Neutral Pion and Eta Meson Measurements with the sPHENIX Detector

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Abstract

sPHENIX is a new detector at the Relativistic Heavy-Ion Collider (RHIC) designed to make precision jet and upsilon measurements in $200GeV\ p+p, p+Au,$ and $Au+Au$ collisions and will begin taking data in 2023. In addition to having the first hadronic calorimeter (HCal) at midrapidity at RHIC, sPHENIX also contains a tungsten-scintillator based Electromagnetic Calorimeter (EMCal) for measuring the energy of photons and electrons. Before physics analyses can take place using the EMCal, however, it must be calibrated to the electromagnetic energy scale, and this will be done by calibrating the EMCal's response relative the neutral pion's (π^0's) invariant mass. π^0's are reconstructed from pairs of EMCal clusters that were produced by decay photons from π^0's. However, due to cluster merging effects, this procedure is not practical at high momentum. Thus, as a high-energy cross-check on the energy scale calibration, the calorimeter's response relative to η mesons, whose heavier mass allows for reconstruction without merging to much higher momenta, will also be measured. The EMCal's successful calibration will enable measurements with the π^0 and η mesons, which will take advantage of both sPHENIX's large acceptance and the high luminosity 200GeV $Au+Au$ data set currently being recorded. This poster will show the status of the sPHENIX EMCal's energy scale calibration and the status of sPHENIX's first neutral meson analyses.

The sPHENIX Electromagnetic Calorimeter

The role of the sPHENIX calorimeter is to measure the energies of electrons and photons. The EMCal is composed 6,144 modules, or blocks, composed of tungsten and epoxy and embedded with scintillating fiber. Each block is further subdivided into 4 towers, giving the EMCal a granularity of $\Delta\eta\times\Delta\phi = 0.024\times 0.024$. The EMCal has an acceptance of 2π in azimuth, as well as $|\eta| < 1.1$ in pseudorapidity. As particles enter the EMCal blocks, they begin to produce electromagnetic showers, and the energy sampled from these showers is readout by a set of four silicon photomultipliers each surmounting a light guide.

