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A TIME PROJECTION CHAMBER FOR HEAVY ION PHYSICS

HLINKA, V.[1]), POVINEC, P.[1]), SITÁR*, B.[1]), Bratislava
KLADIVA,* E.[2]), SEMAN, M.[2]), ŠPALEK, J.[2]), Košice
ARTUKH, A. G.[3]), BUDAGOV, Yu. A.[3]), SEMENOV, A. A.[3]), TETEREV, Yu. G.[3]), Dubna

Characteristics of a large volume time projection chamber (TPC) and its possible utilization for experiments with heavy ions are described. The results of test measurements performed with the 10 GeV beam at the Serpukhov accelerator are discussed. The best spatial resolution σ_y is 0.2 mm, σ_x is 1 mm and the doubletrack resolution is 4.5 mm and 10 mm in the y- and the x- direction, respectively.

I. INTRODUCTION

A time projection chamber is a large volume tracking detector. It measures true three-dimensional points along the tracks, which is very important for the reconstruction of multi-track events [1]. The multiple dE/dx measurements allow to use the TPC for particle identification, which can be very effective in the case of heavy ions.

In the framework of Bratislava—Dubna—Košice collaboration we built a TPC with a sensitive volume of about 450 litres and 80 layers for the dE/dx measurements [2]. In this paper we present parameters of chamber, the results of the TPC module tests and the perspectives of its utilization for heavy ion experiments.

II. DESIGN OF THE CHAMBER

The sensitive volume of the TPC is given by a 350 mm height that is a maximum drift distance. Its width is 800 mm and the length is 1600 mm (Fig. 1). Sense wires 820 mm long and 20 μm in diameter are stretched perpendicular to the beam direction. There are 160 sense wires along the chamber. Every two are

[1]) Comenius University, Faculty of Mathematics and Physics, 842 15 BRATISLAVA CSFR
[2]) Institute of Exp. Physics, Slovak Acad. Sci., KOŠICE, CSFR
[3]) Joint Inst. for Nuclear Research, DUBNA, USSR.
*) Present address: JINR, DUBNA, USSR.

connected and are read-out by a common amplifier, thus 20 mm wide layers for dE/dx sampling are created in the chamber (Fig. 2). There are 80 sampling layers along the beam direction in the TPC.

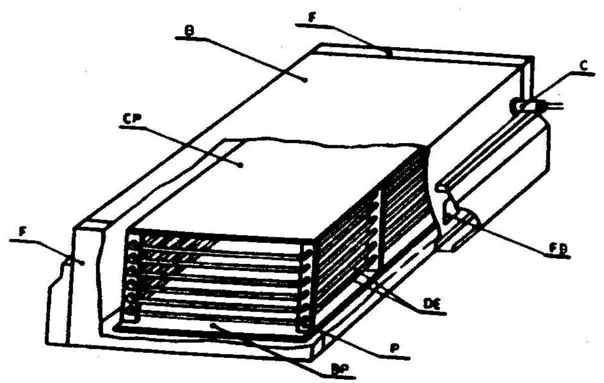

Fig. 1. The scheme of the TPC. B — container, F — cover, C — high voltage connector, BP — the main plate, DE — field-forming electrodes, P — fibre glass stands, CP — cathode, FB — electronics.

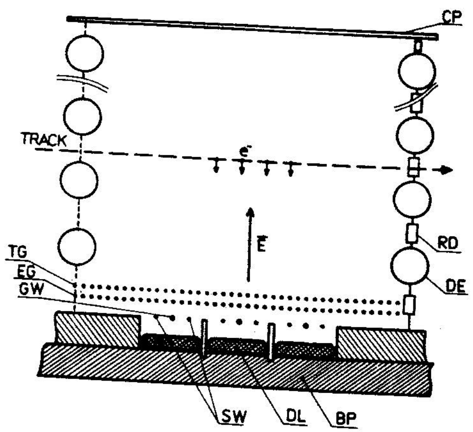

Fig. 2. The sectional view of the TPC. DL — delay line, SW — signal wires, GW, (EG) — field-forming (earthed) wires, TG — trigger grid, RD — divider, the other symbols are the same as in Fig. 1.

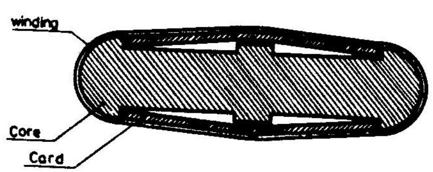

Fig. 3. The section of a delay line.

