Journal of Academic Research and Trends in Educational Sciences
Journal home page:
http://ijournal.uz/index.php/jartes

ABSOLUTE LUMINOSITY DETECTOR: PROBLEMS AND PROSPECTS

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KEYWORDS

Luminosity, detector, target material, beam thickness, energy

ABSTRACT

The work proposed a detector to measure the luminosity at the points of convergence of beams at the collider NICA (Nuclotron-based Ion Collider fAcility). Based on scintillation counters, the proposed detector is compact and can be used independently and as part of the base detectors NICA. The estimates of the counting rate show that for pp and AuAu the number of valuable counts per minute exceeds 10^4.

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DOI: 10.5281/zenodo.7514082

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Introduction

Luminosity (L) determines the average number of interactions per unit time (dR/dt) for a reaction with a known cross section σ [1]:

$dR/dt = L \cdot \sigma$. (1)

The unit of luminosity is as follows $[L] = sm^{-2}s^{-1}$.

In some cases, for example, for a fixed target, the luminosity can be calculated from accelerator parameters and measurement conditions. Based on the measured count rate for a reaction with a known cross section, the absolute luminosity is calculated from equation (1).

The paper discusses the possibilities of determining the absolute luminosity for the NICA collider. Information about the absolute luminosity is needed already at the stage of experiment planning to estimate the speed of collecting statistics. At the final stage of processing the obtained data, information about the luminosity is needed to calculate the absolute cross sections. Without knowledge of the absolute cross sections, it is impossible to carry out ``difference`` measurements. For example, the study of analyzing abilities for neutron scattering from measurements on beams of polarized deuterons and protons [2].

For experiments with a fixed target, the luminosity depends not only on the parameters of the extracted beam (intensity, repetition frequency), but also on the properties of the target (target material, beam thickness, etc.). In a collider experiment, the luminosity is determined by the parameters of the colliding beams and the conditions for their intersection. The maximum achievable luminosity is one of the key characteristics of the collider.

It follows from definition (1) that the absolute luminosity can be calculated by measuring, with known efficiency, the count rate for a reaction with a known cross section. A research program is planned for the NICA collider in a wide range of energies (for heavy ions 4 GeV≤$\sqrt{S_{NN}}$≤11 GeV) and a large set of colliding nuclei (from protons to gold). Under such conditions, finding a reaction(s) with a well-known cross section is a difficult task. It is even more difficult to create a detector that registers signals from such a reaction with a well-known efficiency

This paper discusses a method for measuring absolute luminosity based on relative count rate measurements $d\tilde{R}/dt$ for a reaction with an unknown cross section ($\tilde{\sigma}$).

In this case, the count rate is written as:

$d\tilde{R}/dt = \varepsilon_D L \cdot \tilde{\sigma} = k \cdot L;\ k = \varepsilon_D \cdot \tilde{\sigma}$, (2)

where ε_D is the detection efficiency of the respective detector. The normalization coefficient k depends on the detection efficiency ε_D and the cross section of the reaction, the events from which are registered by the selected detector. Measurements of the counting rate $d\tilde{R}/dt$ with a known normalization coefficient k make it possible to determine the absolute luminosity:

$$L = \frac{1}{k} d\tilde{R}/dt\,. \quad (3)$$

The value of the normalization coefficient can be obtained from theoretical calculations of the cross section and simulation of the detector efficiency.

Detector for measurement and control of luminosity

The construction of the detecting system is shown in Fig.1. The system consists of two scintillation detectors (conditionally left and right). They are located at the same distance L on opposite sides of the interaction point along the collision axis. Each detector contains three planes consisting of four concentric rings. All rings are divided into eight sectors. The number of sectors can be changed (up or down), if necessary. Detector sectors adjacent to each other along the collision axis are connected according to the coincidence scheme.

The preliminary parameters of the detector system are given in Table 1.

