Neutron Induced Nuclear Counter Effect in Hamamatsu APD & PIN

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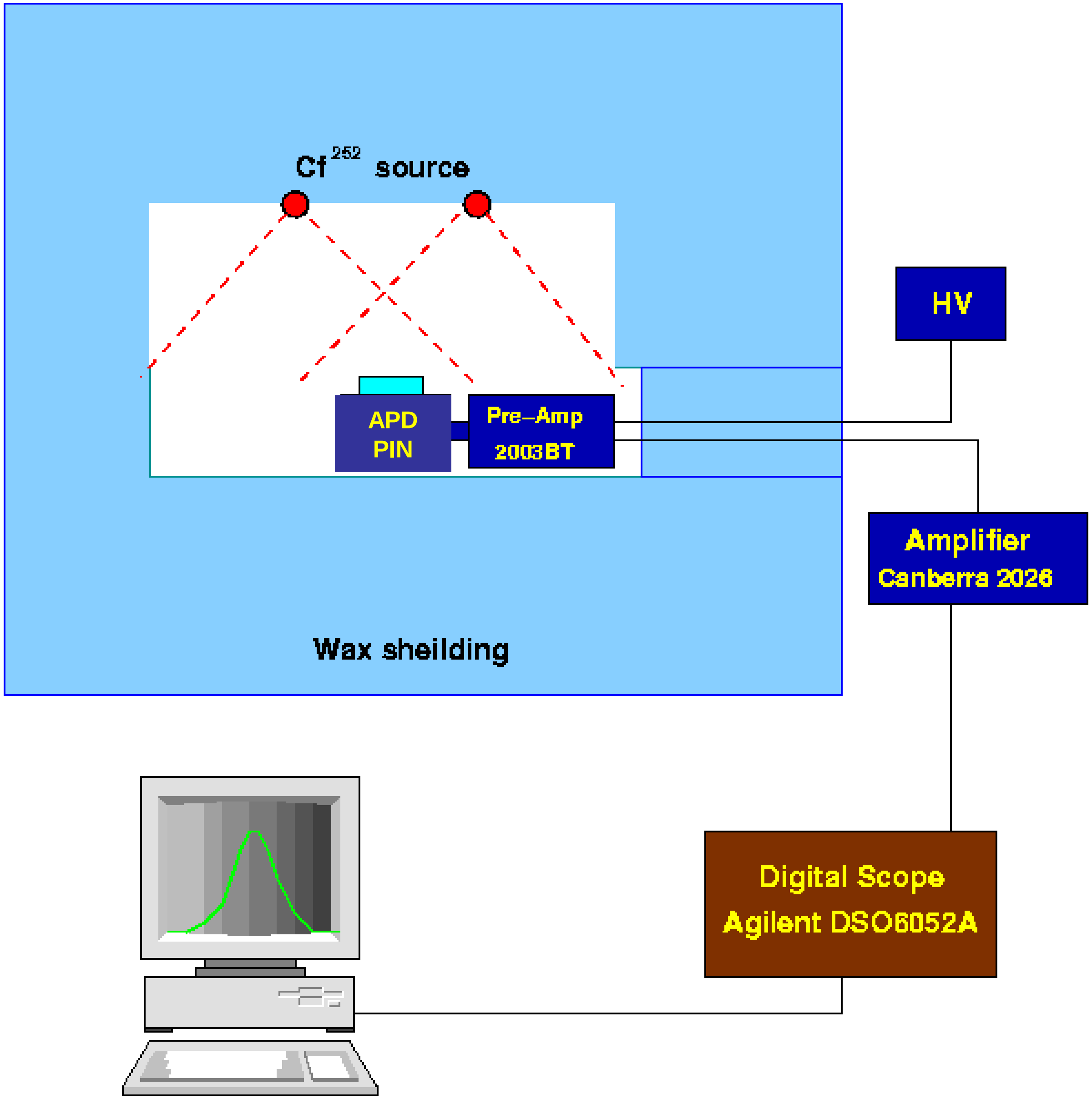
Introduction

- Because of its immunity to magnetic field silicon based readout devices are widely used for calorimeter readout. They are often located in particle showers, where neutrons are produced copiously. While the nuclear counter effect caused by charged particles is well understood, it is less known for neutrons.
- Hamamatsu silicon devices tested:
  - A pair of S8664-55 APD: 2 x 5 x 5 mm^2
  - An S2744-08 PIN: 1 x 2 cm^2
- Neutron sources: ^{252}Cf and ^{241}Am-Be.
- ɣ-ray sources: ^{55}Fe, ^{241}Am, ^{57}Co and ^{60}Co.

The ^{252}Cf Setup

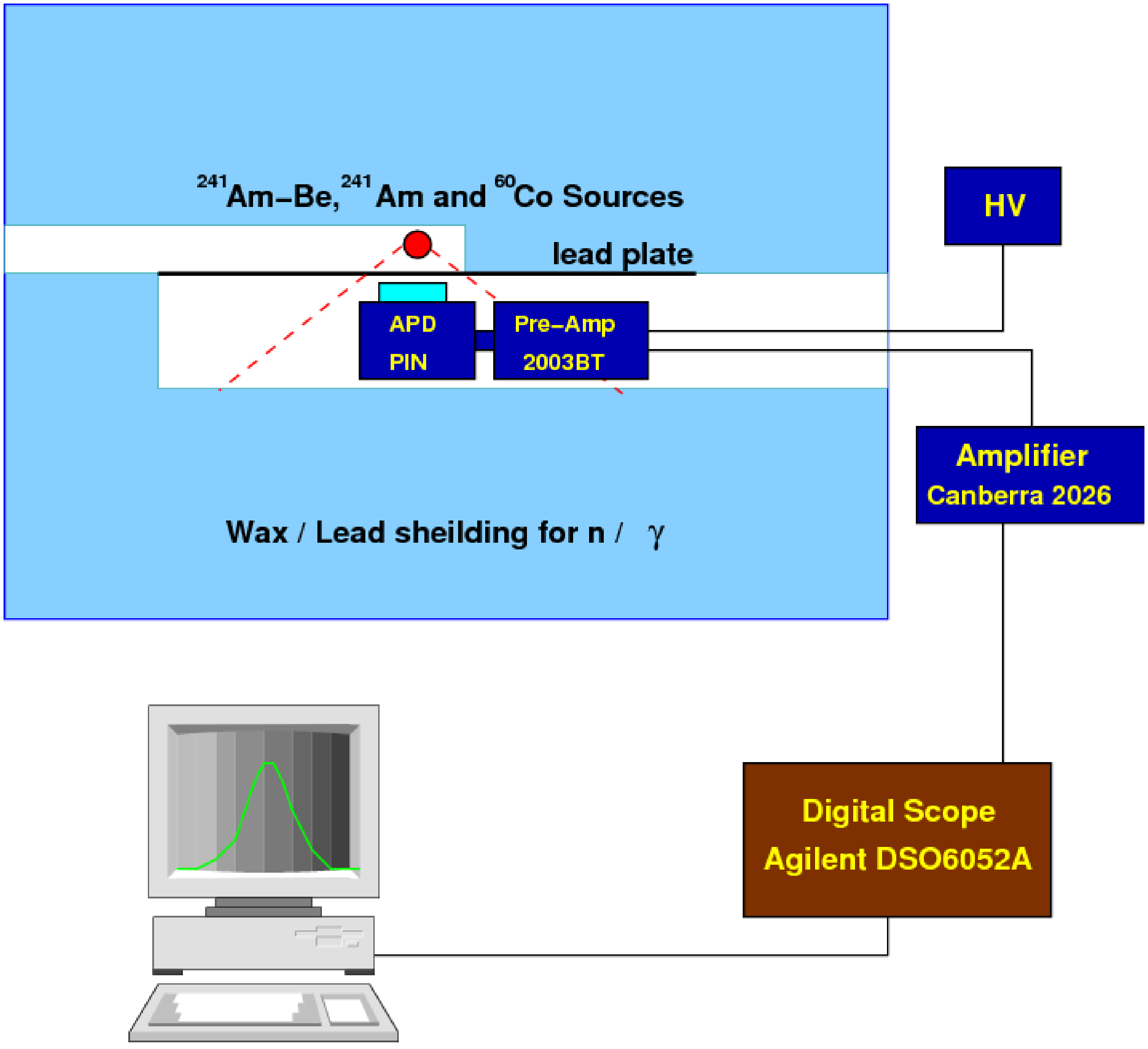


Si APDs/PIN were placed at 8 cm from a pair of ^{252}Cf sources with neutron flux of 1.4×10^4 n/cm^2/s at the device surface.

The APDs were biased for gains of 10, 35, 50, 100 and 200. The PIN was biased at 70 V.

The readout of the Si APDs/PIN consists of a preamplifier (PA) Canberra 2003 BT and a shaping amplifier (SA) Canberra 2026, and a digital storage oscilloscope Agilent 6052A.

