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The Sensitivity of GaAs and Silicon Particle Detectors to Fast Neutrons

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Abstract

The sensitivity of Gallium Arsenide (GaAs) and Silicon (Si) particle detectors to 1-10 MeV neutrons has been studied i.e. in a range similar to that expected at the LHC. Signal pulses were observed from neutron interactions in GaAs. Evidence is presented which indicates that the signals are mainly produced by ionisation from nuclear recoils in neutron-nucleus elastic scattering and the interaction probabilities have been measured.

1 Introduction

It is planned to use GaAs and Si microstrip detectors for charged particle detection in future experiments at the Large Hadron Collider (LHC) at CERN. These detectors will need to operate in fast neutron fluxes up to a few times 10^6 neutrons/cm^2/sec. Interactions from such neutrons will give hits unassociated with charged particle tracks and hence increase the occupancy of the detector. This should be acceptable providing that the interaction probability of the neutrons is low enough. To measure this interaction probability a GaAs particle detector was bombarded by neutrons from an AmBe source and the signals have been studied. Comparison was made between the observed pulse amplitude spectra and those expected from Monte Carlo simulation. In this paper the results of these studies are reported.

The AmBe source consisted of an intimate mixture of Americium (^{241}Am) and BeO powder sealed in a stainless steel container. The ensemble was contained in a 3 mm thick lead container to absorb the 60 keV X rays produced from the decay of ^{241}Am. Neutrons of energy 1-10 MeV with a low energy tail down to 0.1 Mev[1] were produced by interactions of alpha particles from the

^{41}Am with ^{9}Be. In about half the interactions the daughter ^{12}C nucleus was eft in the first excited state leading to the emission of a 4.43 MeV gamma ay. These were the only gamma rays emitted from the source apart from a mall number of e^+ annihilation gammas of energy 0.511 Mev. Here the e^+ were produced from pair conversions of the 4.43 MeV gamma ray in the source material.

2 Experimental Method

Fig. 1 shows a diagram of the apparatus. The pulse from the GaAs detector was integrated within a 70 nsec gate using a fast digital oscilloscope. The gain of the system was calibrated using minimum ionising particles(MIPs) from a ^{90}Sr beta source. Fig. 2 shows the spectrum obtained by triggering the system by two scintillation counters which forced each beta ray to penetrate at least 5 mms of scintilator as well as the GaAs detector. From this the calibration is found to be 1970 electrons per bin and the pedestal channel is 5.2 bins. A detailed description of the measurements with MIPs and the electronics used may be found in [2].

To observe pulses from neutrons in the arrangement of Fig. 1 the system was triggered from a signal from the GaAs detector itself so there is a natural threshold in the spectra. The inefficiency introduced by this threshold was measured by observing the spectrum from ^{90}Sr beta particles stopping in the GaAs detector. For this purpose the GaAs detector was irradiated by the ^{90}Sr beta rays through a collimator installed on the opposite side of the detector to the AmBe source (see Fig. 1) and the scintillation counter was in veto. The spectrum, shown in Fig. 3, falls rather slowly for amplitudes greater than bin 14. Assuming that the trigger is 100% efficient above bin 14 and that the true spectrum is roughly flat from bins 10-16, the trigger efficiency in bins 10-13 can be determined from the ratio of the count rates in each of the latter bins to the average in bins 14-16. Here we neglect the small downward slope of the spectrum in extrapolating from bins 10-13 to bins 14-16.

Fig. 4 shows the measured pulse amplitude spectrum from the AmBe source with the scintillation counter (Fig. 1) in veto. This scintillation counter was necessary to eliminate background from electrons produced by conversions of the 4.43 MeV gamma rays in the source material. The peak below channel 10 is due to triggers on noise pulses. The dashed histogram shows the spectrum with the source removed normalised to the noise peak area. The dash-dotted curve in Fig. 4 shows a spectrum from a 100 μCi ^{60}Co source, in place of the AmBe source, normalised to the expected total number of events from conversions of the 4.43 MeV gamma rays in the GaAs detector. The measured counting rate from the ^{60}Co source agreed well with the value predicted from the Compton scattering cross section and the known source intensity. The agreement between the data and the normalised ^{60}Co spectrum for pulse amplitudes above bin 25, where little contribution is expected from neutrons(see below), indicates that the ^{60}Co spectrum gives a reasonable measure of the background from gamma conversions.

