Analysis of the 2017 test beam data for the Hadronic Calorimeter

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Abstract

This analysis note gives the details on the HCal analysis for the T1044-2017a test beam data.

Contents

1 Introduction

The 2017 T-1044 beam test was the first test of the prototype of the large pseudorapidity, ($\eta \approx 1$), design of the sPHENIX calorimetry system, following the successful beam test of the mid-rapidity prototype in 2016 [1]. The inner and outer HCal prototypes are both based on the version of the calorimeter that has tapered plates and 5 tiles per tower. Discussions in the collaboration are ongoing about the final design of the inner HCal—agreed upon are flat plates instead of tapered and 4 tiles per tower instead of 5, as yet to be determined is whether the SS310 absorber is traded for Aluminum. The 2018 prototype will encorporate all design changes to the inner HCal, and the results from the 2017 beam test will provide an important baseline to assess the impact of these design changes.

1.1 Comments on energy resolution

In this analysis note we discuss the performance in terms of the constant term (independent of energy) and the stochastic term (inversely proporational to the square root of the energy). The constant term is due to various detector quality features like geometry, mechanical structure, and the like. This term contributes linearly to the energy resolution σ_E and this contributes a constant to the relative energy resolution $\sigma_E/\langle E\rangle$. The stochastic term is due to the energy sampling. Since this is, at its core, a matter of counting photons, it is Poissonian in nature. Therefore, the contribution to σ_E is proportional to $\sqrt{E}$ and so its contribution to $\sigma_E/\langle E\rangle$ is proptional to $1/\sqrt{E}$. Although we generally do not explicitly discuss it in sPHENIX, in principle there is also a noise term that comes from the calorimeter readout electronics. This is intrinsic to the electronics and is therefore independent of energy, meaning the contribution to σ_E is constant and therefore the contribution to $\sigma_E/\langle E\rangle$ is proportional to $1/E$.

Considering these contributions, the observed energy resolution can be modeled as

$$\sigma_E/\langle E\rangle = c \oplus s/\sqrt{E} \oplus n/E, \tag{1}$$

where c, s, and n are the constant, stochastic, and noise coefficients, respectively. The binary operation $\oplus$ indicates sum in quadrature, meaning the coefficients are determined from data by

$$\sigma_E/\langle E\rangle = \sqrt{c^2 + s^2/E + n^2/E^2}. \tag{2}$$

As stated above, for the beam test data, we typically ignore the noise term. Further, the incoming energy is not perfectly known due to the usual accelerator physics considerations, so one needs to consider an additional constant term due to the beam momentum spread. This has been determined by the FNAL accelerator division to be $\delta p/p \approx 2\%$. Since it is customary to report the constant and stochastic (and noise) terms as percentages, e.g. $C\% = c * 100$, the final results will be quoted as

$$\sigma_E/\langle E\rangle = 2\%(\delta p/p) \oplus C\% \oplus S/\sqrt{E}\%. \tag{3}$$

1.2 Comments on energy linearity

Another important performance measure for the calorimeters is the linearity, which is the measure of the input ("truth") energy to the measured ("reconstructed") energy. The linear slope is trivially just a calibration constant, but any non-linearity will result in degradation of physics performance. For example, for the highest beam energies, a deviation from linear may indicate leakage.

2 Documentation

Extensive documentation can be found on the test beam pages of the sPHENIX Wiki. The main page has a significant amount of information, and links to other pages relevant to the analysis (including good run lists, Cherenkov detector configurations, etc), located here (clickable). Publication of the 2017 beam test results has been delayed until after the 2018 test beam due to poor block boundaries in the 2017 EMCal prototype. However, the wiki page for the paper contains a lot of useful information and is located here (clickable). Most importantly, extensive information about the T1044 setup can be found in the 2016 beam test paper [1].

3 Experimental setup

The experimental set up is discussed extensively on the wiki, and is the same as it was for the 2016 beam test paper [1]. However, we briefly discuss the salient features here. Figure 1 shows the T-1044 setup in 2017. The left panel shows a closeup of the calorimeter system, with the upstream direction pointing to the right. In order of upstream to downstream (right to left) the subsystems seen are the EMCal, the inner HCal, the mock magnet, and the outer HCal. The right panel shows a slightly zoomed out view where the upstream direction is to the left. Visible here is the hodoscope upstream of the EMCal. The hodoscope is used to select events where the position of the particle is known. This is especially important for position dependent measurements, which is of great interest for the EMCal. In the HCal analysis we generally only require a valid hit in the hodoscope, which ensures that the particle is in within the boundaries of the calorimeter.

