EMC Calibration Procedure for the 2001 run

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Abstract

Calibration of EMC is very important task for any physics analysis. Compared to other STAR detectors, EMC has some special requirements during run time. These requirements are discussed for tower and SMD. In essence we need to have L3 tracks saved on the events and should provide a larger pedestal run for SMD.

1. Overview

STAR Electromagnetic Calorimeter will take data in the 2001 run. With the inclusion of 24 modules (1/5 of the total EMC coverage), the physics capabilities of STAR will increase in many different ways. One of the most important aspects to be covered with EMC is the study of the spin-physics program with pp data. But several new avenues will be opened for AuAu collisions as well when STAR data will be analyzed taking information obtained from EMC into consideration.

In order to acquire the desired quality on EMC physics results it is very important to calibrate the detector properly. The sensitivity and precision of the measurement depends on the way the calibration is done. There are two different aspects of the calibration:

1. **Absolute calibration**: by which the proper correspondence is made between the measured ADC value to the energy deposited in the calorimeter;

2. **Relative calibration**: which we need to adjust the gain parameters between different detecting units (towers or strips) so that the response of the detector becomes uniform.

In a general way, we plan to use any or all of the following methods to make the EMC calibration:

1. **Minimum Ionizing Particle (MIP) response**[1]: this will possibly be the fastest approach we will have after taking the data. This will be based on projecting high

[1]T. M. Cormier, A. I. Pavlinov, M. V. Rykov, V. L. Rykov and K. E. Shestermanov, STAR note 436 (he-pex/0107081), 2001.

p_t tracks (from TPC) and collecting the MIP spectra for towers. The energy deposition of non-showering, high p_t hadrons is approximately constant and provides a convenient calibration reference.

2. **Single electron spectra**: the conversion electrons obtained from downstream conversions can be used to calibrate the detector when the electron momentum is known from the TPC.

3. **Use of π^0 invariant mass spectra**: this will provide us the natural calibration, because the mass of π^0 is known. But this method needs a large number of events to obtain the mass peak, and needs to have uniform response of the detector before generating the mass spectra.

The way we apply these methods for EMC calibration differs from tower (and pre-shower) to shower max detector. In some cases, it is not possible to apply the same method in both detectors. For this reason, the following discussion is made separately for each detector.

2. EMC tower (BEMC) calibration

During the life-time of the STAR EMC project, the calibration issues were under continuous and extensive development. It was determined that, in the long run, the EMC towers' energy scale will eventually come from "direct" calibrations, measuring EMC responses to electron and photon hits themselves, coming from heavy-ion and proton collisions at RHIC. These are conversion electrons of known momenta, measured in the STAR tracking system, known electromagnetically and weakly decayed resonances, such as π^0 -, η^0 -, and J/ψ-mesons, Z^0-boson, etc. However, the "direct" EMC calibrations, using the physical processes above, may require a rather long time (months and years) to obtain sufficient statistics and do the appropriate data analysis to have each tower calibrated in a sufficiently wide energy range. Therefore several "indirect" complimentary methods will be used first to reasonably accurately set the tower gains and obtain the initial calibration constant immediately after a module installation and/or during a few first days or even hours of running RHIC.

During the first weeks EMC will take data, the basic method for calibrating the towers will be based on indirect methods. One of these methods is based on measuring and comparing the EMC towers' responses to the penetrating charged particle (MIP) hits from physics events at the running RHIC.

2.1. Tower calibration using MIP's

The use of MIP spectra for EMC calibration comes from the fact than many charged hadrons will be produced in every collision at RHIC. When striking the EMC, a significant fraction (~30-40%) of high energy charged hadrons do not deposit a large amount of energy via nuclear interactions, instead depositing ~250-350 MeV (the upper

range should be taken for η~1) of electron equivalent energy in the calorimeter due largely to electromagnetic ionization. We call these hadrons as "Minimum Ionizing Particles" (MIP) producing "MIP-hits" in the EMC towers. The calibration procedure using MIP-hits includes basically two stages:

2.1.1. Tower equalization

In the first stage we must equalize all towers in the same η bin. We understand by η bin all EMC towers or strips in a well-defined $\eta \pm \Delta\eta$ region. This equalization means determine the relative gain and shift between towers in the same η bin. Because the tower spectra (for a given trigger) for different towers in the same η should not be different if the detector is working properly, this procedure allows us to get the desired MIP statistics with less events because it is possible to add the statistics of all towers in the same η. For example, for the 24 modules already installed, a η bin width of 0.1 corresponds to 96 towers which means almost 100 less events to get the same MIP statistics if the calibration is done tower by tower.

