Design and Testbeam Results for the 2D Projective sPHENIX Electromagnetic Calorimeter Prototype

***Abstract*—sPHENIX is a future experiment at the Relativistic Heavy Ion Collider that aims to study the properties of the quark gluon plasma, a high density, high temperature, strongly interacting state of matter produced in relativistic heavy ion collisions. The sPHENIX detector is designed with a tracking system, a calorimeter system with an electromagnetic calorimeter and a hadronic calorimeter, and a solenoid magnet. The electromagnetic calorimeter (EMCal) is a sampling calorimeter that measures electrons, positrons, and photons, with a coverage of $|\eta| < 1.1$ in pseudorapidity and full azimuth. The EMCal is made of calorimeter modules that consist of scintillating fibers embedded in a tungsten powder and epoxy matrix, and are read out using light guides and silicon photomultipliers. One particular feature of the EMCal is its 2D projectivity, meaning that the scintillating fibers point towards the interaction region. A prototype of the EMCal was tested in 2018 at the Fermilab Test Beam Facility. The prototype corresponds to a slice $\Delta\eta \times \Delta\phi = 0.2 \times 0.2$ centered at $\eta = 1$. The goal of the beam test was to study the prototype's energy response as a function of input energy and position. This talk presents details on the calorimeter design as well as the results of the 2018 beam test.**

sPHENIX is an upcoming experiment that will allow for a detailed study of the quark gluon plasma and QCD matter and interactions. The sPHENIX physics program includes various jet measurements that will improve understanding of jet energy loss, flavor dependence of jet energy loss, jet substructure, among others. The sPHENIX detector design includes a tracking system, an electromagnetic calorimeter, a hadronic calorimeter and a solenoid magnet. The calorimeter system has a coverage of 2π in azimuth and $|\eta| < 1.1$ in pseudorapidity. The sPHENIX detector is currently under construction at the Relativistic Heavy Ion Collider.

The sPHENIX electromagnetic calorimeter (EMCal) is a sampling calorimeter that measures electromagnetic showers. The EMCal consists of calorimeter blocks that are produced by embedding scintillating fibers (SciFi) in a tungsten powder (W) and epoxy matrix. The blocks are designed with a 2D projective geometry in the sense that they are tapered in two dimensions, with the fibers pointing approximately back to the center of the sPHENIX detector. It is the first W/SciFi calorimeter of this type ever to use this 2D design and is currently being implemented in the construction of the sPHENIX EMCal.

A high pseudo rapidity prototype of the 2D projective EMCal design was tested at the Fermilab Testbeam Facility in 2018. The 2D projectivity and the high pseudorapidity are the main features that distinguish the 2018 prototype from older prototypes.

After producing a W/SciFi block, a 2×2 set of acrylic light guides are glued onto one end and an aluminum reflector plate is glued onto the other end. Light from the scintillating fibers is collected using four silicon photomultipliers (SiPM) coupled to each light guide. A block equipped with light guides and SiPMs is called a module (see Figure 1). The signals from the four SiPMs per light guide are summed into a single output, which defines one calorimeter tower, with a total of 2×2 towers per module.

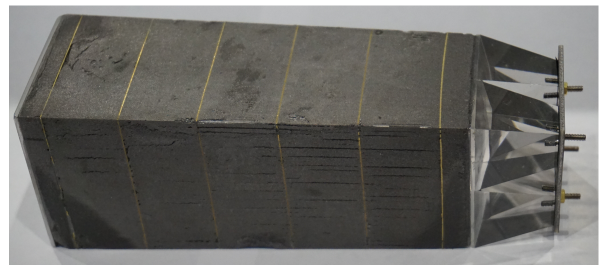

Fig. 1. EMCal block equipped with lightguides and silicon photomultipliers. The blocks are made of scintillating fibers, tungsten powder and epoxy. The blocks are tapered in two dimensions, giving 2D projectivity.

The EMCal prototype was constructed by epoxying 4×4 modules into the nominal position of a slice $\Delta\eta \times \Delta\phi = 0.2 \times 0.2$ centered at $\eta = 1$. The prototype was equipped with electronics that shape, amplify and digitize the signal from each tower. A water-based cooling system was included in the prototype to cool down the electronics. Figure 2 shows schematic drawings and a picture of the prototype.