The ^{241}Am-Be, ^{241}Am and ^{60}Co Setup

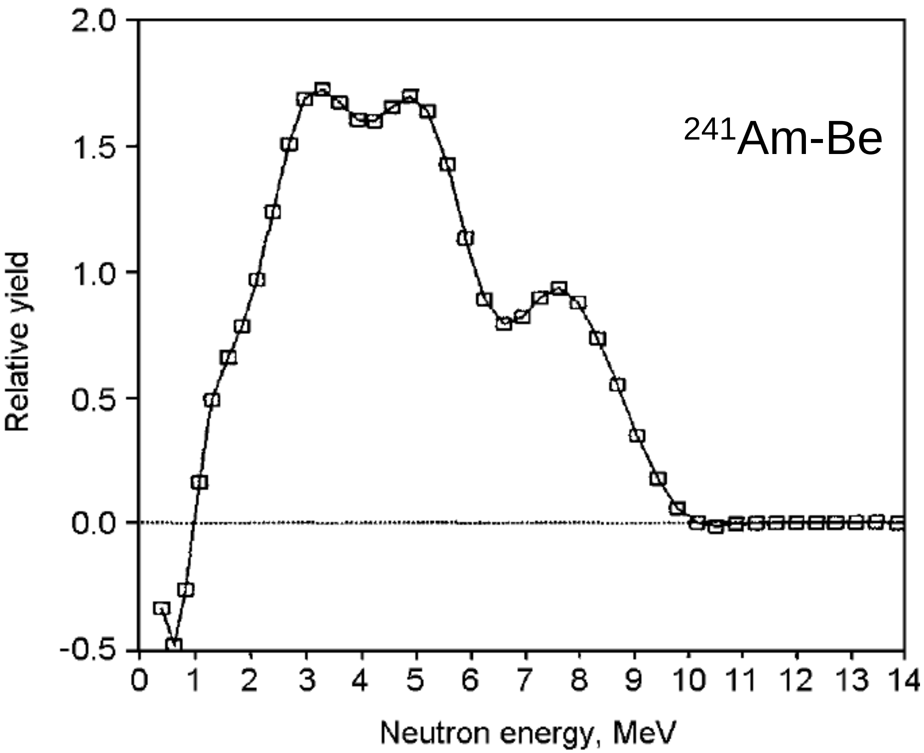


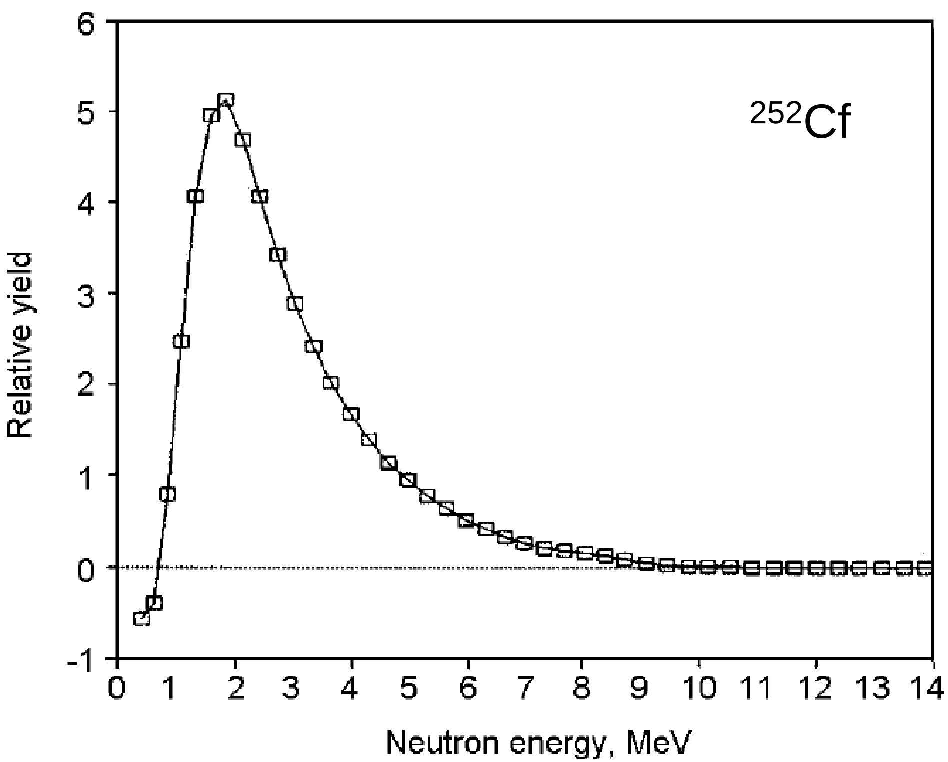
Si APDs/PIN were placed at 2 cm from several sources: ^{241}Am-Be, ^{241}Am and ^{60}Co with the neutron and γ-ray flux of 6×10^4, 1.06×10^7 and 1.54×10^6 /cm^2/s.

The readout is the same as that for the ^{252}Cf source.

$E_{Neutron}$ from ^{241}Am-Be and ^{252}Cf Sources

Neutrons from ^{241}Am-Be source has a broad distribution from 2 to 9 MeV with an average energy of 4.5 MeV. The energy of neutrons from ^{252}Cf source is peaked at 2.2 MeV.





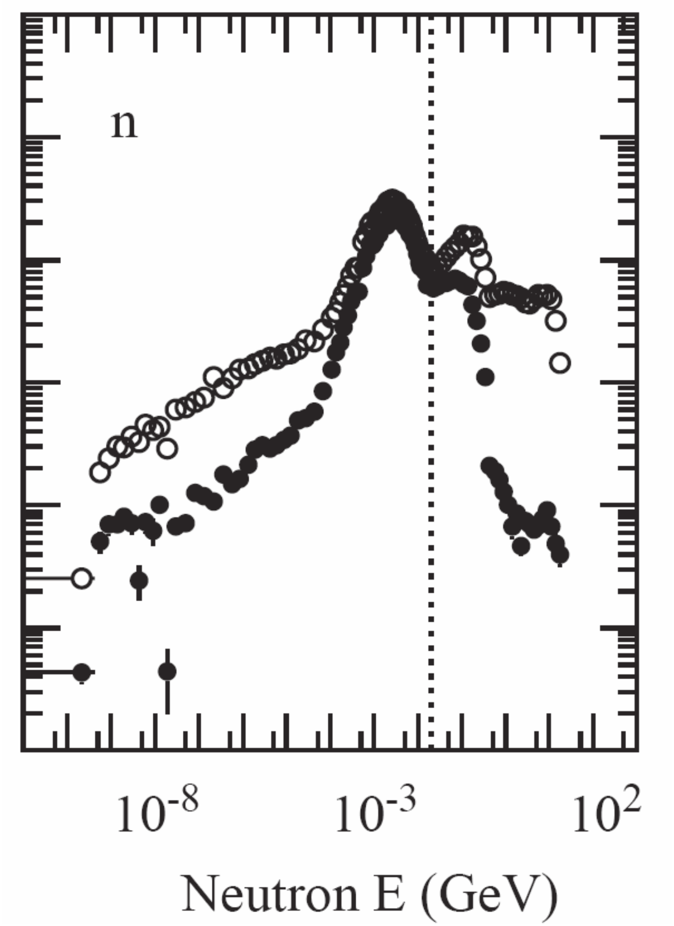
S.-T. Park, J. Rad. & Nucl. Chem., **Vol 256** (2003) 163

