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The CLAS12 pre-shower performance studies

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Abstract

In this report, new studies of the CLAS12 pre-shower calorimeter performance are presented. The energy resolution, photon detection efficiency, and the efficiency of two photon cluster reconstruction from high energy π^0 decays were studied. Version of the GSIM with added pre-shower and the modified EC cluster reconstruction algorithm were used. Several different configurations of PCAL with different number of lead-scintillator planes and with different readout segmentations were tested. These studies confirmed that 9 layer configuration of the PCAL is not efficient even with added lead layers. Configuration with 12 lead-scintillator layers, where first 3 lead layers had double thickness is as efficient as the 15 lead-scintillator layer configuration, but has slightly worse energy resolution. Two cluster reconstruction efficiency studies with varying the readout segmentation, showed that using 4.5 cm width of the readout segment in the forward region and the doubling it in the backward region allows to cover the full angular range of the forward part of the CLAS12 with 64 PMTs per stereo readout view. This number of readout channels was in the initial proposal when the coverage was the half of the full detections range of the CLAS12 forward detector.

Introduction

The initial GEANT studies of the pre-shower calorimeter for CLAS12 (PCAL) were focused on the reconstruction of two photon clusters from high energy π^0 decay [1]. Based on those studies it was determined that 15 lead and scintillator layers (5 layers per readout view U, V, and W) are needed for efficient cluster reconstruction. In [1], the low efficiency of 9 and 12 layer configurations was explained by not having enough material in the pre-shower for photons to develop shower to be detected. It was also found, that the readout segmentation must be less than 5cm in order to resolve photon clusters for pion momenta up to 10 GeV. Since the initial design assumed 3 cm width for a readout segment and the PCAL covered only half of the detection angular range of the EC, the wider readout segmentation opens a possibility to cover the full range of the EC with the same number of readout channels. Keeping the number of readout channels the same is important, since the estimated price for PMTs is ~50% of the price for the materials of the whole PCAL.

In this report, additional studies of the energy resolution, photon detection efficiency, and the efficiency of the π^0 reconstruction are presented for the different number of lead-scintillator planes and for the different readout segmentations of the PCAL. The goal of these studies was to finalize the design parameters of the PCAL with the aim of having a coverage in the full angular range of the CLAS12 forward detector.

Varying the number of lead-scintillator planes

As in early studies, three configurations of PCAL with 9, 12, and 15 layers of scintillators were tested. The difference from [1] was that the total thickness of the lead was kept the same in all configurations. The five-module version contained fifteen layers of lead and scintillator planes (Fig. 1). This configuration was taken as the standard model. The three-module version contained fifteen layers of lead and nine layers of scintillators. The first six layers had double lead thickness (Fig. 2). The four-module version contained fifteen layers of lead and twelve layers of scintillators with the first three layers having double lead thickness (Fig. 3). For these studies segmentation in all three readout views was 108.

The single gammas and π^o's were simulated using a single particle generator, SPGEN [2]. The single photons were generated in the momentum range < 9 GeV at azimuthal angle $\varphi=0^o$ and the polar angle $\theta=25^o$. The generated π^os had a momentum range up to 9 GeV, θ range from 24^o to 27^o, and φ range of -3^o to 3^o.

The particles were then run through the modified GSIM, which included the pre-shower. The pre-shower was inserted into the GSIM code where the current Cherenkov Counters (CC) and Scintillator Counters (SC) are, so the geometry of these two detectors needed to be turned off while running the configuration with PCAL. This was done by modifying the GSIM code such that if the geometry of the preshower was specified in the "ffread" file then the geometries of the CC and SC would be turned off.

To change the number of lead-scintillator layers the number of modules, NMOD2, was changed in ec2geom.inc and gsim_c_common.h. To insert additional lead layers and to change the size of the PCAL, Fortran routine geom_ec2.F was modified.

After being run through the simulated CLAS detector, events were processed with the CLAS event reconstruction program, RECSIS [3], and the resulting Ntuples were used to analyze the different models. Data analysis was performed using the physics analysis workstation, PAW++ [4], FORTRAN functions, and kumac files. The same histograms were filled for each model, so the comparison between the various configurations could be made easily.

