The LAC response to neutrons via the $p(e,e'\pi^+)n$ reaction

M.Battaglieri, M.Anghinolfi, P.Corvisiero, A.Longhi, M.Ripani, M.Taiuti

Istituto Nazionale di Fisica Nucleare - Sezione di Genova

Via Dodecaneso 33, I - 16148 Genova (Italy)

***Abstract**: The evaluation of the response to neutrons (momentum resolution and* detection efficiency) of the Large Angle Calorimeter (LAC) of CLAS *is proposed using the reaction $p(e,e'\pi^+)n$ like a source of monochromatic neutrons. 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.*

Introduction

The Large Angle Calorimeter [Ta95] is the extension of the forward calorimeter of CLAS to angles larger than 45° in the lab. LAC is a multilayer sampling calorimeter made by lead sheets and plastic scintillator bars with a depth of about 13 radiation lengths and about 1 hadron absorption length. 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. Each scintillator is read out from both sides with two PMTs. Also Z coordinate is partly accessible being LAC splitted into two parts (Inner and Outer) with independent light read out. The calorimeter features include: e/π separation, π°/η mass reconstruction and neutron detection. The position of LAC in CLAS is shown in fig.1: we assumed to cover the ranges $45° \leq \theta \leq 75°$ and $-25° \leq \phi \leq 25°$.

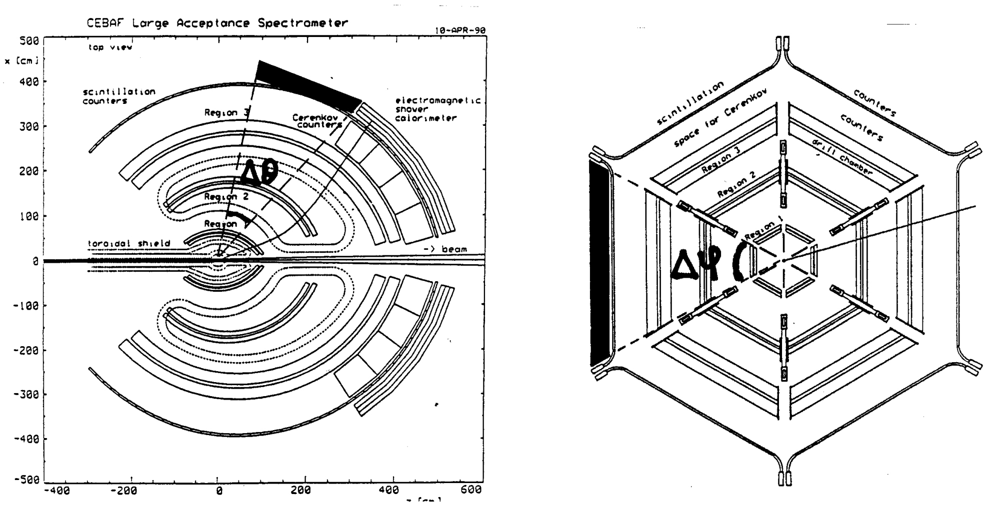

Fig. 1: the configuration of LAC inside CLAS

Before using LAC in real experimental conditions an accurate knowledge of its response function is necessary. We already measured [Ta96] the calorimeter main features (attenuation lengths, timing resolution, etc.) using the minimum ionising particles (cosmic rays) and we proposed [Ba96] to use the reaction *p(e,e'p)π^0* as a tagged source of high energy photons to measure the energy resolution of LAC.
Regarding neutron detection, two important characteristics have to be determined: neutron detection efficiency and momentum resolution. These two functions were optimised by means of Monte Carlo simulation. The procedure described in this paper is a simple and preliminary study of the reaction *p(e,e'π^+)n* as a mean to measure them: the reaction kinematics is investigated, the response of CLAS to the different particles is simulated using FAST_MC code and on this base, the best detector set-up and an estimate of the necessary time to perform the calibration are given.

