STUDY OF THE PROCESSES OF SECONDARY ELECTRON EMISSION IN DIAGNOSTIC SYSTEMS FOR CHARGED PARTICLES AND HEAVY ION BEAMS.

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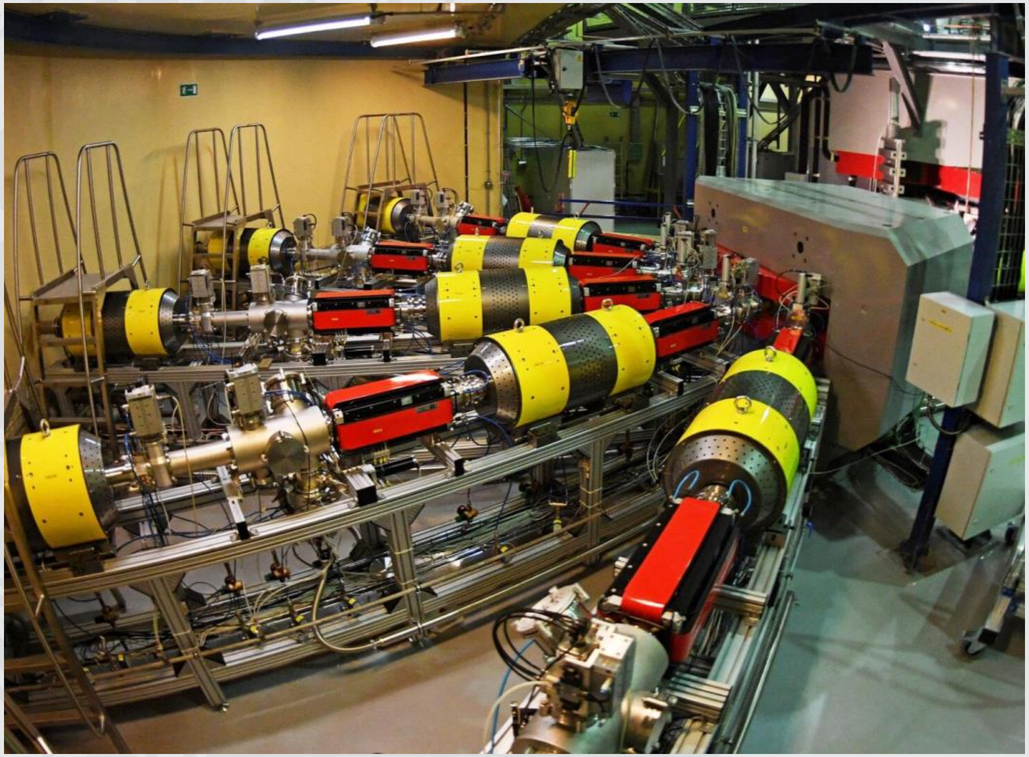
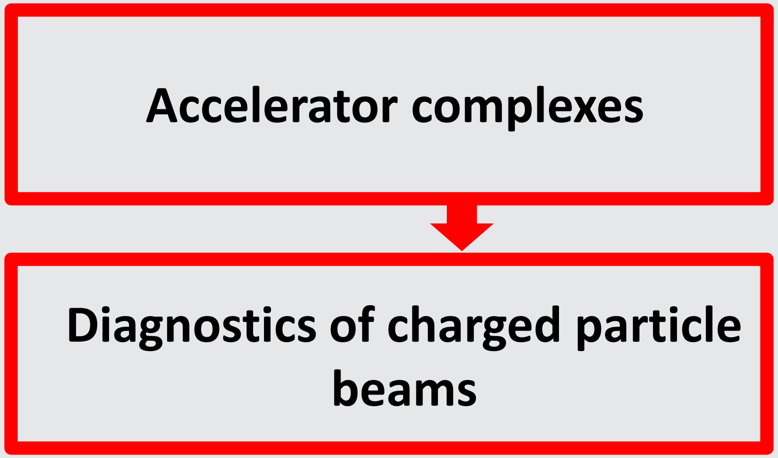
Introduction

The most important condition for using accelerator technology is to achieve optimal parameters of charged particle beams.



Cyclotron DC-280, Superheavy elements factory, JINR, Dubna, Russia



Accelerator complexes

Diagnostics of charged particle beams

For beams extracted from the accelerator, their diagnostics is necessary.

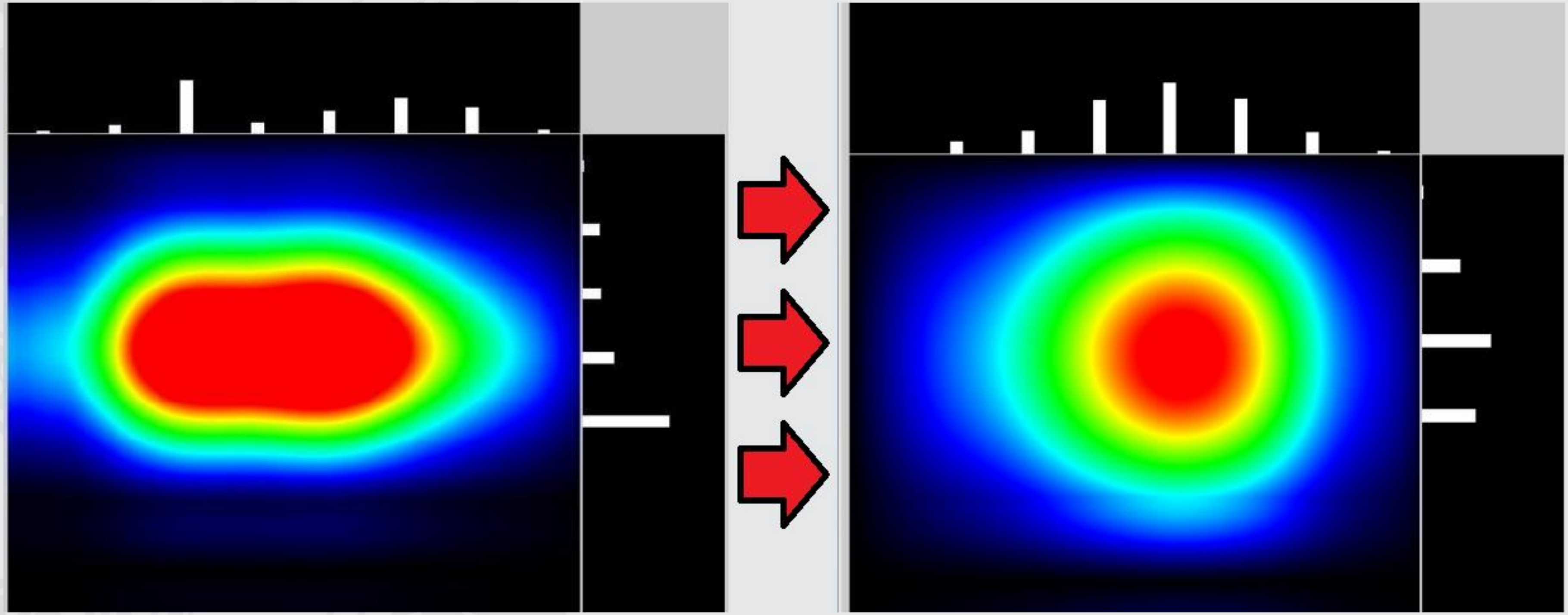
The purpose of diagnostics: quick and accurate determination of beam parameters.

