Some remarks on the identification of fragmentation products of heavy projectiles

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1. Introduction

The identification of heavy projectile fragments is a rather difficult task. First, the requirements on the resolution of the detector equipment are especially high and, secondly, the identification requires very accurate calibration procedures and a good stability of the response of the detectors.

It is advantageous to start the analysis from the basic kinematical relationships including the ion-optical equations. When the physically correct equations are used, both the resolution and the identification should be simultaneously optimised. We will see that the standard method, generally used for the isotopical identification of fast recoil ions, is applicable only for the lighter products. For the heaviest products the appearance of incompletely stripped ions demands for an alternative method which takes advantage of the specific ion-optical properties of the fragment separator.

2. The standard identification method

The method generally applied to identify fast recoil ions with a magnetic spectrometer is based on the deflection in a magnetic dipole:

$$B\rho = \frac{m_0 \cdot \gamma \cdot v}{q} \approx \frac{A \cdot u \cdot \gamma \cdot v}{q} \qquad (1)$$

B is the magnetic field, ρ the radius of the particle track in the magnet, m_0 the rest mass, q the charge state, v the velocity and γ the relativistic parameter to describe the increase of the mass. A is the mass number, and u is the atomic mass unit.

The identification is particularly simple if the ions are completely stripped, that means if $q = Z$. In this case, the determination of the magnetic rigidity $B\rho$ by the deflection in the magnet and of the velocity v is sufficient to determine the ratio A/Z. However, in a set-up where the ions have to pass layers of matter, the velocity and the magnetic rigidity should be measured on the same path, e. g. from the central image plane to the final image plane. For a good resolution in A/Z it is required to consider that the flight path between the central image plane and the final image plane depends on the horizontal angle measured at the final image plane. It is sufficient to correct for a linear dependence. The magnetic rigidity is deduced from the horizontal positions measured at the central image plane and at the final image plane by applying the appropriate ion-optical equations.

The calibration of the set-up can be performed with the primary beam, taking into account the energy loss in the layers of matter before the magnet. According to our observation, the stability of the magnets is very high, e. g. in the order of a few 10^{-4}. Thus, in order to control the time-of-flight values, the calibration of A/Z can be based on the magnetic rigidity if the energy loss in the target and other layers of matter as well as the velocity shift induced in the fragmentation reaction is taken into account.

For a full isotopic identification, the nuclear charge is determined by the specific energy loss in an ionisation chamber. For a good resolution both the dependence of the energy-loss signal on velocity and on position has to be corrected for. The absolute height of the energy-loss signal is influenced by gas pressure, temperature and the purity of the counting gas. Therefore, the absolute Z calibration should be based on the primary beam and it should be followed from setting to setting.

The calibration procedure is required to be correct for the primary beam. It may happen that the calibration deviates slightly from the correct values with increasing distance from the projectile. This is not crucial if the deviations can be followed and corrected for. For this purpose it is useful to consider that mass number and nuclear charge number must be integer.

3. The identification method using the intermediate degrader

For the description of this identification method we refer to the articles of M. de Jong et al.. (Nucl. Phys. A 628 (1998) 479), T. Enqvist et al. (Nucl. Phys. A 658 (1999) 47) and J. Benlliure et al. (Nucl. Phys. A 660 (1999) 87).

4. Properties of the detectors

4.1 Current grids

Unfortunately, the current grids in front of the target are not exactly aligned with respect to the other components of the beamline. Therefore one must expect an unknown devition of the beam spot from the center of the hydrogen target.

4.2 Current monitor SEETRAM

The beam-current monitor SEETRAM is expected to follow exactly linearly the intensity of the primary beam. From investigations at SATURNE and CERN it is known that the sensitivity (charge per beam particle) changes slowly with time. At GSI it has been measured, that the sensitivity is position dependent. The sensitivity must be calibrated with another detector, based on particle counting. A reliable calibration can be obtained by use of an ionisation chamber (see the article of A. Junghans et al., Nucl. Instrum. Methods A 370 (1996) 312).

