Test of the GEM Front Tracker for the SBS Spectrometer at JLab

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A new Large-Acceptance Forward Angle Spectrometer (Super BigBite) is under development at JLab/Hall A 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 (GEM) technology, which has been chosen to optimize cost/performance, position resolution and meet the high hits rate (>1 MHz/cm^2).
The first GEM detector were designed, built and tested, during different periods, at the DESY test beam facility in Hamburg, by using an electron beam with an energy from 2.0 to 6.0 GeV. In particular, different chambers, with a dimension of 40x50 cm^2, were equipped with a new implementation of the APV25 readout chip. Measurements were performed at different impact points and angles between the electron beam and the plane of the GEM chambers.
In this report we present the technical characteristics of the detector and comment on the presently achieved performance.
Keywords: GEM Detector, Tracker.

INTRODUCTION

The Jefferson Laboratory [1] (JLab) is one of the most important experimental facility providing a multi GeV, high intensity, longitudinally polarized, electron beam. The laboratory is undergoing a major upgrade of its CEBAF electron beam and experimental halls. In late 2013, CEBAF will deliver electron with energy up 12 GeV (twice the present 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 3 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 (SBS [2], Fig. 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 $10^{39}/(\mathrm{s}\cdot\mathrm{cm}^2)$). The new spectrometer will consist, in its full configuration, of a dipole magnet with field integral up to 3 T·m (it will operate at about 2 T·m), a primary charged particle tracker (first tracker), 2 identical proton polarimeters (made of a Carbon analyzer and large tracker), and an hadron calorimeter. SBS will initially serve 4 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 GEM chambers. In the next section the main features of the SBS tracker and of the GEM detector will be presented and finally the preliminary results of the test performed at DESY will be discussed.

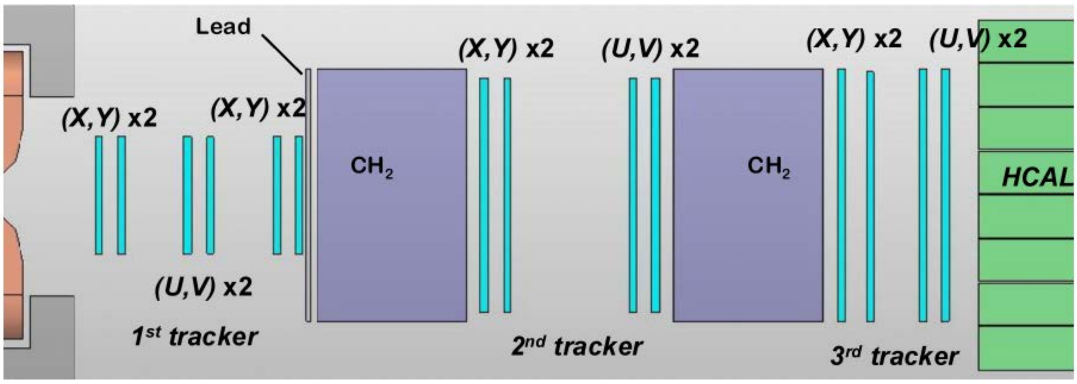

Figure 1. Schematic layout of the SBS Spectrometer.

SBS TRACKER AND 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 (40x150 cm^2) and high resolution (~70 µm) GEM chambers, for a total tracker length of about 50 cm. Each chamber is made by 3 adjacent GEM modules of 40x50 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 (~0.5 MHz/cm^2) and MIPs (~0.2 MHz/cm^2). The primary tracking will be reinforced by combination with two small (10x20 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 3 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 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 ~100K channels of the tracker is based on the APV25 [8] chip, successfully used in the LHC experiment CMS. The APV25 is a serial output analogue ASIC running at 40 MHz. The FE cards, each with 128 channels, are placed around the GEM module. Custom backplanes are used to distribute power and control to the FE cards and to collect the analogue outputs.

Figure 2. Fully equipped GEM module.

In Figure 2 a fully equipped 40 x 50 cm^2 GEM module prototype setup under test at DESY is shown. The module is equipped with the APV25 electronics and 18 front-end cards are located behind the 4 rectangular backplanes that sit along the 4 sides of the module. During the test, a gas mixture of Ar (70%) and CO_2 (30%) has been used and HV has been powered by the first version of the HV-GEM system [9] providing 7 independent HV levels. Moreover, precise tracking has performed by small silicon strip detectors located before the GEM.
The test has been performed in the T22 DESY Test electron/positron beam area [10]. The test beam is originated from the lepton synchrotron DESY II by converted bremsstrahlung on carbon fiber target. The energy of the beam varies between about 1 and 6 GeV/c with typical intensity of 1000 particle/($s \cdot cm^2$) (divergence is about 2 mrad).