Introduction

One of the most important parameter of the beam – beam profile.

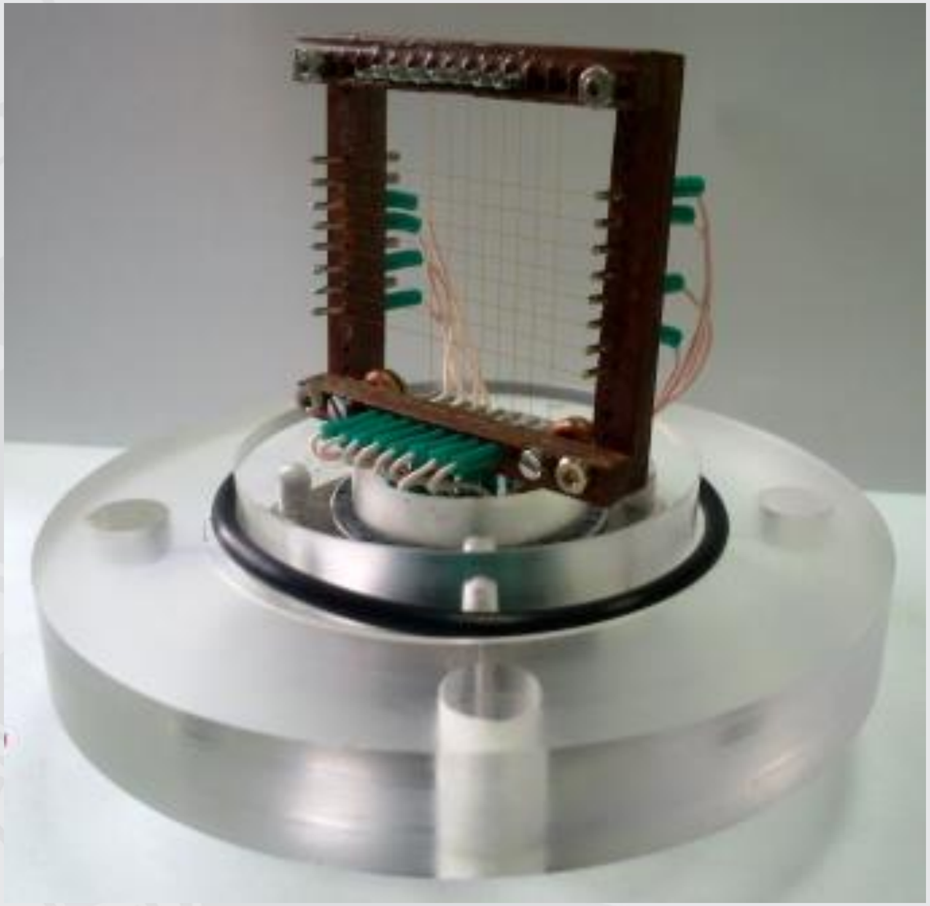
Beam profile visualization:

- Determine the position of the beam inside accelerator or the beam pipe;
- Control of transverse beam dimensions;
- Increase the particle density of the beam.



An example of visualization of the alpha particle beam profile of the U-120 Cyclotron of St. Petersburg State University .

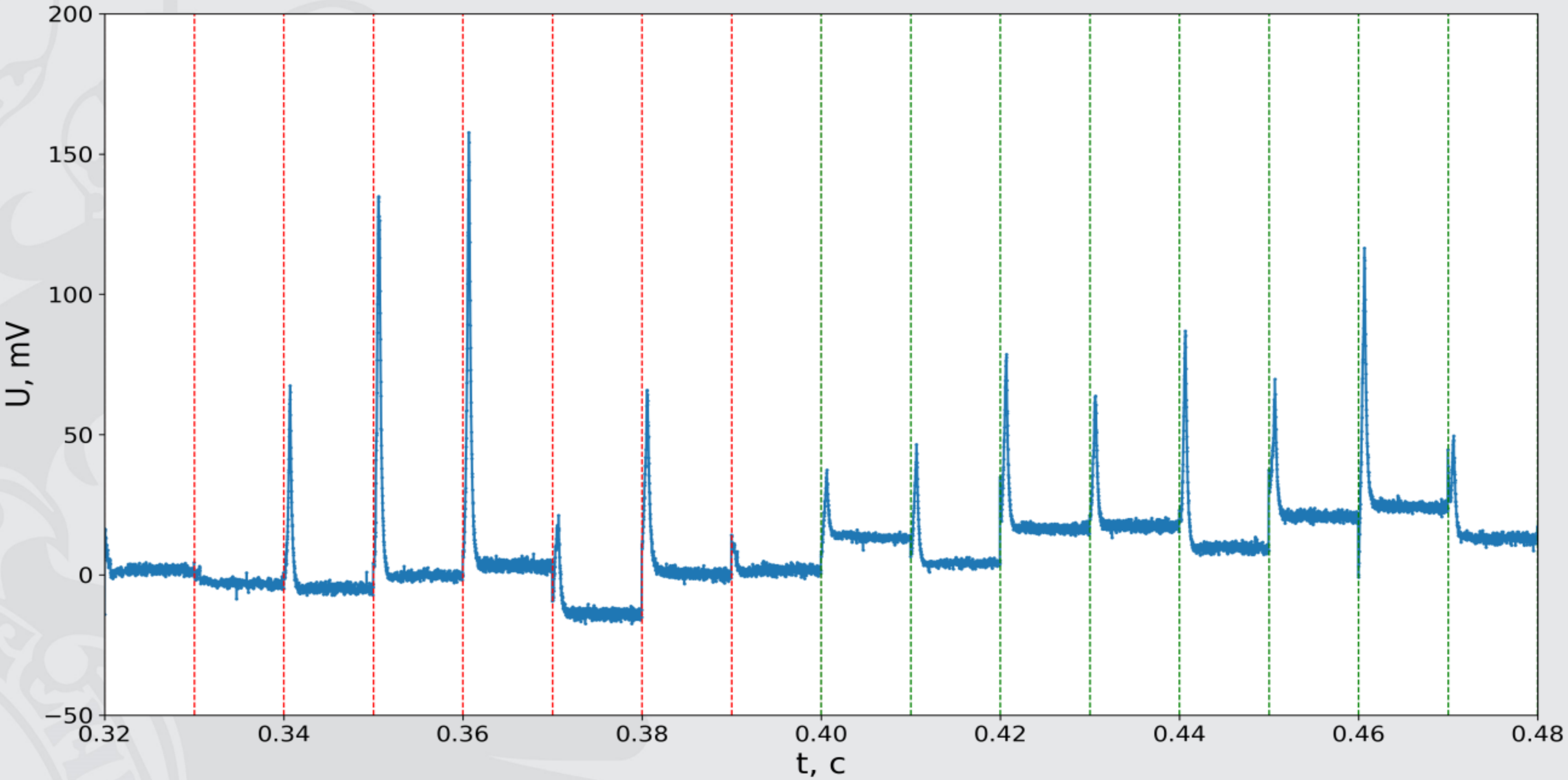
Multi-wire beam monitoring system



Support frame with a grid of sensors for a system for monitoring charged particle beams, developed at the Educational Laboratory of Nuclear Processes of St. Petersburg State University .