The equalization method must find a relative gain (A) and a relative shift (B) in such a way that the ADC value in one spectra corresponds to an ADC value in the other spectra by the relation ADC'=A*ADC+B. The main goal of equalization is to determine the relative gain and shift between two EMC towers.

This can be done using two different methods in the current software:

1. **Mean and RMS** - In this method, the mean and RMS values of the two tower spectra are compared to find the relative gain and shift.

2. **Spectrum fit** - This method consists of fitting one spectrum into another, point by point to find the best combination of relative gain and shift using χ^2 minimization.

2.1.2. MIP Calibration

After the towers are equalized we can accumulate MIP hits for each η bin and, by fitting this MIP spectrum (which has a peak near 250-350 MeV of electron equivalent energy) and knowing the equalization constants, we can calculate the absolute calibration constants for each tower. To be accepted as a valid MIP for calibration, the track candidate should satisfy the following conditions

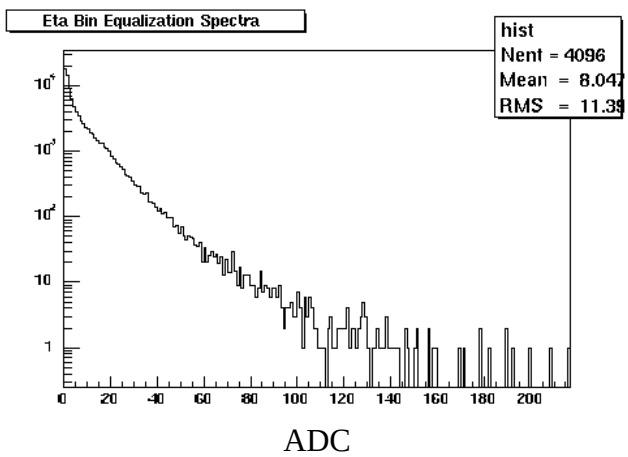
1. The momentum of the track must be above a given threshold (usually 1-1.5 GeV/c)
2. The projection of the track in the inner and outer EMC radius must be in the same tower.
3. All adjacent towers shall not have any projected tracks.

Figure 1 shows a typical η bin spectrum before (figure 1-a) and after (figure 1-b) the tracks cuts. It is possible to notice that the MIP peak becomes evident after the cuts.

After acquiring a satisfactory statistics for MIP tracks in each η bin, a gaussian + background fit is done and the position of the MIP peak is determined. Figure 2 shows a typical MIP spectrum. The continuous line is a fit of the MIP peak from which we can calculate the absolute calibration constants. In figure 3 it is shown the effect of MIP calibration in the reconstructed hit energy. It is plotted the calibrated hit energy versus the hit energy obtained from simulation for minimum bias AuAu event. The calibration constants were obtained using about 2800 minimum bias events, but the full detector (120 modules) was used to acquire the desired MIP statistics. In the first year, as we will have only 24 modules installed (less that 10 instrumented in the very beginning of the run), a larger number of events will be necessary to have a good set of calibration constants (see next section).

The calibration software based on MIP peak fit has been developed and will provide a good set of calibration constants in the first few days of EMC running. The calibration constants are loaded into STAR database to be used by the makers in the reconstruction chain.

(a)



(b)

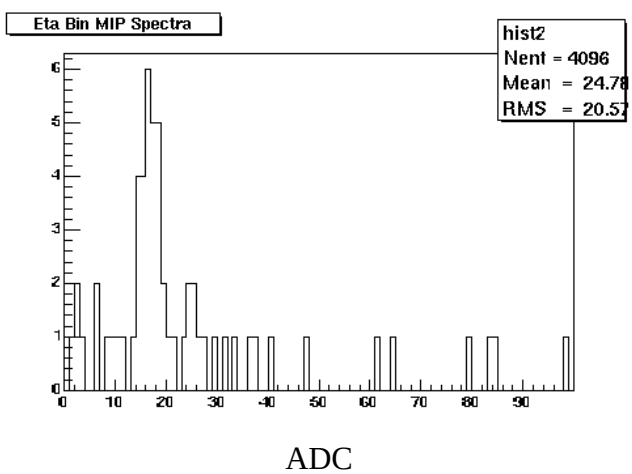


Figure 1 – Typical η bin spectrum before (a) and after (b) the tracks cuts.