The coordinate along the sense wires is measured by delay lines [3]. Each delay line is 5 mm under a pair of sense wires (Fig. 2). It is of an elliptic form (Fig. 3) with dimensions $6 \times 18 \times 850$ mm. The delay line core is made of epoxy-resin. Fiberglass printed boards are glued on both sides — one with strips along the delay line, another one with strips tilted at 45° (strip width is 1 mm, the pitch 2 mm). An isolated Cu wire 0.12 mm in diameter is wound on the core with a pitch of 0.15 mm. The time delay of the line is 4.76 ns/mm and the attenuation 1.5 dB/μs.

The drift volume is surrounded by field shaping electrodes, made of aluminium tubes 20 mm in diameter. The tube walls at the front and the end of the TPC are only 0.2 mm thick. On the top of the drift volume, there is a high-voltage electrode (a 1 mm thick aluminium plate) under the voltage of up to 50 kV. The drift volume is separated from the proportional chamber plane by two grids (Fig. 2). The lower one, with wires perpendicular to the beam direction, is earthed. In upper one wires (0.1 mm in diameter and 2 mm pitch) are stretched down the chamber — parallel to the beam direction. The grid is divided into sections, 1 cm wide in the middle of the chamber and 2 and 4 cm wide on the sides. When the neighbour wires are on the alternate potential (± 50 V), the grid is closed. In this way it is possible to make in the chamber dead zones for a free passing of the beam. The width of the dead zone could be of different size, from 1 to 20 cm. These zones could be also triggered, if necessary. This provides a possibility to work at high intensity beams.

The chamber is closed in a sealed container with the dimensions of $500 \times 1200 \times 2000$ mm. The gas mixture is flown in through two inlets on the sides of the TPC and it is flowing out through an output between double-mylar windows at the front and the back sides.

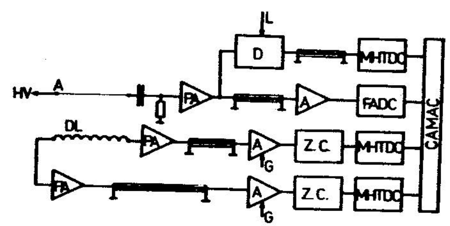

Fig. 4. The block diagram of the electronic channel. DL — delay line, PA — preamplifier, D — discriminator, A — adjustable amplifier, ZC — zero crosser, MHTDC — multi-hit TDC, FADC — flash ADC, HV — high voltage.

A scheme of the electronics is shown in Fig. 4. Signals from the sense wire and both ends of the delay line are fed to a preamplifier, then through a regulating amplifier (gain 1—10) to a multi-hit TDC [4] which can measure up to 256 signals with 2 ns resolution at the time interval 16 μs. The signals from the anodes are fed also to a 6-bit flash ADC [5], which works with a frequency of 15.6 MHz.

III. TEST RESULTS

A 3-layer TPC module has been tested in a 10 GeV beam of positively charged particles at the Serpukhov accelerator. The scheme of the set-up is shown in Fig. 5. The tests were performed also in a magnetic field of up to 1.5 T. The vertical (y) coordinate is determined by the measurement of the electron drift time. The spatial resolution of $\sigma_y = 0.2$—0.5 mm has been achieved (Fig. 6). It depends on the drift distance y as $\sigma_y(y) = \sqrt{a^2 y + b^2}$, where $a = 0.086$ mm/$\sqrt{\text{cm}}$, $b = 0.189$ mm.

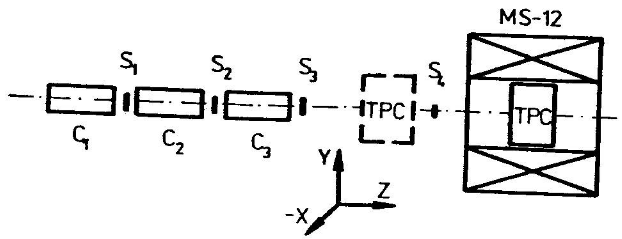

Fig. 5. The test beam layout. C_1—C_3 — Cherenkov counters, S_1—S_4 — scintillation counters, MS-12 — electromagnet, TPC — time projection chamber.

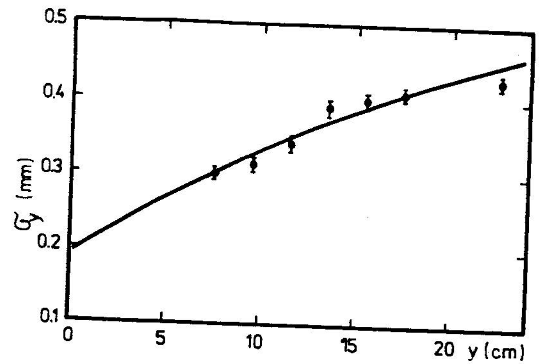

Fig. 6. The spatial resolution σ_y as a function of the electron drift length y.