- 16 thin (25 microns) gold-plated tungsten sensors (mesh);
- Placed in a plane perpendicular to the direction of the beam at a distance of 2.5 mm from each other. 8 vertical and 8 horizontal.
- The sensors are fixed on a special support frame, which is mounted on a flange. Then the entire diagnostic system is placed in the beam pipe.
- Each sensor can be considered as a current generator. The current is proportional to the number of secondary electrons knocked out of the sensor material by beam particles

Multi-wire beam monitoring system



An example of a signal from the sensors of a multiwire beam monitoring system.

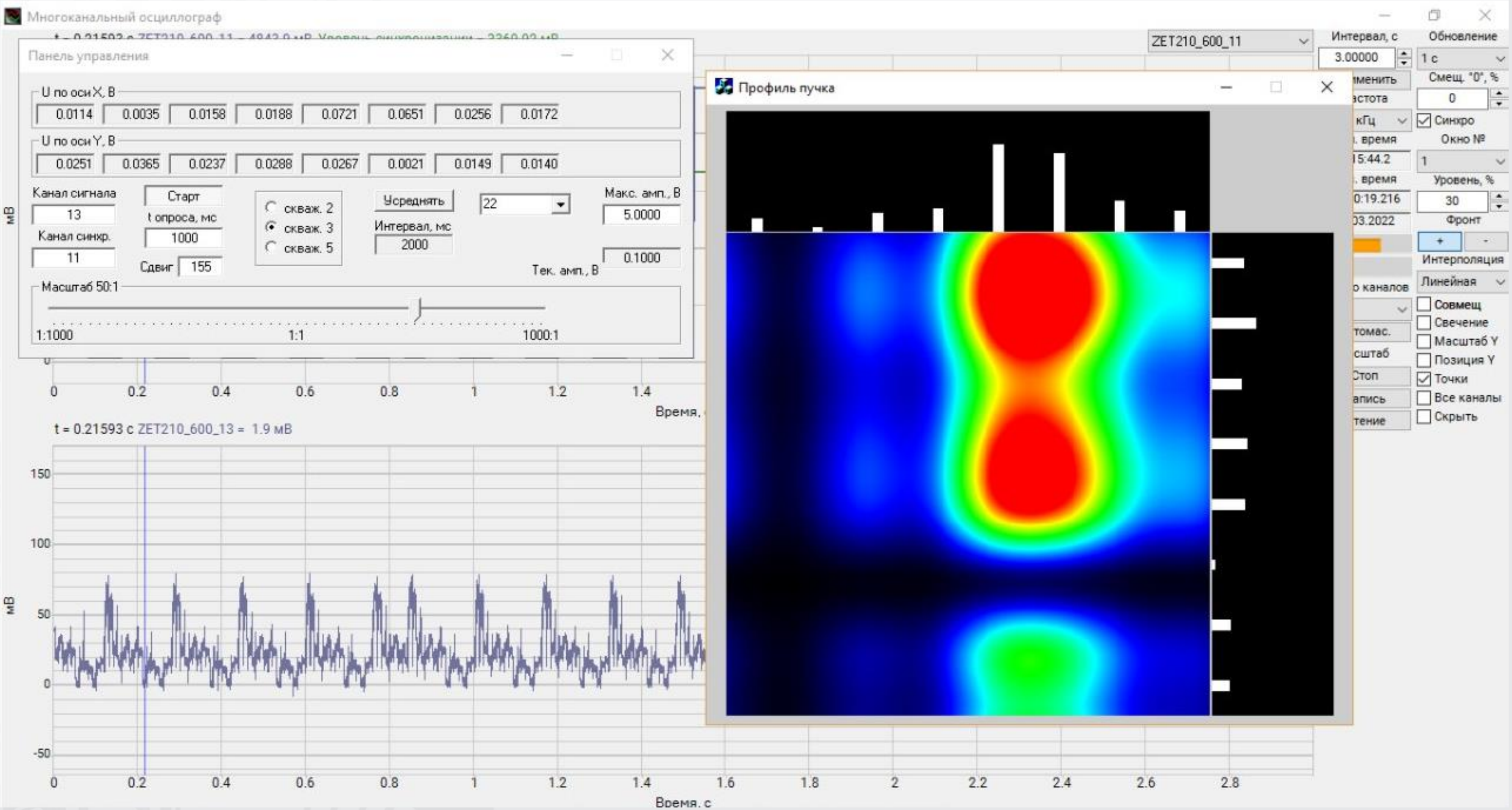
Experiments using a multi wire beam monitoring system

The experimental setup was mounted on the extracted beam of the Unique Scientific Installation (UNU) “Cyclotron of the Physicotechnical Institute named after. A.F. Ioffe type U-120."

General view of the experimental setup.

Experiments using a multi wire beam monitoring system

Beam position control was carried out using a beam profile visualization program, which provided accurate monitoring of its position in real time.



Многоканальный осциллограф

Панель управления

U по оси X, В: 0.0114 0.0035 0.0158 0.0188 0.0721 0.0651 0.0256 0.0172

U по оси Y, В: 0.0251 0.0365 0.0237 0.0288 0.0267 0.0021 0.0149 0.0140

Канал сигнала: 13
Канал синхр.: 11
t опроса, мс: 1000
Сдвиг: 155
○ скваж. 2
● скваж. 3
○ скваж. 5
Интервал, мс: 2000
22
Макс. амп., В: 5.0000
Тек. амп., В: 0.1000
Масштаб 50:1

t = 0.21593 с ZET210_600_13 = 1.9 мВ

ZET210_600_11
Интервал, с: 3.00000
Обновление: 1 с
Смещ. "0", %: 0
☑ Синхро
Окно №: 1
Уровень, %: 30
Фронт
Интерполяция: Линейная
☐ Совмещ
☐ Свечение
☐ Масштаб Y
☐ Позиция Y
☑ Точки
☐ Все каналы
☐ Скрыть

Methodology for calculating the secondary electron emission coefficient

The secondary electron emission coefficient can be calculated as:

$$N_{Secondary} = N_{Primary} * \delta_{se},$$

where $N_{Primary}$ is the number of beam particles that interacted with the sensor of the multiwire system; $N_{Secondary}$- the number of electrons emitted as a result of such interaction; δ_{se}- the secondary electron emission factor.

Analyzing signal from the sensors one can determine the number of secondary electrons $N_{Secondary}$ emitted from the sensor.

Analysis of the signal maxima of each individual channel (sensor) allows us to determine $N_{Primary}$.

$\rho(x)$ and $\rho(y)$ – one-dimensional distributions of beam particles. They are independent if $\rho(x,y) = \rho(x) * \rho(y)$.

