# A Pre-beam Calibration Plan

# for the

# STAR EEMC

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# 1 Goals of the EEMC Calibration Program

The calibration and monitoring systems of the STAR EEMC must provide the following capabilities:

1. The gains of the individual EEMC towers, and the effective gains of the SMD scintillating strips, must be known to $\pm 10\%$ and matched to $\pm 20\%$, respectively, prior to commissioning with beam at RHIC.

2. For diagnostic purposes, the response (gain stability) of each component of the EEMC, at the single tile or strip level, should be measurable online, without requiring access to the detector.

3. The absolute energy calibration of each tower (SMD strip) must ultimately be determined in offline analysis at the level of $\pm 2\%$ ($\pm 10\%$), and the stability of these calibrations must be monitored to the same level of precision.

4. In addition, the systems should provide a secondary level of quality control on the assembled megatiles, including the response of the scribed fiber.

The primary emphasis in this report will be on item 1 above: development of a scheme for pre-calibration of the EEMC towers and ESMD strips to the needed level of precision, and a program of how to implement this scheme. This is discussed in Sect. 3. The diagnostic functions of the various systems (item 2) should become clear from the short descriptions of these systems presented in Sect. 2 below. The final energy calibrations, derived largely from offline reconstruction of meson invariant masses, will not be discussed here. Also, the role played by the scribed fibers in providing additional information on the performance of the assembled megatiles will be presented at the Review, and only referenced here.

# 2 EEMC Calibration Subsystems

## 2.1 Pulsed UV laser and 'leaky' fibers

The most comprehensive monitoring system for the endcap calorimeter is based on an externally triggerable, pulsed UV laser that will be used to inject light directly into every scintillating tile of all 720 calorimeter towers. Following a three-tiered distribution network, the UV pulses will be delivered to the tiles via "leaky" (scribed) UV-transparent optical fibers, running radially inward through the fiber-routing layer (FRL) adjacent to each megatile scintillator. This system will provide nearly complete monitoring of the entire optical chain for the towers and the pre-/post-shower layers; the only process not tested in this scheme is the actual showering and ionization of charged particles within the scintillator.

The 15 mJ Nd:YAG laser (New Wave Research) is tuned to operate at its third harmonic of 355 nm, in the near UV. A remotely adjustable attenuator, mounted within the primary laser housing, has been empirically calibrated over three orders of magnitude, and will enable us to perform linearity checks of the tower light collection, digitization, and readout over the entire dynamic range of interest. A special diffraction grating will send a small, but constant fraction of the primary laser light into a PMT that also views an $\alpha$ source embedded in scintillator, for long-term monitoring of the laser output intensity.

A series of 7 partially-reflecting mirrors will divide the light into 8 beams of roughly equal intensity, each of which is then focused down into 600-$\mu$m silica core fibers for transport to the

back of the STAR poletip. At the entrance to each fiber, though, a variable neutral density filter will allow us to 'dial in' the intensity desired for each of these 8 beams; this is a crucial feature for the diagnostic role of this system. On the poletip, the light emerging from each quartz fiber is divided 7 ways using a transmission splitter, with the output light collected into 2-mm clear fibers, one of which goes to a PIN diode. The relative intensities recorded with these diodes provide a check on our primary splitting with the neutral density filters. Finally, the 6 remaining output fibers from each transmission splitter are routed to different 60° sectors on the poletip, where each is now split 37 ways. 30 of the 1-mm clear output fibers will carry light to 'leaky' fibers, while three will be used for a third level of monitoring, leaving four fibers for spares. What is perhaps not obvious from this description is that the proposed network will not only provide the $8 \times 6 \times 30 = 1440$ light pulses required for the megatiles, but will do so in a way that allows us to illuminate, via adjustment of the neutral density filters, *only a selected set of layers (tiles) within the EEMC towers*, a powerful and unique (short of disconnecting fibers) diagnostic tool.

The status of this system, and in particular the extensive development work that was required to fabricate large numbers of scribed fibers that could meet our specifications on output light intensity and uniformity, are discussed in more detail in the set of enclosed EEMC Quarterly Reports.

