NEW LIMIT ON PROBABILITY OF THE MUONIUM-TO-ANTIMUONIUM CONVERSION IN PNPI–JINR EXPERIMENT

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On the whole, the standard model of the electroweak interaction describes available experimental data very well. However some questions are unanswered until now. Here are some of them only:

- the properties of the particles of the scalar Higgs's field (charge, mass and etc.) responsible for the mechanism in which fundamental particles become massive objects;
- the neutrino nature (Dirac or Majorana);
- a kind of the conservation law of the leptonic number (additive or multiplicative).

The very strict limitations on the alternatives mentioned above may be obtained from the research of the $M\bar{M}$ – conversion process.

B. Pontecorvo was the first who pointed out the possibility of the $M\bar{M}$ – conversion process [1]. The detailed analysis was performed in [2]. The appropriate hamiltonian can be written in the next form:

$$H_{M\bar{M}} = \frac{G_{M\bar{M}}}{\sqrt{2}} \bar{\Psi}_\mu \gamma_\alpha (1+\gamma_5) \Psi_e \cdot \bar{\Psi}_\mu \gamma_\alpha (1+\gamma_5) \Psi_e + h.c. \qquad (1)$$

The most realistic model which allows the $M \to \bar{M}$–transition is the H^{++}–exchange process (Fig.1).

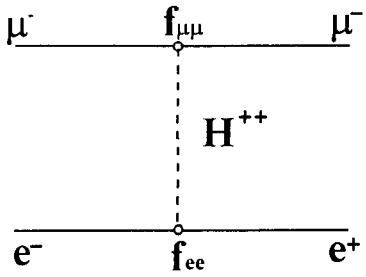

Fig.1. The $M \to \bar{M}$– transition in the model with the Majorana neutrino

Such double charged Higgs's particles are unavoidable within the SU(2) – symmetric theories with the Majorana neutrino. In this case the ratio $G_{M\bar{M}}/G_F$ (G_F – the Fermi constant of weak interaction) is defined as follows:

$$\frac{G_{M\bar{M}}}{G_F} = \frac{f_{ee} \cdot f^*_{\mu\mu}}{g_w^2} \left(\frac{M_W}{M_{++}} \right)^2, \qquad (2)$$

where $f_{ee}, f^*_{\mu\mu}$ are the coupling constants; $g_w^2 = 8G_F M_W^2/\sqrt{2}$; M_W and M_{++} are the masses of W- and H^{++} - bosons correspondingly.

The present experimental status of the problem under consideration is represented in Table 1. As it is seen, the best results have been obtained in the PNPI-JINR experiment [3-5].

Table 1

The results of studying the $M\bar{M}$ transition
(Particle Data Group, June 1995)

LIMIT ON MUONIUM → ANTIMUONIUM CONVERSION

Forbidden by lepton family number conservation.

$R_g = G_{M\bar{M}}/G_F$

The effective Lagrangian for the $\mu^+e^- \to \mu^-e^+$ conversion is assumed to be

$$\mathcal{L} = 2^{-1/2}G_{M\bar{M}}[\bar{\psi}\gamma_\lambda(1-\gamma_5)\psi_e][\bar{\psi}_\mu\gamma_\lambda(1-\gamma_5)\psi_e] + \text{h.c.}$$

The experimental result is then an upper limit on G_{MM}/G_F, where G_F is the Fermi coupling constant.

VALUE	*CL%*	*EVTS*	*DOCUMENT*		*TECN*	*CHG*	*COMMENT*
<0.13	90		GORDEEV	93	SPEC		JINR phasotron
···We do not use the following data for averages, fits, limits, etc.···							
<0.14	90	1	GORDEEV	94	SPEC	+	JINR phasotron
<6.9	90		NI	93	CBOX		LAMPF
<0.16	90		MATTHIAS	91	SPEC		LAMPF
<0.29	90		HUBER	90	CNTR		TRIUMF
<0.88	90		HUBER	88	CNTR		TRIUMF
<7.5	90		NI	87	CBOX		LAMPF
<20	95		BEER	86	CNTR		TRIUMF
<42	95		MARSHALL	82	CNTR		TRIUMF

GORDEEV 94 quote limits on both $f = G_{M\bar{M}}/G_F$ and on the probability $W_{M\bar{M}} < 5.1 \times 10^{-7}$ (90% CL). Final results are based on the full data set.

The realization of this project is outlined below.

A direct method for seeking the events of the $M\bar{M}$-process was proposed in PNPI and the necessary equipment was created [6,7]. During 1989-1990 an adjustment of new system was completed and background conditions were investigated. The $M\bar{M}$ - conversion experiment was carried out by the joint PNPI-JINR group on the NPL-JINR phasotron.