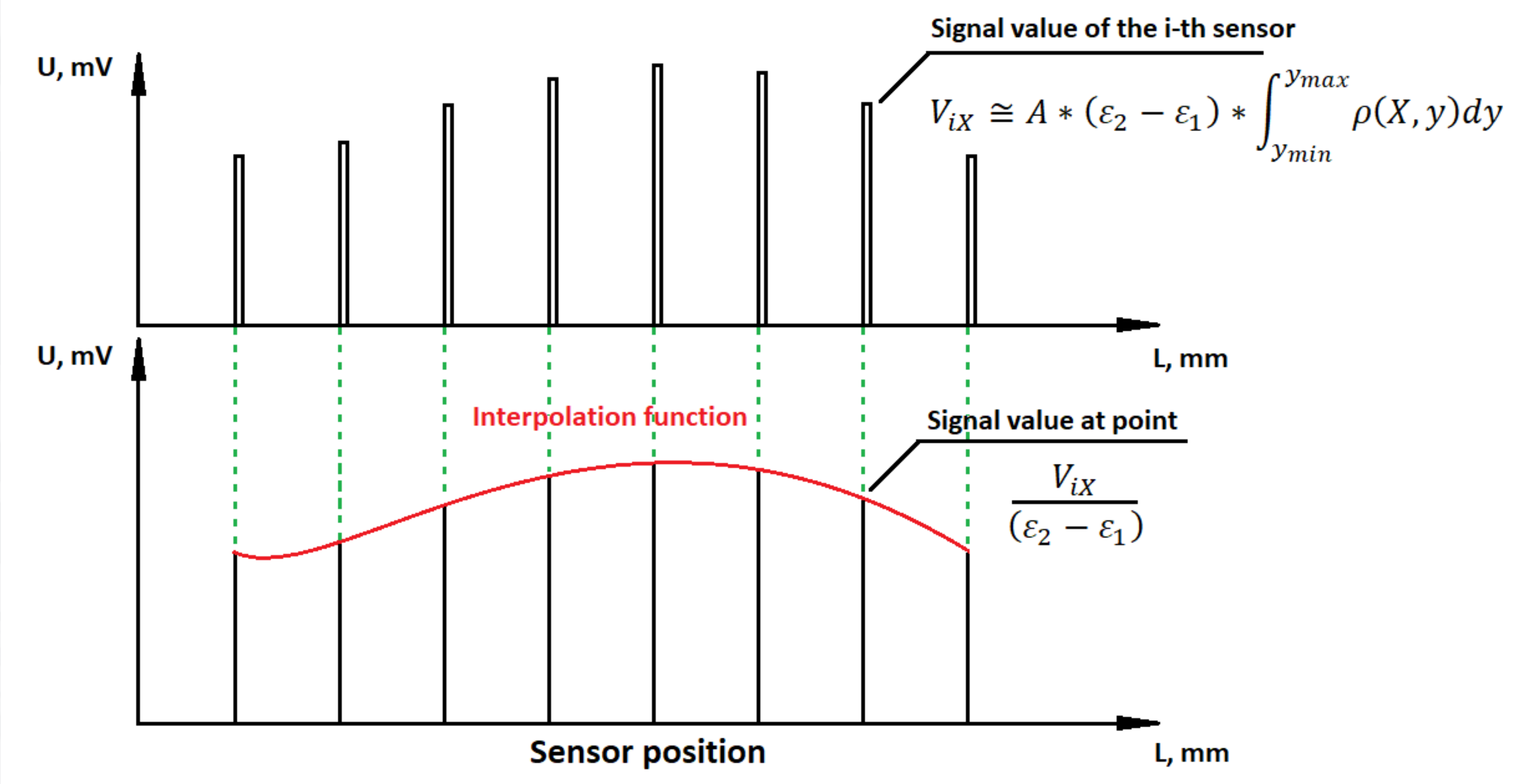
Taking this simplification, we can consider the signal of an individual sensor as an integral:

$$V_{iX} = A * \int_{\varepsilon_1}^{\varepsilon_2} dx \int_{y_{min}}^{y_{max}} \rho(x,y)dy \cong A * (\varepsilon_2 - \varepsilon_1) * \int_{y_{min}}^{y_{max}} \rho(X,y)dy$$

$$V_{jY} = K * \int_{\zeta_1}^{\zeta_2} dy \int_{x_{min}}^{x_{max}} \rho(x,y)dx \cong K * (\zeta_2 - \zeta_1) * \int_{x_{min}}^{x_{max}} \rho(x,Y)dx$$

Methodology for calculating the secondary electron emission coefficient

Applying interpolation to the values of sensor signals (separately for vertical and horizontal), we obtain interpolation functions $F(x)$ and $G(y)$.



$$V_{iX} \cong A * (\varepsilon_2 - \varepsilon_1) * \int_{y_{min}}^{y_{max}} \rho(X, y)dy$$

$$\frac{V_{iX}}{(\varepsilon_2 - \varepsilon_1)}$$

Integrating these functions within the coordinates of the sensor grid and normalizing them to the number of particles in the beam, we obtain the constants A, K.

Methodology for calculating the secondary electron emission coefficient

The number of beam particles per pulse can be found as:

$$N_{beam\ particles\ in\ a\ pulse} = \frac{I * t}{Z * e},$$

where I is the beam current averaged over the period of the cyclotron beam pulse; t – cyclotron beam pulse period; Z –beam particles charge; e – elementary electric charge.

The number of beam particles which interacted with sensor:

$$N_{iX} = A * V_{iX},$$
$$N_{jY} = K * V_{jY},$$

where V_{iX}, V_{jY} - are the signals peaks values from vertical and horizontal sensors; A, K are normalization constants.

Experimental results

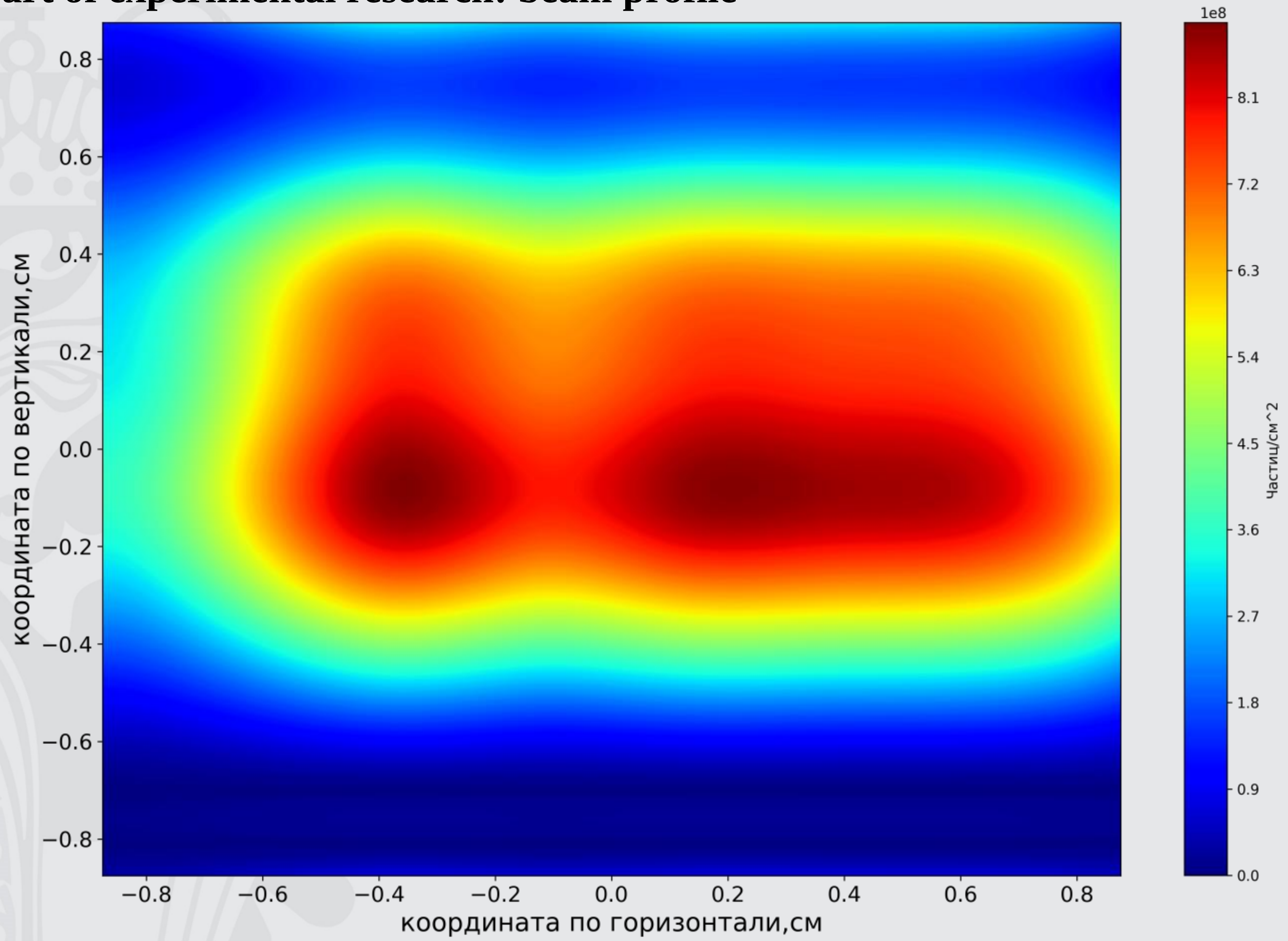
First part of experimental research:

Beam of $^{40}Ar^{+8}$ ions with an energy of 53 MeV and intensities: 40 nA, 70 nA, 100 nA, 130 nA, 160 nA.

	vertical sensors (electrodes)		horizontal sensors (electrodes)	
Beam current, nA	δ_{se}	$\Delta\delta_{se}$	δ_{se}	$\Delta\delta_{se}$
40	28,75	2,00	19,01	1,20
70	22,93	0,98	20,03	0,73
100	24,13	0,74	21,39	0,63
130	23,80	0,65	17,23	1,90
160	21,18	1,10	17,57	0,52
Mean	δ_{se}	$\Delta\delta_{se}$	δ_{se}	$\Delta\delta_{se}$
	23,74	0,95	19,24	0,79

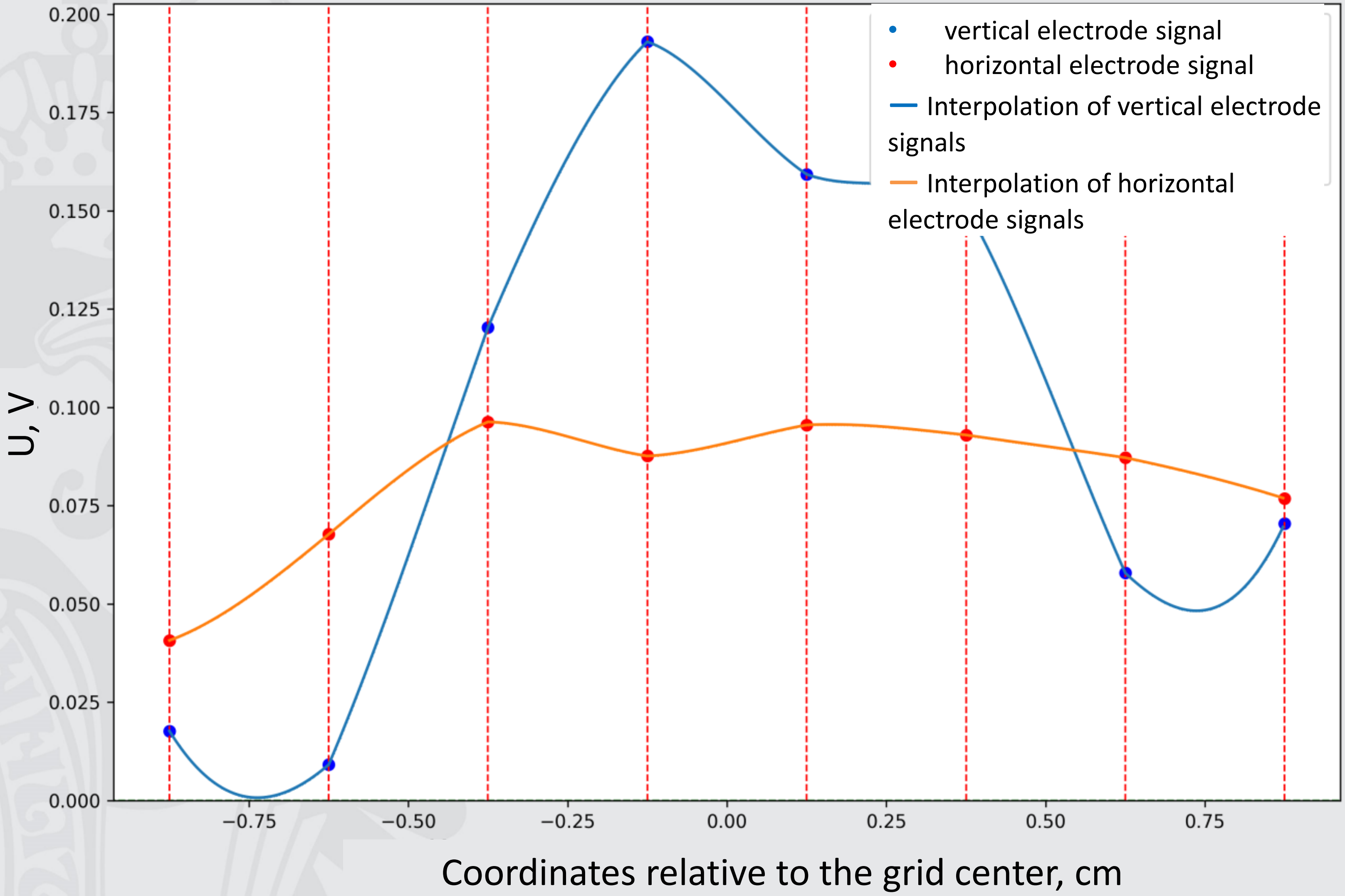
Experimental results

First part of experimental research: beam profile



Experimental results

First part of experimental research:



Experimental results

Second part of experimental research:

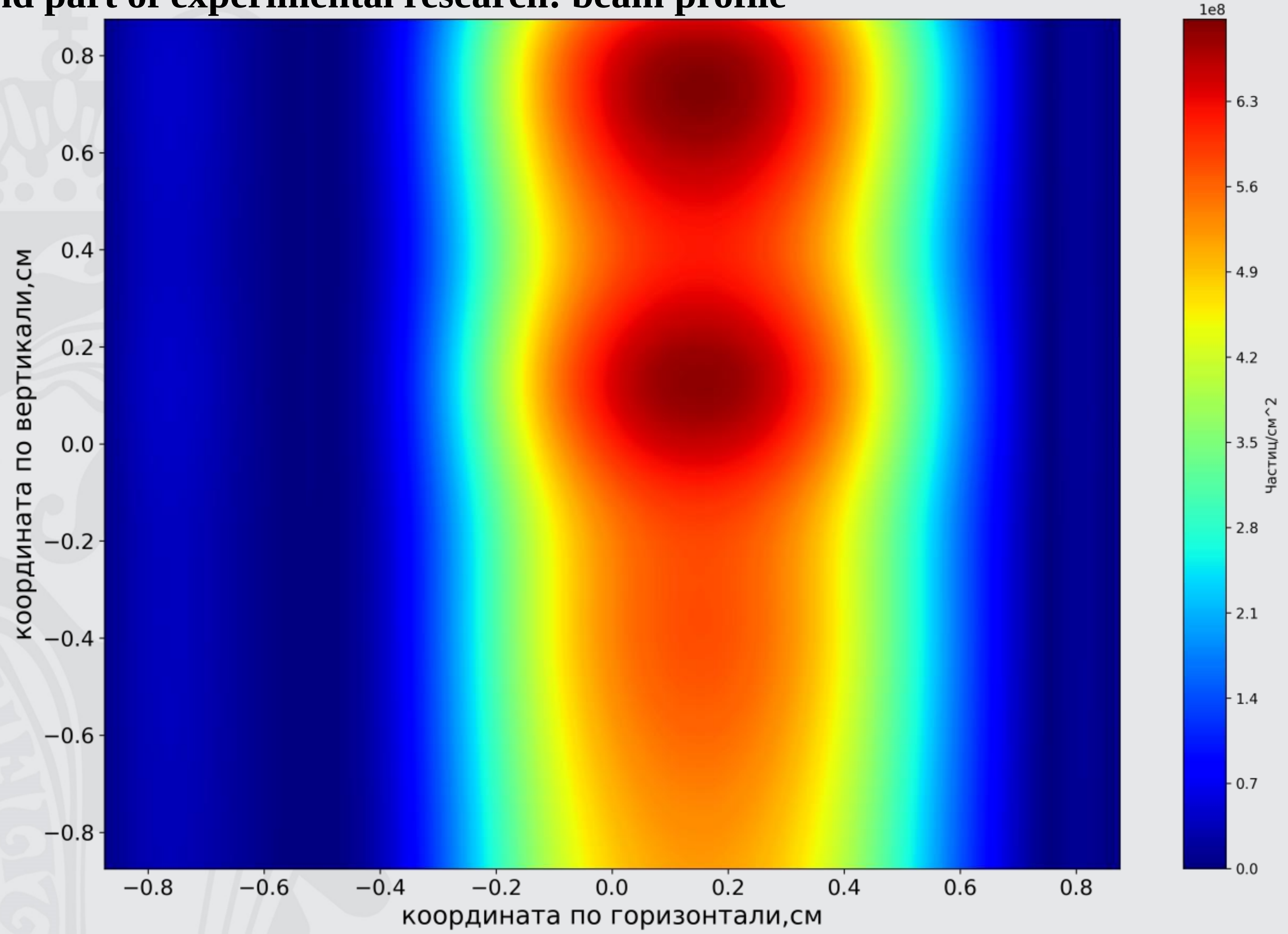
In the second experiment using an ion-optical system we reduce only the horizontal transverse dimensions of the beam. (reducing to size of the sensor grid).

Beam of $^{40}Ar^{+8}$ ions with energy 53 MeV with intensities: 50 nA, 70 nA, 100 nA. (3 times)

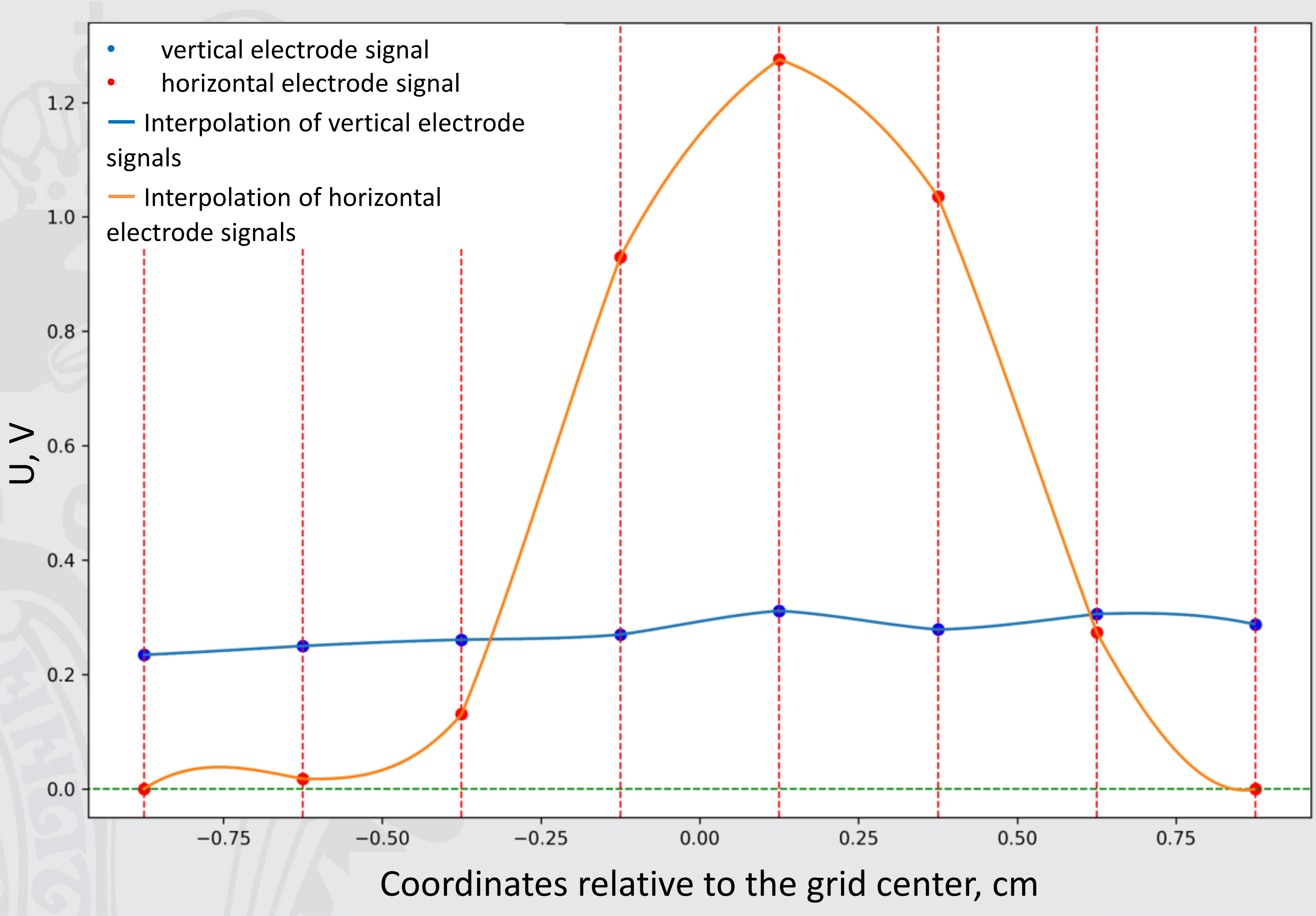
	vertical sensors (electrodes)		horizontal sensors (electrodes)	
Beam current, nA	δ_{se}	$\Delta\delta_{se}$	δ_{se}	$\Delta\delta_{se}$
50	22,17	0,19	40,87	0,51
70	19,03	0,08	37,95	0,26
100	20,63	0,06	40,41	0,19
100	21,07	0,04	41,90	0,14
100	21,46	0,04	37,95	0,11
Mean	δ_{se}	$\Delta\delta_{se}$	δ_{se}	$\Delta\delta_{se}$
	20,93	0,43	39,68	0,75