Not visible in the photographs are the SWIC and MWPC, which are part of the FTBF beam line and used primarily for online beam diagnostics. Information from these detectors is also saved to the PRDF files, although they are not used in the present analysis. Also not visible in the photographs are the Cherenkov counters, called C1 and C2, which are part of the FTBF beam line, upstream of the MT6.2 experiment hall. Information from these detectors is saved to the PRDF files, and they are a key part of all beam test analysis. The Cherenkov counters are used for separating pions from electrons, and the approximate beam composition as a function of energy is shown in Figure 2.

Figure 1: Photographs of the T-1044 setup in 2017. The left plot shows a closeup of the calorimeter system, and upstream is to the right. The right plot shows a slightly zoomed out version where upstream is to the left.

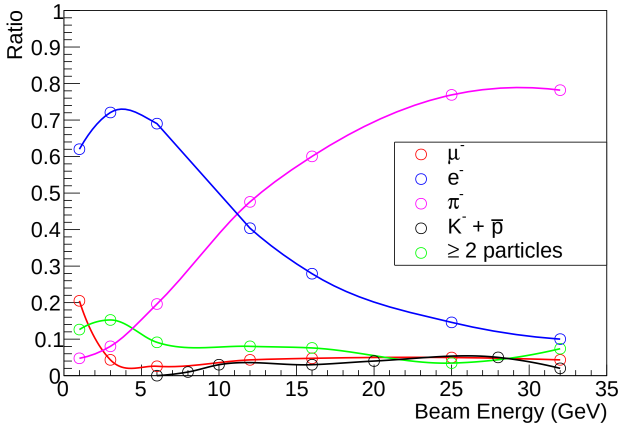

Figure 2: Beam composition as a function of beam energy.

4 Analysis

The production code can be found:

- on github: analysis/Prototype3/HCAL/ShowerCalib
- on RCF: `/sphenix/user/belmonrj/analysis/Prototype3/HCAL/ShowerCalib/`.

The analysis code can be found:

- on github: belmonrj/BeamTestHCalAna2017
- on RCF: `/sphenix/user/belmonrj/abhisek_shower/`.

The main cut in the analysis is `good_h`, which requires the following:

1. a valid hodoscope hit in the vertical direction (ADC > 30);
2. a valid hodoscope hit in the horizontal direction (ADC > 30);
3. a null signal in the C2 Cherenkov Counter (ADC < 20);
4. a valid trigger.

5 Results

5.1 Tower by tower cosmics

Figure 3 shows the tower-by-tower ADC distribution from cosmics in the inner HCal. Figure 4 shows the same with a comparison to the 2016 prototype.