1. The calibration reaction

We chose the reaction *p(e,e'π^+)n* where *e´* and π^+ are detected by the rest of CLAS and the *neutron* goes in LAC: for a fixed beam energy, measuring *e´* and π^+ four-momenta and reconstructing *n* mass, it provides a tagged source of neutrons suitable to study the calorimeter response.
For example, using $E_{beam} \approx 4$ GeV (the same value proposed for LAC energy calibration [Ba96]), the neutron go in LAC (from 45° to 75°) with momenta in the range $0.5 < p_n < 1.5 \quad GeV\ /\ c$ as shown in fig.2.

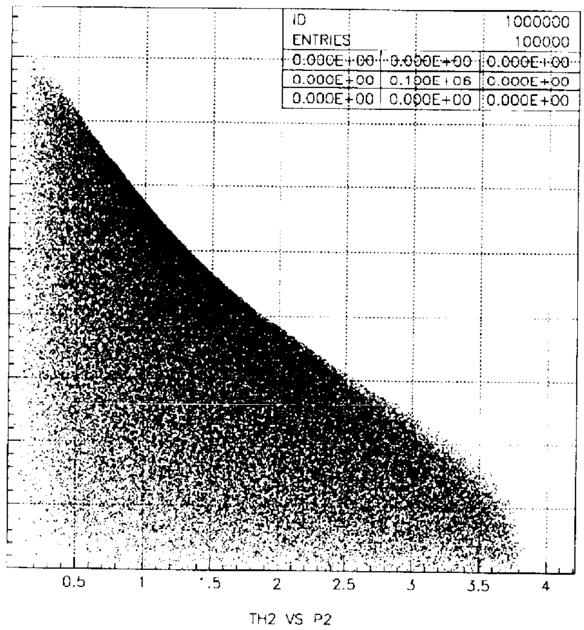

Fig. 2: correlation between ϑ_n and p_n in the reaction p(e,e'π^+)n for E_0 = 4 GeV:

in the range covered by LAC (45°< θ<75°) neutrons have momentum between 0.5 and 1.5 GeV/c

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 $Q^2 \approx 0.4$ $(\mathrm{GeV/c})^2$) σ_T is assumed to follow the dipole fit:

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

and normalised to the real photon cross-section σ_T^0 of the order of 20 μbarn/srad; σ_L is assumed equal to 0.
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.

Particle		***Range***	***Distribution***
e'	*Lepton plane*	$0 \le \varphi_e \le 360°$	*Uniform*
	Energy	$1/10\,E_0 \le \omega \le 9/10\,E_0$	*Monte Carlo algorithm*
	Scattering angle	$10° \le \vartheta_e \le 45°$	*Monte Carlo algorithm*
π^+	*production angles*	$0° \le \vartheta_\pi^{CM} \le 180°$	*Uniform in CM*
		$0 \le \varphi_\pi \le 360°$	*Uniform*
n	*produced neutron four-momentum obtained from conservation law*		

The Lorentz boost between CM and Lab frame compresses the kinematics, therefore the adopted simple-minded uniform pion distribution doesn't affect much the results.
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).

2. Simulations

2.1 Simulation of LAC response

A Monte-Carlo algorithm [Mo95] was used to simulate the LAC response: geometry, materials and read-out were correctly taken into account using the CERN GEANT 3.14 code.
The neutron has a very long mean free path in the calorimeter and only few interactions occur. Its momentum can be therefore reconstructed using the TOF information only, the energy released in the shower being strongly uncorrelated to the initial one.
As a neutron hits the calorimeter, due to the grid of scintillators, the X and Y coordinates of the interaction point can be reconstructed with a position resolution of about ±5 cm. The Z coordinate could be measured with a resolution better than ±1/4 the LAC thickness. Measuring the time of flight and knowing the distance between the target and the interaction point, the neutron velocity (and its momentum) can be reconstructed.
Even if a single scintillator gives signals, the other coordinate can be known from the time differences measured at the two bar's ends (in this way the detection efficiency grows up but the momentum resolution decreases).
In figs.3 and 4 are shown the results of the MC simulation for an uniform irradiation of LAC with neutrons in the momentum range of our interest.

