SYSTEM OF SPECTROMETERS OF HIGH RESOLUTION FOR THE "SALO" PROJECT

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System calculation from two spectrometers of high resolution for the "SALO" project is carried out. Both spectrometers have own resolution on an impulse better $1 \cdot 10^{-4}$ and solid angle $4.9\,msr$. Ranges of angles for carrying out researches with use of only one spectrometer, and also for simultaneous use of two spectrometers when carrying out experiments on coincidence of two loaded particles taking off of a studied nuclear target are determined.

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1. INTRODUCTION

According to the project "SALO" [1] which is developed in NSC KIPT, it is planned to create the accelerator of electrons with energy of $750\,MeV$. The exit electron beam of the accelerator will have a diameter of $0,2\,mm$, with angular divergence equal to $5 \cdot 10^{-5}$ radian and energy spread of 10^{-4}. To study nuclear reactions caused by electrons and photons, it is necessary to create the equipment with the energy resolution comparable with beam energy spread.

Investigation of the structure of nuclei currently requires the registration in coincidence of scattered electron and taking-off fragment of nuclel. Usually the $(e,\, e'p)$ reaction is used. Such experiments require two high resolution spectrometers. High energy resolution allows to separate different reaction channels and thus to obtain more exact results. The experiments of this type with heavy-nuclei give information on how the properties of a nucleon change when it is in the nuclear environment.

The planed High Resolution Spectrometer (HRS) has to have momentum resolution better than $1 \cdot 10^{-4}$ and will be placed in the existing room with the spectrometers SP-103 and SP-02 [2] of the LINAC-2000 complex. The decision on the use of the existing spectrometers SP-103 and SP-02 for HRS creation was made to reduce the financial expenses.

The carried out earlier calculations of the HRS on the base of the spectrometer SP-103 [3] have showen the possibility of construction of such device with the necessary momentum resolution. NSC KIPT has an experience in calculation and creation of spectrometers [2] with momentum resolution of $1 \cdot 10^{-3}$. Good agreement between calculated and real characteristics of such spectrometers allows to hope that for HRS it also will be possible to obtaine good results.

Two identical high resolution spectrometers have been created in the Hall A of the Jefferson Lab (Jlab) [6] with the maximum momentum of $4\,GeV$. Superconducting magnetic elements were used in these spectrometers. However, in this work it is noted: "Both superconducting, and normal conducting options were considered. Normal conducting had advantage of being a well-established technology that was very likely to produce a robust, inexpensive magnet with almost no risk of failure. However, an evaluation of the operating costs for such a large dipole showed the superconducting option to be more favorable". HRS for the "SALO" project are calculated with normal conducting magnetic elements which have significantly smaller sizes than in Jefferson's laboratory and therefore will have, respectively, smaller operational expenses.

2. RESULTS OF CALCULATION

Because of considerable difference in sizes of the magnets SP-103 and SP-02, it is impossible to create two identical HRS as it was done in JLab. In our case the HRS using the magnet of SP-103 [3] has two quadrupoles and two dipol magnets with the central trajectory length of $11,306\,m$ from the experimental target to the detector. The spectrometer has the momentum resolution of $h = 4.74 \cdot 10^{-5}$ and solid angle of $4.9\,msr$. Total momentum resolution in the focal plane is determined not only by momentum resolution of the spectrometer but also by beam energy spread. With the planed value of the energy spread about $\pm 1 \cdot 10^{-4}$, the energy resolution should be not better than $h = 2.23 \cdot 10^{-4}$, i.e. close to the best possible energy resolution. Reducing the beam energy spread, it is possible to come nearer to the momentum resolution of this HRS $h = 4.74 \cdot 10^{-5}$.

