CALIBRATION AND PERFORMANCE OF A LARGE MODULAR NEUTRON DETECTOR USED IN AN ON-LINE ELECTROPRODUCTION EXPERIMENT*

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The successful application of a large aperture modular neutron detector, consisting of 145 plastic scintillator elements, operating in a high intensity background environment is reported. A description of the on-line data acquisition and monitoring system is also presented. The threshold on each counter was maintained within ± 1 dB and the timing was monitored to $\pm$ 300 psec, using a multiplexed light diode system under computer control. The efficiency and spatial resolution measurements in the neutron kinetic energy range 15 - 120 MeV are reported and compared with Monte Carlo predictions.

1. INTRODUCTION

A large aperture neutron detector is currently being used in a series of electroproduction experiments(1) at the Daresbury Nuclear Physics Laboratory, in which the final state neutron is detected in coincidence with the inelastically scattered electron. The first experiment completed was a measurement of the total cross section and angular distribution of the process $e^-p \rightarrow e^-n\pi^+$ (PION ELECTRO-PRODUCTION) near the threshold region(2).

The experimental layout is shown in fig. 1. A high energy electron beam (typical intensity 5×10^{11} e^-/sec) is focussed onto a liquid hydrogen target, 3.8 cm diameter by 10 cm long. The scattered electron is detected in a conventional high resolution spectrometer; the energy and production angles of the associated neutron are measured in a large neutron TOF spectrometer, having a total sensitive area and volume of 3.39 m^2 and 0.916 m^3 respectively. A double fence of scintillation counters (veto counters), covering the front face of the neutron counter and biassed for minimum ionizing particles, is used to measure the charged particle background from the target. The whole assembly, housed in a lead/steel bunker, weighing approximately 40 tons, can be set at angles between 12° and 63° to the incident electron beam and at a distance between 3 m and 8 m from the target.

2. THE PEP NEUTRON COUNTER

The design and performance of the neutron counter were dictated by the requirements of the threshold experiment. A counter was required which would:

i) have a high and reproducible detection efficiency (of the order of 20%) for neutrons in the energy range 30 - 200 MeV;
ii) measure the polar and azimuthal angles of the neutron over the total solid angle, ~ 0.24 sterad, covered in PEP;
iii) determine the energy of the neutron using time of flight technique with an accuracy of $\pm$ 1 nsec;
iv) operate effectively in the high background environment associated with an intense electron beam.

These considerations led to a hodoscope type of counter consisting of a 2x2 m array of 145 plastic scintillator (NE110) blocks, each 15.3x15.3x27. cm long. The basic constructio-

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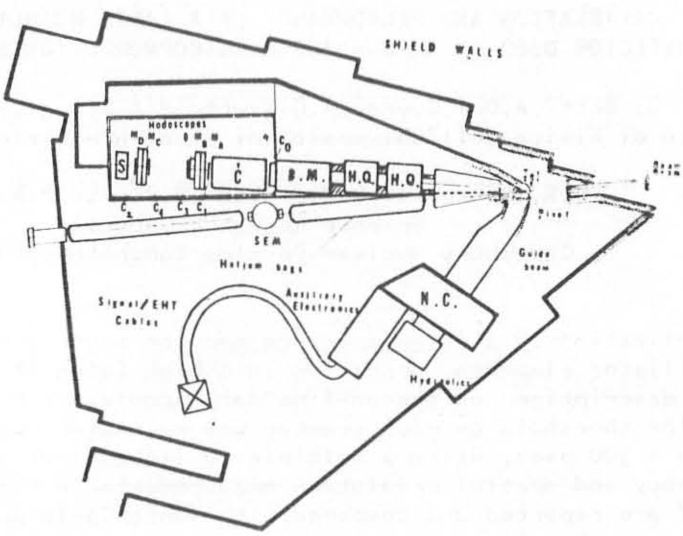