Resolution studies

The resolution of a sampling calorimeter can be expressed:

$$\frac{\Delta E}{E} = \frac{Const}{\sqrt{E}} \oplus \frac{a}{E} \oplus b\,.$$

Term a is important at low energies, term b is important at high energies. In the range of energies we are interested, 1 to 10 GeV, the resolution can be approximated with the following expression:

$$\frac{\Delta E}{E} \approx \frac{Const}{\sqrt{E}}$$

The energy deposited by a showering particle, ΔE, was calculated by adding the energy of the clusters in both the pre-shower and the EC. Then the sampling fraction was calculated by dividing the shower energy to the simulated energy of the photon. The resolution of the CLAS12 calorimeter was attained by fitting a Gaussian function to the sampling fraction distribution over several energy bins. Using the corresponding standard deviations (σ) and the mean values of the Gaussian fits, the resolution constant was calculated according to the following equations:

$$\frac{\Delta E}{E} = \frac{\sigma}{Mean} \Rightarrow Const = \frac{\sigma}{Mean}\sqrt{E}$$

The graphs were created by plotting $\frac{\sigma}{Mean}\ vs\ \frac{1}{\sqrt{E}}$ and the slope of the linear fit was taken as the resolution constant.

As shown in Fig. 4, the resolution measured in the five-module version is 0.97258E-01+/-0.10796E-02. As shown in Fig. 5, the resolution of four-module is 0.11137+/-0.11742E-02. The resolution of the three-module configuration is 0.14884+/-0.15186E-02, see Fig. 6.

The larger the constant term, the worse the resolution and the less accurate the calorimeter is at reconstructing the hit energy. The four-module version differed from the five-module version by only 1.4% in resolution. The three-module version, however, showed marked difference differing by 5% in resolution. The three-module version is not as adequate as the four-module version because the decrease in the resolution does not outweigh the saved financial cost of constructing the pre-shower with fewer scintillator planes.

Single Photon Detection Efficiency

For each model, the single photon detection efficiency was determined by comparing the Monte Carlo momentum distribution after a cut was performed on the sampling fraction to that of the Monte Carlo momentum distribution without any cuts. The sampling fraction cut was determined by plotting the sampling fraction distribution and placing a cut where the beginning of the sampling fraction distribution was. Events with sampling fraction above 0.15 were accepted. Both the five- and four-module versions had 99% efficiency above 0.5 GeV, while the three-module version had 99% efficiency above 1.5 GeV (Fig. 7).

The depletion of photons below 1 GeV in the three-module version is most likely due to absorption of photons in the first few layers of double thickness lead. In order to be reconstructed, visible energy must be deposited in all three stereo readout planes. Since the three-module version has the first six layers of lead with double thickness, many photons cannot be properly reconstructed because they do not have enough energy to reach the third stereo readout panel. Even if they only make it through the first 3 readout panels, the photon may not have deposited enough energy to meet the threshold values and thus not be properly reconstructed. Considering the four- and five-modules versions are almost indistinguishable, the three-module does not appear to be a good choice for the preshower geometry.

Conclusion

With only a difference of 1.4% in the energy resolution, and a negligible difference in detection efficiency between the five- and four-modules, the suggested preshower configuration is the four-module pre-shower with twelve layers of scintillators and fifteen layers of lead.

The next step will be to do further analysis of the four-module version such as checking two-cluster efficiency and π^o mass reconstruction to verify if it is an acceptable preshower geometry in performance and cost. Also, studies with double thickness lead layers moved to last layers must be conducted.

Varying PMT configurations

The goal of these studies was to find a readout configuration with an average of 64 readout channels per stereo view, with full angular coverage of the CLAS12 forward region and a good efficiency of two cluster reconstruction. All tests were done using the five-module version with alternating 15 layers of lead and scintillator. In GSIM, the PCAL covers full angular range of the forward part of the CLAS12 and had 86 segments per readout view (4.5 cm scintillator strip width). In order to change the number of readout channels, the simulated segments in the view were combined in the reconstruction algorithm [5], doubling the size of the readout segments. The π^os were generated with momentum up to 12 GeV, θ range of 15^o to 35^o, and φ range of -3^o to 3^o.

