Pattern recognition in the PHENIX PbSc electromagnetic calorimeter [1]

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Abstract

The pattern recognition algorithm for the PHENIX PbSc electromagnetic calorimeters are presented. The algorithm is based upon energy and impact angle dependent description of the electromagnetic shower shape as measured in the test beam and reproduced in GEANT simulation. The efficiency of the pattern recognition for identification of single and multiple showers is studied and discussed.

I. INTRODUCTION

Electromagnetic calorimeters are the popular particle detectors used in Particle and Nuclear Physics experiments. When distance from the target (production point) is small (like in most of the collider experiments) it is common to build a calorimeter using towers pointing to the production point (projection geometry) even at the expense of drastically increased cost. We have chosen a different approach designing electromagnetic calorimeter for the PHENIX [1] experiment at RHIC. The calorimeter is built of identical rectangular read-out towers $5.535 \times 5.535 cm^2$ in cross section grouped into 6 flat non-projective sectors ($2 \times 4\ m^2$ each). When installed the sectors will cover $3/8$ of the the surface of a 4 m long and 10 m diameter cylinder [2]. In this geometry neutral particles entering the calorimeter are spread over $0° - 20°$ impact angle range (angles are computed from normal). Our solution allowed to build the fine-granular calorimeter able to handle extremely high event multiplicities predicted for heavy-ion collisions at RHIC energies at a minimal cost. Our solution includes also a second important component which is the pattern recognition algorithm based upon energy and impact angle dependent description of the projected electromagnetic shower shape as measured in the test beam and reproduced in GEANT simulation.

II. ELECTROMAGNETIC SHOWERS IN THE PHENIX PBSC EMCAL

Fig. 1 is the compilation of the experimental data on the electromagnetic shower energy sharing between calorimeter towers.

Pictures in the left and right panels show the same data plotted as a function of the distance between the centre of tower and physical impact point on the detector surface (left) and shower centre of gravity (right). Fig. 1(a,b) and Fig. 1(d,e) are for the electromagnetic showers orthogonal to calorimeter plane, fig. 1c and Fig. 1f are for 20^o impact angle. One can see that for orthogonal impacts energy left by shower in the central (hit) tower is rather incencitive to the exact shower location in the area around the tower centre but varies rapidly close to the tower edges. On the contrary using the centre of gravity as a

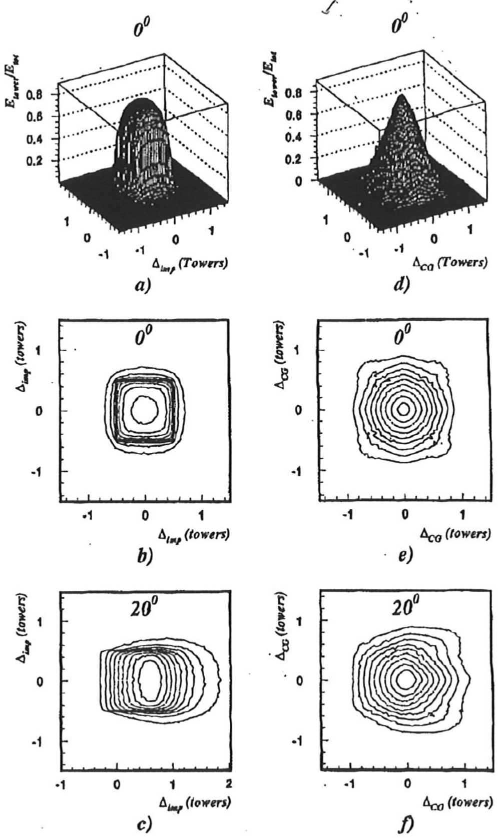

Fig. 1 Energy sharing between readout towers in the PHENIX PbSc EMCal. Energy in the tower is plotted as function of the distance between tower centre and impact point (left panels) and tower centre and shower centre of gravity (right panels).

