New limits on heavy neutrino at NA62

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on behalf of the NA62 collaboration

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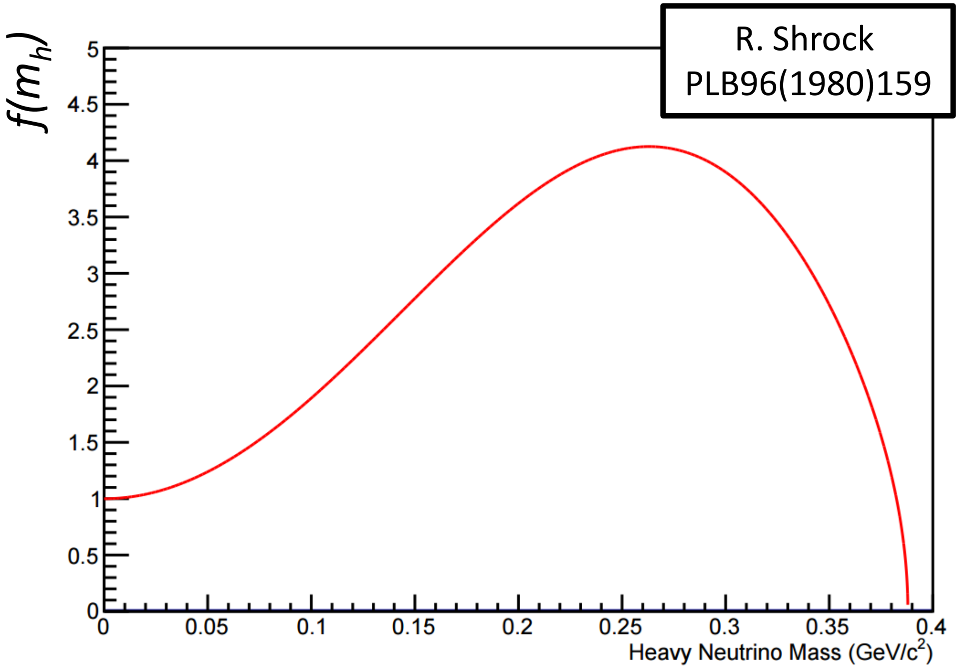
Motivation

- There are various extensions of the Standard Model that accommodate massive neutrinos
- Typically heavy neutrino mass states are introduced to drive the SM neutrino masses to small values via the see-saw mechanism
- These heavy mass states mix with the SM flavour states

- The ratio of the $K^+ \rightarrow \mu^+ \nu_N$ decay rates between the SM (ν_μ) and heavy neutrino (ν_h) is

$$\frac{\Gamma(K^+ \rightarrow \mu^+ \nu_h)}{\Gamma(K^+ \rightarrow \mu^+ \nu_\mu)} = |U_{\mu 4}|^2 f(m_h)$$

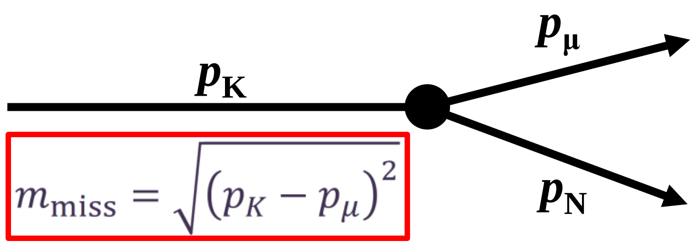
where $f(m_h)$ accounts for phase-space and helicity suppression



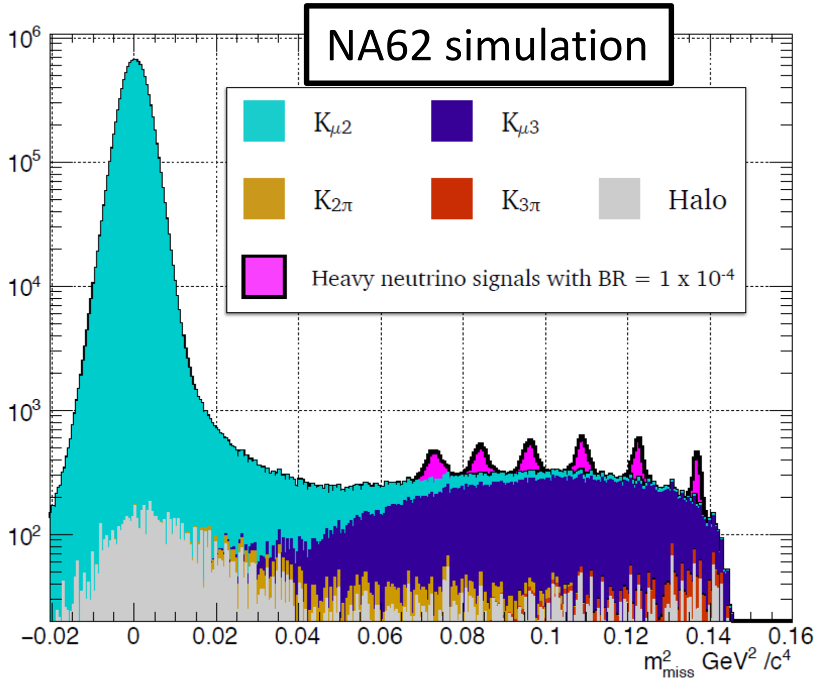
R. Shrock
PLB96(1980)159

Measurement Strategy

- Many existing limits require the heavy neutrino to decay within the fiducial volume of the experiment
- This is not required at decay-in-flight Kaon experiments like NA62 where “missing mass” methods can be used
- NA62 makes a measurement of heavy neutrino **production**
  - NB limits on production scale linearly with the number of Kaons



