The reaction $p(e,e'p)\pi^0$ to calibrate the Forward and the Large Angle Electromagnetic Shower Calorimeters

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***Abstract**: The energy calibration of the two electromagnetic shower calorimeters (forward and large angle) of CLAS is proposed using the reaction p(e,e'p)π° like a uniform source of monochromatic pions. A preliminary study to understand the reaction kinematics, the energy range and the calibration feasibility as well as an estimate of the counting rate is presented.*

1.1 F.E.S.C in CLAS

The CLAS Forward angle Electromagnetic Shower Calorimeter [Br95] consist of six triangular submodules which are assembled together into a hexagonal endcap. The active area of this assembly covers scattering angles of 8 to 45 degrees. The detector is a sampling calorimeter comprised of 39 layers of scintillator strips alterned with lead, divided into two stages of longitudinal read-out. The strips vary in length from 20 to 470 cm. Each submodule is constructed in a pointing geometry, such that the scintillator volume of any three mutually overlapping strips forms a truncated triangular pyramid with its apex at the target location.
The detector as constructed consists of 16.5 radiation length of material (95% in the lead) and 0.98 nuclear interaction lengths (48% in the scintillator) for perpendicular incidence.
The purposes of the forward electromagnetic shower calorimeter include: to provide significant electron-pion discrimination; measurement of time, energy and direction of neutrons and photons; and the identification of electrons at the trigger level with good position uniformity.

1.2 L.A.E.S.C. in CLAS

The Large Angle Electromagnetic Shower Calorimeter [Ta95] is the extension of the forward calorimeter of CLAS for angles larger than 45° in the laboratory system.
It is a multilayer calorimeter (see fig. 1) made by lead sheets and plastic scintillator bars; in each layer of scintillators, the bars are oriented at 90° with respect to the neighbour one, giving a measurement of X and Y coordinates of the energy deposition. Also Z is partly accessible being LAESC splitted into two parts (Inner and Outer) independently read out. It adds capability to FESC in e/π separation, π°/η mass reconstruction and neutron detection.

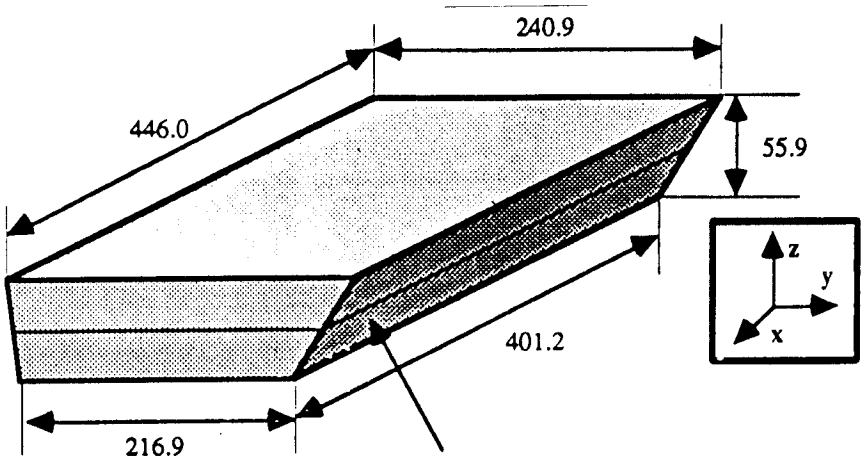

Fig. 1: the shape of LAESC

The thickness of plastic scintillator and lead have been chosen to have a depth of about 13 radiation lengths and about 1 hadron absorption length, close to the values of the forward calorimeter.

Each module of LAESC can cover, when placed in CLAS, a solid angle of about 30° in θ and 50° in ϕ and its tapered shape fits the CLAS geometry.

To perform our calibration we assumed to cover the ranges $45° \leq \theta \leq 75°$ and $-25° \leq \phi \leq 25°$ (fig. 2).

