Simulation of an experiment on nuclear fission of heavy secondary projectiles using a large dipole magnet

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Introduction

The secondary-beam facility of GSI is a unique place world-wide for experiments with relativistic secondary beams from fragmentation of ^{238}U in the energy range up to 1 *A* GeV. In a previous experiment [1], the fission characteristics of a large number of neutron-deficient actinides and pre-actinides after electromagnetic excitations in a lead target have been investigated. The experiment allowed determining the atomic numbers of the fission products with excellent resolution and their mean total kinetic energy. It would be very interesting to improve this kind of experiment by measuring the magnetic rigidities of the fission fragments from the deflection in a large dipole magnet[a]. This way, also the masses of the fission products could be determined. The high velocity of the fissioning systems leads to a focussing of the fragments in forward direction and a compression of their velocities due to relativistic effects. Therefore, straggling phenomena are very critical, and the resolutions of the detectors need to be very high. Compared to previous experiments performed at ALADIN, the demands on the mass resolution are very ambitious, since masses up to about *A*=160 need to be well separated. For simulating the different effects that determine the mass resolution, a computer code has been developed that allows studying their different influences one by one in a systematic and transparent way. The COde for simulating experiments on Nuclear FIssion using a large Dipole (CONFID) is freely available [2].

Concept of the code

The experimental set-up, which determines the structure of the simulation code is shown in figure 1. The atomic numbers Z_1 and Z_2 of the fission fragments are deduced from the energy-loss signals in a subdivided ionization chamber (TWIN), and the velocities are determined by two time-of-flight (ToF) detectors. The *Z* determination and its resolution is rather well established and, thus, it is not considered in the code. The masses of the fission fragments are determined from their velocities mentioned just before and from the deflection angles in a dipole magnet, which are determined by three position detectors (Pos1, Pos2, and Pos3).

The starting point of the code is a fission process with a given total kinetic energy in some direction in space in the frame of the fissioning system. The trajectories of the two fission fragments are followed through the experimental set-up, consisting of a positions detector (Pos1), a first time-of-flight detector, the TWIN chamber, a second position detector (Pos2), a large dipole magnet, a third position detector (Pos3), and, finally, a second time-of-flight detector. Additional layers of matter, including gas sections, can be added. Also an eventual gas filling of the dipole may be specified.

In a first step, the trajectories of the fission products are calculated through the whole set-up, disregarding all straggling phenomena. Only the energy loss in the different layers of matter is considered. The time-of-flight and the positions of the ions are recorded, disregarding the uncertainties introduced by the finite detector resolutions. In a second step, the trajectories of the same fission products, emitted under the same conditions, are calculated with energy-loss straggling and angular straggling included. The time-of-flight and the positions of the ions are recorded, including the uncertainties due to the detector resolutions. All simulated detector parameters of these two events are written to an output file. These simulated events might be very useful as input for an analysis program to be developed for the analysis of the real experimental data.

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a An experiment of this kind had been proposed and approved in 2000 (S104), but it was not realized.