$$\boxed{m_{\text{miss}} = \sqrt{(p_K - p_\mu)^2}}$$

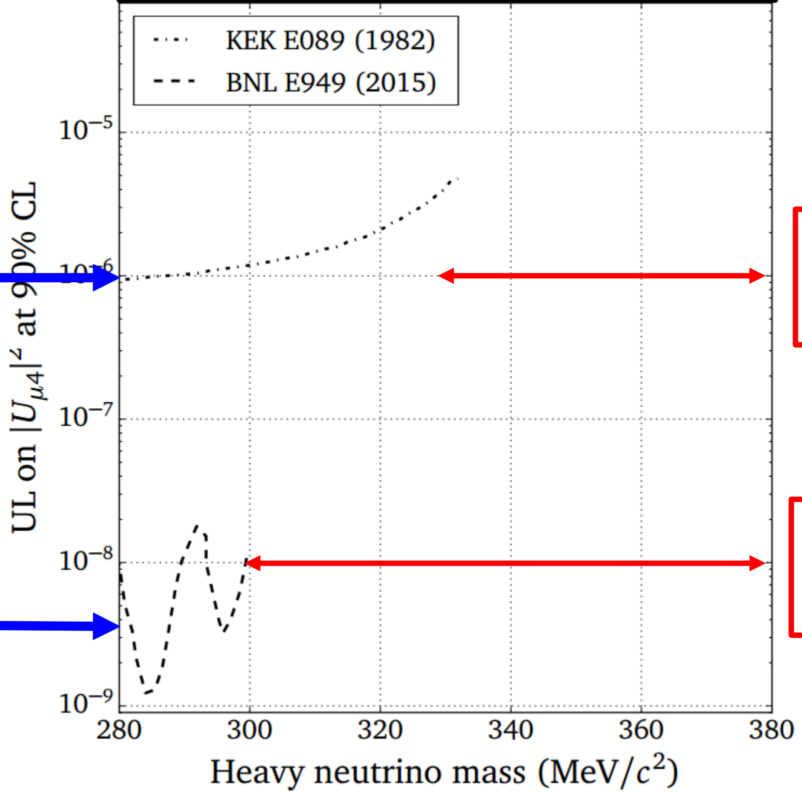


- The missing mass is the mass of the heavy neutrino

$$m_h^2 = p_N^2 = (p_K - p_\mu)^2$$

Existing production measurements

Production measurements only



Limits @ 10^{-6} from the KEK E089 experiment for $m_N < 330\text{MeV}/c^2$
Phys. Rev. Lett. 49 (1982) 1305

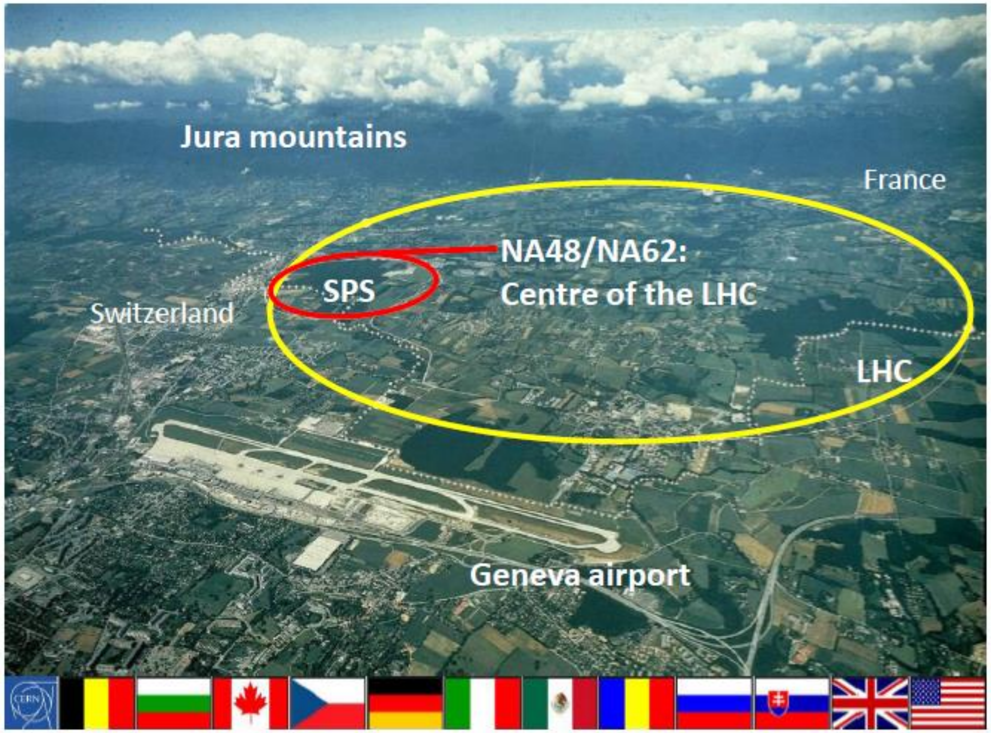
Limits @ 10^{-8} from the BNL E949 experiment for $m_N < 300\text{MeV}/c^2$
Phys. Rev. D 91 (2015) 052001

No limits on production @ 10^{-6}

No limits on production @ 10^{-8}

Kaon experiments at CERN

- The NA62 experiment is located at the North Area (NA) of CERN
  - Protons are extracted from the SPS with *p*=400 GeV/c
  - The protons impinge on a target, producing a secondary beam of hadrons
  - About six percent of those hadrons are Kaons