In the reconstruction code, the readout configuration of the PCAL, the number PMTs, was controlled via 3 flags in the “tcl” file: **maxpcalstrips** sets the total number of strips per readout layer, in our case it was 86. Parameter **singlepcalstripsu** sets the number of single segment readout (one PMT per simulated segment) for the U view starting from its shortest strip. The U –view is the one that has scintillator strips oriented perpendicular to the beam line. The parameter **singlepcalstrips** sets the number of single segment readout for the V and W stereo views starting from their longest strips. The rest of the simulated segments, (**maxpcalstrips-singlepcalstripsu)** and (**maxpcalstrips-singlepcalstrips),** were combined in pairs making a double segment readouts (one PMT for two simulated segments), see Fig. 8.

Two-cluster efficiency

Four different configurations of the readout segmentation were tested. The first one was the 86 readout channels in U, V, and W strips, **maxpcalstrips=86, singlepcalstripsu=86** and **singlepcalstrips=86**. The second configuration had 86 segments in the U view and 42-single and 22-double segment readout for V and W readout views, **maxpcalstrips=86, singlepcalstripsu=86** and **singlepcalstrips=42**. The third configuration had 42-single and 22-double segment readout for U and 86 segment readout for V and W, **maxpcalstrips=86, singlepcalstripsu=42** and **singlepcalstrips=86**. The last configuration had 42-single and 22-double segment readout for U, V, and W views, **maxpcalstrips=86, singlepcalstripsu=42** and **singlepcalstrips=42**.

In Fig. 9, the two cluster reconstruction efficiency is shown as a function of π^0 momentum for all four configurations. Two cluster events were selected when two hits in the preshower or two hits in the EC were detected. The figure shows that with 64 PMTs for each readout view the efficiency of separation of two phtons decreases by about 5%. It also shows that reduction of the number of single-segment readout in the U view contributes the most to the decrease in the efficiency.

Now that it was determined that the U-strips had the most effect on the efficiency, the next step was to improve the efficiency by increasing the number of single U segment readout and decrease the number of single V and W segment readout, keeping the total number of readout channels (PMTs) per sector to 192 (an average of 64 PMTs per readout view). Three versions were tested: 50 single U and 38 single V and W segment readout; 58 single U and 34 single V and W, and 66 single U and 30 single V and W. In Fig. 10, the results of these studies are shown. In the figure all three readout views with 86 channels is shown with black line. This is the best efficiency that one can reach. The magenta line corresponds 42 single segment readout for U, V, and W. Newly simulated configurations 58/34 and 66/30 has the same efficiency as 86/86. These preliminary results confirm that 64 PMT readout channels will be possible with little loss in the efficiency. Further studies are needed to test the $\boldsymbol{\pi}^o$ mass reconstruction and $\boldsymbol{\pi}^o$ detection efficiency to better understand and differentiate between each of the versions.

π^o mass reconstruction for events with one hit in the EC

Before the $\boldsymbol{\pi}^o$ detection efficiency can be correctly calculated, the $\boldsymbol{\pi}^o$ mass reconstruction must be correct. The $\boldsymbol{\pi}^o$ mass was calculated from the following equation:

$$\boldsymbol{M}_{\gamma\gamma} = 2\boldsymbol{E}_{\gamma_1}\boldsymbol{E}_{\gamma_2}(1-\cos\theta_{\gamma_1\gamma_2})$$

Where E_{γ_1} and E_{γ_2} are energies of decay photons and $\theta_{\gamma_1\gamma_2}$ is the angle between the photons' momentum vectors. There are two types of events: when two clusters were reconstructed in the pre-shower and in the EC and when only one cluster was reconstructed in the EC. In the first case the energies of the photons were found by adding the cluster energies of each photon in the preshower and in the EC (using the geometrical matching) and then correcting with the sampling fraction. The sampling fraction was determined from the average ratio of the detected energy and the Monte Carlo simulated momentum of the photon. The positions of those photons reconstructed in the PCAL were then used to calculate the angle of separation between the decay photons. In the second case, the energy of the single cluster in the EC was distributed between the two photons according to the energy left in the pre-shower by each photon.

