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GEANT simulations of the CLAS12 pre–shower calorimeter

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Abstract

Results of GEANT simulations of the CLAS forward electromagnetic calorimeter (EC) with added pre-shower are presented. For this study the default version of GSIM, GEANT model of the CLAS detector, was used. The pre-shower geometry was added to the GSIM in front of the EC. The EC cluster reconstruction algorithm was modified to include the cluster reconstruction in the pre-shower. The whole reconstruction was performed using the CLAS event reconstruction framework, RECSIS. The efficiency of the detection of high energy (<10 GeV) π^0s via their two photon decays was studied. Preliminary results on two cluster reconstruction efficiency dependence on the number of lead-scintillator layers and the transverse granularity of the readout are presented. The goal of this study was to establish preliminary design parameters for the pre-shower.

Introduction

The 12 GeV physics program with CLAS12 requires a reliable detection of photons and π^0s at very high energies. With the increase of the pion energy, the opening angle between the decayed photons decreases. At energies above 5 GeV the spatial distance at the CLAS forward calorimeter becomes too small (< 30cm) to reconstruct two photons as separate clusters [1], see Fig. 1. At these energies, most of two photon hits in EC will be reconstructed as a single cluster (a single "photon").

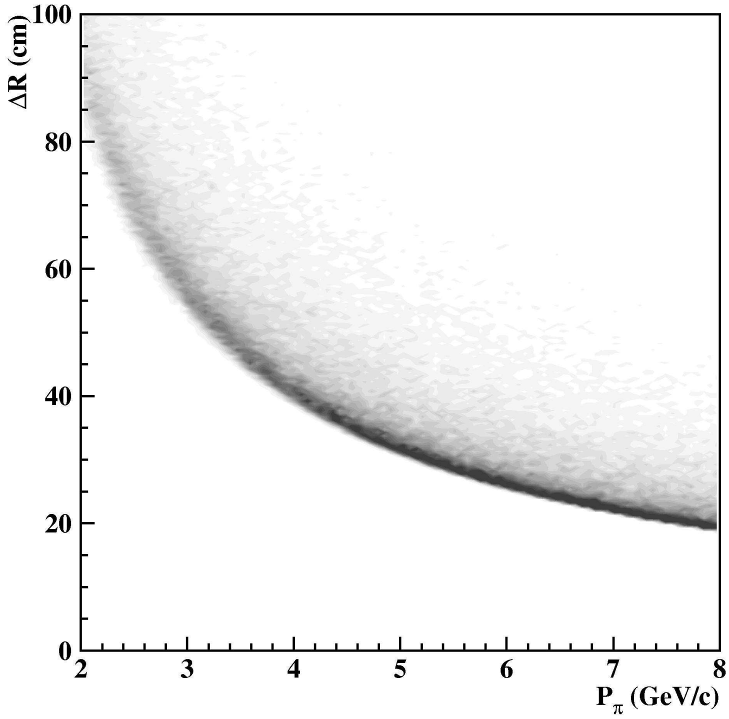

Figure 1 Distance betweenn two photons from π^0 decays as a function of pion momentum at the EC.

To separate high energy π^0s and photons, a finer transverse granularity of the readout plane for the electromagnetic calorimeter is required. A pre-shower detector, with finer transverse readout segmentation, was proposed to build and install in front of the EC for the CLAS12. The pre-shower should allow separation of two photon clusters from π^0 decays for up to 10 GeV energies.

In the initial proposal, the pre-shower covered only 50% of the EC in the forward region where the high energy pions and photons will be produced, see Fig. 2. Proposed structure of the pre-shower was similar to the existing EC, lead-scintillator sandwich with three stereo readout planes. In the initial proposal the scintillator strips were up to 2m long and had $3x1cm^2$ cross section. It was proposed to have nine layers of scintillators, 64 scintillator strips in each layer. As in EC, 2 mm lead shits were proposed to use between the scintillator layers (eight layers of lead in total). The total amount of material, including the front support plate, was estimated to be ~3r.l..

