The in-beam tracking detectors of the R^3B experiment*

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Introduction

The R^3B experiment at FAIR is designed to perform kinematically complete measurements of reactions with relativistic radioactive beams with unprecedented efficiency and resolution. This will open up the way to fully exploit the rarest of the isotopes that will be available at the FAIR facility.

The R^3B apparatus is located at the high-energy branch behind the Super Fragment Separator (Super-FRS). The fully stripped ions ranging from Helium up to Uranium and moving at energies of about 1 AGeV are first selected and identified by the fragment separator before impinging on the secondary target at the entrance of the R^3B setup (see Fig. 1). A large acceptance superconducting dipole magnet (GLAD) is responsible for bending the rigid beams and dedicated detection systems are currently being developed for the efficient and precise detection of all reaction products.

The group of detectors dedicated for the tracking of the incoming beam and the tracking and identification of the beam-like charged particles constitutes an important part of the R^3B setup and is the subject of the present report. The Technical Design Report (TDR) for this detection system has been completed and submitted for evaluation in November 2014. In addition, in the last year two in-beam test experiments have been performed and enabled an extensive test of prototype tracking detectors. Here we report first on the choices for the future detectors and then present some results from the in-beam prototype-detector tests.

In-beam tracking detection system

The in-beam tracking detectors are measuring time-of-flight to extract the velocity of the ions, energy loss to obtain their charge, and positions to determine the trajectory of the ions. The timing is performed using plastic-scintillator detectors coupled to photomultiplier tubes. Their shape, size and type vary from few cm to more than one meter, depending on their position along the beam line. Position measurements are realised with a combination of position-sensitive Si detectors and plastic-scintillator fiber detectors. The energy loss is measured by Si and plastic scintillator detectors. Finally, a large area gas detector based on the strawtube detector technology is used for the detection of evaporated protons.

Start detector

In front of and close to the target a small and thin plastic scintillator (LOS) acts as the start timing detector whose time resolution is well below any other detector used in the R^3B setup. Its square-shape size of 5×5 cm^2 is optimised for direct coupling with four 2-inch photomultiplier tubes at each side for maximum light collection. The thickness is chosen for each experiment to minimise the material in the beam line while maintaining sufficient light output and excellent time resolution. For example, typical thicknesses for medium-mass nuclei are 200-500 μm allowing for a timing resolution of $\sigma \leq 10$ ps. The timing information is the average of the four photomultiplier signals. The read-out of the four photomultiplier signals is performed using the PADI [1] preamplifier board and the VFTX TDC electronics [2].

Si detectors

Thin Si detectors are used along the beam line before and after the target in vacuum. Their purpose is twofold: 1) To obtain with minimum material adequate charge identification and 2) to obtain precise tracking information of the ions that impinge on or emerge from the target. The planned detector types that will be used are position-sensitive Si detectors based on resistive charge division and Si micro-strip detectors. The detectors between the target and the dipole magnet are the largest with a size of 10×10 cm^2 in order to cover most of ± 80 mrad acceptance of the dipole magnet. Its thickness of about 100-200 μm is a compromise between minimal angular straggling and sufficient energy loss. Their position resolution requirement is on the order of 100 μm (σ), in both x and y coordinates. The signals from the Si detectors are digitised after the preamplifier stage with the FEBEX readout system [3].

Fiber detectors

Five detection systems based on plastic scintillator fibers are planned to be used for in-beam tracking. Three fiber detectors with an active area of 10×10 cm^2 are planned for position measurements before and after the target, to replace the Si detectors in experiments where the beam

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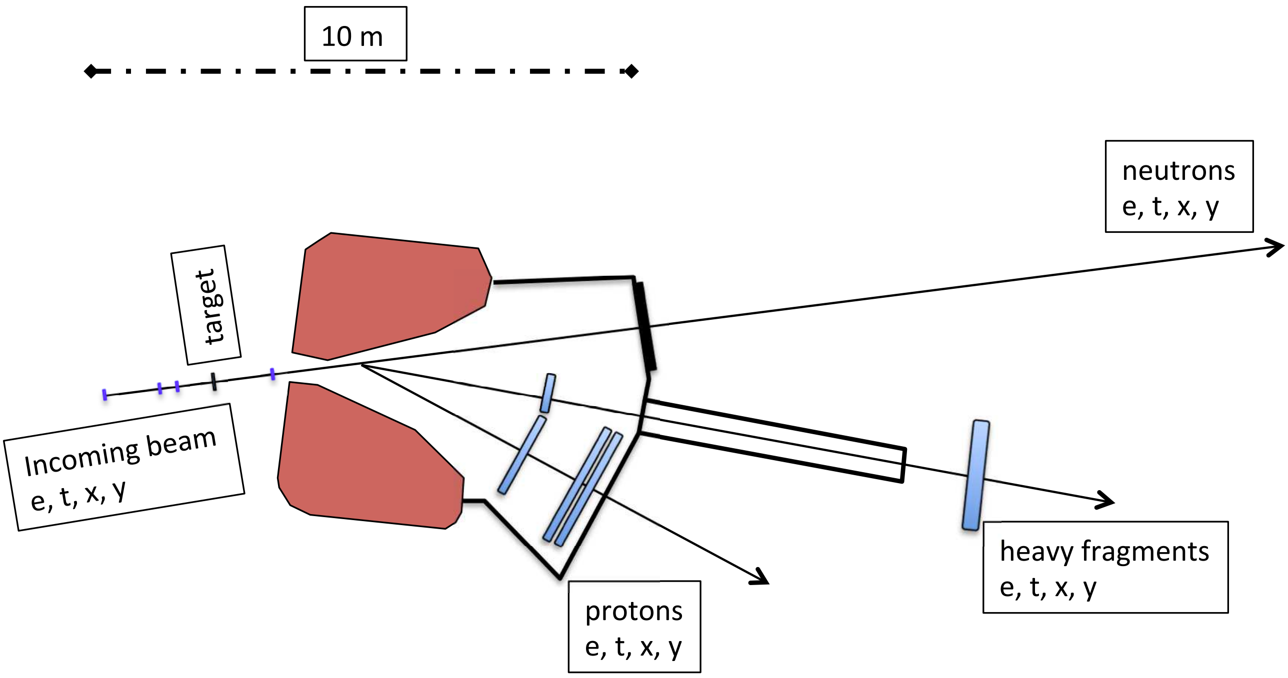