If there are two hits in the EC and two hits in preshower the $\boldsymbol{\pi}^o$ mass reconstruction is accurate (Fig. 11). However, if there is only one hit in the EC and two hits in the preshower, the $\boldsymbol{\pi}^o$ mass reconstruction is considerably less accurate (Fig. 12) and we believe this is mainly due to incorrect distribution of the EC cluster energy between two photons and consequently incorrect sampling fraction correction. One of the main reasons the preshower was added to the CLAS12 calorimetry was because at high energies the opening angle between the two-decay-photons becomes too small for the EC to differentiate between and it only detects one conglomerated cluster. We are having difficulty accurately differentiating the energy of the single cluster into its prospective two photons. Dividing the single-cluster by the ratio of the energy each photon left in the preshower over the total energy in preshower did not work well. The ratio of energy deposited by each photon in the EC is not exactly the same as the ratio of the energy each deposits in the preshower. It is thought more detailed analysis of energy reconstruction have to be done on the single-cluster hit in the EC in order to correctly distribute the energy and accurately reconstruct the $\boldsymbol{\pi}^o$ mass.

Next Step

The next step will be to include in the reconstruction code the data gathered from the testing of the scintillators and light guides, and estimate the resolution and efficiencies again. In addition, a more realistic particle generator should be used to get more realistic efficiency curves. Pion mass reconstruction when two clusters are reconstructed in the PCAL and only one cluster in EC needs more work.

[1] N. Dashyan and S. Stepanyan, CLAS-NOTE 2007-001.

[2] S. Stepanyan, Event generator SPGEN.

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

[4] PAW, CERN program library.

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

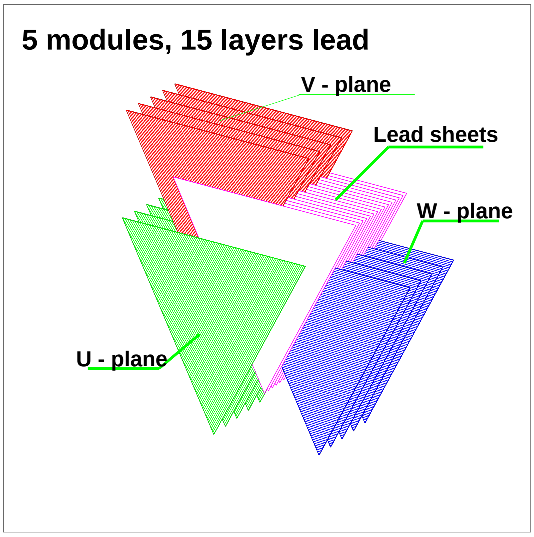


Figure 1. 5 module version with 15 layers of scintillator and 15 layers of lead.

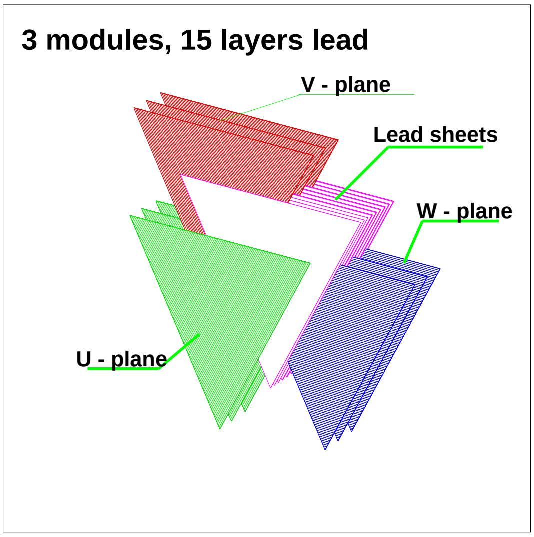


Figure 2. 3 module version with 9 layers of scintillator and 15 layers of lead. The first 6 layers of lead are doubled in thickness

