PHENIX Electromagnetic Calorimeter (EMCal) – Detector Basics

Gabor David
Stony Brook University, Brookhaven National Laboratory

Purpose, technology, dimensions

The primary goal of the EMCal is to identify photons and electrons and measure their energy and position of impact on the surface of the EMCal. It is also used to confirm charged tracks and contributes to particle identification (PID). The EMCal is built with two different technologies: 3/4 is lead-scintillator (PbSc) sandwich sampling calorimeter, 1/4 is lead glass (PbGl) homogenous Cherenkov radiator. The two subdetectors have different response characteristics. Before analyzing EMCal data get familiar with [1], the authoritative NIM paper.

The smallest units, read out individually, are called *towers*. PbSc towers are 5.5*5.5cm^2 laterally, and 37.5cm deep. PbGl towers are 4*4cm^2 laterally, and 40cm deep, providing finer granularity. Towers are grouped in *supermodules*, consisting of 12*12=144 towers in PbSc, and 6*4=24 towers in PbGl. These are then arranged in *sectors*, the largest single mechanical unit of the EMCal. Sectors are rectangular, approximately 2m high (y coordinate) and 4m long (z coodinate). Six sectors are populated with PbSc (36*72 towers), two sectors with PbGl (48*96 towers). Towers within a sector are identified with integer iy, iz indices, which always start from the bottom left of the sector *when viewed from the collision point*.

The West arm has 4 PbSc sectors, called W0, W1, W2 and W3, with W0 being at the bottom. The East arm also has 4 sectors, with E0 and E1 (the bottom two) being PbGl, while E2 and E3 (top two) are PbSc. Note that in most neutral meson a photon analysis codes a different convention, a single number (0-7) is used to identify the sectors, running around a circle. Therefore, W0 is sector 0, W3 is sector 3, but E3 is sector 4 and E0 is sector 7.

The geometric center of each sector is the closest point to the nominal center of the beam diamond. For PbSc the sensitive part of the detector starts at R=510cm, while for PbGl at R=540cm. Each sector covers approximately $\pi/16$ in azimuth and ± 0.35 in pseudorapidity.

Principle of operation

The EMCal is sufficiently deep to fully stop (absorb all energy of) $\gamma, e^{\pm}$, but most hadrons punch through it with (most the time) only partial energy loss. Comparing the measured energy of a charged particle to its momentum measured by tracking (E/p) is a powerful tool to separate electrons ($E/p \approx 1$) from hadrons ($E/p < 1$). Electrons and photons lose their energy in a laterally compact *shower* (cascade of secondary particles). Lost energy is converted to light, propagated to the far end (back) of the EMCal tower and read out by photomultipliers.

Electromagnetic showers (energy from a single particle) by design extend to several neighboring towers (typicaly 3-15). The offline *clustering* algorithm looks for a contiguous set of towers with non-zero energy with empty towers outside the perimeter. If there is only one single local maximum (in the calibrated tower energies) within such *cluster*, it is assumed that the cluster corresponds to the physical shower from a single particle. In case of multiple local maxima, the algorithm assumes it comes from *overlapping* showers and tries to break up the single contiguous area into several clusters.

For each cluster the energy deposit pattern (energies in the participating towers) is compared to a *shower model* that predicts the deposit pattern for an electron impinging at the same angle and has the same energy as measured in the cluster, then χ^2 of the predicted and actually measured tower energies is calculated. Small χ^2 means the cluster is consistent with a physical shower from a single γ or $e^{\pm}$.

