sPHENIX EMCal Design, Construction and Test Beam Results

Anabel C. Romero Hernandez, for the sPHENIX Collaboration

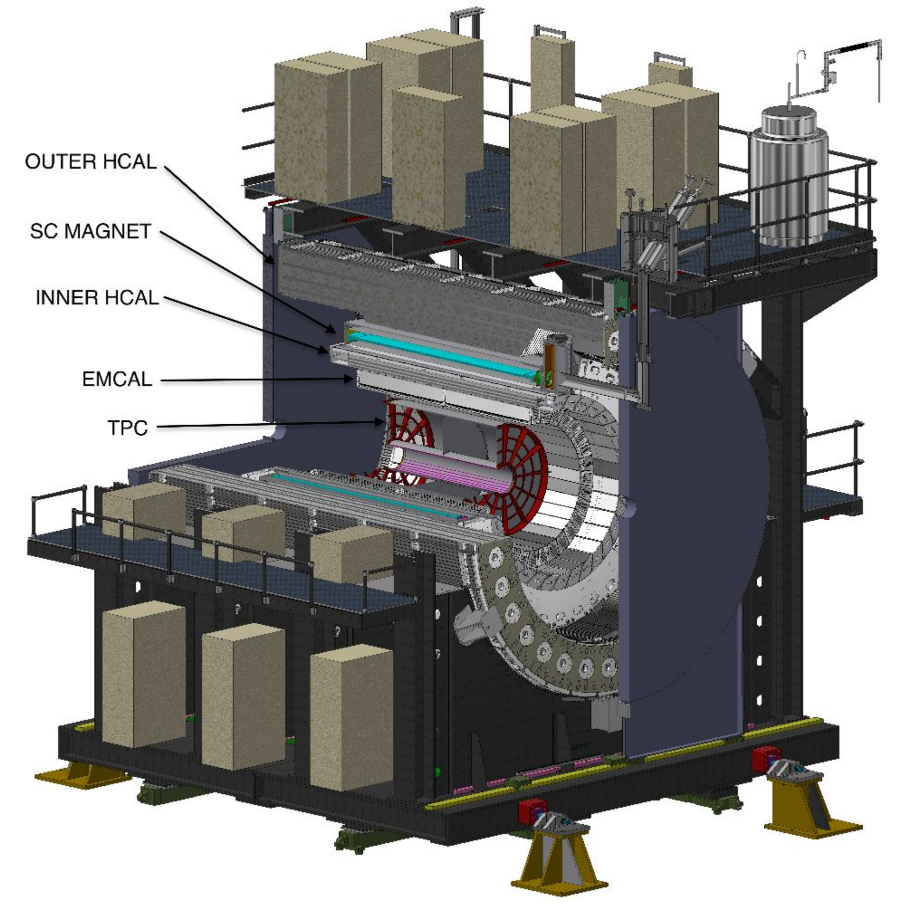
Department of Physics, University of Illinois at Urbana-Champaign

Abstract

The sPHENIX detector at the Relativistic Heavy Ion Collider is designed to accurately study proton-proton, proton-nucleus, and nucleus-nucleus collision systems. The design of sPHENIX, including calorimeter coverage of pseudorapidity $|\eta|<1.1$ and full azimuth, will allow it to precisely study properties of the quark gluon plasma through open heavy flavor production, jet modification, and Upsilon measurements. It will also perform a variety of cold QCD studies. Helping to enable the broad measurement capabilities of sPHENIX is the electromagnetic calorimeter (EMCal), which is the primary detector for identifying and measuring the energy of photons, electrons, and positrons. The EMCal is constructed of scintillating fibers embedded in blocks of tungsten powder in an epoxy matrix, with the emitted light collected with acrylic light guides and read out through silicon photomultipliers. This poster discusses the design and construction of the EMCal, as well as the results from the 2018 beam test.

sPHENIX

- The sPHENIX experiment aims to study the quark gluon plasma and QCD matter and interactions.
- The physics program includes measurements related to jet energy loss, flavor dependence of jet energy loss, jet substructure, among others.
- The detector is currently under construction at the Relativistic Heavy Ion Collider and consists of:
  - Tracker.
  - Solenoid magnet.
  - Hadronic and electromagnetic calorimeters.



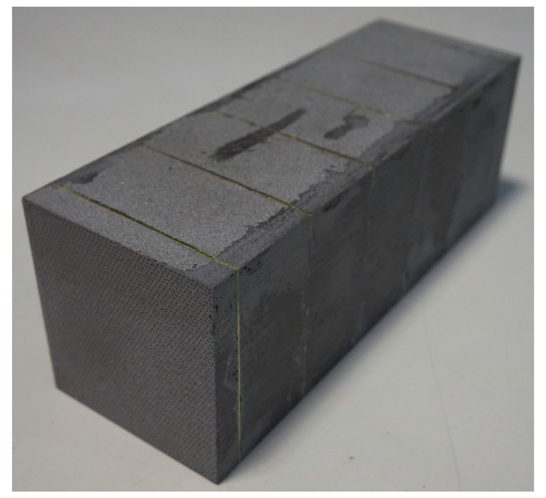
Schematic view of the sPHENIX detector.