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reference allows a representation of the shower shape which is characterized by nearly linear dependence of the tower energy on the distance from CG. An even more important conclusion can be drawn from Fig.1(b,e) where the data from above are shown as contour lines (spaced by 10% change in value). The CG representation exhibits at least approximate central symmetry while tower energy in natural coordinates depends crucially on tower orientation.

Approximate symmetry of the projected shower shape in the CG system suggests that neglecting effects related to the relative orientation of the shower plane and of the calorimeter towers one can parameterise the shower shape in the polar coordinates as function of the distance r_{CG} between CG and a tower centre. The parameterisation looks trivial in the case of orthogonally impinging particles

$$E_{tower}(r_{CG}) = p_1 \times \exp(-\frac{r_{CG}^3}{p_2}) + p_3 \times \exp(-\frac{r_{CG}}{p_4}),$$

where p_i are parameters defined by the physics of shower development in this particular calorimeter.

When a particle hits the calorimeter at an angle (Fig. 1(c,f)) the projected position of the shower maximum gets displaced from the impact point (Fig.1c) and the shower shape gets skewed. Probably the most important feature of nonorthogonal impact is the energy dependence of the shower shape:

- asymmetry of the shower in projection on the calorimeter surface increases with energy;
- distance between projected shower maximum and real impact position logarithmically depends on energy;
- longitudinal shower fluctuations become dominant contributors to the spread in amplitudes measured in individual towers.

Fortunately, for impact angles below 20° the CG stays very close to projected shower maximum so the shower profile in the right panel remains centered and relatively symmetric.
Multidimensional analyses of simulated data in the range of energies 0.3 - 20 GeV and impact angles $0^o - 20^o$ have shown that, for the purposes of this work, the appropriate parameterisation can be achieved introducing energy and impact angle dependence to the coefficients p_i. We used a common functional dependence

$$p_i(E_0, \theta) = a_i + (b_i + c_i \ln(E_0)) \times \sin^2(\theta), \qquad i = 1 \div 3$$

for the first three coefficients but kept p_4 constant. Here θ is an impact angle computed with respect to normal, the coefficients a_i, b_i, c_i were found from multidimensional fit of available data. The quality of the data description can be assessed from the data presented in Fig. 2.

We used similar approach to parameterise the energy and impact angle dependence of the variances which are assigned to energies measured in the calorimeter towers

$$\sigma_i^2 = C \times E_i^{pred} \times (1 + f(E_0, \sin(\theta))) \times (1 - \frac{E_i^{pred}}{E_0}) + q$$

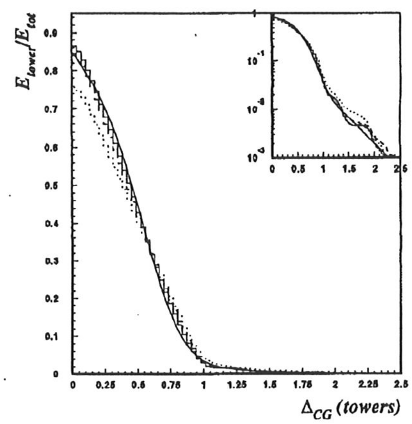

Fig. 2 The dependence of the energy in the calorimeter tower hit by 1 GeV photon on the distance between tower centre and shower CG. The solid histogram is for orthogonal impacts, dashed and dotted histograms are for 10^o and 20^o impact angles respectively. The fit for $\theta = 0^o$ is shown by the solid line. Insert: the same data shown on logarithmic scale.

$$E_0 = \sum_i E_i^{meas},$$

$$f(E_0, \sin(\theta)) \; = \; k \times \sqrt{E_0} \times \sin^4(\theta), \; k = const.$$

The constant term q accounts for electronics noise and the C sets the scale for energy fluctuations in the shower. The value of C was measured to be 0.03 GeV from the test beam data. The factor $(1 - \frac{E_i^{pred}}{E_0})$ allows to introduce the correlations between energies in the towers while keeping the covariance matrix diagonal. The parameterisation for energy and impact angle dependence of the errors $f(E_0, \sin(\theta))$ was chosen to fit test beam data.