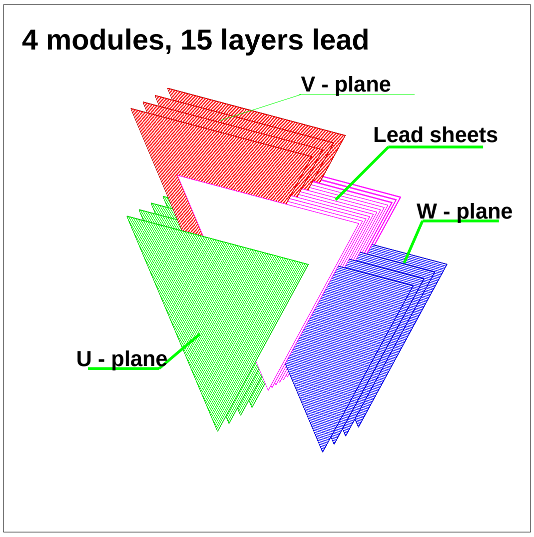


Figure 3. 4 module version with 12 layers of scintillator and 15 layers of llead. The first 3 layers of lead are doubled in thickness.

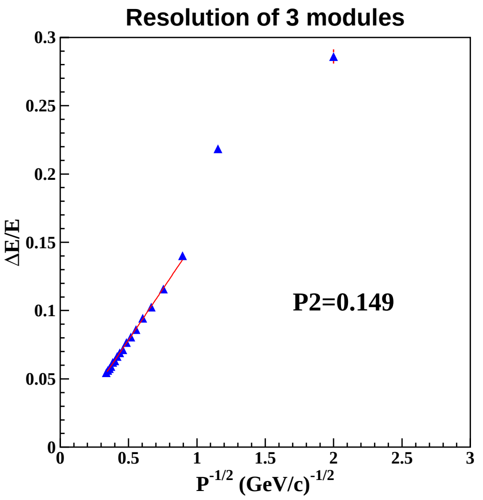


Figure 4. Resolution of 3 module. The slope, P2, is constant term.

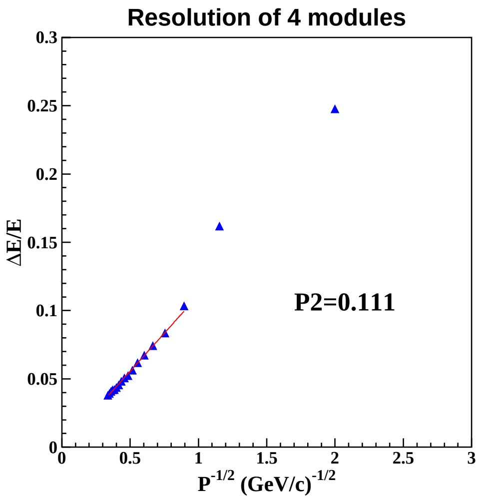


Figure 5. Resolution of 4 module. The slope, P2, is constant term.

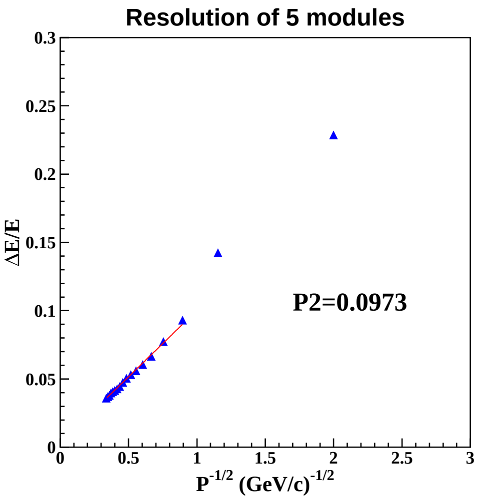


Figure 6. Resolution of 5 module. The slope, P2, is constant term.

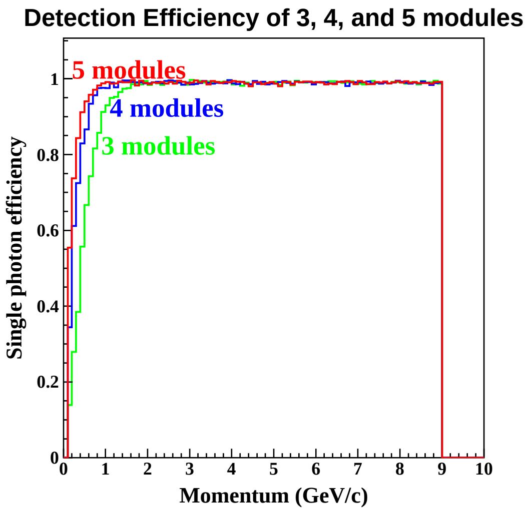


Figure 7. Photon detection efficiency for different versions. A sampling fraction cut, above 0.15, was used.