The dotted curve in Fig. 4 is that obtained from the Monte Carlo simulation of neutron interactions in the GaAs detector. In this simulation neutrons from the source were generated with the published energy spectrum[1]. Interactions in the GaAs detector were simulated with a frequency expected from the published total cross sections [3]. Inelastic collisions were neglected since their cross sections are small [3]. The energy deposited in the GaAs detector was taken to be that imparted to the recoil nucleus in each collision which was assumed to be elastic. The pulse amplitude for each interaction was then calculated using the known calibration, the measured charge collection efficiency of 45% [2] and the known energy of 4.2 eV required to produce each electron-hole pair in GaAs[4]. The trigger inefficiency in bins 10-13 was included in the neutron spectrum in Fig. 4.

The noise subtracted total count rate observed from the AmBe source was 1.01 Hz. The calculated absolute rates from gamma ray conversions in the GaAs detector was 0.54 Hz and from neutron interactions was 0.35 Hz i.e. 0.89 Hz in total. The 13% discrepancy between the calculated and observed total counting rates is within the uncertainties in the geometry of the system. The neutron Monte Carlo and the ^{60}Co spectra in Fig. 4 have both been renormalised by 13% to account for this discrepancy.

Fig. 5 shows the data with the noise spectrum subtracted compared to the sum of the neutron Monte-Carlo and ^{60}Co spectra shown in Fig. 4. There is reasonable agreement between the data and the calculated spectra, showing that we understand well the interaction mechanisms of the radiation from the AmBe source in the GaAs detector.

Encouraged by this good agreement between calculation and data we can go on to compute the occupancy in a GaAs detector operating in a region of high fast neutron flux. Table 1 shows the detected interaction rate per cm^3 of GaAs per unit neutron fluence as a function of detection threshold (in electron charges) calculated from the Monte Carlo simulation. Here the neutron fluence is the number of neutrons per cm^2 passing through the detector. Two neutron spectra were simulated, the AmBe spectrum [1] discussed above, and a simulation of the spectrum observed at the ISIS irradiation facility [5]. This neutron spectrum is expected to be similar to that expected at the LHC. The figures for each spectrum are given in table 1. The values calculated from the LHC spectrum are slightly lower than those from the AmBe source since the energy spectrum from the source is somewhat different from that expected from the LHC. The exact threshold of operation at the LHC will depend on the charge collection efficiency of the detector and the noise in the electronics. A threshold of 2000 electrons is close to the minimum expected. This corresonds to a fast neutron count rate of 0.12 per cm^3 of GaAs per unit neutron fluence at the LHC. Thus for a 200 μm thick microstrip detector with microstrips of length 5.0 cms and pitch 100 μm in a flux of 10^6 n/cm^2/sec the count rate will be 120 Hz. This corresponds to an occupancy of 3×10^{-6} per bunch crossing. Such an occupancy should not present problems in operating a GaAs microstrip detector at the LHC.

Table 1

Threshold (electron charge)	Interaction rate (per cm^3 of GaAs per unit fluence) AmBe spectrum.	Interaction rate (per cm^3 of GaAs per unit fluence) LHC spectrum
0	0.18	0.17
2000	0.14	0.12
4000	0.12	0.09
6000	0.11	0.07
8000	0.09	0.05

The fast neutron interaction cross sections in Si are somewhat lower than those in GaAs, hence the mean free path of a fast neutron in Si is longer by about 50% than that in GaAs. Thus, assuming that signals due to fast neutrons will be produced by the same mechanism in Si as that in GaAs the occupancy in Si microstip detectors due to fast neutrons will be lower than that in the same thickness of GaAs. Again this should not present problems in operating Si microstrip detectors at the LHC.