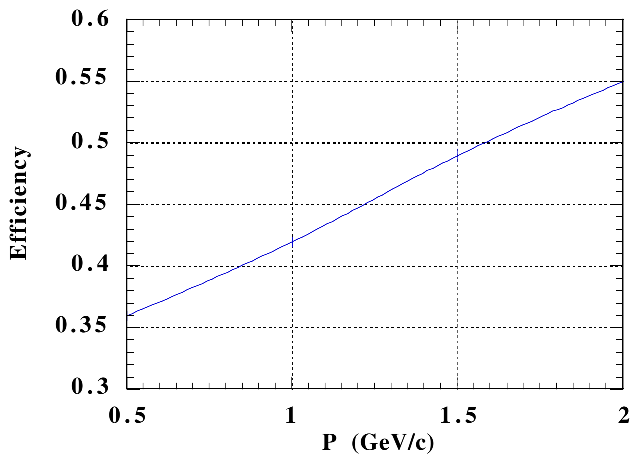

Fig.3: the neutron efficiency as obtained by the GEANT simulation

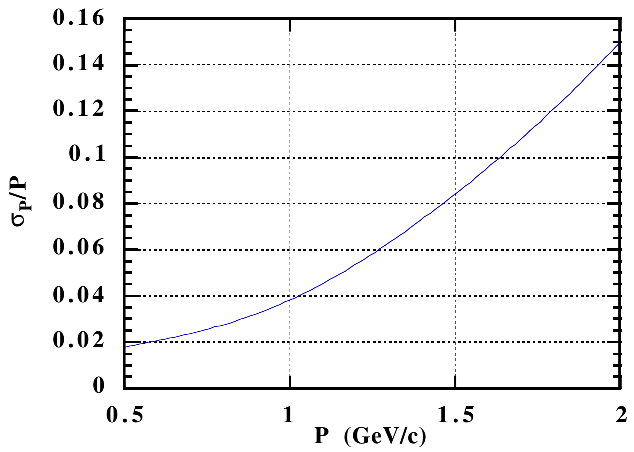

Fig.4: the neutron momentum resolution as obtained by the GEANT simulation

These obtained efficiency and momentum resolution curves were included in FAST_MC code [Co96] to simulate the LAC response to neutron.

2.2 Calibration procedure

We propose the following calibration procedure:

1) the *e´* and π^+ are measured by CLAS (excluding LAC) with $\approx 1\%$ precision in momentum reconstruction;

2) the $p(e,e'\pi^+)n$ channel is identified using missing mass technique;

3) the *neutron* four-momentum is reconstructed from known initial kinematics.

In our simulation the final state particles were processed with an extended version [Co93] of FAST_MC. Some cuts (see Table II) were imposed to identify the detected particles.

Table II: constraints to accept events in LAC calibration

e´ gives signal in:	*I, II, III wire chamber; Cherenkov counters; T.O.F.; EC*
π^+ *at least in:*	*I, II, III wire chamber; T.O.F.*

Then i) detection efficiency can be evaluate comparing the number of LAC-detected neutrons respect to the generated ones ("signature" in the rest of CLAS) and ii) the "missing" momentum of *n* can be compared with the momentum reconstructed by LAC.

We stress that the only information used from LAC to select final states is the neutron geometrical acceptance.

2.2 Background evaluation

We have generated multi-pions channels according to the following statements:

- *proton* in initial state;
- π^+ and not more than another pion in final state.

The relative weight was given according to $\sigma_{ch}(W)$ and the generated particles have uniform distribution in the CM In Table III the three contributing channels are shown.