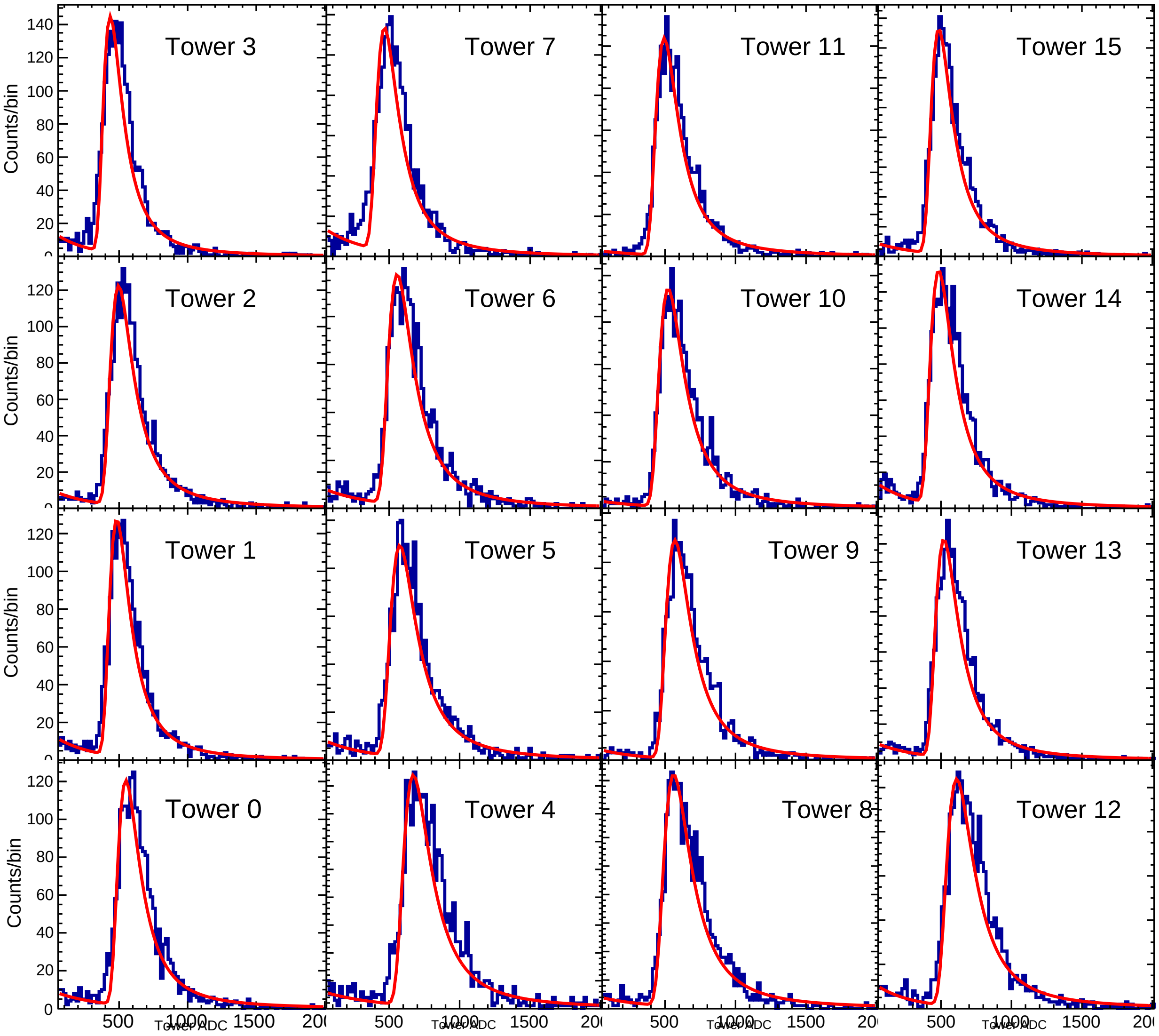

Figure 3: Tower by tower ADC distributions from cosmics for the inner HCal.

