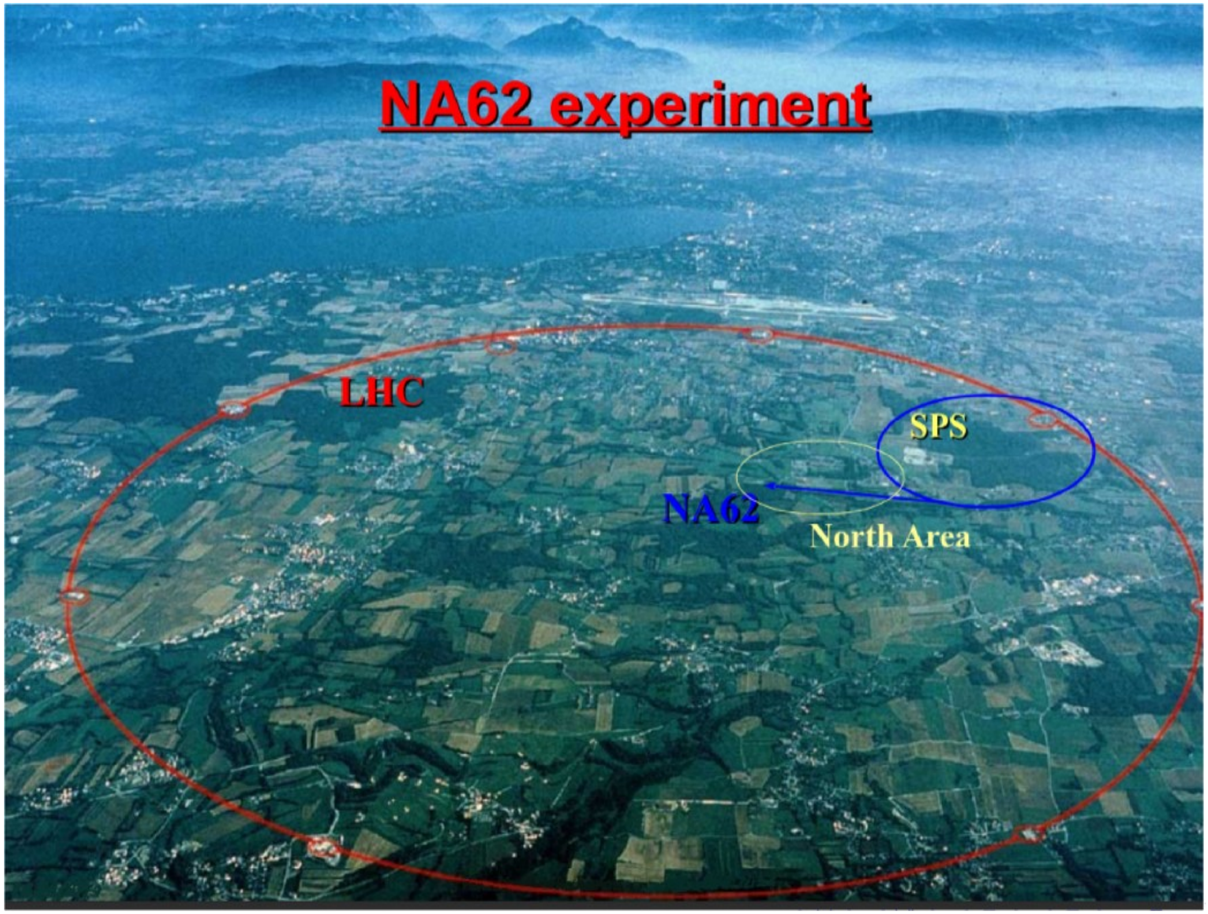
Elisa Minucci†
on behalf of the NA62 Collaboration

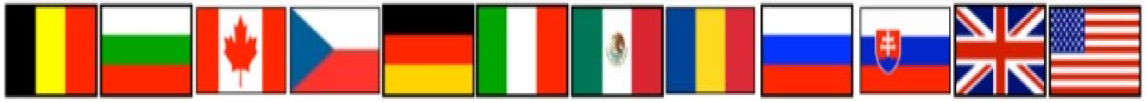
Rencontres du Vietnam : Neutrinos 2017

Quy Nhon July 21, 2017

† UCLouvain-CP3, Louvain-la-Neuve, Belgium

Kaons experiment @ CERN





Kaon decay in flight experiments.
NA62: ~200 participants, ~30 institutes

NA48 1997 – 2001
Discovery of direct CPV
K_L/K_S beam

NA48/1 2002
K_S/ hyperons

NA48/2 2003 – 2004
K^+/K^- beam **$K \rightarrow \mu\nu_h$, $\nu_h \rightarrow \pi\mu$**

NA62 – 2007 - 2008 phase
$R_K = K^{\pm}_{e2} / K^{\pm}_{\mu 2}$
K^+/K^- beam
$K^+ \rightarrow \mu^+\nu_h$

NA62
2014 pilot run
2015 commissioning run
2016 -: $K^+ \rightarrow \pi^+ \nu\nu$ run
K^+ beam
$K^+ \rightarrow e^+\nu_h$

This talk

Outline

- Theoretical motivations
- Search for HN production in $K^+ \to \mu^+ \nu_h$ with NA62 2007 data sample
- Search for HN production in $K^+ \to e^+ \nu_h$ with NA62 2015 data sample
- Conclusions

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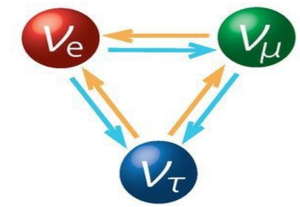
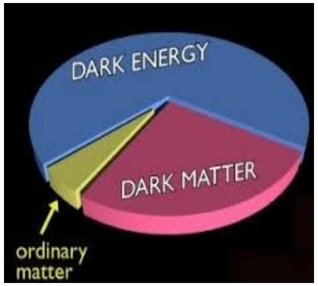
Why looking for heavy neutrinos?

- **Open theoretical issues:**
  - Neutrinos oscillations → non-zero neutrinos masses
  - Why neutrinos are lighter than the other leptons?
  - Presence of dark matter → no SM particle satisfies the dark matter properties
  - Baryon asymmetry
  - ...

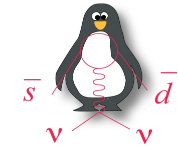




- **SM extentions →** Some of these issues:
  - neutrinos masses
  - the baryon asymmetry of the Universe
  - cosmic dark matter

can be explain **adding right handed (sterile) neutrinos** to the SM, which can mix with SM flavor states.

Why looking for heavy neutrinos @ GeV-scale?



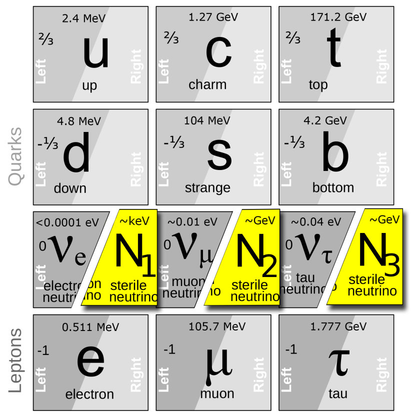
Gev-scale seesaw:

- HNLs with such masses can be efficiently searched for with the existing experimental techniques.
- HNLs for masses of active neutrinos can generate the baryon asymmetry of the universe via HNL oscillations
- HNLs with 0.2 GeV mass can play an important role in supernova explosions
- HNLs at GeV scale are also important for lepton number violation, flavor violation, lepton universality violation and neutrino-less double beta decay

A simple model is the Neutrino Minimal Standard Model (νMSM):

[Asaka et al., PLB 620 (2005) 17]

- 3 right-handed neutrinos N_i are added with m_i of the order or below the electroweak scale $O(10^2)$ GeV
- N_1, m_1 ~ O(10 KeV) possible dark matter candidate
- $N_{2,3}$, $m_{2,3}$ ~ O(1 GeV)→ additional CPV-phases to account for Baryon Asymmetry