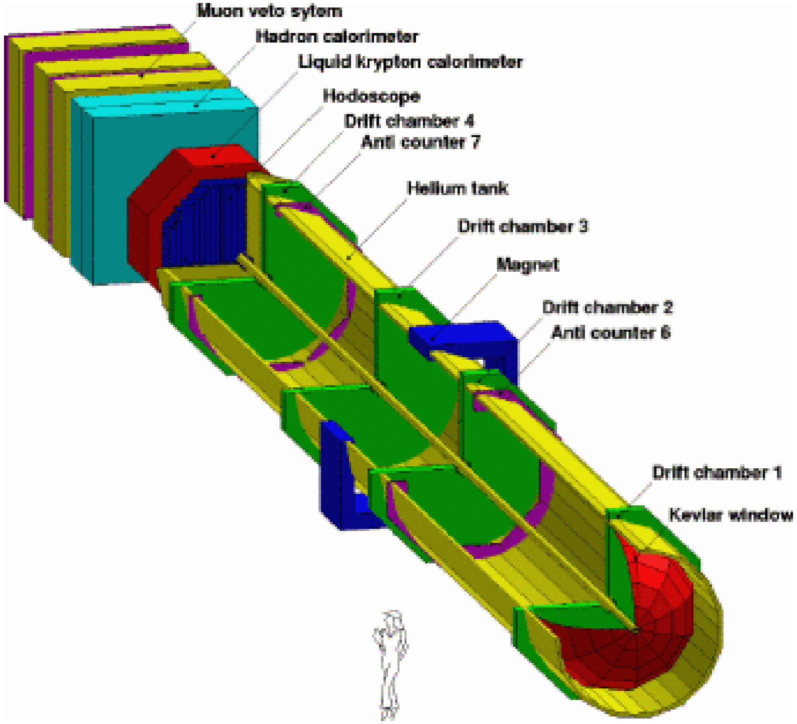
NA Kaon experiments		
2007 ↓ 2008	NA62 2007 (K^+/K^-)	$R_K = K^\pm_{e\nu}/K^\pm_{\mu\nu}$
2009 ↓ 2018	NA62 (K^+)	$K^+ \to \pi^+\nu\nu$ Rare K^+ and π^0 decays

NA62: currently ~200 collaborators from 28 institutes around the world

The NA62 (2007) detector

Principal detector systems

- Scintillator hodoscope (HOD)
  - Low-level trigger,
    time measurement (150ps)
- Magnetic spectrometer (4 DCHs)
  - 4 views/DCH high efficiency
  - $\sigma_p/p = 0.48\% \oplus 0.009\% \cdot p$ [GeV/c]
- Liquid Krypton EM calorimeter (LKr)
  - High granularity, quasi-homogeneous
  - $\sigma_E/E = (3.2/\sqrt{E} \oplus 9.0/E \oplus 0.42)\%$ [GeV/c]
  - $\sigma_x = \sigma_y = (4.2/\sqrt{E} \oplus 0.6)$ mm
    (1.5mm @ 10GeV)
- Muon veto system (MUV)



Data taking conditions

- $P_K = 74 \pm 2$ GeV/c
- Triggers: 1-track e^+, 1-track μ^+
- Alternate K^+/K^- beam,
  possibility to block both beams (K_{less})

Data sample (2007)

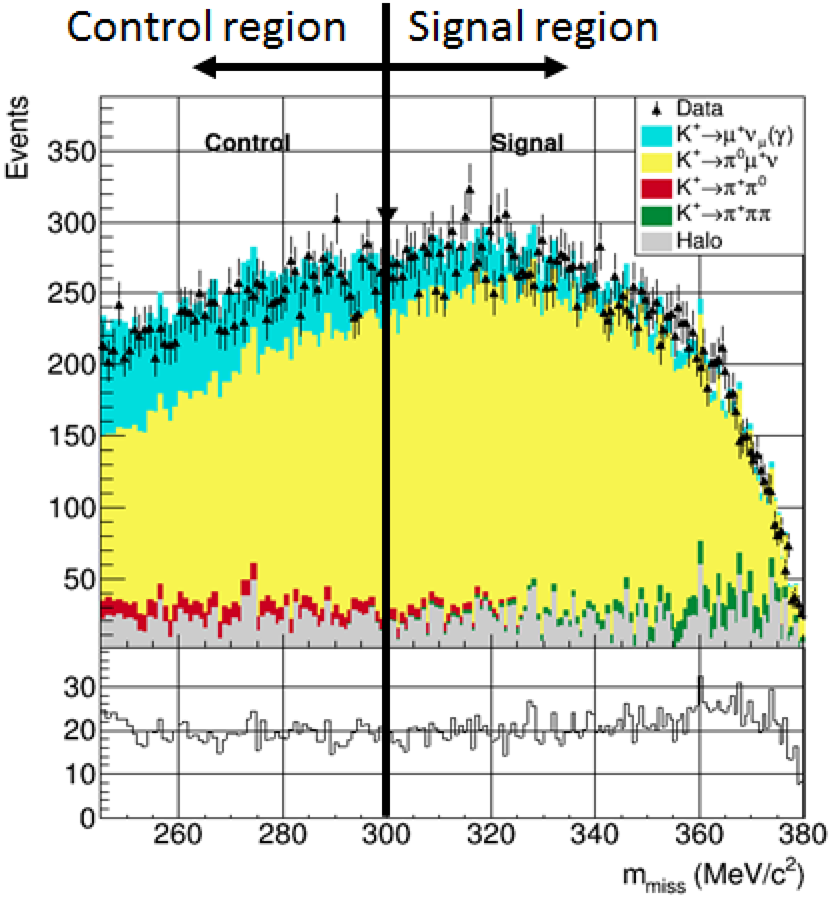
Dataset collected in during 2007

Trigger requirement:

- One-track $\mu^{\pm}$ trigger (downscaling = 150)

Selection requirements:

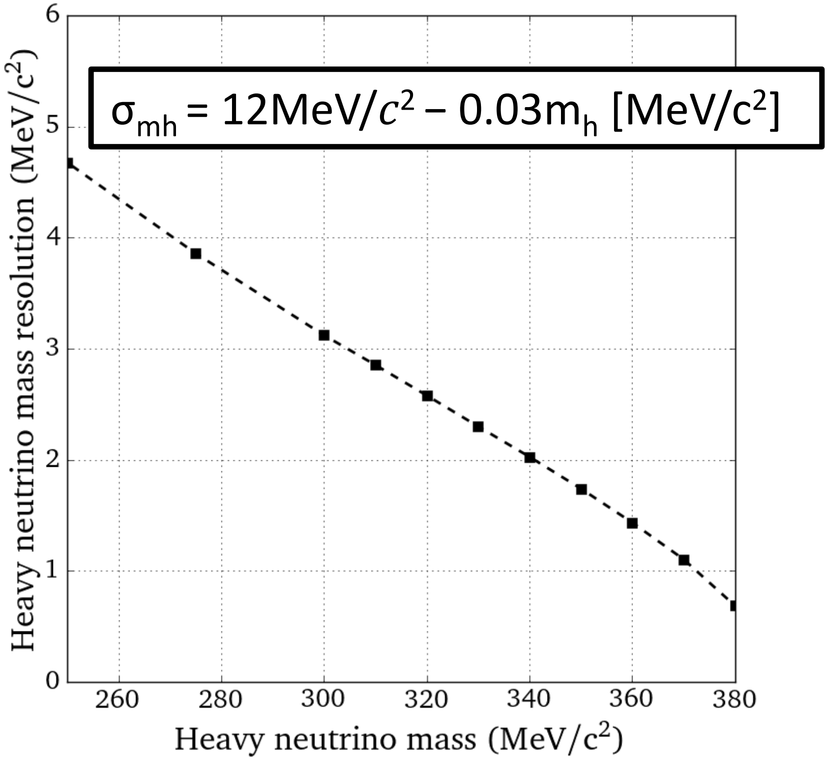
- One positively-charged muon track
- No cluster of energy deposition with E > 2GeV not associated with the track
- Multi-dimensional cuts in (z_{vtx}, θ, *p*, CDA, ϕ) to suppress **halo muons**
- Signal region: $300 < m_{miss} < 375$ MeV/c^2



Around 8M $K^+ \to \mu^+ \nu_\mu$ decays satisfy the trigger and selection criteria

Upper limit on signal events

- Set a limit on the number of heavy neutrino decays $n_{UL}(m_h)$ using the Rolke-Lopez method [ref]
  - $n_{UL}(m_h)$ obtained from numbers of **n_{obs}** and **$n_{expected}$** events, and the uncertainty on $n_{expected}$
  - Step size of 1MeV/c^2, window size defined by heavy neutrino mass resolution

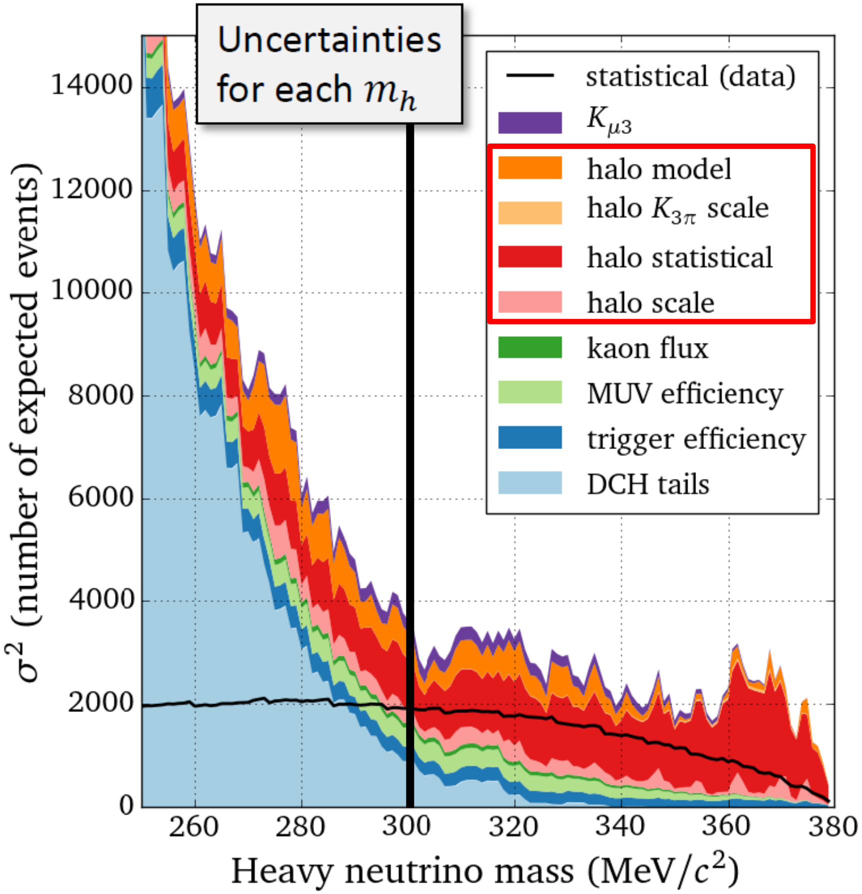


σ_{mh} = 12MeV/c^2 – 0.03m_h [MeV/c^2]

