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Status and New Results for the sPHENIX Calorimeter Systems

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Abstract. The PHENIX Experiment at RHIC is planning a major upgrade that involves building an entirely new spectrometer, sPHENIX, that is based around the former BaBar solenoid magnet which will enable a comprehensive study of jets and heavy quarkonia in relativistic heavy ion collisions. It will include two new calorimeter systems, one electromagnetic and one hadronic, that will cover an acceptance of ±1.1 units in pseudorapidity and 2π in azimuth. The hadronic calorimeter will be a steel plate scintillating tile design that is read out with wavelength shifting fibers and silicon photomultipliers. It will be divided into two sections: one (the Inner HCAL) will be situated inside the magnet and the other (the Outer HCAL) will be outside the magnet. The electromagnetic calorimeter will be a SPACAL design consisting of a tungsten powder epoxy matrix absorber with embedded scintillating fibers which are also read out with silicon photomultipliers. The design of sPHENIX and its calorimeter systems has made considerable progress over the past several years and is described in this paper. Prototypes of all three calorimeters were built and tested in the test beam at Fermilab in April of 2016, and the first preliminary results from this test, along with a comparison to Monte Carlo simulations, are also discussed.

1. Introduction

The sPHENIX Collaboration is planning a series of major upgrades to the PHENIX experiment at RHIC that will enable an extensive set of new physics programs over the next decade. This will involve replacing the current PHENIX spectrometers with a new central spectrometer based around the former BaBar solenoid magnet. It will require the construction of two new large calorimeter systems, one electromagnetic and the other hadronic, covering ± 1.1 units in pseudorapidity and 2π in azimuth. They will be used to measure jets and heavy quarkonia in heavy ion collisions and allow a detailed study of the Quark Gluon Plasma near the region of its critical temperature. The hadronic calorimeter will be the first mid rapidity hadronic calorimeter ever used in a RHIC experiment and will provide a much better measurement of jets than has previously been possible at RHIC energies. The requirements for the calorimeters are an energy resolution ~ 100%/√E for the hadronic calorimeter for single particles and ~ 15%√E for the electromagnetic calorimeter, and to provide an electron/hadron separation ~ 100:1 for measuring Upsilons in heavy ion collisions.

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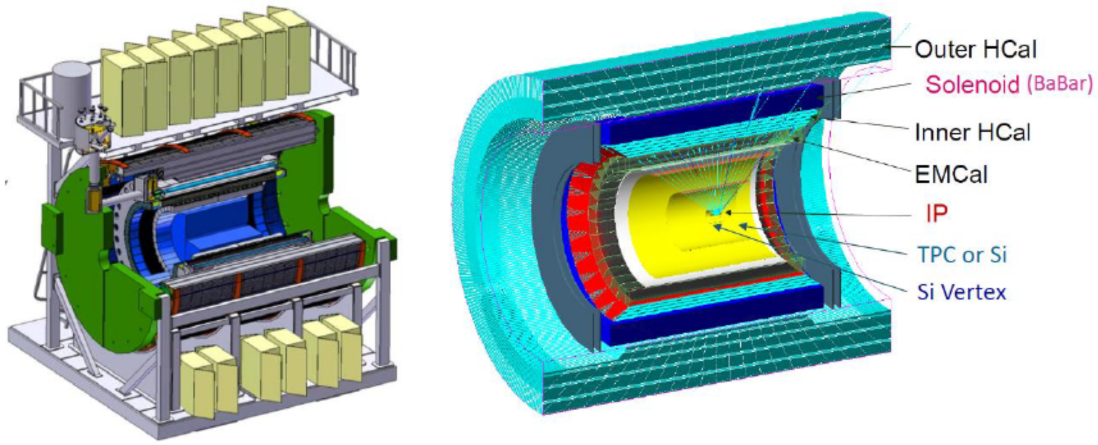

Figure 1. The sPHENIX detector utilizing the former BaBar solenoid magnet, new electromagnetic and hadronic calorimeters, a central TPC tracker and a silicon vertex tracker.

Earlier designs of the sPHENIX detector have been presented at previous conferences [1,2]. This design has now advanced considerably and is shown in Figure 1. The BaBar solenoid magnet has already been acquired from SLAC and is currently undergoing magnetic field testing at BNL. Inside the magnet, there will be a tracking system consisting of a TPC with GEM readout and a MAPS silicon vertex tracker. Figure 2 on the left shows a radial view of the two calorimeter systems. The hadronic calorimeter will be divided into an Inner HCAL located inside the magnet and an Outer HCAL located outside the magnet. It will be a steel plate and scintillating tile design that is read out with wavelength shifting fibers and silicon photomultipliers. The steel plates will be oriented parallel to the beam, serving also as a flux return, and tilted in the azimuthal direction to prevent channelling. The electromagnetic calorimeter will be a compact SPACAL design consisting of a matrix of tungsten powder and epoxy with embedded scintillating fibers that are also read out with silicon photomultipliers. This design was originally developed by the group at UCLA [3,4] and has now been further developed by a commercial company, Tungsten Heavy Powder (THP), and the group at the University of Illinois at Urbana Champaign (UIUC).