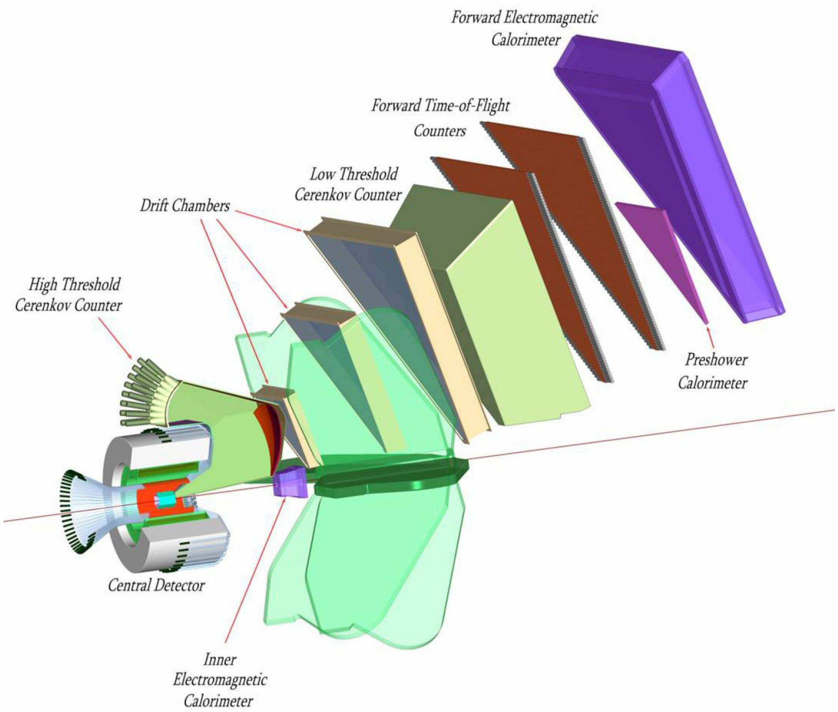

Figure 2 CLAS12: one sector view of the forward detector and the central detector. The pre-shower covers only 60% of the angular coverage of EC.

In the proposed design of the pre-shower, light transmission to a photo-detector, in this case to a photomultiplier tube (PMT), will be conducted via 1mm diameter green wave-shifting (WS) fibers embedded in the surface of the scintillator strips, see Fig. 3. The number of fibers will be defined based on the test measurements. It is expected to use 2 or 3 fibers for each scintillator strip. For high photoelectron yield, the green sensitive photo-multiplier tubes will be used. Both, the energy and the time information for each PMT signal will be measured. The total number of channels for all 6 sectors of CLAS will be 1152.

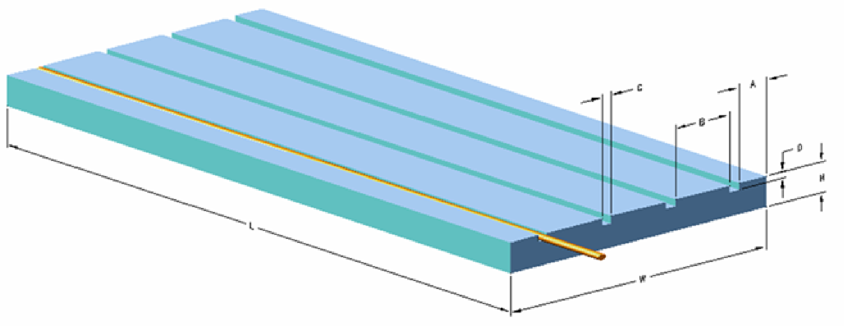

Figure 3 Scintillator strip with groves (4) on the surface foe WS fibers.