DATA ANALYSIS AND DISCUSSION

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 two of 40x50 cm^2. All chambers were readout by the APV electronics which were under development at the same time. During the test, different configuration have been used: energy of the electron beam (from 2.0 to 6.0 GeV), 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.

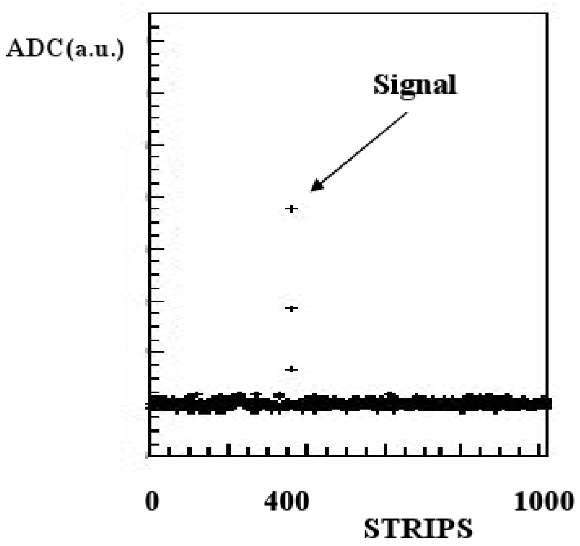

Figure 3. Single electron signal in the x-direction.

A single signal in the x-direction is shown in figure 3: it is clearly visible at about strip #400 and it is obtained after the pedestal subtraction. By using APV 25 chips, it is possible to register different parts of the signal (every 25 ns), event by event. The shape of the signal was fitted by using the formula:

$$A\left(1-e^{\frac{-(t-t_0)}{\tau_1}}\right)\cdot e^{\frac{-(t-t_0)}{\tau_2}}$$

in which τ_1 and τ_2 are the slope and falling time of the signal, respectively, t_0 is the stop time and A is the Amplitude (see figure 4).

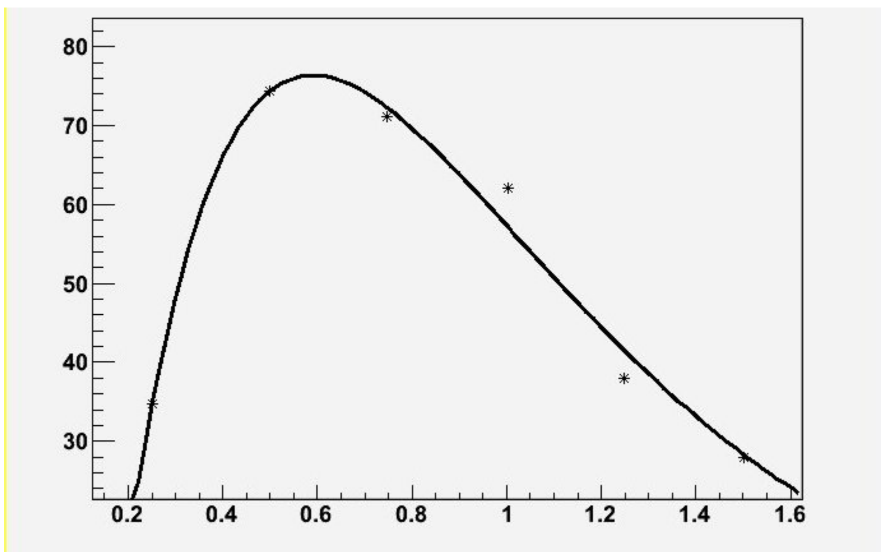

Figure 4. Signal shape: time is in the x-direction and ADC in the y-direction, respectively.

Adjacent firing strips are grouped in clusters and both number of clusters (figure 5) and number of strips (figure 6) of each cluster was evaluated. In both cases, distributions are consistent with the data from COMPASS GEM characterization [11].