Heavy neutrinos observable via production or decay

Assuming Heavy Neutrinos (HN) masses are below the kaon mass

PRODUCTION

Search for a peak in $m_h^2 = m_{miss}^2 = (p_K - p_l)^2$

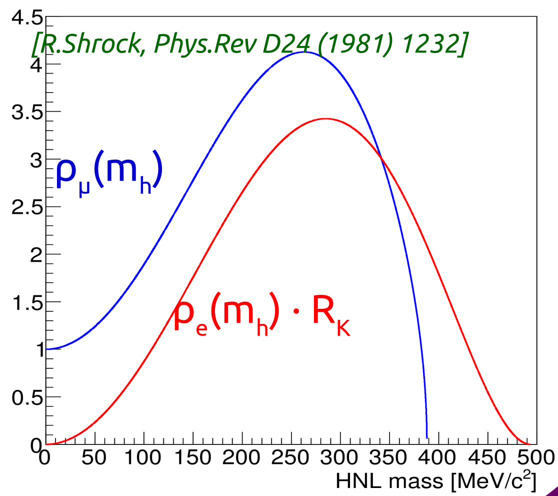
Width of the K^+ leptonic decay involving SM neutrino

Mixing matrix element

$$\Gamma(K^+ \to l^+ \nu_h) = \Gamma(K^+ \to l^+ \nu) \cdot \rho_l(m_h) \cdot |U_{l4}|^2$$

Kinematic factor phase space and helicity suppression

This Talk



DECAY

Heavy neutrinos decay only into SM particles

$$\Gamma(\nu_h \to \text{SM particles}) \sim |U_{l4}|^2 \cdot m_h^3$$

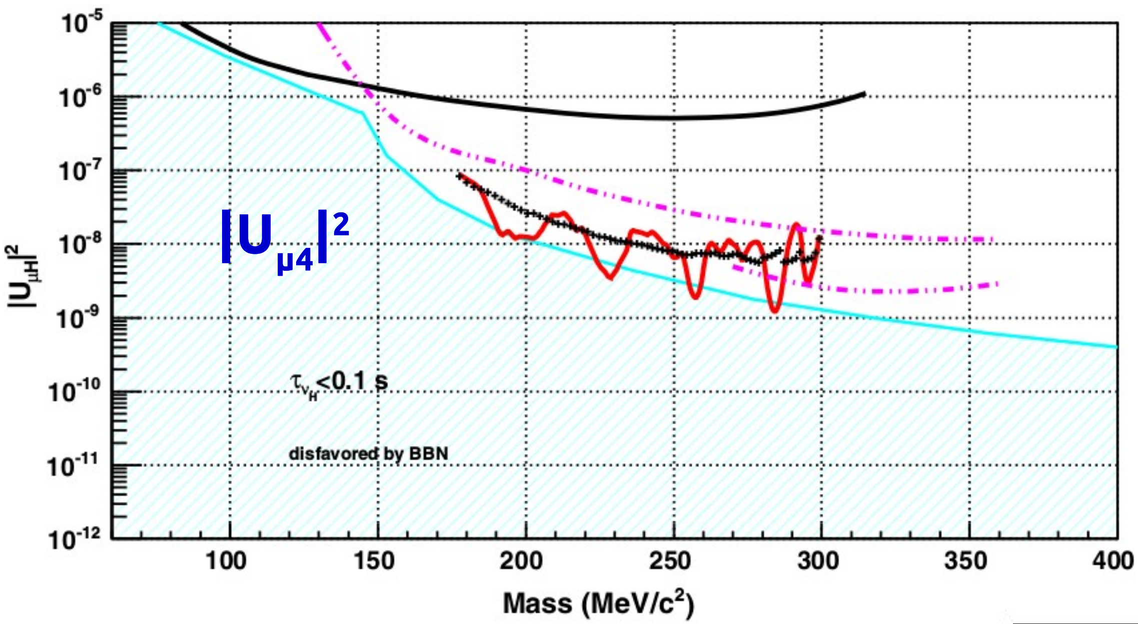
For HN mass below 500 MeV/c² the dominant decays are:

$$\nu_h \to \pi^0 \nu, \ \nu_h \to \pi^\pm \mu^\pm, \ \nu_h \to \pi^\pm e^\pm, \ \nu_h \to \nu\nu\nu$$

In NA62 the mean free path for $K^+ \to \mu^+ \nu_h$ and $K^+ \to e^+ \nu_h$, assuming $|U_{l4}|^2 < 10^{-4}$ is greater than 10 Km → heavy neutrinos decays are negligible.

Possible analysis in dump mode

Some previous Limits on $|U_{l4}|^2$



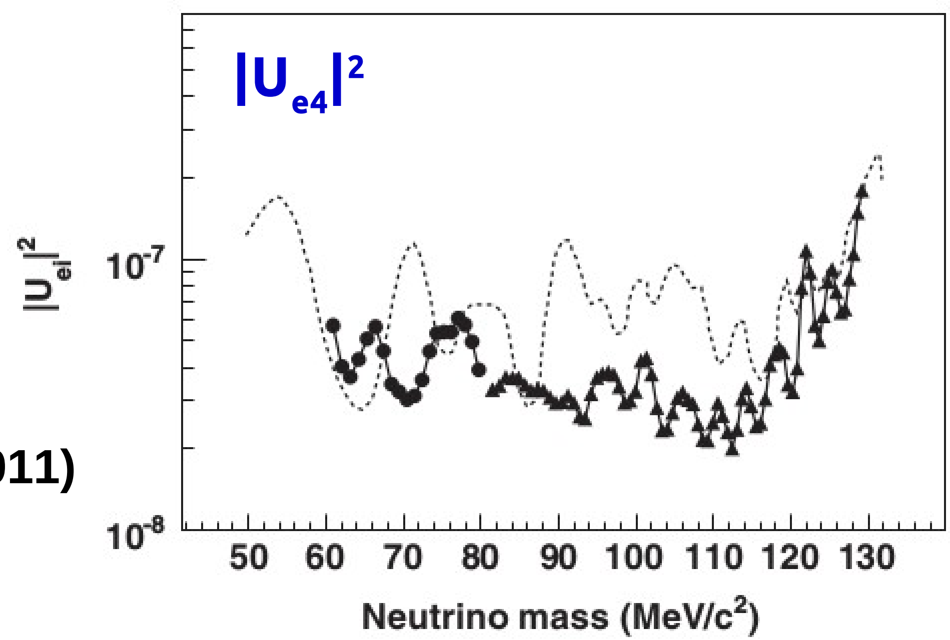
[M. Artamov et al., Phys Rev D91 (2015)]

Results from KEK K^+ decay (1984)

Results from PS191 HN decay

Results from E949 K^+ decay (2015)

Low masses limit set at 10^{-8} → NA62 analysis restricted to [300,380] MeV mass range



Results from PIENU π^+ decay (2011)

[M. Aoki et al., Phys Rev D84 (2011)]

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NA62 2007 experimental setup

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

[Phys. Lett. B 719 (2013) 326]

K^+ / K^- beam

Beam momentum: (74 ± 1.4) GeV/c

Sub-detectors

Magnetic spectrometer:

4 drift chambers(DCHs) + dipole magnet

$\sigma_P/p = 0.48\% \oplus 0.009\% \cdot p$

- LKr EM calorimeter

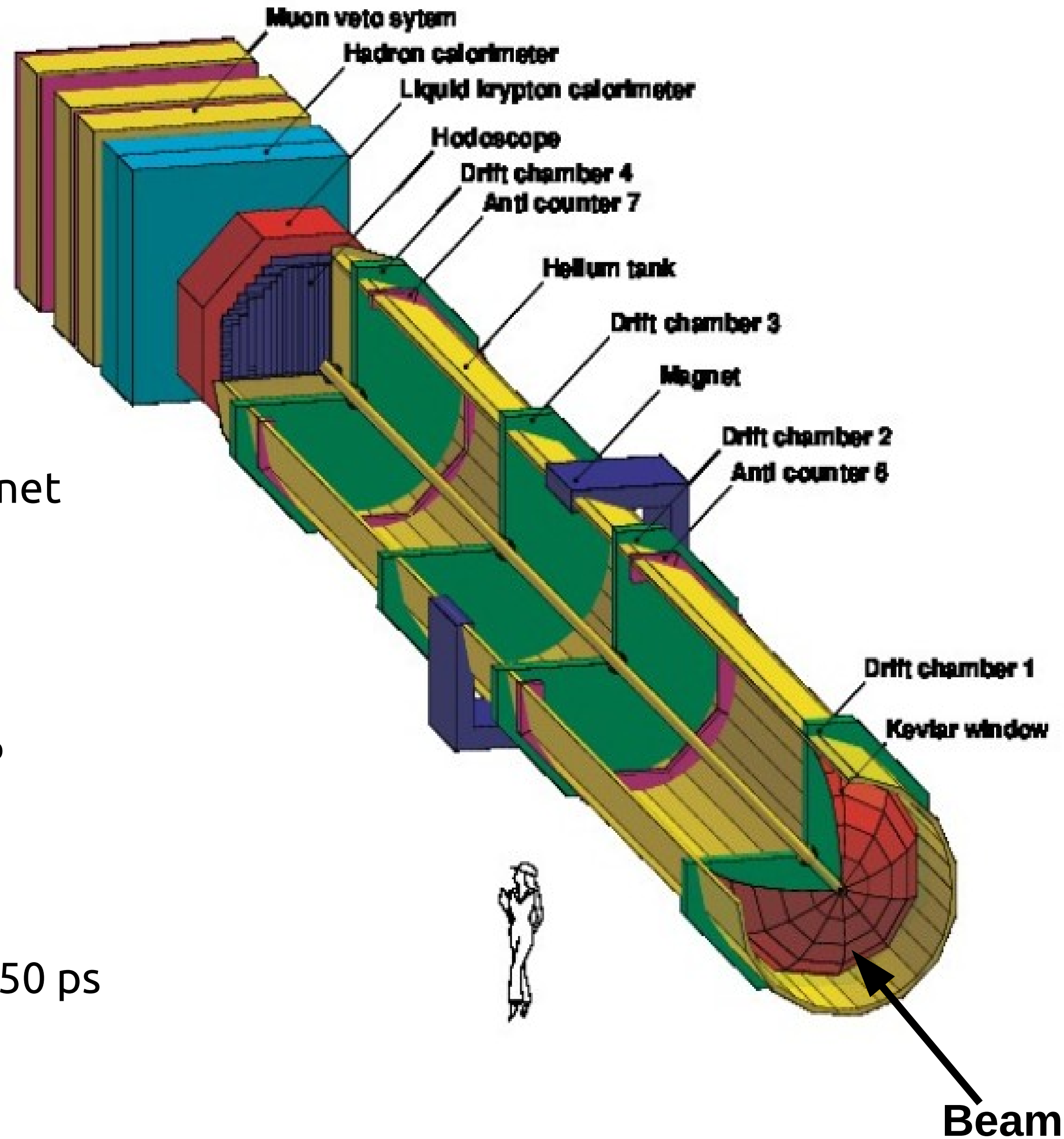
  $\sigma_E/E = 3.2\% /\sqrt{E} \oplus 0.9\% / E \oplus 0.42\%$

  $\sigma_x = \sigma_y = 4.2\text{ mm} /\sqrt{E} \oplus 0.6\text{ mm}$

- Hodoscope

  fast trigger, good time resolution ~ 150 ps

- Muon Veto system (MUV)



Heavy neutrino in NA62 – 2007: data sample

HN search in $K^+ \to \mu^+ \nu_h$ missing mass distribution

$$m_h^2 = (P_K - P_\mu)^2$$

in the 300-375 MeV/c² mass range

$P_K \to$ not on event-by-event basis from K3π reconstruction every 500 SPS spills

$P_\mu \to$ reconstructed charged track assumed to be a muon

Trigger:
one track event downscale D = 150

Event Selection:

- One positively charged track with $P \in [10,65]$ GeV/c in DCH, Lkr and MUV acceptance
- Distance of closest approach < 3cm
- No clusters in Lkr with E>2 GeV not associated to the track
- Multi dimentional cut in $(Z_{vtx},\theta,p,CDA,\Phi)$ to suppress muon halo background

Data sample

Analysis based on data with K^+ beam only
(muon halo background smaller than for K^- beam)

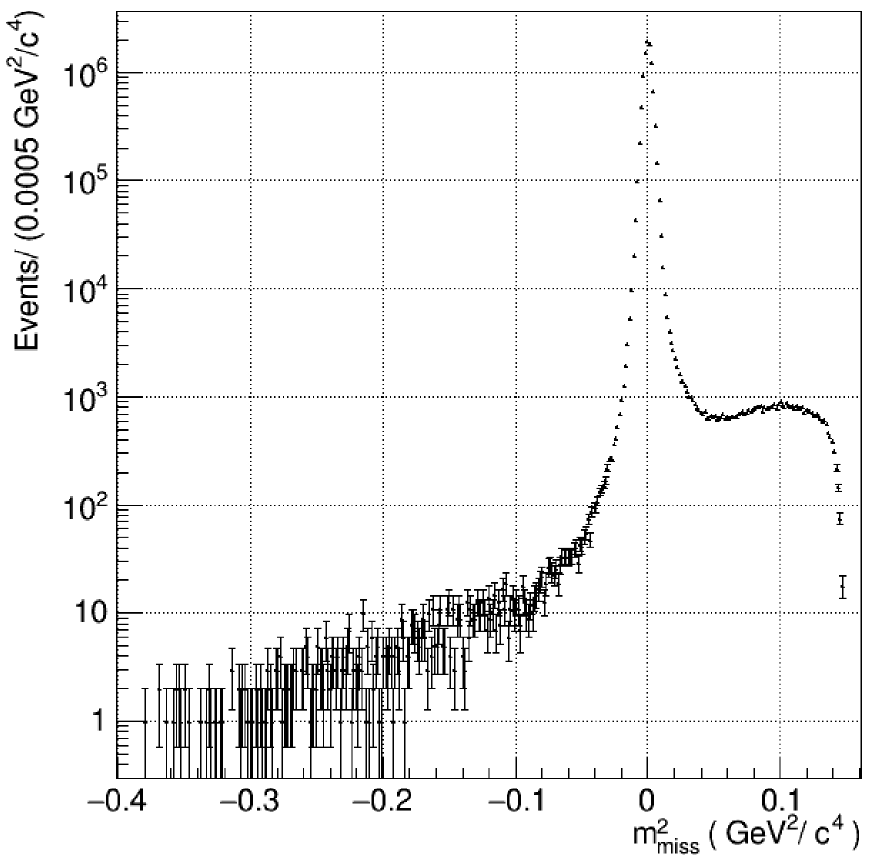
Data taken with K^- beam only used to study the background from halo muons

Dedicated HN MC simulation with mass m_h [240,380] MeV/c² for acceptance and resolution studies as a function of HN's mass at 1MeV/c² intervals

Heavy neutrino in NA62 – 2007: Background

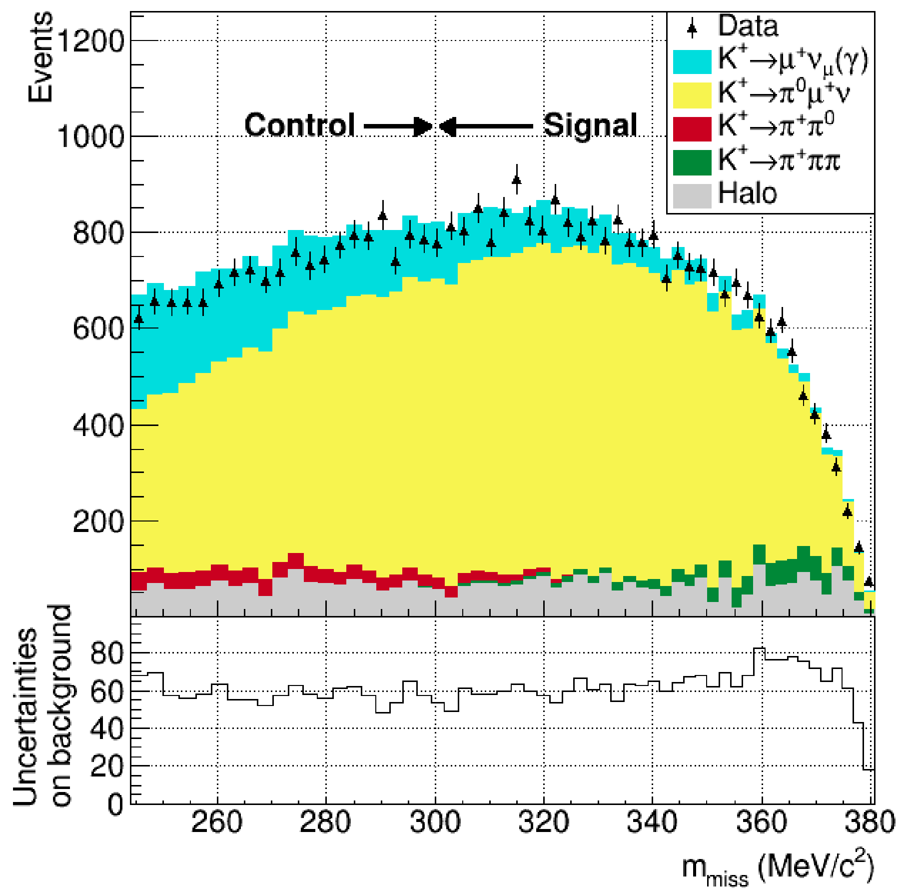
Kaon decays in the fiducial volume from reconstructed $K^+ \rightarrow \mu^+ \nu$

