Novel Search for Heavy Neutrino Mixing from the $^{+}$ Decay of ^{38m}K Confined in an Atom Trap

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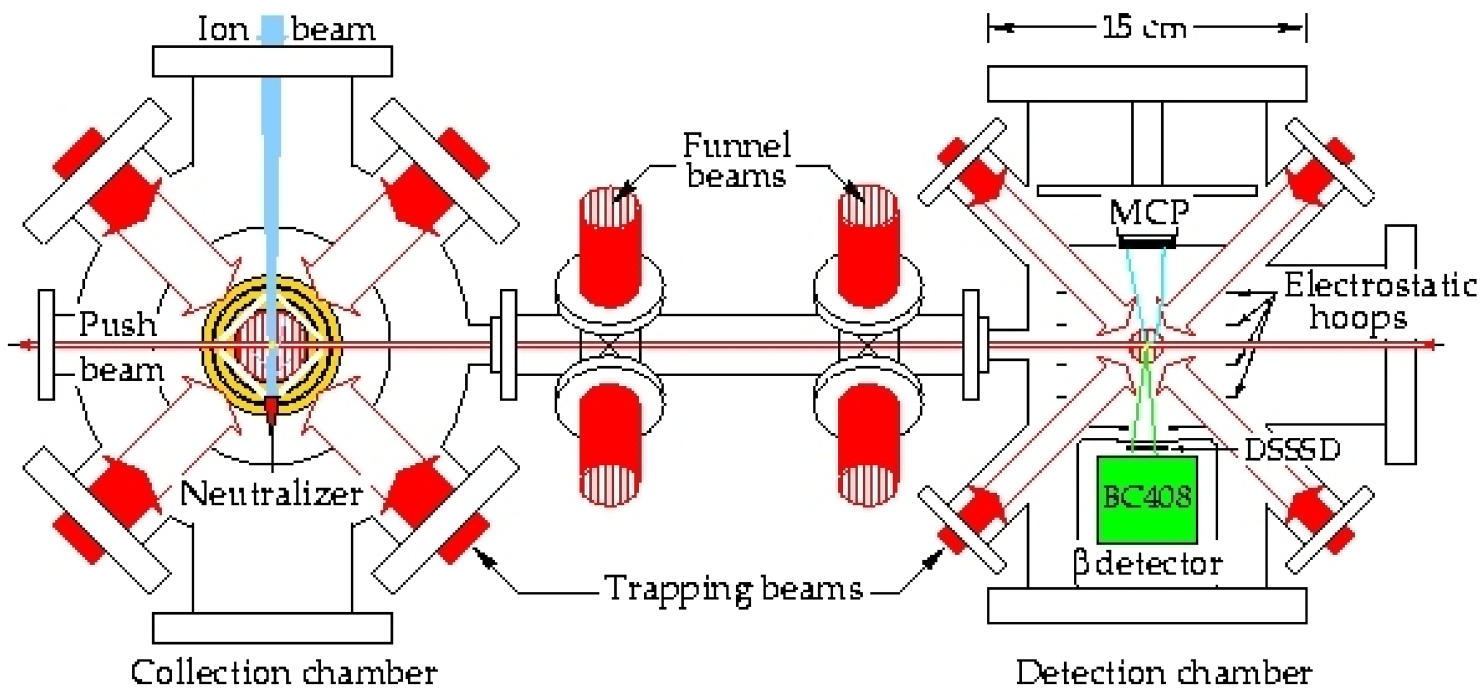
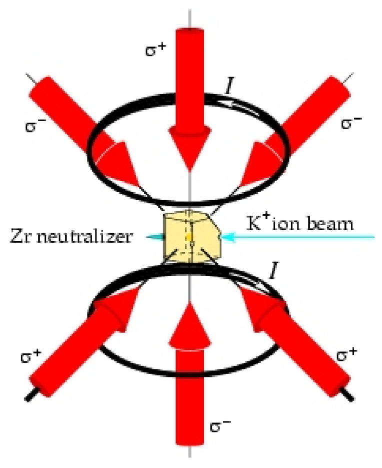
Abstract