Figure 1: Schematic drawing of the R^3B setup showing the position of the in-beam tracking detectors before and after the GLAD dipole magnet.

rate is very high (1 MHz). These detectors will consist of 0.2×0.2 mm^2 square fibers placed in both x and y directions for two-dimensional position measurements. A fiber detector of 40 cm width with a single layer of fibers (x-position only) is used for the very critical first position measurement after the magnet, which serves as the starting point for the determination of the deflection angle. The distance between this detector and the subsequent position measurement is typically several meters, such that the angular measurement is a small fraction of a mrad. However, the angular straggling in the material of this detector is the dominant factor for the angle measurement after the magnet. A much larger fiber detector of 120×80 cm^2 is foreseen at the end of the fragments' flight path. We use two readout schemes. For the small and medium size detectors the fibers are coupled to Multi-Pixel-Photon Counters (MPPCs) whose signals are shaped and digitised with the FEBEX digitiser system. The larger size detector uses Multi-Anode Photomultiplier Tubes (MAPTs) which are read out using the GEMEX boards [4] equipped with n-XYTER readout chips [5].

Time-of-flight wall

The time-of-flight measurement is performed between the LOS detector in front of the target and a large-area-plastic-scintillator wall located at the end of the fragment arm (typically 20 m downstream from the target). At this position the fragments' spatial distribution is very broad and a size of 120×80 cm^2 is required to obtain a satisfactory acceptance. The 120 cm wide wall consists of four layers of vertically placed 2.7 cm wide scintillating paddles (44 paddles / layer). Each paddles is read out by photomultiplier tubes at each end. For the heavier isotopes an outstanding performance of 20 ps (σ) time-of-flight resolution is required. This resolution can be obtained as the average of the time measured by the four layers. The purpose of this wall is, however, twofold as it also acts as a precise nuclear-charge detector for the heavy fragments at the end of their flight path. A charge-to-time converter (QTC) coupled to the PADI preamplifier board and the VFTX TDC electronics will be used for the readout of the signals from the photomultipler tubes.

Straw-tube proton spectrometer

Large area gas detectors of up to 2.6×1 m^2, based on straw-tube technology, are planned in order to measure precisely the trajectory of the evaporated protons. Their position resolution is expected to be about 100-200 μm and they are designed to be vacuum compatible. Four detector stations are planned for obtaining x and y position information at two different locations about 1 m apart in the longitudinal direction. The first detector will be made out of kapton-wall tubes to introduce minimal material budget, and the following stations are made of aluminium-wall tubes.

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In-beam performance of prototype tracking detectors

Rich data sets have been collected from recent in-beam test experiments (beam ions of ^{58}Ni and ^{48}Ca) where prototypes of the tracking detectors have been used. In this section we report on some of the results.

Si detectors

The Si detectors that have been tested in the two in-beam experiments are listed in Tables 1 and 2 together with some of their characteristics.

Table 1: The types of the Si detector that have been tested in the 1st in-beam experiment (s438) with a ^{58}Ni primary beam. Characteristics of the detectors used are given in the table, R_p stands for the positioning resistance. HM is used for the Hamamatsu S5378 two-dimensional position-sensitive detector type, while X1 is used for the Micron-semiconductor position-sensitive strip detector. The X1 detectors also include both P- and N-type Si.

det name	HM	HM	HM	X1	HM	X1
type	2D	2D	2D	N-1D	2D	P-1D
thick (μm)	300	300	300	300	300	300
size (cm^2)	4.5^2	4.5^2	4.5^2	5.0^2	4.5^2	5.0^2
R_p (kΩ)	2.0	2.0	2.0	1.5	2.0	1.5

Table 2: The types of the Si detector that have been tested in the 2nd in-beam experiment (s438b) ^{48}Ca primary beam. Characteristics of the detectors used are given in the table, R_p stands for the positioning resistance. X1 is used for the Micronsemiconductor position-sensitive strip detector and W1 is a double-sided strip detector (not position sensitive) from the same company. The X1 detectors also include both P- and N-type Si.