$N_K \sim 6 \times 10^7$



Background contributions:

- Muon halo data driven study
- Kaon decays MC simulation



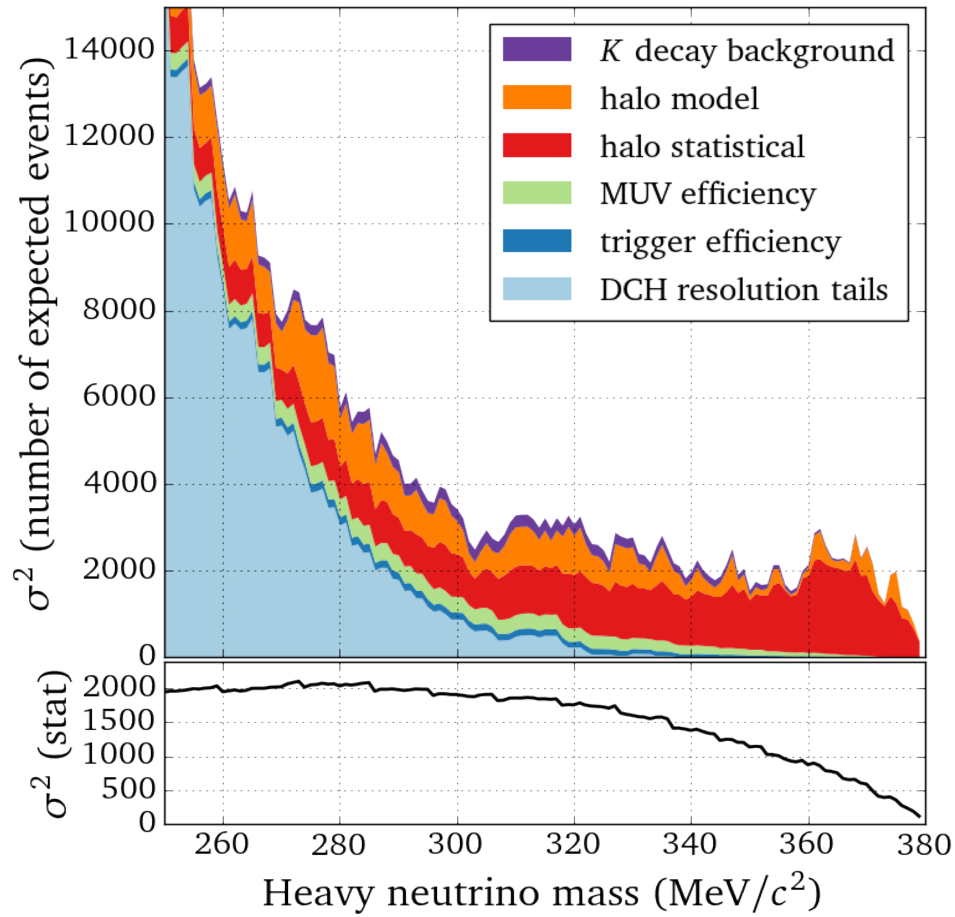
Heavy neutrino in NA62 – 2007: Background

Systematic uncertainties as a function of the m_{miss}

Systematic uncertainties: N_K, Br, limited size of the control sample

Kaon decay background:
0.6% - 1% systematic uncertanty
Dominated by Br(Kμ3)
0.2% → associated with N_K
0.15% → contribution from Br(Kμ2)

Muon Halo background:
5% - 20% systematic uncertainty

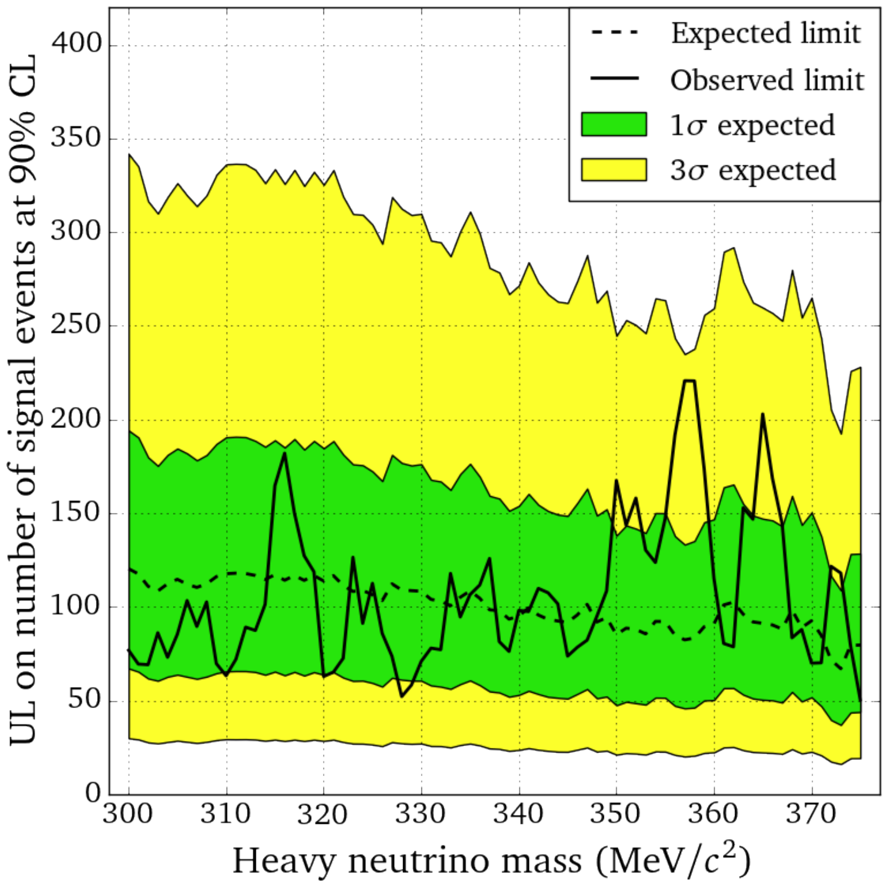


Heavy neutrino in NA62 – 2007: Results

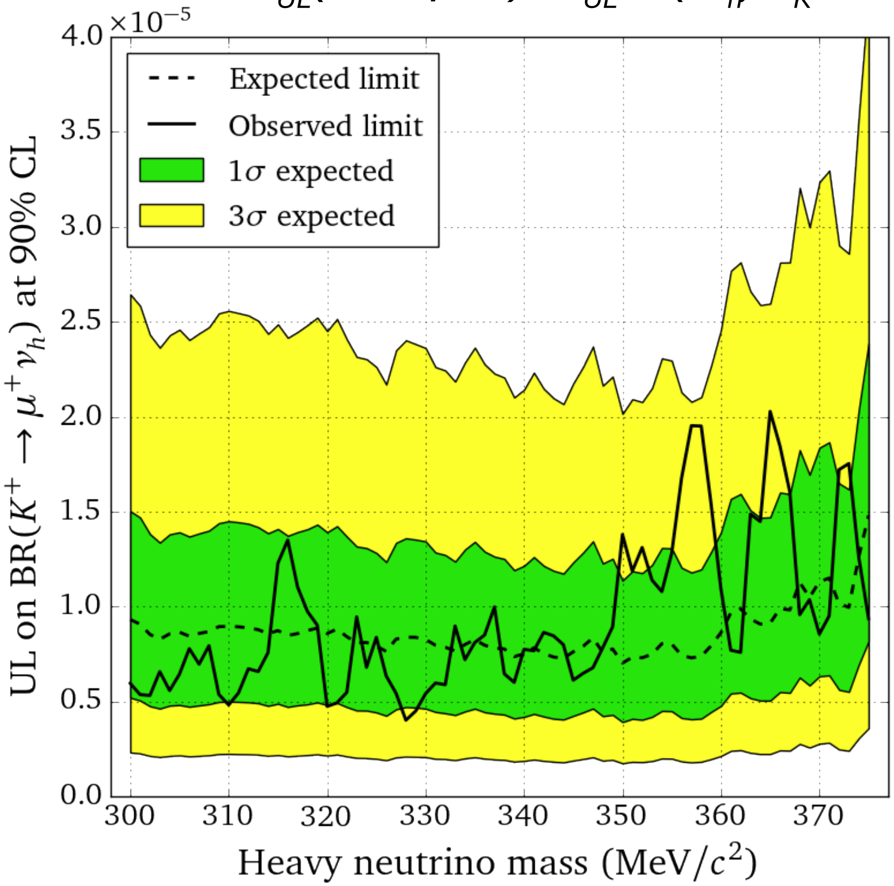
Rolke-Lopez method to find upper limits (Poisson process/Gaussian backgrounds)

