MONDE: MOmentum Neutron DEtector

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Abstract. MONDE is a large area neutron momentum detector, consisting of a 70x160x5 cm\textsuperscript{3} plastic scintillator slab surrounded by 16 photomultiplier tubes, standard NIM signal processing electronics and a CAMAC data acquisition system. In this work we present data from a characterization run using an external trigger. For that purpose, coincident gamma rays from a $^{60}$Co radioactive source were used together with a NaI external detector. First results with an "external" trigger are presented.

1. Introduction.

The study of the scattering of neutrons off all kinds of targets, has relevance not only for the advancement of basic scientific knowledge, but also for its practical applications. It is a source of information for nuclear reaction mechanisms and nuclear structure. Neutron interferometry provides unique information on material structure. In industry it is used for instances to analyze large structures and humidity levels in wood. Neutrographs open a new window to study valuable art work without destroying it. Neutron scattering is also used for medical topographies. These are just a few of the many applications, it’s not our purpose to mention them all [1]–[3].

When neutrons are used as probes it is often required a neutron detection system that covers a large solid angle. Some years ago, our group faced this problem [4]–[6]. In that experimental setup, a number of small neutron detectors were used to study the scattering of neutrons off Lead. Angular distributions were merely sampled and limited to a short angular range. It was realized that a very large fraction of the monochromatic neutrons scattering off the Lead target were not detected, a significant part of the effort to produce them was simply wasted. Such technical difficulties inspired the design and creation of MONDE (MOmentum Neutron DEtector) [7].

Large solid angle coverage fast neutron detection systems have been developed before, for instances: Japan [8], United States [9], Germany [10] and India [11].

In this work we use gamma rays ($^{60}$Co) to characterize MONDE. Taking advantage of the quasi-simultaneous emission of two gamma rays we were able to run MONDE with an external trigger.

Position of the incident tagged radiation is derived from the data with a Center of Mass algorithm.
In section 2 all experimental details are given. Results are given in section 3 and the conclusions can be found in section 4.

2. Experimental Details.

2.1. MONDE

MONDE it’s built of a single 160 x 70 x 5 cm^3 sheet of BC-408 plastic scintillator, surrounded by 16 photomultiplier tubes (Thorn EMI 9903b) disposed as shown in figure 1a [12]. High-voltage for each photomultiplier is controlled independently by a LeCroy 1450 power supply to match the gain of each channel. Data acquisition is handled by a homemade program (LabView) which organizes the data in an event by event mode for off-line analysis.

MONDE can also detect, with low photoelectric efficiency, gamma rays. Taking advantage of this feature, we used a 60Co source to generate an external electronic trigger. 60Co beta decays to 60Ni exited state (4+ at 2.5 MeV) which then decays by two sequential electromagnetic transitions (1.33 and 1.17 MeV, E2 both of them) to its ground state (0+). The intermediate state (2+) has a half-life of 9 ps [13]. The angular distribution of these gamma rays relative to each other (angular correlation) is described by the associated Legendre Polynomial of second order. Increasing the probability of emission of the two photons around 0° and 180°, relative to an isotropic distribution [14].

A general picture of MONDE is shown in figure 1b together with the simple scaffold holding the (3” x 3”) NaI detector facing MONDE.

![MONDE with the external detector mounted in the scaffold](image)

Figure 1. (a) Positions of each PMT. (b) MONDE with the external detector mounted in the scaffold.

2.2. Electronics

Figure 2 shows, schematically, the electronics used to handle all analog signals from the detectors, indicates how the logic signals are generated and used to provide a trigger for the analog to digital conversion with CAMAC modules.

When MONDE is run in standalone mode, the trigger is constructed by taking the two “t” signals of each amplifier (Mesytec MDS-8) which correspond to the average signal in each module, this two signals pass through a constant fraction discriminator (set to 50 mV) to generate two logic signals. A Logic Unit set on inclusive OR mode generates the logic signal for a valid MONDE event. An ORTEC Gate and Delay module is used to synchronize this signal with the analogic ones from the 16 PMs. Since the analog signals from the PMs are very fast, 1 µs time window width for the CAMAC ADCs is enough.
To study the correlated gamma rays in MONDE and the external NaI detector (Canberra Model 802 photomultiplier tube with a 2007p preamp) we need to define a concept of “External Trigger”.

Our first attempt was to generate a “logic NaI signal” from the full energy gamma peaks of $^{60}$Co. However, we found that MONDE is much too fast and its analog signals were long past gone by the time we were able to construct the logic from the NaI signals. It was then decided to open wide the “waiting time” for the ADCs from 1 up to 10 µs and trigger with a logic “OR” between the MONDE and NaI signals. For count-rates below 10 kHz, this extra waiting time is not a significant problem.