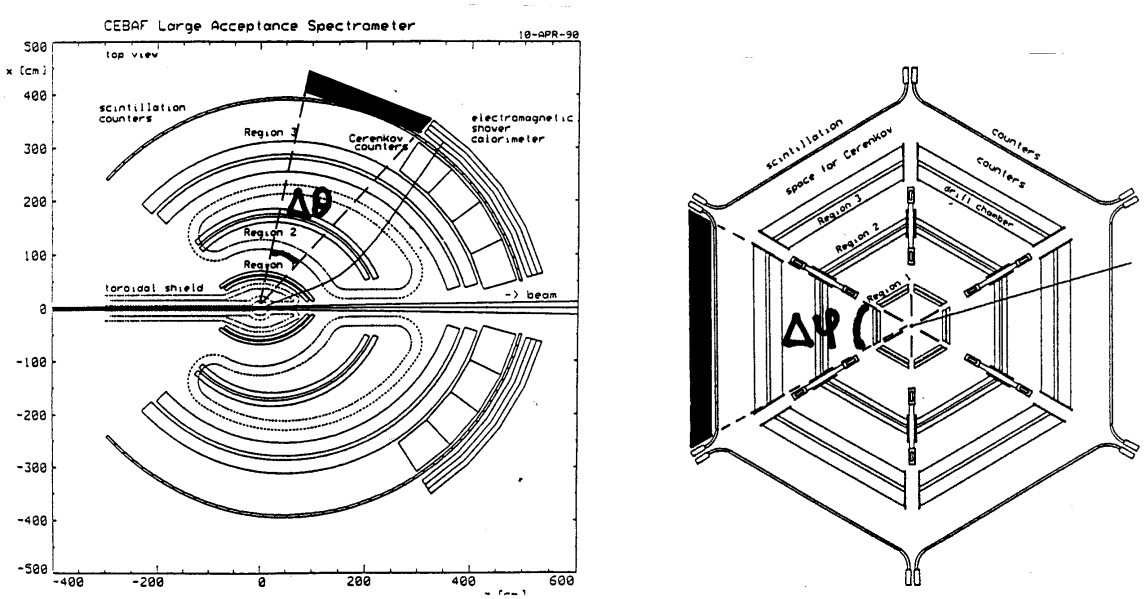

Fig. 2: the configuration of LAESC inside CLAS

2. The calibration reaction

The procedure described in the paper is a simple and preliminary study to understand wheter the $p(e,e'p)\pi^\circ$ reaction could be used to perform an energy calibration of FESC and LAESC: the reaction kinematics is investigated, the response of CLAS to the different particles is simulated using FAST_MC code and on this base, a very crude estimate of energy range and counting rates are given.

We chose the reaction $p(e,e'p)\pi^\circ$ where e' and p are detected by the rest of CLAS and the two gammas from π° decay go in the selected sector to be calibrated (one of the six modules of FESC or LAESC). For a fixed beam energy, measuring e' and p four-momenta and reconstructing π° mass, this reaction provides a tagged source of pions suitable to calibrate the calorimeter.

For $E_{beam} \approx 4$ GeV, the maximum energy of the π° is $E_{\pi^\circ} \approx 2.7$ GeV for FESC and $E_{\pi^\circ} \approx 1.4$ GeV for LAESC as shown in fig.3, while a relatively uniform irradiation of the calorimeter with a rather weak angular dependence of the energy range is obtained (fig.4).