GEANT model of the pre-shower

The initial design of the pre-shower with 3x1 cm^2 scintillator strips and 2mm lead sheets was based on preliminary simulations with high energy π^0s, when the geometry of the forward electromagnetic calorimeter in the GEANT [2] model of the CLAS, GSIM, and in the CLAS reconstruction algorithm, RECSIS [3], was replaced with a finer transverse granularity calorimeter. These studies showed that 3cm strip width will allow to separate high energy (>4 GeV) π^0s and photons. For the final determination of the width and the thickness of the scintillator strips and the thickness of the lead sheets more studies with realistic configuration of EC and the pre-shower were needed.

The pre-shower geometry was inserted before the forward electromagnetic calorimeter. Reconstruction algorithm for EC [4] in the CLAS data analysis software was modified to include pre-shower reconstruction. Simulations of a single photon and π^0 events were used to study pre-shower & EC configuration and to derive preliminary design parameters for the pre-shower.

In this simulation, the pre-shower covers the full detection range of the EC. The active part of the pre-shower surface was expanded for 50mm from each side. This was done in order to have coverage for particle detection in the regions that will be opened up with a use of thinner torus coils for CLAS12. In Fig. 4 the GEANT picture of the CLAS with pre-shower and the pre-shower layout are shown. The volume name for the pre-shower in GSIM is PCAL. The PCAL consists of six geometrically identical modules – one in every sector. PCAL volume layout is shown in Fig. 5. Each module is a lead-scintillator sandwich, with 10 mm thick scintillator planes followed by 2.2 mm thick lead planes. Initially, each triangular scintillator layer was sliced into 108 equal width strips*. To maintain three stereo readout capability, the scintillator strips in each alternating layer were oriented parallel to the one of the edges of the triangle. Altogether, there were 15 scintillator planes and 15 planes of lead†. The geometry of the CLAS scintillator counters (SC) and the Cherenkov counters (CC) in GSIM must be turned OFF to run simulations with PCAL. The geometry switches in GSIM were modified in such a way that if in the “ffread” card the following line was specified -
GEOM ‘PCAL’
than the geometry of SC and CC will be turned OFF automatically. Bellow is the list of new routines for the pre-shower simulation in GSIM.

init_ec2.F	**ec2sets.inc**	**trev_ec2.F**
ffpar_ec2.inc	**sets_ec2.F**	**out_ec2.F**
ec2geom.inc	**step_ec2.F**	**last_ec2.F**
ec2tmed.inc	**bos_ec2.F**	
ec2mate.inc	**bos_ec2_t.F**	
geom_ec2_init.F	**digi_ec2.F**	
geom_ec2.F		

* 108 was the maximum number of slices used. This number was a parameter that was used to study the reconstruction with different width of strips.
† The number of layers was a parameter in the studies. 15 layers were maximum number used.

Several other GSIM routines were modified to include PCAL in the standard scheme of GSIM simulation used for the other detectors. The BOS bank “EC2” was created for the raw ADC and TDC information from the PCAL.

