PROCEEDINGS OF SCIENCE

# Test beam measurements of calorimeters for the PHENIX upgrade at RHIC

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After 15 years of successful data taking the PHENIX experiment at the Relativistic Heavy Ion Collider, RHIC, at Brookhaven National Laboratory, BNL, is undergoing a major update to expand its physics capabilities. The originally four experiments were designed to study high energy heavy ion collisions to create a dense, high temperature matter called the Quark Gluon Plasma, QGP [1]. This QGP is believed to be a stage of the forming universe a few microseconds after the big bang. RHIC showed that in high energy collisions of gold nuclei one performs that phase transition from nuclear matter to the QGP. Its temperature was measured to over 4 trillion degrees and studies of the density showed that the QGP behaves like a perfect liquid with hardly any viscosity. The best tool to study the properties of the QGP turns out to be jets from hard quark – quark or quark – photon scattering as data from RHIC and the Large Hadron Collider, LHC [2], have shown. A necessity for a detailed jet measurement is hermetic calorimeter coverage which none of the RHIC experiment currently has. Also the melting of quark bound states like the $J/\Psi$ and $\Upsilon$ states in the QGP are one of the proposed measurements. This let to a redesign of the PHENIX experiment into an updated version currently called sPHENIX to address these challenges.
Recently sPHENIX was granted CD-0 from DOE, with a planned installation by 2021 and first measurements in 2022.

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†A footnote may follow.

## 1. sPHENIX design

The approach to upgrading PHENIX into sPHENIX was to use as much of the existing infrastructure as possible but new detectors and magnet were necessary. We managed to obtain the 1.5T superconducting solenoid from the Babar experiment and have already performed a cool–down and low current test, a full field test is planned for early 2017.
The calorimeters will be build with cost in mind but achieving the required resolution which we determined by Monte Carlo to be $100\%/\sqrt{E}$ for the Hadronic calorimeter, HCal, and $15\%/\sqrt{E}$ for the electromagnetic, EMCal, section. For the tracking we require about $1\%\delta p/p$, provided by central Silicon detectors and a small TPC.

A 3D model, see Fig.1, of the current sPHENIX design [3] shows a basic collider detector with Silicon tracking around the beam pipe, a TPC, EM and Hadronic calorimeter sections, a superconducting solenoidal magnetic field and the main HCal as the flux return, it will have full coverage in $\phi$ and $|\eta| < 1.1$.

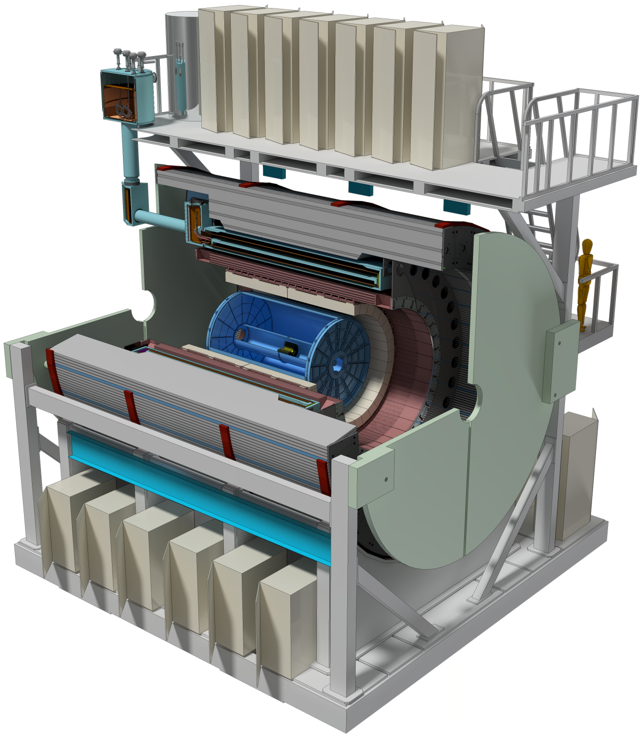

**Figure 1:** sPHENIX layout

The layout has been developed in much detail already and first prototypes are being tested.

## 2. Calorimeters

The calorimeters are subdivided into three parts, inside the magnet an EMCal measuring electrons and photons and a smaller stainless steel section of the HCal. Outside the cryostat a larger section of HCal, which also serves as the magnet flux return, provides complete energy measurements. To reduce costs all calorimeters are read out by Silicon Photomultipliers, SiPM, and use the same readout electronics.