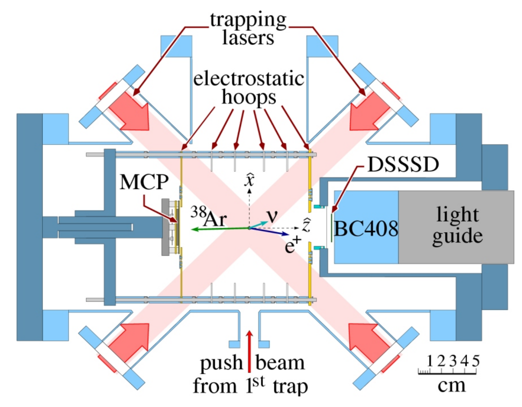
A new technique, neutrino momentum spectroscopy, is used to set limits on the admixture of heavy neutrinos into the electron neutrino. We measure coincidences between nuclear recoils and positrons from the beta decay of trapped radioactive atoms and deduce the neutrino momentum. A two-dimensional maximum likelihood search for peaks in the resulting reconstructed time-of-flight spectrum as a function of positron energy is performed. The admixture upper limits range from 4 x 10^{-3} to 2 x 10^{-2} and are the best direct limits for neutrinos (as opposed to antineutrinos) for the mass region of 0.7 to 3.5 MeV/c^2.

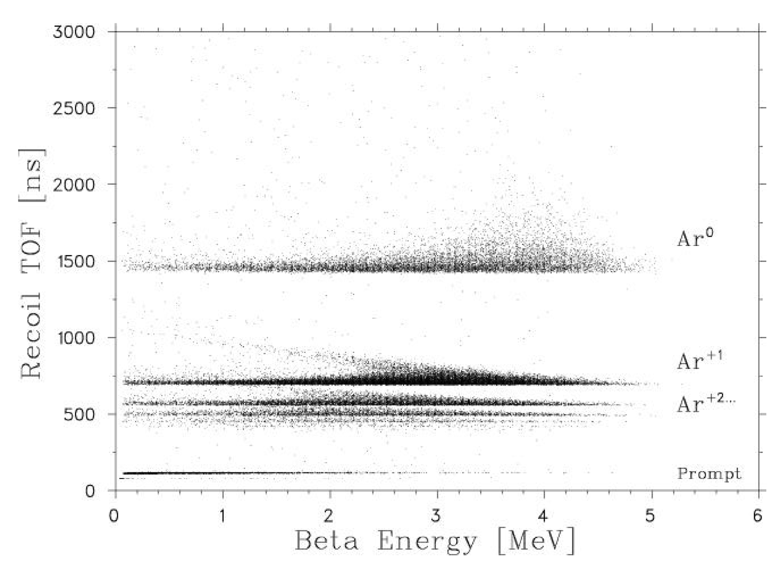


The TRINAT facility, located at TRIUMF in Vancouver, Canada, uses a double Magneto-Optical Trap system to do precision, low-energy experiments with radioactive atoms to test the Standard Model. A MOT holds the atoms suspended in space by laser light and a weak magnetic quadrupole field and allows the observation of the momenta of the recoiling daughter atom and the positron free of distortions as both escape the trap. By measuring the angle of the recoil, the angle and energy of the positron and knowing the trap position, we are able to correct for the kinematic spread in the TOF distribution through momentum reconstruction. The MOT in the first chamber is used to maximize the collection of the ^{38m}K atoms from the ISAC radioactive ion beam facility at TRIUMF.