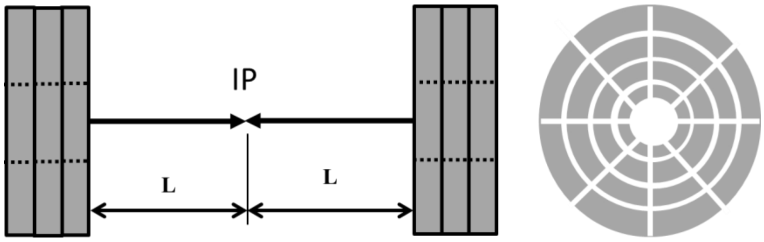

Fig.1. Scheme of a scintillation detector for measuring luminosity. The central hole is made for the ion guide.

Table 1.

Ring No.	Distance to IP, sm	Overlap area	Area, sm^2	Thickness, sm
1	300	$R_1 = 7\ sm \leq r \leq R_2 = 11 sm$	$S_1 = 226.2$	0.5
2	300	$R_3 = 11.3\ sm \leq r \leq R_4 = 15.3 sm$	$S_2 = 343.3$	0.5
3	300	$R_5 = 15.6\ sm \leq r \leq R_6 = 19{,}6 sm$	$S_3 = 442.3$	0.5
4	300	$R_7 = 19.9\ sm \leq r \leq R_8 = 24\ sm$	$S_4 = 565.4$	0.5

Consider the parameters of this system in more detail:

1. The system is mobile and compact:

a. the thickness of the assembly of three planes does not exceed 2.5 sm (with support structures);

b. cross dimension $\emptyset \leq 25\ sm$ (with support structures);

c. mass of three assembled planes $m \leq 3\ kg$ (with support structures);

d. due to its small size and weight, the system can be located autonomously. This makes it possible to adjust beams without mounting detectors.

2. Scintillation detectors are highly efficient in detecting charged particles in the NICA energy range.

3. Scintillation counters have high speed (signal duration on the basis of 10-15 ns, and the rise time of the front 1-2 ns [3]).

4. Scintillation detectors have good radiation resistance, which allows them to be used at the beginning of beam adjustment.

5. It is possible to consider the results of measuring the time of flight, which allows you to have an additional option to determine the maximum interaction.

Let us present estimates of the count rate for pp and Au-Au collisions and NICA boundary energies.

Let's start with pp collisions. The proposed detector scheme is suitable for detecting elastic pp collisions in the range of scattering angles 0.023 rad≤θ≤0.08 rad. At the same time, the design of the detector system is such that the "left" and "right" scintillation detectors can be connected to the coincidence scheme. This will noticeably reduce the amount of background from scattering by the residual gas. In this case, the counting rate of elastic collisions practically does not decrease.

The count rate estimate is determined from an approximation of the elastic scattering cross section. Approximation is based on the dependence of the elastic scattering cross section on the square of the transmitted four-pulse [4-7]:

$$\frac{d\sigma}{dT} = A \cdot exp(B \cdot T)\,, \qquad (4)$$

where T is the square of the transmitted four-pulse. In NICF kinematics it is equal to:

$$T = (P_b - P')^2 = -2p_b^2\big(1 - cos(\theta)\big) \cong -p_b^2\theta^2. \qquad (5)$$

Here p_b denotes the beam momentum and for the proposed registration scheme the scattering angle is small (see Table 1). For NICA energies $B \cong 10\ GeV^{-2}$ [4-6]. The values of the square of the transmitted four-pulse lie in the interval

$$-4.\cdot p_b^2 \leq T \leq 0. \qquad (6)$$

Due to the sharp drop in the cross section as a function of the transmitted four-pulse, the following normalization condition can be adopted:

$$\int_{-\infty}^{0} \frac{d\sigma}{dT} dT = \sigma_{el}. \qquad (7)$$

the following is obtained:

$$\frac{d\sigma}{dT} = \sigma_{el} \cdot B \cdot \exp(B \cdot T)\,, \qquad (8)$$

the elastic proton-proton cross section in the NICA energy range is equal to [4-6]:

$$\sigma_{el} \cong 10 \text{ мбн}, \qquad (9)$$

registration angles, intervals of transmitted squares of four-pulses and counting rate for each of the rings are shown in table 2:

Table 2

Ring No.	Angles (Rad)	Squares of four-pulse (GeV^2)	$dR/dt\ (s^{-1})$; $L = 10^{30} sm^{-2} s^{-1}$
		$\sqrt{S_{pp}} = 8\ GeV$	
1	$0.023 \le \theta \le 0.037$	$-0.020 \le T \le -0.008$	$1 \cdot 10^3$
2	$0.038 \le \theta \le 0.051$	$-0.039 \le T \le -0.021$	$1.3 \cdot 10^3$
3	$0.052 \le \theta \le 0.065$	$-0.065 \le T \le -0.041$	$1.4 \cdot 10^3$
4	$0.066 \le \theta \le 0.080$	$-0.100 \le T \le -0.067$	$1.3 \cdot 10^3$
		$\sqrt{S_{pp}} = 22\ GeV$	
1	$0.023 \le \theta \le 0.037$	$-0.161 \le T \le -0.065$	$3.2 \cdot 10^3$
2	$0.038 \le \theta \le 0.051$	$-0.312 \le T \le -0.170$	$1.4 \cdot 10^3$
3	$0.052 \le \theta \le 0.065$	$-0.512 \le T \le -0.325$	320
4	$0.066 \le \theta \le 0.080$	$-0.769 \le T \le -0.528$	46

We estimated the statistics accumulation rate for (Au+Au) collisions. The radius of the gold nuclei is:

$$R_{Au} = (r_0 = 1.2\ fm)(197)^{\frac{1}{3}} = 7\ fm. \quad (10)$$

The geometric estimate of the interaction cross section gives the following:

$$\sigma(AuAU) = \pi(2 \cdot R_{Au})^2 = 616\ fm^2 = 6.16 \cdot 10^{-24} sm^2 = 6.16\ bn. \quad (11)$$

For projected luminosity for NICA $L_{AuAu} = 1 \cdot 10^{27} sm^{-2} \mathrm{s}^{-1}$ the number of interactions per second is:

$$(dR/dt)_{AuAu} = 6000\ 1/c\ .$$

The interaction cross section σ(AuAU) remains constant in the NICA energy range. According to the energy data from the spectators, in [7] the requirement to limit the impact parameters to 2 fm ≤b≤12 fm with 100% probability leads to the registration of at least one proton in the right and left detectors. Such a constraint on the impact parameters corresponds to the effective cross section:

$$\sigma(AuAU; 2\ fm\ \le b \le 12\ fm) = \sigma(AuAU)\left(\frac{12}{14}\right)^2 (1. - \left(\frac{2}{12}\right)^2) \cdot= 4.4\ b\ . \quad (12)$$

It follows that for the maximum luminosity $L_{AuAu} = 1 \cdot 10^{27} sm^{-2}s^{-1}$ and the conditions for the appearance of at least one charged particle in each of the arms of the detector gives the number of counts per second:

$(dR/dt(2\ fm\ \leq b \leq 12\ fm))_{AuAu} \geq 4400\ 1/s$.

Thus, at maximum luminosity, the statistics accumulation rate per 1 second for Au-Au collisions can be controlled with an accuracy of no worse than 2%.

Conclusion.

In conclusion, we can list the achieved results of the work:

1. A detector and an algorithm for measuring the absolute luminosity at NICA are proposed.
2. It is shown that, at a planned luminosity, such a detector makes it possible to measure the absolute luminosity with a percentage accuracy over times of the order of 1 minute for both pp and Au-Au collisions in the entire NICA energy range.
3. The proposed detector is compact and can be used autonomously, the adjustment time for beam convergence.

Acknowledgement

The work was partially supported by the RFBR/CNRS grant 18-52-15007 and the International Bank of the Fund for Academic Innovation Ministry of Higher Education of the Republic of Uzbekistan, project ID 128516, as well as a memorandum of joint activity between JINR (Dubna) and JizPI (Jizzakh).

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