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METHOD FOR DETERMINING THE LUMINITY OF pA- and dA-REACTIONS WITH THE HELP OF THE E – E DETECTOR RECORDING DELTA ELECTRONS FROM THE INTERNAL NUCLOTRON TARGET

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Abstract. Diagnostic device for determining the luminosity of the reaction by using delta-electrons has been proposed. The device was tested in experiments at the internal targets (C, Al, Cu, Ag, W) of the accelerator Nuclotron, LHEP JINR. Estimates of the differential cross section and the expected yield of delta-electrons have been made for the angle of emission of Delta-electrons from internal target = 64 degrees. Possibility of operative control of the luminosity of reaction during operation of the accelerator is shown.

Keywords: electron, delta, reaction, luminosity, detector, particles.

In physical experiments on the internal target of the Nuclotron with a circulating nuclear beam, it is necessary to control the intensity of the interaction of the beam with the internal target. This value is defined as the reaction luminosity $L_c$ (cm$^{-2}$, s$^{-1}$). The number of secondary particles registered per unit time $dN/d\Omega$, the differential cross section of their production $d\sigma / d\Omega$ at an angle $\theta$ are related by the following relationship:

$$\frac{dN}{d\theta}(\theta) = L_c \frac{d\sigma}{d\Omega}(\theta)$$  \hspace{1cm} (1)

Thus, the creation of an accessible method for diagnosing the luminosity of the reaction and the corresponding diagnostic device for it is an urgent task.

This article proposes a new method for determining the luminosity using a semiconductor $\Delta E - E$ detector, which will be installed in the chamber of internal targets at an angle of 64° from the ion guide axis (Fig. 1).

In addition to the semiconductor detector itself, one flange is required to install it in the vacuum chamber of the ion guide and a vacuum connector installed in the flange for feeding the detector and picking up the signal. The advantage of the method is that the beam itself is not disturbed by our setup, which is the main condition for diagnostic devices of this kind.

At present, emission electrons from thin targets are successfully used to develop monitors for the extracted beam from accelerators [1]. It is of great interest to use the pairwise Coulomb interaction of the beam particles with the electrons of the target atoms when controlling the reaction...
luminosity. When particles interact with atoms of the medium through which they fly, it is natural to compare the value of the impact parameter $b$ with the size of atoms $a$.

Fig. 1. Arrangement of the semiconductor $\Delta E - E$ detector in the vacuum chamber of the internal targets of the Nuclotron

Depending on how the quantities $b$ and $a$ relate to each other, this or that interaction process takes place. With ionization losses in each collision of a passing particle with an electron of the medium, on average, it loses a very small portion of energy. And only in rare cases is significant energy transferred, i.e. a $\delta$-electron is formed. Hence it follows that a large energy transfer with the formation of a $\delta$-electron occurs at small values ($b \sim a$) of the impact parameter.

A diagram of the "pure" pair interaction of a $Z_p$ nucleus with an electron is shown in Fig. 2. Here $Z_p$ and $Z_t$ denote the charges of the beam and target nuclei, respectively; $\beta$ and $\beta_0$ are the velocities of the projectile nucleus and the target electron; $\theta_e$ is the angle of electron emission and $E$ is its kinetic energy after interaction with the beam nucleus, $\gamma = 1 / (1 - \beta^2)$.

Fig. 2. "Pure" pair interaction of an incident particle with a free electron

In the case $b \ll b_z$ (see Fig. 2), the influence of the field of the target's own nucleus $Z_t$ can be neglected, and at $\beta_0 \ll \beta$ the electron can be considered initially at rest. As a result of interaction with
the projectile nucleus, it acquires energy $E_e$, which is kinematically uniquely related to the exit angle $\theta_e$ ($\delta$-electron) [2]:

$$E_e = 2m_e \left( \frac{y^2 - 1}{y^2 - (y^2 - 1) \cos^2 \theta_e} \right)$$

(2)

Its value is related to the impact parameter of interaction ($b$) by the expression [3]:

$$E_e = (Z_p)^2 \frac{2m_e r_e^2}{b^2 \beta^2}$$

(3)

Combining (2) and (3), taking into account $d\sigma_e = 2\pi b db$, we obtain

$$d\sigma_e = 2\pi (Z_p)^2 \frac{r_e^2}{\beta^2} \frac{\sin \theta_e}{\cos^3 \theta_e} d\theta_e = (Z_p)^2 \frac{r_e^2}{\beta^2 \cos^3 \theta_e} d\Omega$$

(4)

where $r_e = 2.82 \cdot 10^{-13}$ cm is the classical radius of the electron, and $0 \leq \theta_e \leq 90^\circ$ (Fig. 3).