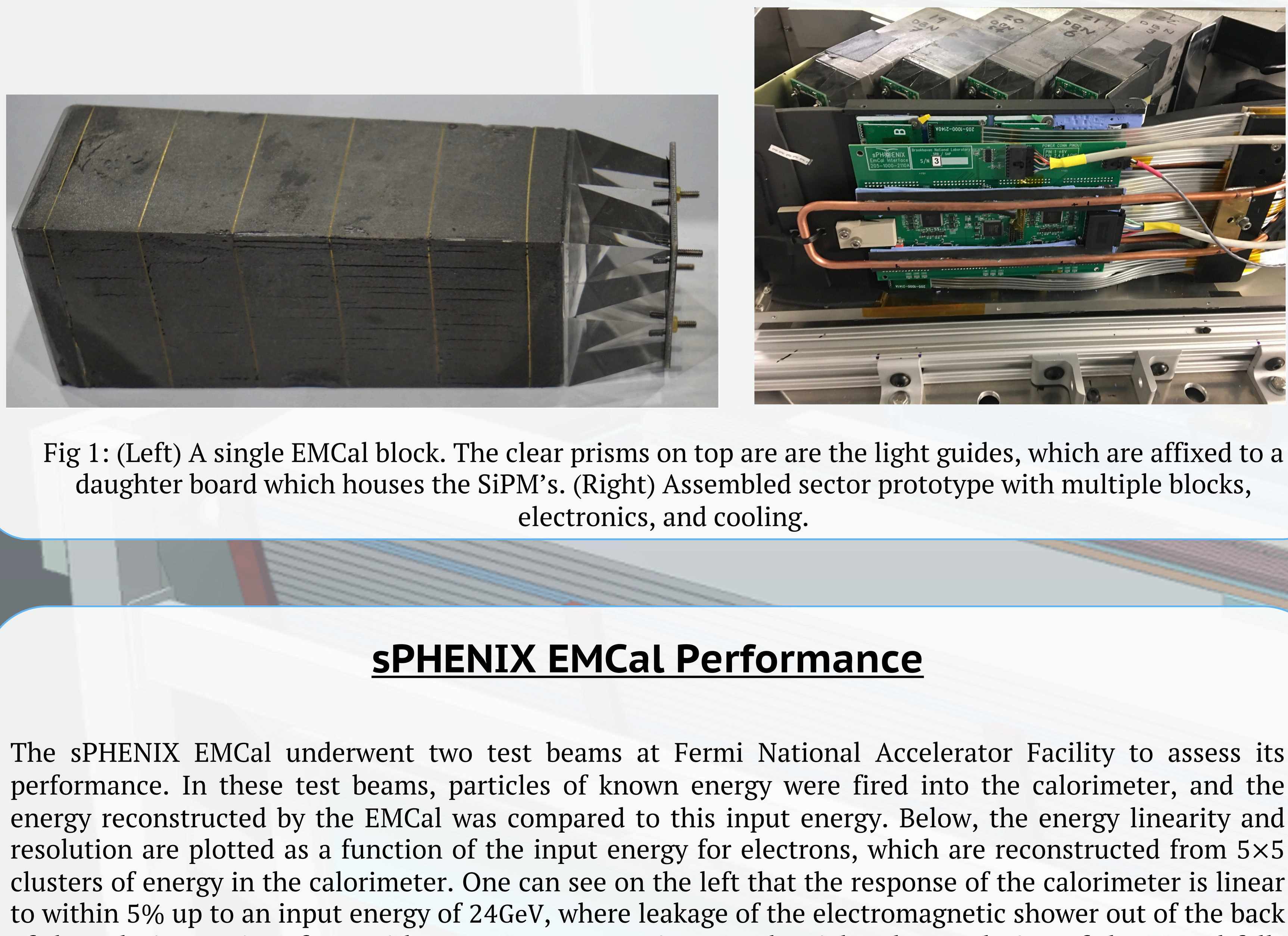

Fig 1: (Left) A single EMCal block. The clear prisms on top are are the light guides, which are affixed to a daughter board which houses the SiPM's. (Right) Assembled sector prototype with multiple blocks, electronics, and cooling.

sPHENIX EMCal Performance

The sPHENIX EMCal underwent two test beams at Fermi National Accelerator Facility to assess its performance. In these test beams, particles of known energy were fired into the calorimeter, and the energy reconstructed by the EMCal was compared to this input energy. Below, the energy linearity and resolution are plotted as a function of the input energy for electrons, which are reconstructed from 5×5 clusters of energy in the calorimeter. One can see on the left that the response of the calorimeter is linear to within 5% up to an input energy of 24GeV, where leakage of the electromagnetic shower out of the back of the calorimeter interferes with energy reconstruction. On the right, the resolution of the EMCal falls sharply as a function of the input energy, yielding a resolution with a constant term of approximately $15\%/\sqrt{E}$, exceeding the requirement for the key physics performance parameter[1].