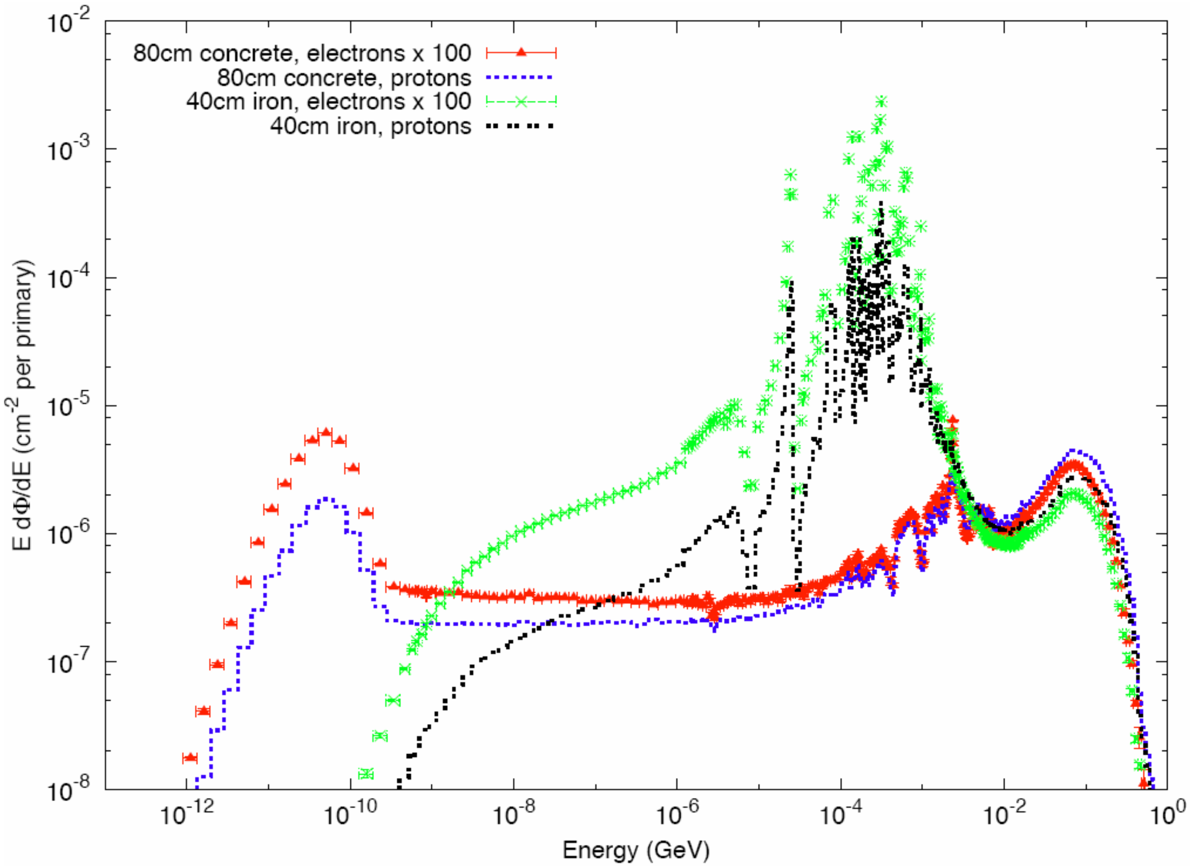
Neutron Energy Spectrum

Simulation shows that shower neutrons peaked at ~1 MeV

M. Huhtinen *et al*, NIM **A545** (2005) 63

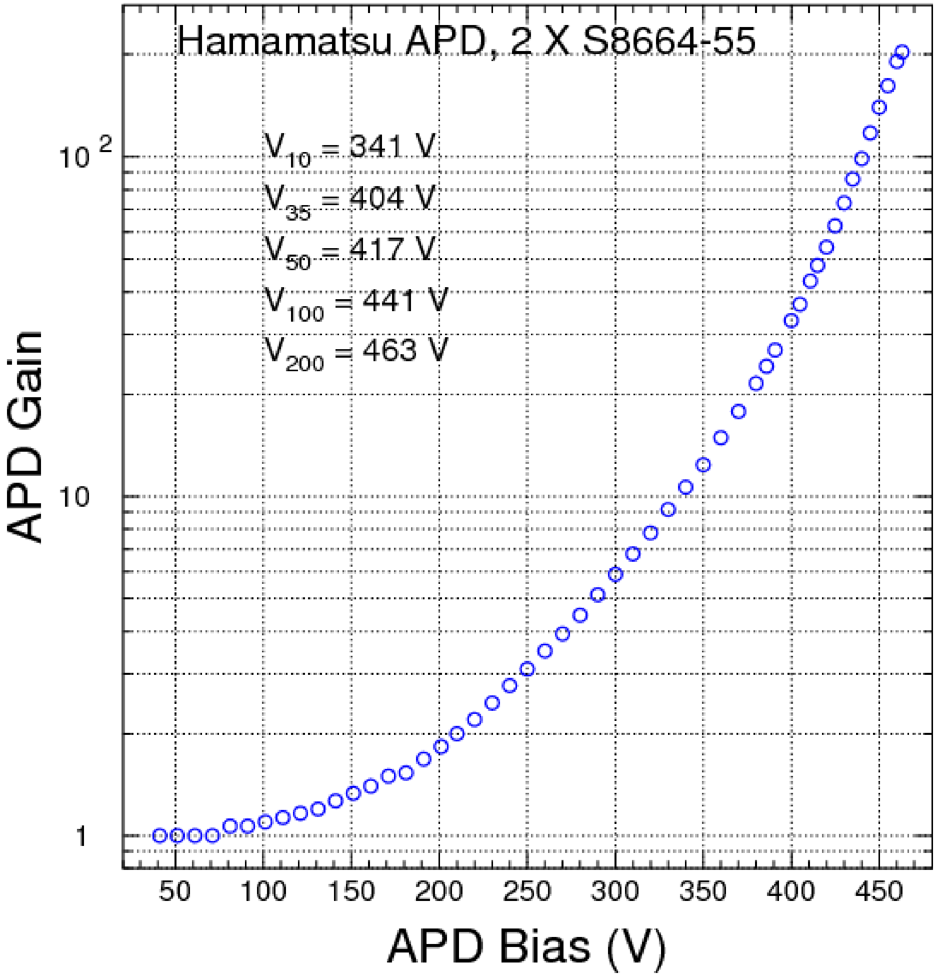
Fig. 29.2 of PDB, Simulations with FLUKA