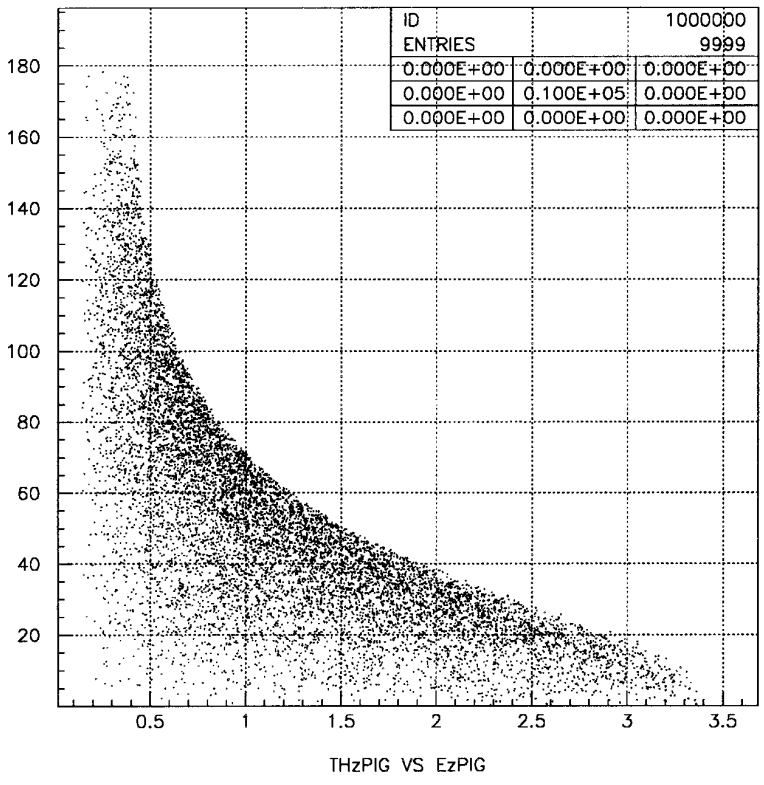

Fig. 3: correlation between ϑ_π and E_π in the reaction $p(e,e'p)\pi^\circ$ for $E_0 = 4$ GeV

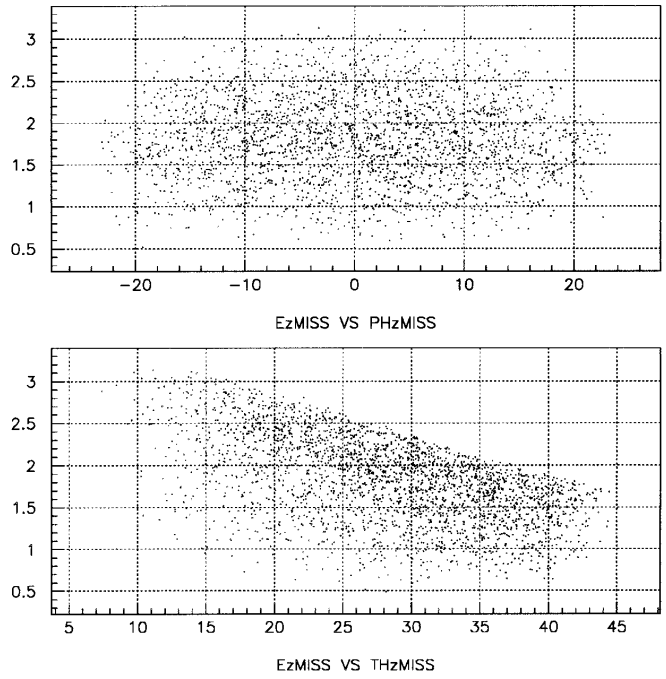

Fig. 4: FESC calibration; with the chosen reaction an almost π° uniform irradiation *of the calorimeter can be achieved.*

The cross-section for this reaction can be written as follows:

$$\left(\frac{d\sigma}{d\Omega_{e'}dE_{e'}}\right) \approx \Gamma_v(\sigma_T + \varepsilon\sigma_L)$$

where Γ_v is the virtual photon flux, σ_T and σ_L are the usual Transverse and Longitudinal cross-sections and ε is the virtual photon transverse polarisation.
In the kinematical region selected for calibration (W ≈ 2 GeV and $Q^2 \approx 0.4$ (GeV/c)^2) σ_T is assumed to be given by the dipole fit:

$$\sigma_T = \sigma_T^0\left(\frac{1}{1+Q^2(GeV)/.71}\right)^4$$

where σ_T^0 is the real photon cross-section of the order of 20 μbarn/srad, assuming $\sigma_L = 0$.
The π° decays into two photons with a relative angle given by:

$$m_{\pi^0} = 2E_{\gamma_1}E_{\gamma_2}(1-\cos\vartheta_{\gamma_1\gamma_2})$$

where $E_{\gamma_{1,2}}$ are the photons energies.

