Testing of Cellular automata clustering algorithm for Forward EM Calorimeter.

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ABSTRACT: We have implemented Forward Calorimeter (FoCAL) geometry using GEANT code in AliRoot Frame work[1]. As designed FoCAL contains 4 super modules and each containing 30 unit modules. We have also implemented Cellular Automata clustering algorithm for reconstruction of clusters from Hits seen by our FoCAL detector. We have tested efficiency & reliability of this algorithm. We have developed a code in C++ object oriented language. Various adjacent active cells are included in the Clusters of more energy and the cluster centroids are determined. Using Invariant mass analysis code, we have reconstructed π⁰s from the Gammas found in FoCAL.

1. Introduction

From the Monte Carlo simulation results, it is clear that π⁰ production rate increases at LHC energies. During any high energy heavy ion collisions the π⁰ particles are produced in quite high amounts (about 85%), therefore, it is easier to study physics based on π⁰ production events. Also from the simulation results it is found that π⁰ production is much enhanced for low PT at LHC energies. This means that π⁰ production will be more in forward direction at LHC energies. It also suggests that the ratio of π⁰ production at low PT to that at high PT is greater than unity at LHC energies. The π⁰ production study has one important advantage that it can be used to subtract background events when high energy π⁰s faking γs. In the following sections we will discuss the design and simulation study of the proposed FoCAL detector in ALICE, which is used to study the π⁰ production in forward direction. In order to extract π⁰s from FoCAL detector, we have employed cellular automata clustering algorithm method to reconstruct π⁰s. Using this algorithm we have made clusters by clubbing the hits (as per the procedure discussed in the following sections) seen by the FoCAL detector. By regrouping these small clusters further cluster centroids and their total energies are estimated for each photon. Those obtained Photons are used for making invariant mass plot of π⁰s.

2. Forward Calorimeter (FoCAL)

Calorimeters are most useful detectors which allow us to explore new physics in the energy range from eV to more than 10¹⁰ eV. Till now there is no calorimeter in Alice in the
forward direction. The proposal is to put a calorimeter (ie) FoCAL(Forward Calorimeter) in Alice at $2.4 \leq \eta \leq 4.0$. The ALICE experiment at the LHC is dedicated for the heavy-ion collisions to exploit the unique physics potential of high energy heavy-ion collisions at LHC energies. Forward Calorimeter (FoCAL) is a sampling EMCAL. It is one of the upgrade plans for the ALICE. FoCAL intends to locate at $z = 366$ cm from Interaction Point. FoCAL detector will do electromagnetic measurements such as $\pi^0$ and photons, jet measurements and their correlations with respect to the central rapidity region. FoCAL also allows us to study the parton distributions and high gluon density (Color Glass Condensate) in proton and nuclei at small-$x$ region, which is the key to understand the early thermalization of the hot and dense medium.

The FoCAL design consists of the following parts:
- 40 layers of (W Scintillator)
- Super Modules
- Unit Module

The FoCAL is sampling type calorimeter in which tungsten follows Polystyrene scintillator for all the 40 layers. The tungsten is used as the converter material because of space restriction in the forward region. The Polystyrene scintillator gives the better position resolution.

Each Polystyrene pad detector is $0.3$ mm thick, also tungsten (W) absorber is $0.3$mm thick. It has $21 \times 0$ depth and 3 longitudinal segments. The total radiation length of $21 \times 0$ of the modules provide the full energy absorption of the electromagnetic particles upto very high energies. Each layer consists of two types of super modules $A$ $-$ type and $B$ $-$ type. Each type of super module has unit modules distributed in a matrix of specific rows and columns.

$A$ $-$ type super module has 30 unit modules distributed in 6 Col $\times$ 5 Row while $B$ $-$ type super module has 30 unit module distribute in 5 Col $\times$ 6 Row as shown in Fig 1(a).