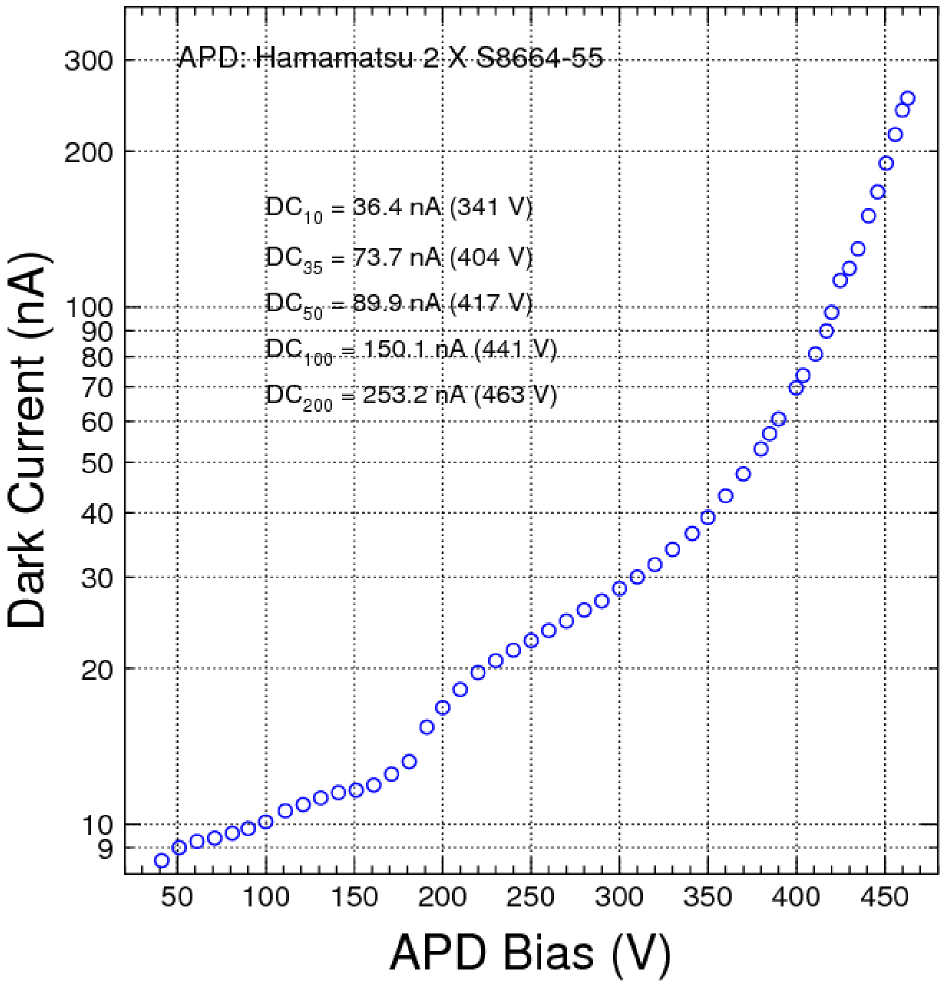




S8644-55 Gain and I_{dark} versus Bias

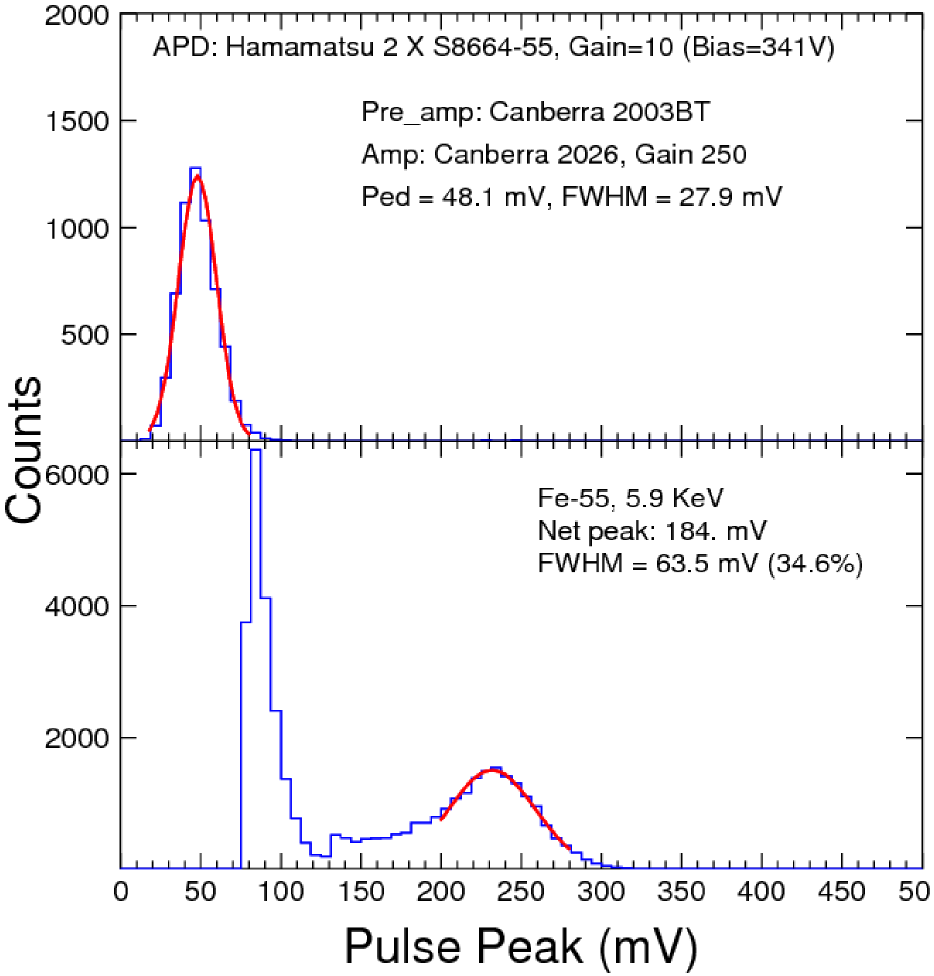
Actual APD gain measured with LED

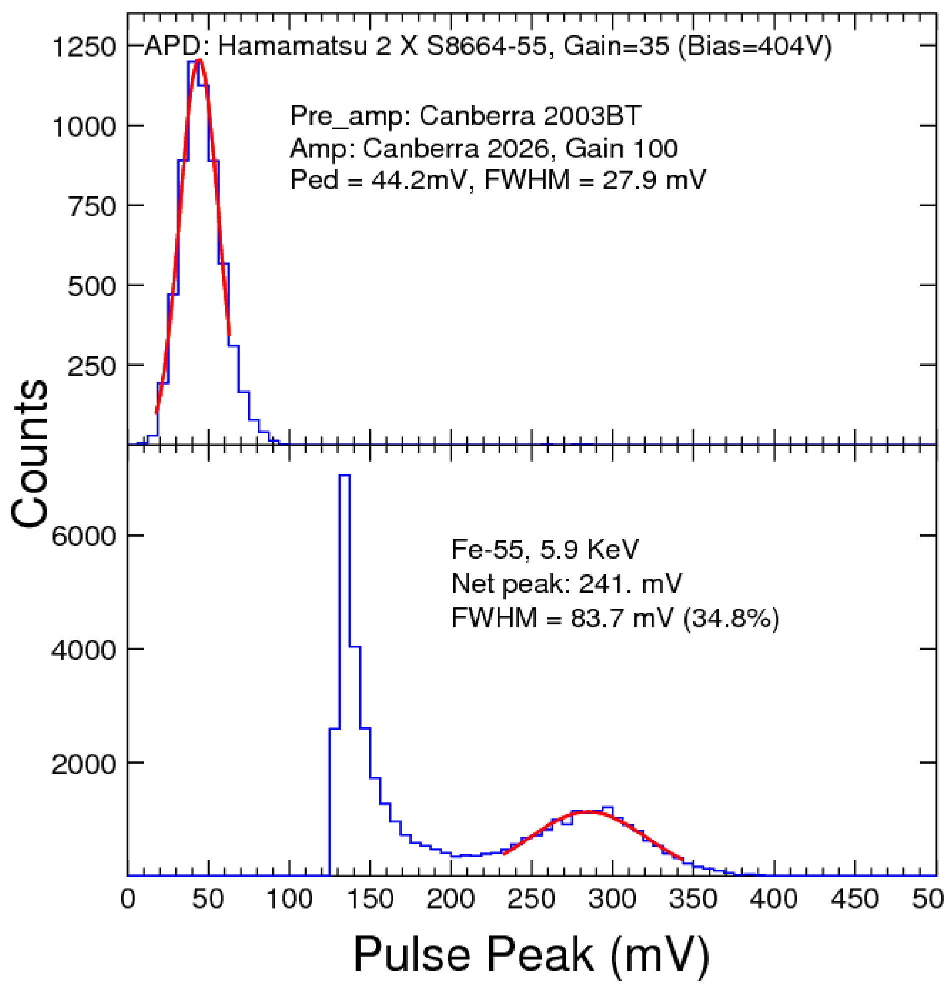




S8664-55 Calibration with ^{55}Fe (I)

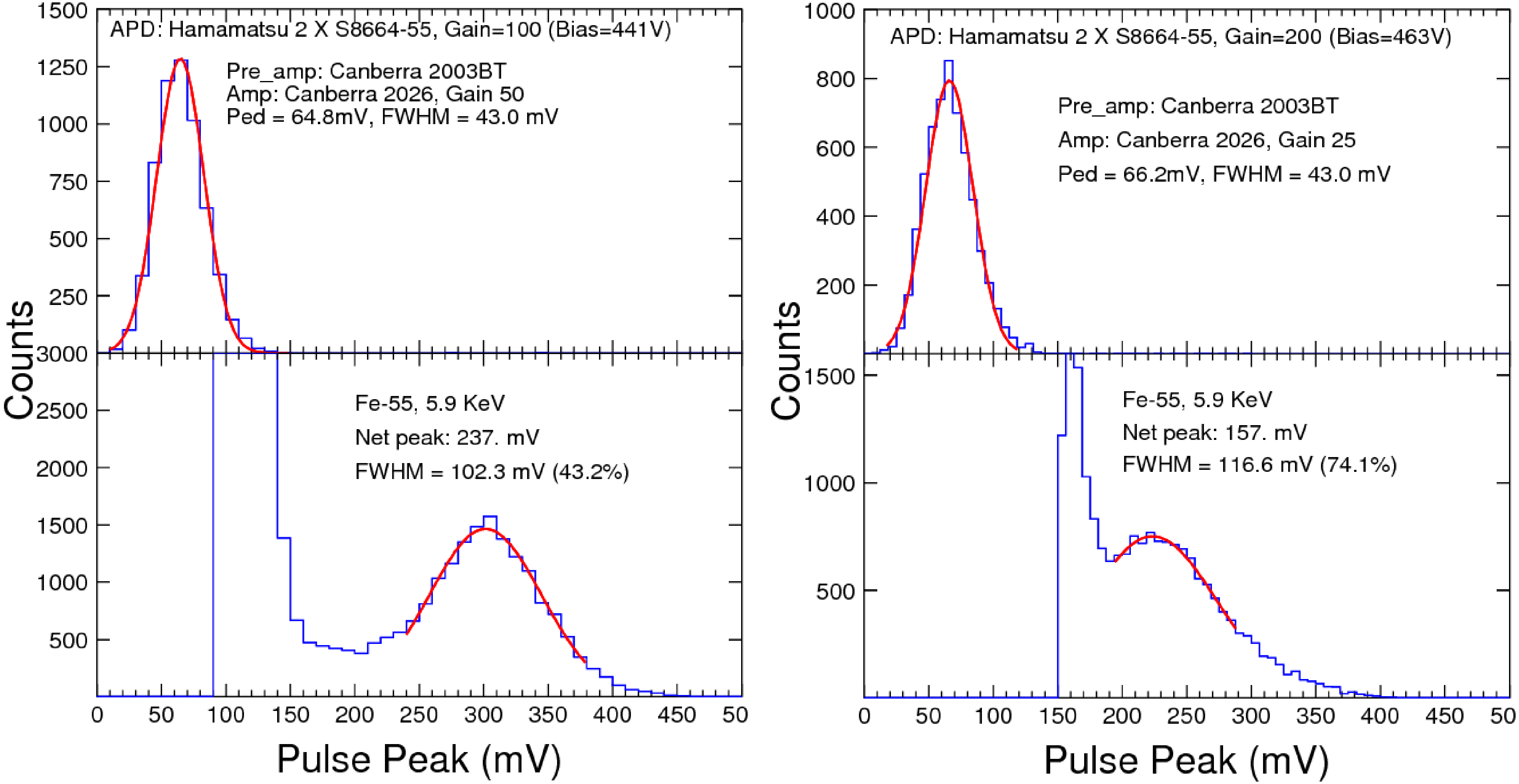
APD gain was set at 10 and 35



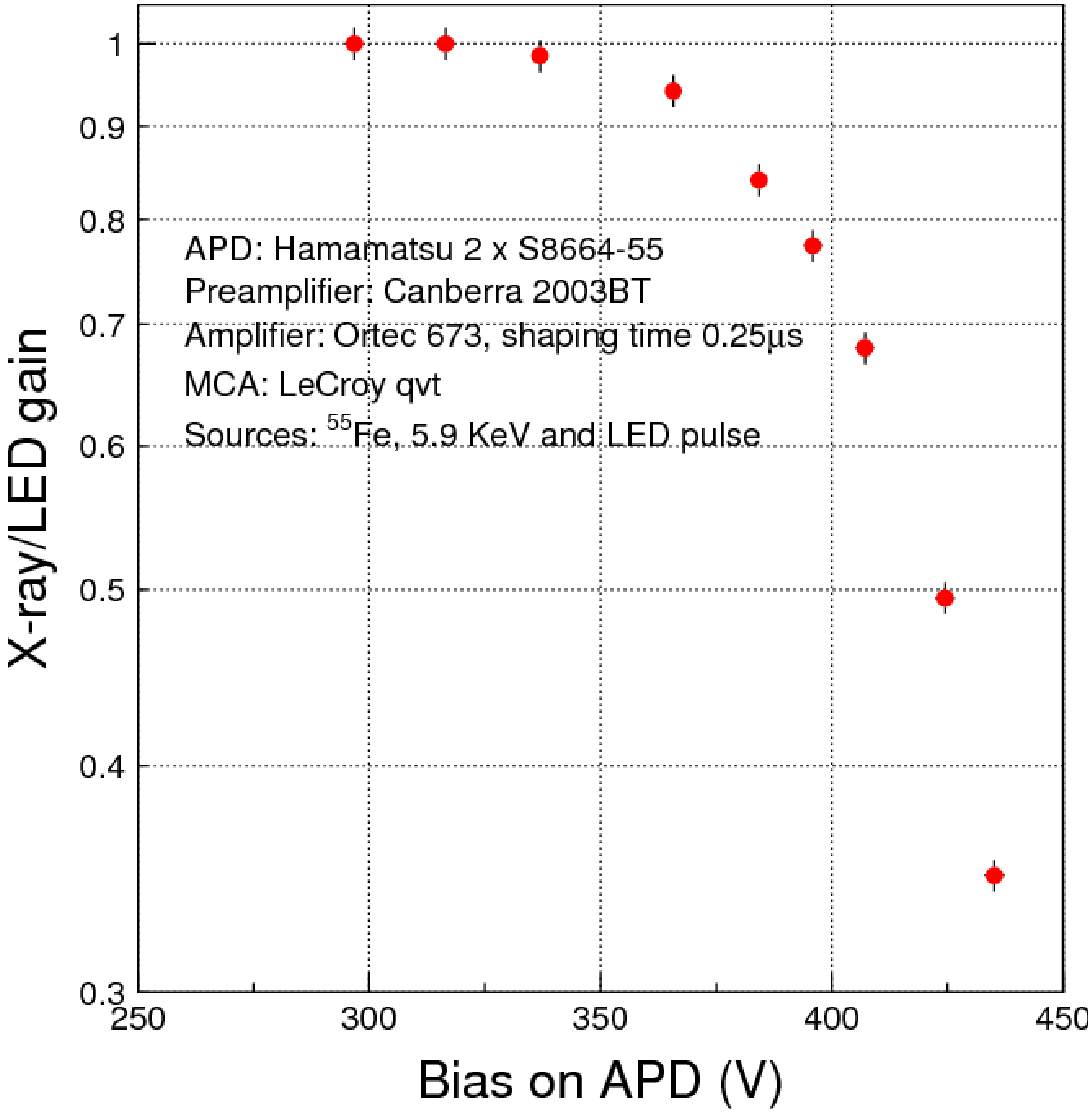


S8664-55 Calibration with ^{55}Fe (II)