The most probable angle is obtained when $E_{\gamma_1} = E_{\gamma_2} = \frac{E_{\pi^0}}{2}$:

$$\vartheta_{\gamma_1\gamma_2} \approx 15^\circ \text{ for } E_{\pi^0} = 1\,\text{GeV}$$

Therefore we expect that in our kinematical region ($0.5\,\text{GeV} \le E_{\pi^0} \le 1.4\,\text{GeV}$) both gammas go into LAESC with a high probability.
For FESC, the situation is most favourable: the forward π_0 has a higher energy and then a smaller $\vartheta_{\gamma_1\gamma_2}$ angle.

3 The event generator *e+p —> e´+p+π°*

To study this reaction a specific event generator code was written. In Table I are shown kinematical constraints and procedure used.

Table I: the procedure to generate final state particles

e'	Lepton plane	$0 \le \varphi_e \le 360^\circ$	Uniformly
	Energy	$1/10\,E_0 \le \omega \le 9/10\,E_0$	Monte Carlo algorithm
	Scattering angle	$10^\circ \le \vartheta_e \le 45^\circ$	Monte Carlo algorithm
π^0	production angles	$0^\circ \le \vartheta_\pi^{CM} \le 180^\circ$	Uniformly in CM
		$0 \le \varphi_\pi \le 360^\circ$	Uniformly
	π^0 decay by FAST_MC code		
p	scattered proton four - momentum obtained from conservation law		

For all different electron beam energy tested (E_0=2,3,4 GeV) the initial proton is at rest in CLAS-Lab frame (Z along the beam, XZ parallel to floor plane, Y orthogonal to XZ).

4. Kinematical CUTs and reconstruction algorithm

The calibration procedure is the following:

i) the e' and p are measured by the rest of CLAS[1] (with $\approx 1\%$ precision in momentum reconstruction);

ii) using missing mass technique, the $p(e,e'p)\pi^\circ$ channel is identified;

iii) the π° four-momentum can be reconstructed from known initial kinematics.

Then the reconstructed energy of π° has to be compared with the real energy measured by FESC or LAESC.

In our simulation the final state particles were processed with an extended version [Co93] of FAST_MC (where also LAESC effective response to photons has been taken into account). Some cuts (see Table II and Table III) were imposed as signatures of the detected particles.

Table II: constraints to accept events in LAESC calibration

e'	gives signal in: I, II, III wire chamber; Cerenkov counters; T.O.F.; FESC
p	at least in: I, II, III wire chamber; T.O.F.

Table III: constraints to accept events in FESC calibration

e'	gives signal in: I, II, III wire chamber; Cerenkov counters; T.O.F.; the rest of FESC
p	at least in: I, II, III wire chamber; T.O.F.
e', p, π^0	have to involve 3 different sectors of FESC

We stress that the only information used from the sector of FESC or LAESC under calibration to select final states is the two photons geometrical acceptance. The channel can be identified reconstructing and checking the π° missing mass (see fig.5): the same reconstruction algorithm could be therefore used in real calibration.

The contamination from other possible reactions where multi-pions are produced is negligible as shown in fig.5 where the missing mass spectrum obtained including all possible channels of the $e(p,e'p)x$ reaction have been considered for E_0=4 GeV.

[1] With "rest of CLAS" we mean: FESC (6 sectors, just used as additional trigger for electrons), drift chambers, TOF, Cerenkov in the calibration procedure for LAESC and the other 5 sectors of FESC (same as before), drift chambers, TOF, Cerenkov in the calibration procedure for one module of FESC.

