Heavy-ion tracking detectors for the R^{3}B setup*

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Overview

The high-intensity radioactive ion beams foreseen within the FAIR project will give us access to study the most exotic nuclear systems. In order to fully explore these rare short-lived species the experimental apparatuses are undergoing major upgrades. In this challenging environment the R^{3}B collaboration is working towards the development of a versatile system offering an unprecedented combination of high-efficiency, high-resolution and high-rate-capable kinematically complete measurements.

A pivot point in these developments is the installation of the new superconducting magnet GLAD. This magnet is capable of bending effectively the high-rigidity beams and allows for projectile-like neutrons to be detected at zero degrees and the bent beam to be momentum analysed. A series of charged-particle detectors are placed along the trajectory of the beam in order to measure precisely the position, charge and time of the incoming beam particles and the outgoing beam-like fragments. Although the current technologies of charged-particle detectors offer solutions that could meet our resolution requirements alone, the challenge is to combine this with minimum material budget, high-rate capability, radiation hardness, large active area, large dynamic range, low cost and high flexibility.

Heavy-ion tracking detectors

Along these lines we are focusing our developments on the following detectors: 1) Ultra-thin scintillating fiber detectors. 2) Ultra-thin resistive strip Si detectors. 3) Large area time-of-flight wall. In this report we present the current status of these developments.

Plastic-scintillator fiber detectors

Some of the advantages of using plastic-scintillator material is the low cost, fast response and high-rate capability. Five new fiber detectors are being developed for the needs of precision position measurement. Each detector plane provides precise information in one dimension and, where two-dimensional information is needed two detector planes are packed closely into one detector. All planes are built using a 200 μm square fiber and have varying dimensions ranging from small 5x5 cm^2 active area up to 110x80 cm^2. The total number of fibers needed to cover these areas is almost 3x10^4 and the total length exceeds 60 km of fiber.

The light collection is performed by multi-pixel photon counters (MPPC) and multi-anode photomultiplier tubes. The boards for powering the MPPCs and providing a first stage amplification are designed and built in-house at the electronic workshop of the Institut für Kernphysik at the Technical University of Darmstadt. The electronic readout is performed using a combination of NXYTER, FEBEX and TAMEX depending on the physical location of the detector and the needs for a high multi-hit capability readout. We have currently tested, for example, a fully independent single-fiber readout based on NXYTER [1]. In many cases, however, the large number of fibers makes it impractical and costly to read out all fibers individually. A readout scheme, in which the different fibers are bundled in a unique way in both ends, enables a way of determining the hit fiber with a reduction of the readout channels to $2\sqrt{N_{\text{fiber}}}$ per plane. This reduces the readout of the 3x10^4 fibers to 944 channels, but at the same time compromises the multi-hit capability of the detector. A simple example of the bundling is shown in Fig. 1.

Resistive strip Si detectors

The Si detectors, in general, are one of the most popular tracking devices, since they combine high-resolution position and energy-loss measurements. The Si micro-strip detectors deliver excellent position resolution, but have a large number of readout channels and the total energy-loss reconstruction for heavy-ions is not trivial. For these reasons, without excluding the use of micro-strip technology for certain experiments, we are also working on optimising the concept of resistive charge division. Detectors based on this technology can deliver excellent position and energy resolution when the deposited energy is sufficiently high, as is the case for most heavy-ion experiments at R^{3}B. In addition, the number of readout channels is significantly reduced compared to the micro-strip Si detectors.

However, these detectors suffer from slow charge collection as the charge is defused at the resistive side with a time-constant defined by the detector capacitance and the anode resistance. This limits the rate capability of the detector. Compared to the micro-strip detectors they also have higher noise levels due to the presence of the anode resistance and due to the generally higher capacitance. This noise is, however, not the dominant factor in the energy-loss measurements as discussed in [2].

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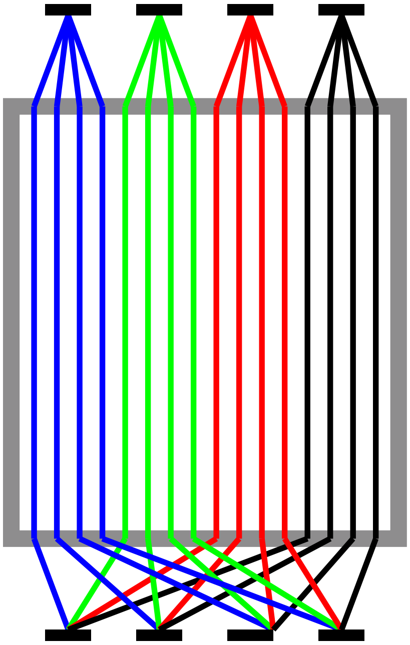

Figure 1: A fiber-bundling scheme that reduces the number of readout channels to $2\sqrt{N_{\text{fiber}}}$ pr. plane.

These limitations of the resistive charge division detectors can be reduced by e.g. segmenting the detectors and reducing the anode resistance, which however increases the number of readout channels and worsens the position resolution, respectively. The aim of this work is to find the optimum trade off between the number of channels, position resolution, thickness, and rate capability, and to take full advantage of the varying pulse shapes in this type of detectors.