Background estimation

- Set a limit on the number of heavy neutrino decays $n_{UL}(m_h)$ using the Rolke-Lopez method [ref]
  - $n_{UL}(m_h)$ obtained from numbers of n_{obs} and $n_{expected}$ events, and the uncertainty on $\mathbf{n_{expected}}$

- Dominant systematic uncertainty in the signal region is from halo muons
  - These muons are produced along the beamline, but nevertheless pass through the NA62 fiducial volume
  - Extensively studied to reduce their contribution in the signal region
  - Remaining contribution modelled using K^- and K_{less} data-taking periods



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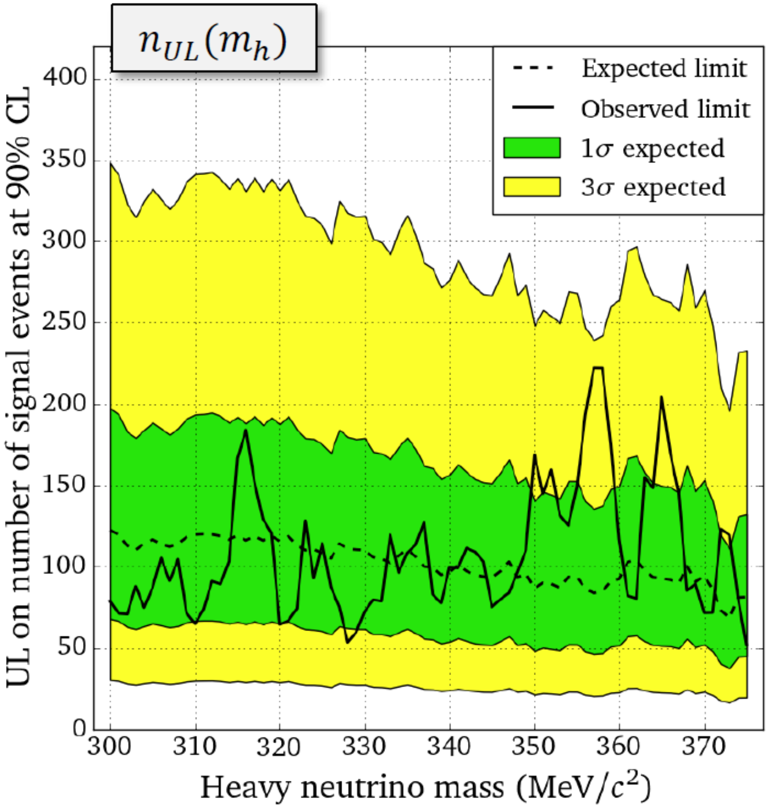
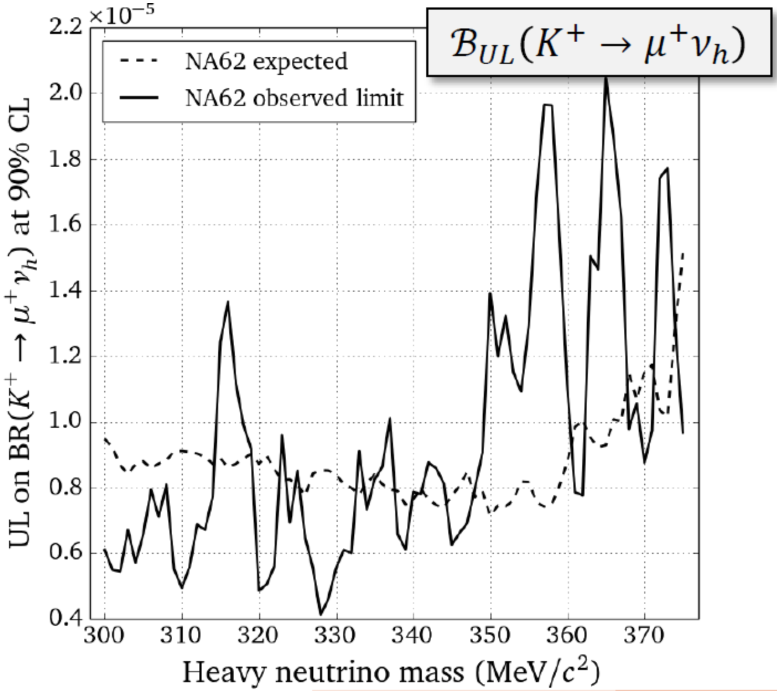
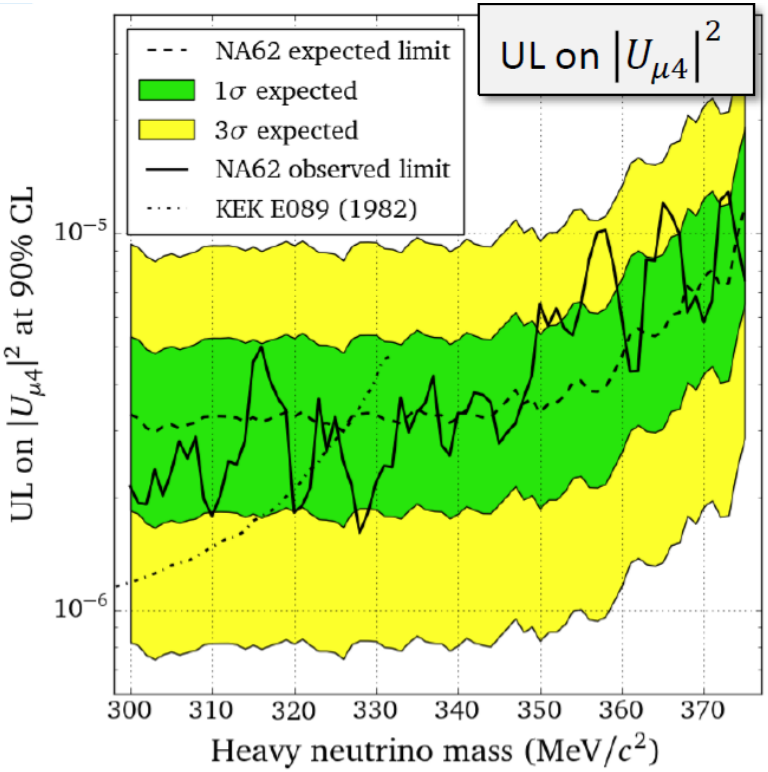