Experimental results

Second part of experimental research: beam profile



Experimental results



Experimental results

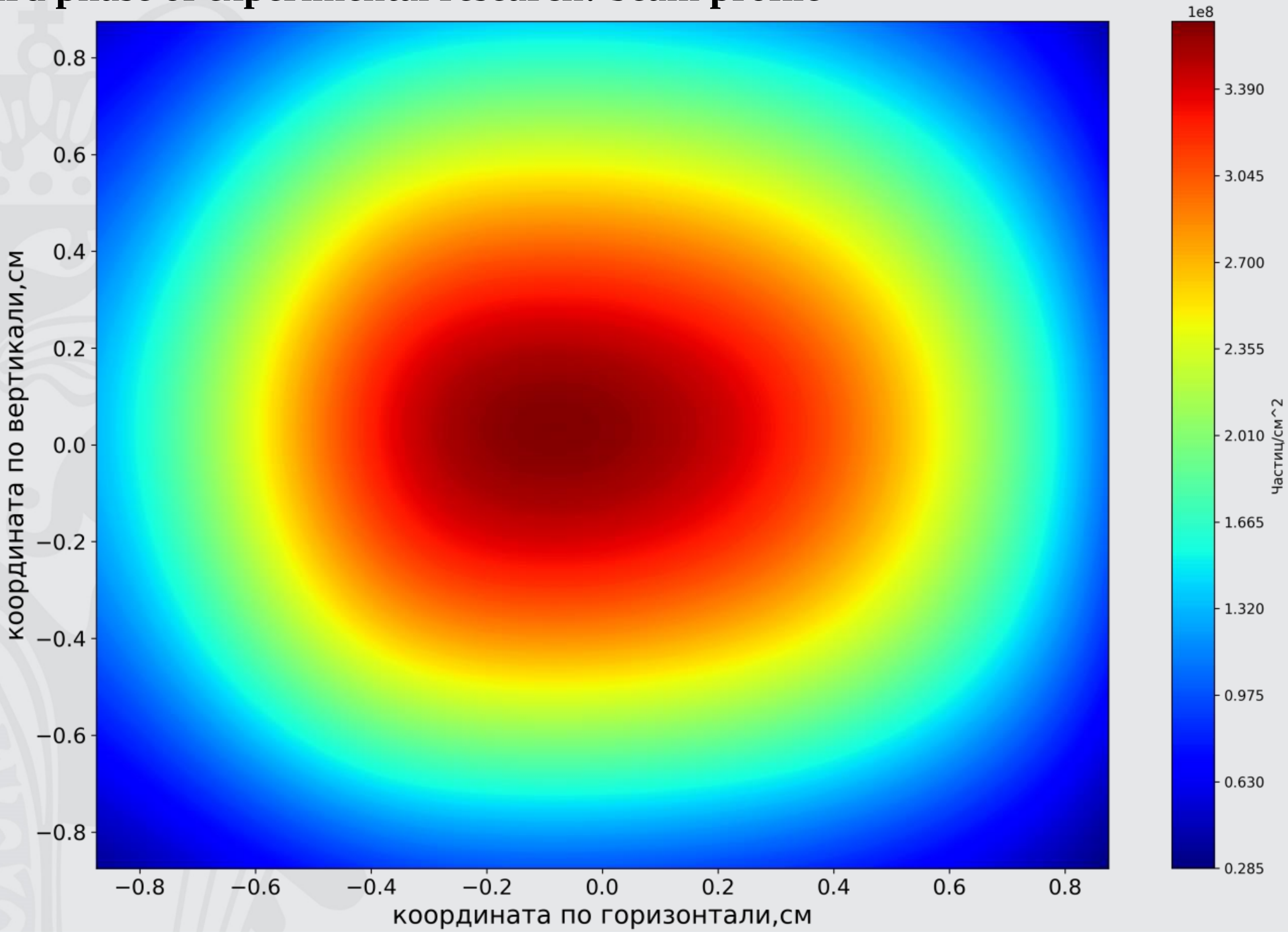
The third part of experimental research:

Beam of $^{40}\mathrm{Ar}^{+8}$ ions with energy 53 MeV with intensities: 80 nA

	verticalsensors (electrodes)		horizontal sensors (electrodes)	
Beam current, nA	δ_{se}	$\Delta\delta_{se}$	δ_{se}	$\Delta\delta_{se}$
80	40,21	0,64	39,54	0,53