### 2.2 Radioactive sources

In order to transfer absolute calibration information (obtained using cosmic ray muons or beam tests) from one configuration of the detector to another, a radioactive source will be used to inject $\sim 1$ MeV $\gamma$-rays into all SMD strips and into tower layers that are near the SMD in depth. A 300 $\mu$Ci $^{60}$Co source, enclosed in a sealed capsule (Isotope Products Lab, model 3814) and mounted on the end of a 2-m long, 1/8″diameter rod, will be slowly moved along one of 60 grooves machined radially through the passive spacer layers within the SMD. As the source is scanned through the groove, currents from the PMT's of nearby SMD strips and towers will be integrated over 10–20 ms intervals, digitized, and read out. Designs now exist for the grooves and the tube each will contain (which is non-trivial, as the tubes must be removable and also pass through the light-tight skin), and for the motorized driver, mounted to the EEMC front plate, that will move the source through this tube. The electronics required for this slow-integration, 'current-mode' read-out of the EEMC will be incorporated into the standard FEE cards to be used for all SMD strips, but a stand-alone DAQ system will be needed for the 12 towers that surround the groove being scanned. Note that the source system can only be used when the endcap calorimeter (and hence poletip) is physically separated from the main body of the STAR detector.

Because we are limited to a single 300-$\mu$Ci radioactive source by Brookhaven safety standards, it was important to verify that the time-averaged anode currents expected from our MAPMT's, when carrying out the calibration procedures described above, would be easily detectable above the allowed level of dark current. We therefore used a Hamamatsu H6568 16-channel MAPMT to detect light from a single SMD scintillator strip illuminated by a 2-mCi $^{60}$Co source placed 20 cm away and collimated to a 3-cm aperture at the strip. When shielded from the source, an average anode current of 41 pA was recorded (the MAPMT's are spec'd to have dark currents below 500 pA per channel), while exposure to the source resulted in an average current of 6.4 nA, in close agreement with our estimate of $\sim 5$ nA for our planned configuration. Thus, with the system described above, we believe we can obtain (DC) currents due to the source that are at least an order of magnitude larger than the maximum dark currents expected. Moreover, because the output currents will also be measured before and after the source illuminates the specific tower or strip of interest, the dark currents will be accurately determined for subtraction.

### 2.3 LED pulsers and 'clasps' for the ESMD

To monitor the complete optical chain from each SMD strip, and thereby provide a diagnostic tool for the strips analogous to that supplied by the laser system for the calorimeter towers, a network of blue LED's will inject light into the SMD WLS fibers immediately after they leave the scintillator. To do this, small lucite clasps will encase 8 or 12 fibers (depending on the type of connector) just before the fibers go into the edge connectors. A single 1-mm optical fiber will carry the LED light into the clasp. Tests of this scheme have been carried out at Kent State, to gauge the efficiency of light transfer and the uniformity of illumination among the 8 or 12 fibers. While obtaining sufficient light proved to be quite easy, uniform illumination of the enclosed fibers was only achieved through a combination of painting the entire exterior of the clasp with $TiO_2$ paint, to provide diffuse reflection, and painting a black, triangular pattern on the interior surface between the input and receiving fibers, to block 'no bounce' light transmission. This last point was crucial, and yielded $\pm 20\%$ uniformity among all fibers, an acceptable level of variation. All components of this system are now in production, other than triggering and controls.

### 2.4 Other systems

Two additional calibration tools will be used on the Endcap EMC, both of which are presently being installed on the Barrel EMC, and so will be mentioned only briefly. A set of individually triggerable LED's will send light directly into the mixers for each of the 720 tower PMT's, and into a single pixel for each of the pre- and post-shower MAPMT's. These will be used primarily to monitor the short and long term gain stability of each tube. Also, a DAC-controlled current source will inject charge into the integrator circuit in the front-end electronics for all tower channels. This allows linearity and diagnostic checks to be performed on the signal shaping, digitization, and readout electronics beyond the PMT's.