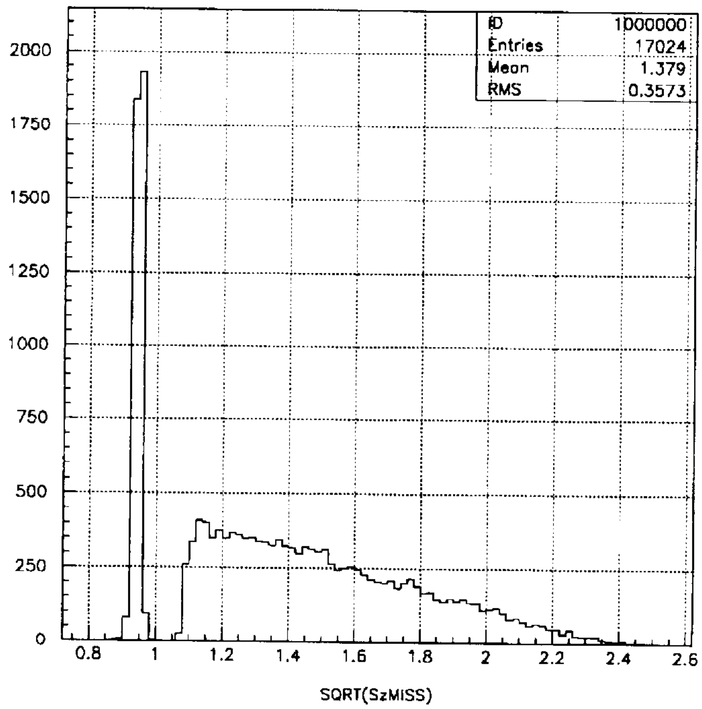

Fig.5: missing mass reconstruction; one pion channel is well defined

Table III: possible reactions and relative weights when π^+ is detected in final state.

$\gamma_v + p \rightarrow \pi^+ + n$	22%
$\gamma_v + p \rightarrow \pi^+ + \pi^0 + n$	22%
$\gamma_v + p \rightarrow \pi^+ + \pi^- + p$	56%

The *p(e,e'π^+)n* channel can be identified reconstructing and checking the *n* missing mass. Fig.5 shows the peak corresponding to the missing mass of a neutron well separated from channels with two pions. No contamination and no efficiency loss are therefore present when missing mass and angular cuts (*neutron* in LAC) are performed.

3. Results

3.1 Detector set-up

The simulation of the response of LAC to neutrons and the definition of both the kinematical CUTs and reconstruction algorithm could be used to determine the best detector set-up to run the calibration.

Two parameters had to be fixed: the CLAS magnetic field (B) and the electron beam energy (E_0).

To choose the running energy, we simulated neutron spectra at different energies: as shown in fig.6, a 4 GeV beam is preferable because it allows to perform calibration up to $p_n = 1.5\ GeV\ /\ c$.