For HRS with the magnet of SP-02, the scheme $QQDDQQ$ was chosen, where Q is a quadrupole and D is a dipole magnet. The basic geometrical sizes were determined taking into account the sizes of the

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existing room. The dipole magnet of the spectrometer SP-02 constructed to analyze the scattered electrons with the energy up to $1\,GeV$ and having the central trajectory length of $1.309\,m$ was used as the first dipole magnet in $QQDDQQ$ scheme. The second dipole magnet with a length of $1.1\,m$ along the central trajectory and with a gap of $8\,cm$ will need to be made. It was chosen the same as for the HRS of SP=103, calculated earlier [3]. Each dipole magnet has the bending angle equal to 30^0, thus, the general bending angle of the spectrometer is 60^0. The distance from the target to the detector along the central trajectory is $11.498\,m$.

The particles scattered from the target through an angle up to $45\,mrad$ in the median plane of a dipole and up to $27.2\,mrad$ in the plane perpendicular to the median plane were focused to a point at the focal plane. First order focusing was made by choosing the tilt angles ϵ_1 and ϵ_2 of the pole faces at the entrance and the exit of both dipoles. The angles ϵ_1 and ϵ_2 are considered positive if center of curvature of the central trajectory and external normal to dipole bondary are at oposite sides of the trajectory, and negative in the opposite case.The entrance angle of the first dipole is $\epsilon_1 = 56.69^0$, and the exit angle is $\epsilon_2 = -60.00^0$. For second dipole the angles are $\epsilon_1 = -41.76^0$ and $\epsilon_2 = 45.09^0$.

Second order focusing was made by choosing the curvature radiuses of the entrance and the exit pole faces. The entrance curvature radiuse of the first dipole is $1/R_1 = 8.65\,m^{-1}$, and the exit curvature radiuse is $1/R_2 = 0.037\,m^{-1}$. Both curvature radiuse have a convex shape. The entrance boundary of the second dipole has a convex shape and the radius of a curvature of $1/R_1 = 1.00\,m^{-1}$, and the exit boundary has a concave shape with the radius of a curvature of $1/R_2 = -1.00\,m^{-1}$.

The trajectories of the particles in the HRS are shown in Fig. 1 for monochromatic beam with the diameter of $0.2\,mm$ at the target. It is seen that the maximum horizontal size is after the exit from the first magnet, and the vertical size doesn't exceed $1.4\,cm$ on the way from the target to the exit from the last quadrupole $Q4$. After $Q4$ the vertical size increases and reaches $4.5\,cm$ at the detector. The horizontal size at the exit of the first magnet is less than the width of the existing dipole. The image horizontal size at the detector is $x = 0.047\,cm$, and the vertical size is $y = 4.47\,cm$. It is mainly the contribution of the beam sizes at the target. The obtained dispersion at the focus is equal to $12.00\,cm/\%$ and the momentum resolution is $7.8 \cdot 10^{-5}$.

For the non-monochromatic beam with the energy spread of $\pm 10^{-4}$ the vertical size at the detector remains the same as for monochromatic beam, and the horizontal size becomes equal to $0.167\,cm$ that gives momentum resolution of $2.78 \cdot 10^{-4}$. In this case the main contribution to momentum resolution of the spectrometer is from the beam energy spread. Reducing the energy spread it will be possible to come nearer to the spectrometer momentum resolution of $7.8 \cdot 10^{-5}$.

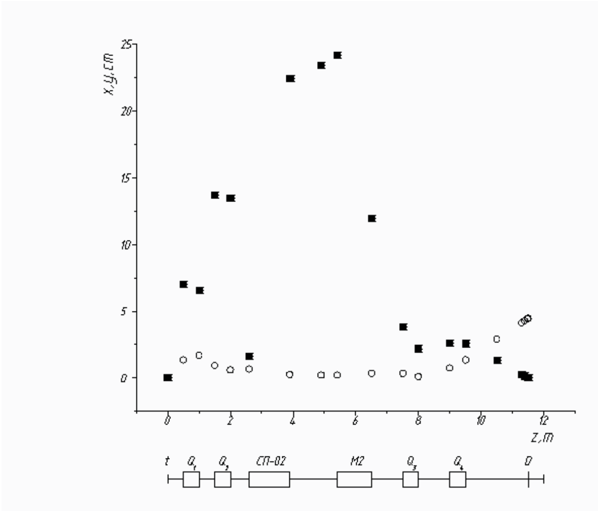

Fig.1. *Maximum deviation of the particles from the central trajectory in the spectrometer. Squares show the horizontal deviation and circles show the vertical deviation. The location of the spectrometer components along the central trajectory is shown below, t is the target, Q1, Q2, Q3, Q4, are the quadrupoles, SP-02 and M2 are the dipoles, D is the detector*

The carried-out calculations show that in a design of the first dipole (SP-02) it will be necessary to change the angle and radiuses of a curvature of the pole faces at the entrance and at the exit of the magnet.