APD gain was set at 100 and 200



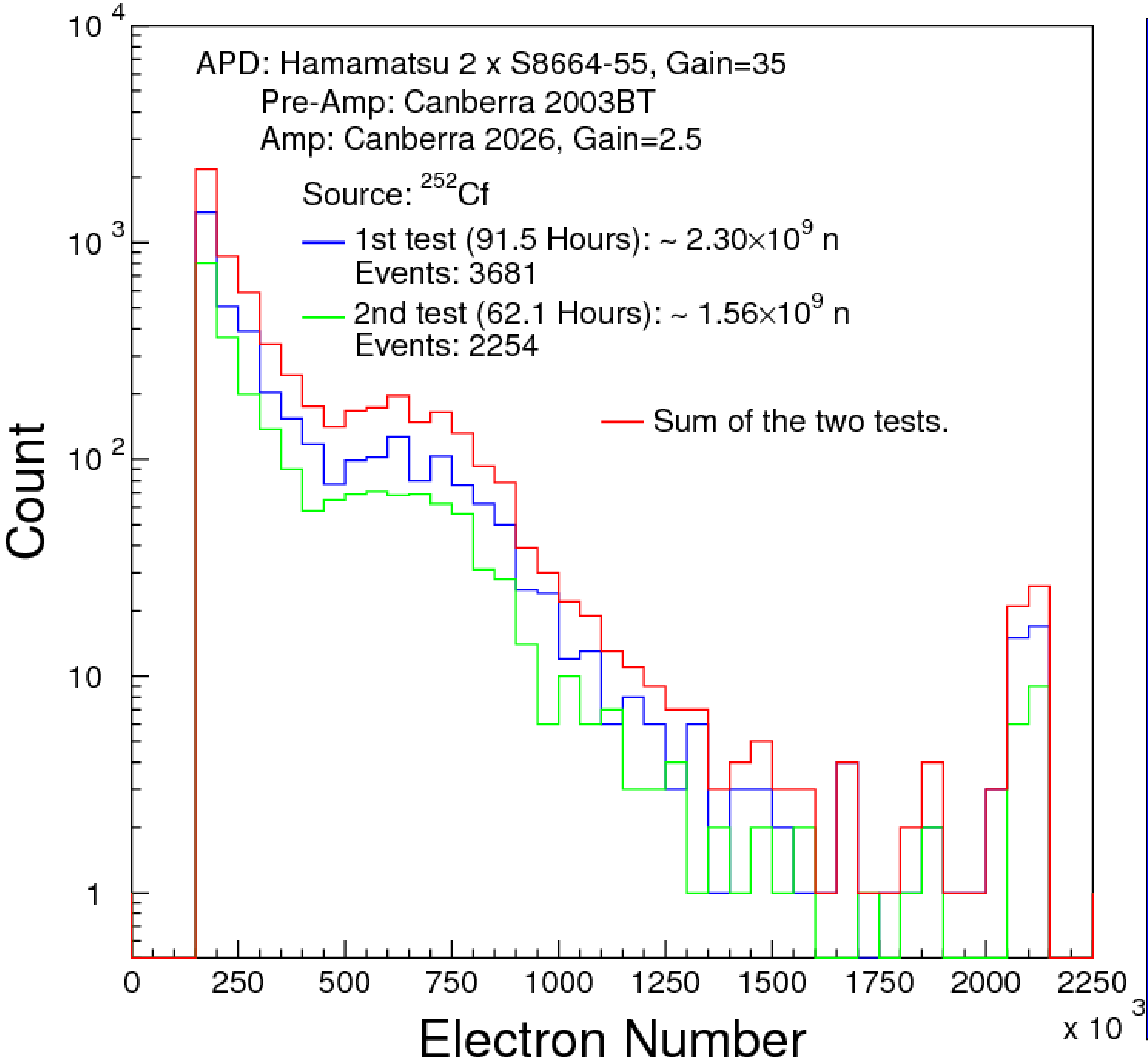
Fe-55/LED Corrections



Large correction factors are noticed for high APD gains.

The correction factors are consistent with published data in J. Chen *et al, IEEE Trans. Nucl. Sci. Vol 54* (2007) 718.

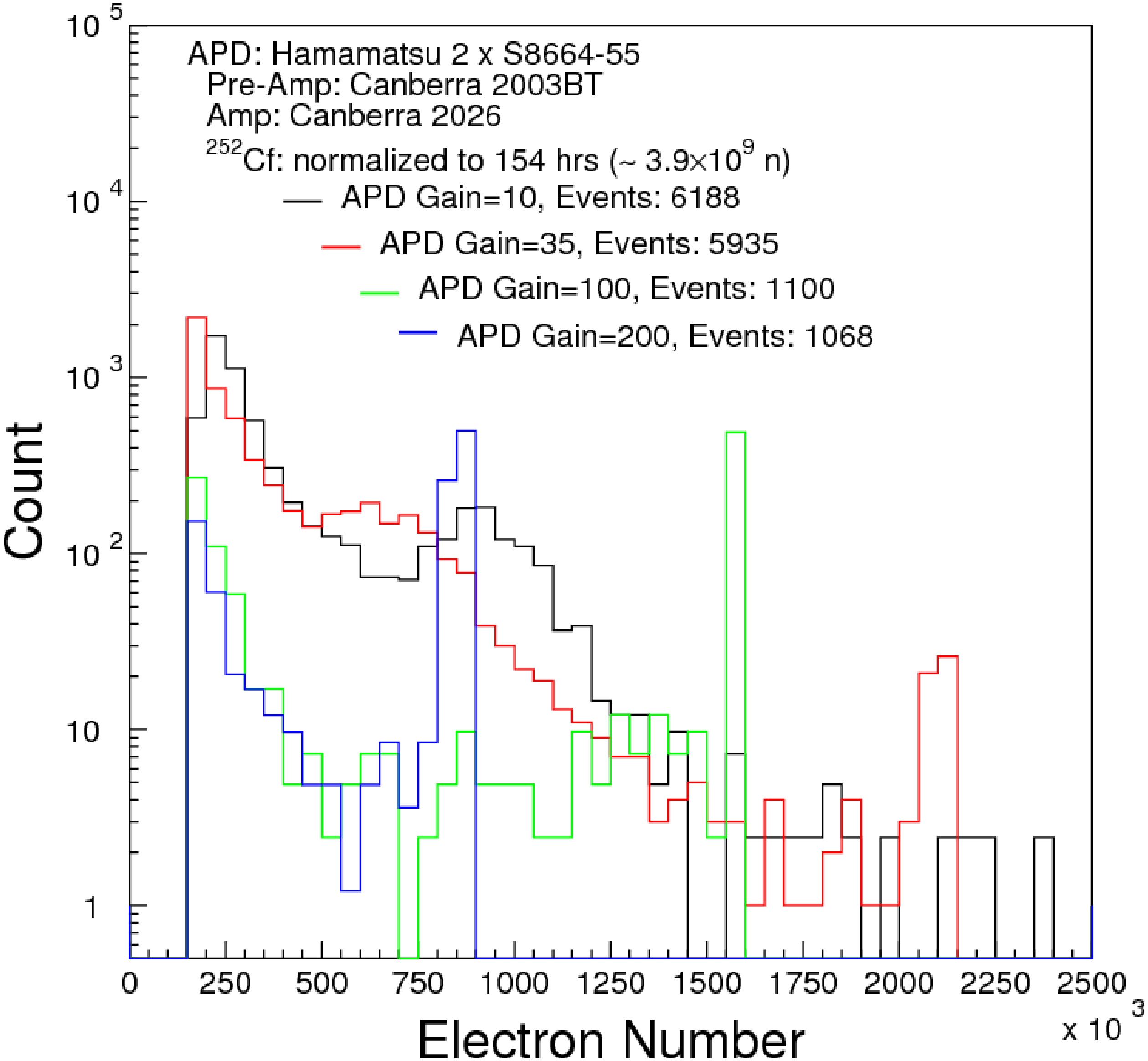
^{252}Cf Spectra with S8664-55 Gain 35



Data were taken with the SA gain at 2.5. The up-limit of the pulse height distribution is ~2 M electrons, or 7.2 MeV deposition in APD, which corresponds to 1000/ 500 GeV, assuming the light yield is 2/4 p.e./MeV.

There are a few tens overflow events with saturated SA energy scale, indicating energy deposition higher than 7.2 MeV.