3 Conclusion

The detection of fast neutrons by GaAs and Si charged particle detectors has been investigated. The signals in GaAs are found experimentally to be from nuclear recoils produced by elastic neutron scattering. The induced occupancy due to this effect in an LHC detector will be small and should not present problems in analysing the data from such a detector. Assuming that signals from neutrons in Si detectors will be produced by the same mechanism, the occupancy in Si microstrip detectors should be even lower and again should not present a problem at the LHC.

4 References

1. Compendium of Neutron Spectra and Detector responses Technical Report Series number 318 IAEA Vienna (1990) pp 70-71.

2. A Chilingarov and T Sloan, Proceedings of the 3rd International Workshop on GaAs and Related Compounds, San Miniato, March 1995.

3. D I Garber and R R Kinsey Neutron Cross Sections Vol 2 Brookhaven National Lab Report Number 325 (January 1976).

4. Radiation Detection and Measurement by G F Knoll (published by Wiley, 1989).

5. The Radiation Hardness Test Facility. M Edwards and D R Perry Rutherford Laboratory Report RAL-90-065 (1990).

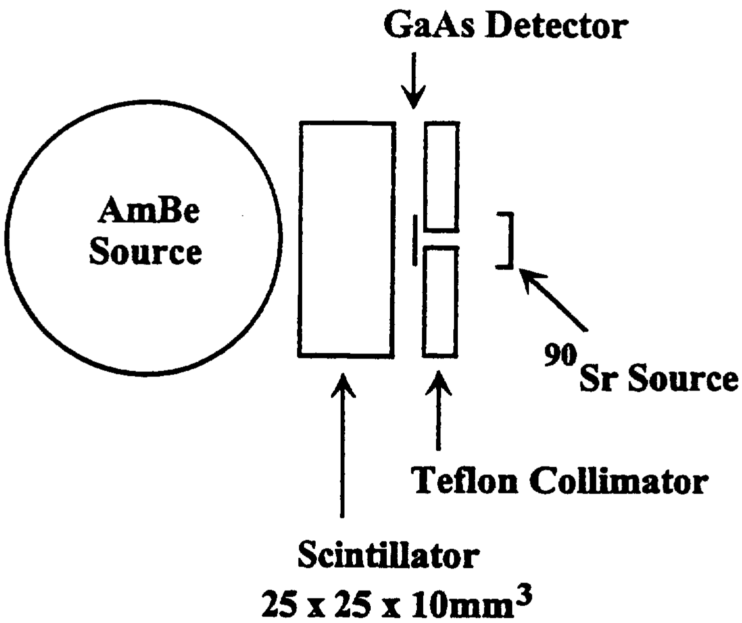

Figure 1: The apparatus diagram. All dimensions are to scale. The size of the GaAs detector is 3x2x0.32 mm^3. The ^{90}Sr source was removed when not in use.