Interpretation of the upper limit

The limit on n_{UL} can be converted into a limit on the branching fraction…

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



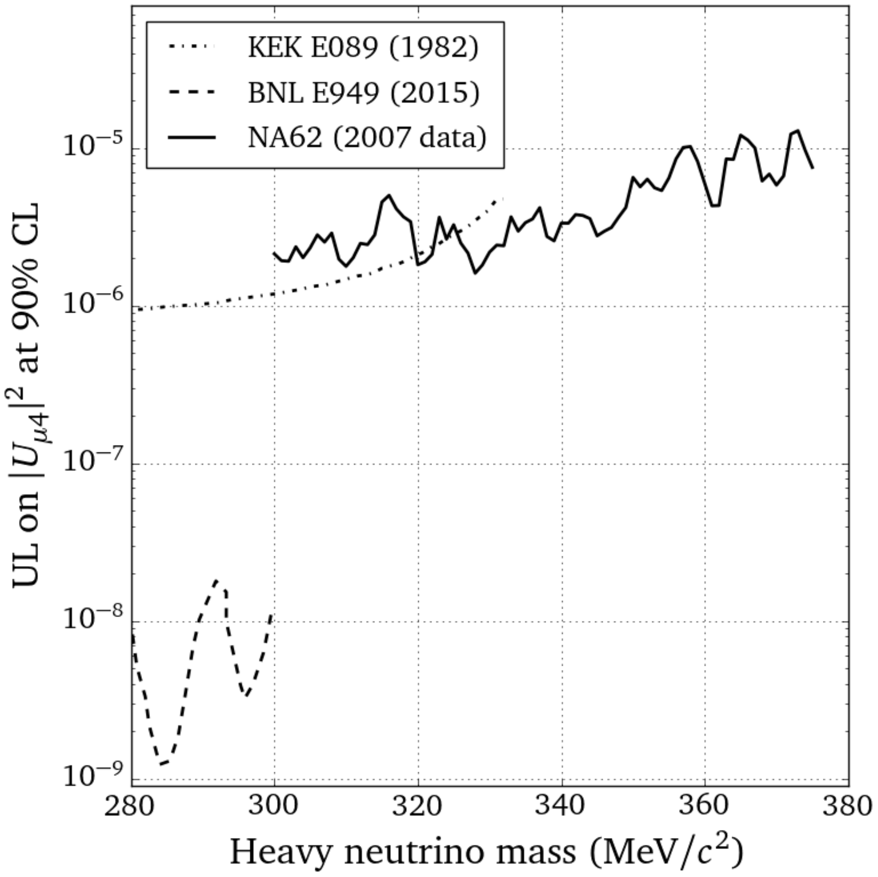


… and into a limit on $|U_{\mu4}|^2$

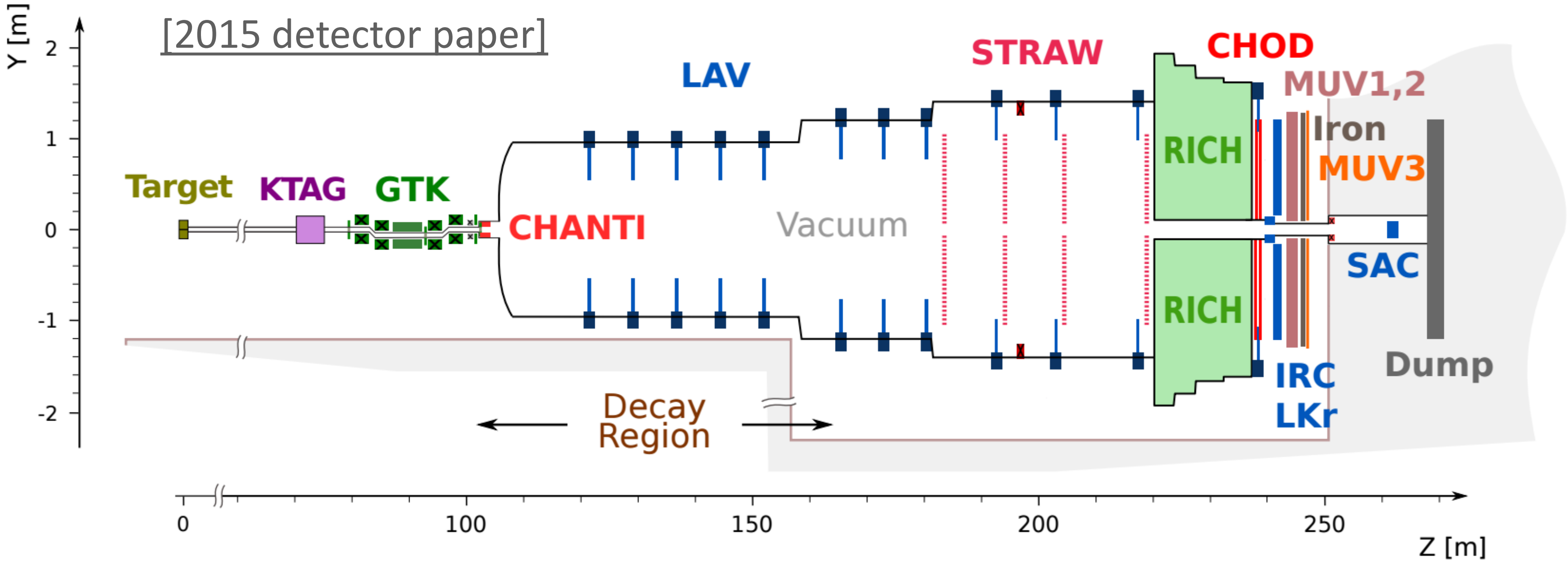
$$|U_{\mu4}|^2 = \frac{\mathcal{B}(K^+ \to \mu^+ \nu_h)}{\mathcal{B}(K^+ \to \mu^+ \nu_\mu)} \times \frac{1}{f(m_h)}$$