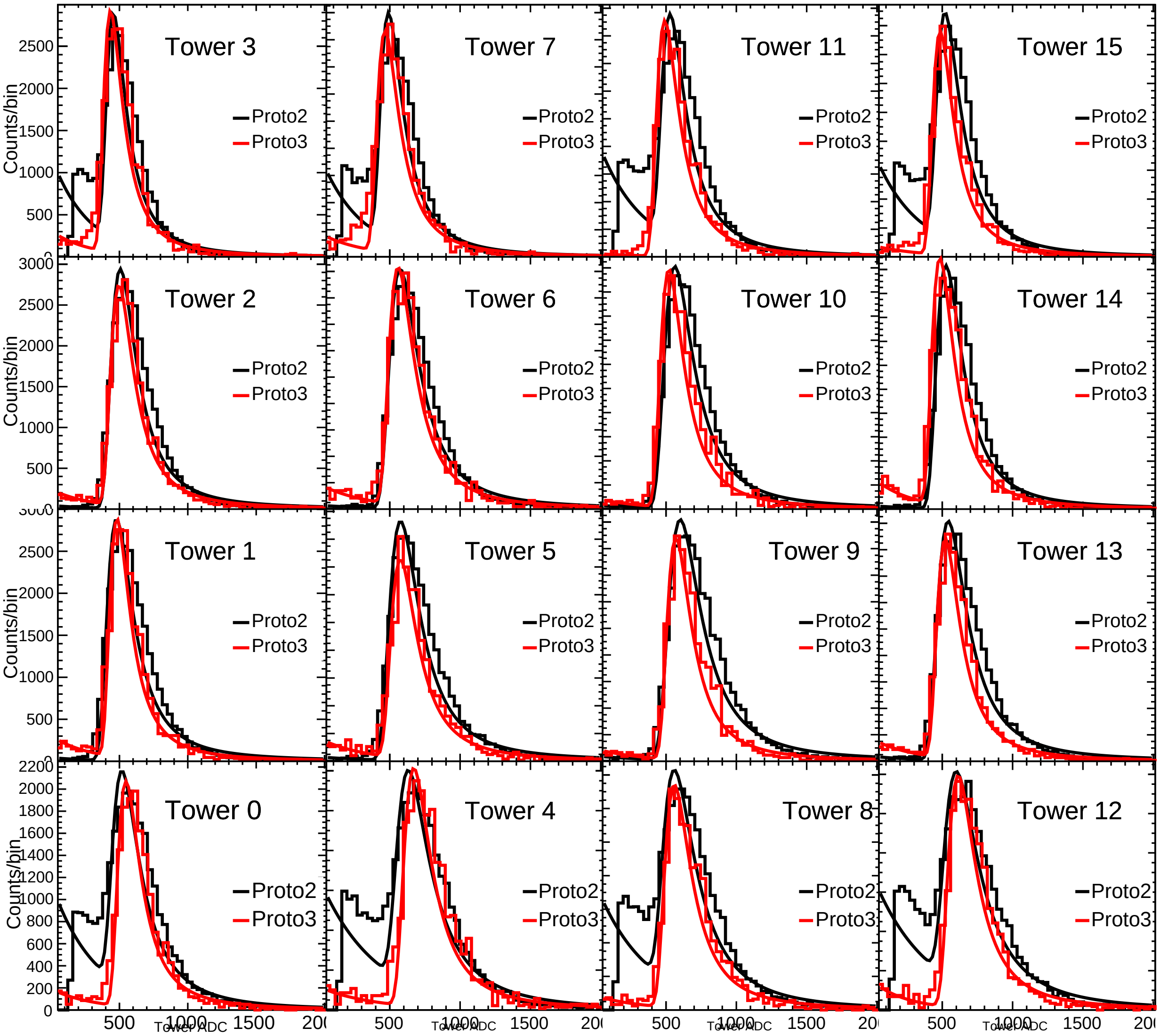

Figure 4: Tower by tower ADC distributions from cosmics for the inner HCal and a comparison to the 2016 prototype.

Figure 5 shows the tower-by-tower ADC distribution from cosmics in the outer HCal. Figure 6 shows the same with a comparison to the 2016 prototype.