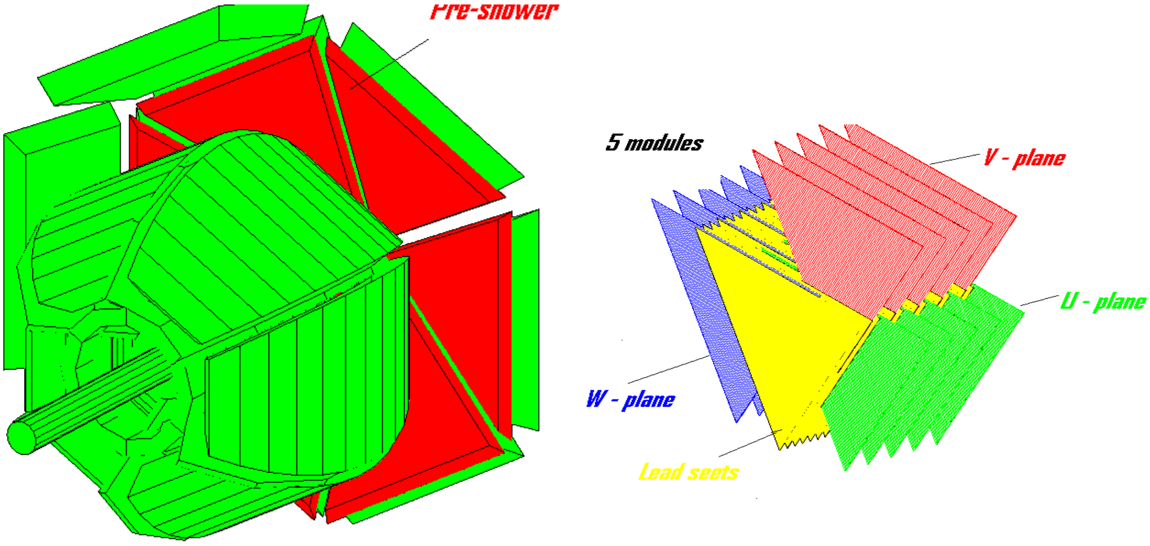

Figure 4 Po Positioning of the pre-shower (PCAL) in GSIM before the forward calorimeters. The pre-shower internal geometry: lead layers are shown in yellow. U, V, and W are three layers of scintillator stripe with orientation of strips parallel to the triangle edges.

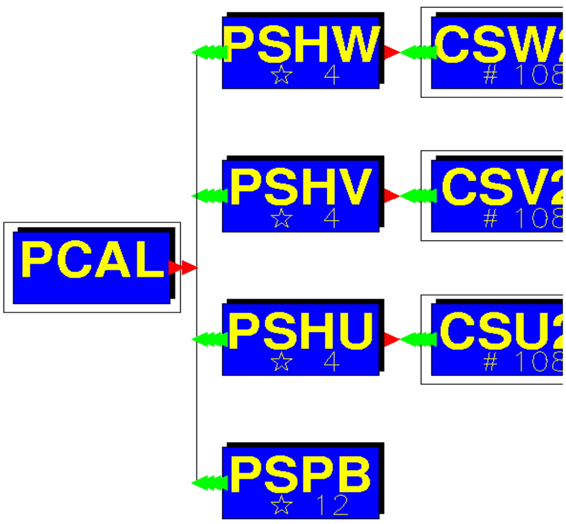

Figure 5 Volume layout for PCAL in GSIM.

PCAL implementation in RECSIS

EC reconstruction algorithm in the CLAS reconstruction software, RECSIS, was modified to include reconstruction of the pre-shower information. In addition to the three layers of EC, the forth layer was added to the EC cluster reconstruction loop. The naming convention for the existing three layers is “Whole”, “Inner”, and “Outer”, with layer numbers 9, 10, and 11, respectively. The layer “Whole” is a software layer, constructed from the raw information in the layers “Inner” and Outer”. In the EC algorithm, there was a spare data structure for the forth layer under the name “Cover” with the layer number 12. We used this data structure for the pre-shower cluster reconstruction. Cluster reconstruction in the layer “Cover” was initiated only when the data in the “EC2” BOS bank were found. The same algorithm was used to reconstruct clusters in each layer. The geometry of the layer and the number readout segments in the layer were set accordingly, depending on the layer. In this study, the new peak finding algorithm for the EC was used [5]. Reconstructed cluster information was stored in “ECHB” BOS bank. For the final analysis, the “ECHB” information was packed into Ntuple [6].

Simulations

The initial simulations of the pre-shower were carried out with 15 planes of the scintillator and lead (the first plane being lead). This configuration is similar to the “Inner” layer of the EC and allowed the initial debugging of the pre-shower software. Initially each scintillator plane was sliced into 108 readout channels (3.5 cm wide scintillator strips). Reconstruction efficiency of two clusters from π^0 decay was studied for the PCAL configurations with different number of lead-scintillator planes and with different number of readout segmentation.