The goal of the Fermilab beam test was to study the prototype's energy response as a function of input energy and position. In the beam test, the prototype was placed on a motion table and a particle beam was pointed at the prototype. The beam had energies ranging from 2 to 28 GeV, a spot size in the order of centimeters, and was composed of various types of particles. A lead-glass calorimeter was used to verify the beam momentum average and spread. Cherenkov detectors were used to tag electron signals. A hodoscope was used to measure the position of the particles in the beam, as well as to reject measurements that had more than one particle. Veto detectors were used to suppress particles traveling outside the beam position. Energy cuts based on these external detectors were applied in order to select data corresponding to single electrons. The energy measured by the prototype (here called *cluster energy*), was calibrated to the beam input energy in a tower-by-tower manner using 8 GeV data.

To study the prototype's energy response as a function of position, the beam momentum was fixed at 8 GeV and the prototype was placed at different positions with respect to the beam. The studies showed that the prototype had a non-uniform energy response as a function of position, which motivated the development of a position dependent energy correction. Two position dependent energy corrections were considered. The *hodoscope-based correction* used the position

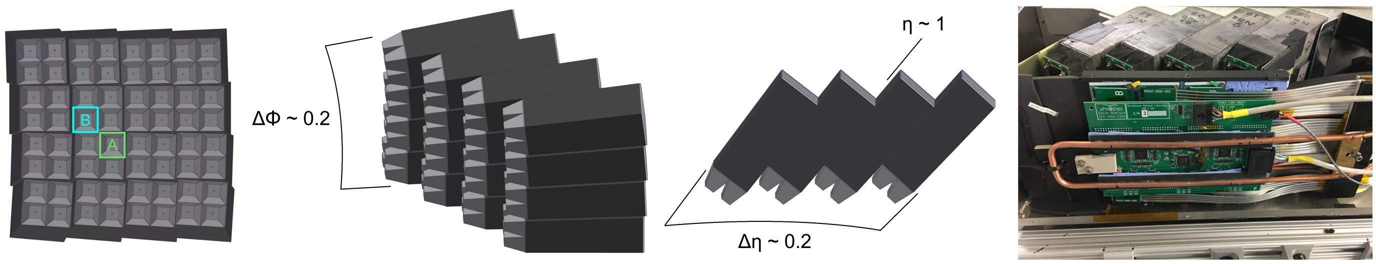

Fig. 2. (left) Schematic view of the EMCal prototype showing the blocks (dark gray) and lightguides (light gray). The prototype consists of 4×4 EMCal modules corresponding to a solid angle of $\Delta\eta \times \Delta\phi = 0.2 \times 0.2$ centered at $\eta = 1$. The testbeam resolution analysis focused on the Towers A (light green) and B (light blue) highlighted in the front view of the prototype. (right) EMCal prototype. Part of the calorimeter modules, the electronics, and the cooling system are shown.