The two parameterisations are used together to compute χ^2 values characterising the 'electromagnetness' of the shower and to separate clusters of amplitudes due to single showers from those resulting from shower overlaps.

$$\chi^2 = \sum_i \frac{(E_i^{pred} - E_i^{meas})^2}{\sigma_i^2}$$

where E_i^{meas} is the energy measured in the tower i, $E_i^{pred} = E_{tower}(r_{CG}, E_0, \theta)$.

In the Fig. 3 we compare the efficiency of the χ^2 testing (99% of real test beam electromagnetic showers at all impact angles satisfy the cut $\chi^2/ND < 3$, see Fig. 3 solid line) to similar numbers computed using standard approach neglecting energy and angle dependencies of the projected shower shape [3]. The improvement amounts to 10% for 1 GeV showers and close to factor 5 for 20 GeV showers.

The shape of the χ^2 distribution computed using this parameterisation is almost insensitive to energies and impact angles of showering particles (see Fig. 4). Residual χ^2

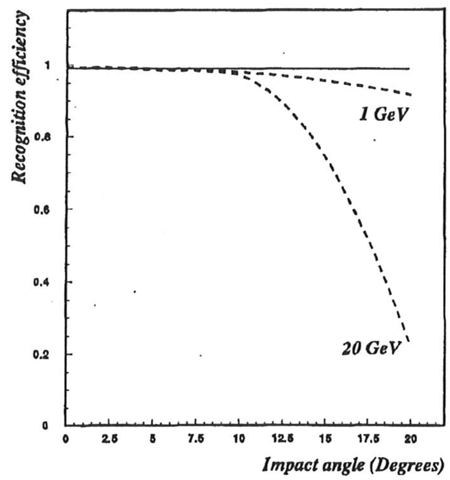

Fig. 3 Recognition efficiency for individual electromagnetic showers in PHENIX EMCal. Solid line - shower shape corrected for energy and impact angle dependence, dashed lines - neglecting energy and impact angle dependence of the projected shower shape.

dependence on energy and angle which reflects the variation in the number of participating towers does not affect the discriminating power of the algorithm.

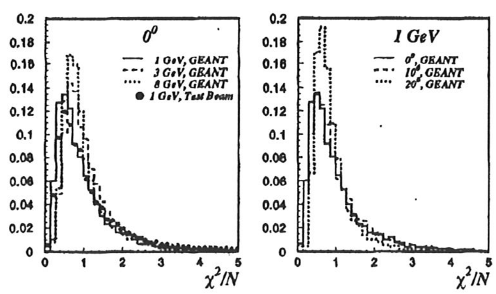

Fig. 4 χ^2 distributions for *(left panel)* electromagnetic showers produced by the orthogonally impingent electrons of different momenta and *(right panel)* by 1 GeV/c electrons entering the calorimeter at a different angles.

III. SOFTWARE IMPLEMENTATION.

The pattern recognition procedures written and tested for data analysis in the PHENIX Electromagnetic calorimeter are structurally close to those developed and used for GAMS programs at IHEP and CERN. The analysis consists of three stages, different in the degree of output data abstraction:

- *Cluster search.* Cluster is defined as a contiguous group of calorimeter towers with measured energies above certain threshold. For all pattern recognition purposes the clusters are assumed to be totally independent thus setting a natural scope for pattern recognition procedures;

- *Search for local maxima.* Local maximum is associated with as a tower which has a deposited energy in excess of energies measured in any of the 8 surrounding towers. It is assumed that local maximum signals the presence of the electromagnetic shower. It is important to understand that neither this *nor* any other algorithm known to be used for pattern recognition in calorimeters, includes any notion of hadronic activity. It is implicitly assumed that all showers in the calorimeter, including those due to hadrons, follow common parametrisation. Each maximum is assigned a cluster of towers (multiple association is now allowed) whose energies are sheared between maxima using an iteration procedure based upon crude shower shape parametrisation;