No HN signal observed with >3σ significance

$n_{obs} = n_{exp} = n_{bkg}$

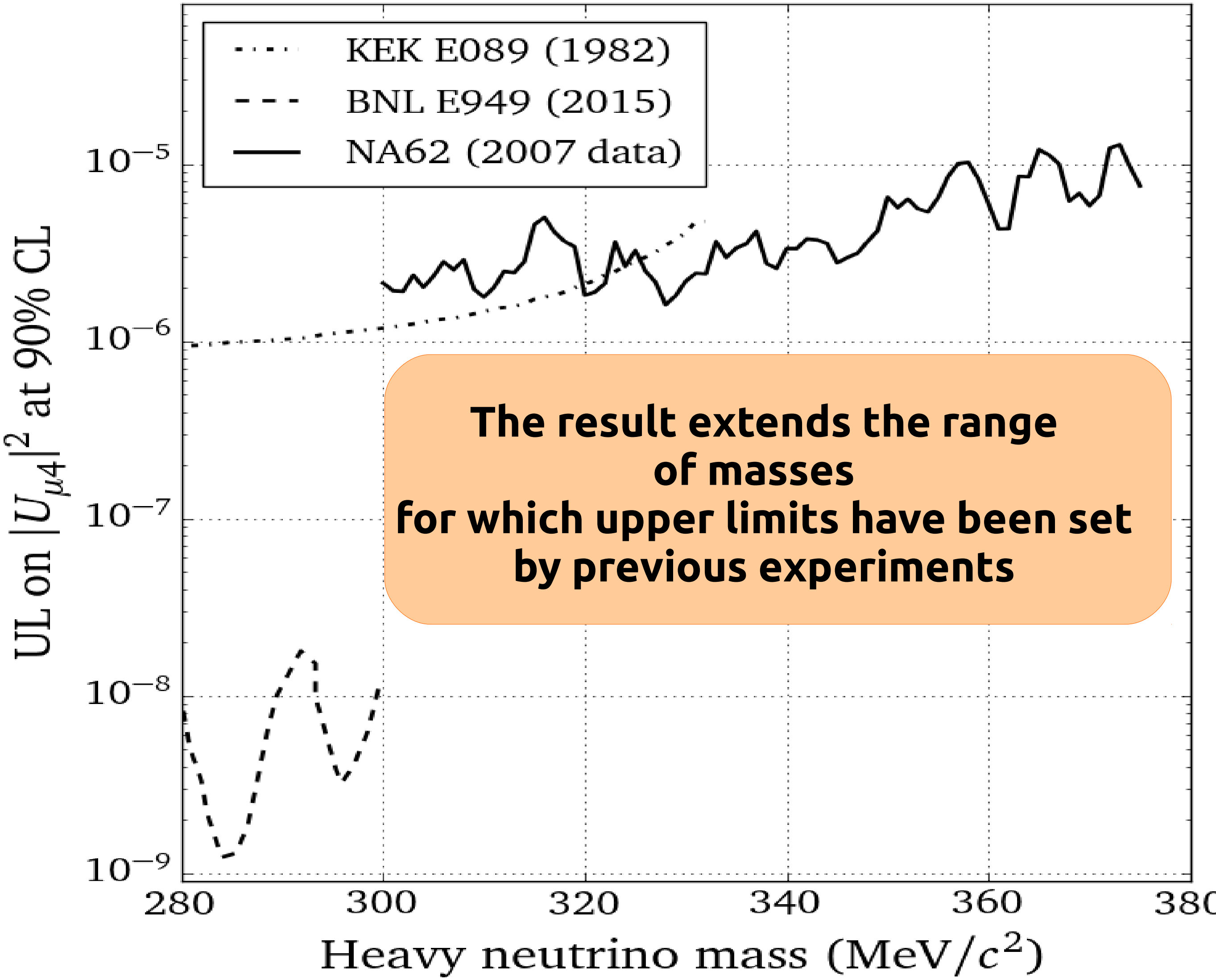


$\mathcal{B}_{UL}(K^+ \to \mu^+ \nu) = n_{UL} / A(m_h) N_K$



Heavy neutrino in NA62 – 2007: Results

Comparison with existing measurements



The result extends the range of masses for which upper limits have been set by previous experiments

arXiv:1705.07510

Submitted to Phys. Lett B

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NA62 experimental setup

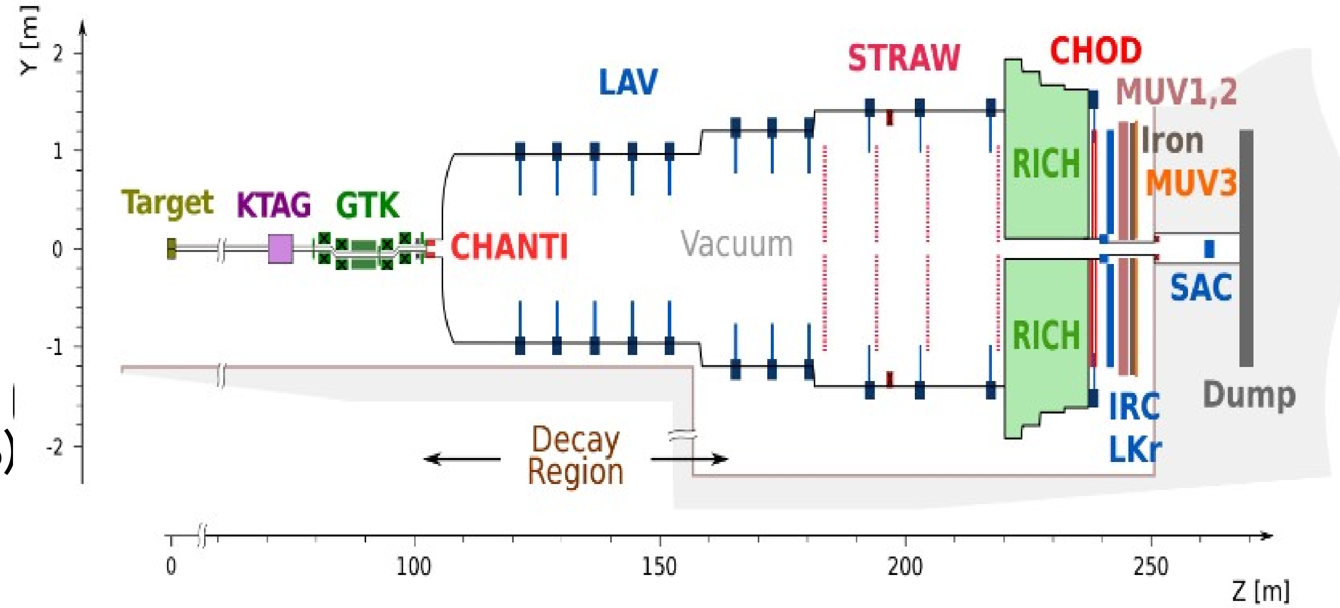
Main goal 10% precision measurement of $\mathcal{B}(K^+ \rightarrow \pi^+\nu\nu)$

High beam intensity

Large signal acceptance

Precise timing → 100-150 ps

Beam momentum: 75GeV/c (±1%)



Sub-detectors:

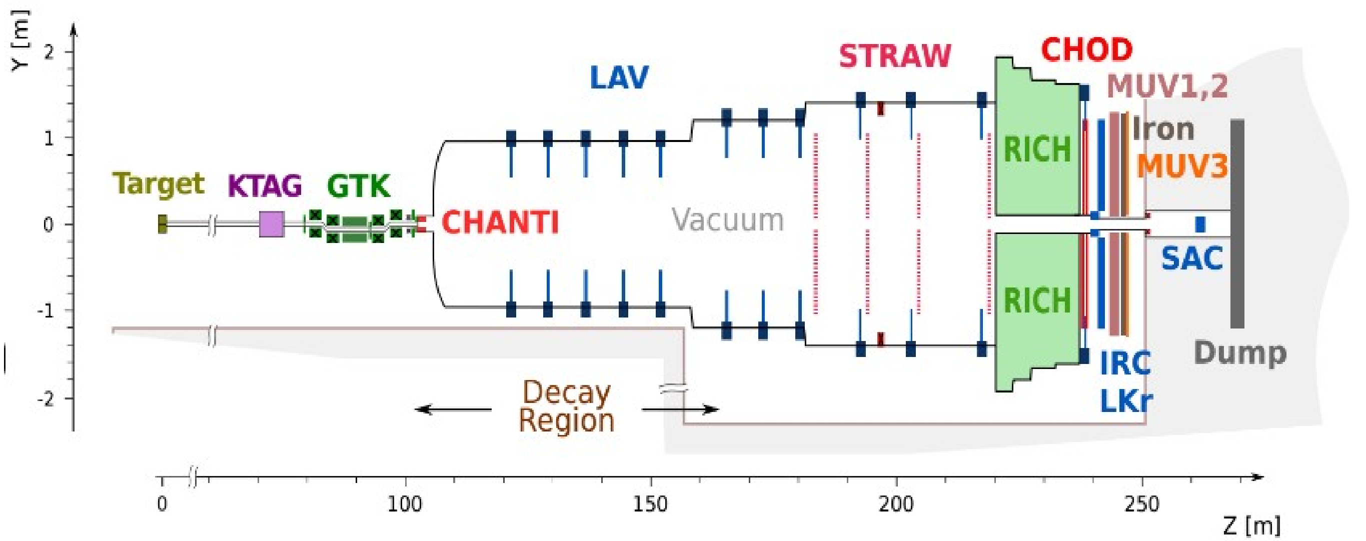
- **Tracking**: Kaon (GTK)
  π/μ/e (STRAW)
- **Particle Identification**:
  - Kaon in the beam (KTAG)
  - π/μ/e (RICH, Lkr, MUV)
- **Hermetic Veto detectors**:
  - Photons (LAV, LKr, SAV)
  - Muons (MUV)

Heavy Neutrino with NA62 2015 data sample

Minimum bias runs

Beam intensity 0.4% – 1.3% of the nominal one

kaon tracker not yet available
beam momentum K3π sample



Trigger conditions:

CHOD/D_1 *

CHOD x !MUV3

MUV3/D_2 *

* D_1, D_2 downscaling factors

Background studies with MC sample:
- standard decay region → for K^+ decays
- standard upstream region → to study the beam bkg from kaon decays upstream

$K^+ \rightarrow e^+ N$ event selection:
- 1 positive track with p ∈ [5,70]GeV/c and in STRAW, Lkr, MUV acceptance
- CDA < 25 mm, Z_{vtx} > 115 m
- No Lkr cluster d>50 mm from track impact point
- LAV, SAV and MUV veto
- 0.9 < E/p < 1.15

Heavy Neutrino with NA62 2015 data sample

HN search in $K^+ \to e^+ \nu_h$ missing mass distribution

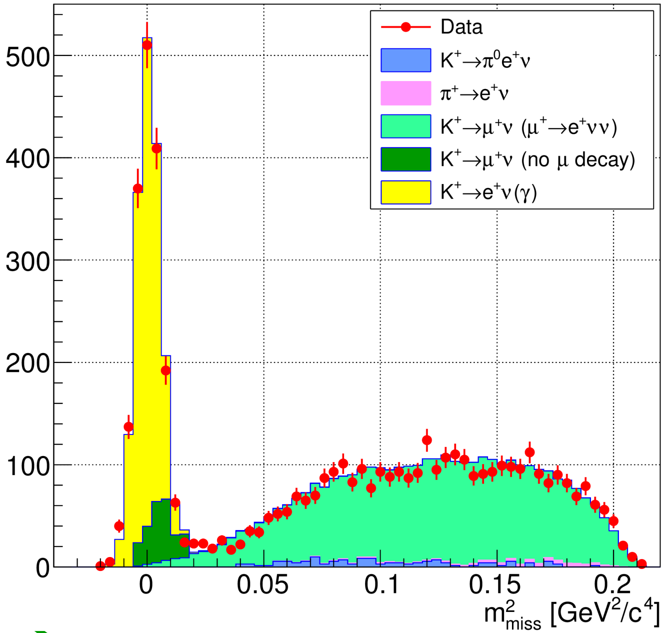
$$m_h^2 = (P_K - P_e)^2$$

in the 170 - 448 MeV/c² mass range

$P_K \to$ event-by-event basis from K3π reconstruction
$P_e \to$ reconstructed charged track assumed to be an electron

$$N_K^e = (3.01 \pm 0.11) \times 10^8$$

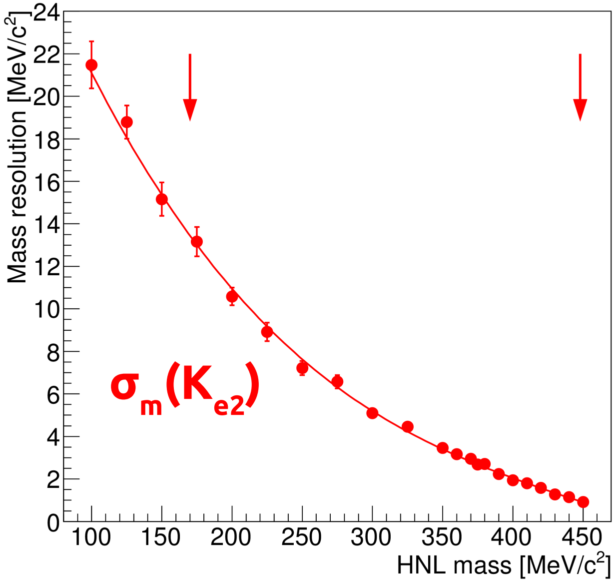
$$N_K^e = N_K / (A_e(K_{e2}) \cdot \mathcal{B}(K^+ \to e^+ \nu) + A_e(K_{\mu 2}) \cdot \mathcal{B}(K^+ \to \mu^+ \nu))$$



Mode	Branching fraction	Background
Kμ2(γ)	0.6356	3289 ± 10
Kμ2(γ) – μ Mis-ID	0.6356	0.6 ± 0.4
Kμ2(γ) (upstream)	0.6356	< 3.4
$K^+ \to e^+\nu\gamma$ (IB)	$1.582 \cdot 10^{-5}$	0.2 ± 0.1
$K^+ \to e^+\nu\gamma$ (SD+)	$1.30 \cdot 10^{-5}$	7.3 ± 0.2
$K^+ \to \pi^0 e^+\nu$	5.07 %	143 ± 14
$\pi^+ \to e^+\nu$	$1.123 \cdot 10^{-5}$	66 ± 7
Total		**3506 ± 19 ± 128**
Data Events		**3390**

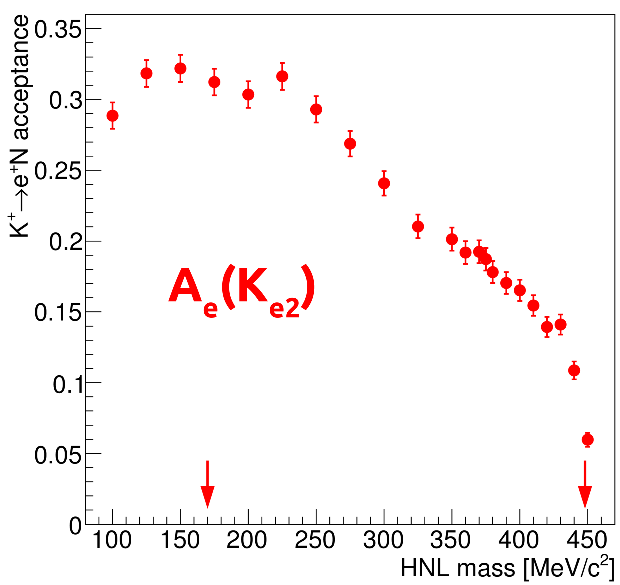
Heavy Neutrino with NA62 2015: Single Event Sensitivity