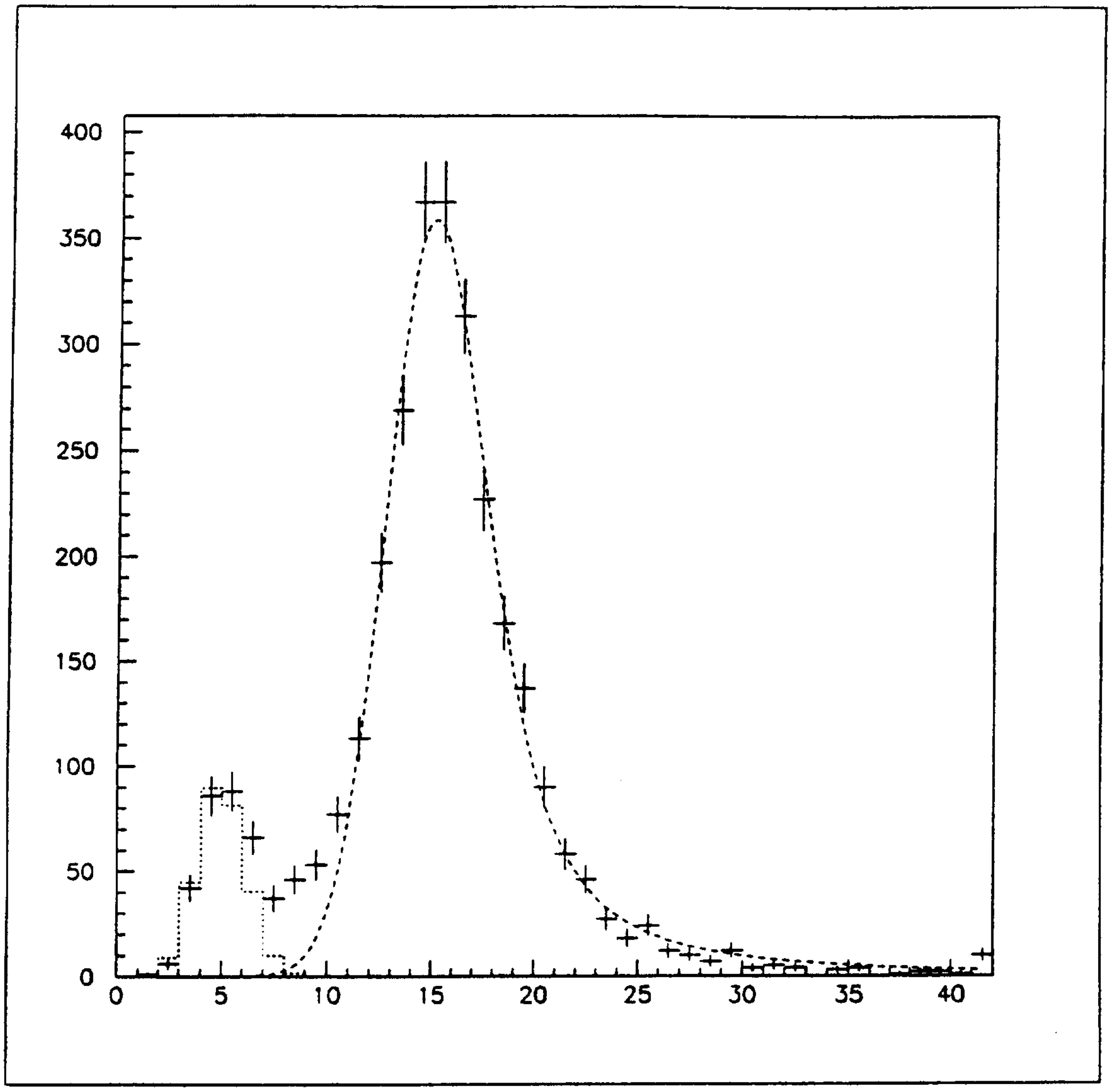

Figure 2: Minimum ionising particle spectrum with Landau fit (dashed curve). Dotted curve (wrong trigger events) shows the pedestal peak position. See [2] for the detailed description of these measurements.