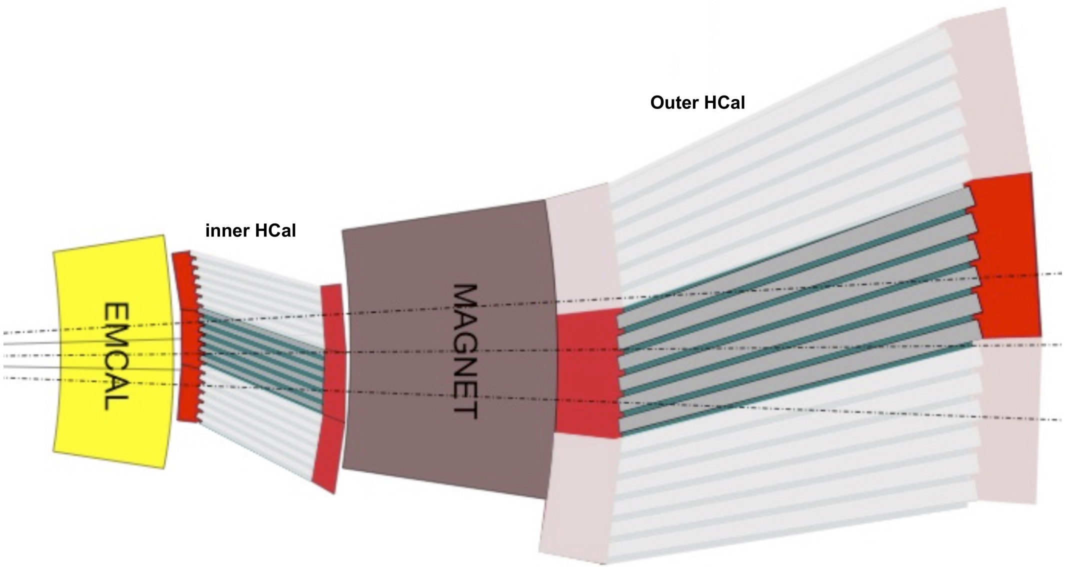


**Figure 2:** sPHENIX calorimeter layout

The EMCal will be a Scintillating fiber / Tungsten calorimeter with 0.025 $\times$ 0.025 binning in $\eta$ and $\phi$, covering 2 $\pi$ in $\phi$ and $70cm < r < 116cm$, which follows a design by the UCLA group [4]. The modules are constructed by first setting up the 0.47 mm diameter fibers inside a mold spaced by meshes and then filling it with fine Tungsten powder. Via a vacuum system epoxy glue is spread into the mold forming the final module. The modules should have a density of about $\approx 10\ g/cm^3$ which results in a sampling fraction of about 2.3% and the radiation length of $X_0 \approx 7mm$. Each module is read out by 4 SiPMs, sitting on top of a short plastic light guide. the four signals are summed and read out by an ADC measuring the light output peak.

The HCal will be build from tilted steel plates with polystyrene panels creating the towers with a segmentation of 0.1 x 0.1 in $\eta$ and $\phi$. The inner HCal, $1.\lambda_I$, inside the magnet with be made from stainless steel, the outer, $5.5\lambda_I$, to provide the magnet flux return from magnet steel. The tilt angle was chosen so that a straight track would traverse at least four gaps for non-field detector calibrations. The polystyrene scintillator contain an embedded loop of a wavelength shifting fiber to collect the produced light and will be read out by a SiPM covering the ends of the fiber. Five of these SiPMs will be ganged together to form a tower.

## 3. FNAL test beam facility

Since 2005 Fermi National Accelerator Laboratory, FNAL, provides a dedicated test beam facility, FTBF [5], which uses the 120GeV primary proton beam and provides beams of electrons and hadron from 1 to 120 GeV as well as all infrastructure to test your prototype. In 2016 we took measurements with our calorimeter setup for the second time. Figure 3 shows the 2016 arrangement of the prototypes in the FNAL test beam facility.

