# MEASUREMENT OF THE HEAVY NEUTRINO ADMIXTURE UPPER LIMIT FROM MUON CAPTURE BY $^3$He

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According to the minimal Standard Model, neutrinos ($\nu$) are massless. From the GUT (Grand Unified Theory) standpoint it is more natural for the $\nu$ to have mass: a $\nu$ is a member of a multiplet together with a charged lepton and charged quarks which all have masses. The present experimental upper limits of the $\nu_\mu$ and $\nu_\tau$ rest energies are 0.16 MeV [1] and 24 MeV [2], respectively.

If some of the $\nu$ have non-vanishing masses, the flavor $\nu$ eigenstates $\{\nu_\ell\}(\ell = e, \mu, \tau)$ can be linear combinations of the mass $\nu$ eigenstates $\{\nu_i\}(i = 1, 2, 3)$ $\nu_\ell = \sum_i U_{\ell i}\nu_i$, where U is the neutrino mixing matrix. One may think of (rare) decay processes with the emission of another (neutral) particle which has yet escaped detection.

Two types of lepton mixing experiments were performed: the upper limit of the admixture into the electron flavor has been determined by looking for anomalies in $\beta$ spectra and for oscillations of $\nu$ emitted in reactors, whereas $\mu$- flavor admixture upper limits were obtained by accelerator experiments. The $\mu$-heavy $\nu_i$ mixing strength $|U_{\mu i}|^2$ was determined by a CERN experiment sensitive for $\nu$ decays to be $|U_{\mu i}|^2 < 10^{-4}$ for $E_{o\nu} > 20$ MeV [3]. Thus, the result is model dependent. Model independent $|U_{\mu i}|^2$ upper limits were obtained from kinematically determined exclusive reactions by measuring the $\mu^+$ from the $\pi^+$ [4] and $K^+$ [5] two-body decays into the $\mu$ channel. A heavy $\nu_i$ admixture to the $\nu_\mu$ would be measured by a peak at lower $\mu$ energy than that associated with the emission of the $\nu_\mu$ without admixture. The lower bound of $E_{o\nu}$ is determined by the experimental resolution, the upper bound by the $Q$ value of the reaction.

We estimate the heavy neutrino admixture from the experimental data on the $\mu$ capture reaction

$$\mu^3\mathrm{He} \rightarrow t + \nu \qquad (1)$$

observed in two experiments of the MCF collaboration at Paul Scherrer Institute in Switzerland, using the Petersburg Nuclear Physics Institute (PNPI) ionization chamber (IC). The first one was with an H/D gas mixture of 3% D concentration at 161 bar, where $\mu^3$He was