Table shows the main characteristics of the spectrometers calculated for the "SALO" project and of the spectrometer created in JLab in a hall A. The calculated values of the momentum resolution of our spectrometers are a little better and the solid angles are a little less than of the spectrometer of JLab.

The spectrometer arrangement in the existing hall is presented in Fig. 2. The quadrupoles are represented with squares and dipole magnets are shown with circle sectors. The central trajectory length in the dipole is indicated with an arch. t is the target location, and D is the detector position. The installation angle of the spectrometer is the angle between the electron beam direction and the central trajectory of the spectrometer. This angle is measured counterclockwise for HRS with SP-103 and clockwise for HRS with SP-02. The spectrometer with SP-103 can be moved in the range 0^0 to 110^0, and the spectrometer with SP-02 in the range 0^0 to 95^0. The angle between the spectrometers cannot be smaller than 57^0. It is necessary to consider this restriction carrying out coincidence experiments with two spectrometers.

Main characteristics of the high resolution spectrometers for the SALO project and the spectrometer of JLab (CEBAF) [6]

Configuration	Horizontal bend, QQDD [3]	Horizontal bend, Present work QQDDQQ	Vertical bend, QQDQ
Bending angle	60°	60°	45°
Optical length (m)	11.306	11.498	23.4
Momentum range (GeV/s)	0.3...0.75	0.3...0.75	0.3...4.0
Momentum acceptance (%)	$-4.5 < \Delta p/p < +4.5$	$-4.5 < \Delta p/p < +4.5$	$-4.5 < \Delta p/p < +4.5$
Momentum resolution	4.74×10^{-5}	7.83×10^{-5}	1×10^{-4}
Dispersion at the focus ($cm/\%$)	4.2	12.0	12.4
Angular acceptance ($mrad$)			
Horizontal	±45	±45	±60
Vertical	±27.2	±27.2	±30
Solid angle, (msr)	4.9	4.9	6.0