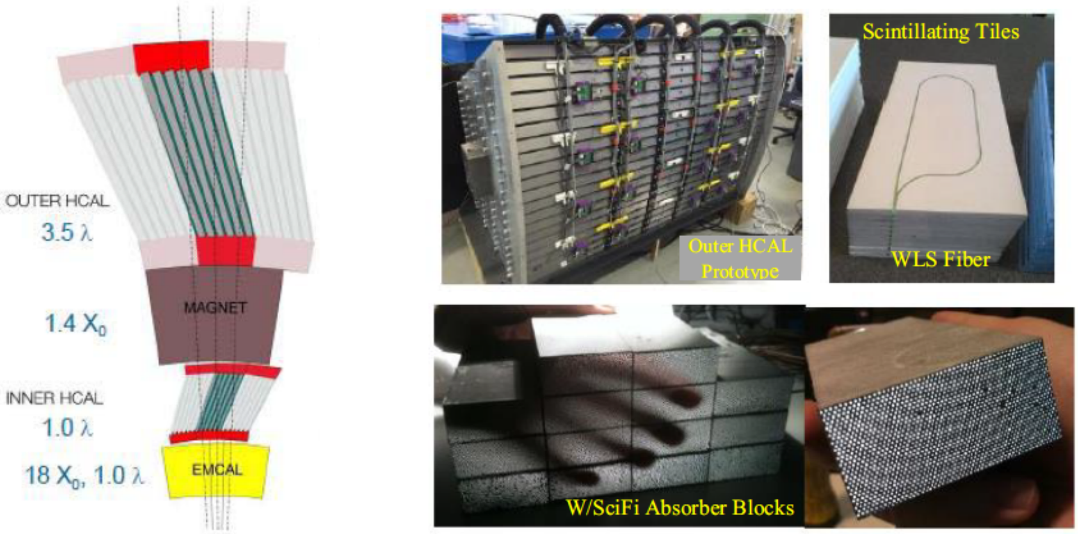

Figure 2. Left: Radial view of the sPHENIX calorimeter systems and BaBar magnet. Right: Prototype Outer HCAL with scintillating tiles (top) and W/SciFi absorber blocks for the prototype EMCAL (bottom).

2. Prototype Calorimeter Tests

Prototypes of all three calorimeters were built and tested at Fermilab in April 2016. The Inner and Outer HCAL (IHCAL and OHCAL) prototypes each consisted of a 4x4 array of towers. Each tower contained 5 scintillating tiles, each with its own embedded scintillating fiber that was read out on both ends with a single SiPM. All five SiPMs were summed together to form the readout from a given tower. Figure 2 top right shows the OHCAL prototype with its tilted steel plates and a stack of scintillating tiles that go in between the steel plates with the groove for the wavelength shifting fiber. The SiPMs are coupled to the fiber ends at the edge of the tile.

The EMCAL prototype consisted of an 8x8 array of towers constructed out of 1x2 tower absorber blocks that were tapered in one direction. The bottom right side of Figure 2 shows some of the absorber blocks used in the prototype along with a close up of the fibers within a block. Half of the absorber blocks were manufactured by THP and the other half was made at UIUC.

The calorimeters were measured over an energy range from 1 GeV to 32 GeV with electrons and hadrons, both individually and as a combined system as they will be used in sPHENIX, and for incident particle angles of zero and ± 4.5°. The calorimeters were initially calibrated with minimum ionizing particles to equalize the response of each tower and establish an approximate energy calibration. The HCAL was calibrated in situ with cosmic ray muons and the EMCAL was calibrated using the 120 GeV primary proton beam passing through each tower. For the EMCAL, an improved energy calibration was also developed that used electron showers to equalized the response of each tower.

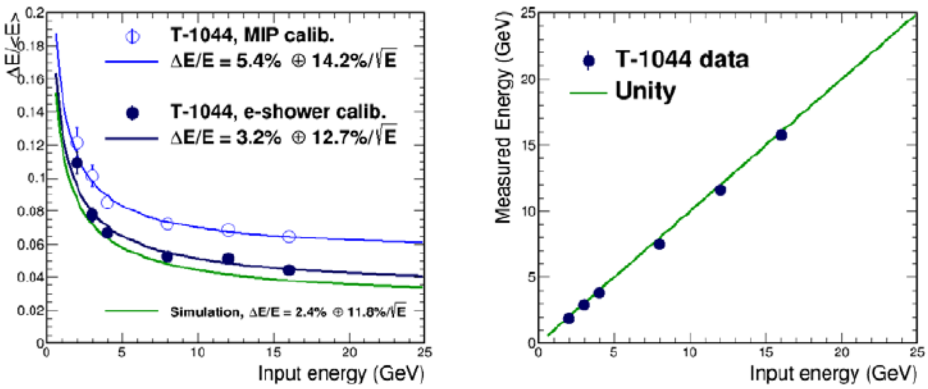

Figure 3. Energy resolution and linearity of the EMCAL prototype. The initial calibration was done using MIPs and a more sophisticated calibration was done using electron showers.