4.3 Multiwire detectors

The position information of these detectors is obtained from the time difference of two signals in x and two signals in y. The multiwire detectors are equipped with well-defined delay lines. Therefore the position calibration is stable and well defined. There is only a shift in absolute position to be expected, due to different lengths of the cables.

For a reliable position determination, a condition has to be imposed on the “delay sum”.

The detection probability is below 100%. The voltage has to be adapted to the range in Z in order to obtain a high detection probability. If the voltage is too low, the particles are not seen.

If it is too high, the signal of the δ electrons spoils the position information, and the “delay-sum” condition is not fulfilled.

The position resolution is about 1 to 2 mm.

For detailes see the diploma thesis of M. Steiner (Institut für Kernphysik, TU Darmstadt).

4.4 Scintillation detectors

The scintillation detectors provide the time-of-flight and the position. Both values may depend on the pulse height (Z) of the fragments. Instabilities due to the influence of temperature effects and whenever the voltage is changed are expected. The time resolution is optimum when the output signals amount to about 5 volts. Therefore, the voltage is adapted to the corresponding Z range of the fragments, that means it may be changed from setting to setting. If the voltage is modified, this has an influence on the TOF calibration.

The position calibration is known to deviate from a linear dependence due to border effects and due to irradiation damages. The position calibration can be checked by use of the multiwire detectors.

The position resolution of the scintillation detectors is in the order of a few millimeters. The time-of-flight resolution is normally better than 100 ps (FWHM).

The scintillation detector SC21 is the only detector to determine the position at the central image plane.

The detection probability is close to 100%.

The time and position resolution deteriorates if the counting rate exceeds 50000 per second (in the beam pulse). Note that the counting rate in the central focal plane may be much higher than the trigger rate, taken at the exit of the fragment separator!

For more detailed information on the scintillation detectors see B. Voss et al. (Nucl. Instrum. Methods A364 (1995) 150).

4.5 Ionisation chambers

The ionisation chambers are normally operated under atmospheric conditions.

The ionisation chambers deliver an energy-loss signal and a drift-time information. The calibrations of both depend on pressure, temperature and gas impurities. The resolution in nuclear charge is normally good (ratio of width (FWHM) of one peak to distance of two adjacent peaks is about 0.4), when the sum of 4 anodes is considered. Heavy elements, however, which are not fully stripped, cannot be identified properly with these detectors. Due to border effects and due to recombination, the energy-loss signal is position dependent.

The position resolution of one anode amounts to a few 100 microns. This value deteriorates if the counting rate exceeds about 1000 per second (in the beam pulse). The charge resolution is much more stable with respect to counting rates.

The detection probability is close to 100%, however, due to the long drift-time there is a probability for loosing the correlation between the signals in the other fast detectors and in the ionisation chamber.

More detailed information on the ionisation chambers can be found in M. Pfützner et al..

5. Corrections

The following corrections have to be applied in order to obtain a good charge resolution:
o Position dependence of the energy-loss signal.
o Velocity correction of the energy-loss signal.

The following corrections have to be applied in order to obtain a good mass resolution:
o Delay of the light signal inside the scintillators by taking the average of left and right time-of-flight signals.
o Dependence of the flight path on the angle (determined by the multiwires MW41 and MW42 or by the drift-times of the 1. and the 4. anode of the ionisation chamber).
o Eventually the dependence of the flight path on the magnetic rigidity.

The following corrections have to be applied in order to obtain precise production cross sections:
o Normalisation to the number of SEETRAM counts during the file.
o Secondary reactions in the layers of matter at F0 and F2.
(Use the modified Karol code http://www-wnt/kschmidt/karol.htm)
o Ionic charge-state distributions in the first and the second magnetic sections.
o Detection probabilities of the detectors.
o Losses of the data acquisition due to dead time.
o Transmission of the fragments through the FRS.