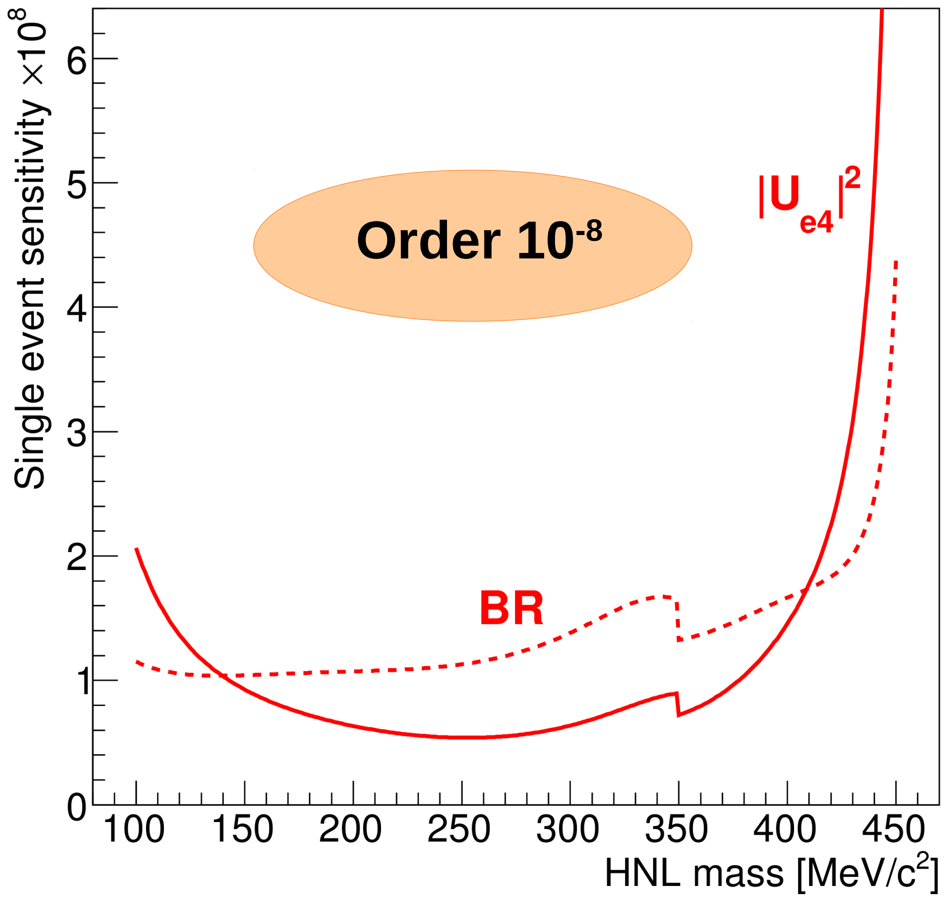
Single event sensitivity defined for each HN mass :



$$BR(K^+ \to e^+ N) = 1/N_k^e \cdot A(K^+ \to e^+ N)$$

$$|U_{e4}|^2 = BR(K^+ \to e^+ N)/BR(K^+ \to e^+ \nu) \;\cdot\; \rho_e(m_h)$$





Heavy Neutrino with NA62 2015: limits

Background estimate comes from polynomial fit of data missing mass spectrum

(MC sample used only for qualitative understanding of the bkg)

Rolke-Lopez method to compute 90% CL

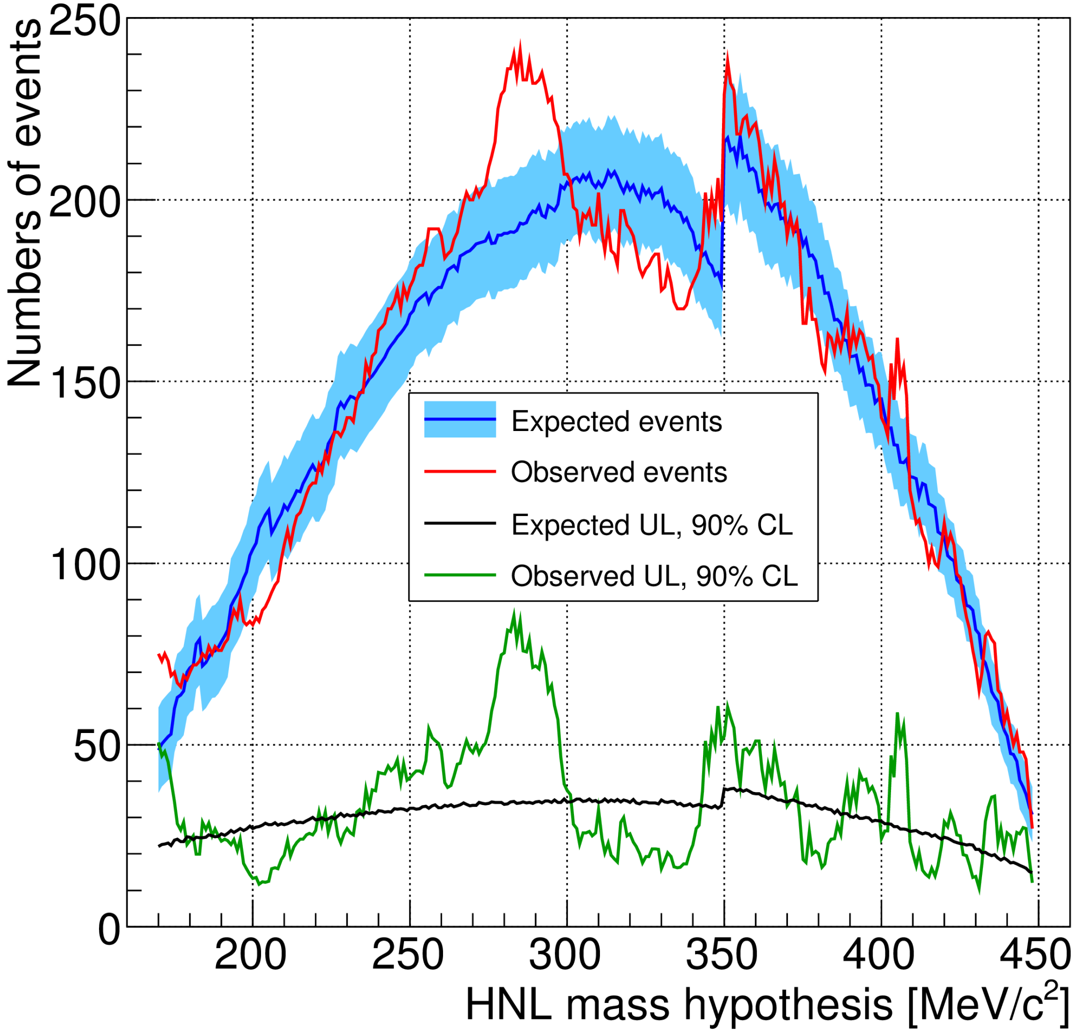
N_{obs} → number of observed events in each HN mass hypothesis evaluated within ±1.5σ_m signal window

N_{exp} → number of expected bkg

Uncertainties on N_{exp} typically ~ 10%

- Limited size of data sample
- Systematic uncertainty

(assesed using toy MC)