Figure 3 shows preliminary results for the energy resolution and linearity measured for the EMCAL using both the MIP and electron calibration. The energy resolution improved from 14.2%/√E ⊕ 5.4% with the MIP calibration to 12.7%/√E ⊕ 3.2% with the electron calibration. Neither resolution has yet been corrected for the beam momentum spread, which believe is ~ 2% over this energy range. The data also showed good linearity over the energy range measured.

For the combined energy resolution of the EMCAL + HCAL system, a procedure was used to select hadronic showers starting each separate detector which was then used to equalize the energy response of all three calorimeters. Figure 4 shows the energy distributions for particles which start showering in the various parts of the calorimeter (MIP in the EMCAL, MIP in the EMCAL and IHCAL, and all showers irrespective of their starting position). Figure 5 shows preliminary results for the energy resolution and linearity measured for the combined calorimeter system. Also shown on the resolution plot are curves for 95.7%/√E and 70.6%/√E, indicating that the data lie between these two values. A two component fit to the data gives a resolution of ~ 70-80%/√E ⊕ ~ 10-15%.

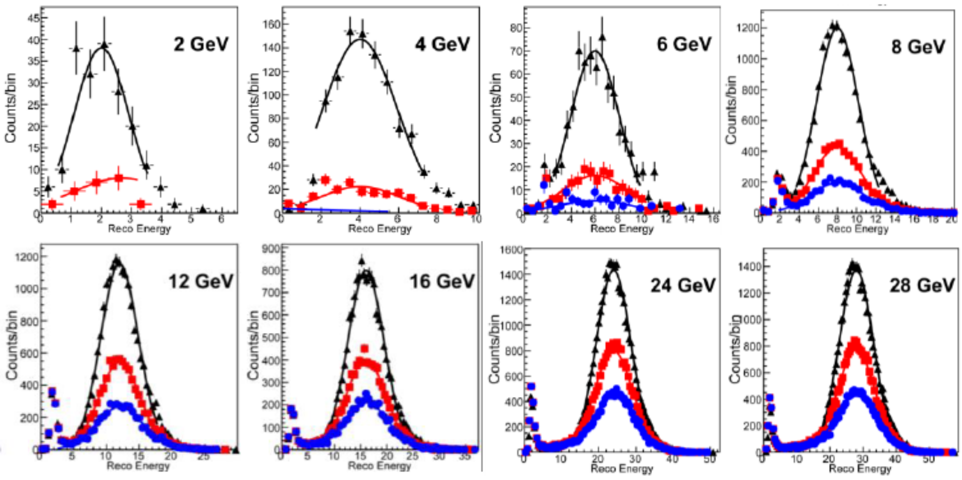

Figure 4. Energy distributions for various energy hadronic showers originating in different parts of the combined calorimeter after applying equalizing weighting factors. Red: MIP in EMCAL, Blue: MIP in EMCAL+IHCAL, Black: All showers irrespective of starting position.

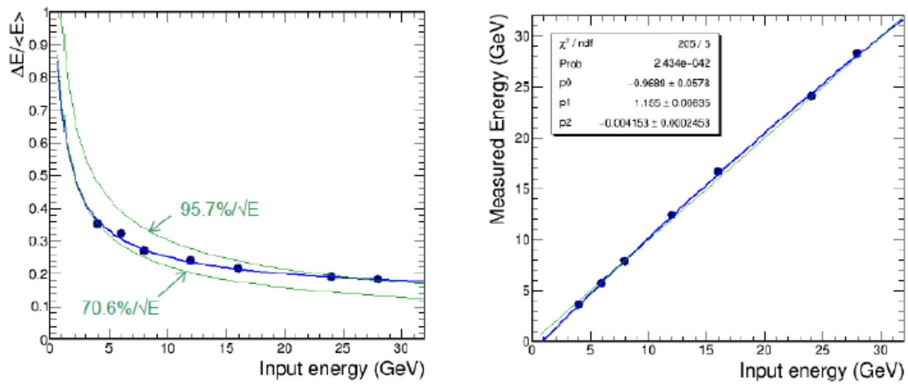

Figure 5. Combined EMCAL + HCAL (Inner + Outer) energy resolution and linearity. Curves are also shown for energy resolutions of 95.7%/√E and 70.6%/√E for comparison.

3. Summary and Conclusions

The sPHENIX experiment at RHIC has developed a detailed design of the entire detector including the new electromagnetic and hadronic calorimeters. Prototypes of these calorimeters were built and tested at Fermilab in April of 2016 and the first preliminary results indicate that both calorimeters, as well as the combined calorimeter system, will meet the design requirements of the sPHENIX experiment. Further analysis of the test beam data is currently under way and we expect new and improved results within the next few months.

4. References

[1] C.Woody and E.Kistenev, Proceedings of the 15th International Conference on Calorimetry in High Energy Physics (CALOR2012), Journal of Physics Conference Series, 404 (2012).
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