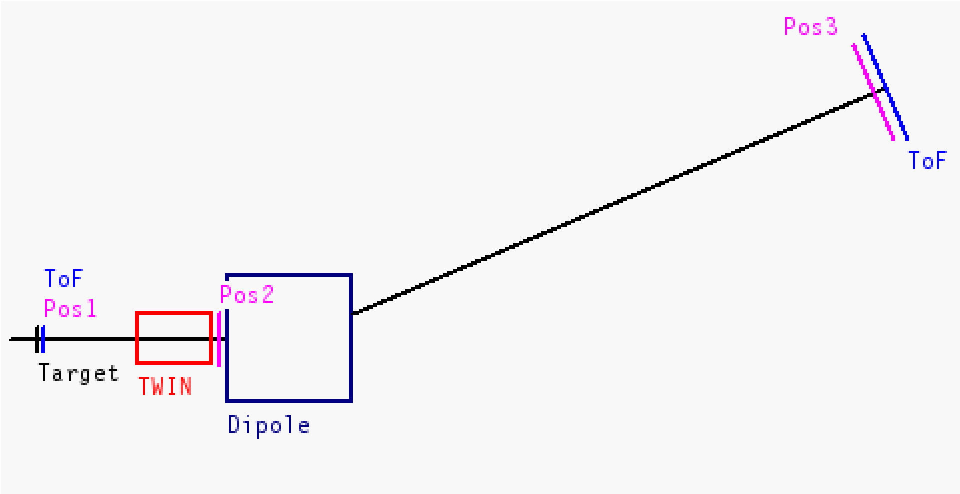

Fig. 1: Schematic drawing of the experimental set-up

The discrepancies of the numerical values of the two events are used to determine the mass resolution of the set-up under the condition that the magnetic field is perfectly known. The programme provides the numerical values of the mass resolution for the two fission products and a graphical output of the mass spectra. Moreover, the programme estimates the resolution of the total kinetic energy.

The influence of any uncertainty in the field mapping on the determination of the magnetic rigidity and, thus, on the masses and the total kinetic energies of the fission fragments is not considered in the code, because this would need the exact knowledge of the deficiencies of the field mapping. The magnetic field is assumed to be ideal in the sense that the field is constant between the entrance plane and the exit plane. In addition, the field is assumed to be exactly zero outside this volume. Although this assumption appears to be a bit crude, its influence on the estimated resolution is negligible in most cases: As long as the magnetic field does not deviate too much from this ideal case, the resolution of the experiment is independent from any local deviations, if the field mapping is perfectly known without any uncertainty. This implies that the analysis of the "real" experimental data needs to be performed using the perfect mapping knowledge. Any deviations from the real field strength in space will deteriorate the resolution and needs to be considered in addition.

Algorithms

The calculation of the trajectories outside the magnet is straightforward. For calculating the atomic interactions (energy loss, energy-loss straggling, and angular straggling) in the layers of matter, the code uses the fast algorithms described in ref. [3]. This allows calculating the energy loss and straggling phenomena in thin layers in one step. Atomic interactions in gas sections are determined by numerical integration along the trajectories. The trajectories in the magnet are expressed by the analytical formula of a circular curve, determined by the coordinates of the entrance point and the entrance angles. The radius of the circle is given by the magnetic rigidity of the ion. The trajectories inside the dipole with gas filling are calculated in steps by numerically propagating circular trajectories with varying radius as given by the energy loss in the gas. Fluctuations in energy and angle due to straggling are included, too.

For establishing the resolution in mass and TKE, the apparent trajectories of the ion with and without fluctuations due to straggling phenomena and detector resolutions are determined. This is done by exclusively using parameters, which are accessible to the experiment. The trajectories are assumed to be straight lines outside the magnet and a circular curve inside. They are determined by the three position measurements. The requirements that the coordinates and slopes of the trajectories meet at the entrance and at the exit of the dipole are expressed by analytical relations[b]. The apparent magnetic rigidity $B \times \rho_{app}$ is

b The condition on the slopes at the exit of the dipole is met by a very fast converging iteration. All other conditions are met exactly.

deduced from the radius ρ_{app} of the circle inside the magnet and the magnetic field *B*. The apparent flight path is given by the length of the apparent trajectory.

Since the mass is proportional to $B\rho/(\beta\gamma)$, the relative deviation of the apparent mass from the correct one is given by the difference of the relative deviations of apparent radius and $(\beta\gamma)_{app}$ of the trajectory with fluctuations from the values of the undisturbed trajectory.

A similar approach is used to determine the resolution in TKE. It is based on the velocity vectors of the two fragments in space. The longitudinal components are given by the magnetic rigidities and the masses, determined as just described. The transversal components are determined from the horizontal and vertical positions of the trajectories measured with the position detector near the entrance of the dipole.

CONFID is designed as a Monte-Carlo code. Trajectories of individual fission fragments are calculated, and the desired resolution values are determined from the distribution of the discrepancies of the correct and the apparent values of masses and TKE.

Conclusion

A computer code has been developed, which simulates the response of the detectors in an experiment on nuclear fission of heavy secondary projectiles at relativistic energies. Straggling phenomena and the finite resolution of the different detectors can be studied individually one by one. This kind of study helps specifying the necessary resolutions of the detectors to be developed and to fix the length of the flight path and other parameters of the experiment. The code also produces simulated experimental data, which are useful for developing analysis tools for this kind of data.

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