FIG.1 - Experimental Layout

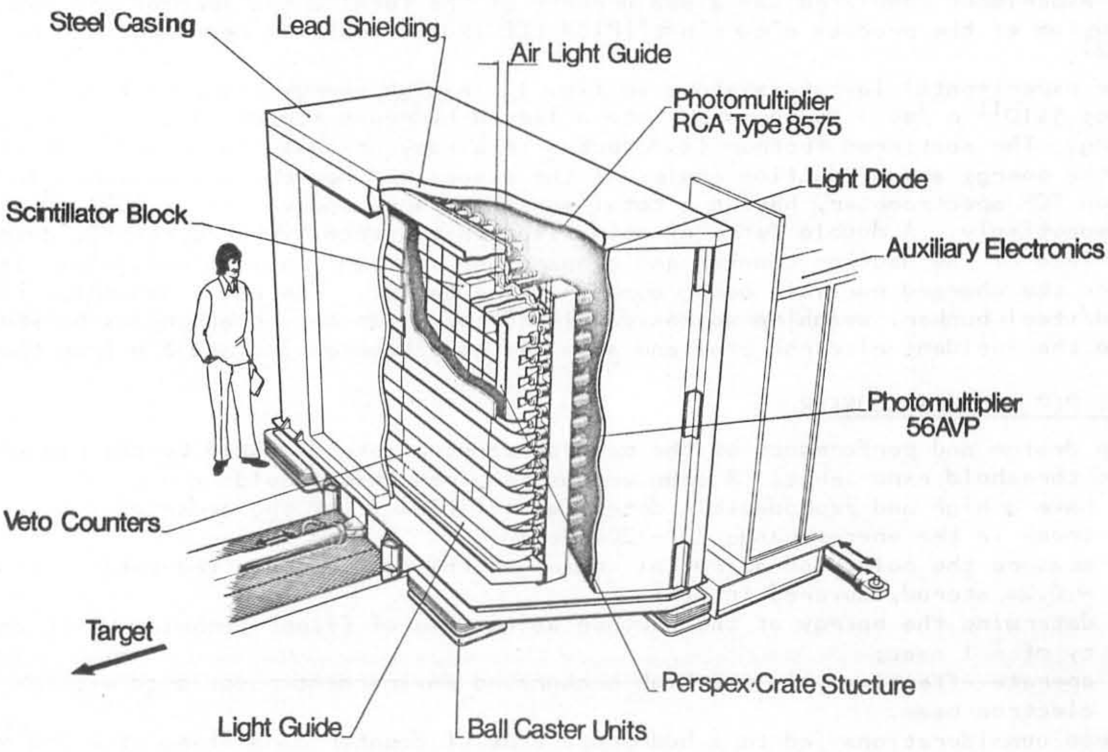


FIG.2 - PEP Neutron Counter

nal simplicity is shown in fig. 2. The scintillator blocks, wrapped in reflecting aluminium foil, are supported in a 13x13 lattice formed by interlocking black perspex sheets, 6 mm thick, the ends of which are retained in slots machined on the inside of a 50 mm thick black perspex box. Six compartments at each corner of the lattice are unoccupied giving the counter an approximately cylindrical geometry. Each block is viewed by an RCA8575 photomultiplier via an air light guide, which is simply an extension of the scintillator compartment coated with a diffusive reflective paint (NE560). The veto system consists of 26 pairs of scintillation counters, each covering a single neutron block in the vertical direction and extending half way across the face of the neutron counter. NE110 scintillator, 1 cm thick, was chosen for its excellent light transmission and Philips 56AVP photomultipliers for their high gain. To provide a compact and accessible structure the solid perspex light guides are bent through 90°. Each neutron and veto counter is fitted with a solid state light source (Ferranti type PD5002) for the purpose of checking the counter's timing, gain and associated logic channel. To reduce the background rates the counter system is shielded towards the target by 2.5 cm of lead and by 10 cm elsewhere. The whole assembly is supported on a steel base, resting on four large ball castor units. It can be set at any desired position within the constraints imposed by the shield walls and the electron beam line by means of two hydraulic rams attached to a guide beam passing beneath the counter.

A simplified schematic of the fast logic is shown in fig. 3. Five scintillation counters ($C_0C_1C_2C_3C_4$) a gas Cerenkov ($\check{C}$) and a lead-lucite shower (S) counter define the "electron trigger". This is fanned out to strobe the neutron and veto coincidence latches and generate the TOF start pulses. Trigger counter C_1 contains the "zero time" information; since this a large counter the transit time variations of the light within the scintillator are corrected for by reconstructing the electron's interaction point using the electron arm hodoscope information. After gating, the neutron and veto TOF stop pulses are grouped in 20 and 8 separate time encoder channels respectively, in such a way as to maximize the physical distance between counters in the same channel. Zero crossing discriminators, triggering at the 50% amplitude phase point of the clipped anode pulses, are used to reduce the time slew due to the large dynamic range of pulse heights produced in neutron interactions.