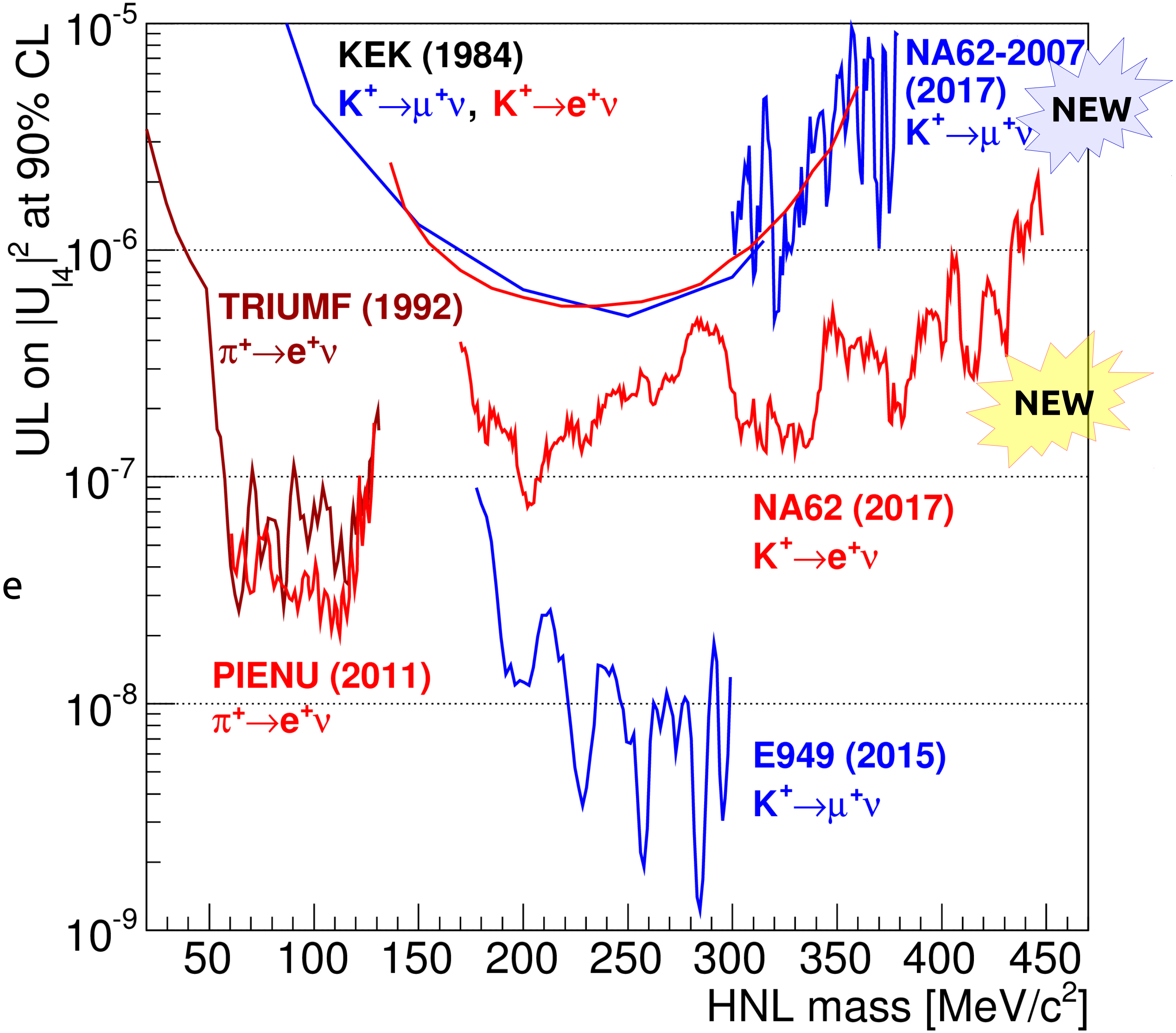
World Limits on $|U_{l4}|^2$

$K^+ \rightarrow \mu^+ \nu_h$ **NA62-2007**

Set limits in a new mass range
At the 10^{-5} level

$K^+ \rightarrow e^+ \nu_h$ **NA62**

Limit O(10^{-7})improved in a large mass range

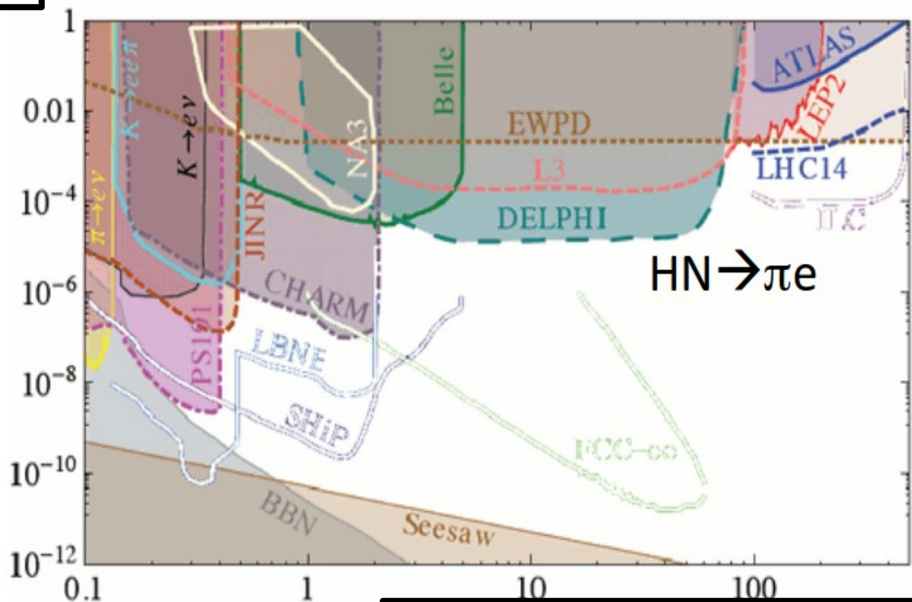


Prospects for HN decays in NA62: dump mode

Decay modes HN → πμ, HN → πe

Search for appearance of single electron/muon afer dump

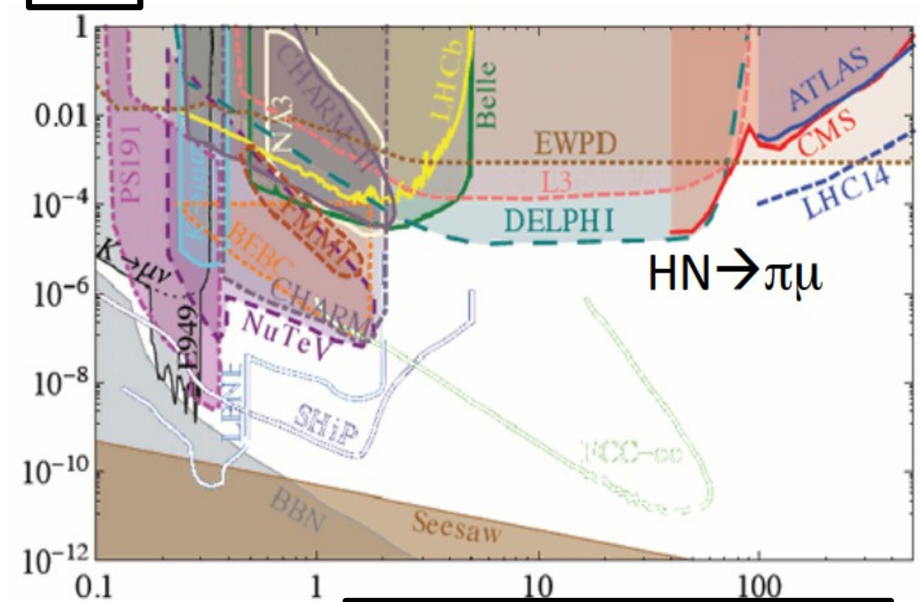
|U$_{eH}$|



sterile neutrino mass (GeV)

|U$_{\mu H}$|

[Alekin et al.,arXiv:1504.04855)]



sterile neutrino mass (GeV)

NA62 sensitivity: improvement of two-three orders of magnitude with respect to past experiments between the kaon and the beauty mass.
Zero-background limit with 2x10^{18} 400 GeV POT(~ 1year long data taking in dump mode)

Conclusions

- NA62 searches for heavy neutrino production in charged kaon decays were presented:

No heavy neutrino signal observed

- **Analysis of NA62 2007 data**
  - $N_K \sim 6 \times 10^7$ kaon decays in the fiducial volume
  - Set limits on $|U_{\mu 4}|^2$ for $m_h \in [300,375]$ MeV/c^2

- **Analysis of NA62 2015 data**
  - $N_K \sim 3 \times 10^8$ kaon decays in the fiducial volume
  - New limits on $|U_{e4}|^2$ for $m_h \in [170,448]$ MeV/c^2

- **Future prospects:** analysis of data taken in the 2016: higher beam intensity, kaon tracking available give more statistics, improved resolution, lower background → improve limits

Thanks for your attention