- χ^2 test of the '*single electromagnetic shower*' hypothesis for newly defined and possibly overlapping clusters-maxima. Clusters satisfying criteria $\chi^2/ND < 3$ (minimisation is made with respect to impact point position) are classified as being due to a single particle hit. If fit fails, an attempt is made to interpret the cluster as an overlap of the two 'major' contributers and to compute an estimates for individual energies and impact coordinates of those contributors. The impact coordinates and individual energies are found minimising χ^2 value redefined in terms of three variables: $\alpha = (E_1 - E_2)/E_0$, $\Delta X = X_1 - X_2$ and $\Delta Y = Y_1 - Y_2$ where $E_{1,2}$, $X_{1,2}$ and $Y_{1,2}$ are individual energies and CG coordinates.

It is for sure that large fluctuations which are the intrinsic feature of the showering process could make phase 3 results prone to uncontrollable losses or creation of ghosts. Our declared phase 3 goal is to extend dynamic range for measuring high p_t π^0's. The $\chi^2/ND < 3$ is a rather loose criterion resulting in a loss of $\sim 1\%$ of a real electromagnetic activities in the calorimeter. A cluster of amplitudes failing this test has an extremely high chance to be either due to a single hadronic hit spreading its energy well outside the hit tower or due to an overlapping showers. The ghost showers which may result from deconvoluted hanronic activities would be difficult to account for if data are used to measure photon spectra but they are of no consequences for cross section measurements based upon effective mass distributions.

The probability to identify correctly two overlapping showers using phase 3 procedure is shown in Fig. 5 as function of the distance between impact points.

The two sets of the data points shown are for the 1+1 GeV and 8+8 GeV combinations of photons and impact angles of 0^o, 10^o and 20^o. The efficiency improves with energy of photons what reflects $1/\sqrt{E}$, dependence of the calorimeter energy resolution [2]. The efficiency stays close to 100% down to the two shower separation of the order of

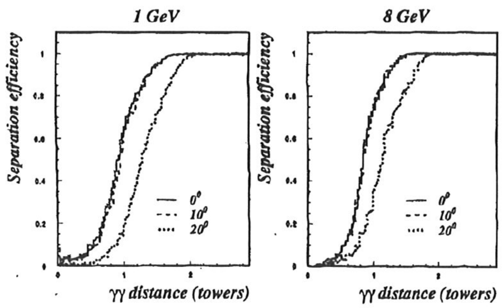

Fig. 5 Two-photon separation efficiency in PHENIX EMCal.

$1.5 \times$ *tower size* and drops to 60% at a 1 tower separation (neighbour towers). It is almost insensitive to impact angles down to 10^o. At larger angles longitudinal shower fluctuations projected on the calorimeter front surface become dominant in the shower profile fluctuations and separation efficiency deteriorates earlier, starting from the distances of the order of $2 \times$ *tower size.*

This study shows that shower separation procedure based upon χ^2 testing is an effective tool which allows to decrease the separation limit from $\Delta \sim 2 \times$ *tower size* in the phase 2 down to $\Delta \sim 1 \times$ *tower size.* Fig. 6 details the performance of the algorithm when applied to two overlapping 1 GeV showers.

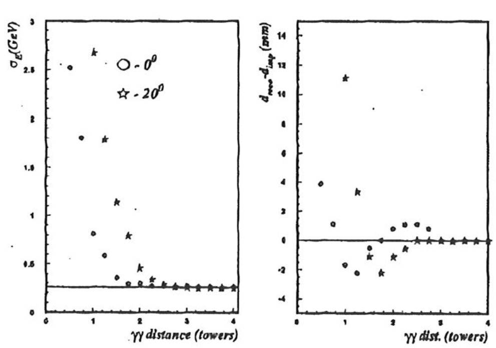

Fig. 6 Performance of the phase 3 pattern recognition for the case of two overlapping 1 GeV electromagnetic showers