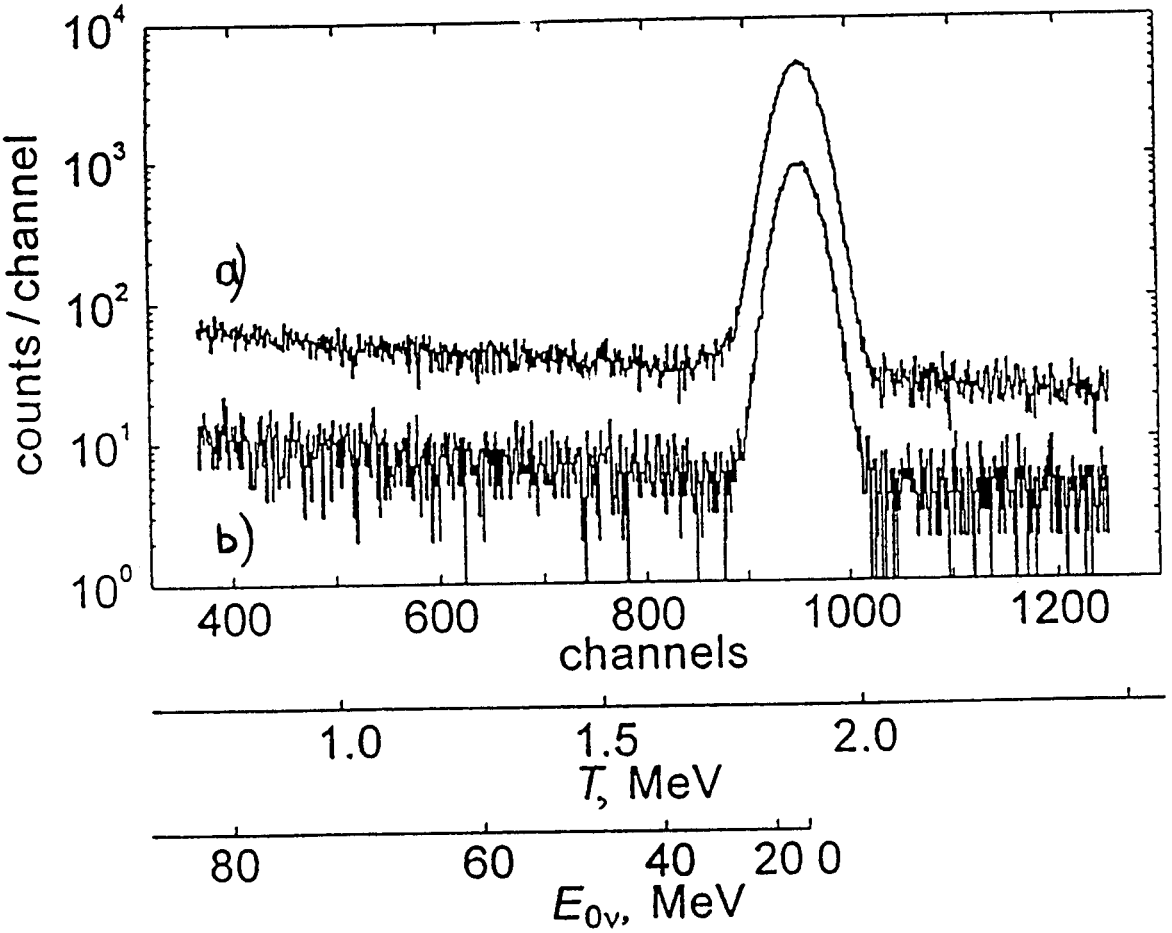


**Fig.1.** Charge spectra showing triton events after $\mu^-$ capture in $^3$He. T means real energy, $E_{o\nu}$ is the $\nu$ rest energy. *a*) Charge collected on B1,B3,B4,B5, *b*) Charge collected on anode B1

formed via the p$\mu$d fusion reaction yielding $|U_{\mu i}|^2 \leq 2.3 \cdot 10^{-3}$ at $E_{o\nu} = 60$ MeV [6]. The second experiment, aimed at precision measurement of nuclear muon capture by $^3$He [7], was done with pure $^3$He of 120 bar in a larger IC. The method and the experimental setup were described in detail in [8].

The IC anode is subdivided into 14 parts with separate readouts. The IC pulses are analyzed with flash ADC's. We consider the events with muon stops in the volume of 15 cm$^3$, between the IC cathode and the grid, over central B-anodes B1,B3,B4,B5. Fig.1*a* shows the measured triton lines in the collected charge spectra. The spectrum a) contains 38,800 triton events measured at the first anode B1, whereas in spectrum *b*) 220,000 triton events of the B1 and the further downstream B-anodes (B3, B4, B5) are added. The charge was corrected for a small peak motion (4.3% at maximum) during the run due to an impurity increase of the IC gas and a small peak position dependence on the triton pulse width. A Gaussian could be well fitted to the triton line in Fig.1*a*, whereas a Gaussian with a tail was fitted to the triton line in Fig.1*b* yielding the widths (FWHM) 83 keV and 88 keV for these spectra, respectively. The background around the triton line, caused by triton breakup reactions with emission of $p$ and $d$, could be well approximated for both spectra by an expo-