In order to minimize the number of control operations, the neutron counter photomultiplier EHTs are kept constant (within $\pm$ 0.1%) and the bias levels are adjusted using variable attenuators situated before the discriminators. In this way it is possible to compensate for large gain changes without affecting the counter timing. Prior to data taking the following setting up procedure is carried out:

i) the bias on all the 145 counters is initially set at a level corresponding to the mid point of the Compton edge of the $ThC^{11}\gamma$-spectrum. A fixed amount of attenuation is then added to each channel to give a working proton bias level of 15 MeV;

ii) the relative timing of the counters is determined using cosmic ray tracks defined by the top and bottom counter rows. An analysis of the tracks gives a time accuracy better than $\pm$ 300 psec;

iii) an absolute TOF calibration is carried out using the process $\gamma p \rightarrow \pi^+ n$, detecting the π^+ in the electron spectrometer;

iv) the correct operation of each counter channel is automatically checked using a computer controlled monitoring system; reference tables of the neutron counters' gain and timing are recorded for control purposes.

3. ON-LINE DATA ACQUISITION AND MONITORING SYSTEM

A schematic of the on-line system is shown in fig. 3. Data acquisition, control and setting up of the experimental hardware is achieved using a 5-crate CAMAC system(3), interfaced to Honeywell DDP 516 (8K) computer connected via a fast data link(4) and an IBM 1800 multiplexer to the laboratory's large time shared IBM 370/165 computer. An ASR 35 teletype, several CAMAC interfaced keyboards and two Tektronix 611 storage displays provide operator interactive control over the experiment. The DDP 516 is programmed entirely in machine language (DAP 16); a fixed partition foreground/background configuration was adopted, servicing 8 real time interrupts and organising a background cyclic JOBQ.

The resident 370 on-line programme occupies 70 Kbytes of core. Use of the rollin-rollout procedure in the MVT operating system allows additional subtasks to be attached at the request of the "main task" or at the specific request of the experimenter via the data link. The main functions of the system are:

3.1.1. - Data acquisition. Upon receipt of the master trigger event data are strobed into the CAMAC system and read into a 50 word event buffer in the DDP 516. When five buffers are filled the DDP 516 generates an interrupt to request service at the IBM 1800. When the request is granted the transfer commences asynchronously at a rate of 50×10^3 16-bit words per second, although rates of 260×10^3 words are possible using a DMA channel. The data are stored on a 2311 disk at the IBM 370, being automatically transferred to magnetic tape when the disk is full. Magnetic tape back up is provided in the event of 370 failure.

3.1.2. - On-line analysis. The DDP 516 performs a simple unpacking and histogramming of selected words from the data event block on a sampling basis. A more complex analysis such as kinematic reconstruction and multiplicity calculations is carried out by the IBM 370 on a statistically significant number of events. The current or any previous run, while the data are still on disk, may be analyzed at a rate of $\sim$500 events per second of the CPU time. On demand, the results of the analysis are returned down the link and displayed in tabular and histogram form on a storage scope (fig. 4). These displays form an invaluable control of the data quality and reproducibility.

3.1.3. - On-line monitoring. The values of important parameters such as counter gain and timing are periodically scanned and measured by the DDP 516; the basic philosophy and procedures used are well established[5]. The results of these measurements are displayed on a storage scope by the DDP 516 (fig. 5a) and are sent to the IBM 370 to be compared against standard reference values held on disk. Out of limit values together with the correct settings are returned to the DDP 516 so that corrections can be made to errant channels (fig. 5b). A complete scan of all the 145 neutron counters including feedback, measuring a single parameter in each channel, takes as little as two minutes. A schematic of the monitoring system hardware is shown in fig. 6. Each counter is fitted with a light diode driven by multiplexing, under CAMAC control, the output of a common avalanche pulser. Extensive stability tests, made on the light diodes, showed that the gain and the timing of the counters can be controlled to better than $\pm$ 1 dB and $\pm$ 300 psec respectively. Analogue and logic signals are routed by means of input strip line multiplexers to common monitoring systems to measure counter gain and timing, gated and ungated singles rates, discriminator threshold levels and to checkout the data acquisition system. The multiplexers, implemented in NIM format, use transistor can relays mounted in a 50Ω strip line configuration. Up to sixteen 60 way systems may be linked together and driven from a single 16 bit CAMAC output driver. An analogue voltage multiplexer is used to scan the counter EHTs and crate voltages.