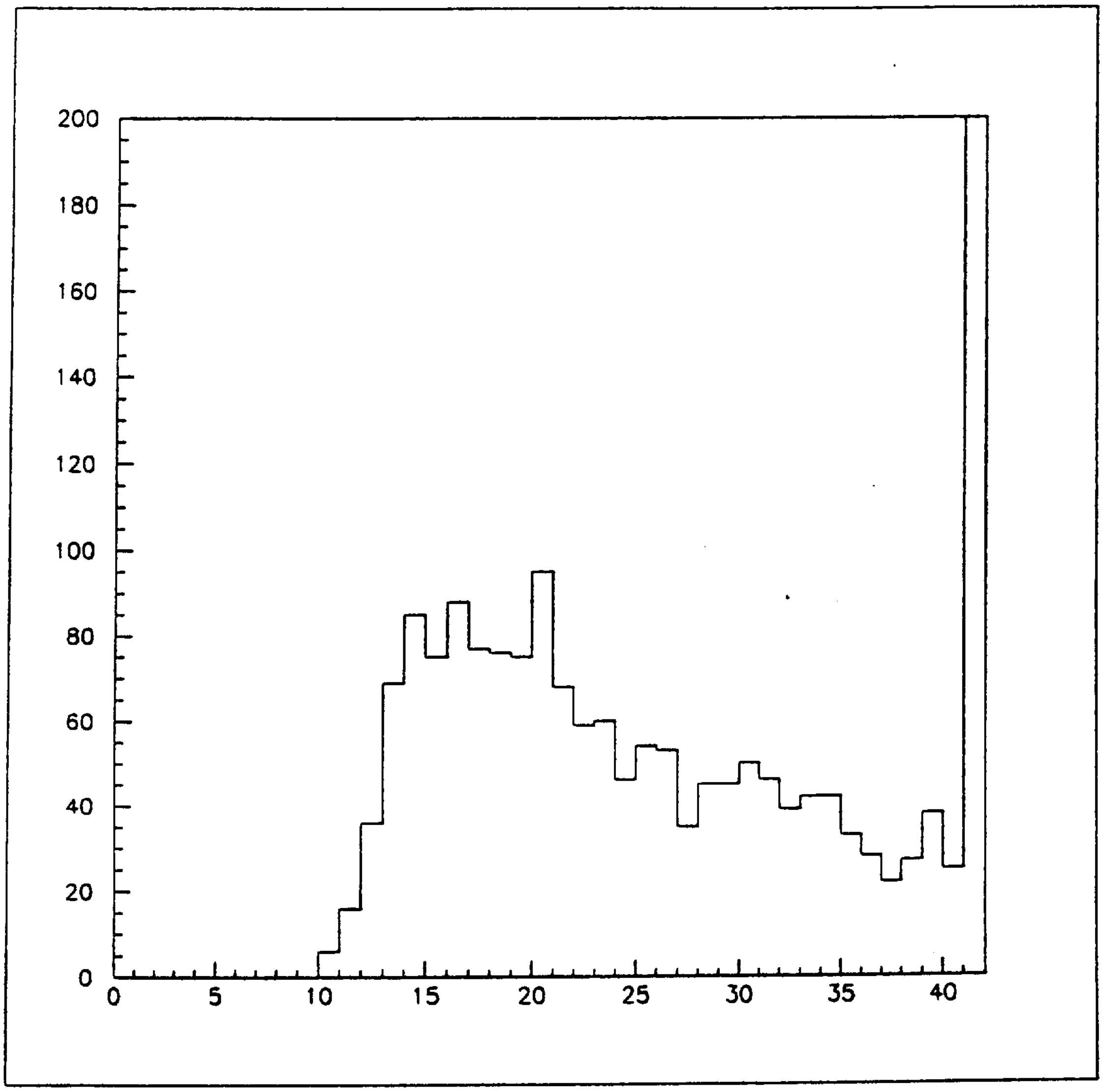

Figure 3: The spectrum used for determination of the trigger threshold. See text for the details.