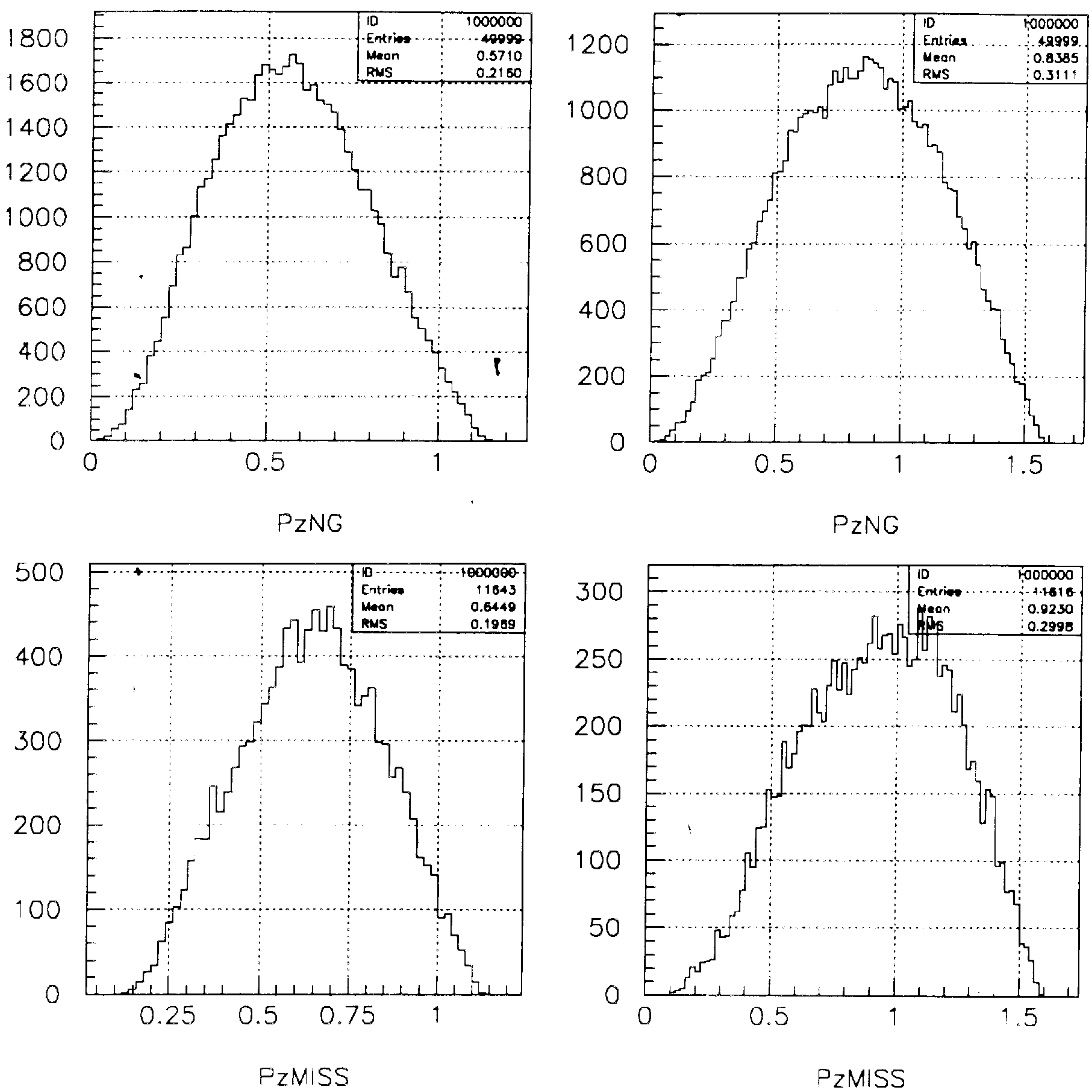

Fig.6 spectra of generated (up) and detected (down) neutrons for two energy beam; left E_0 = 3 GeV; right E_0 = 4 GeV

High B gives better resolution in reconstructing e´ and π^+ (and therefore better missing mass reconstruction) but less efficiency (longer run time) because electrons are more deflected toward the beam pipe.

The detection efficiency for this reaction is crucial: as shown in fig.7 about 50% of electrons and pions are stopped by coils and when the triple coincidence is requested (neutron gives signal in calorimeter) only a few percent of the total events are detected. Fig.8 shows that the maximum detection efficiency is obtained when B = -1/2 B_{max}. The curve is not symmetric due to the different bending of the pion with respect to the electron in the two different field polarities (+ or -).