A modular approach was also adopted for the monitoring system software. Each systems programme module, which performs a specific monitoring function, is stored on the IBM 370 disk from the DDP 516. On demand, anyone of 26 such programmes may be "OVERLAYED" into a reserved 512 word sector of the DDP 516 core, and run on a time sharing basis with other jobs in the JOBQ during data taking. Subroutine links made between the DDP 516 executive programme and the OVERLAY sector lead to an efficient utilisation of the limited core space available.

4. EFFICIENCY AND SPATIAL RESOLUTION MEASUREMENTS

The efficiency of the neutron detector was determined by measuring the efficiency of a 3x3 element module of identical construction[6], using the Harwell Time-Of-Flight facility[7]. The neutron beam, produced by deflecting the extracted 143 MeV proton beam from the synchrocyclotron onto a thin Al target, was then collimated along a 50 m path to produce a "beam spot" of $\sim$ 20 mm square at the neutron module. The maximum neutron energy was 137 MeV, but for statistical reasons the useful range was between 15 and 120 MeV. For each trigger, the address of each counter firing and the time of flight of the event was recorded. A standard counter of known efficiency pariodically replaced the module in the beam. The efficiency as a function of energy was then determined by comparing the two TOF spectra, normalized to the same number of incident neutrons. Several measurements