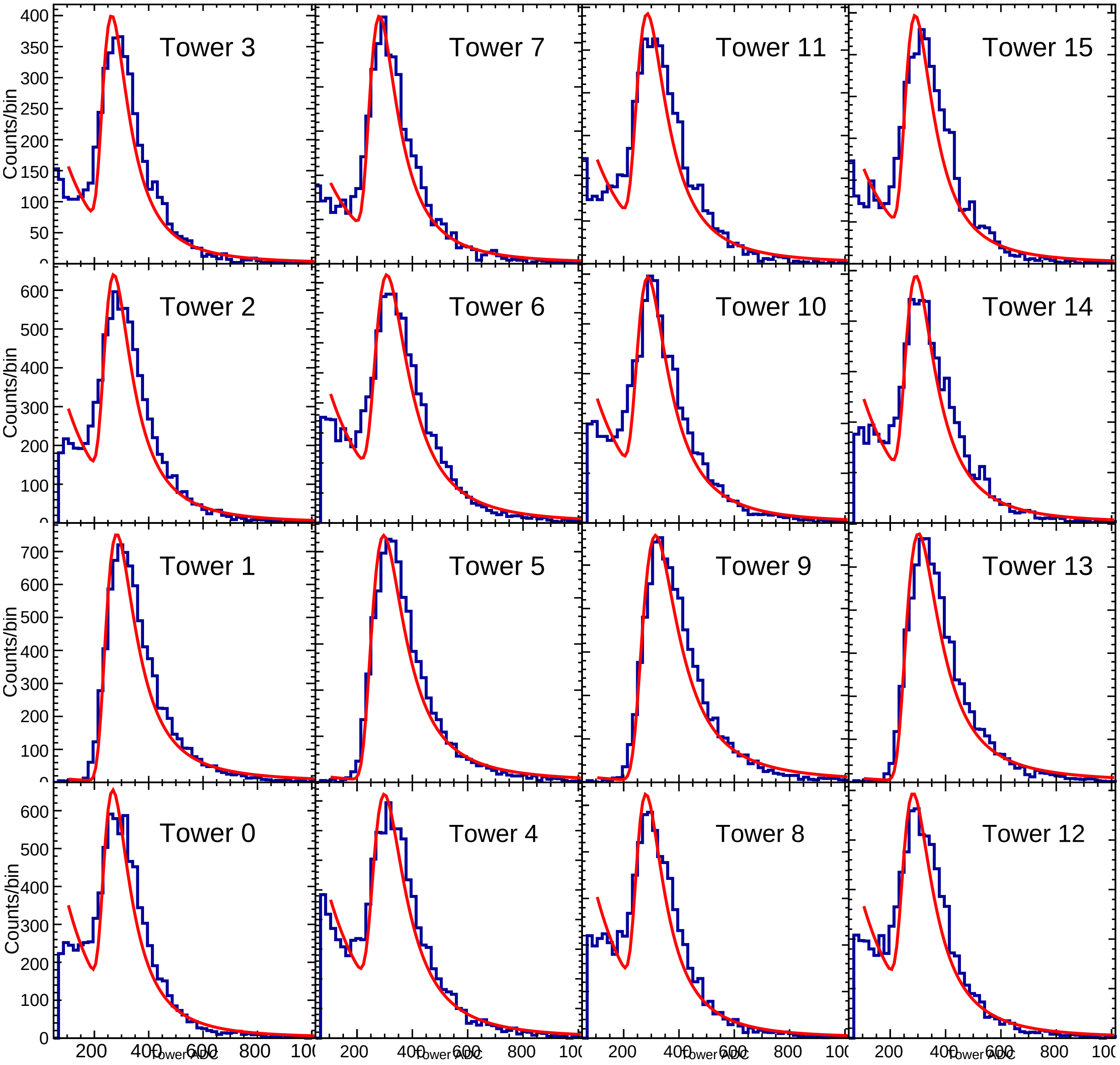

Figure 5: Tower by tower ADC distributions from cosmics for the outer HCal.

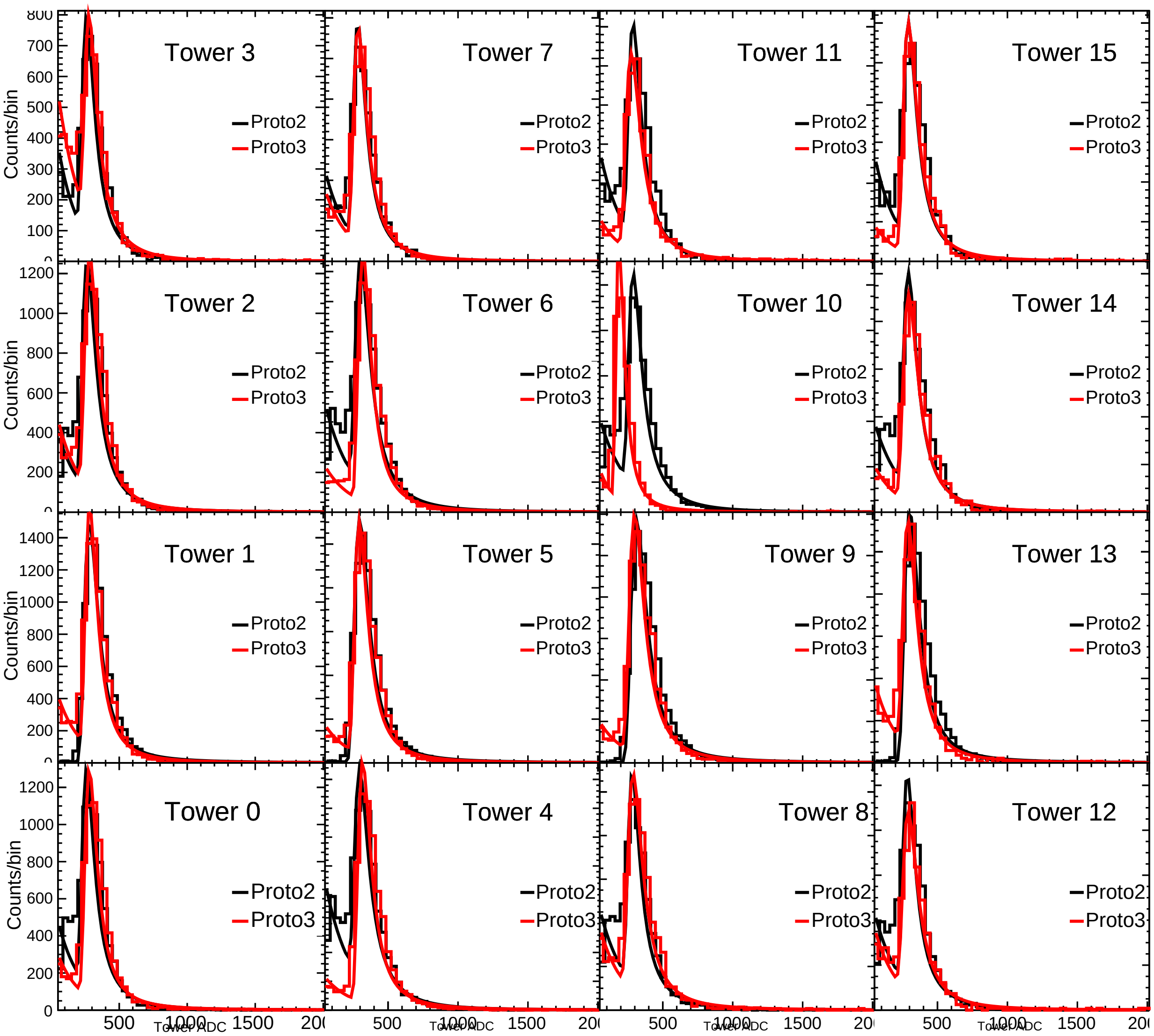

Figure 6: Tower by tower ADC distributions from cosmics for the outer HCal and a comparison to the 2016 prototype.