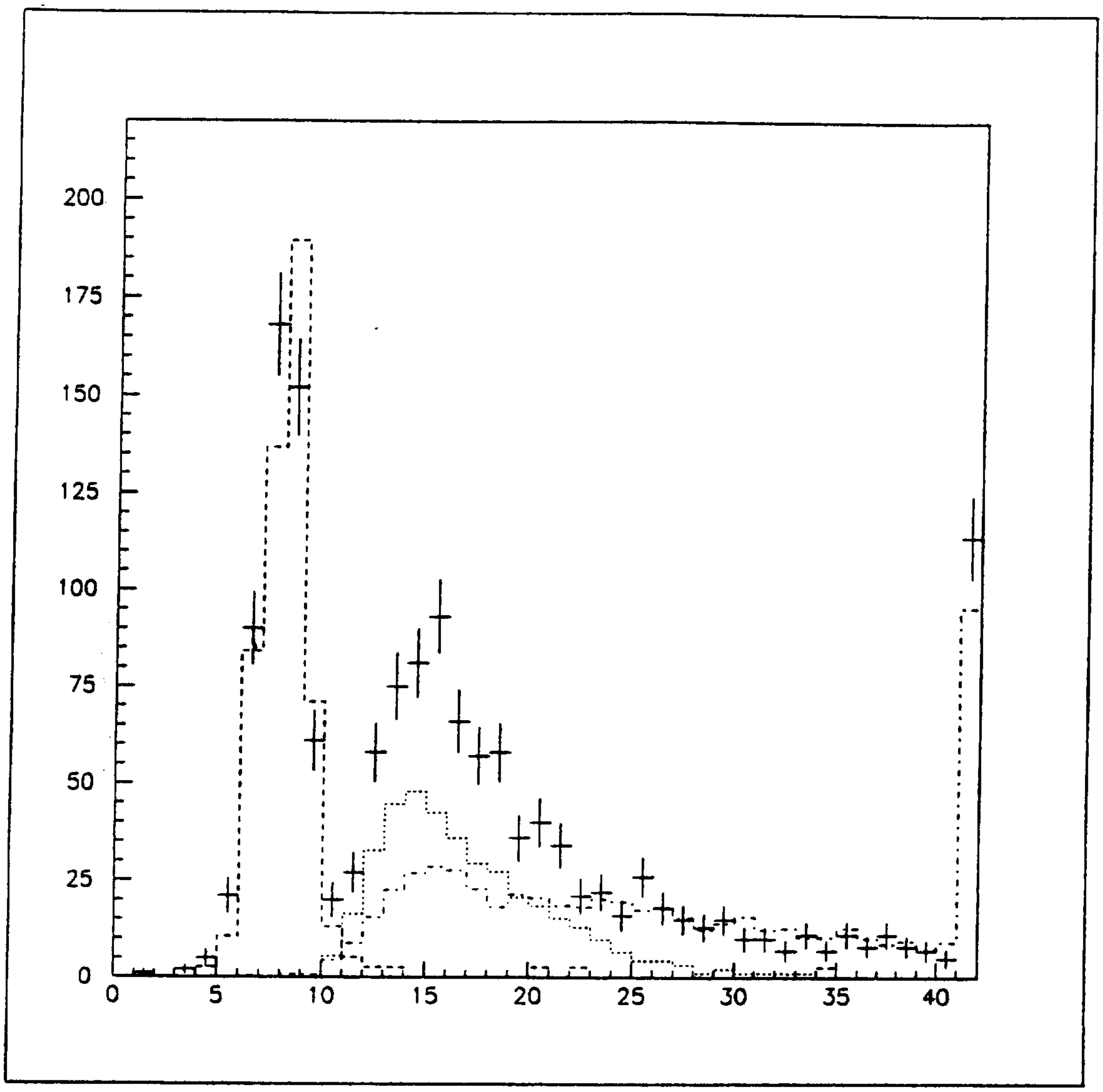

Figure 4: The experimental spectrum (crosses) measured with the AmBe source. The dashed curve is the separately measured noise spectrum normalised to the observed noise peak. The dashed-dotted curve is the measured ^{60}Co spectrum normalised to the expected total rate from AmBe gamma rays. The dotted curve is the absolutely calculated spectrum from neutron-neucleus elastic scattering.