The spatial resolution in a horizontal (x) coordinate, measured by delay lines is 1—1.5 mm. Double-track resolution is 4.5 mm in y-direction and 10 mm in x-direction.

Signals are measured on both sides of the delay line and they are coupled with the relation:

$$t_R + t_L - 2t_d = \text{const.},$$

where t_R and t_L is signal propagation time to the right and the left side of the delay line, respectively, and t_d is the electron drift time. This allows an unambiguous determination of all coordinates at every point of the particle track, which is a significant advantage of our TPC.

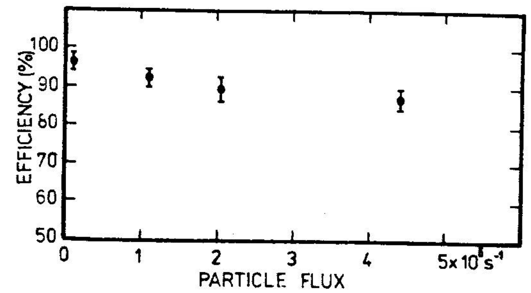

Fig. 8. The scheme of the magnetic mass-spectrometer COMBAS. D_1D_8 — special dipole magnets, Q_1—Q_2 — quadrupole magnets, PPAC — parallel plate avalanche chambers.

The track efficiency for minimum ionizating particles versus particle flux per wire is shown in Fig. 7. The flux density corresponding to the highest intensity beam is about 5×10^3 part./cm^{2}s.

In a magnetic field of up to 1.5 T the efficiency is practically not affected and the spatial resolution degrades by about 20%.

Tests with the minimum ionizating particle beams have shown that the TPC module works reliably, with designed parameters.

IV. TPC AS A DETECTOR FOR HEAVY ION EXPERIMENTS

The characteristics of the TPC, described in the previous parts show the possibility to use it for studying nuclear reactions induced by heavy ions. There are several interesting problems is nuclear physics which could be studied with the help of this new technique:

1. to set limits for the stability of nuclei with extremal N/Z states;
2. to check the influence of the different terms on the nucleon-nucleon potential and to find the optimal (the most realistic) form of it;
3. highly excited nucleus states with an excitation energy higher than the separation energy for nucleons;
4. a search for new decay modes, as: delayed double or multi-neutron decay; delayed α-decay; spallation to the charged clusters; direct neutron emission from isomer states, etc.;
5. a search for new closed shells of light nuclei and new zones of deformation;

6. a search for new states of nuclear matter (existence of neutron bound states in a nuclear drop with $A = N$; existence of nuclei with the low density $\varrho < \varrho_{normal}$).

It seems that the perspective way how to study the problems mentioned above is to use nuclear reactions induced by heavy ions in the energy range of several tens MeV per nucleon. In the design of a spectrometer for experiments with exotic nuclei we should bear in mind these basic features:

a) the production cross section for isotopes with high N/Z is low (from one to several tens nanobarns);

b) their half-lives are short (microseconds);

c) the angle distribution of products is wide.

The spectrometer should provide:

i) a reliable separation of synthetized isotopes from the beam and also from scattered nuclei;

ii) the identification of products according to their mass A and atomic number Z;

iii) a large aperture;

iv) a high data acquisition rate;

v) a possibility to study all characteristics of synthetized nuclei.

A magnetic mass-spectrometer COMBAS [6] built in a cyclotron tandem U400 + U400M in the Laboratory of nuclear reactions JINR is shown in Fig. 8. It provides all necessary parameters to perform the above mentioned experiments. The target is bombarded by an ion beam with an energy of up to 50 MeV per nucleon. The products from the reactions are transported down the mass-spectrometer to the final detector — TPC.

The spectrometer has a wide angle and momentum acceptance, with a triple focusing in horizontal (x), vertical (y) directions and energy (E). A separator is picking on necessary nuclei from the beam and selects the studied reaction channels from the background.

A significant advantage of the spectrometer is a possibility to store all characteristics of the reaction products in the process of their analysis. The atomic number of the products is determined according to their deflection in the magnetic elements of the channel and also by the time-of-flight method, based on parallel plate avalanche chambers (Fig. 8).

