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# SOME EXPERIMENTAL RESULTS FROM MARUSYA EXPERIMENT★

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*Abstract.* The main goals of the MARUSYA Project are the investigations of rare subthreshold and cumulative processes of hadronic production, antimatter production and the spin phenomena in the transition regime and single spin asymmetries. For the adjustment of the MARUSYA setup there were some calibration runs. We used the time of flight (TOF) method for the particle identification (PID) in C-Cu reactions at the JINR-NUCLOTRON energies.

*Key words:* nuclotron, MARUSYA experiment, relativistic nuclear collisions, time of flight method, particle identification.

## 1. INTRODUCTION

Recent theoretical works [1–3] have shown that the transition regime from nucleon-meson to quark-gluon phase – so-called *mixed phase of the nuclear matter* – can occur already at the energies available at the *NUCLOTRON* (up to *6 A GeV*) from the *Joint Institute for Nuclear Research (JINR) Dubna* (Russia). *The MARUSYA Experiment* is associated with the heavy ion program at the JINR NUCLOTRON. The aim of this experiment is to study the charged particles yields in proton-nucleus and nucleus-nucleus collisions with the help of this magnetic spectrometer.

Unlike expensive installations with the geometry close to $4\pi$, the specific feature of MARUSYA Experiment is the use of the wide-aperture magneto-optical

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spectrometer in combination with the multiplicity detector capable of handling high intensities of the primary beams. This feature allows one to measure small cross sections of deep subthreshold processes, obtain statistically grounded values of polarization characteristics of investigated reactions and perform experiments with the secondary beams. The interest of the investigation of antiproton and kaon productions is due to their antiquarks content, which proves the creation of these particles only via the hadronisation of the "sea" quarks. The novelty of the proposed research is the investigation of rare subthreshold and cumulative processes taking into account the extraction of events by the degree of centrality and reaction plane on the basis of the additional measurement of multiplicity and identification of the part of nuclear fragments not participating in an interaction. The aim of this work is to present the particle identification in the MARUSYA experimental set-up using the time of flight technique.

## 2. THE MARUSYA EXPERIMENTAL SET-UP

The magnetic spectrometer MARUSYA consists of two quadrupole magnets and two bending magnets in the Q-Q-D-D configuration (K100-ML17-SP57-SP40, see Fig. 1 and Fig. 2). The angular range of the charged particles detection varies between 20° and 70° in the laboratory reference frame. The acceptance of the spectrometer is 50–80 milisteradians. The advantage of this spectrometer is the high selectivity of the magnetic channel to the rare probes, such as negative kaons and antiprotons, which is the main goal of this experiment.

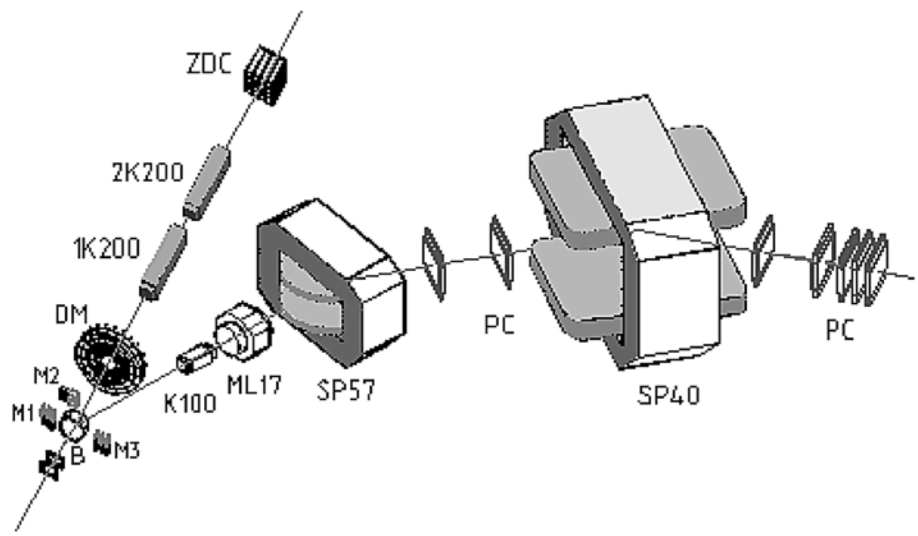


Fig. 1 – MARUSYA experimental set up – large view.