The acquired data is saved in an event by event mode. Each event consists of an array of 17 integers, one corresponding to the digitalized signal from the NaI detector and 16 from each PM of MONDE.

Given the logic in which our electronic data acquisition trigger is constructed, we keep the ability to look, in an off line analysis, at MONDE and NaI “single” events, as well as conditioned ones: MONDE events given some extra condition on the NaI signals, for instances.

This is how we are set to look for “externally triggered MONDE events”.

3. Results.

We will describe two data runs in this work. In the first one we took background radiation by 2 hours and in the second one a $^{60}$Co was place in the vicinity of PMT number 15 (125, 0), an external NaI was placed in the scaffold, data was taken by 2 hours.

In figure 3 we superimposed spectra of all 16 PMT from the background run to show how well the gains were matched.

Figure 4 presents the spectrum of the $^{60}$Co source from the NaI detector. The red area represents the photo-peak events from the two gamma rays from the Cobalt source.

In figure 5, the data from the 15th PMT detector is presented in three cases: i) background radiation (yellow). ii) When the $^{60}$Co source was present (blue) and iii) events correlated with the photo-peaks in the NaI detector spectrum (red). It is worth mentioning that PM-9 showed an unexpected behavior. Even though its gain is matched and its spectrum coincides with all the others for large signals, it presented a much larger count-rate for small signals, for this reason the detector was powered off via software and ignored in the further analysis. We found out about this after data taking runs. That PM-tube has been now replaced for future experiments.
Figure 3. Background raw spectra from all the 16 PMT of MONDE superimposed.

Figure 4. Spectrum of the $^{60}$Co source in the NaI detector. The photo-peaks from the two gamma rays from $^{60}$Co source are colored red.
Figure 5 shows a clear distinction between background and gamma ray data. It also showed that the signals produced by the gamma rays in MONDE are small. With this, we continue the analysis to reconstruct from the data, the known position of the source.

We used the C.O.M. (Centre of Mass) algorithm which is widely used reconstructing images in ANGER cameras and imagology in medical applications [15].

Our off line analysis has been implemented in CERN ROOT (1.1 and 1.2). The program uses the signal of each photomultiplier and its known position to reconstruct the position of the spark. It is written to organize the data in highly ordered structures called “branches” this branches allowed us to manipulate the data and generate histograms to understand the data.

\[ x = \frac{\sum_i^n x_i I_i}{\sum_i^n I_i} \quad (1.1) \]
\[ y = \frac{\sum_i^n y_i I_i}{\sum_i^n I_i} \quad (1.2) \]

In equations 1.1 and 1.2 \( I_i \) is the peak amplitude of the signal and \( x_i, y_i \) are the position of each PMT in MONDE.

Once we got a clear distinction between the two experiments we implement the position algorithm. A clear difference is appreciable between background in figure 6 and the \(^{60}\text{Co} \) gamma ray source data of figure 7. The source was place in the vicinity of the PMT labeled 15 (125 cm in the X axis) where a peak is formed near that position. In figures 6 and 7, events with at least two PMT signals above a given threshold were admitted. This algorithm produces structures are artificial.
Figure 6. 3-dimensional representation (x, y, counts) of Background data using MONDE and the center of mass position reconstruction algorithm. PMT number 10 was “noisier” producing a larger count-rate than the rest.

Figure 7. 3-dimensional representation of the position reconstruction of events in MONDE when the $^{60}$Co gamma source is used (Blue Circle), requesting coincidence with the photo-peaks in the NaI detector.

The 10th detector shows an unusual high count making it look like a source was placed nearby. This behavior disappears when the $^{60}$Co source was placed. The C.O.M. algorithm causes the line patrons in figure 6, this effect will be solved with the implementation of a new algorithm [12].
4. Conclusions

The background count-rate is important due to the large volume of MONDE (typically 600 Hz). The use of an external trigger with correlated gamma rays and an external NaI detector, allowed us to select the events of interest to characterize the position response of MONDE using a simple center of mass algorithm.

This work is still in progress. In spite our efforts to carefully match the gains in all of MONDE’s PMTs, the results proved that at least two out of the sixteen were working differently. Also the center of mass algorithm is too simple, a better one (PRADA) is being implemented [12], to improve the special resolution in the reconstructed position.

Position resolution is best when the source is placed in the proximities of a PMT.

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