To test the FoCAL Geometry, we have put a 200 GeV Photon on to FoCAL detector, to see the response. The EM shower has expanded into the detector to Various layers. We have summed up the total Energy deposited in each FoCAL Layer and plotted. In the fig 2.0, one can see that the energy distribution has a nice peak at 18th layer and Energy deposition almost runs upto 36th Layer. It shows that the FoCAL is capable of measuring Photons upto 200 GeV and above.

3. Clustering

In complex events and within particles, multiple particles will deposit energy in the same calorimeter cells and showers will overlap. Fine calorimeter segmentation and good clustering
are essential to resolve such showers. Additionally, an intelligent cluster splitting and merging strategy is needed. The basic unit for clustering is a cell. The Cell contains an index by which it is referenced. For instance, a two-dimensional cell Cell2D could contain an Index 2D composed of integer indices i and j to indicate row and column. The Cell also contains a value for relationship to the other cells. Given an Index, a Neighborhood is responsible for returning a list of neighboring Indices. Since the dimensionality of the problem is encapsulated within the Index, the clustering algorithm can be written very simply and its extension to higher dimensions is automatic. When developing calorimeter designs with varying segmentation in the transverse ($r$-$\phi$ or $r$-$z$) and longitudinal directions (layer depth) it will be essential to be able to easily investigate these different clustering elements. We discuss below the 'Cellular Automata' algorithm, which we employed for clustering our FoCAL hits.

4. Cellular automata

The Clustering method called Cellular Automata is also used to find clusters in EMCAL [2]. A cellular automaton is an array of simple individual processing cells [3]. The input of each cell is the set of information from the other neighbouring cells. The corresponding output is uniquely determined with a set of fixed rules acting on the inputs. A cellular automaton evolves iteratively at each step, each examines its inputs, decides on the basis of a transition rule whether or not to change its state, and sends its new output value to the inputs of its neighbours. At the next step, these new inputs are examined and the cells evolve simultaneously.

5. Cellular Automaton Evolution Rules

- A cellular automata evolves iteratively: at each step, each cell examines its inputs, decides on the basis of a transition rule whether or not to change the state.
- Each cell is connected to a limited number of neighbouring cells (3 x 3).
- The change in that cell occurs, once it sees all of its neighbours.

6. Cellular Automaton Transition Rules

The first step is to identify local maxima, i.e. cells with larger energy deposit than their neighbours. These cells are identified with a tag. The second step is to treat them as a virus that is going to propagate to the other cells. Propagation rules are as follows:

- A given Cell is only sensitive to its eight neighbours in a 3 x 3 cell matrix. The cell is treated as a virus, if its value is more than its each neighbour.
- At a given step a cell will take the value of its highest energy neighbour.
- A cell already contaminated in an earlier stage by a virus is immunized against any other virus. This is restriction to the RULE-2.

This simple set of rules allows us to find clusters very efficiently in the E142/E143 calorimeter as illustrated in the following example. Using a test sample of pion and electron showers from a Monte–Carlo simulation based on Geant 3.16, we generated pseudo-events in the calorimeter. Considering a pseudo-event where two electrons hit the calorimeter,

![Figure 3: Initial state of the cellular Automation](image1)

![Figure 4: State 2 of cellular automaton.](image2)
giving two overlapping clusters, the initial state of the active part of the cellular automaton is shown in Fig 3, where each box represents a CA cell. The initial value is the energy deposit in the it cell. Only hit cells have been represented, as the other cells do not evolve. According to Rule−1, the cells containing 7.0 and 8.0 GeV are viruses because they are local energy maxima. At the next step, the CA reaches the state 2, as shown in Fig. 4. Due to what we call contamination, two groups of cells are appearing; however a steady state has not been reached yet. So the CA evolves further to state 3, shown in Fig 5. Rule−3 stops the CA evolution at this stage, avoiding that the cluster tagged by the 8.0 GeV cell absorbs the cluster tagged by the 7.0 GeV cell. Once the clusters are identified, the energy of each particle is obtained by adding the true energy deposit in each block of the cluster.