EMCal Design

- The sPHENIX electromagnetic calorimeter (EMCal) is a sampling calorimeter that measures electrons, positrons, and photons.
- The EMCal is made of calorimeter blocks that consist of scintillating fibers embedded in a mix of tungsten powder and epoxy. The blocks are arranged in an overall cylindrical geometry.
- Each block is divided into 4×4 calorimeter towers and each tower has an approximate volume of $(1.1\ R_M)^2 \times 20\ X_0$, where $R_M \approx 2.3$ cm is the Molière radius and $X_0 \approx 7$ mm is the radiation length.
- 2D projectivity: the blocks are tapered in two dimensions and the fibers point approximately to the center of the sPHENIX detector.
- Energy resolution requirement: $16\%/\sqrt{E} \oplus 5\%$ or better.

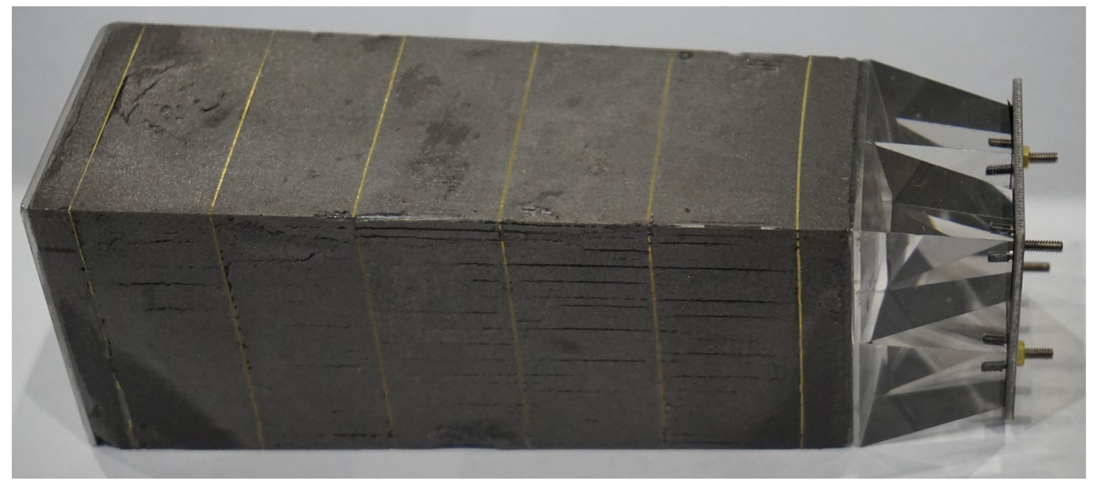
EMCal Construction

- Block production:
  - Scintillating fibers are dropped into mesh screens and the fiber-screens assembly is placed into a mold.
  - The mold is filled with tungsten powder and the powder is packed using a vibration table.
  - The mold is filled with epoxy and the mix is left to dry until solid.
  - The block is unmolded and its sides are machined.
  - The blocks are tested for light transmission, scintillation and density.



An example EMCal block. The blocks have a 2D projective design.

- Light collection:
  - Each block is equipped with 2×2 acrylic light guides on one end and an aluminum reflector on the other end.
  - Each light guide is coupled to four silicon photomultipliers (SiPM), and their output defines each calorimeter tower.