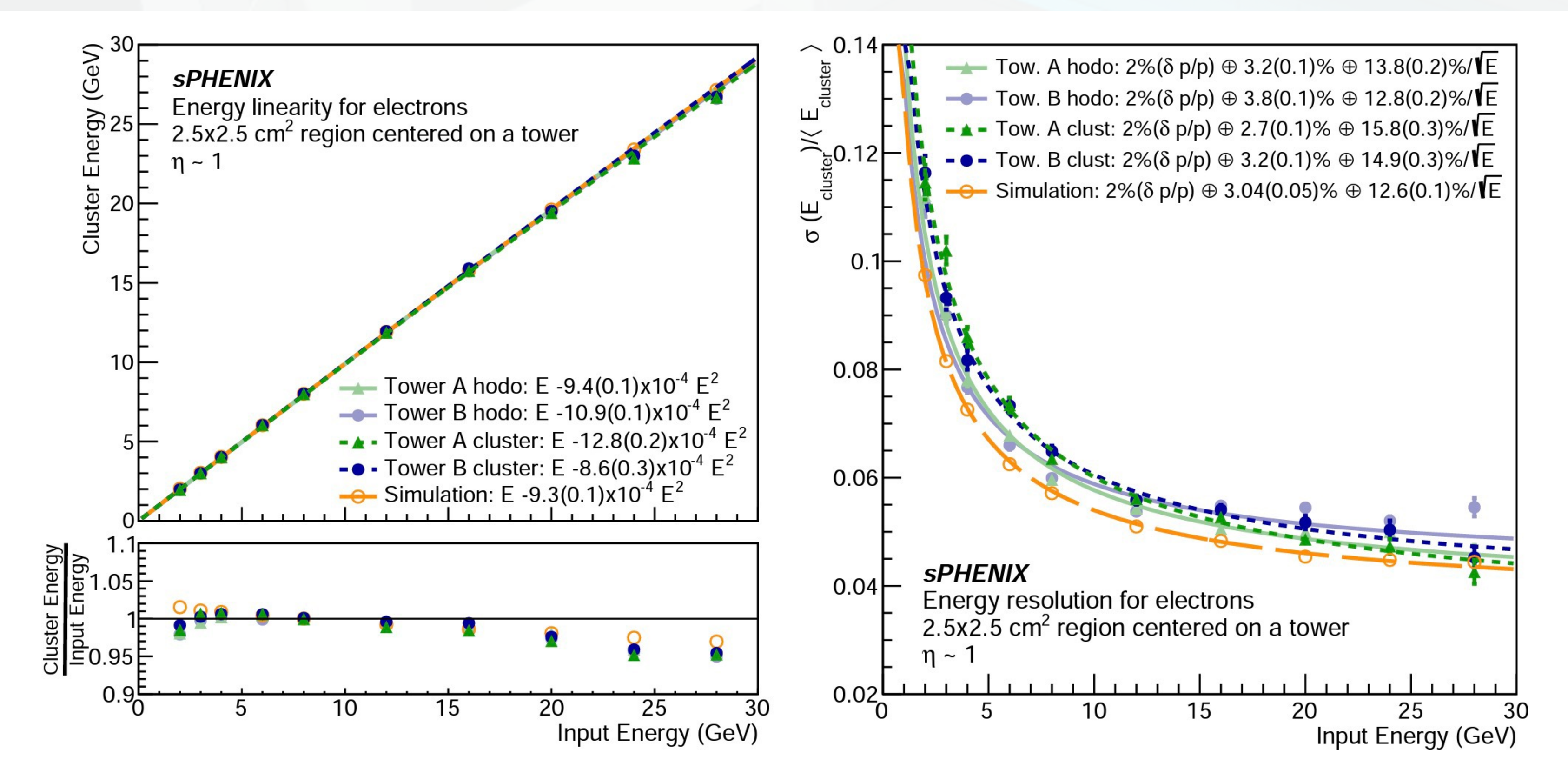

Fig 2: (Left) EMCal linearity as a function of input energy obtained via test beam. (Right) Reconstructed energy resolution for electrons obtained via test beam as a function of input energy[1].

sPHENIX EMCal Installation and Initial Testing

Installation of the sPHENIX EMCal began in the winter of 2023 with the insertion of all 64 sectors into the sPHENIX bore. All sectors underwent basic sector testing, revealing that all but one of 24,576 channels responding within tolerance, a nearly 100% success rate. Later tests with the fully-cabled EMCal validated the >99% readout rate by pulsing each SiPM with an LED and reading out the response.