7. Clustering implementation in FoCAL

The Cellular Automata algorithm is implemented in FoCAL detector, for making clusters from the hits seen in individual cells of FoCAL. The cellular automata not only gave us better cluster number estimate but also produced clusters whose energies are more close to the energy of the particle. The Figure 6 shows the XY distribution of FoCAL for different layer 2 for incident gamma at 15 GeV. As can be observed, the clusters obtained for starting layer 2 is found to be near to the actual number of Gammas falling on the FoCAL. In further layers of the detector cluster numbers increased a little more. Our motive is to identify individual photons using our clustering algorithm and to do invariant mass analysis later. M.C simulations of π0 production cross-section during quark-gluon interaction in QCD at LHC, RHIC shows that π0 production is much enhanced for low P_T at LHC energies. This means that π0 production will be more in forward direction at LHC energies, that’s the reason we implemented FoCAL in ALICE. It also suggests that the ratio of π0 production at low P_T to that at high P_T is greater than unity at LHC energies.

8. Reconstructed π^0 mass distribution.

To reconstruct π^0, the first step is to consider cluster strategies. It was observed that for each layer the number of clusters in a layer increases with increasing incident energy. It is observed that No. of cells increases in each cluster produced by the incident particle increases for the studies of incident Gamma energies of 1, 5 and 100 GeV. Combinatorial background increases if an incorrect number of clusters are summed over, because the clusters summed over should have a strict dependence on energy. We have studied and observed that maximum number of cell hits as seen in FoCAL for various energies of various particles. It is observed that for 1 GeV gamma, we have less number of clusters.
We have studied # of cells for one cluster for different incident energies for (e.g.) 1 GeV, 5 GeV, 50 GeV π^0's. The cluster number also increases and shows increase in splitting in the clusters. From figure 7, we can see that for energy above 50 GeV of π0, the number of clusters with No. of cells as many as 10 and above. This plot shows that still a large number of clusters are splitting and need to be taken care in the clustering algorithm. π^0's are identified via the \( \pi^0 \rightarrow \gamma \gamma \), channel with a branching ratio 98.8%.

To get the total energy for incident gammas, we have defined a cone around the cluster of maximum energy. We took all clusters falling in that cone to get the total clusters and by using the fit parameter we got the energy of gammas in GeVs. For different cone radii, we have studied the efficiency of gammas detected in FoCAL. The total energy within the cone is calculated to be \( E = \Sigma E_i \). We have studied different cone radii, \( 0.2 \leq R \leq 2.0 \) and tested efficiency of the π0 detection. The uncorrelated photon pairs, which were not originating from a parent π0, produce a combinatorial background. These backgrounds were separated via event mixing technique.

We have tested the clustering algorithm for a small statistics and generated an invariant mass spectrum using the combinatorial method. The plot is shown in figure 8. We have also fitted this histogram with a gaussian. From the fit of gaussian, the mean is obtained to be 138.5 ± 2.0 with a sigma 7.176 ± 2.183. As the statistic is low, the sigma looks to be some what more. We require to test our clustering algorithm with very large statistics to see a better mean and sigma. Also we need to test our clustering algorithm for better estimation of the π^0 peak.

![Figure 8: π^0 Invariant Mass.](image)

9 Conclusions

The geometrical implementation of the new design of the FoCAL in ALICE framework was done successfully. A full simulation study of the basic characteristics of the FoCAL such as deposited energy distributions, linearity response and relative energy resolutions have been performed. The clustering algorithm Cellular automata gives good results but we need to further tune it to take care of splitting clusters. We have also used Cone algorithm to sum up energies of various photons coming from π^0. Some small discrepancies are found in energy estimations of gammas and the Cone algorithm requires some more refinement. One of the gamma (γ2) verses Cone radius looks to be quite satisfactory and does not show any dependency on the Cone radius. π^0 reconstruction looks to be good and generation of larger statistics will solve these specified problems and make way for further progress to get better results.

References