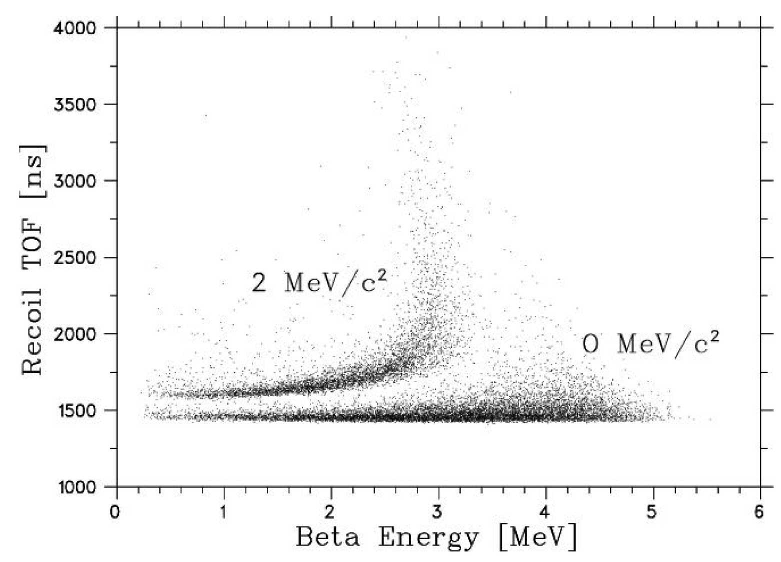
The trapped atoms are pushed to a second MOT by a laser beam. It is from this MOT that the coincidences between the ^{38}Ar recoil and the positron are measured, allowing the deduction of the neutrino momentum.





The experimental data is shown on the left as a two-dimensional scatter plot of recoil TOF versus the energy of the positron. The different charge states of the Argon recoils have been separated by an applied electric field. The search for evidence of heavy neutrino mixing will be done with the neutral Argon recoils.

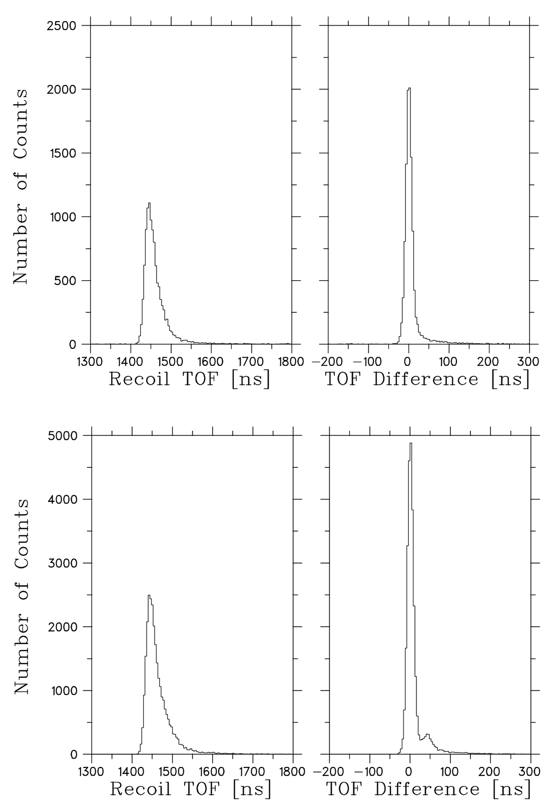
A detailed Monte Carlo simulation with GEANT is used to model the dominant decay involving a neutrino of negligible mass as well as one with the massive neutrino. The figure on the right shows a simulation for a 0 MeV/c^2 neutrino in our system and the location of the ridge of points which would correspond to a 2 MeV/c^2 heavy neutrino. Thus, the search for possible mixing of a heavy neutrino into the electron neutrino will be done by examining the experimental data for ridges in the correct position that correspond to a certain mass of heavy neutrino.



The experimental data is divided into a series of bins in beta energy and the resulting recoil TOF projections are examined for peaks corresponding to heavy neutrinos.