Separation of delta electrons can be carried out with a semiconductor $\Delta E - E$ detector as in Fig. 1. Angle $64^0$ was not chosen by chance, the warm section of the Nuclotron has an outlet flange at this angle, where a semiconductor detector can be installed without any additional expenses, only by removing the signal through a vacuum connector. In this case, for homogeneous targets in the first approximation, the required characteristic $L_c$ is determined using expression (1) from the one shown in Fig. 3 the value $d\sigma_e/d\Omega_e (\theta_e)$ and the measured value $dN_e/d\Omega_e (\theta_e)$ using a semiconductor detector $\Delta E - E$.

Let us consider the possibilities of implementing this method for controlling the luminosity in experiments with internal targets at the Nuclotron. Fig. 4, in accordance with expression (2), shows the calculated energy of $\delta$-electrons $E_e$ ($\theta_e \approx 64^0$) at different energies $E_p$ of nuclei incident on the target characteristic of the Nuclotron.

![Fig. 3. Dependence of the differential cross section for the yield of $\delta$-electrons $d\sigma_e/d\Omega_e (cm^2\cdot sr^{-1})$ on the angle $\theta_e$ relative to the momentum of the incident particle](image-url)
Fig. 4. Dependence of the energy of delta electrons on the energy of the beam of incident deuterons of the Nuclotron at an angle of emission of electrons from the target $\theta_e \approx 64^0$

Table 1 below shows the calculated values of $d\sigma_e/d\Omega_e$ (cm$^2$·sr$^{-1}$) for $\theta_e \approx 64^0$ and a number of energies for incident nuclei (GeV nucleon-1):

<table>
<thead>
<tr>
<th>$d\sigma_e/d\Omega_e$ ($\times 10^{-22} Z_p^2$)</th>
<th>9.65</th>
<th>10.1</th>
<th>11.5</th>
<th>12.9</th>
<th>16.0</th>
<th>28.3</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_d$, GeV/n</td>
<td>6</td>
<td>4</td>
<td>2</td>
<td>1.5</td>
<td>1</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Here $Z_p^2$ is the charge of the incident particle.

If the incident nuclei is Ar, then the differential cross section, taking into account $Z_p^2 = 324$, will be:

<table>
<thead>
<tr>
<th>$d\sigma_e/d\Omega_e$ ($\times 10^{-22}$)</th>
<th>3.13</th>
<th>3.27</th>
<th>3.72</th>
<th>4.18</th>
<th>5.18</th>
<th>9.17</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_d$, GeV/n</td>
<td>6</td>
<td>4</td>
<td>2</td>
<td>1.5</td>
<td>1</td>
<td>0.5</td>
</tr>
</tbody>
</table>

The expected number of $\delta$-electrons from the internal target during its interaction with the circulating beam of nuclei on the synchrotron during its cycle of operation (Tc) is determined by the expression:

$$\frac{dN_e}{d\Omega_e} (\theta_e) = \bar{L} c T_c Z_p \frac{d\sigma_e}{d\Omega_e} (\theta_e),$$

where $\bar{L}$ is the luminosity averaged over the cycle time. The maximum value of $\bar{L}$ is reached when the lifetime of the accelerated beam interacting with the target in orbit is shorter than the duration of its circulation without it, i.e., it circulates many times. This is usually done for foil or filamentary targets with a thickness of the order of tens of microns.