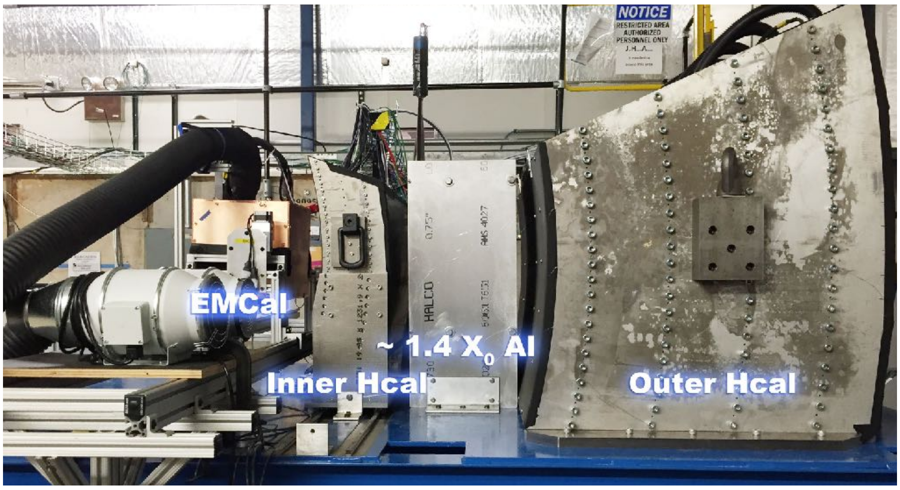


**Figure 3:** sPHENIX calorimeter prototypes in the FNAL test beam facility

We took data with a $8 \times 8$ module EMCal and a $4 \times 4$ tower inner and outer HCal prototype. A Aluminum box simulates the material of the superconducting magnet. The EMCal can be moved in and out of the beam and the support table can be tilted to vary the impact angle. Beam particle types were selected by FTBF Cherenkov counters and a small Scintillator hodoscope provided the beam particle position. The complete calorimeter setup was simulated using Geant4, see Figs.4 and 5, the comparison of the beam – test data and these simulations will provide feedback to the full detector simulations which is ongoing.

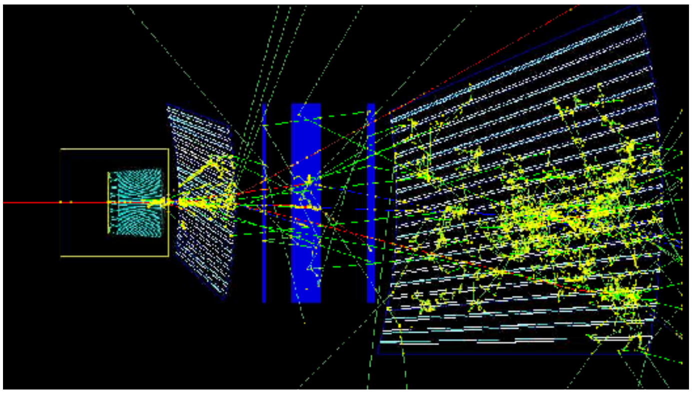

**Figure 4:** GEANT4 simulation of the sPHENIX calorimeter prototypes in the FNAL test beam facility

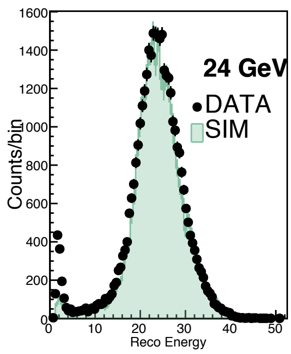


**Figure 5:** GEANT4 simulation and data comparison for 24GeV pion response

## 4. Preliminary results

Detailed calibrations of the modules are an important step to achieve the final results and also

to develop a procedure to calibrate the over 30k calorimeter modules once they are installed in the detector. A detailed paper describing all the corrections and calibration steps will be published soon.
Fig. 6 shows the preliminary energy resolution for all three calorimeters as a function of the beam energy.

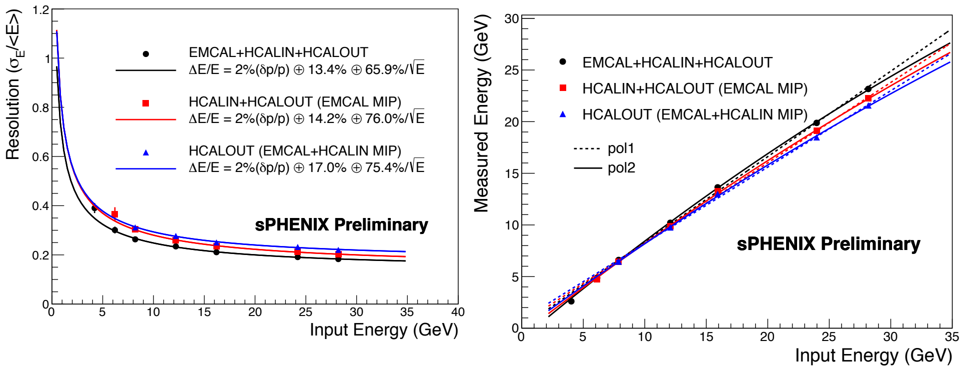


**Figure 6:** Preliminary energy resolution for the calorimeter setup

Even so the data need more work on calibrations, e.g. beam momentum spread, the preliminary results already show that the calorimeter in the current setup would provide the energy resolution sufficient for the planned physics measurements. A detailed publication describing all calibration steps and corrections will be published soon.

## 5. Summary

The sPHENIX upgrade will continue the successful RHIC program and extend its capabilities for detailed QGP measurements which overlap with LHC. First tests of the new calorimeters at the FNAL test beam facility have shown that the current design will provide the required resolution for the jets and $\Upsilon$ measurements. Another beam – test to measure the higher $\eta$ range is in preparation for early 2017.
The sPHENIX collaboration is growing and would welcome more interested groups.

## References

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