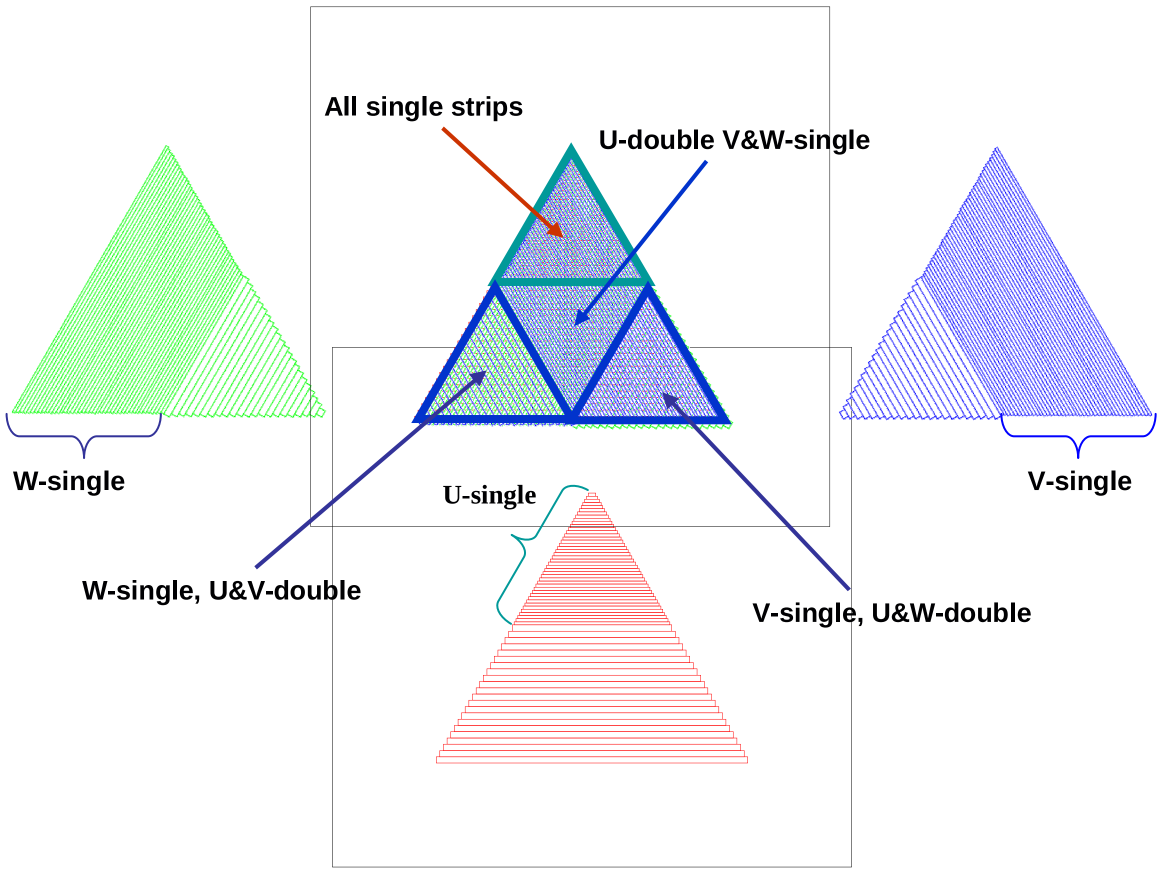
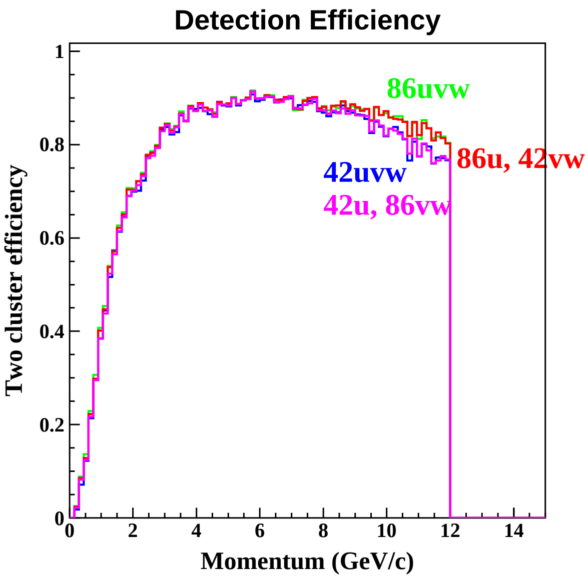