In Fig. 6, the distribution of reconstructed energy in the “Inner” layer of the EC and in the pre-shower from simulation of 5 GeV muons is shown. High energy muons leave about 2 MeV energy per g/cm^2 of material (MIP) and it is expected to have ~ 30 MeV energy depositions in the EC “Inner” and the pre-shower. Both distributions in Fig. 6 similar and correspond to the energy distribution of MIP.

Configurations with EC only and the EC with PCAL were studied with photons with energies up to 9 GeV, generated at polar angle of 25^o and the azimuthal angle of 0^o (at the center of the Sector 1 EC). In Fig. 7, distributions of sampling fractions (reconstructed energy over simulated) for both cases are shown. Slightly narrow distribution in the case of EC with PCAL is due to less leakage than in the case of EC only configuration. Overall, MIP and single photon simulations showed that PCAL implementation in GSIM and in RECSIS works correctly.

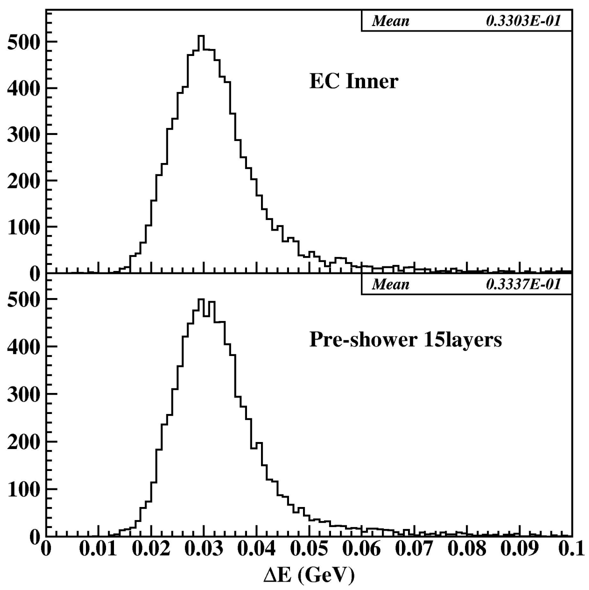

Figure 6 Energy deposition from MIP in the EC "Inner" and in the pre-shower.

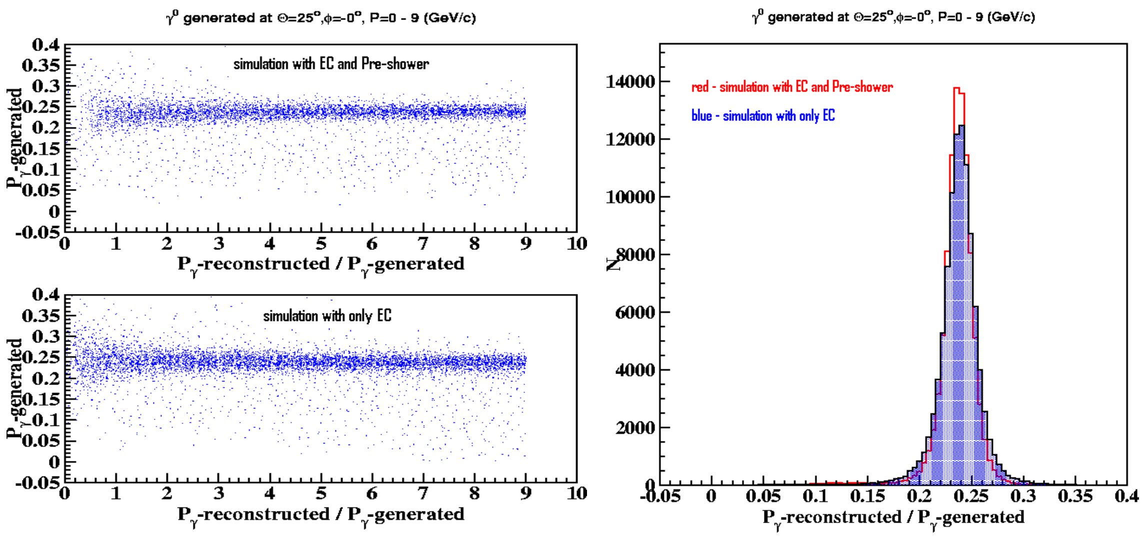

Figure 7 Photon energy fraction (sampling fraction) reconstructed in the EC and in the EC and pre-shower.

