GEM tracker for high-luminosity experiments at the JLab Hall A

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ABSTRACT
A Large-Acceptance Forward Angle Spectrometer (Super BigBite) is under development for the upcoming experiments in Hall A at Jefferson Lab to optimally exploit the exciting opportunities offered by the 12 GeV upgrade of the electron beam. The tracking of this new apparatus is based on the Gas Electron Multiplier technology, which has been chosen to optimize cost/performance, position resolution and meet the high hits rate (> 1 MHz/cm\(^2\)). In this report we present the technical features of the detector and comment on the presently achieved performance.

1. Introduction
The Jefferson Laboratory (JLab) is one of the most important experimental facility providing a multi GeV, high-intensity, longitudinally polarized, electron beam; the origin of the quark and gluon confinement, the dynamics of the quarks and gluons in the nucleon and of the nucleon in the nucleus, the structure of the nuclei and the limits of the standard model are some of the relevant fields of fundamental physics investigations at JLab. The laboratory is undergoing a major upgrade of its continuous electron beams accelerator facility (CEBAF) electron beam and experimental halls. In particular, CEBAF will deliver electrons with energy up to 12 GeV (twice the past limit) with excellent intensity (up to 100 µA) and longitudinal polarization (up to 85%). In order to take advantage of the new scenario, the equipments of the three existing experimental Halls are under upgrading to optimally exploit the opportunities of the new beam. In particular, members of Hall A collaboration are developing a new reconfigurable spectrometer, the Super BigBite Spectrometer (SBS (2), Figure 1), featuring very forward angle (down to 7 degree), large momentum (2–10 GeV/c) and angular (64 mrad) acceptance, high rate capability (1 MHz/cm\(^2\)) and very high luminosity environment (up to 10\(^{39}\)/s cm\(^{-2}\)). The new spectrometer will consist, in its full configuration, of a dipole magnet with field integral up to 3 Tm (it will operate at about...
Figure 1. Schematic layout of the SBS. There are three tracker stations, two analyzers and a Hadron calorimeter.

2 Tm), a primary charged particle tracker (first tracker), two identical proton polarimeters (made of a Carbon analyzer and large tracker), and a hadron calorimeter. SBS will initially serve four experiments (3) dedicated to the study of the nucleon structure in terms of elastic electromagnetic form factors at high 4-momentum transfer $Q^2$ up to 15 GeV$^2$ and of transverse momentum distributions of the quarks in the SIDIS (Semi Inclusive Deep Inelastic Scattering) region. The tracking systems of SBS will be mainly based on gas electron multiplier (GEM) chambers. In the next sections we will present the main features of the GEM detector, the Tendigem Tension control system used to assemble the detector and the preliminary results of a test performed at the MAinz MIcrotron (MAMI) accelerator in Mainz.

2. GEM detector

The SBS tracking system is made of three stations. The primary (front) tracker, placed just after the dipole momentum analyzing magnet, will consist of six large area ($40 \times 150$ cm$^2$) and high-resolution ($\sim 70 \mu$m) GEM chambers, for a total tracker length of about 50 cm. Each chamber is made by three adjacent GEM modules of $40 \times 50$ cm$^2$ active rectangular area, for a total of 18 modules. It is designed to be capable to track accurately particles emerging from the electron scattering in a large background of soft photons ($\sim 0.5$ MHz/cm$^2$) and MIPs (minimum ionizing particles $\sim 0.2$ MHz/cm$^2$). The primary tracking will be reinforced by combination with two small ($10 \times 20$ mm$^2$) planes of silicon µstrips placed in proximity of the target. The other stations are meant to track particles after a polarization analyzer wall and will require less accuracy. The primary tracker is under the responsibility of INFN groups. GEM technology (4) has been chosen to optimize cost/performance, position resolution and meet the high rate ($> 1$ MHz/cm$^2$) (5). The single module is made of three GEM foils and double layer x/y strips readout with 400 µm strip pitch (Figure 2). The 8 mm wide mechanical frame incorporates high voltage (HV) feeding protection resistors and gas inlet/outlet holes. The signals from each triple GEM module are read out in two coordinates through COMPASS-like (6) strip conductors planes. The front-end electronics (7) (FE) for the $\sim 100$ K channels of the tracker is based on the APV25 (Analogue Pipeline Voltage) (8) chip, successfully used in the large hadron collider experiment compact muon solenoid. The APV25 is a serial output analogue amplification specific integrated circuit running at 40 MHz. The FE cards, each with 128 channels, are placed around the GEM
Figure 2. Schematic layout of the GEM chamber. There are different layers: a drift cathode, three GEM foils and a readout PCB (printed circuit board) with a dimension of $10 \times 10 \text{ cm}^2$. Different values (order of $10^3 \text{ V}$) of bias voltage can be used.

Module. Custom backplanes are used to distribute power and control to the FE cards and to collect the analogue outputs.

