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Tile Light Output Requirements for the EMC

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Abstract

In this note it is shown the physics motivation for the EMC tile light output specification of 2 photoelectrons per minimum ionizing particle.

The EMC collaboration has specified that the minimum light yield for a calorimeter tile is 2 photoelectrons per minimum ionizing particle (or p.e.'s per m.i.p., often abbreviated pe/mip). Is this justified? Is this too restrictive a requirement? Is it not restrictive enough? In this note, I show how this specification was derived.

A fundamental limit on the resolution of this type of calorimeter is the *sampling limit.* This limitation arises because only a relatively small part of the shower's energy is deposited in active part of the calorimeter (the plastic scintillator); the majority is deposited in the inert lead. Shower fluctuations cause variations in the ratio of energy deposited in the active region (which is what we measure) to the total energy of the shower (which is what we want to know). For the STAR barrel EMC, the sampling limit is approximately $14 - 15\%/\sqrt{E}$.

Another limit on the resolution is that of photostatistics. We often treat the amount of light coming from the calorimeter as a continuous variable, but the nature of the photoamplification process is fundamentally discrete. An ensemble of showers that produce an average of 100 photoelectrons per shower will have a 1 σ variation of ± 10 photoelectrons (or $\pm 10\%$) from this effect.

We would prefer that the loss in resolution due to photostatistics be about half the size of the sampling limit. This way we are limited by the physics of shower development, not by our measurement ability. This is a more stringent requirement (it requires that the resolution contribution from photostatistics be no worse than $7 - 7.5\%/\sqrt{E}$. than requiring that the total resolution not be worse than $20\%/\sqrt{E}$ (which requires that the resolution contribution from photostatistics be no worse than $13 - 14\%/\sqrt{E}$.

GEANT and test beam studies show that a minimum ionizing particle deposits approximately 0.263 GeV in the EMC. The calorimeter has 21 sampling layers, so this corresponds to a deposition of 0.01252 GeV/mip in each layer. For a tile-fiber combination that produces n photoelectrons per minimum ionizing particle we can calculate the number of photoelectrons N for a given energy E (in GeV):

$$N = \frac{nE}{0.01253} = 79.8nE$$

The relative uncertainty on N is just $1/\sqrt{N}$, so

$$\frac{\Delta N}{N} = \frac{1}{\sqrt{79.8nE}}$$

$$= \frac{11.12\%\sqrt{n}}{\sqrt{E}}$$

Thus, for a requirement that this term be less than $7-7.5\%/\sqrt{E}$, we can calculate that n has to exceed 2.2 to 2.5 photoelectrons per mip. Should n drop below 0.6-0.7 pe/mip, it becomes impossible to construct a calorimeter with resolution that meets our physics specification of $20\%/\sqrt{E}$.

The stated specification of 2 pe/mip doesn't quite match up with the "half the sampling limit" requirement, but it's quite close. 2 pe/mip has the photostatistics term at 47% of the total resolution, as compared to 43% for half the sampling limit. Coupling this with the sampling limit gets us an overall resolution limit of $16.5\%/\sqrt{E}$, which is within our specification of $20\%/\sqrt{E}$.