Two cluster reconstruction efficiency was studied with high energy π^0s simulated in the polar angular range 24° to 27° and in the azimuthal angular range -3° to +3°. As an efficiency the ratio of the number of events with two clusters reconstructed in a given detector configuration to the number of generated events was calculated. In Fig. 8, the dependence of this efficiency on the momentum of generated π^0s is plotted. The red points correspond to the configuration without PCAL in GSIM. As it was expected the number of two cluster events in EC[‡] decreases with increasing pion momentum for momenta above 5 GeV. With increase of pion momentum more events are reconstructed as a single cluster events. The blue points on the graph correspond to the simulation with the pre-shower. Any event that had two clusters either in PCAL and/or in EC was considered as two cluster event. In this case, the efficiency stays almost constant for momenta up to 12 GeV. The results presented in Fig. 8 are for PCAL with 15 lead-scintillator layers and 108 readout segments in each stereo view, U, V, and W.

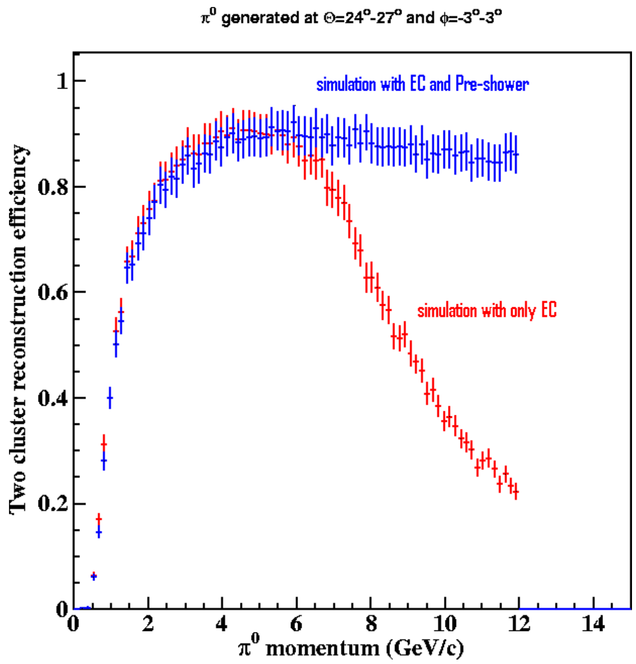

Figure 8 Two cluster reconstruction efficiency as a function of π^0 momentum. The red points correspond to the reconstruction of two clusters in the EC. The blue points when two clusters were reconstructed in PCAL and/or in EC.

Preliminary results on the two cluster reconstruction efficiency for a different number of lead-scintillator planes of PCAL are shown on the left graph of Fig. 9. The blue points are the same as in Fig. 8, 15 planes of lead and scintillators. On the graph it is noted as “5 modules”, since in this case there are 5 lead-scintillator planes in each stereo readout views U, V, and W. Accordingly, “4 modules”, the green points, correspond to the case with 12 lead and scintillator plans. The red points, “3 modules”, correspond to the case

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‡ Events with two clusters reconstructed in any of EC layers, “Inner” or “Outer”, were considered as “two cluster” events.

when the total number of planes in PCAL was 9. Two cluster reconstruction efficiency decreases at high energies when number of lead-scintillator planes decreases. This is due to the decreasing efficiency for single photon detection with smaller number of planes in each readout view (not enough material for the shower to develop).

Dependence of the two hit separation efficiency on the number readout segments is shown on the right graph of Fig. 9. For this studies the 15 layer configuration of the PCAL was used. The red points correspond to the initial configuration, 108 segments in each readout view. As it was expected, with decrease of the number of segments the efficiency of two cluster reconstruction decreases. There is not much difference between 108 and 90 segment cases, while for 65 segment case the efficiency around 9-10 GeV decreases by about 25%.