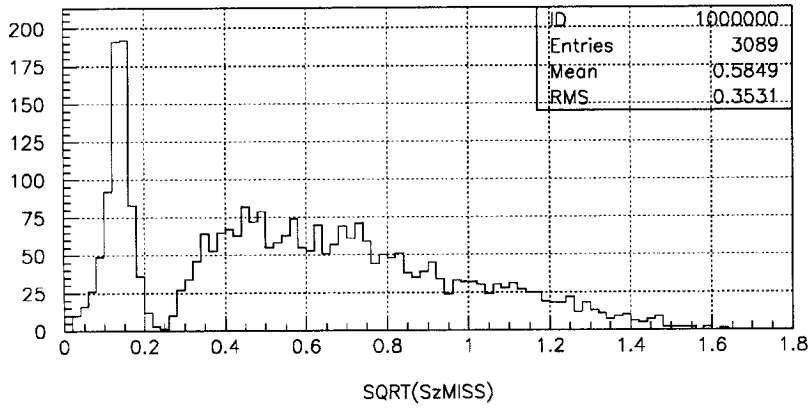

Fig.5: missing mass reconstruction; one pion channel is well identified

5. Detector set-up

Two parameters had to be fixed: CLAS magnetic field (B) and electron beam energy (E_0).
High B gives better resolution in reconstructing e´ and p (and therefore better missing mass reconstruction) but less efficiency (longer run time).
We chose B = -1/2 B_{max} that gives a reasonable compromise between efficiency and missing mass reconstruction (see fig. 6). This choice represents also a compromise with respect to the calibration with neutrons (reaction $e + p \rightarrow e + \pi^+ + n$) where detection efficiency is crucial (CLAS note under way).

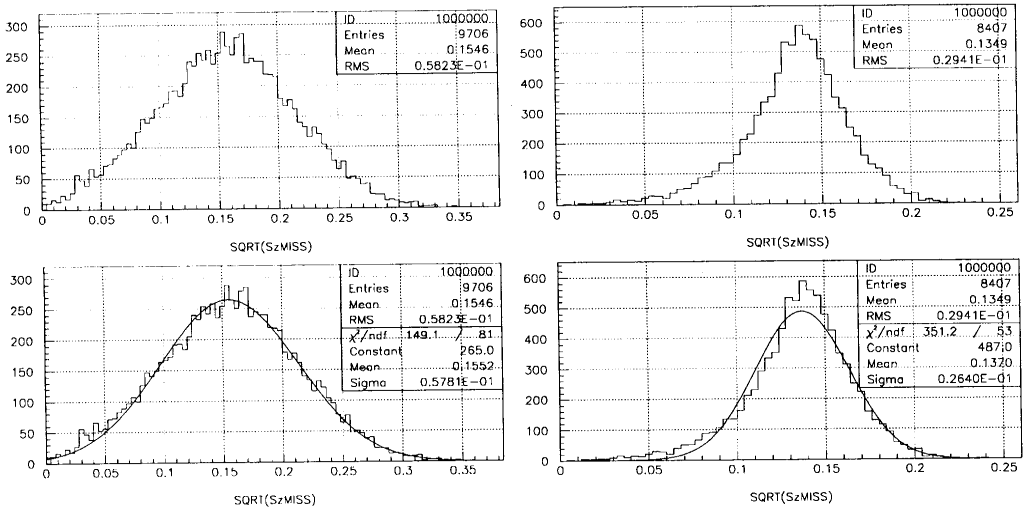

Fig. 6: Missing mass reconstruction for two values of magnetic field: left B = -1/4 B_{max}; right B = -1/2 B_{max}

Once $\sigma_{M_{miss}}$ is known, to avoid two pions contamination, we fixed the following cut:

$$\langle M_{2\pi} \rangle - 3\sigma_{M_{miss}} \approx 0.2 \text{ GeV} \qquad \Rightarrow \qquad 0.09 \text{ GeV} \leq M_{miss} \leq 0.2 \text{ GeV}$$

A 4 GeV beam energy allows to perform calibration up to $E_{\pi^0} = 1.4\, GeV$ for LAESC, as shown in fig. 7, and $E_{\pi^0} \approx 2.7$ GeV for FESC as in fig. 8.