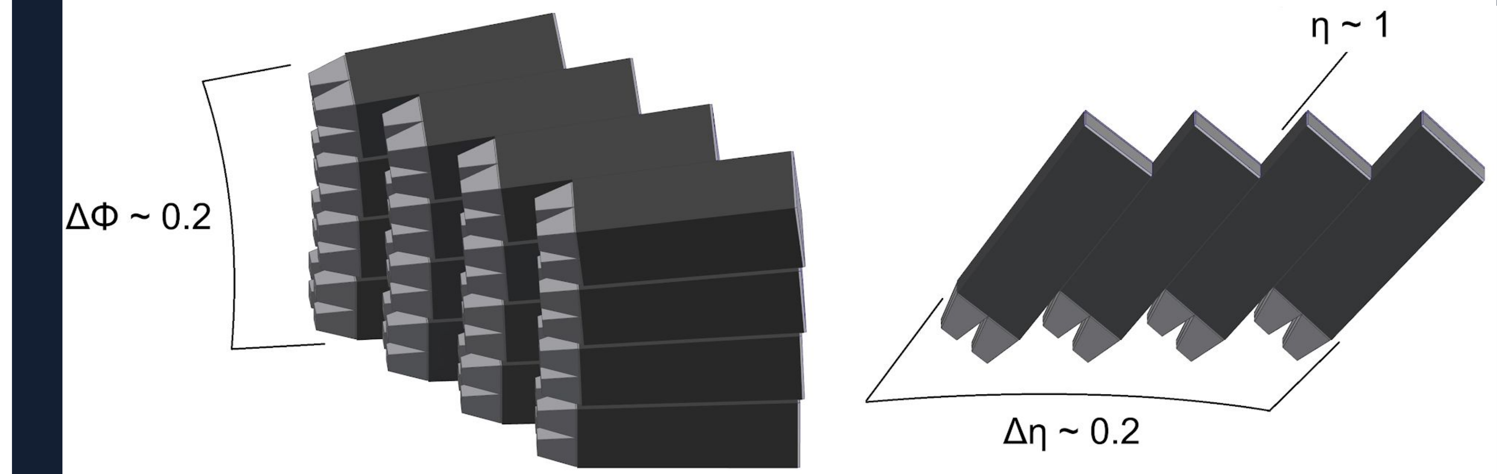


An EMCal block equipped with light guides, SiPMs and reflector.

- SiPMs are read out by electronics that shape, amplify and digitize the signals. Heat from the electronics is removed using a water-based cooling system.

2018 Prototype and Beam Test

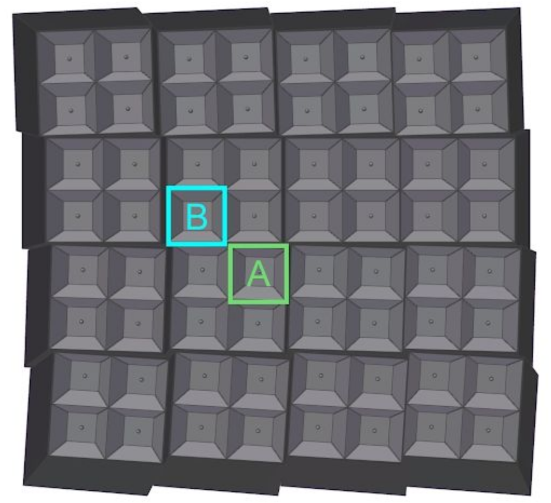
- An EMCal prototype, corresponding to a slice $\Delta\eta\times\Delta\phi = 0.2\times0.2$ centered at $\eta = 1$, was tested at the Fermilab Test Beam Facility in Spring 2018.



Schematic view of the EMCal prototype.

Picture of the EMCal prototype showing the blocks, light guides, SiPMs, electronics and part of the cooling system.

- Beam:
  - Energies ranging from 2 to 28 GeV.
  - Spot size of a few centimeters.
  - Composed of multiple types of particles.
- Uniformity study: the beam momentum was fixed at 8 GeV and the prototype was placed at different positions with respect to the beam.
- Energy resolution study: the beam was pointed at two particular towers of the prototype (labeled A and B) and the beam energy was varied from 2 to 28 GeV.

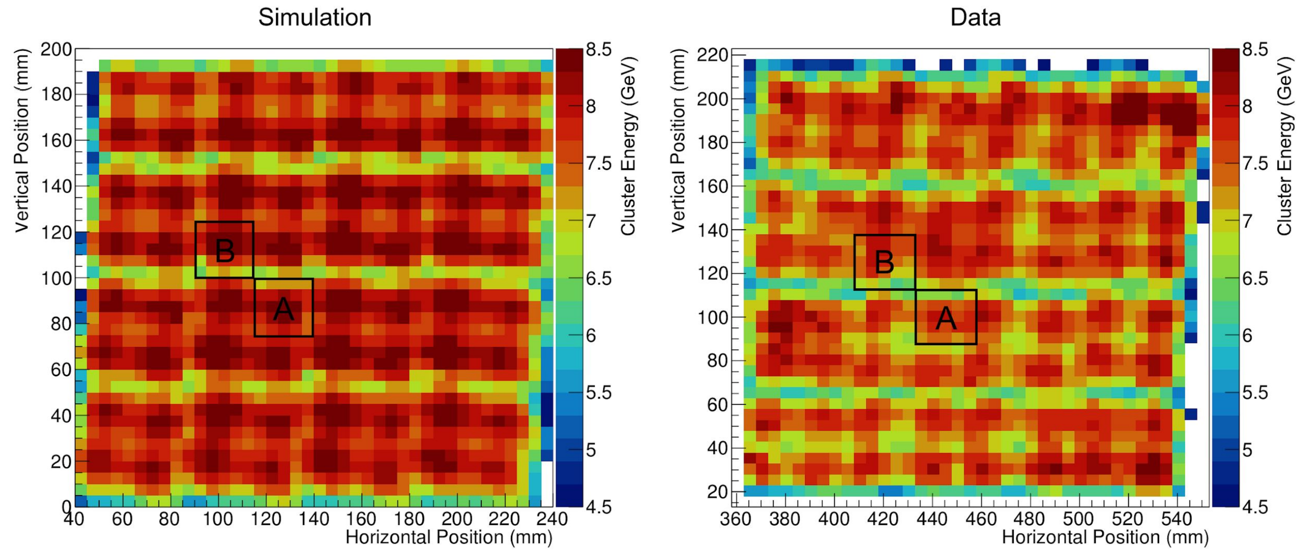


Schematic view of the prototype showing the towers selected for the energy resolution study.