5.2 1d energy distributions

Figure 7 shows a comparison of the 1-dimensional energy distribution of π^- in data (black points) and simulations (solid green). Figure 8 shows the same for π^+. Currently available simulation data does not cover the entire range of energies measured at the beam test.

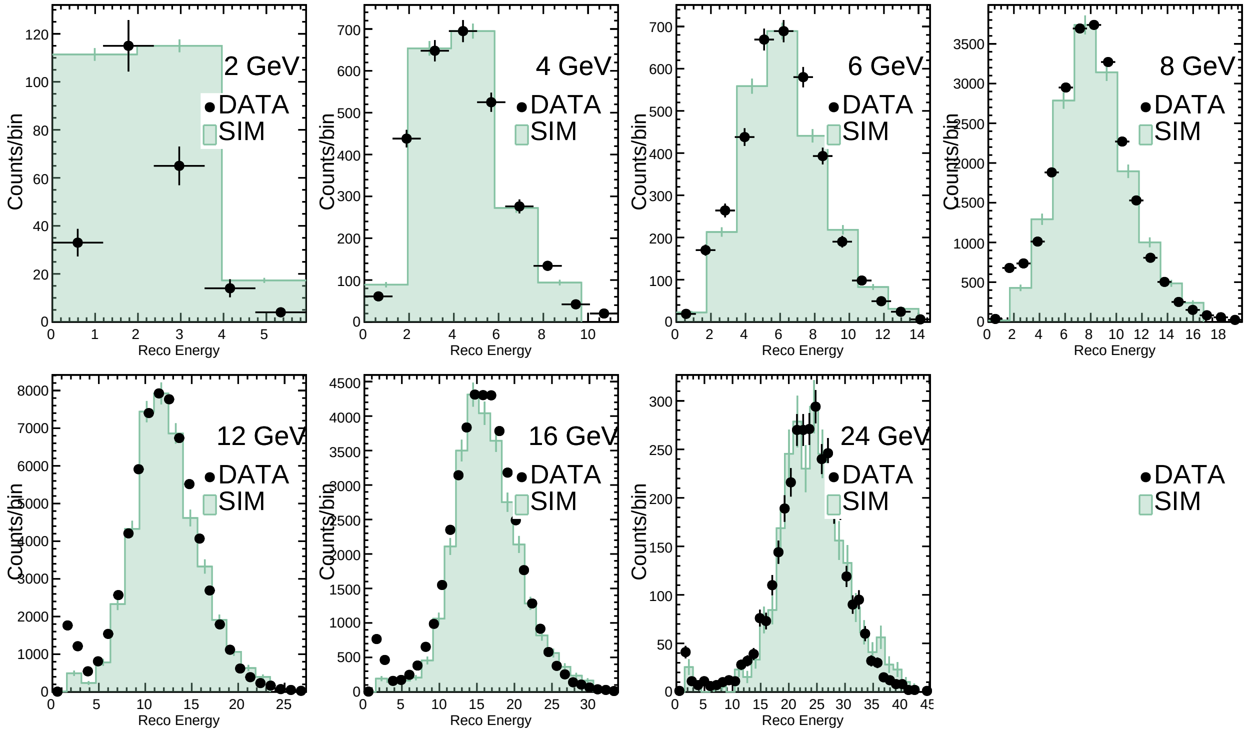

Figure 7: 1d energy distributions for π^- and comparison to simulations.