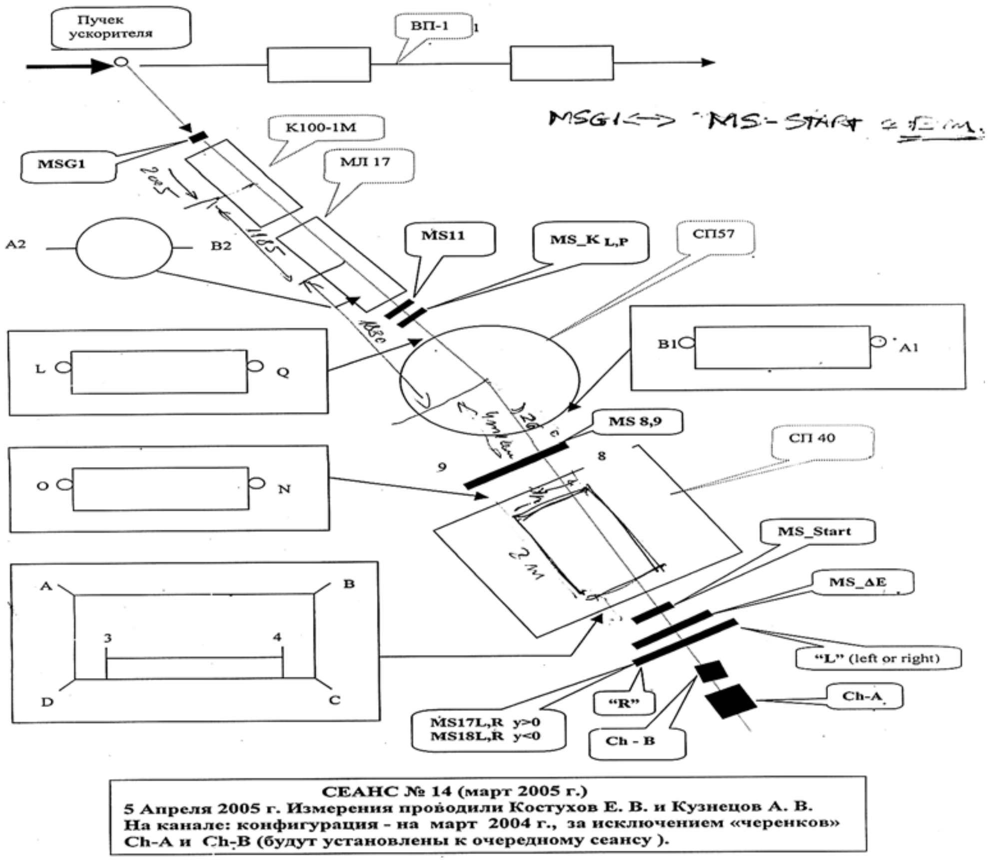


Fig. 2 – MARUSYA experimental set-up – the index of the silicon detectors.

The beam monitoring system consists of three scintillation telescopes located around the target at an angle of 90° (noted *M1–M3* in figures). The information on the extracted beam intensity will be obtained by an ionization chamber placed on the beam axes in front of the target (noted *K100*). Magnetic lenses are used, too (*ML17*). The magnetic dipoles, *SP57* and *SP40* are placed on the particle tracks. The small size barrel system, *B*, is located around the target which provides the trigger from the interaction in the target. The other components of the MARUSYA spectrometer are: proportional chambers (*PC*), scintillator hodoscopes (*G*), multiplicity detector (*MD*) and zero degree hadronic calorimeter (*ZDC*).

Today, the MARUSYA Program has a new perspective. A few new detector systems will be added. The most important is the Cherenkov spectrometer DELTA 2. It will be included for studying the production mechanisms of η neutral mesons and for determining the intrinsic strangeness of the nucleon. Others, like the detector for measurement of transverse energy of neutral particles (DTE), the charged particles multiplicity detector (CMD) and the detector for measurement of energy of spectator nucleons (ZDC) will be added to the initial MARUSYA experimental set-up.

## 3. THE TIME OF FLIGHT TECHNIQUE (TOF)

The particle identification based on the time of flight (TOF) method is a fast and efficient technique. The TOF technique measures time intervals between two detectors: the START (MS START) detector, near the exit from the SP40 dipole magnet, and a charged particle STOP detector as MS8-9, MS_$K_{L,R}$, MS11 or MS$17_{L,R}$ ones (Fig. 2), each of which heaving a specific resolution on particle arrival times. Knowing the time intervals $\Delta t$, the length of the path $l$ from geometry and the momentum $p$ for which the experimental set-up was calibrated one can calculate, first of all, the inverse velocity of the particle using the following relation:

$$\frac{1}{\beta} = \frac{c \cdot \Delta t}{l}, \tag{1}$$

and, then, the particle mass can be determined from this relationship:

$$M = p \cdot \sqrt{\left(\frac{1}{\beta}\right)^2 - 1}\,. \tag{2}$$

In this work some experimental data obtained in the frame of the MARUSYA Collaboration, in the 2005 run, for C-Cu collisions at the JINR NUCLOTRON energies, are used for obtaining some preliminary experimental results taking into account that was a MARUSYA experimental set-up adjustment run.