3. TENDIGEM tension control system

TENDIGEM (Figure 3) is a tool designed to stretch a GEM-foil before gluing it to the frame. This tool is a sensor-based device which uses load cells to measure the tension. The load cells of the TENDIGEM monitor the tension on the different sides of the foil. It is important to stretch the foils because if a GEM-foil shrivels, it could touch another foil and, in this case, there would be a big chance that an electrical shock occurs. The GEM-foil is placed in the TENDIGEM by using 14 clips and only half of the clips are connected with the load cells. After a foil is correctly stretched, the frame is glued on it. Metal pins, located on the sides of the TENDIGEM, are arranged asymmetrically in order to easily match the appropriate sides of either one. The frame is glued, by polymeric glue, to the GEM-foil. Once the glue has dried, the foil glued to the frame is removed from the TENDIGEM and it is ready to be used in a GEM chamber. To improve the GEM detector assembly method, an electronic control system is

Figure 3. The TENDIGEM tension control system. A system with a dimension of $40 \times 50 \text{ cm}^2$ is shown.
used. By using TENDIGEM, the goal is to create the correct tension on a GEM-foil before gluing it to the frame. There are different ways to put tension in a controlled way on a system as, for example, Sensor-Based Tension Control or Open Loop Tension Control. The Sensor-Based Tension Control uses load cells that measure the tension in a point and compare it with the expected tension level. If it is necessary, the load cells induce the controller to do some adjustments. This is an example of a closed-loop control system and it has an accuracy of 1–2%. In an Open Loop Tension Control System there is no feedback: the system only estimates which is the value at the output. The accuracy for an Open Loop Tension Control System is 8–10%. In the TENDIGEM, the system used is Sensor Based Tension Control that uses load cells (9).

4. MAINZ test

In this section we present preliminary results of data analysis performed on about hundreds of beam runs obtained by using three GEM chamber prototypes with a dimension of $10 \times 10$ cm$^2$. The test has been performed at MAMI. MAInz Microtron is an accelerator for electron beams run by the Institute for Nuclear Physics of the University of Mainz used for hadron physics experiments (10). In Figure 4, three equipped $10 \times 10$ cm$^2$ GEM modules under test at MAINZ are shown. All chambers were readout by the APV electronics which were under development at the same time. During the test, a gas mixture of Ar (70%) and CO$_2$ (30%) has been used, HV has been powered by the first version of the HV-GEM system (11) providing seven independent HV levels. Moreover, precise tracking was performed by small silicon strip detectors located before the GEM.

Different configurations have been used: energy of the electron beam (from 400 to 800 MeV), HV settings, angle between the beam and the plane of the chamber and position of the chamber with respect to the beam; moreover, in order to have pedestals, without beam runs were acquired.

A single signal, obtained after the pedestal subtraction in the $x$-direction, is shown in Figure 5(a) left panel: it is clearly visible at about strip #200. By using APV25 chips, it is possible to register different parts of the signal (every 25 ns), event by event, obtaining different

![Figure 4](image.png)

**Figure 4.** Fully equipped GEM modules. The distance between the three detectors is 50 cm.
samples. The shape of the signal was fitted by using the following equation:

$$Q = A(1 - e^{-(t-t_0)/\tau_1}) \cdot e^{-(t-t_0)/\tau_2},$$

in which $Q$ is the total charge and $\tau_1$ and $\tau_2$ are the slope and falling time of the signal, respectively, $t_0$ is the start time and $A$ is the signal amplitude (see Figure 5(b) right panel). Adjacent firing strips are grouped in clusters and both number of clusters (Figure 6(a) left panel) and number of strips (Figure 6(b) right panel) of each cluster was evaluated. In both cases, distributions are consistent with the data from COMPASS GEM characterization (12).

The schematic layout of the three chambers during the test is shown in Figure 7, in which chamber #0, #1 and #2 have an area of $10\times10$ cm$^2$. In order to select the single events of a run, we check if there is a cluster on each chamber in the $z$-direction. Each cluster provides the hit position $P_n(Z_n, X_n)$ and its uncertainty $\sigma_n$, where $n$ is the index of the chamber. By using two points, for example $P_0(Z_0, X_0)$ and $P_1(Z_1, X_1)$, a straight line $X = aZ + b$ is reconstructed in the $Z$-$X$ two-dimensional space ($a$ and $b$ are obtained by a linear fit). Finally, we consider $P_2(Z_2, X_2)$ and if $|X_2 - aZ_2 - b| < \sigma_2$ then the signal of the three chambers belongs to the same particle otherwise it is rejected. The ratio between the number of selected events and the total number of events in which a cluster was found on each chamber gives

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure5.png}
\caption{(a) Single electron signal in the $x$-directions (left panel) and (b) signal shape: time (ns) is in the $x$-direction and ADC (A.U.) in the $y$-direction, respectively (right panel).}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure6.png}
\caption{(a) Number of clusters (left panel) and (b) number of strips on each cluster (right panel).}
\end{figure}
a percentage value from 88% and 92%; the GEM detector has a high sensitivity to electrons and this percentage seems to be independent from their energy.

5. Conclusions

Nowadays most of the design of the GEM-based tracker and its readout electronics is finalized; analytical considerations and numerical simulations have been used to verify and optimize the adopted solutions. The main purpose of the MAINZ test was to verify the overall functionality of the main solution adopted in the first GEM prototype under well-defined beam conditions. Both GEM hardware and readout electronics were under early development and therefore final results on efficiency and chamber resolution are only preliminary. Anyway, the GEM chambers operated fairly stably during the test and the results show reasonable indications of the general validity of the adopted solutions to analyze the distribution of the collected charge. Some critical aspects, to be further investigated, have been pointed out.

Disclosure statement

No potential conflict of interest was reported by the authors.

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