Comparison with existing measurements

- NA62 (2007) sets the world's most stringent limit on heavy neutrino production in the mass region 325 < m_h < 375 MeV/c^2



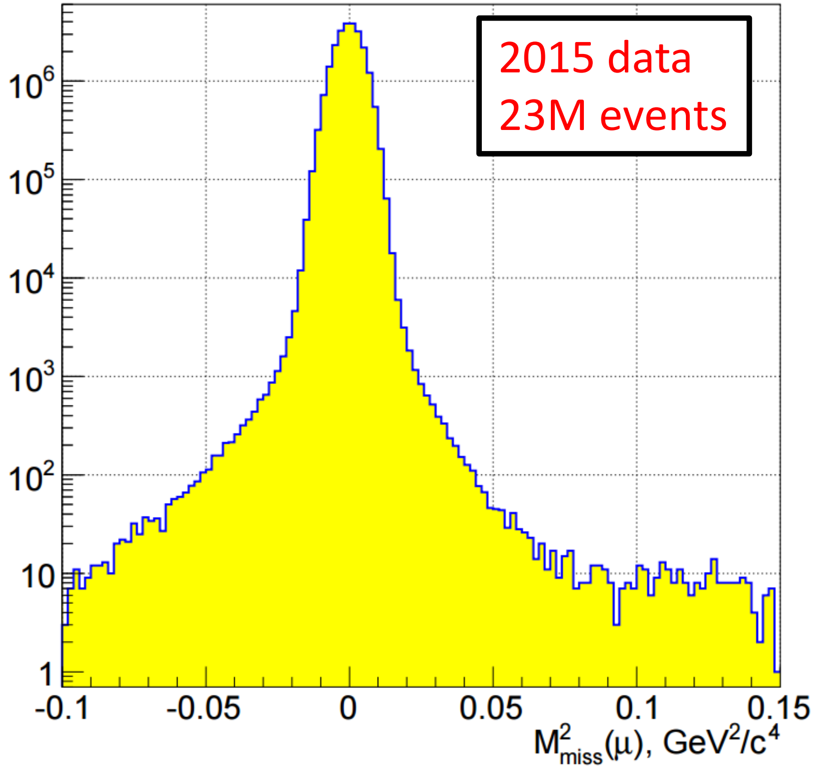
The NA62 (2015) detector



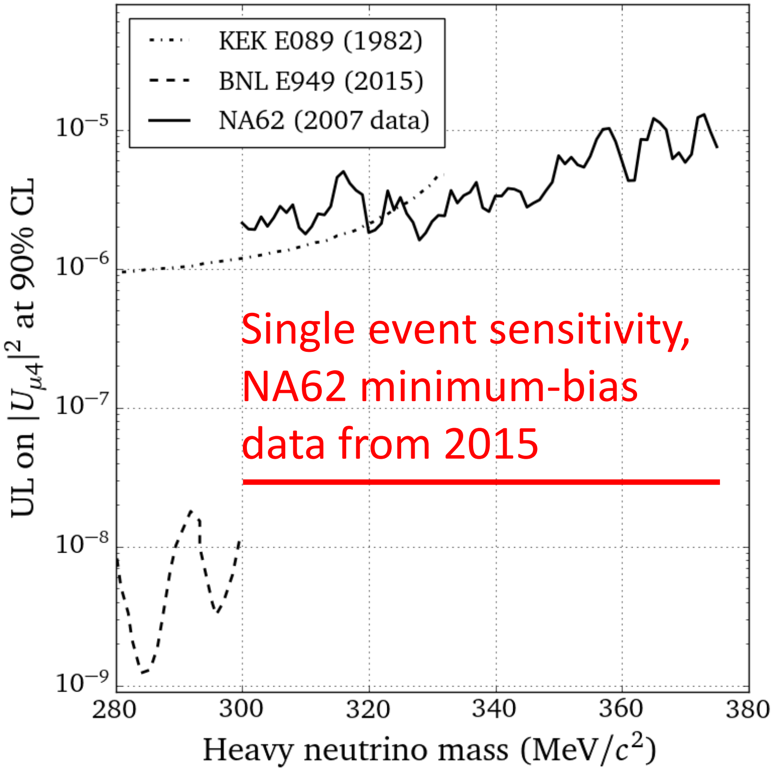
- Key improvements for ν_h production measurements since 2007:
  - **BEAM:** intensity increased by a factor of 90
  - **KTAG**: precise measurement of Kaon time (~80ps) provides dramatic reduction in size of halo background
  - **GTK:** factor 3 improvement in missing mass resolution
  - **Hermetic photon vetoes (LAV, IRC, SAC)**: π^0 veto reduces largest background contributions from Kaon decays ($K^+ \to \pi^0 \mu^+ \nu$)
  - **MUV** and **RICH:** excellent separation of pions and muons