Figure 8. Single and double segment readout setup for the PCAL. The U-single is controlled by the tcl parameter **singlepcalstripsu**. The V- and W-single are set by **singlepcalstrips.**



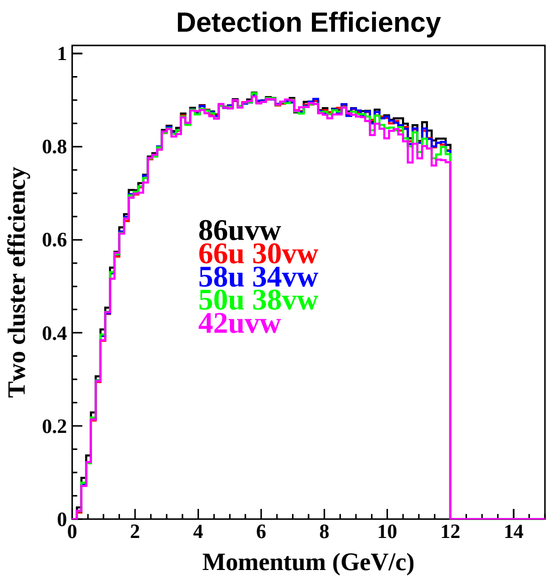
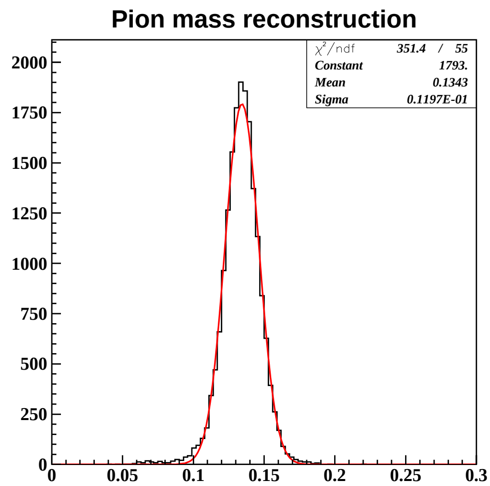


Figure 9. Two-cluster efficiency as a function of pion momentum for the different versions varying in the number of single and double strip readout. Two clusters in the pre-shower or in the EC were required.

Figure 10. Two cluster efficiency for different versions with average 64 PMTs per readout panel. A cut of two hits in the pre-shower or two hits in the EC was used.



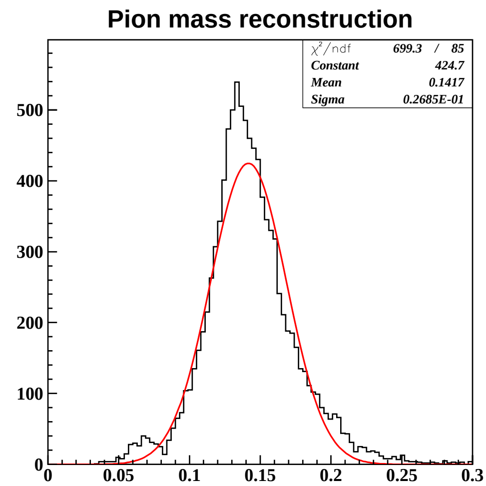


Figure 11. π^o mass reconstruction for events with reconstructed two hits in the EC and in the pre-shower.

Figure 12. π^o mass reconstruction for events with reconstructed one hit in the EC and two hits in the pre-shower.