- Auxiliar detectors:
  - Lead-glass calorimeter: to verify the beam properties.
  - Hodoscope: to measure the position of the beam particles and to reject measurements with more than one particle.
  - Veto detectors: to suppress particles traveling outside the beam position.
  - Cherenkov detectors: to tag electron signals.

Analysis and Results

- The measured energy was calibrated to the beam input energy using 8 GeV data.
- Two position dependent energy corrections were developed:
  - Hodoscope-based correction: position measured by hodoscope.
  - Cluster-based correction: position measured by the prototype.
- An additional correction took into account the energy dependence of the beam profile.



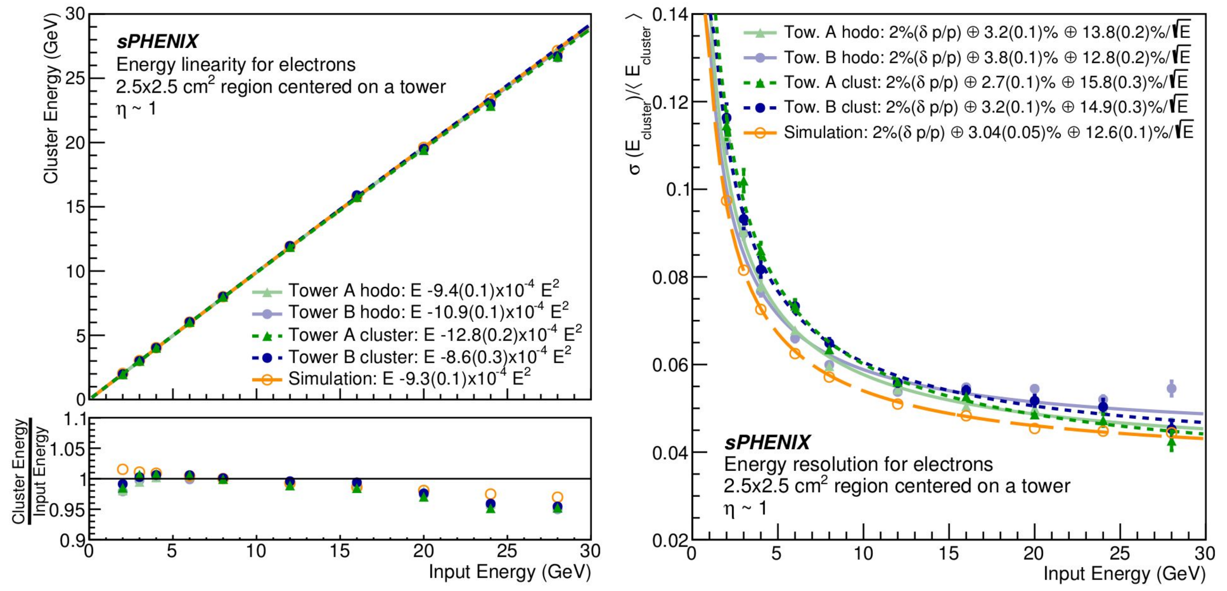
EMCal energy response as a function of position.

- The prototype's energy linearity and resolution was obtained for Towers A and B using a cut of the size of a tower (2.5×2.5 cm^2) centered at each tower.

E = input energy
$E_{cluster}$ = measured energy
a, b, c = constants

Energy linearity: $E_{cluster} = E + c\,E^2$

Energy resolution: $\sigma(E_{cluster})/\langle E_{cluster}\rangle = a \oplus b/\sqrt{E} \oplus 2\%$ (beam momentum spread)



EMCal energy linearity and resolution. Results are shown for data from Towers A and B, using the hodoscope-based or cluster-based correction, and also for simulations.

Conclusions

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. The energy resolutions obtained for this 2D projective EMCal prototype meet the sPHENIX physics requirements. More details about the EMCal design, construction, beam test and analysis are given in: https://arxiv.org/abs/2003.13685.

The authors would like to thank the technical staffs of the University of Illinois at Urbana-Champaign, Brookhaven National Laboratory, and Fermilab for their technical assistance, as well as the funding agencies: National Science Foundation and the US Department of Energy.