An experimental determination of the quantity $d\sigma_e/d\Omega_e$ can in principle be carried out; in this case, it is only necessary to control with sufficient accuracy the target thickness $t$ and the...
number $N_0$ of nuclei incident on it per cycle. In this case, the number of $\delta$-electrons from the one-component internal target will be equal to:

$$
\frac{dN_{\delta e}}{d\Omega_{\delta e}}(\theta_e) = t \cdot \frac{Z_t}{A_t} \cdot 6 \times 10^{23} \frac{d\sigma_{\delta e}}{d\Omega_{\delta e}}(\theta_e),
$$

(6)

where $t$ is the thickness of the target (g/cm$^2$), $Z_t$, $A_t$ are the charge and atomic weight of the target.

The value $d\sigma_{\delta e}/d\Omega_{\delta e}(\theta_e)$ found as a result of such measurements (for a specific combination of beam and target characteristics) can then be substituted into (5) to determine $L_e$. For the expected intensities of nuclear beams at the Nuclotron [4], the relation $N_0(Z) \geq (Z_p)^2 \times N_0(d)$ is valid. Thus, it is sufficient to estimate the yield of $\delta$-electrons for the deuteron beam (d).

The results obtained for the interaction of deuterons with thin targets C (CH$_2$), Al, Cu, Ag and W 10 $\mu$m thick for $N_0=10^{10}$, $\gamma = 2.07$ (1 GeV/n) and 7.4 (6 GeV/n) with an acceleration cycle period $T_c = 10$ s are presented in Table 3 ($\theta_e=64^\circ$).

The value of the expected yield of delta electrons $\frac{dN_{\delta e}}{d\Omega_{\delta e}}$ in units (electron·sr$^{-1}$ s$^{-1}$); $n_e$ - the bottom line contains the number of electrons per unit time entering the semiconductor detector, taking into account its $\Delta\theta=1.6 \times 10^{-5}$ sr$^{-1}$ angular acceptance.

<table>
<thead>
<tr>
<th></th>
<th>1 GeV/ nucleon</th>
<th>6 GeV/ nucleon</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C(CH$_2$)</td>
<td>Al</td>
</tr>
<tr>
<td>$\frac{dN_{\delta e}}{d\Omega_{\delta e}}(\theta_e)$</td>
<td>1.1 $\times 10^7$</td>
<td>1.2 $\times 10^7$</td>
</tr>
<tr>
<td>$n_e$</td>
<td>176</td>
<td>192</td>
</tr>
</tbody>
</table>

When interacting targets with other nuclei, one can be guided by the values of Table 3 multiplied by $(Z_p)^2 \times N_0(Z_p)/N_0(d)$ [5]. Suppose that Ar nuclei with $Z = 18$ and $N_0=2 \times 10^7$ c$^{-1}$ are accelerated, then from the ratio $(Z_p)^2 \times N_0(Z_p)/N_0(d)$ we get $18^2 \times 2 \times 10^7/10^{10}= 0.648$ and go to Table 4 already for Ar kernels.

<table>
<thead>
<tr>
<th></th>
<th>1 GeV/ nucleon</th>
<th>6 GeV/ nucleon</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C(CH$_2$)</td>
<td>Al</td>
</tr>
<tr>
<td>$\frac{dN_{\delta e}}{d\Omega_{\delta e}}(\theta_e)$</td>
<td>7.1 $\times 10^6$</td>
<td>7.8 $\times 10^6$</td>
</tr>
<tr>
<td>$n_e$</td>
<td>115</td>
<td>125</td>
</tr>
</tbody>
</table>
From the results given in Table 4, it can be seen that, with the acceptance of the $\Delta E$-$E$ detector $\Delta \Omega_e \approx 1.6 \times 10^{-5}$ sr, the expected fluxes of the registered $\delta$-electrons are quite large. They make it possible to quickly monitor the luminosity in experiments with internal targets on the circulating beam of the Nuclotron in each cycle of its operation.

**Conclusion**

The above analysis and calculations indicate the possibilities of the new method and the semiconductor detector for operational control of the luminosity in experiments with various foil and filamentous internal targets on circulating beams of the Nuclotron nuclei by $\delta$-electrons in each cycle of its operation. The proposed calibration algorithm with finding the proportionality coefficient between the operating and the luminosity measured by $\delta$-electrons allows us to hope for the effective use of this method of operational diagnostics also for multicomponent internal targets with different $Z_t$.

**References**

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