## 3 EEMC Pre-beam Calibration

### 3.1 Goals and limitations

As discussed in the EEMC Requirements Document, achieving the physics goals of the STAR spin program requires that absolute shower energies can be determined from calorimeter pulse height information to the $\pm 2\%$ level. The ultimate calibrations will be derived offline based on data taken *in situ* at STAR, by reproducing the known invariant masses of $\pi^0$, $\rho^\pm$ and $Z^0$ from detected decay daughters. However, matching all tower gains to $\pm 10\%$ *before* taking beam is crucial, in order to ensure that all processes of interest lie within the dynamic range of the readout electronics, and to avoid domination/biasing of trigger rates by (a few) high-gain channels. Since the SMD and pre-/post-shower layers of the calorimeter are not (presently) included in the trigger logic, it is not essential to match the gains of different channels to quite this precision. However, one must still match the relative gains to the $\pm 20\%$ level in each case, in order to fit within the dynamic range of the 10-bit ADC's, and to ensure that $\gamma/\pi^0$ and electron/hadron discrimination can be achieved at the needed level.

For our 'pre-beam' calibration strategy, we have assumed that we must operate within the following constraints:

- Statistically useful cosmic ray (muon) data can be collected in the EEMC towers only when the detector is mounted horizontally.

- Cosmic ray data, taken with trigger scintillators and wire chambers for tracking, can only be collected for a single 30° sector at a time.
- Given the above, there will not be sufficient time at BNL for cosmic ray measurements on all sectors of the EEMC.
- It will not be possible to expose the EEMC – or even a 30° sector of it – to test beam at, for example, the FFTB facility at SLAC, but the EEMC prototype detector, suitably modified, could be used.

### 3.2 Calibration equipment and procedures

With these factors in mind, we intend to construct a cosmic-ray test stand, to be used at IUCF, which will be capable of reading out all the detectors in a single 30° sector of the EEMC, *i.e.*, 60 calorimeter towers, associated pre- and post-shower layers, and the close to 600 scintillator strips that comprise two planes of the SMD. For each of these, readout can proceed in a 'pulse' mode, with integration times (ADC gate widths) comparable to those to be used at STAR, or in 'current' mode, where integration times will be on the order of 10 ms. Measurements will take place with the detectors mounted in a mechanically complete EEMC structure, consisting of the backplate and hub, a full set of radiators, and the aluminum frontplate, lying horizontally. In addition to the readout electronics mentioned above, parallel planes of thin scintillator (for triggering and timing) and $x$-$y$ multiwire proportional chambers (for particle tracking) will be fully instrumented. The radioactive source system described in Sect. 2 will be available, and the pulsed UV laser, with a somewhat simplified distribution network, will be optically connected to the full complement of (120) leaky fibers and to the final $3^{rd}$-level monitor detectors.

In broad strokes, we envision the pre-beam calibration involving the following steps: the absolute scale will be set by cosmic rays, measured while the detector is horizontal; this calibration will be transferred to higher energies by means of the laser system, and will be transferred from IUCF to Brookhaven (different detector orientation, different PMT's) by means of the $^{60}$Co source system. The validity of this scheme will be checked using cosmic rays measured in a vertical orientation (for a subset of the towers), and, if possible, verified with SLAC test beams for the EEMC prototype. In more detail, the absolute calibration sequence for each 30° sector would proceed as follows for the tower calibration:

1. Operating in pulse mode, the response of each tower to cosmic ray muons will be recorded. Adjust PMT HV's to match gains of all towers.
2. Set laser intensity to approximately match the cosmic-ray peaks. This provides a cross-calibration between the MIP response and the laser monitor for each tower.
3. Increase laser intensity by calibrated factors, to check the linearity of tower responses over the full dynamic range of the readout electronics.
4. With the above complete (~2–3 days), switch all SMD FEE cards to run in current-mode. Re-route the PMT anode signals from the 12 towers in one 6° sector to a separate DAQ system, also operating in current mode.
5. Perform a source scan of this 6° sector, noting the peak current from each tower as the source passes by. Repeat for remaining sectors, to calibrate the (integrated) energy deposition from the source in units of MIP equivalent.

6. Disassemble megatiles from the 30° sector and prepare for shipment to BNL.

7. At BNL, reassemble EEMC, checking integrity of towers, fibers, PMT's, and connections to readout electronics using full arsenal of diagnostic tools: DAC charge injection in FEE cards, LED pulses to tower PMT's, laser pulses to subsets of tower layers.

8. With EEMC in final configuration (vertical) on the poletip, repeat source scans, adjusting PMT HV to achieve same peak current for each tower as was obtained at IUCF.