det name	X1	X1	W1	X1	X1
type	1D	1D	2D	N-1D	P-1D
thick (μm)	140	140	70	300	300
size (cm^2)	5.0^2	5.0^2	5.0^2	5.0^2	5.0^2
R_p (kΩ)	3.0	1.5	N/A	3.0	1.5

Fig. 2 shows the reconstructed position after selecting interstrip events from two position-sensitive Si strip detectors placed with their strips perpendicular to each other. The reconstructed lines allow for a position calibration of the detectors without the need of an external device and demonstrate their position resolution. The x projection of a y slice of Fig. 2 is shown in Fig. 3 and a position resolution better than 80 μm (σ) is obtained for the central peaks.

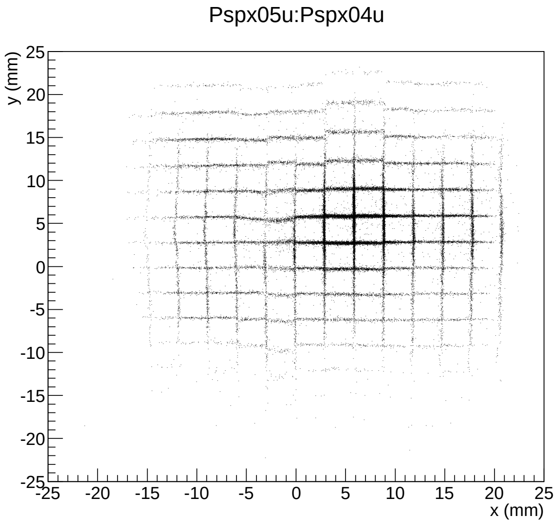

Figure 2: Position reconstructed from two position-sensitive Si strip detectors placed perpendicular to each other (the last two detectors in Table 2). The reconstructed lines in one detector correspond to the interstrip region of the other detector. The interstrip events have been selected by requiring energy signals in neighbouring strips. The detector signals have been gain matched with a linear function, higher order corrections are needed for the detector measuring the y coordinate.

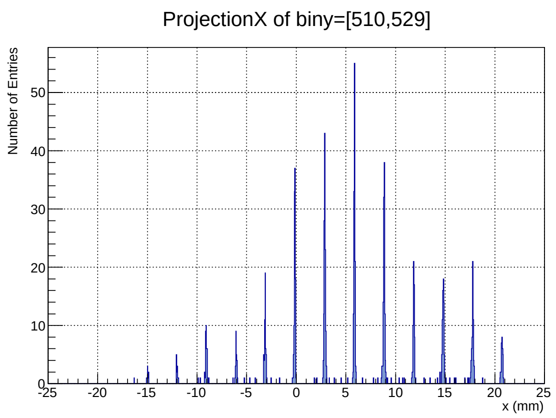

Figure 3: The projection on to the x axis of Fig. 2 for a narrow y slice. The position resolution obtained from a gaussian fit of the most intense central peaks is better than 80 μm (σ).

Fiber detectors

Two fiber detectors made of about 1000 fibres each with a cross section of 200×200 μm^2 and 250×250 μm^2 have been tested during the in-beam test experiments. One of the detectors is bundled in the way suggested in Ref. [6] in order to reduce the number of readout channels. In this detector the fibres are coupled to MPPCs whose signals are shaped and then digitsed by the FEBEX system. The second detector has each of its fibers individually read out by

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multi-anode photomultiplier tubes. The signals from the PMs are read out using four GEMEX boards which employ two n-XYTER chips each. More details on this second fiber detector can be found in Ref. [7]. A correlation of the positions obtained from the two fiber detectors is shown in Fig. 4 for a dedicated in-beam run in which the field of the dipole magnet preceding the detectors was varied in order to illuminate the full detector size. Besides the strong correlation there is also a substantial number of background events that originate from misidentification of the hit fibers. The analysis for improving this correlation is ongoing.

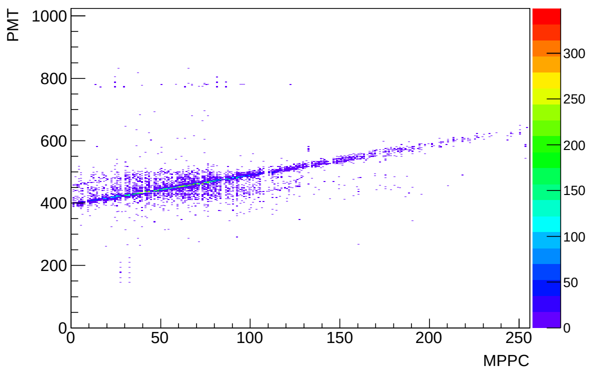

Figure 4: Correlation of x-position measurement, obtained from the two fiber detectors in units of fiber number.

Start detector and time-of-flight wall

A detailed description of the performance of both the start detector (LOS) and the time-of-flight prototype wall from the recent in-beam tests is presented separately in Ref. [8].

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