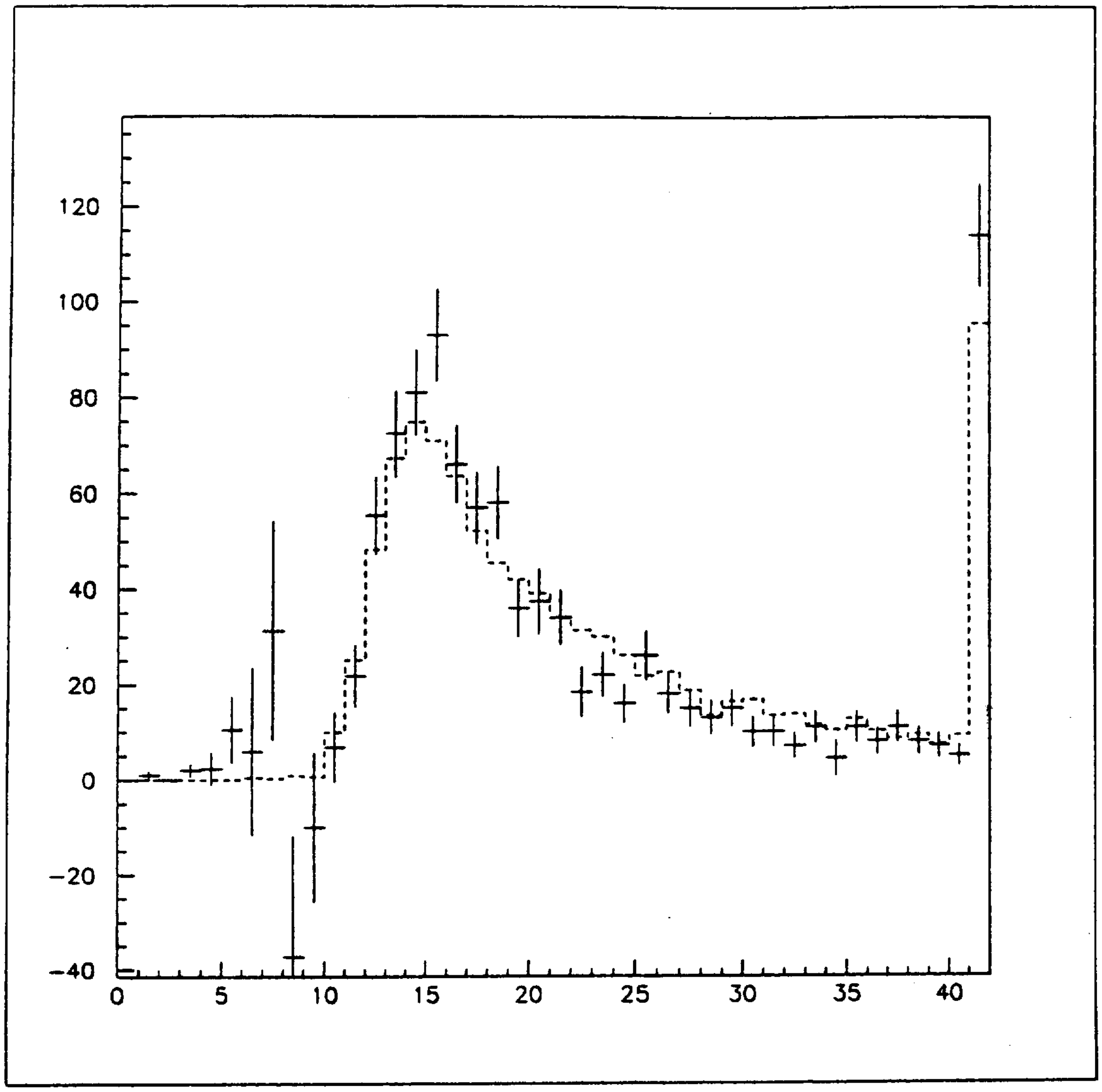

Figure 5: The noise subtracted AmBe spectrum (crosses) compared to the calculated sum of the γ ray conversion and the neutron-nucleus elastic scattering spectra shown in Fig. 4.