NA62 2015 minimum-bias data

- In 2015 NA62 collected five days of minimum bias data
- **Preliminary analysis of the data shows:**
  - Around 23M $K^+ \rightarrow \mu^+ \nu_\mu$ decays satisfy the trigger and selection criteria
  - Background level more than 100x lower than in 2007
  - Single event sensitivity close to 10^{-8}



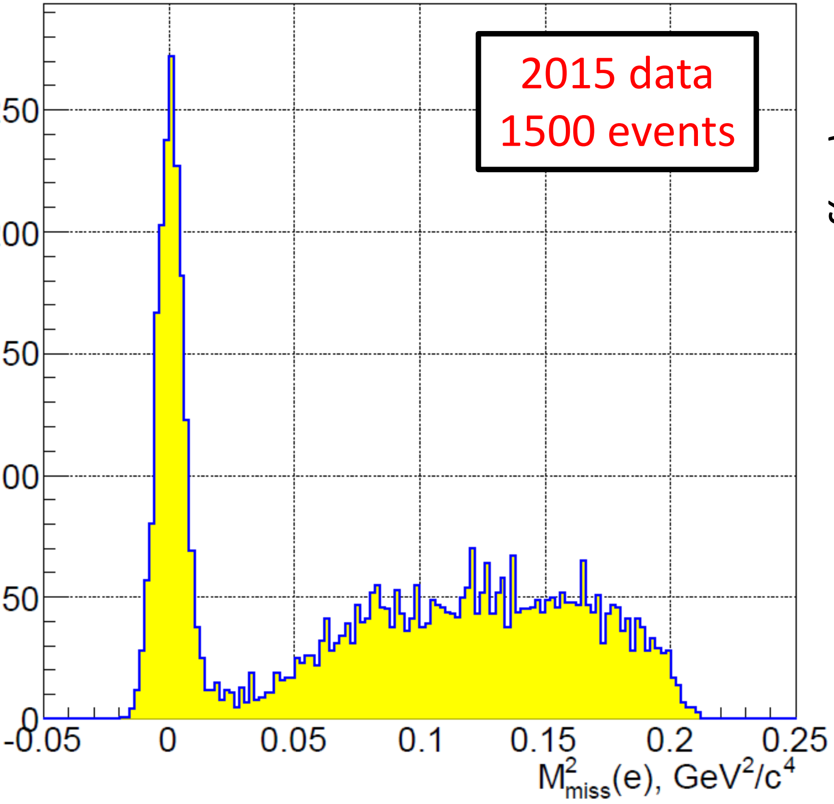
2015 data
23M events

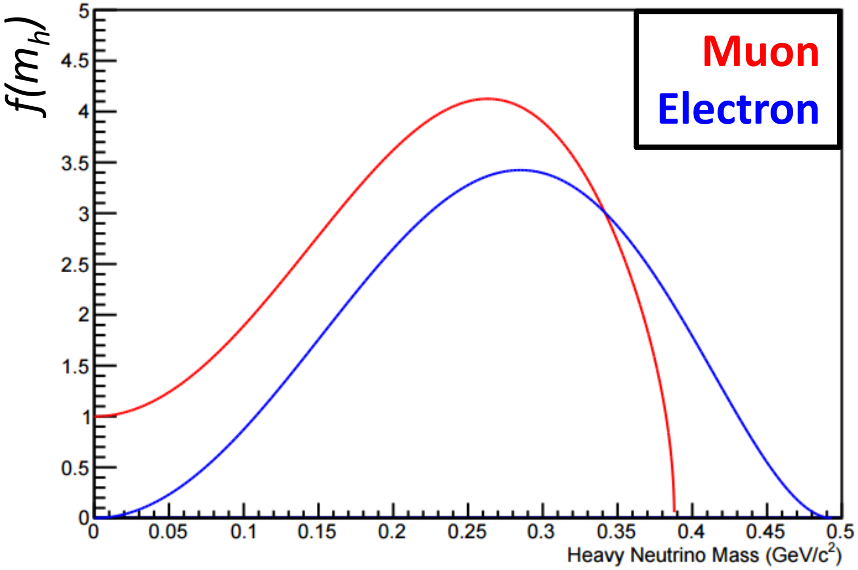


Single event sensitivity, NA62 minimum-bias data from 2015

NA62 2015 minimum-bias data

- In 2015 NA62 collected five days of minimum bias data
- **Preliminary analysis of the data shows:**
  - About 1500 $K^+ \rightarrow e^+ \nu_e$ decays satisfy the trigger and selection criteria
  - Background is low enough to improve current limits by an order of magnitude





Conclusion

- A measurement of heavy neutrino production at NA62 (2007) was presented
  - More than 8M $K^+ \rightarrow \mu^+ \nu_\mu$ events selected
  - World's most stringent limits on $|U_{\mu 4}|^2$ are set between $325 < m_h < 380 \mathrm{MeV}/c^2$
  - Journal publication in preparation

- The NA62 2015 experimental setup was outlined
  - Several improvements in the experimental setup relevant to measurements of heavy neutrino production were identified

- Prospects for the analysis of NA62 data collected in 2015 was shown
  - More than 23M $K^+ \rightarrow \mu^+ \nu_\mu$ events selected from five days of data taking
  - Background level reduced by a factor of 100 compared to 2007 data
  - Good prospects for analysis of $K^+ \rightarrow e^+ \nu_e$ events