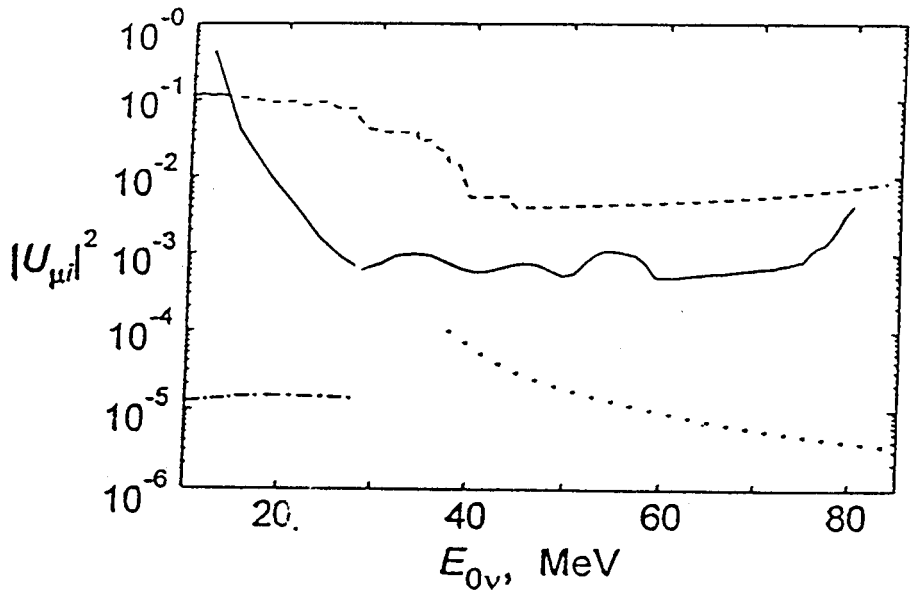


**Fig.2.** $\mu$-heavy $\nu_i$ mixing strength vs $E_{o\nu}$. The solid line obtained from spectrum *a*) ($E_{o\nu} \leq 28$ MeV) and *b*) ($E_{o\nu} > 28$ MeV) of Fig.1, respectively. Dashed line taken from ref.[9], dash-dotted line from ref.[4] , and dotted line from ref.[5], respectively

nential function with a second-order polynominal in the exponent. A separate peak in $E_{o\nu} > 0$ indicating a heavy $\nu_i$ admixture to the $\mu$ flavor cannot be seen. Thus, only upper limits of the $|U_{\mu i}|^2$ mixing strengths can be given.

In Fig.2 the 90% C.L. $|U_{\mu i}|^2$ upper limits vs $E_{o\nu}$, which were obtained from the two spectra, are drawn. Spectrum in Fig.1*b* yields a smaller $|U_{\mu i}|^2$ upper limit for $E_{o\nu} \leq 28$ MeV because of better energy resolution, whereas for $E_{o\nu} > 28$ MeV the smaller $|U_{\mu i}|^2$ upper limit results essentially from Fig.1*a* because of the better statistics. Taking always the more restrictive result yields the final $|U_{\mu i}|^2$ upper limit vs $E_{o\nu}$ plot shown in Fig.2 together with other model-independent experimental values [4,5,9]. Accordingly, among these experiments the lowest $|U_{\mu i}|^2$ upper limit values are obtained by our measurement in the range 28 MeV $\leq E_{o\nu} \leq$ 40 MeV. We want to emphasize that recoil experiments such as the present one are model-independent and the experiments whose interpretation needs the lowest amount of theory: as long as a massive particle of any kind is emitted there must always be a corresponding recoil.

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## STUDY OF FEATURES FOR PARTICLE PRODUCTION IN NUCLEUS-NUCLEUS INTERACTIONS

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The study of nucleus-nucleus interactions is one of sources of information about quark degrees of freedom in nucleus, which are displayed through features of secondary particle production in such interactions, in comparison with those of nucleon-nucleon interactions.

To obtain such an information about particle production and, hence, about new laws of nuclear interactions one needs to develop new approaches for analyse experimental results. For this purpose the searches of new kinematical variables or correlation dependences the most sensitive to exhibition of expected effects are carried out. The important information may be received also by studing correlation dependences between various kinematical parameters of particles.

Some results for similar analysis for $\pi^-$-meson production in interactions of protons, deutrons, He and C nuclei at incident momenta 4.2 GeV/c per nucleon and deutrons at momentum 1.7 GeV/c per nucleon with carbon nuclei in JINR's two meter propan bubble chamber were presented in [1,2].

The distributions of average momentum for $\pi^-$-mesons in dependence on their cumulative number $n_k = \frac{E-p_{\parallel}}{m_N}$ for various incident momenta of deutrons are shown on Fig.1. It is visible, that the presented dependences have the identical characteristic features as minimum at cumulative number 0.1–0.4. In [3] the similar behaviour of this correlation dependence was associated with indication of quark degrees of freedom in nuclei. However study of dependence between Feynman variable for $\pi^-$-mesons $x_F = p^*_{\parallel}/p^*_{max}$ and their cumulative number, presented in [1] has shown, that it is due to only change for region of $\pi^-$-meson production. Moreover this correlation does not vary at change of incident nucleus masses, and depends only on its energy.