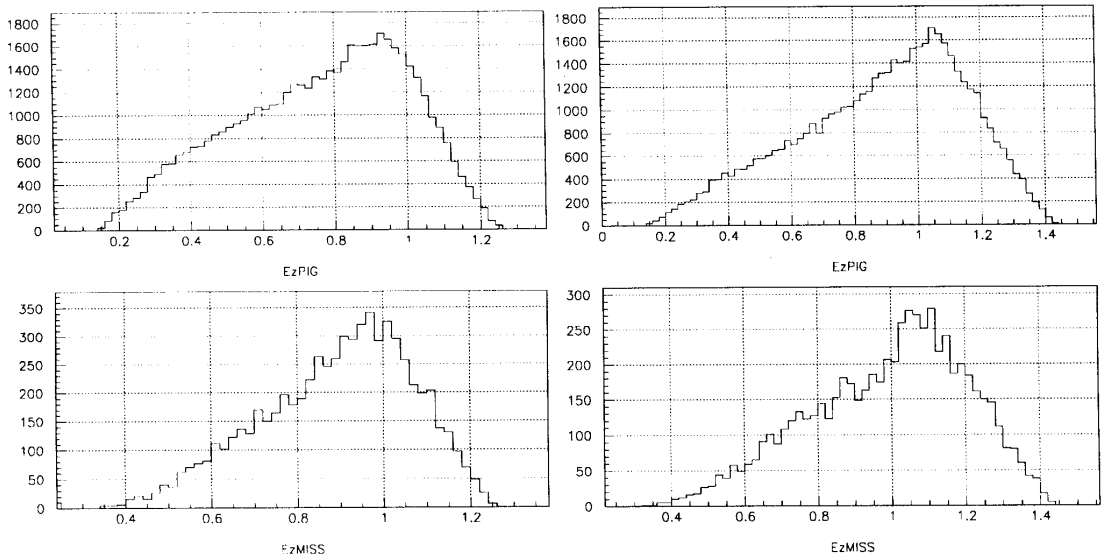

Fig. 7: LAESC calibration; spectra of generated (up) and detected (down) pions for two energy beam: left E_0 = 3 GeV; right E_0 = 4 GeV

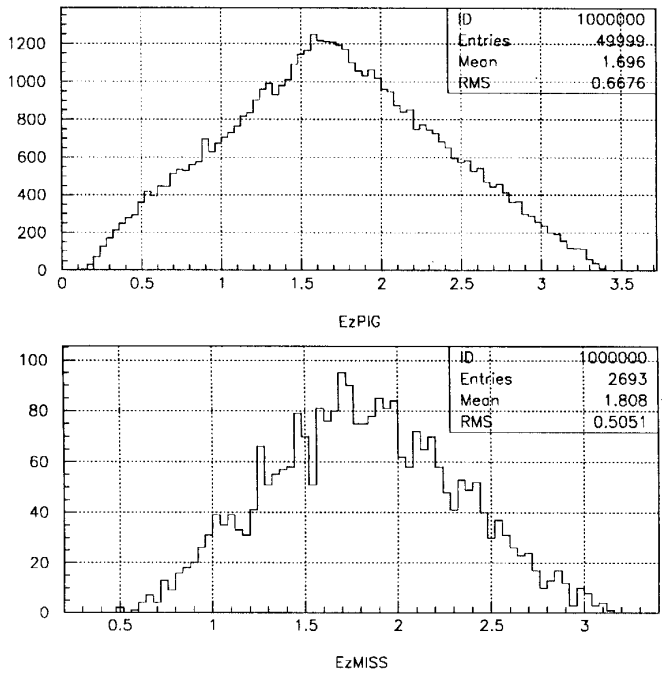

Fig 8: FESC calibration; spectra of generated (up) and detected (down) pions with E_0 = 4 GeV

6. Monochromatic π°

In order to get monochromatic pions for calibration, another cut has to be done. The intrinsic LAESC energy resolution (estimated with a Monte Carlo GEANT - based code [Mo95], is $\sigma^{LAESC}_{E_{\pi^0}\,\mathrm{recon}} \approx 70$ MeV at $E_{\pi^0} \approx 1$ GeV; the missing energy bin was therefore fixed as 20 MeV.

With this choice, we were able to simulate the measurement of the intrinsic resolution and estimate the efficiency per energy bin (see fig 9).

For FESC, we assumed an intrinsic resolution given by [Ce90] $\sigma^{FESC}_{E_{\pi^0}\,\mathrm{recon}} \approx 0.085\sqrt{E(GeV)}$ and we requested that the quadratic sum of $\sigma^{FESC}_{E_{\pi^0}\,\mathrm{recon}}$ and $\Delta^{bin}_{E_{\pi^0}}$ had to be less than 3%. This gives a 20 MeV bin at $E_{\pi^0} \approx 1$ GeV and 40 MeV bin at $E_{\pi^0} \approx 2.7$ GeV.