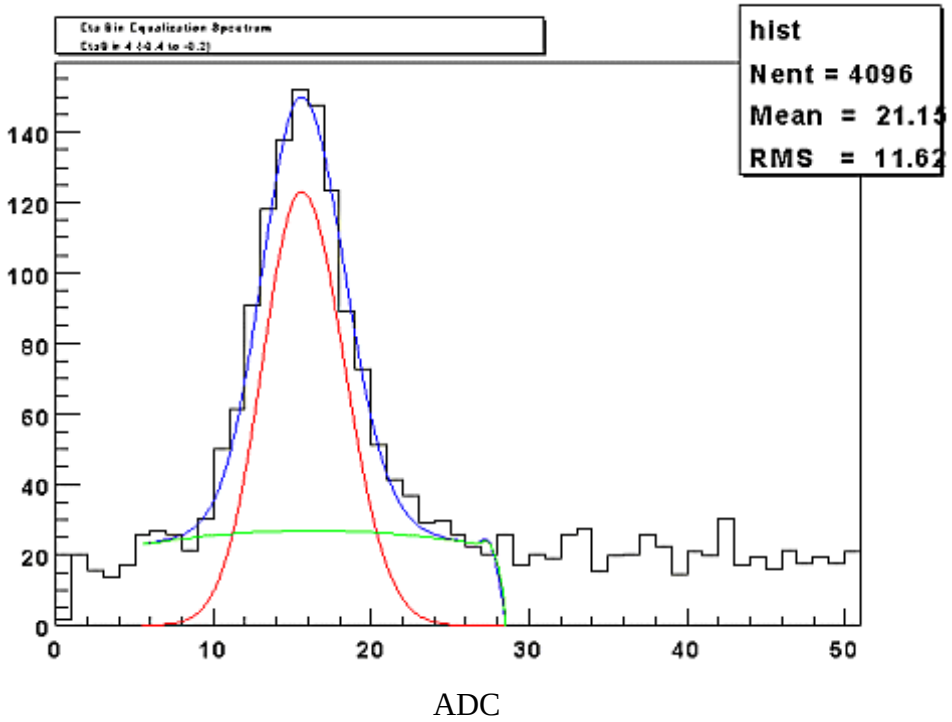


Figure 2 – Typical MIP peak. The continuous line is a gaussian + background fit

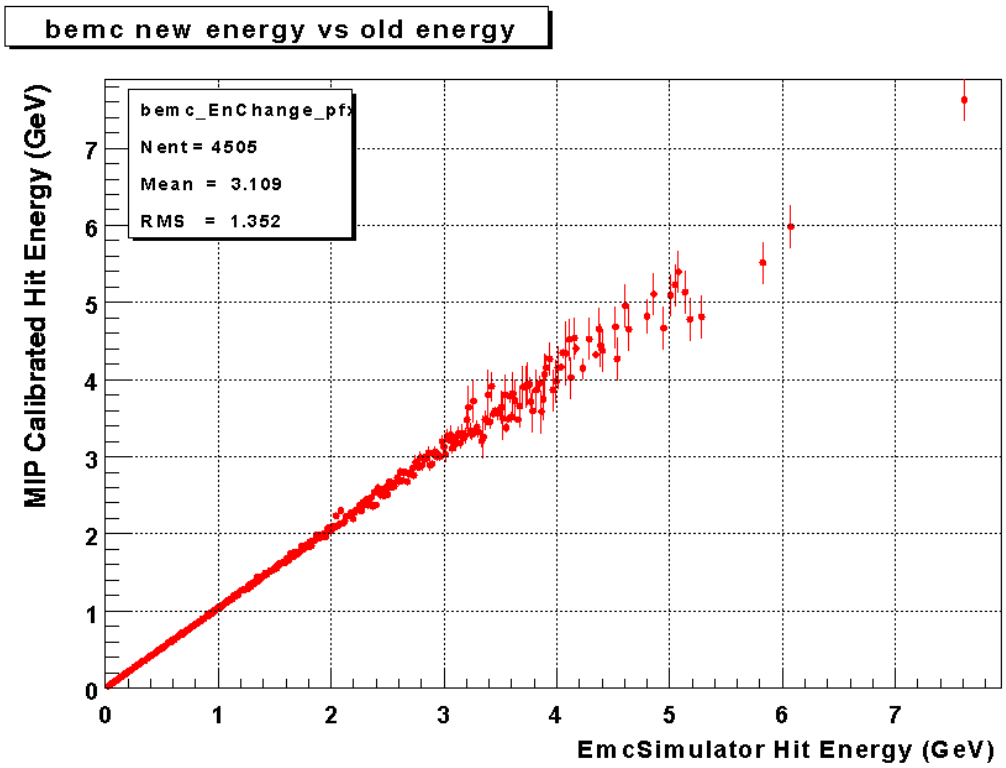


Figure 3 – Effect of MIP calibration on reconstructed hit energy.