During the first stage (1991) the following tasks were solved:

- the determination of the muon beam parameters;
- the study of background processes;

- the measurement of muonium yield out of the SiO_2–target to vacuum.

As a result the first estimations of the values $W_{M\bar{M}}$ and $G_{M\bar{M}}$ were obtained [3]:

$$W_{M\bar{M}} < 3.6 \times 10^{-6}, \qquad G_{M\bar{M}} < 0.38 G_F \qquad (90\% C.L.),$$

which are comparable with results of meson accelerator facilities.

During the second stage (1991÷1992) a number of activities devoted to the modernization of setup and the surface muon beam channel was completed. This allowed to raise the intensity of the surface muon beam by 3 times, increase the angular acceptance of a spectrometer and hasten the read-out from the proportional chambers. New runs were performed making use of the muon beam with the parametres as follows [8]:
the momentum of the beam was 21.5 MeV/c ($\Delta P/P = 7.7\%$); the beam intensity was $I_\mu = 4.8 \times 10^5$ s^{-1}; the positron admixture in the beam was $N_{e+}/N_{\mu+} \simeq 2$; the size of the beam near the target was 7×8 cm^2 (FWHM); the duty factor was 75%.

The experimental results and their comparision with the achievements of the other groups are in Table 1. Only 1 event satisfying the selection criteria of the $M\bar{M}$–conversion events was detected.

The method of registration of the conversion events is based on the detection of high energy electrons resulting from the decay of an antimuonium muon by the large acceptance magnetic spectrometer. The identification of useful and background events was performed by comparative analysis of space, amplitude and time distributions of the useful events when registrating the positrons (from the μ^+–decays) and the electrons (from the μ^-–decays).

When the spectrometer detects the positrons, resulting from the μ^+–decays, the main scope of information belongs to the useful events. In this case one can determine the principal parameters of the distributions mentioned above (the average values and dispersions). Then these values and the range of their changes were used for the rejection of the background events when registrating electrons resulting from the μ^-–decays; now the overwhelming majority of events is the background.

Fig. 2 demonstrates how the experimental distributions of the electron events (either measured or obtained in the treatment of data) change when imposing the limitations on some parameters, obtained from the analogous distributions of the positron events.

Now the treatment and the analysis of all scope of the experimental data are completed. The total results of all runs are represented in Table 2. The preparation of the final paper is in progress.

Using the formula (2) it is possible to obtain the lower estimation of the mass of the H^{++}– boson which is responsible for the $M\bar{M}$–process ($M_{++} \geq 210$ GeV) if one assumes that the constants f_{ee} and $f_{\mu\mu}$ are of the same order as g_w.

At present the preparation for new experiment is completed. The last one will be performed in the absence of external magnetic and electric fields in the target area. The geometrical and time parameters of the setup will be improved. The aim is either to obtain the more strict limitation (factor ~10) or to detect 10 events under investigations if the process $M \to \bar{M}$ takes place really.