9. Repeat linearity checks with UV laser, compare to laser monitor normalization, resolve discrepancies.

10. For lowest portion of lower half ($\eta$=1 edge near 6 o'clock), compare locations of cosmic ray peaks to those obtained at IUCF, to verify overall consistency of calibration chain.

For pre-beam calibration of the SMD strips, the philosophy is much the same: the source scans, carried out simultaneously for the strips and towers, should provide a very reproducible, if somewhat arbitrary (from groove to groove, and certainly from plane to plane) peak current amplitude, which can be used to account for differences in clear fiber runs and MAPMT pixel gains between a test setup at IUCF and the final deployment at BNL, and thus be used to transfer the absolute response to cosmic ray muons measured at IUCF. The linearity checks will be performed using the LED clasps, rather than the laser, so the steps will be more poorly calibrated, but a 'boot-strapping' technique developed by D0 for their forward pre-shower detector may be possible. A second difference in technique is that, after setting the MAPMT high voltages to achieve an acceptable average response, strip-to-strip gain variations within a MAPMT will be corrected for by adjusting the conversion gain factor in the integration process on the FEE cards.

For the pre- and post-shower tiles (layers 1, 2, and 24), the source scans will provide essentially no useful information. In this case, we will rely on our ability to send UV light pulses from the laser to just these specialized tiles, once the tower gain-matching is complete. The laser will enable us to obtain direct measurements of the *ratio* of the light output from the two fibers exiting each tile. After installation and precalibration of the EEMC towers at BNL, the pre- and post-shower FEE gains can be set to restore these same ratios.

### 3.3 Procedure checks and fall-back options

As a check that the above procedure has worked, we plan to take limited cosmic ray data at BNL. This should be most useful for those towers whose projection is closest to vertical, but without tracking, we expect little useful information for most towers and for the SMD strips. A more ambitious test of this scheme would involve retrofitting the existing EEMC prototype detector with an SMD spacer layer capable of accommodating a source tube, going through steps 1–6 above, and then reassembling the detector at a test beam facility. Unfortunately, even this modification would not allow for use of the laser, so linearity checks and transfer of the low-energy MIP peak to a more suitable mid- to high-energy regime would not be possible. Construction of a completely new prototype, more similar in design to a true subsection of the current EEMC, is not currently being considered.

Finally, we note that it is highly probable that the lower half EEMC mechanical structure — an integral part of the proposed calibration procedures — will need to be transported to BNL before all of the megatiles for the half have been fabricated and individually tested. To minimize

the consequences of this for pre-beam calibration (and to maximize the usefulness during data-taking of a less-than-complete EEMC, if this becomes necessary), our plan is to fill the detector with megatiles sector-by-sector, rather than layer-by-layer, so that, for example, four of the six 30° sectors might be calibrated following this scheme. Choosing an optimal fall-back procedure obviously depends on knowing many factors that will not be measurable for several months, and on the precise way that various production timelines play out, but several options are being considered:

- Assuming the response of any tower to the source scan is determined primarily by details of the specific source tube and spacer layer geometry, a complete set (entire 30° sector) of megatiles could be moved from sector to sector within the EEMC structure. This would cross-calibrate the MIP response of a 'typical' tower to that of a source scan performed in that sector. By loading (at a later date) a set of uncalibrated megatiles into that sector and adjusting PMT HV's to reproduce the results of the source scan data taken earlier, one should be close to matching the MIP response to that of the calibrated towers.

- If a whole sector of megatiles will not be completed in time for installation prior to the FY2003 run, the megatiles could remain at IUCF until the mechanical structure for the EEMC *upper* half was finished. Using a sector in this structure whose geometry matches that of their eventual home, the towers could be calibrated following the procedure outlined above, then transferred to BNL for installation and source scanning at the next convenient opportunity.

- Because the response, in photoelectrons per MIP, of each tile in a tower, and the gain of each PMT as a function of voltage, can be measured, one could in principle determine the appropriate HV setting for any given tower, neglecting variations from smaller effects such as clear fiber runs, etc. To estimate the error in such a procedure, this could be done for a set of calibrated towers; if the results are reasonable, the same procedure could be applied to the uncalibrated towers as well.