To surpass possible uncertainties about the map of the magnetic fields the time of flight technique was used for obtaining the experimental results presented in this work. The start and stop detectors selected were the silicon detectors MS8-9 and MS-START placed at the ends of the SP40 magnetic dipole. In Fig. 3 is presented the distribution of the times of flight for the 14_03_05 22 46 51 file data.

We observe three peaks which correspond to three kinds of particles from the next list: pions, kaons, protons, deuterons, etc. On the x-axis there is the number of the channels. Each value of the channel it is be multiplied with 60 ps, because the time base for the time to digital converters (TDC) is 60 ps/channel. The temporal order is from right to left. The intrinsic value of the channel is useless, only the time differences matters. A multi-peak Gauss fitting reveals the centers of the peaks. The time values are the following:

$$\begin{aligned} &t_{c_1} = -95 \cdot 60 \text{ ps} = -5700 \text{ ps}, \quad t_{c_2} = 168 \cdot 60 \text{ ps} = 10080 \text{ ps}, \\ &t_{c_3} = 309 \cdot 60\ ps = 18540 \text{ ps}. \end{aligned} \tag{3}$$

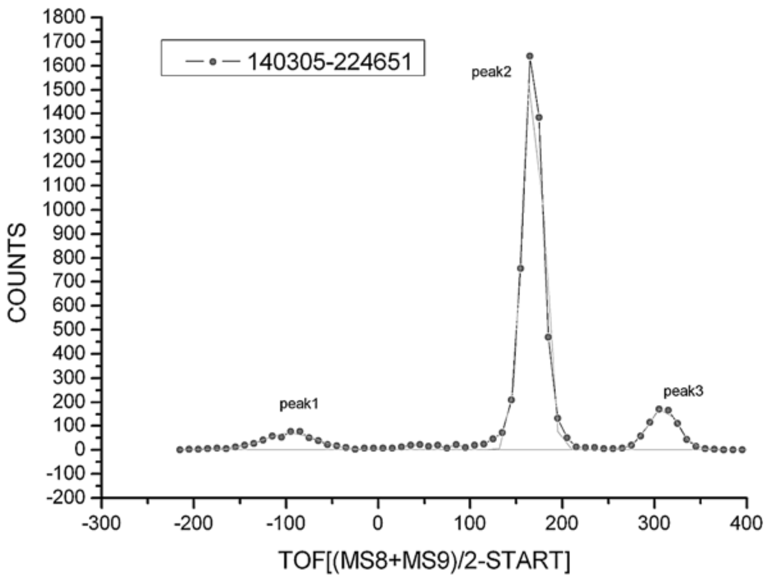


Fig. 3 – The TOF distribution of particles in the SP40 dipole magnet.

Considering the same momentum for the different types of charged particles grouped in the three peaks, we can write the following relationships:

$$p=\frac{m_1 v_1}{\sqrt{1-\left(\frac{v_1}{c}\right)^2}}=\frac{m_2 v_2}{\sqrt{1-\left(\frac{v_2}{c}\right)^2}}=\frac{m_3 v_3}{\sqrt{1-\left(\frac{v_3}{c}\right)^2}}. \tag{4}$$

The following expressions ca be obtained:

$$p^2=p_{12}^2=\frac{-m_1^2-m_2^2+2\sqrt{m_1^2\cdot m_2^2+(m_2^2-m_1^2)^2\cdot\frac{l^2}{c^2(t_{c_2}-t_{c_1})^2}}}{4-\frac{c^2(t_{c_2}-t_{c_1})^2}{l^2}}, \tag{5}$$

and

$$p^2=p_{23}^2=\frac{-m_3^2-m_2^2+2\sqrt{m_3^2\cdot m_2^2+(m_2^2-m_3^2)^2\cdot\frac{l^2}{c^2(t_{c_3}-t_{c_2})^2}}}{4-\frac{c^2(t_{c_3}-t_{c_2})^2}{l^2}}, \tag{6}$$

where the squared momentum is a function of the differences $(t_{c_2}-t_{c_1})$ and $(t_{c_3}-t_{c_2})$, respectively.

For identification of the detected charged particles grouped in the peaks it is necessary to establish their rest masses. Therefore, a order relation among the positions of the centers of the maxims is used for the experimental data, namely: $c_1 < c_2 < c_3$ ... This relation, written in agreement with the time calibration of the channels $t_{c_1} < t_{c_2} < t_{c_3}$ ..., consider the rest masses from the highest to lowest rest mass. For example, if the detected charged particles are pions, kaons and protons, in the peak centered on channel $c_1$ are the protons, and in peak centered on channel $c_3$ are the pions. If our selection is correct, then the equations (5) and (6) offers the same value of $p^2$. In this example the smallest difference between $p_{12}$ and $p_{23}$ is obtained for the combination deuteron, proton and pion: $p_{12}$ = 0.471 GeV/c and $p_{23}$ = 0.511 GeV/c. In this case we observe the time differences between the three peaks: if the time difference between two consecutive peaks is at least 2σ we can separate and measure the yields of the detected particles. If these differences are smaller than 2σ then we have to choose a different mode of operation of the bending magnets for a better separation of the detected charged particles. In our run, the experimental set-up is calibrated for detecting pions, protons and deuterons with $p \approx 0.500$ GeV/c, separated within a 2σ time difference, with the following ratios of the particle yields: $\frac{\pi}{p} = 0.152$, $\frac{d}{p} = 0.031$, and $\frac{d}{\pi} = 0.920$. These rations could offer interesting physical information. For example, the deuteron to proton ration can offer information on the entropy per baryon [4–6]. Using the following relationship:

$$s = S/A = 3.95 - \ln\left(\frac{n_d}{n_p}\right), \qquad (7)$$

where $n_d$ is the average multiplicity of the deuterons, and $n_p$ is the average multiplicity of the protons, we can have some insights about the thermalization in the collision and the emission time moments, taking into account the existing model predictions.

For a given momentum of these particles around $p = 0.500$ GeV/c the average entropy per baryon is $7.421 \pm 0.132$. For a higher value of the momentum, 0.800 GeV/c, for example, the average entropy per baryon is $6.184 \pm 0.153$. An additional analysis related to the associated transverse momenta and new experimental data at different emission angles are necessary to conclude on the thermalization degree in these collisions.

If we consider the pion to proton ratios, we observe that, for a given momentum, the ratio is constant. At 500 MeV/c this ratio have the value $0.212 \pm 0.012$, and at 800 MeV/c the value is $0.202 \pm 0.014$. This behaviour is consistent with the behaviour of the ratio of the average pion multiplicity and average number of participant protons [7–9].

The Fig. 4 presents the TOF distributions for pions and protons for three values of the momentum: $p$ = 0.400 GeV/c, $p$ = 0.450 GeV/c and $p$ = 0.500 GeV/c. We can observe the evolution of the discrimination between pions and protons with the particles momentum increase.

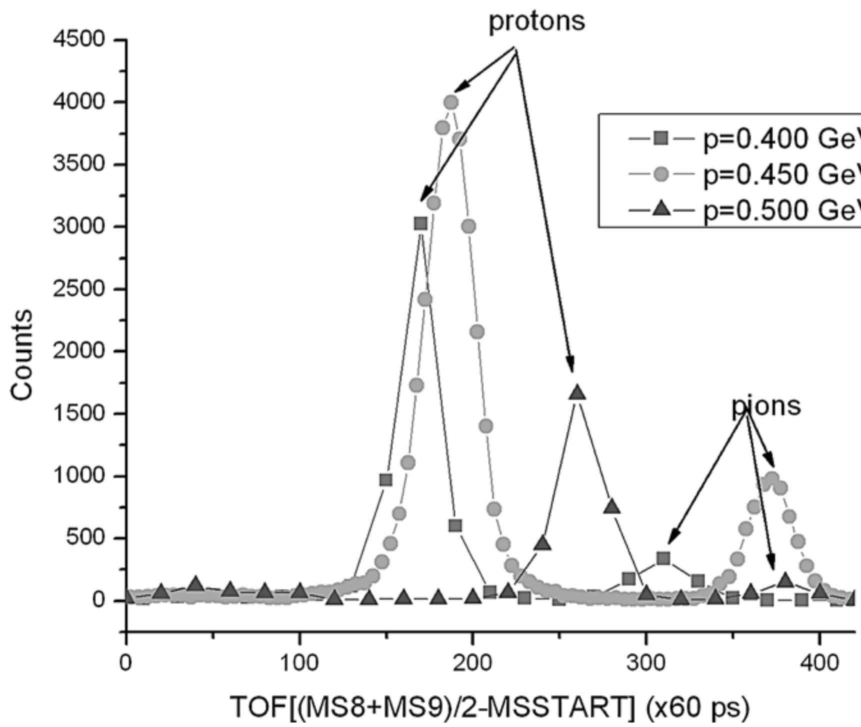


Fig. 4 – The TOF distributions of pions and protons for three modes of operation of the spectrometer.

## 4. CONCLUSIONS

The time of flight (TOF) method presented before is useful for particle identification and, also, for the a given momentum, only if at least three different types of charged hadrons are present. The values of the momentum determined in this way can be compared with those extracted from the expression $p\,[\text{GeV/c}] = 0{,}3B[T]\cdot\rho[m]$, where $B$ is the effective magnetic field, expressed in Tesla, and ρ is the curvature radius of the trajectory into the magnetic dipole, expressed in meters. This method will be combined with energy loss and a more complete $\Delta E$-TOF analysis will be available. The GEANT4 simulations of the MARUSYA set-up will be compared with the experimental results for a better adjustment.

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