2.2. MIP Calibration requirements

It is very difficult to establish the exact needs for tower calibration only from simulation because it is not possible to know the exact response of the detector without data. However, from simulation it is possible to estimate the amount of data and time required to calibrate the detector.

Two aspects affect the final calibration numbers: the number of hits in each tower spectrum used for the η bin equalization and the MIP peak statistics. In a general way, it is much faster to acquire the desired equalization statistics than the MIP one because the equalization procedure is done using the tower spectra without any constraint, except a multiplicity and vertex position cuts. Table 1 shows the number of minimum bias events that is needed to acquire a desired MIP statistics as a function of the MIP momentum cut and the η bin width.

p_{MIP} GeV/c	$\Delta\eta$	Hits/channel equalization	MIPS/etabin	Number of minimum bias events needed to acquire the MIP statistics	Number of Events to Equalize SMD (see next section)
1.00	0.2	~2000	~500	6.5K	30K
1.25*	0.2	~3000	~500	10K	45K
1.50	0.2	~4500	~1000	30K	68K
1.25**	0.1	~6000	~1000	40K	90K

Table 1 – Estimated amount of minimum bias events to get a set of calibration constants.
* Configuration used for EMC monitoring.
** "Minimum" requirement for a set of calibration constants for physics purposes

The above table allows us to estimate the running time required to accumulate the required events. Equally important, however, is the time the software spends to process those events. To have a set of calibration constants every one or two days and to use the calibration as a tool to monitor the performance and stability of EMC, it is necessary to process the events needed in a reasonable time. The calibration software can process 2-3 events per second on average. This time depends basically on the number of MIP candidates we have in each event and increases with the multiplicity. Considering this number, to have 40K minimum bias events processed (which will give a good statistics to get a set of calibration constants that could be used for physics purposes) the calibration software will need approximately 3-5 hours of cpu time.

As shown in the previous section, the MIP method is strongly dependent on the reconstructed tracks. To have a MIP candidate, some track cuts are applied to the data. For this reason, the biggest problem for EMC calibration and monitoring is the time spent to reconstruct the TPC event. It is known that the year-1 reconstruction software (basically TPC reconstruction) takes about 75 seconds/cpu (on average) to reconstruct a minimum bias event on RCF. To reconstruct 40 K events it takes about 1-2 days if the reconstruction job is spread over the RCF cpu's. This is almost the same rate that the event pool can provide us. But to wait for the offline reconstruction has some

inconveniences. First, the offline production is always delayed from the moment the data is taken. This delay avoids us to use the MIP calibration as an EMC monitoring tool. Second, to wait for offline reconstruction to have EMC calibrated will make necessary to reconstruct all events again to include EMC offline reconstruction with calibrated hits, what could delay the EMC physics analysis.

To control this limitation, the STAR Level-3 tracking capability should be explored. There are a few different ways to combine the EMC calibration software with the L3-tracks that could increase the EMC calibration/monitoring performance:

1. **Taking data from event pool** – This method will provide us about 10-20K events per day only. This method will be good enough if we would like to use the MIP calibration as an online monitoring of the detector, which will be very important until we characterize the detector response and stability properly. In this case, the factor that limits the calibration software will be the amount of events that could be saved on event pool. **To use this method within the calibration requirements we should be sure that the L3 tracks are saved on event pool.**

2. **Processing the daq files directly** – This method could provide us a lot of events daily but we should be capable to process these events fast. **To use this method, we must be sure that the L3 tracks are saved on daq files.** If so, the factors that limit the calibration software will be the IO and the time needed for calibration software to process each event but it will be possible to process about 40K/day, which matches our needs. To use this method, we should be able to run a dedicated chain in rcf. If this is available we will also run our electron finder software in this chain to accumulate conversion electrons for calibration.

3. **Running the calibration software as a L3 algorithm** – This method could increase the EMC calibration capability because L3 can process minimum bias events as fast as 100 Hz. But, to implement this method, a lot of development on calibration software should be made to make it faster, less memory consuming and less dependent on root libraries. This option is not available at the moment.

2.3 – Towers' pedestals

To calibrate properly the EMC towers using MIP's it is extremely important to measure correctly the towers' pedestal. A small shift in the MIP peak position because of an incorrect pedestal subtraction could result in a large systematic error on calibration constants because the MIP peak is very close to the beginning of the tower spectrum. There will be basically two pedestal values to be considered in the MIP calibration:

1. **Electronic pedestal** – this is the pedestal that comes from any residual DC level and residual noise in the electronic chain. This pedestal should not be dependent on the event type used for calibration and will be measured in the standard pedestal run which all others STAR sub detectors are included.

