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Tracking algorithms for the active target MAYA

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ABSTRACT

The MAYA detector is a Time-Charge Projection Chamber based on the concept of active target. These type of devices use a part of the detection system, the filling gas in this case, in the role of the reaction target. The MAYA detector performs three-dimensional tracking, in order to determine physical observables of the reactions occurring inside the detector. The reconstruction algorithms of the tracking use the information from a two-dimensional projection on the segmented cathode, and, in general, they need to be adapted for the different experimental settings of the detector. This work presents some of the most relevant solutions developed for the MAYA detector.

1. Introduction

Nowadays, the development of new radioactive beams allows nuclear physics to explore more exotic regions of the nuclear chart, revealing more new properties as they become experimentally available. The access to these regions usually involve exotic nuclei with low intensity and reactions with small cross-sections that force to improve detection and analysis techniques. To overcome these difficulties, experimental setups focus on different solutions, such as high efficiency and signal-to-noise discrimination, and the use of thick targets. Active target detectors, i.e., detection devices that use part of their systems as reaction target, proved to match these needs: since the detection is done inside the target, detection efficiency and effective target thickness are increased without losing resolution due to reaction point indetermination.

The concept of active target, developed more than 50 years ago in high-energy physics uses, is being progressively adapted for its application in nuclear physics. The archetype of active targets in the domain of secondary beams is the detector IKAR [1], used at GSI (Germany) to study elastic scattering of exotic beams at relativistic energies. Another example is the MSTPC detector [2] designed at RIKEN (Japan) to study fusion and astrophysical nuclear reactions in low-energy regions. Presently, new designs are mostly based on gas-filled devices where the gas constitutes both the target and the detection medium. Among these, MAYA [3,4], developed and built at GANIL, is designed to explore very low energy domains not accessible with the use of solid or liquid targets. The MAYA detector applies the concept of Charge and Time Projection to perform a full three-dimensional reconstruction of the detected reaction with the charge collected in a segmented cathode and its associated drift time.

Most of the active targets in development use a similar configuration, with the tracking performed on a segmented layer. Therefore, some of the problems and solutions that appear in the reconstruction process are common to these detectors. In the case of MAYA, the tracking process needs to be adapted to the experimental configurations used to study different reactions, producing a collection of reconstruction protocols to extract the relevant observables. Among these, the angle, reaction vertex, and stopping points need specific formulas to be determined. Here, the most significant of these algorithms are reviewed.

2. The MAYA detector

Fig. 1 shows a typical MAYA setup. Two main zones can be identified within the detector: an active volume of $28 \times 25 \times 20\ cm^3$ where the reaction takes place, and the amplification area where

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detection and readout occur. The amplification zone consists of a Frisch grid, an anode wire plane below, and a segmented cathode in the lower part. The cathode is segmented into 33×32 hexagonal pads, each of which measures 5 mm per side, arranged in rows parallel to the anode wires.

In general, the detection occurs when the beam particles and the reaction products ionize the filling gas along their paths. The electrons released in the ionization process drift toward the amplification area where they are accelerated in the vicinity of the wires, inducing mirror charges on the corresponding pads, which are measured and coded individually. Typically, the image charge from one avalanche will spread over several pads and the resulting distributions are used to obtain a two-dimensional projection of the tracks of charged particles.

Measurements of the drift time of the ionizing electrons up to the amplification wires allow to calculate the vertical position. This information is combined with the reconstruction of trajectories projected on the cathode plane to perform a complete three-dimensional tracking of the reaction products that lose enough energy to be detected. Ancillary detectors, such as cesium iodide crystals [5], silicon [6–8], or diamond detectors are usually placed at the back, corresponding to forward angles in order to detect particles that do not stop inside the gas volume. Also, stoppers are employed for non-reacting beam particles that do not stop in the filling gas. Other modifications include beam-shielding [6] and a modified drift chamber placed before the ancillary detectors.

The filling gas is chosen according to the reaction of interest. So far, MAYA was operated and tested with $^{2}H_2$ or^{4}He, either pure or mixed with standard detection gases such as methyl-propane C_4H_{10} or CF_4, at pressures between 2 mbar and 1 atm.