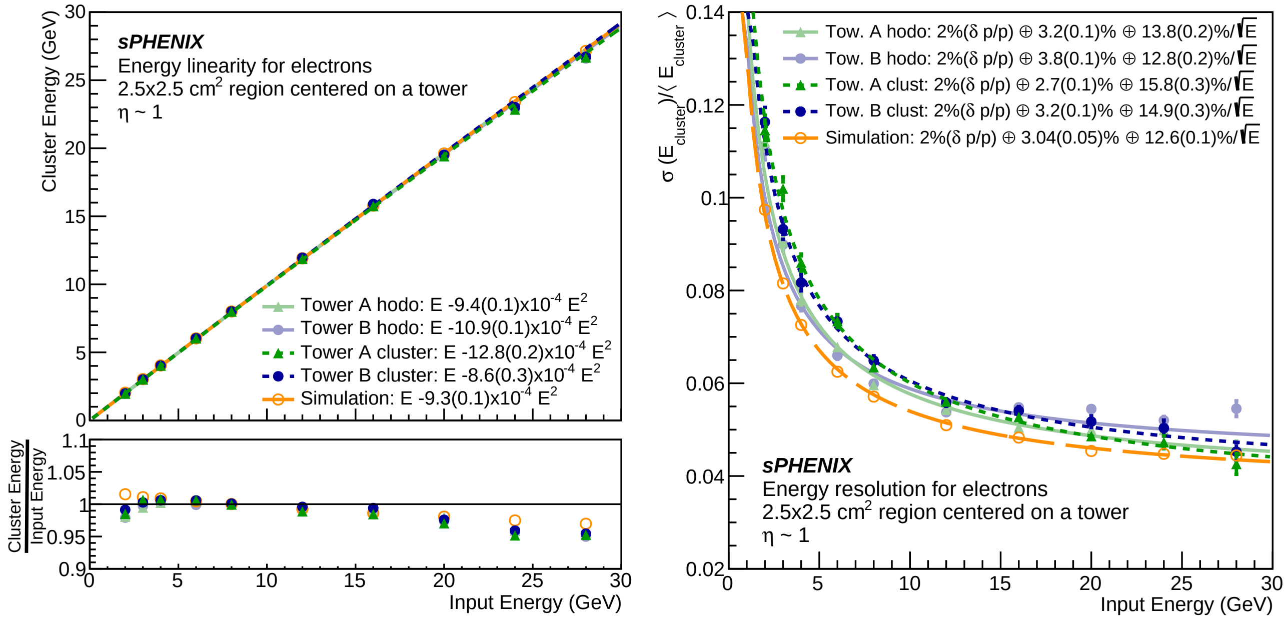

Fig. 3. Linearity and resolution of the EMCal prototype for a 2.5×2.5 cm^2 cut centered on a tower. The figure shows the data from Tower A (green triangles) and Tower B (purple full circles), as well as simulations (orange open circles, coarse dashed line). Both the data and simulations include the position dependent and beam profile corrections. The data was corrected using the hodoscope-based (solid lines) and cluster-based (fine dashed lines) corrections. The uncertainty bars correspond to statistical uncertainties.

measured by the hodoscope, while the *cluster-based correction* used the position measured by the prototype itself.

To study the prototype's energy response as a function of energy, the beam was pointed at two specific towers of the prototype and the beam energy was varied from 2 to 28 GeV. The towers selected for the energy dependent study were located towards the center of the prototype and were labeled as Towers A and B (see Figure 2). The data was corrected using the position dependent energy correction, as well as a *beam profile correction* that accounted for effects coming from the energy dependent profile of the beam. The prototype's energy linearity and resolution was obtained for data from Towers A and B using a cut of the size of a tower (2.5×2.5 cm^2) centered at each tower. The energy linearity as a function of input energy E was obtained as $E_{\text{cluster}} = E + cE^2$, where c is a constant. Similarly, the energy resolution was obtained as $\sigma(E_{\text{cluster}})/\langle E_{\text{cluster}}\rangle = \delta p/p \oplus a \oplus b/\sqrt{E}$, where a and b are constants. The beam momentum spread was was taken into account by including a $\delta p/p = 2\%$ term. Additionally, Monte Carlo simulations of the prototype in testbeam conditions were done using GEANT4. An analogous analysis was carried out for the simulations.

The energy linearity and resolution results are shown in Figure 3. The EMCal prototype was found to have a tower averaged energy resolution of $\sigma(E)/\langle E\rangle = 3.5(0.1) \oplus 13.3(0.2)/\sqrt{E}$ using the hodoscope-based correction, and $\sigma(E)/\langle E\rangle = 3.0(0.1) \oplus 15.4(0.3)/\sqrt{E}$ using the cluster-based correction. To meet the sPHENIX physics goals, the EMCal is required to have an energy resolution equal or better than $16\%/\sqrt{E} \oplus 5\%$. The energy resolutions obtained for this 2D projective EMCal prototype meet this requirement. More details about the EMCal design, the beam test, the analysis, and the results will be given at the conference[1].

[1] More details can also be found here: https://arxiv.org/abs/2003.13685