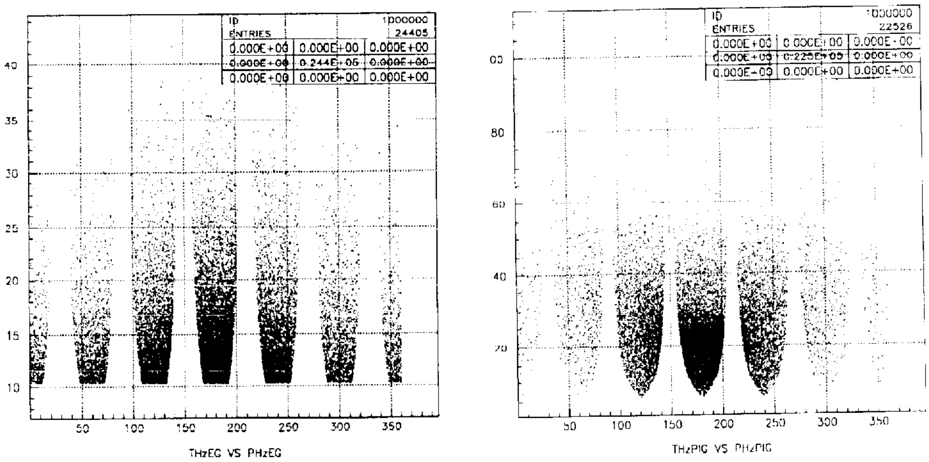

Fig.7 electrons (left) and pions (right) detected by CLAS; the cuts from coils in phi angle are evident

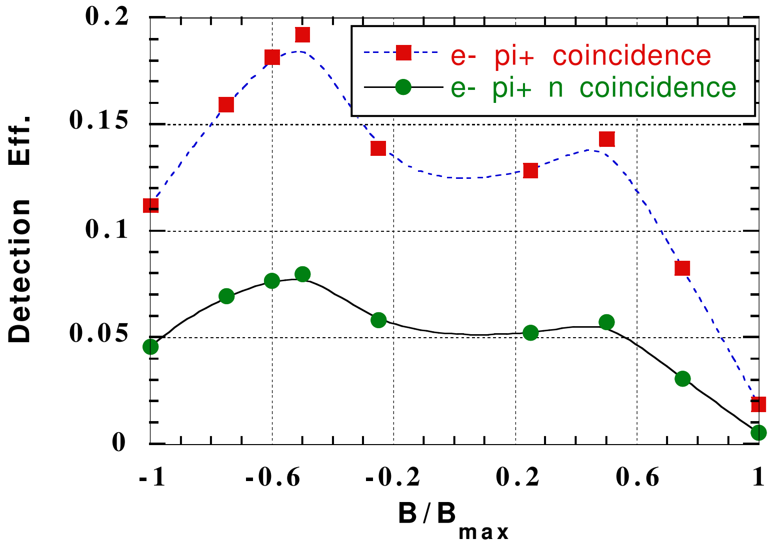

Fig.8: double and triple coincidence efficiency as function of CLAS magnetic field

The resolution of charged particles as function of B was also studied. In fig.9 is shown the error on the missing (neutron) mass when electron and pion are detected by the rest of CLAS (with B=0 the charged particles momentum can not be determined).

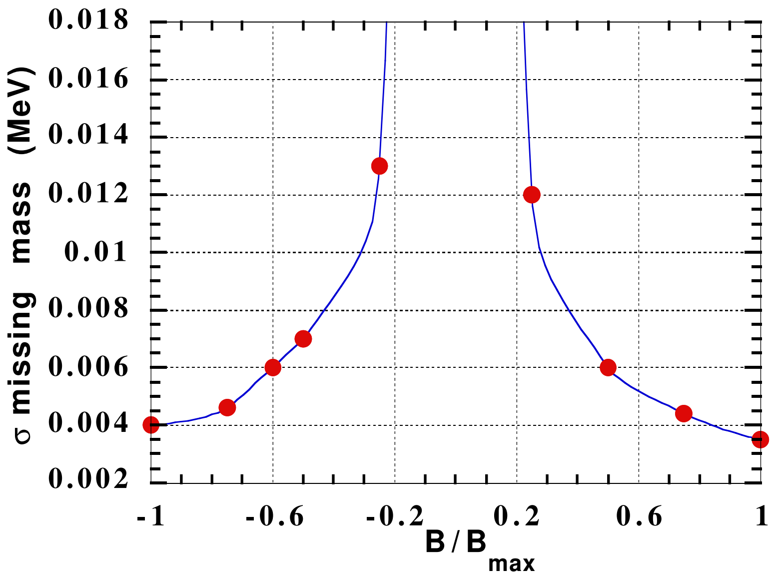

Fig.9: r.m.s. of missing (neutron) mass as function of CLAS magnetic field

A good compromise between efficiency and resolution is therefore obtained fixing |B| = 1/2 B_{max} and negative bending. With this value the resulting $\sigma_{M_{miss}}$ is about 7 MeV.
This procedure allows to determine the missing mass cut: at $3\sigma_{M_{miss}}$ confidence level this is fixed as:

$$0.92\ GeV \le M_{miss} \le 0.96\ GeV$$

This is not a crucial value: as we have already shown the contamination with the background is negligible. It is useful to note that this value of B is the same chosen for the other proposed calibration reaction [Ba96] where the separation was more difficult.