We have performed a detailed characterisation and comparison of two types of resistive charge division detectors: a continuous two-dimensional detector and a strip Si detector using an ^{241}Am source. In addition, the read out of these detectors is performed using digital electronics and the waveforms of the pulses are recorded for further offline processing. We have found that both the position resolution and the pulse rise time are significantly improved in the case of the strip detector compared to a continuous two-diminensional detector. Namely, the position resolution obtained for an ^{241}Am alpha source and a 3 KΩ anode resistance has improved threefold to be $\sigma \approx 150$ μm (see Fig. 2 adopted from Ref. [3]) and the signal rise time from the central detector area has become ten times faster t $\approx$ 350 ns. We plan to verify these results in an in-beam test where the limits of high-rate capability will also be tested. The currently used detectors have a thickness between 100 and 300 μm and typically a 5x5 cm^2 active area. In the future we plan to test also larger detectors with area 7x7 cm^2 and 10x10 cm^2.

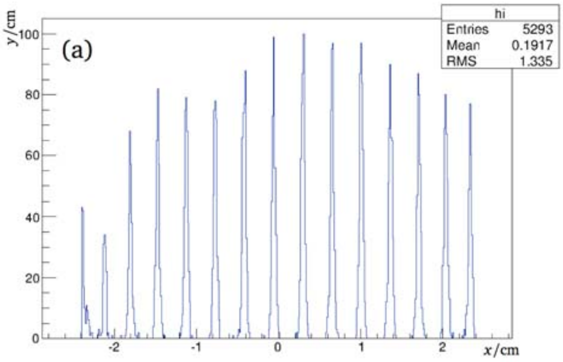

Figure 2: Position resolution obtained with a Si resistive strip 140 μm thick detector and an ^{241}Am source.

Large area time-of-flight wall detector

A large-area plastic-scintillator wall is used in the R^{3}B setup to obtain simultaneously excellent time-of-flight and energy-loss measurement. An optimised wall, with an active area of 110x80 cm^2 (see Fig. 3), is currently being built and will be tested in-beam this year. The optimisation is driven mainly by the requirement for a precise energy-loss measurement at high rate.

Design-wise one can highlight the following differences of this detector compared to older versions: The light guides at the ends of the paddles have been removed and the paddle width and photomultiplier diameter have been chosen to fit well with minimal loss of light collection. The paddles are oriented vertically with respect to the dispersive axis of the dipole magnet. In this way the paddles are mainly hit in their central area minimising the non-uniformity and the “smiley effects” in the total energy reconstruction. Vertically oriented paddles also share the beam rate more evenly. Four such planes with vertical paddles are placed behind each other and are slightly shifted with respect to each other so that there are effectively no dead areas between the paddles.

The paddles are produced with a maximum variation of a few percent in their thickness. The energy-loss measurement is, however, anticipated to be much better than this variation. In order to correct for non-uniformities in the thickness of the paddle and the position dependent response of the scintillator, this detector is packed closely on the same frame with the aforementioned large area fiber detectors that cover the same active area.

On the electronics readout side there have also been major advances. It is found that the energy-loss measurement, when performed with a standard QDC type of electronics, suffers greatly from rate dependencies. The new readout is based on a time-over-threshold technique which effectively cancels any baseline variation and at the same time gives a much higher dynamic range. These electronics are a combination of the in-house TAMEX board and a QTC add-on delivering simultaneously good time and energy measurements.

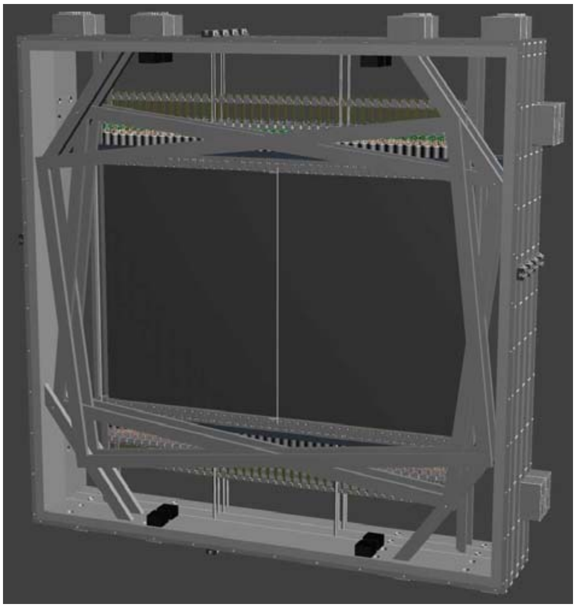

Figure 3: A CAD drawing of the plastic-scintillator wall. In front of the paddles, the tilted frames foreseen to support the large-area fiber planes are also shown.

References

[1] P. Schrock et al., “Development of a Thin Large-Area Fiber Detector for Radioactive-Beam Experiments” GSI-SR2012-PHN-ENNA-EXP-69, GSI Report 2013-1

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