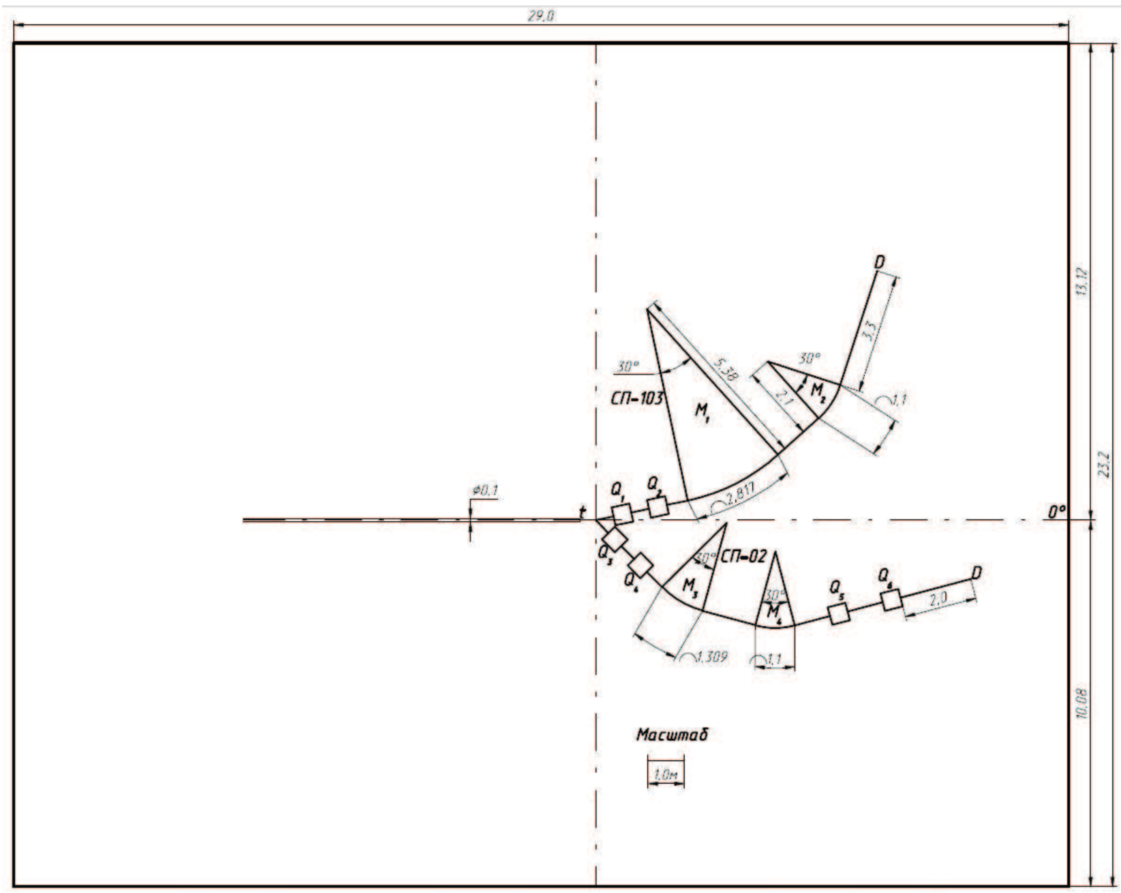

Fig.2. *Arrangement scheme of the spectrometers in the existing hall. t is the experimental target, D is the detectors, M1 and M3 are the existing dipoles of SP-103 and SP-02, M2 and M4 are the additional dipoles, Q1, Q2, Q3, Q4 are the quadrupoles*

3. CONCLUSIONS

The calculation results of the electronic optics of two high resolution spectrometers are presented. The spectrometers have the solid angle of 4.9 msr and the momentum resolution better than $1 \cdot 10^{-4}$. The spectrometer with the magnet of SP-103 can be moved in the range 0^0 to 110^0, and the spectrometer of SP-02 can be moved from 0^0 to 95^0 with the minimum angle between them of 57^0.

Creation of such spectrometers will allow to separate more reliably different channels of electro- and photonuclear reactions and to investigate how the property of a nucleon changes in nuclear environment. The obtained calculated values of the solid angle and the momentum resolution of both spectrometers are close to the existing high resolution spectrometers of Jlab (USA).

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СИСТЕМА СПЕКТРОМЕТРОВ ВЫСОКОГО РАЗРЕШЕНИЯ ДЛЯ ПРОЕКТА "SALO"

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Проведен расчет системы из двух спектрометров высокого разрешения для проекта "SALO". Оба спектрометра имеют собственное разрешение по импульсу лучше $1 \cdot 10^{-4}$ и светосилу $4,9$ мстерад. Определены диапазоны углов для проведения исследований с использованием только одного спектрометра, а также для одновременного использования двух спектрометров при проведении экспериментов на совпадение двух заряженных частиц, вылетающих из исследуемой ядерной мишени.

СИСТЕМА СПЕКТРОМЕТРІВ ВИСОКОГЇ РОЗДІЛЬНОЇ ЗДАТНОСТІ ДЛЯ ПРОЕКТУ "SALO"

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Проведен розрахунок системи з двох спектрометрів високого розрішення для проекту "SALO". Обидва спектрометри мають власне розрішення по імпульсу краще $1 \cdot 10^{-4}$ і світлосилу $4,9$ мстерад. Визначені діапазони кутів для проведення досліджень з використанням тільки одного спектрометра, а також для одночасного використання двох спектрометрів при проведенні експериментів на збіг двох заряджених частинок, що вилітають з досліджуваної ядерної мішені.