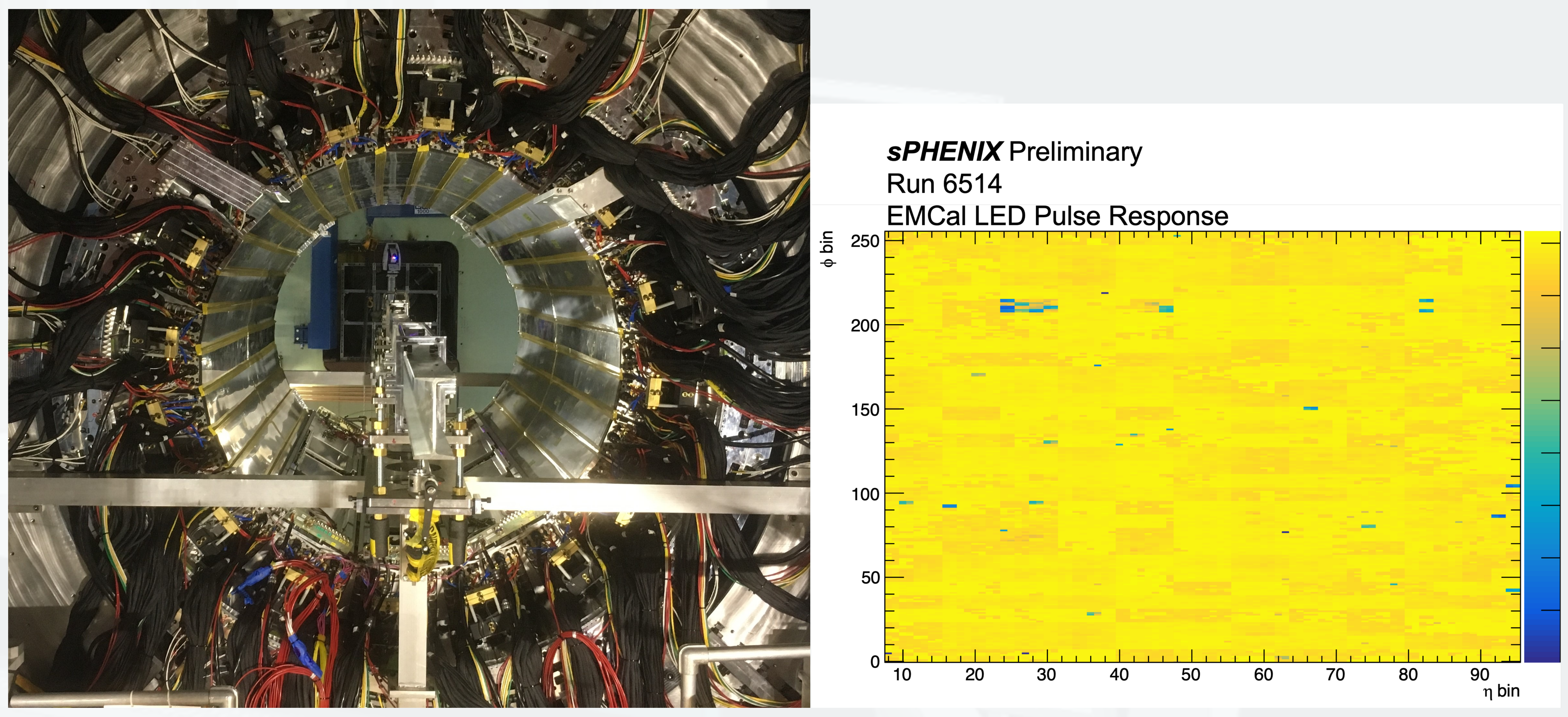

Fig 3: (Left) The sPHENIX electromagnetic calorimeter fully installed and cabled. (Right) response of the EMCal to LED pulses showing >99.9% live area.

Neutral Meson Reconstruction

Neutral mesons such as π^0's and η mesons are reconstructed from pairs of clusters within the electromagnetic calorimeter. The total energy in ADC in the EMCal is used as a proxy for the event centrality, and a cut is made so that mostly peripheral events are selected on. Clusters are formed from towers with greater than 150 ADC counts, and are required to have a reconstructed energy of greater than 500 ADC counts. Additionally, a cut is made on the cluster X^2, which gives the probability a cluster originated from an electromagnetic shower, or some other phenomenon. A lower X^2 means a cluster is more likely to have originated from a photon or electron. In this analysis, clusters are required to have a X^2 of less than 10. Lastly, clusters are required to have an opening angle of $\Delta R > 0.08$ [rad] to further avoid merging effects. Clusters passing these selection cuts are paired together, and an invariant mass is calculated from their kinematics. Fig. 4 shows the invariant mass distribution measured in 56,000 minimum bias 200GeV Au+Au events during sPHENIX's commissioning data-taking run. One can clearly see a pronounced resonance at approximately 100 ADC. The measurement is split between the northern ($\eta > 0$) and southern ($\eta < 0$) hemispheres of the detector as a crosscheck.