3.2 Neutron binning

The momentum resolution can be determined tagging the neutron energy in CLAS as described in section 2.2 and comparing with the momentum reconstructed by LAC.
In order to get monoenergetic neutron a cut on the missing particle momentum has to be done. To fix the bin size we requested a maximum variation of 10% with respect to the intrinsic LAC momentum resolution (GEANT-simulated), when summed (quadratically) with the bin size resolution. For instance, at $p_n \approx 1\ GeV/c$, the resolution is $\sigma_n^{Intr.} \approx 40\ MeV\ /c$ (as reported in fig.4), therefore the missing momentum bin was fixed as 20 MeV/c.

3.3 Counting rate evaluation

The counting rate is given by:

$$R = \int d\Omega_{e'} dE_{e'} \left(\frac{d\sigma}{d\Omega_{e'} dE_{e'}} \right) L \, \varepsilon_{neutron}$$

where:

the luminosity L was fixed at 10^{34} $cm^{-2}s^{-1}$ (E_0=4 GeV);

the overall n detection efficiency $\varepsilon_{neutron}$, given by the product of geometrical acceptance (LAC coverage of solid angle: ≈ 4.5%) and all detection and identification procedure efficiencies (see fig.8: ≈ 8%) was calculated to be 0.35%;

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 turns out to be 1.5 events/s.

The rate of monoenergetic neutrons can be obtained grouping such events in the appropriate energy bins.

The error on efficiency is given, as usual, by:

$$\delta_{eff} = \frac{1}{\sqrt{N}}$$

and the error on momentum resolution is:

$$\delta\left(\frac{\sigma_p}{p}\right) = \frac{1}{p}\delta_p + \frac{\sigma_p}{p^2}\delta_{\sigma_p} = \frac{\sigma_p}{p}\frac{1}{\sqrt{N}} + \left(\frac{\sigma_p}{p}\right)^2 \frac{1}{\sqrt{2N}}$$

while σ_p is the r.m.s. of measured neutron momentum and N the number of counts in each bin. In one day run with a 4 GeV beam, the results shown in table III are obtained.

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

p_n (GeV/c)	Counts after all cuts	Efficiency (%)	Mom. resolution (%)
0.500±0.020	3200	38.0±0.4	3.00±0.05
1.000±0.020	6000	34.0±0.3	4.50±0.05
1.500±0.050	4000	52.0±0.5	9.3±0.1

Conclusions

We have investigated the use of the reaction *p(e,e'π^+)n* to obtain the Large Angle Calorimeter response to neutrons. Using simulated effective LAC 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 detailed neutron interaction in the calorimeter were taken into account (we used only the final results of a GEANT simulation): such a more sophisticated study would require the complete GEANT simulation and event reconstruction. The goal of our study was therefore to understand the gross features of the calibration. In the proposed measurement the neutron momentum resolution and detection efficiency of LAC is obtainable in the 0.5 - 1.5 GeV/c momentum range in, at least, one day run at E_0=4.0 GeV with reasonable statistical error.

Acknowledgements

We would like to thank the CEBAF Hall B Collaboration's physicists for useful discussions; we are particular thankful to Will Brooks, Volker Burkert and Phil Cole for their comments.

References

[Ba96] M.Battaglieri et al. CLAS Note 96-011
[Co93] P.Cole CLAS note 93-006
[Co96] P.Cole *private communication*
[Mo95] V.Mokev et al. INFN/BE-95/02
[Ta95] M.Taiuti et al. INFN/BE-95/03
[Ta96] M.Taiuti et al. *submitted to NIM*