^{252}Cf Spectra Comparison

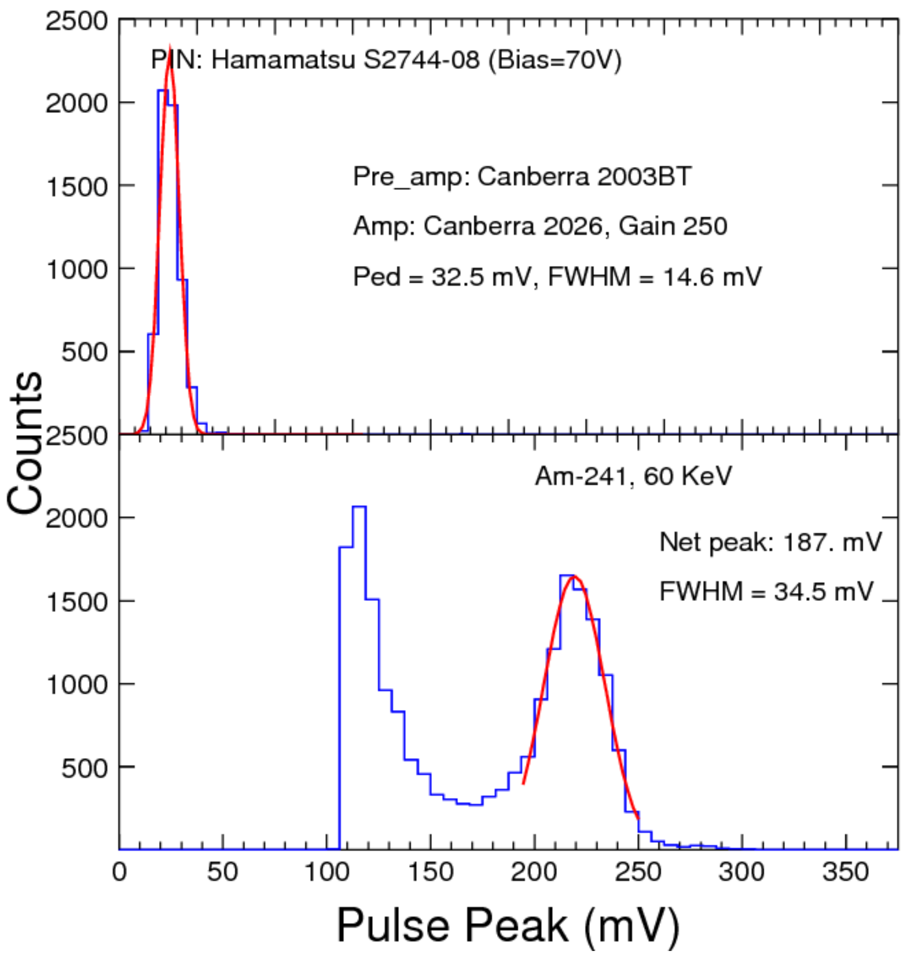


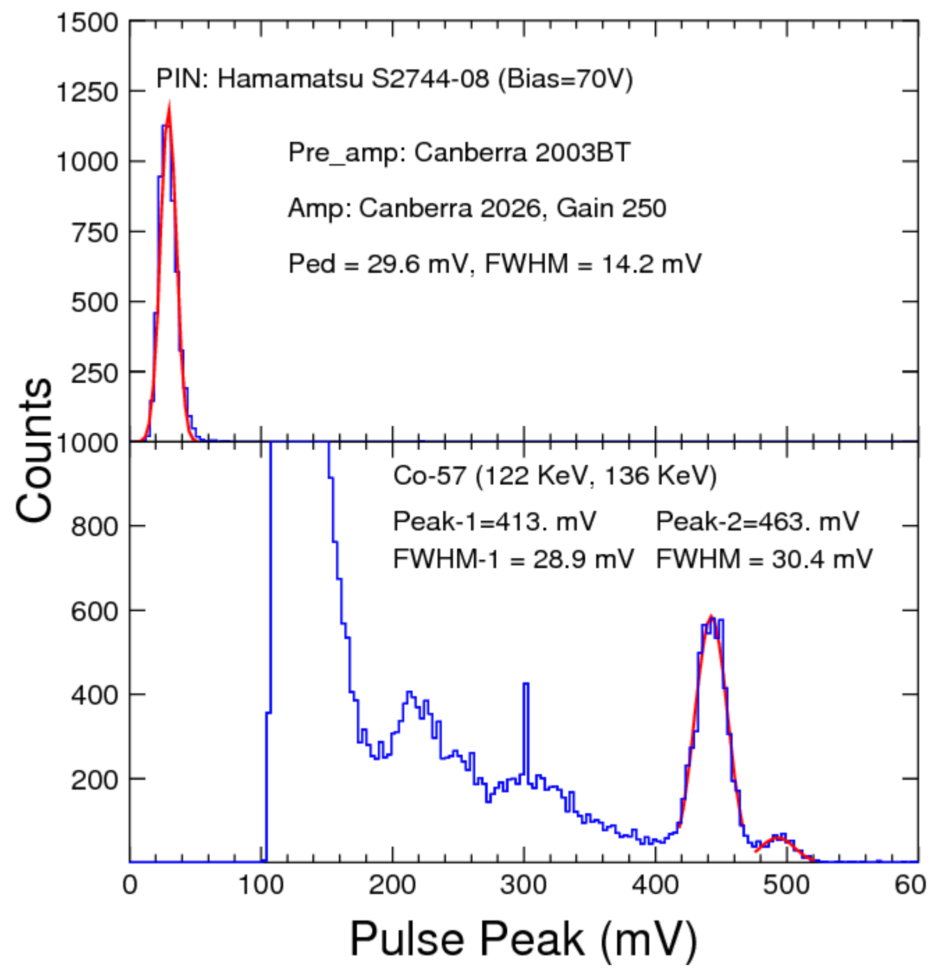
PA saturation was also observed for the APD gains of 100 and 200.

The fraction of events with signals of more than 150 k electrons is 1.6, 1.5, 0.28 and 0.27 x 10^{-6} for the APD gains of 10, 35, 100 and 200 respectively, indicating that a high APD gain reduces the neutron-induced nuclear counter effect in the APD.

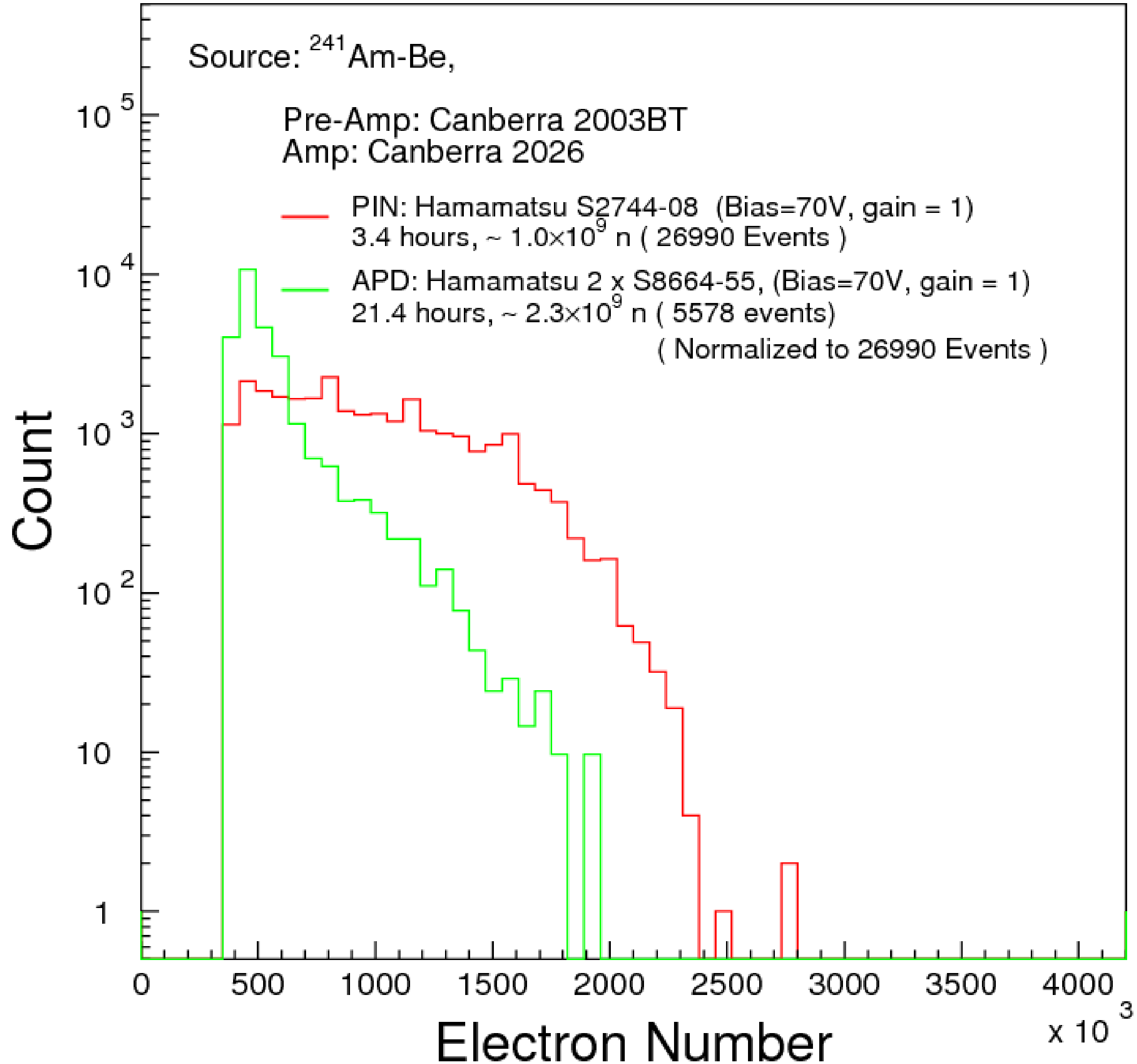
S2744-08 Calibration

Consistent calibration for electron numbers in PIN was obtained by using ^{241}Am and ^{57}Co sources.