2. **Effective pedestal** – this pedestal will be used basically to correct the MIP peak position. The main origin of this pedestal comes from all the neutral particles that hit the tower which signal could not be suppressed on the MIP tracks cuts. This effective pedestal is also generated from all the leakage from neighbor towers. This leakage is minimized in the tracks cuts because it is required that there are no tracks in all neighbor towers to have a track accepted as a valid MIP. But, even in this case, it is not possible to subtract all leakage. This pedestal is strongly dependent on the event multiplicity and will be calculated basically while the calibration software is running. If it is used low multiplicity events to acquire the MIP spectra the effect of neutral change background and leakage should be very small.

To have the contribution of the pedestal errors negligible compared to other systematic errors, which would be, at best, about 1-2%, we must measure the pedestals at the better accuracy, for example 0.5% from the MIP-peak position. If the MIP-peak position is around the 15th ADC channel, the pedestal must be known with a precision of ~0.07-0.1 ADC count. If the pedestal width (noise) is σ ADC counts, then the statistics it should be accumulated to calculate the pedestal mean value should be greater than $(\sigma / 0.07)^2$. Supposing that the pedestal noise is about 2 ADC counts, it will be necessary to have 1000 events to proper characterize the tower pedestal.

3. Shower Max Detector (SMD) Calibration

Each EMC module is equipped with two layer shower max detectors. These are gas proportional chambers with 2-D readout. The granularity of each layer is 10 times higher than the towers.

Due to different detection system (gas instead of PMT based scintillator) and higher granularity, SMD detector needs separate attention than tower. We are therefore trying to list the requirements for SMD separately.

The processing steps which needs to be performed on SMD data can be categorized as follows:

3.1 - Equalization

Each of the amplifiers associated to the strips is to be calibrated, so that they give uniform response. This equalization involves calibrating the electronics chain and does not involve the non-uniformity of the strips on the detector.

Injecting test pulses into the electronics chain and then recording the data will be performed in this step. We will then have processing software, which will obtain the equalization numbers for all strips.

This step will be taken at the beginning of SMD power up and will possibly be repeated every 24 hours at the beginning and then, when the system stabilizes, we will probably not need to perform this step frequently.

3.2 - SMD Pedestals

This is a special issue for SMD. As SMD electronics is a modified version of SVT electronics, each strip is associated to a cyclic buffer of 128 capacitors. Unlike SVT, only one of these capacitors will have a signal to be stored as valid data. But, the capacitor of interest will be different for different events. It is therefore necessary to store pedestals for all 128 capacitors, so that we can subtract the right one.

This leads us to a situation where we will need 128 times more events than SVT to get pedestal for all 128 capacitors.

It is therefore necessary to decide how the pedestal job for SMD will be done. Estimate from current pedestal runs (where TPC, SVT, FTPC, RICH, TOPp are on) takes about 3 minutes per run. This time includes the time needed to calculate and save the pedestals on RCF. But, most of this time is necessary to read all TPC, SVT and FTPC channels. SMD can read events as fast as 100 Hz, so the time needed to get all 12800 events (128 x 100 events/strip) will not increase a lot the pedestal run.

3.3 - η–dependence correction

SMD is located at 5 X_0 when taken at η=0, and the material in front of SMD increases as we go higher in η. For the particles not depositing full energy before SMD will therefore deposit different amount of energy in different η regions. This variation is η and energy dependent. From the estimate of the material in front of SMD we can perform simulation to estimate this effect. But it is necessary to have some estimator to compare this simulation. We can perform this with identified electrons at different locations of SMD. But this requires extremely large number of events if we want to perform this with data.

We can however estimate averaged material dependent variation by taking ‘total energy deposited’ in every η bin for central events. The variation in the mean of this spectrum will give us this estimation. This variation depends on the η–dependence of the energy spectra of the particles. From test data is has been shown that this dependence is almost flat with the energy.

We will have detailed simulated numbers on these effects and will be compared after taking data. Again, we do not need to perform this quite frequently.

3.4 – Strip by strip variation

SMD strips are fabricated and tested to be within 10% variation level in uniformity. But we also need to have a measurement of this uniformity from the data. We plan to adopt a procedure similar to the one used in the case of tower equalization.

We will accumulate the ADC histograms for each strip from central events. With enough accumulated statistics, we will obtain the mean, RMS and 'number of entries/event' for each strip. Out of all three numbers most important are the mean and 'number of entries/event'. As discussed earlier, due to material dependent gain variation in SMD, we need to compare these strips for uniformity in particular η bin. These numbers together will give the variation in efficiency and gain for each strip. In table 1 we have added one column for SMD as the requirement of the number of events to perform this equalization.