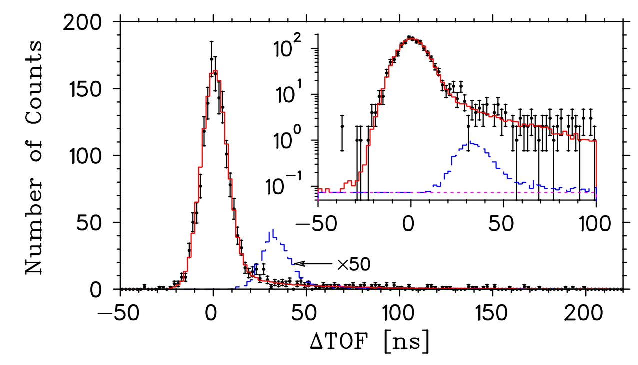
To improve the search, the data is reconstructed event-by-event to remove the kinematic spread and sharpen the TOF projections. An example is given in the top figure on the right. From knowledge of the position of the recoil and the position and energy of the positron, the TOF of the recoil is calculated and compared to the measured TOF. The TOF difference between the measured TOF and the calculated TOF results in both increased sensitivity and increased range of mass for the possibly admixed neutrino. The reconstruction reduces the effects of the size of the detectors, producing a peak whose size is due primarily to the width of the atom trap.

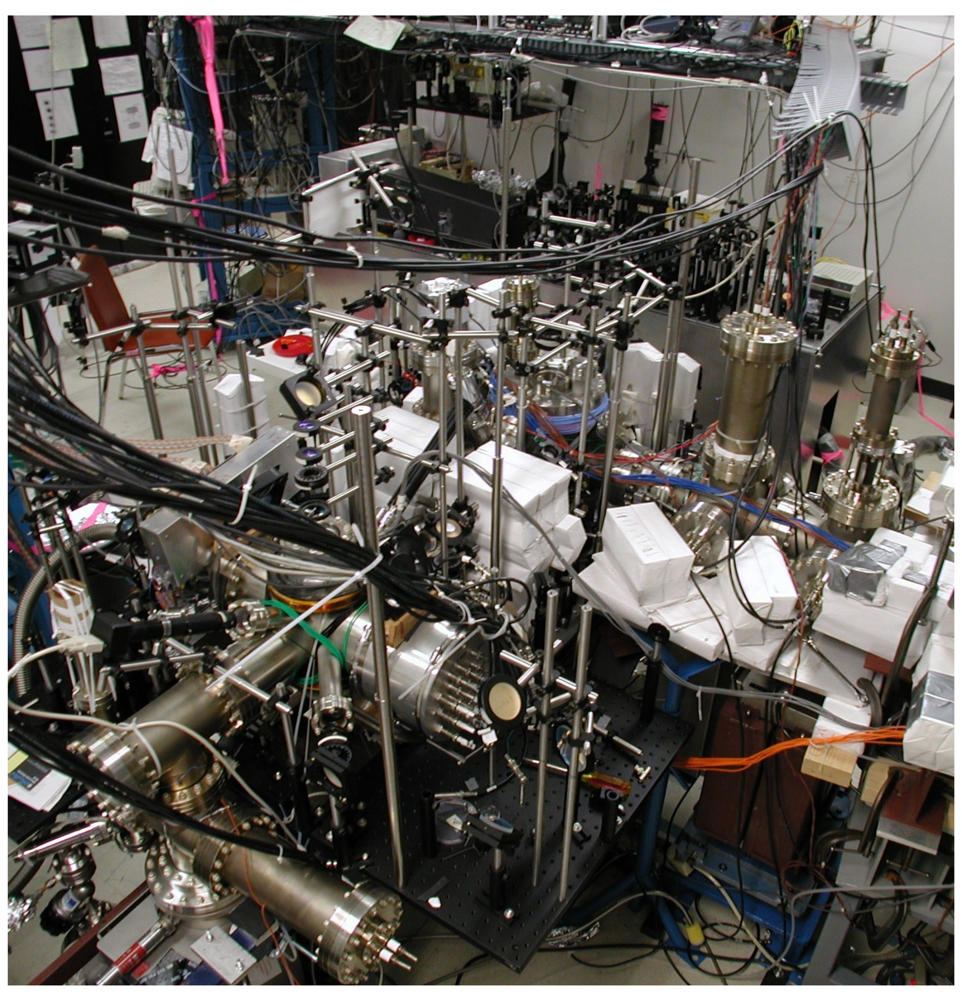
A Monte Carlo simulation of a 1 MeV/c^2 heavy neutrino mixing at 5% into the electron neutrino is shown in the bottom figure on the right. The TOF difference between the measured TOF and the reconstructed TOF clearly resolves the small heavy neutrino peak.