As a final detector of the spectrometer is proposed the TPC. Provided it is filled with argon at atmospheric pressure, the range of reaction products (in a considered energy interval) is fully within the active volume of the chamber (160 cm). The dE/dx sampling in layers 2 cm thick provides highly reliable identification according to the Z of the ions. The resolution which could be achieved in our TPC is shown in Fig. 9 [7]. A large sensitive volume of the TPC allows to work in a wide angle and energy range.

We are building a new vacuum vessel for the TPC, in which the pressure could be either higher or lower than atmospheric, which allows to change the range of ions inside the TPC. Thus the massspectrometer with the TPC included provides all necessary parameters to study the rate phenomena of exotic nuclei production.

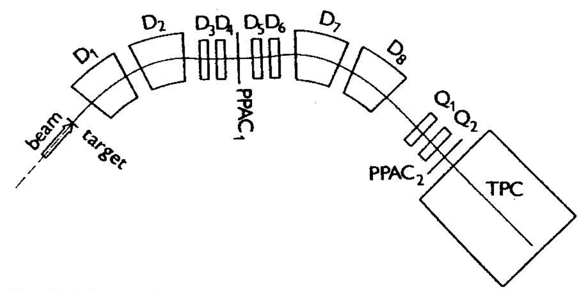

Fig. 7. The track efficiency versus particle beam intensity.

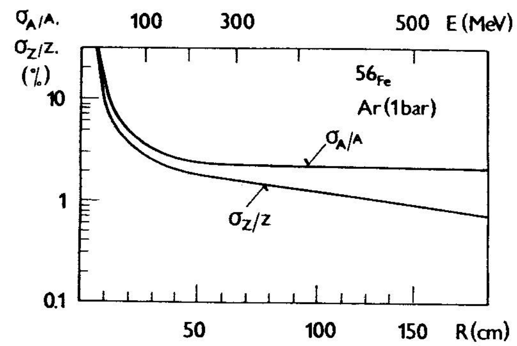

Fig. 9. Charge σ_Z/Z and mass σ_A/A resolution for ^{56}Fe ions versus its range R [5].

The spectrometer with the TPC could also be used for the study of the characteristics of radioactive nuclei. In this case an internal target will be inserted into the chamber. The TPC can visualize nuclear reactions initiated by a secondary (radioactive) beam in the 4π geometry. As the event reconstruction efficiency in the TPC is close to 100% and it can work in a magnetic field, the rare reactions with exotic radioactive nuclei on the nuclear stability border could be also studied. The spatial resolution of the TPC is high enough for a reliable visualization of all products of multiparticle events. The direction of the particle (ion) trajectory can be determined from the rise of dE/dx according to the Bragg curve, which is measured in the TPC. All these features of the TPC can help in the investigation of the coulomb or elastic scattering of nuclei in the search for a new region of highly deformed nuclei and high-spin nucleus states.

V. CONCLUSIONS

The time projection chambers have proved to be very useful devices for experiments in high and medium energy physics. Their high efficiency, very good spatial resolution and the possibility to work in a magnetic field open new possibilities for studies of rare reactions with exotic nuclei on the nuclear stability border.

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REFERENCES

[1] Sitár, B., Phys. Elem. Part. and Atomic Nuclei *18* (1987), 1080.
[2] Budagov, Yu. A., et al.: Prep. UKJF 30/80, Bratislava, 1980.
[3] Grove, R., Perez-Mendez, V., Sperinde, I., Nucl. Instr. Meth. *106* (1973), 407.
[4] Budagov, Yu. A., et al.: Nucl. Instr. and Meth. *A234* (1985), 302.
[5] Budagov, Yu. A., et al.: Prib. Tech. Exp. *1* (1987), 59.
[6] Artukh, A. G., *Proc. II. Int. Symp. JINR on multineutron systems*, Dubna, 1989.
[7] Zlomanchuk, Yu., et al.: Prib. Tech. Exp. *5* (1982), 53.

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КАМЕРА С ПРОПСЕКЦИЕЙ ВРЕМЕНИ ДЛЯ ФИЗИКИ ТЯЖЕЛЫХ ИОНОВ.

Приведены характеристики камеры большого объема и ее возможное применение в экспериментах с тяжелыми ионами. Обсуждены результаты измереней, которые проводились на Серпуховском ускорителе. Получены лучшие характеристики-пространственное разрешение $\sigma_y = 0,2$ mm, $\sigma_x = 1$ mm и разрешение двух треков 4,5 и 10 мм при y и x координатах.