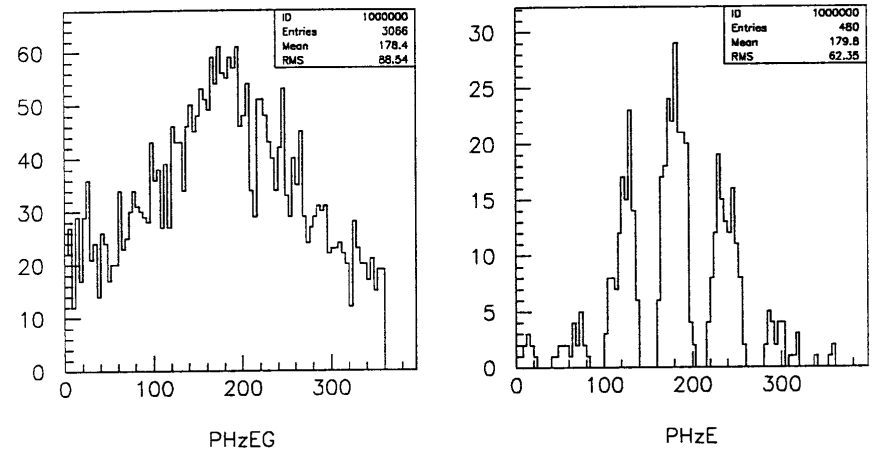

Fig 9: LAESC calibration; ϕ of scattered electrons: left generated; right detected when a 1.00 ± 0.02 GeV pion in coincidence is requested

7. Counting rate evaluation and results

The counting rate is given by:

$$R_{Tot} = \int d\Omega_{e'} dE_{e'} \left(\frac{d\sigma}{d\Omega_{e'} dE_{e'}} \right) L\, \varepsilon$$

where:

the luminosity *L* was fixed at 10^{34} /cm^{2}s (E_0=4 GeV);

the π° detection efficiency ε, given by the product of acceptance and all detection and identification procedures efficiencies was calculated to be 0.2% for LAESC and 0.5% for FESC;

the average value of cross-section ($\vartheta_e = 15°$, $Q^2 = 0.4$ (GeV/c)^2 and W = 2 GeV) is about 8 nbarn/sradGeV and the resulting integrated rate R_{Tot} turns out to be 1 event/s in LAESC and 2 events/s in FESC.

The rate of monochromatic neutral pions (both photons inside calorimeter) can be obtained grouping such events in the appropriate energy bins.

In Table IV and Table V the calibration results, for a day run, are shown.

Table IV: LAESC calibration; results for a 1 day run; values are a sample in the whole energy region accessible

π° Energy (GeV)	Counts after all cuts
0.500±0.015	550
1.100±0.020	5600
1.400±0.020	550

Table V: FESC calibration; results for a 1 day run; values are a sample in the whole energy region accessible

π° Energy (GeV)	Counts after all cuts
0.750±0.015	760
1.500±0.030	7000
2.500±0.040	4600
2.750±0.040	2100

8. Conclusions

We have investigated the use of the reaction $p(e,e'p)\pi^\circ$ for the calibration of Forward and Large Angle Electromagnetic Shower Calorimeters. Using simulated effective FESC/LAESC and CLAS response (FAST_MC code) we optimised detector set-up (magnetic field, energy beam, cuts in reconstruction algorithm).With this simple approach no detailed effects like tracking method in wire chambers or shower development in the calorimeter were taken into account; such a more sophisticated study would require a complete GEANT simulation and event reconstruction; the goal of our study was therefore to understand the gross features of the calibration. We obtained that energy calibration of FESC is feasible in 0.7 - 2.7 GeV π° energy range and the energy calibration of LAESC is feasible in 0.5 - 1.4 GeV π° energy range in a one day run at E_0=4.0 GeV with statistical error less than 2%.

9. Acknowledgement

We would like to thank in particular Will Brooks, Volker Burkert and Phil Cole for useful discussions and their productive comments.

References

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