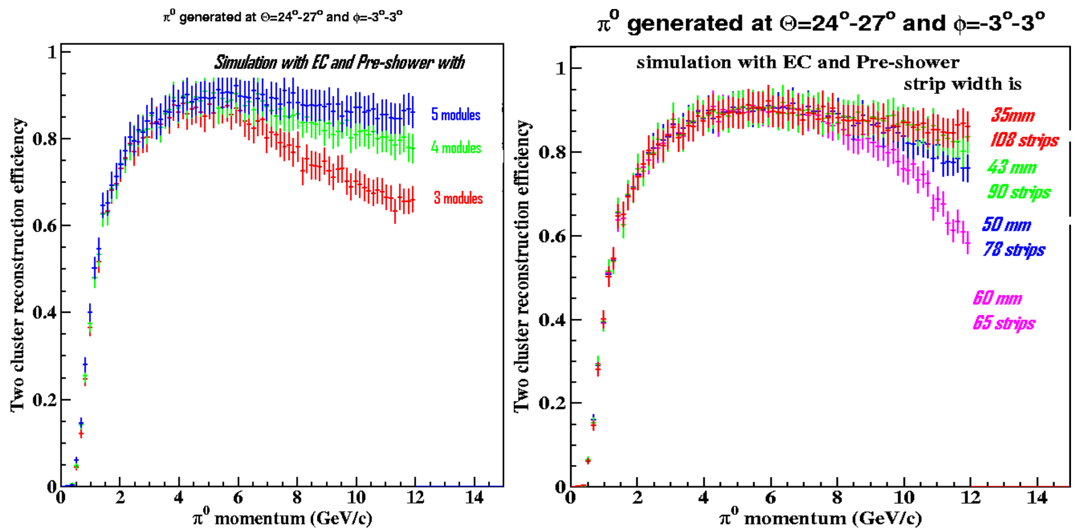

Figure 9 Two cluster reconstruction efficiency as a function of the π^0 momentum for different PCAL configurations.

Summary

In this report, GEANT simulation of the pre-shower calorimeter for the CLAS12 was presented. The GEANT model of the pre-shower (PCAL) was built in GSIM, the GEANT model of the CLAS detector. The CLAS electromagnetic calorimeter (EC) reconstruction algorithm was modified in order to include cluster reconstruction in PCAL. Simulations were performed with EC-PCAL and EC only configurations. The new software for the PCAL was debugged with high energy muons and single photons. Tests with muons and photons showed correct energy reconstruction in the EC and PCAL with the new software.

Simulations with high energy π^0s were limited to two cluster reconstruction efficiency studies. These simulations showed the necessity of the pre-shower with finer transverse granularity of the readout system for the separation of two photon hits from π^0 decays at high energies (> 5 GeV). Although more studies are needed for the determination of the final number of lead-scintillator planes and for the determination of the readout segmentation size, the preliminary results showed that for efficient detection of photon shower 15 planes of lead and scintillator are needed, 5 planes in each stereo readout view. For the separation of showers initiated by two photons from high energy pion decays the size of the readout segment should be < 5 cm. Further studies of these parameters should include energy resolution and the pion mass reconstruction, realistic energy fluctuations due to the limited photoelectron statistical and the realistic attenuation lengths for the light transmission.

[1] M. Amarian et al., NIM A **460**, 239 (2001)

[2] GEANT, CERN program library.

[3] RECSIS, CLAS event reconstruction algorithm, http://clasweb.jlab.org/offline/offline_libs.html.

[4] Cluster reconstruction algorithm for the CLAS EC, http://clasweb.jlab.org/offline/offline_libs.html.

[5] N. Dashyan and S. Stepanyan, CLAS-NOTE 2006-016.

[6] HBOOK, CERN program library.