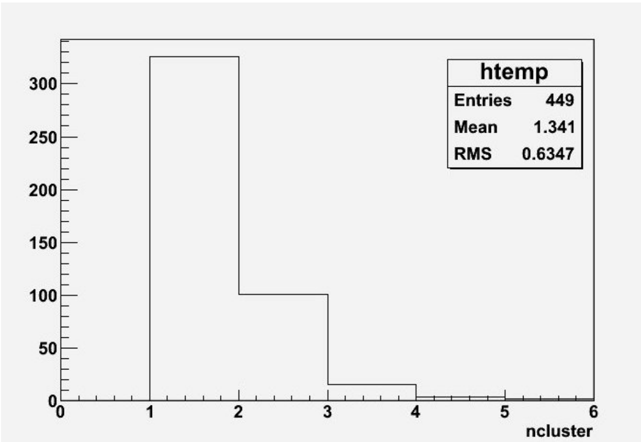

Figure 5. Number of clusters.

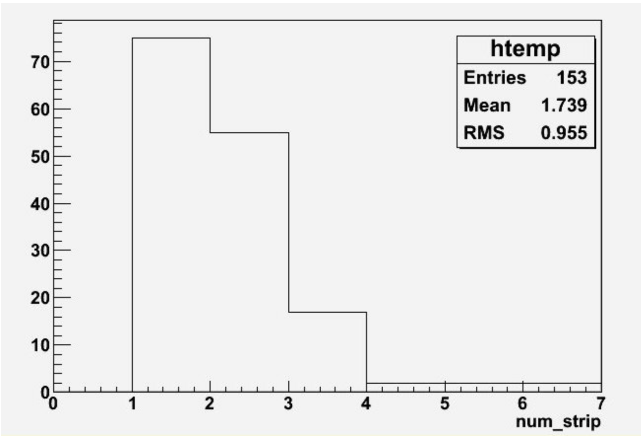

Figure 6. Number of strips on each cluster.

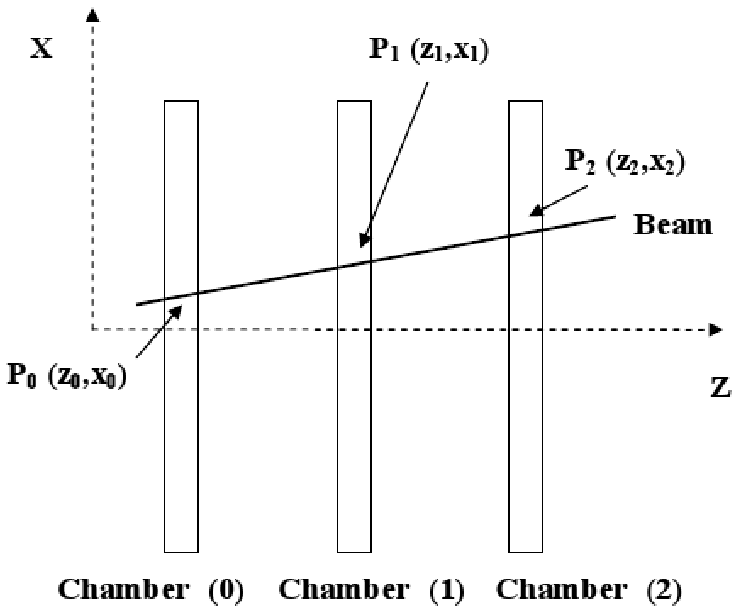

Figure 7. Schematic layout of the 3 chambers.

The schematic layout of the 3 chambers during the test is shown in figure 7, in which chamber #0, #1 and #2 have an area of 40*50 cm^2. In order to select the single events of a run, we check if there is a cluster on each chamber in the x-direction. Each cluster provides the hit position Pn(Zn,Xn) and sigmaN, where n is the index of the chamber. By using two points, for example P0(z0,x0) and P1(z1,x1), a straight line X = a*Z + b is reconstructed in the two-dimensional space (a and b are obtained by a linear fit). Finally, we consider P_2 (x_2,y_2) and if $|x_2 - az_2 - b| < \sigma_2$ than the signal of the 3 chambers belongs to the same particle otherwise it is rejected. As told before, we have used 3 chambers and an event is good if there is a cluster in all chambers otherwise it is rejected. Finally we define efficiency the ratio between the number of good events and the total number of events given by the trigger. In particular we have found an efficiency of about 90%.

CONCLUSIONS

The main purpose of the test was to verify the overall functionality of the main solution adopted in the first GEM prototype under simplified beam conditions. Both GEM hardware and readout electronics were under early development and therefore final results on efficiency and chamber resolution were not very indicative. Anyway, the GEM chambers operated fairly stably during the test and the preliminary results show reasonable indications of the general validity of the adopted solutions for the distribution of the collected charge. The data analysis also pointed out some critical aspects to be further investigated.

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