The reconstructed TOF data is binned by beta energy and fit by the model (consisting of the sum of the Monte Carlo for the electron neutrino decay, the experimentally determined random background and the Monte Carlo for the heavy neutrino) to determine the possible contribution of the heavy neutrino. All energy bins are fit simultaneously for each neutrino mass, for masses from 0.5 to 3.6 MeV/c^2.

An example for the possible mixing of a 1 MeV/c^2 heavy neutrino is shown below. The red line shows the agreement between the data points and the model. The blue dashed line shows the amount of possible mixing attributed to the heavy neutrino, and is magnified by a factor of 50 for illustration in the linear plot.





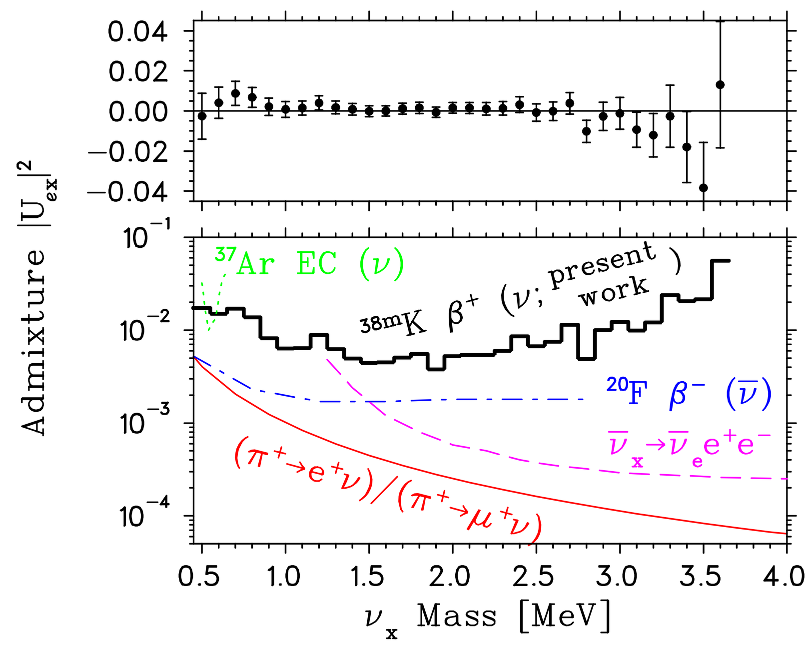
Heavy Neutrino Mixing Limit Results

The admixture results and 1 sigma errors of the full analysis for all masses are shown in the top of the figure and are consistent with no significant deviations from zero.

The results are also interpreted as 90% CL upper limits which are shown in the bottom of the figure, along with the results of other experiments.

This represents the first attempt to use optically trapped radioactive atoms to set mixing limits.

Best direct limits on the mixing of heavy neutrinos (not antineutrinos) into the electron neutrino for the mass range of 0.7 to 3.6 MeV/c^2.



Dotted: M.M. Hindi *et al.*, Phys. Rev. C **58**, 2512 (1998).
Dash-dotted: J. Deutsch, M. Lebrun, and R. Prieels, Nucl. Phys. **A518**, 149 (1987).
Dashed : C. Hagner *et al.*, Phys. Rev. D **52**, 1343 (1995). See R. Tomàs *et al.*, Phys. Rev. D **64**, 095005 (2001).
Solid: D.A. Bryman, Comments Nucl. Part. Phys. **21**, 101 (1993) and D.I. Britton *et al.*, Phys. Rev. D **46**, R885 (1992).