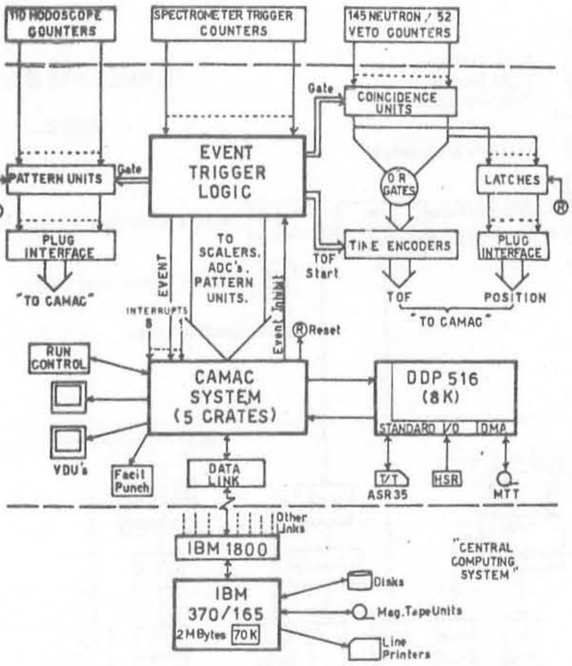


FIG.3 - On-line system

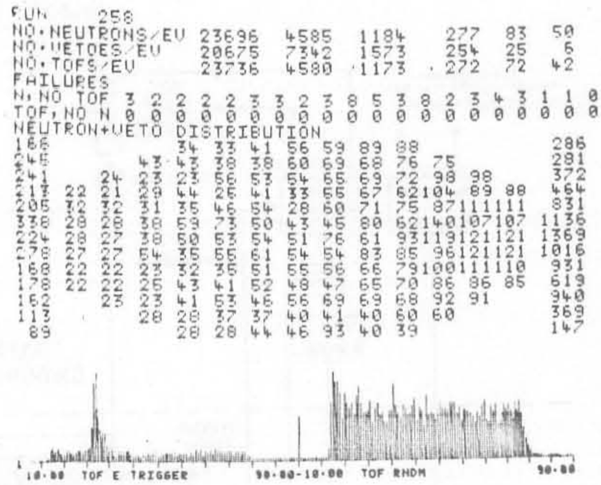
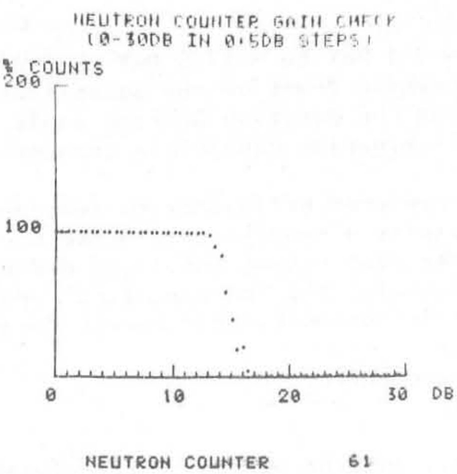
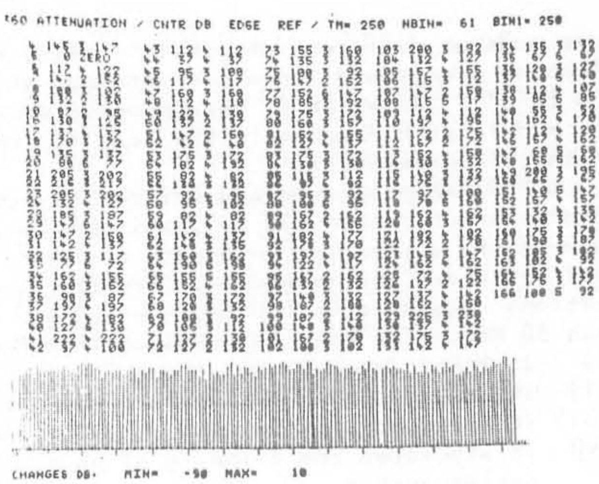


FIG.4 - Typical storage display showing neutron and veto counters and tof channel multiplicities, coincidence latches and tof channels failures, gated singles in the neutron and veto counters, electron and random triggers' tof spectra.



(a)



(b)

FIG.5 - Neutron Counter gain monitoring displays :
(a) DDP 516 generated
(b) IBM 370/165 feedback