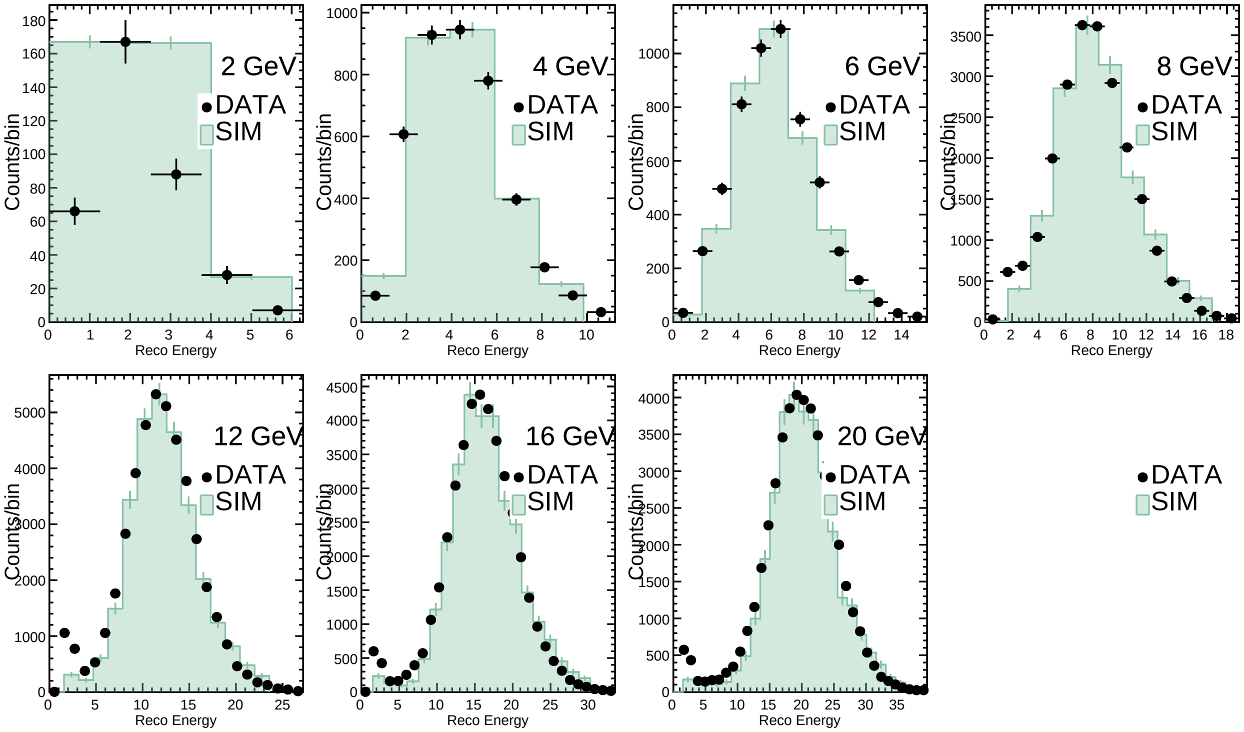

Figure 8: 1d energy distributions for π^+ and comparison to simulations.

5.3 Standalone HCal

Figure 9 shows the energy resolution for the combined inner+outer HCal.

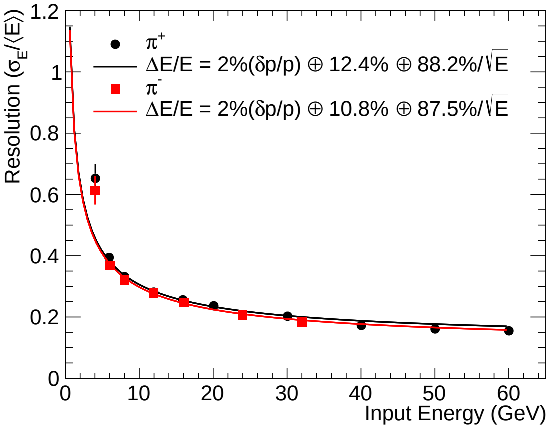

Figure 9: Energy resolution $\Delta E/E$ for the HCal (inner+outer).

Figure 10 shows the energy resolution for the combined inner+outer HCal.

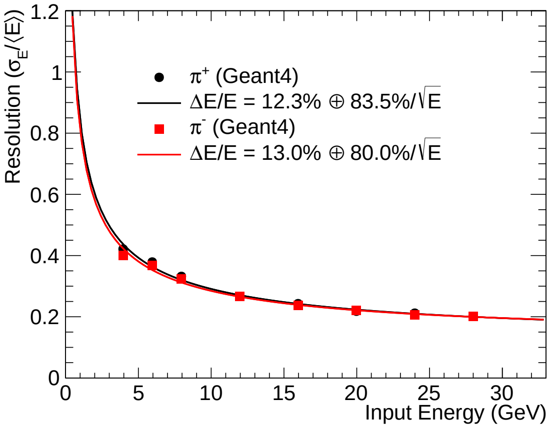

Figure 10: Energy resolution $\Delta E/E$ for the HCal (inner+outer) in simulations.

The energy resolution in the data for positive pions is 12.4% constant term (detector quality) and 88.2% stochastic term (energy sampling). For negative pions the values are 10.8% constant and 87.5% stochastic. This performance is similar to but not quite as good as the simulation performance numbers of 12.3% constant and 83.5% stochastic for postive pions and 13.0% constant and 80.0% stochastic for negative pions.

These values are also reasonably comparable to that of the low η beam test from 2016 where the HCal hadron response is found to be 11.8% constant and 81.1% stochastic.

Figure 11 shows the energy linearity for the combined inner+outer HCal.