Below $\Delta = 1.5 \times$ *tower size* strict correlations between shower energies (total energy is fixed equal to measured in EMCal) result in increased energy asymmetry between two reconstructed showers. Below $\Delta = 1 \times$ *tower size* the algorithm exibits the tendency to distance the showers. Altogether the deterioration of the energy and position resolution makes individual shower parameters too uncertain when showers are separated by less then $0.75 \times$ *tower size*

IV. HIGH p_t π^0 IDENTIFICATION IN EMCAL

The PHENIX electromagnetic calorimeters are relatively transparent for hadrons. When hadron has a momentum in excess of 1 GeV/c the probability that it will deposit more then 50% of its total energy in EMCal in less then $\sim$ 20%. Rejecting high energy clusters associated with charged tracks reconstructed in the tracking detectors will allow to identify almost uncontaminated sample of the high p_t photon showers. This statistics shell allow an easy determination of the π^0 production cross section up to $P_t(\pi^0) \sim 12\ GeV/c$. Above p_t of 12 GeV/c the two photons from symmetrical π^0 decay are too close ($< 2 \times$ *cell size*) for the phase 2 procedure to be effective. The prospects of extending the p_t range for π^0 measurements in PHENIX EMCal are based upon observation that the statistics of clusters with energies above 12 GeV will be nearly 100% saturated by the single photons and by the pairs of overlapping photons from π^0 decays. The χ^2 testing of the single versus two overlapping showers hypothesis will allow to extend the limits for γ/π^0 separation significantly. The predicted dependence for the γ/π^0 discrimination efficiency on cluster energy is shown in Fig. 7.

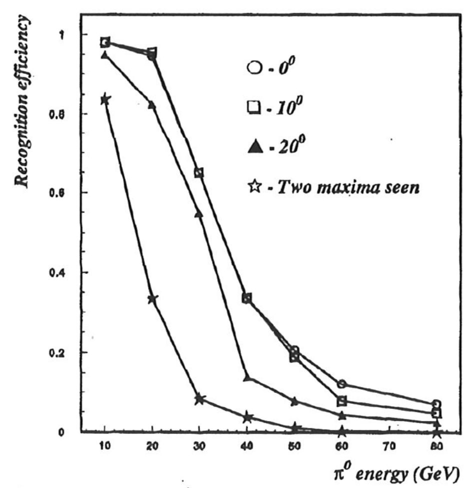

Fig. 7 π^0 recognition efficiency in the PHENIX EMCal

As one can see, even at $p_t = 35\ GeV/c$ two-photon combinations from π^0 decays will be correctly identified in 50% of the cases. Similar data for nonorthogonal impacts ($\theta = 10^o$ *and* 20^o) are also shown in the same figure. We believe that χ^2 testing of the amplitude clusters can provide unique opportunity to measure the γ/π^0 ratio in PHENIX all the way up to the limit imposed by the RHIC interaction rate.

V. CONCLUSIONS

The electromagnetic shower shape parametrisation which accounts for energy and impact angle dependence of the projected shower shape is proposed and tested against test beam and simulated data. It is found that for all practical purposes of the pattern recognition the electromagnetic showers in the calorimeter could be described by azimuthally symmetrical function of the distance between tower centre and shower centre of gravity, shower energy and impact angle.

The pattern recognition procedure based upon this parameterization is subdivided into three phases: search for clusters of amplitudes in the calorimeter; search for local maxima inside the cluster scope and shower reconstruction assuming the equivalence 'one maximum = one shower'; χ^2 testing of the consistency between individual showers and 'single hit' hypothesis. The assumption 'one maximum = one shower' holds if two showers are separated by no less then two calorimeter towers ($\sim 11cm$). The χ^2 testing allows to identify multi hit configurations and to measure energies and impact coordinates of individual showers down to hit-to-hit separation distances smaller then tower size.

VI. References

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