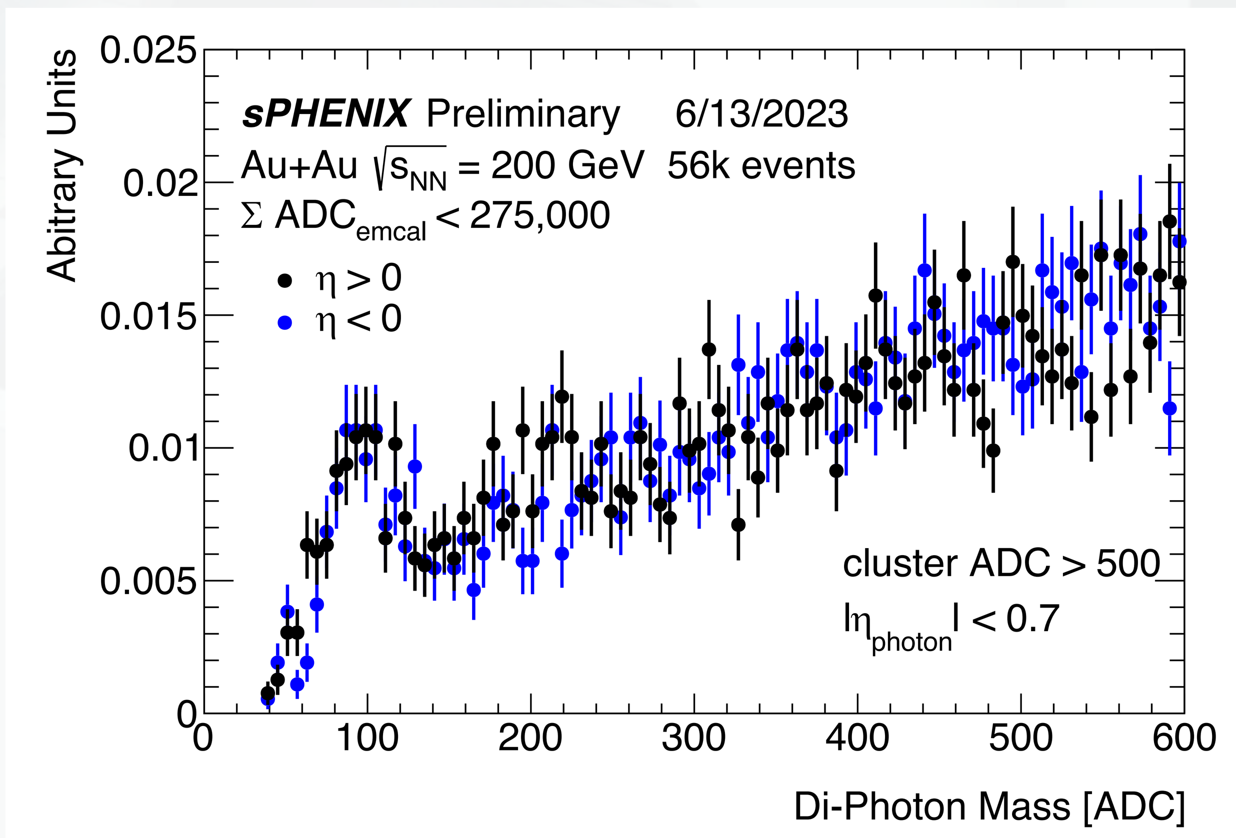

Fig 4: Invariant mass distribution as a function of the reconstructed meson energy in units of ADC measured in minimum bias 200GeV Au+Au collisions

Summary and Outlook

An initial measurement of di-photon invariant mass distribution has been measured from sPHENIX EMCal data from midway through the 2023 commissioning run, and a clear π^0 peak can be seen at about 100 ADC, an important physics object that will aid in the calibration of the EMCal. The π^0 peak is visible with a mere 56,000 events, and, despite the early end of the 2023 RHIC run, analysis of the 200GeV Au+Au data taken during the summer of 2023 continues. This includes the processing of more data into an analyzable format, which will increase the available statistics. Such statistics are necessary, because although one can clearly resolve the lower-mass π^0 peak with 56,000 events and minimal cuts on the reconstructed meson energy, harsher, more statistically intensive cuts are required to cut away the background at higher invariant mass and truly resolve the wider and lower signal-to-background ratio η meson peak. Efforts are also underway to produce initial calibrations using a combination of inputs from simulation and real data. Once the π^0 peak position has been properly calibrated, and enough data has been amassed, the η meson peak will be measured. Specifically, its peak position will serve as a high-momentum cross-check on the energy scale calibration of the EMCal.

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[1] https://arxiv.org/pdf/2003.13685.pdf