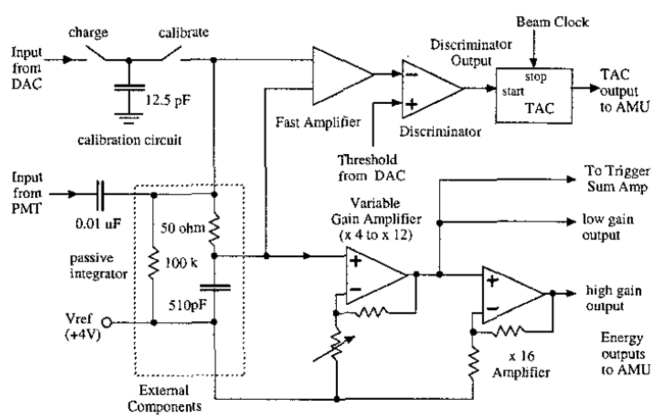

FIG. 1. Single channel circuit diagram

Electronics, readout basics

Light generated in the towers is collected by photomultiplyers (PMT). In the PbGl high voltage is generated separately for each PMT with Cockroft-Walton generators, one for each

PMT. (That's why on the dead channel map you usually see single, isolated channels missing in the PbGl.) In the PbSc 48 towers (1/3 of a supermodule) are powered by a single LeCroy HV channel. Gain differences between PMTs are equalized with Variable Gain Amplifiers (VGA), adjustable channel-by-channel. High voltages and VGAs are rarely changed, adjusted usually only once for a data taking period, followed by an initial calibration. Variations of gains with time are then traced by the laser monitoring system [1].

As seen in Fig. 1 the PMT signal is split in four different outputs: the timing (TAC), the trigger, and two (low and high gain) energy outputs. This is important: it is possible that a channel has valid timing but no (or bad) energy measurement and vice versa.

Timing is done in the *common stop* mode: whenever in a channel the signal exceeds the discrimnator threshold, the time-to-amplitude (TAC) converter starts running and will be stopped by the next beam clock. In other words: the *earliest* signals will have the *largest* TAC values, and, ultimately, the largest TDC counts. This is important to know when you are calculating *slewing correction* to obtain the best possible timing resolution. Least counts (i.e. ps/TDC channel) vary slightly, the typical value is 50ps/TDC count. Achievable timing resolutions for photons are ≈4-500ps in PbSc, 6-700ps in PbGl.

As seen in Fig. 1, energy is measured in two ranges: low gain (→ high energies up to about 30GeV) and high gain (→ low energies up to about 1.5GeV, but with better resolution).

A useful reading on the EMCal electronics is here [2]. One correction: for timing the CFD (constant fraction discriminator), described in the paper, has only been used in Run-1, since then a leading edge discriminator (LED) is used – that's why extensive slewing corrections are necessary.

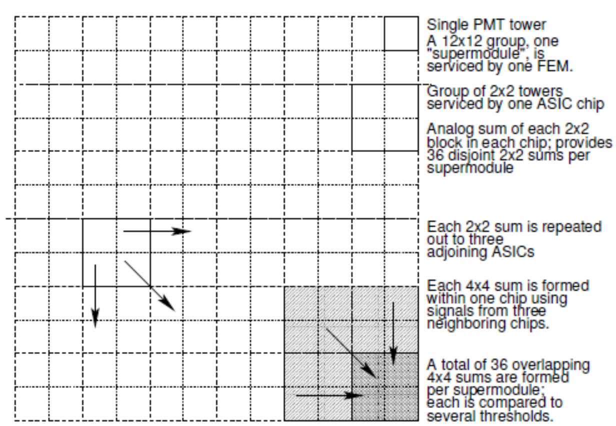

FIG. 2. Schematic of the EMCal fast trigger summing operation

EMCal trigger

In order to enhance rare events in the data (presence of high p_T $\gamma, e^{\pm}$, indicated by large local energy deposits) the EMCal also serves as a trigger. The process is illustrated in Fig 2.

[1] L Aphecetche *et al.* (PHENIX), "PHENIX calorimeter," Nucl. Instrum. Meth. **A499**, 521–536 (2003).

[2] "The mondo chip – a cmos integrated circuit for the phenix electromagnetic calorimeter," `https://www.phenix.bnl.gov/phenix/project_info/electronics/emcal/fem/doc/00774802.pdf` (1999).