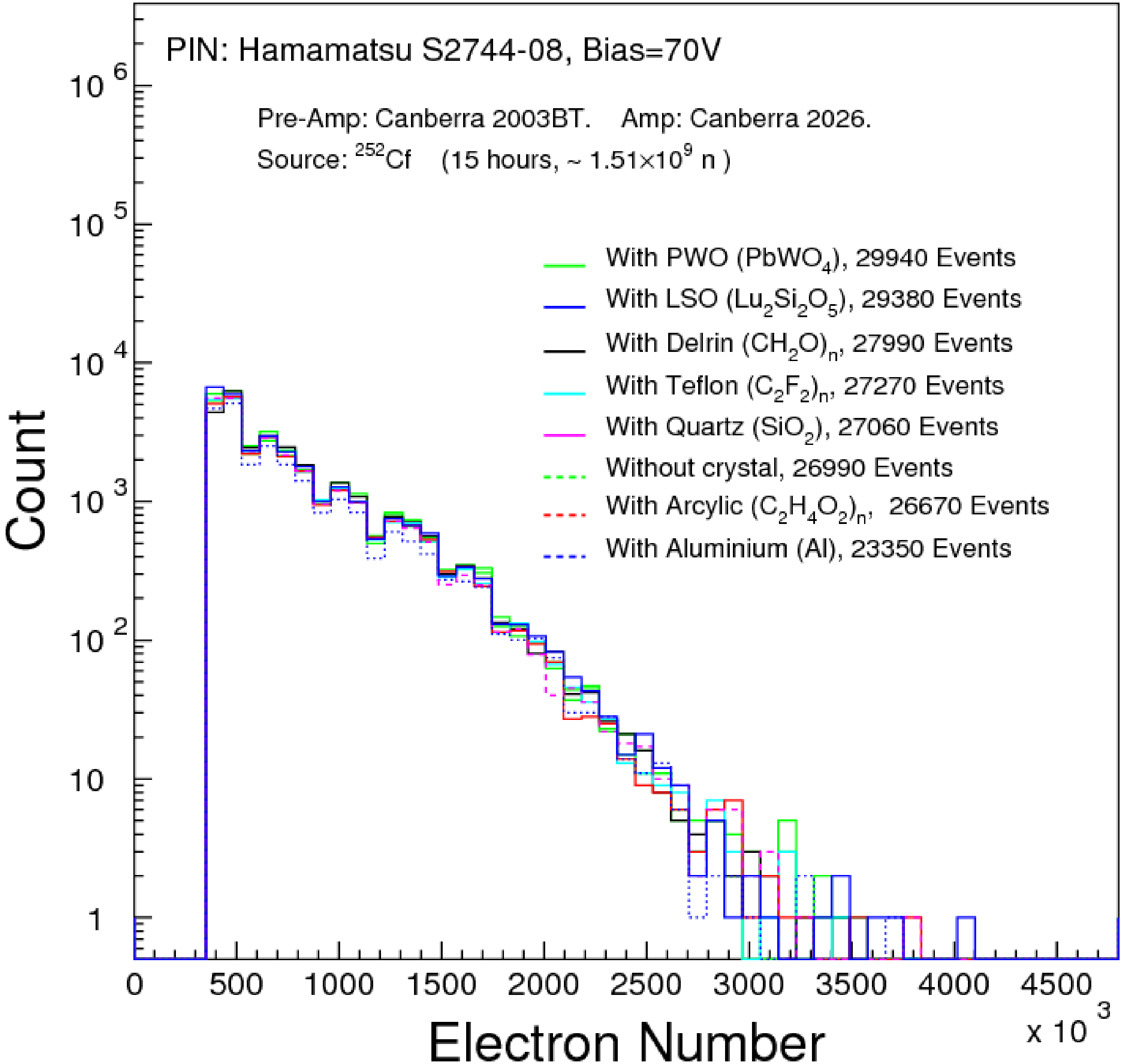
Comparison between APD and PIN



Signals of up to 2.5 and 2 M electrons were observed in the PIN and APD with unit gain respectively, corresponding to 9 and 7.2 MeV energy deposition.

The fraction of events with signals of more than 350 k electrons is 27 and 2.4 x 10^{-6} for the PIN and APD respectively, indicating that the neutron-induced nuclear counter effect in the APD is a factor of ten smaller than the PIN diode.

^{252}Cf Spectra for PIN with Materials

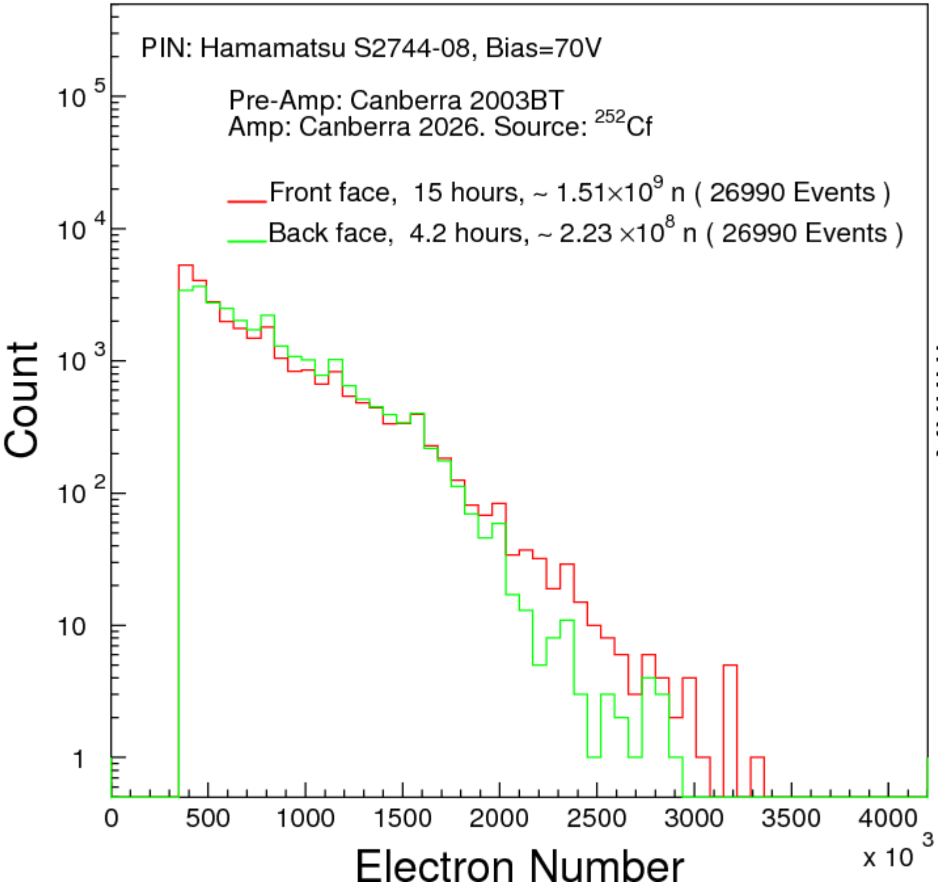


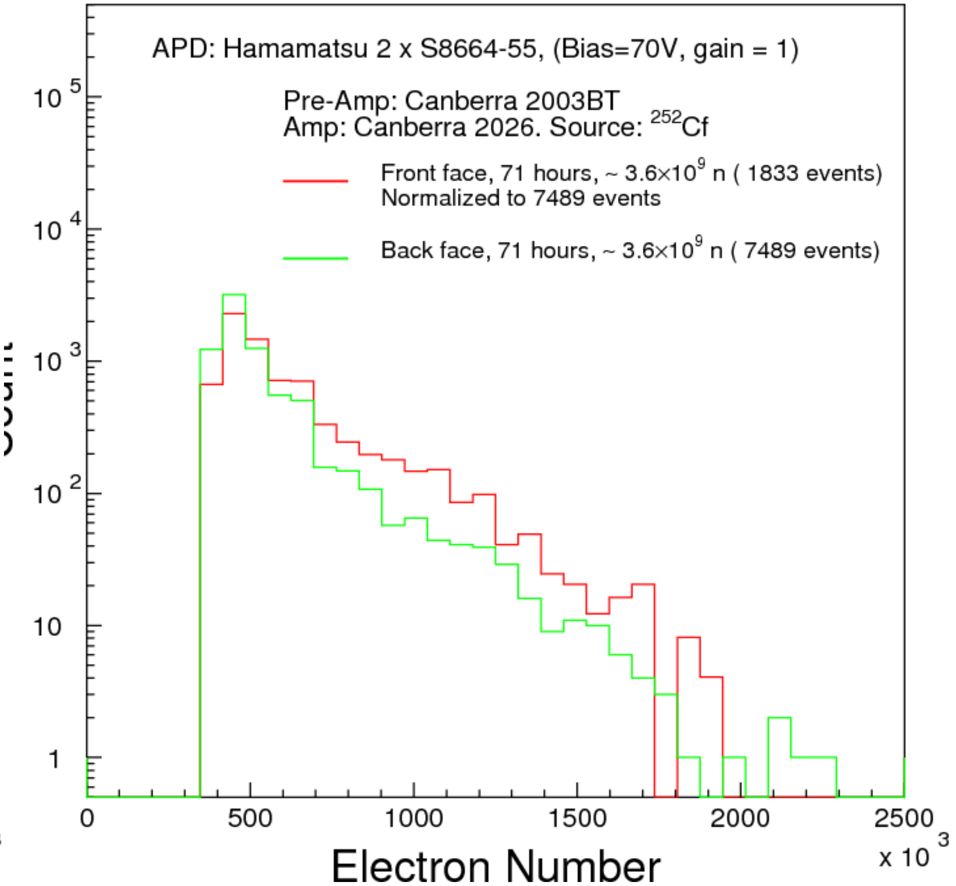
1 to 2 cm thick materials were inserted at the front of the PIN.

It seems that high Z materials, such PWO and LSO, enhance the nuclear counter effect, while the low Z material, such as H, C, O and Al, reduces the effect.