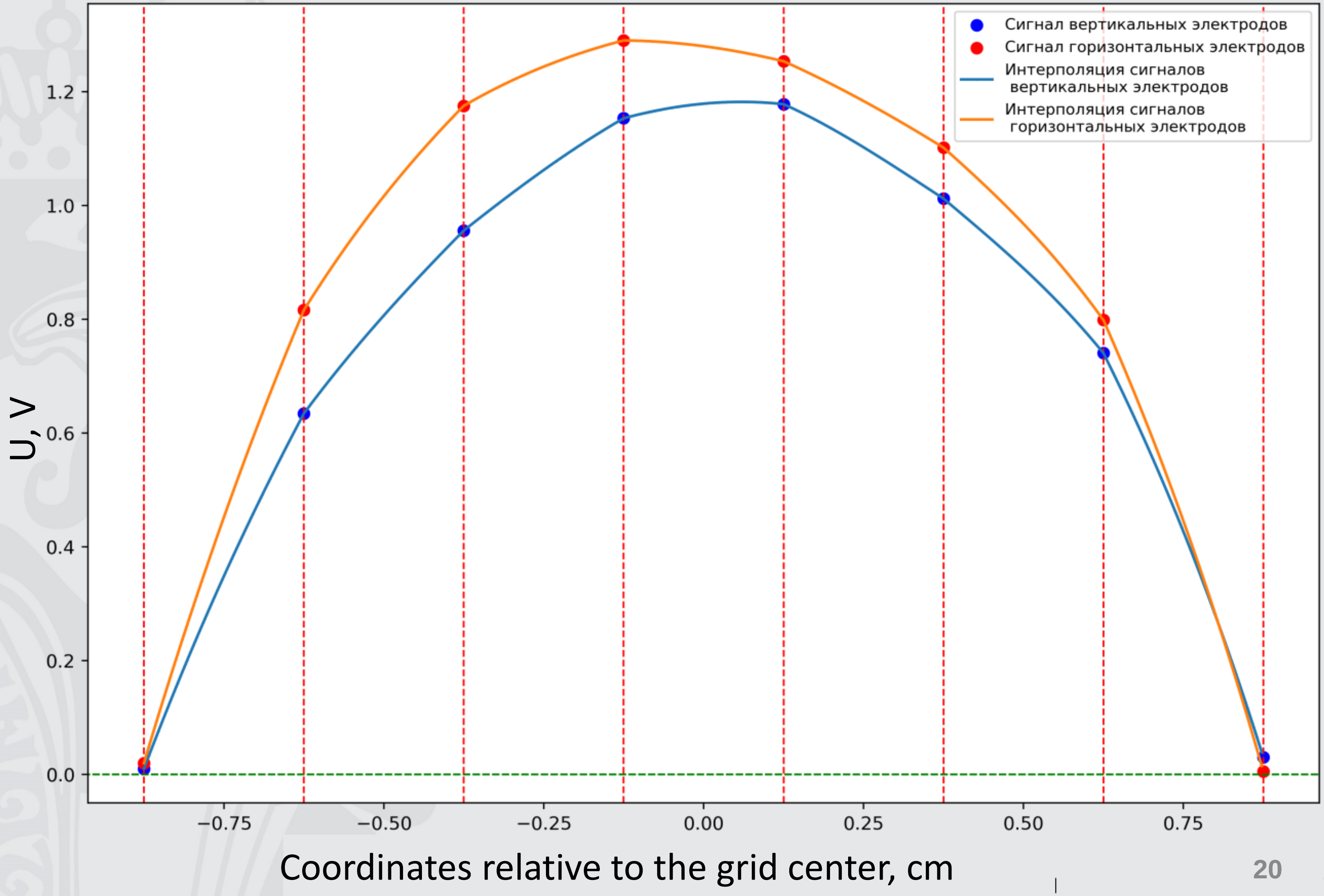
Experimental results

The third phase of experimental research: beam profile



Experimental results

The third phase of experimental research:



Conclusion

- The result of the research was the visualization of profiles of beams of $^{40}Ar^{+8}$ ions with an energy of 53 MeV at different intensities of these beams, as well as a set of statistics of signals from a multi-wire beam monitoring system;
- This made it possible to determine the secondary electron emission coefficient of $^{40}Ar^{+8}$ ions with an energy of 53 MeV during their interaction with the tungsten-gold layer. Its average value is δ_{se}^{exp}=(39.80±0.21);

Next plane:

- Theoretical estimation of the secondary electron emission coefficient.

Thank you for your attention!

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Theoretical analysis

The description of the effect of secondary electron emission is based on two simplifications:

- The yield of secondary emitted electrons is proportional to the specific energy loss $\frac{dE}{dx}$ of the primary particle per unit path length in the substance;
- Secondary electrons are characterized by the average path length in a substance.

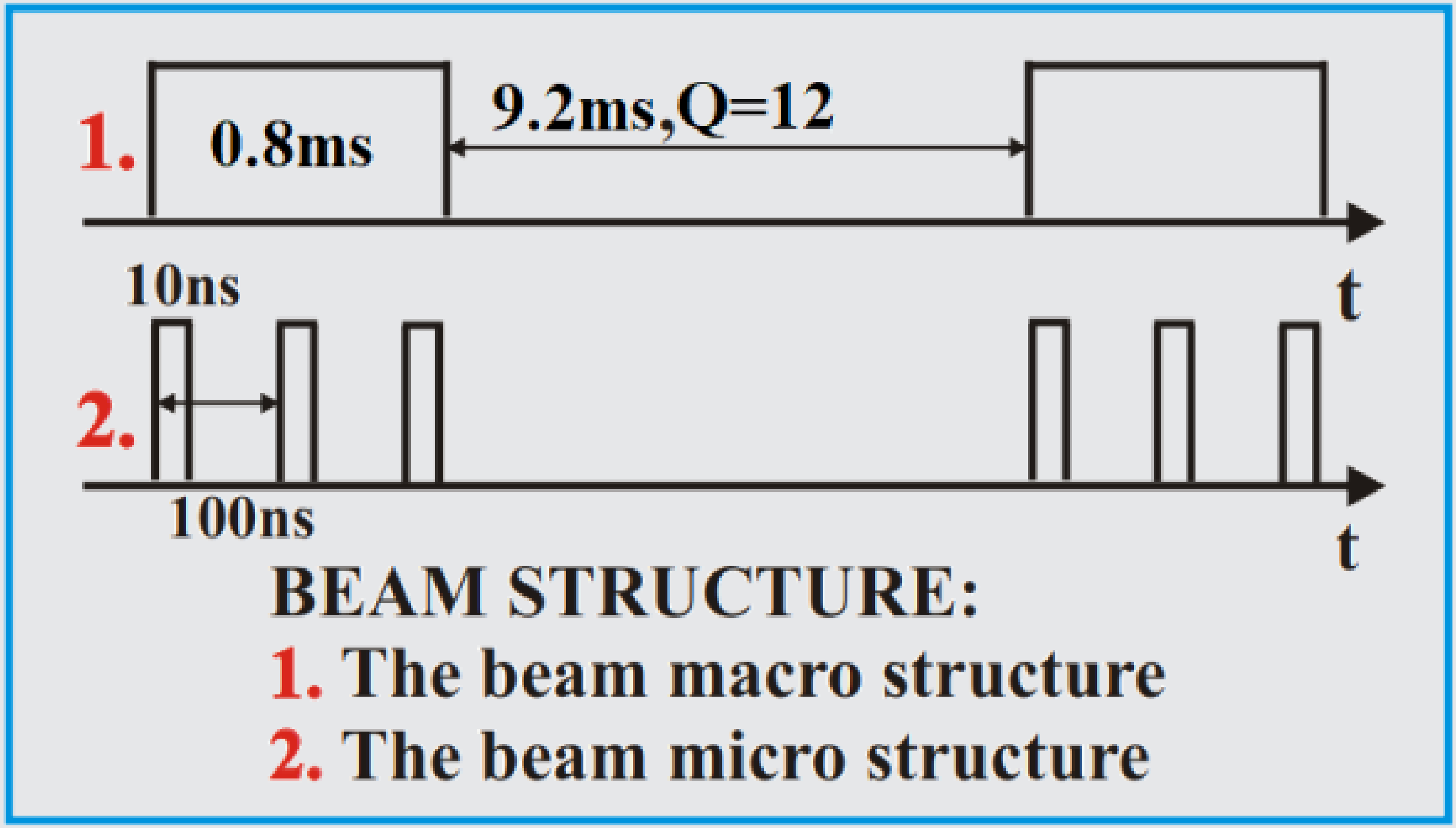
When these assumptions are made, the secondary electron emission factor can be calculated as [2]:

$$\delta_{se} = \left(\frac{dE}{dx}\right)\frac{\Delta x}{\varepsilon * \cos(\theta)},$$

where **ε** is the average energy required to knock out one secondary electron; **Δx** is the thickness of the surface layer from which secondary electrons are emitted; θ is the angle of incidence of the beam of primary particles.

The specific energy loss ($\frac{dE}{dx}$) is described by the Bethe–Bloch formula.

Beam structure



BEAM STRUCTURE:

1. The beam macro structure
2. The beam micro structure