The response is perfectly linear for energies of 8 GeV and higher. Additionally, the deviation is no worse than 5% for 6 GeV. At the lowest energy of 4 GeV, where performance is expected to be poor, the deviation is 20%.

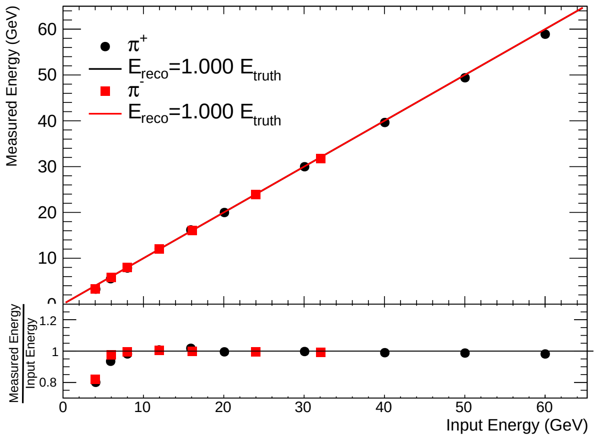

Figure 11: Energy linearity for the HCal (inner+outer).

The linearity is very similar to that found in the low η beam test from 2016.

5.4 Combined calorimeter system

Figure 12 shows the energy resolution for the combined calorimeter system and Figure 13 shows the energy linearity for the combined calorimeter system. The black points indicate that the shower is allowed to develop anywhere in the calorimeter system, indicated in the label as “EMCAL+HCALIN+HCALOUT”. The red points indicate the incoming particle is required to deposit the minimum ionizing radiation in the EMCal and is allowed to shower anywhere in the HCal, indicated in the label as “HCALIN+HCALOUT (EMCAL MIP)”. The blue points indicate the incoming particle is required to deposit the minimum ionizing radiation in both the EMCal and the inner HCal and is allowed to shower only in the outer HCal.

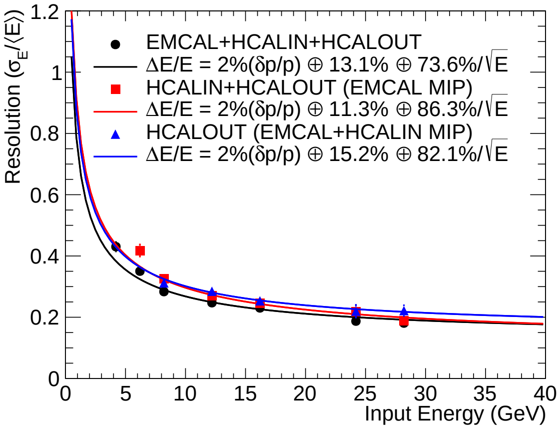

Figure 12: Energy resolution $\Delta E/E$ for the combined calorimeter system.

The energy resolution in the data for hadrons is 13.1% constant term (detector quality) and 73.6% stochastic term (energy sampling). No simulation comparison is available because

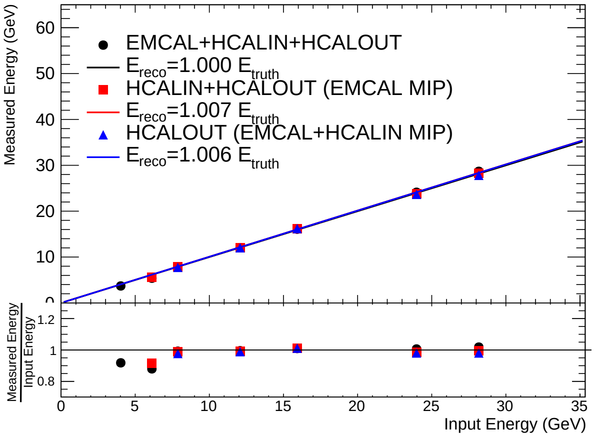

Figure 13: Energy linearity for the combined calorimeter system.

the EMCal performance for the 2017 beam test will not be simulated. The comparison to the full calorimeter system in the 2016 beam test (13.5% constant and 64.9% stochastic) similar detector quality but lower resolution. In both the low and high η prototypes, the best resolution is observed when particles are allowed to shower anywhere in the calorimeter system. When particles are required to shower in the HCal (and "MIP through" the EMCal), a noticeable worsening of the stochastic term occurs.

6 Conclusion

The high η HCal prototypes perform similarly as their low η counterparts from the 2016 beam test [1]. In particular, these prototypes satisfy the sPHENIX specifications and their performance is well reproduced by the simulation.

References

[1] C.A. Aidala et al. Design and beam test results for the sphenix electromagnetic and hadronic calorimeter prototypes. *arXiv:1704.01461*, 2017.