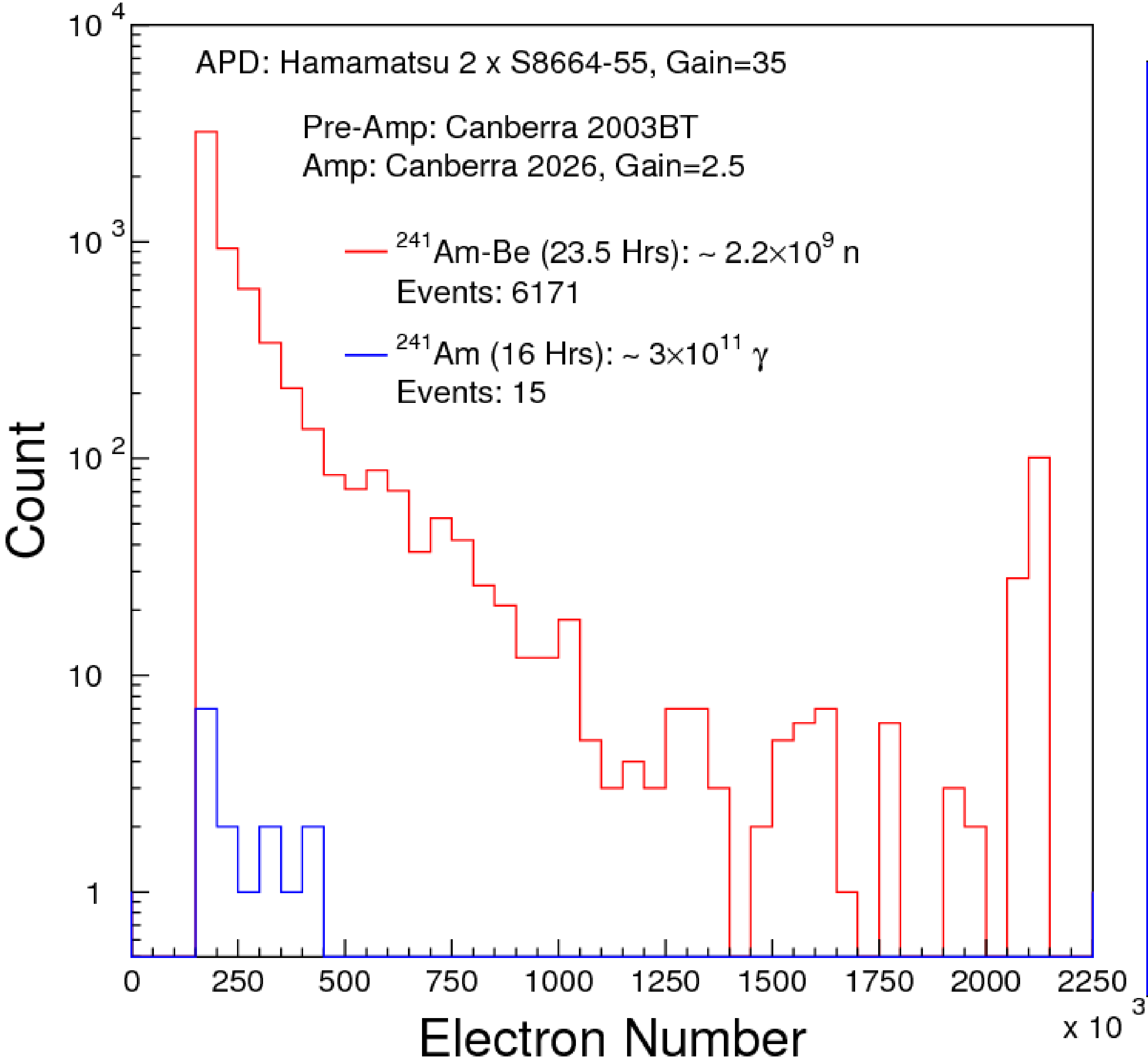
Front & Back Comparison

The back face facing the neutron source enhances the neutron induced nuclear counter effect by a factor of 7 & 4 for APD and PIN respectively, indicating that there is no contamination in the front face data.





^{241}Am-Be and ^{241}Am Spectra



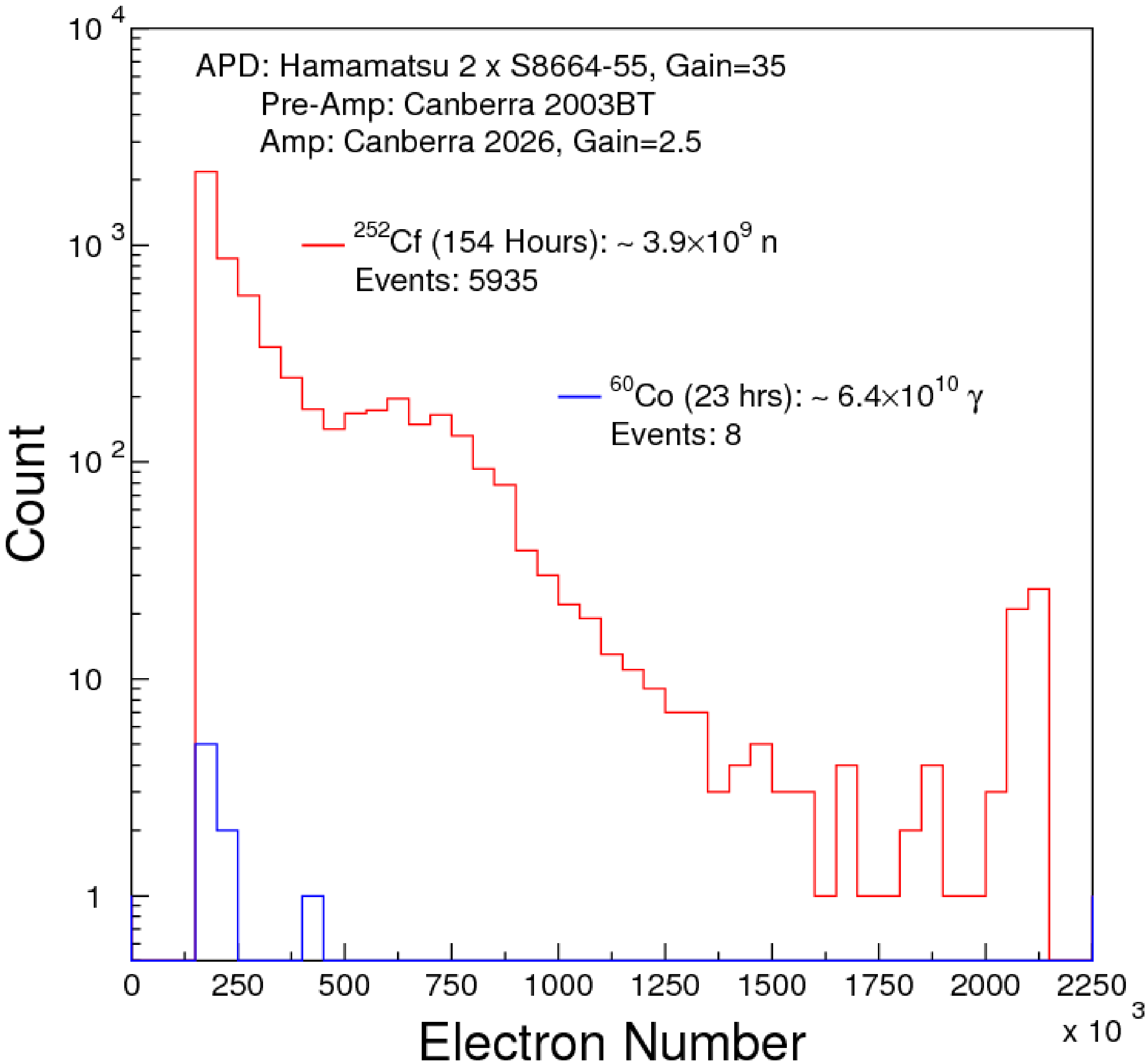
The trigger rate of 15 and 60 keV X-rays from an ^{241}Am source is five orders of the magnitude smaller compared to ^{241}Am-Be neutrons, indicating negligible contamination from X-rays.

Trigger Rate for >150 k electrons:

^{241}Am-Be: 2.8 x 10^{-6}

^{241}Am: 5.0 x 10^{-11}

^{252}Cf and ^{60}Co Spectra



The trigger rate of MeV γ-rays from an ^{60}Co source is 4 orders of the magnitude smaller than ^{252}Cf neutrons, indicating that the contamination from γ-rays in negligible.

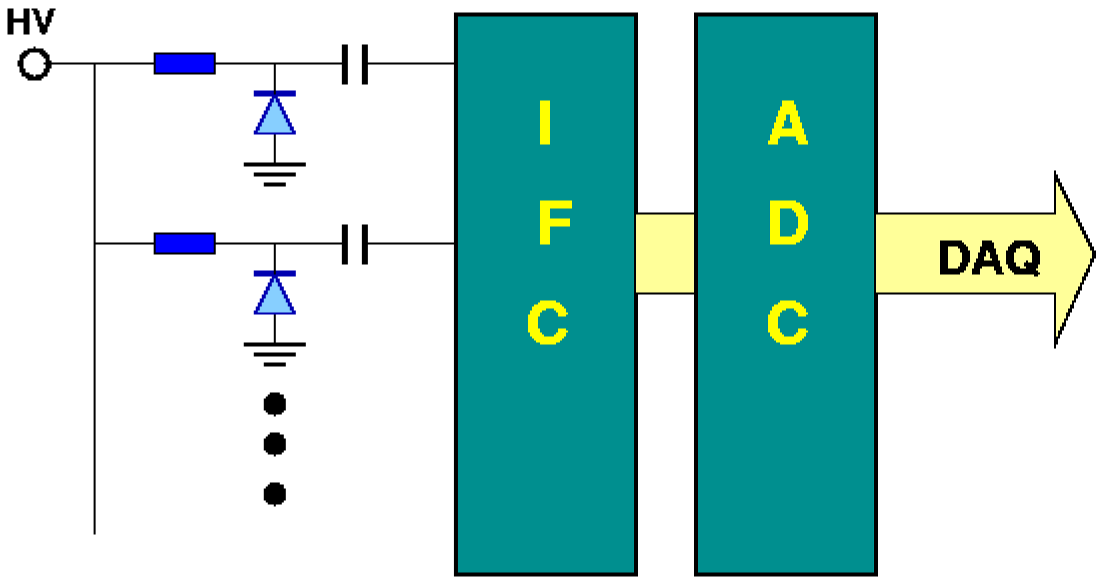
Trigger Rate for >150 k electrons:

^{252}Cf: 1.5×10^{-6}

^{60}Co: 1.3×10^{-10}

Ways to Handle this Effect

Multiple independent readout channels are a good solution. The potential high cost may be minimized by an intelligent frontend chip (IFC) which reads out only uncontaminated signals.



Advanced data analysis may also be implemented to reduce this effect.

Summary

MeV neutrons from ^{252}Cf and ^{241}Am-Be source cause signals up to a few million electrons, or ~10 MeV energy deposition, in Si APD and PIN, indicating that the entire kinetic energy of a neutron may be converted into electron signals in these devices.

The equivalent energy of calorimeter readout depends on the crystal light yield. Anomalous signals of 2 M electrons, for example, correspond to 500 and 2.5 GeV for PWO and LYSO respectively assuming the light yields of 4 and 800 p.e./MeV for long crystals.

The overall effect in APD is a factor of ten less than PIN. Increasing the APD gain reduces the effect since only a portion of the energy in APD is fully amplified as the scintillation photons.

Multiple photo-devices with independent readout chains eliminate this effect completely. An intelligent front-end chip capable of selecting un-contaminated signal will keep the total channel counting under control. The neutron induced nuclear counter effect may also be reduced by advanced data analysis.