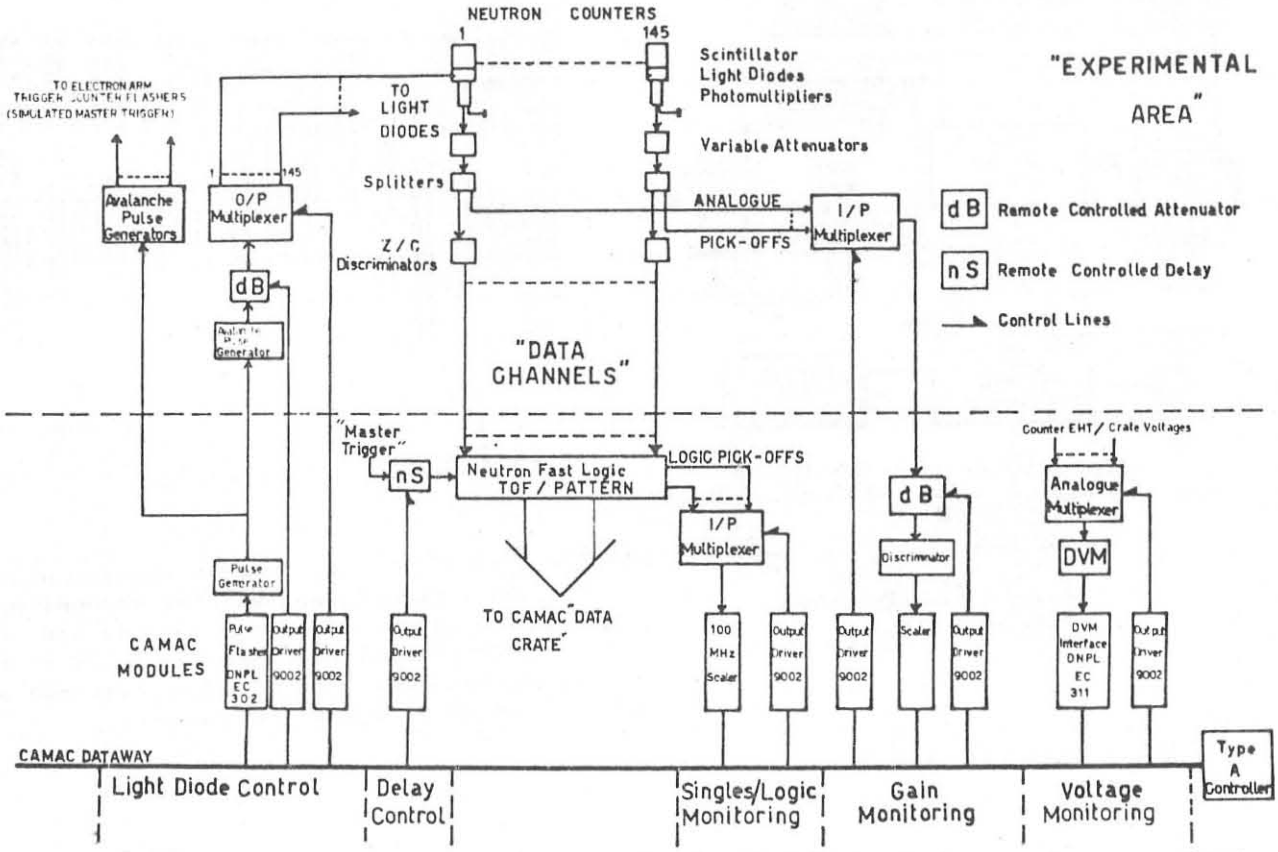


FIG. 6 - Neutron Counter Monitoring System

were made at different threshold levels, ranging from ~ 2.4 MeV to ~ 13.5 MeV equivalent electron energy and for different lead shielding thicknesses in front of the scintillator (up to 3"). A series of measurements were taken changing the position and the angle of the module with respect to the beam to reproduce the illumination conditions encountered in the PEP experiment.

A FORTRAN programme was written to extrapolate the measured efficiency to neutron energies greater than 120 MeV; this programme was essentially a reworking in Monte Carlo form of the successful programme of Kurz[8], based on the most recent total and differential n-C cross sections data. For the inelastic n-C channels, the "parametrized" cross sections suggested by Edelstein et al.[9] were used for a neutron kinetic energy greater than 30 MeV. The main features of this Monte Carlo are:

i) it takes into account the modular structure of the counter,
ii) it includes higher than second order rescattering,
iii) it provides spatial resolution of the counter,
iv) it simulates the clipping of photomultiplier signal and the effect of the electronic gating system.

Both elastic and inelastic scattering of the incoming neutron with the shielding are also considered. The latter has been treated under the assumption that the lead nucleus may be described by the statistical model[10]. Good agreement was obtained with the experimental data for neutron kinetic energy greater than 50 MeV.

Fig. 7 shows the efficiency measurements for two different shielding thicknesses and threshold levels, compared with the Monte Carlo predictions.

The spatial resolution, principally determined by the size of each block, is also affected by the rescattering of the neutron within the scintillator and by the interaction

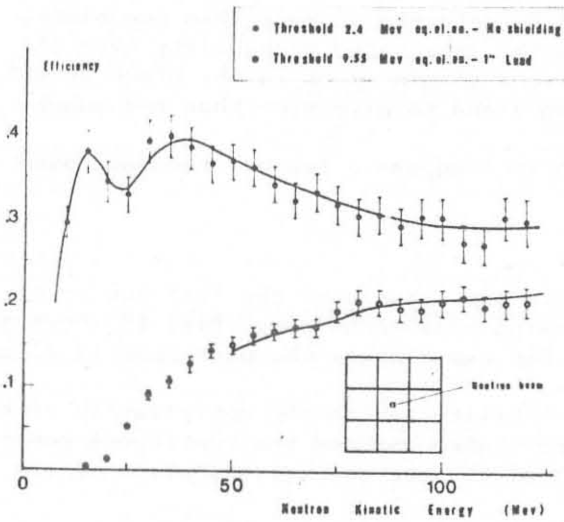


FIG.7 - Efficiency of the 3x3 module for two different experimental conditions. In both cases the neutron beam was coincident with the central axis of the module.