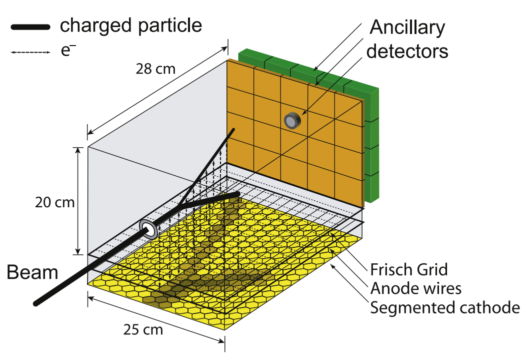

Fig. 1. The picture shows a schematic rendition of the MAYA active-target. A beam projectile enters the detector volume where it reacts with a nucleus in the gas. The particles involved in the reaction may produce enough ionization to induce a pattern in the segmented cathode, after traversing a Frisch grid and a plane of amplification wires. A set of ancillary detectors is used in the exit side of the detector.

The trajectory reconstruction from the sampled positions in the segmented cathode requires different algorithms that may vary from one configuration to the other. The tracking techniques extract information such as projected angles of trajectories, the position of the reaction vertex, and the determination of the stopping points, which are necessary to determined the range of the particles inside the gas.

3. Two-dimensional charge distributions

The two-dimensional projection of the particle trajectories on the cathode plane can be described as the convolution of different processes: the ionization path is digitized perpendicularly to the beam direction as the released electrons are attracted to the amplification wires; the amplification process induces a mirror charge on the pads below the wires that can be described as produced by multiple point-like sources; these are weighted by the energy-loss of the particles; and finally the resulting induced charge is integrated in the hexagonal-shape of each pad. Fig. 2 summarizes these processes. These steps are reproduced in a simulation of the entire process, providing realistic patterns where different algorithms can be tested to reconstruct the original tracks. The simulation code generates two-dimensional patterns by reproducing the different processes:

- The energy-loss along the particle trajectory for different ionizing particles, energies, and gas compositions and pressures is obtained from Monte Carlo simulations using the TRIM code [13]. A typical energy-loss profile of a 2 MeV proton in 1 atm of isobutane is presented in Fig. 3. The calculated energy-loss profiles are projected (digitized) along the wires to determine the total charge induced, Q in Eq. (1), by each point-like source along the trajectory. The straggling of the electrons inside the gas is not yet included. For $E/P > 0.8\ \mathrm{V\,cm^{-1}\,Torr^{-1}}$, it has been estimated to be less than 1 mm.
- The induction from a point-like source can be expressed as an exact electrostatic formula, as it is shown in Ref. [9]:

$$\sigma(x,y) = \frac{-Q}{2\pi} \sum_{n=0}^{\infty} \frac{(-1)^n (2n+1)L}{[(2n+1)^2 L^2 + x^2 + y^2]^{3/2}} \qquad (1)$$

  where Q is the total charge, L is the distance between the point-like source and the observation plane, and x,y is the position with respect to the source. A typical charge distribution created by a point-like source is shown in Fig. 3.
- Finally, the charge-induced distributions from all point-like sources is integrated on the surface of each pad to obtain the charge measured.

The reconstruction algorithms are tested on sets of data that reproduce different experimental conditions in MAYA.

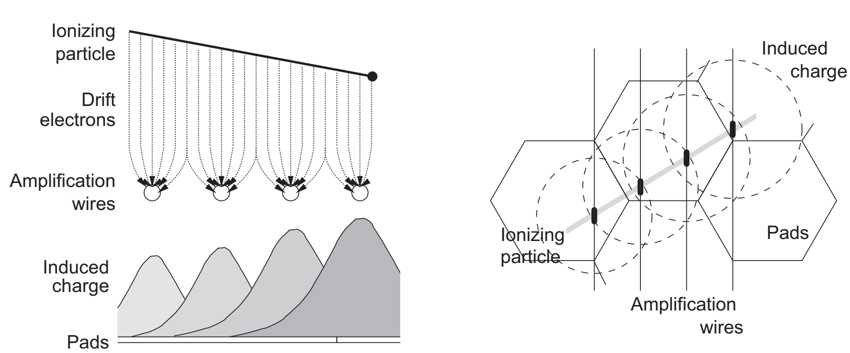

Fig. 2. The processes involved in the formation of the two-dimensional pattern in the cathode plane are schematically summarized in the picture. The left drawing is a vertical scheme of the ionization, digitization, and charge induction. The right figure shows the same processes in the horizontal plane.