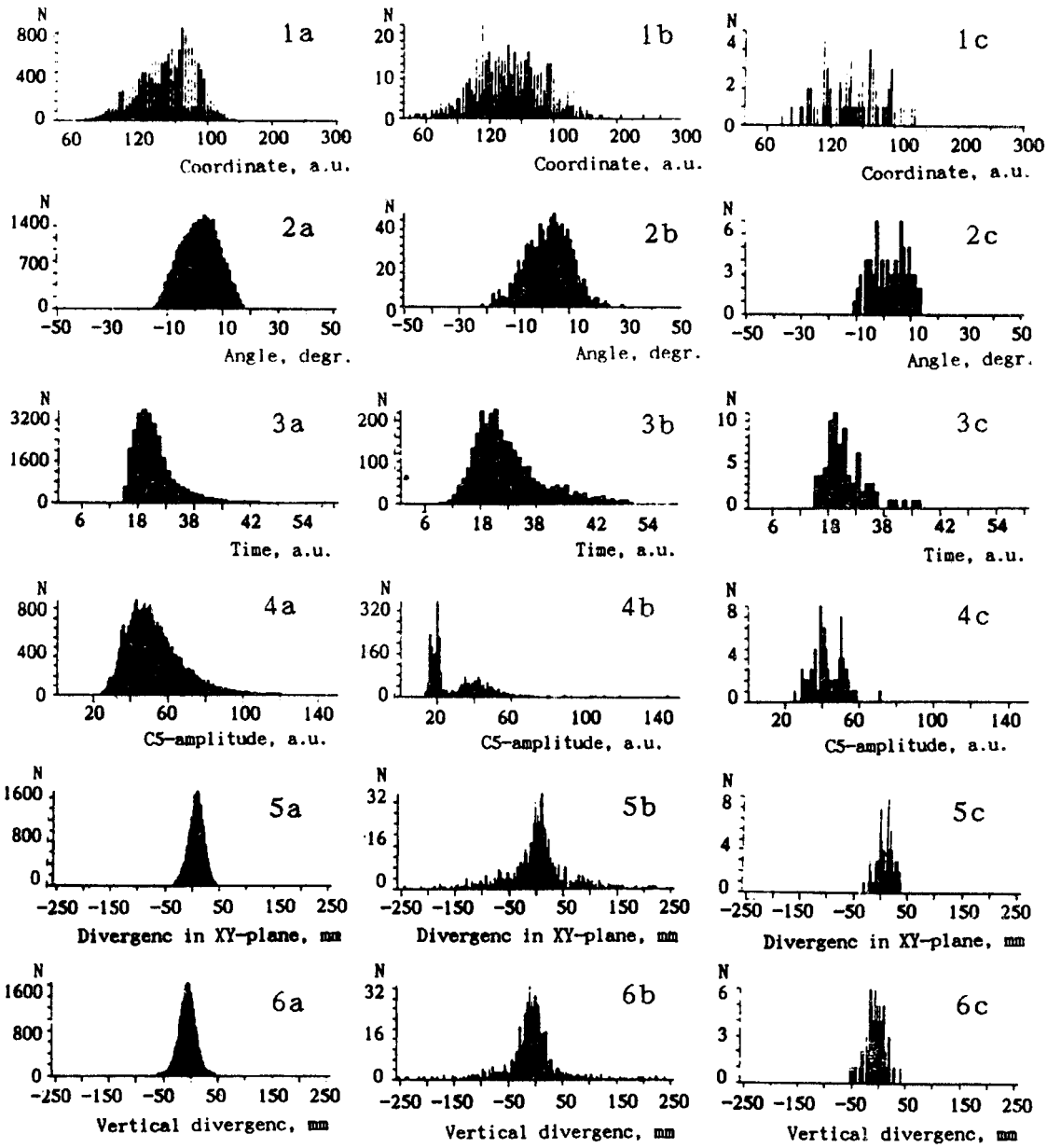

Fig.2. The distributions of positrons (a) and electrons (b–the initial spectrum, c–after applying the cuts on the parameter in question): *1* – on Z-coordinate in the PC1–chamber; *2* – on the angle with respect to the SiO_2–target plane; *3* – on time of flight between PC2–chamber and C_5–counter; *4* – on the amplitude of pulses from C_6–counter; *5* – on the ΔXY–divergence parameter in the XY–plane; *6* – on the ΔZ–divergence parameter in the Z–direction.
PC1, PC2 – the proportional chambers; C_5, C_6 – the scintillation counters.

Table 2

The results of experimental investigation of the $M\bar{M}$–conversion process in the PNPI–JINR experiment

Accelerator run	N_μ	$W(\Delta E)$	W_M	$N_{M\bar{M}}$	$W_{M\bar{M}}$	$G_{M\bar{M}}$
I [4]	$4.5 \cdot 10^{10}$	$1.05 \cdot 10^{-3}$	0.027	0	$< 3.6 \cdot 10^{-6}$	$< 0.38 G_F$
II+III [5]	$3.44 \cdot 10^{11}$	$1.51 \cdot 10^{-3}$	0.029	1	$\leq 5.1 \cdot 10^{-7}$	$\leq 0.14 G_F$
I+II+III	$3.89 \cdot 10^{11}$			1	$\leq 4.7 \cdot 10^{-7}$	$\leq 0.14 G_F$

N_μ – total number of muons passing through the target; W(ΔE) – the probability of registration of electron in the energy range ΔE [7]: W_M – the probability of muon yield out of the SiO_2 – target to vacuum [7]; $N_{M\bar{M}}$ – total number of events registrated; $W_{M\bar{M}}$ – the experimental probability of the $M \to \bar{M}$ – conversion process; $G_{M\bar{M}}$ – the estimation of the upper limit of coupling constant in the process under consideration.

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MEASUREMENT OF THE SPIN ROTATION PARAMETERS A AND R IN $\pi^{\pm}p$ ELASTIC SCATTERING IN THE MOMENTUM RANGE 1.4 – 2.1 GeV/c

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Measurement of the spin rotation parameters A and R in πp elastic scattering in the momentum range from 1.4 to 2.1 GeV/c was started by the PNPI–ITEP collaboration in the framework of general program "Baryon spectroscopy". In the second πN resonance region such measurement is being performed for the first time in the world. The main goal of these experiments is to resolve existing uncertainties of nonstrange baryon resonance spectrum