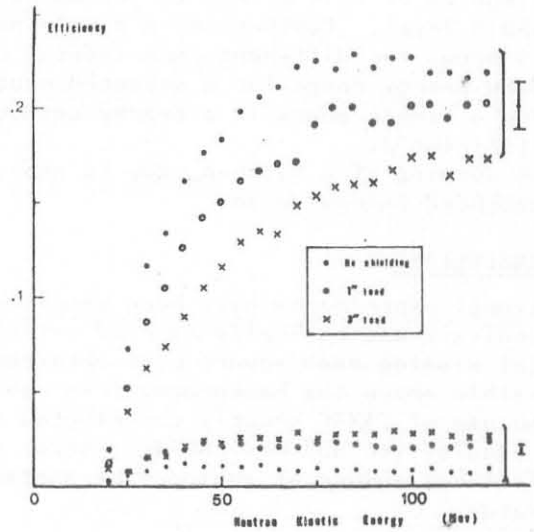


FIG.8 - The upper experimental points show the overall detection efficiency of the module; the lower points show the absolute contribution of the "mixing".

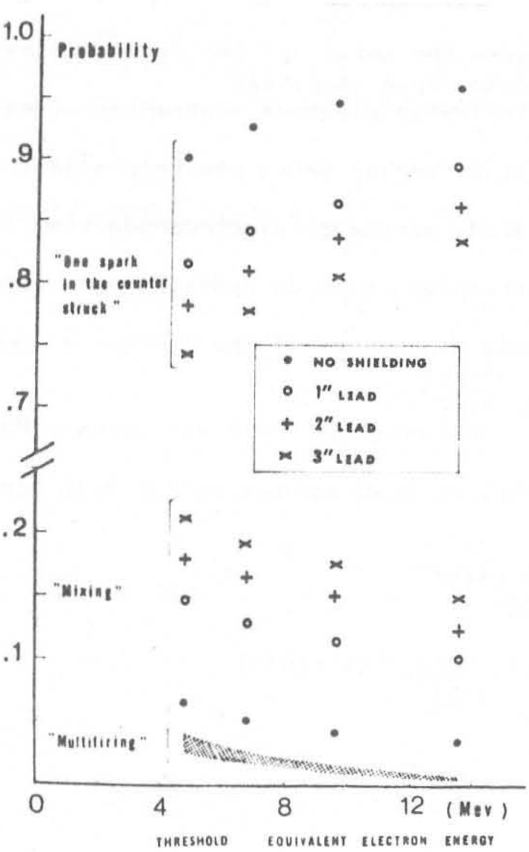


FIG.9

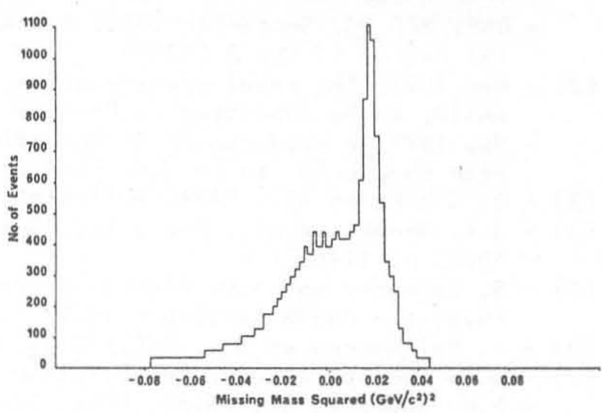


FIG.10 - Typical missing mass square plot obtained for the PEP experiment.

of the neutron with the shielding. The neutron can be detected in a block different from the one struck and the direction of the neutron can be altered by both elastic and inelastic scattering in the shielding. Fig. 8 shows for different shielding thicknesses the contribution of this effect to the detection efficiency as function of energy at the PEP threshold level. Furthermore a single neutron can be detected in more than one block. Fig. 9 shows for different experimental conditions the integrated probability over the accepted energy range for a detected neutron to give a single spark in the block struck, to give a single spark in a nearby counter ("mixing") and to give more than one spark ("multifiring").

The vetoing of a neutron, due to n-p conversion in lead, was a few per thousand over the accepted energy range.

5. CONCLUSIONS

Several experiments have been completed with this apparatus over the last two years; the analysis was basically carried out using a missing mass technique. Fig. 10 shows a typical missing mass square plot obtained for the PEP experiment; the pion peak is clearly visible above the background from random counts.

The use of CAMAC greatly contributed to the flexibility and to the optimization of the data acquisition and monitoring system; the on-line system assured the continuous control of the large number of analogue parameters, essential for the correct operation of the apparatus.

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