DEAR Technical Note IR-4

Linearity test of DEAR CCDs

Ross King

Institute for Medium Energy Physics
Austrian Academy of Sciences, Vienna, Austria

Catalina Petrascu

Laboratori Nazionali di Frascati
I.N.F.N., Frascati, Italy

November 2, 1998

1 Introduction

The calibration of the CCD energy scale is obviously a critical aspect of the DEAR experiment. Based on the assumption that the detector response is linear, we have developed a calibration scheme based on the observation of fluorescence peaks from titanium and zirconium concurrent with the kaonic hydrogen X-ray observation [1]. In order to quantify the effectiveness of this scheme, the assumption of linear detector response must be tested and quantified. This note reports a first attempt to measure the linearity of the CCDs and to place a limit on the systematic uncertainty related to and constrained by linearity measurements.

2 Configuration

This measurement was performed in the DEAR Laboratory on November 15, 1997. The setup is shown in figure 1. The detector was the NTP target

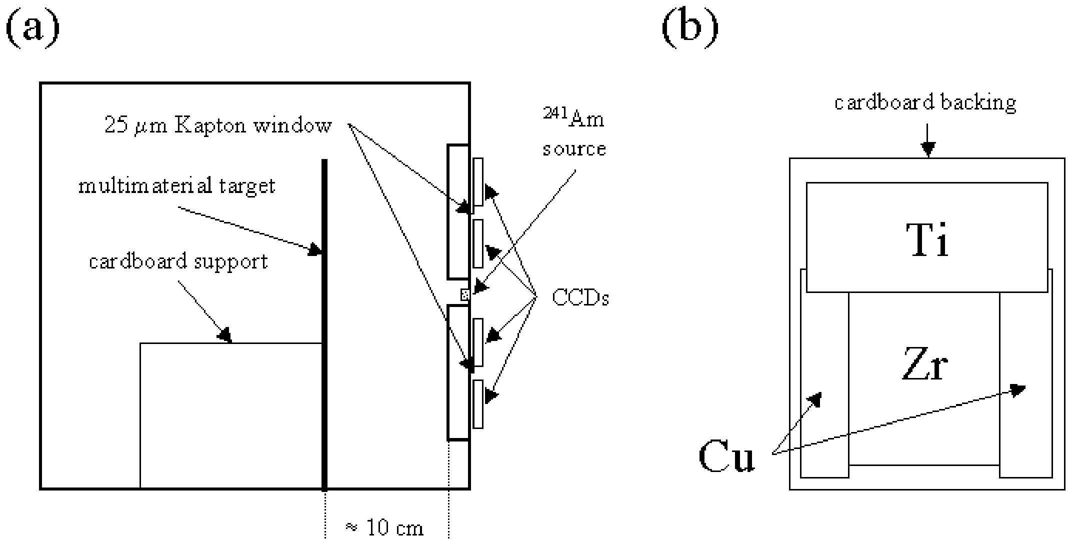

Figure 1: (a) The NTP setup for the linearity measurement, (b) The layout of the multimaterial target

and its associated CCDs (J14, J15, J16, and J17). A multimaterial target consisting of foils of titanium, copper and zirconium was placed inside the NTP gas volume, in front of the CCDs. These materials were excited by a 370 kBq ^{241}Am source, and the 8 half-CCDs installed on NTP target registred the resulting fluorescence X rays.

3 Results

After 20 hours of data acquisition, we obtained the results presented in figures 2 and 3 for the 8 half-CCDS.

Observing these spectra one can see that the "best" half-CCD (in terms of statistics and resolution) is CCD C (20.000 events in the spectrum). We therefore concentrate our linearity analysis on this half-CCD, as described in the following section.

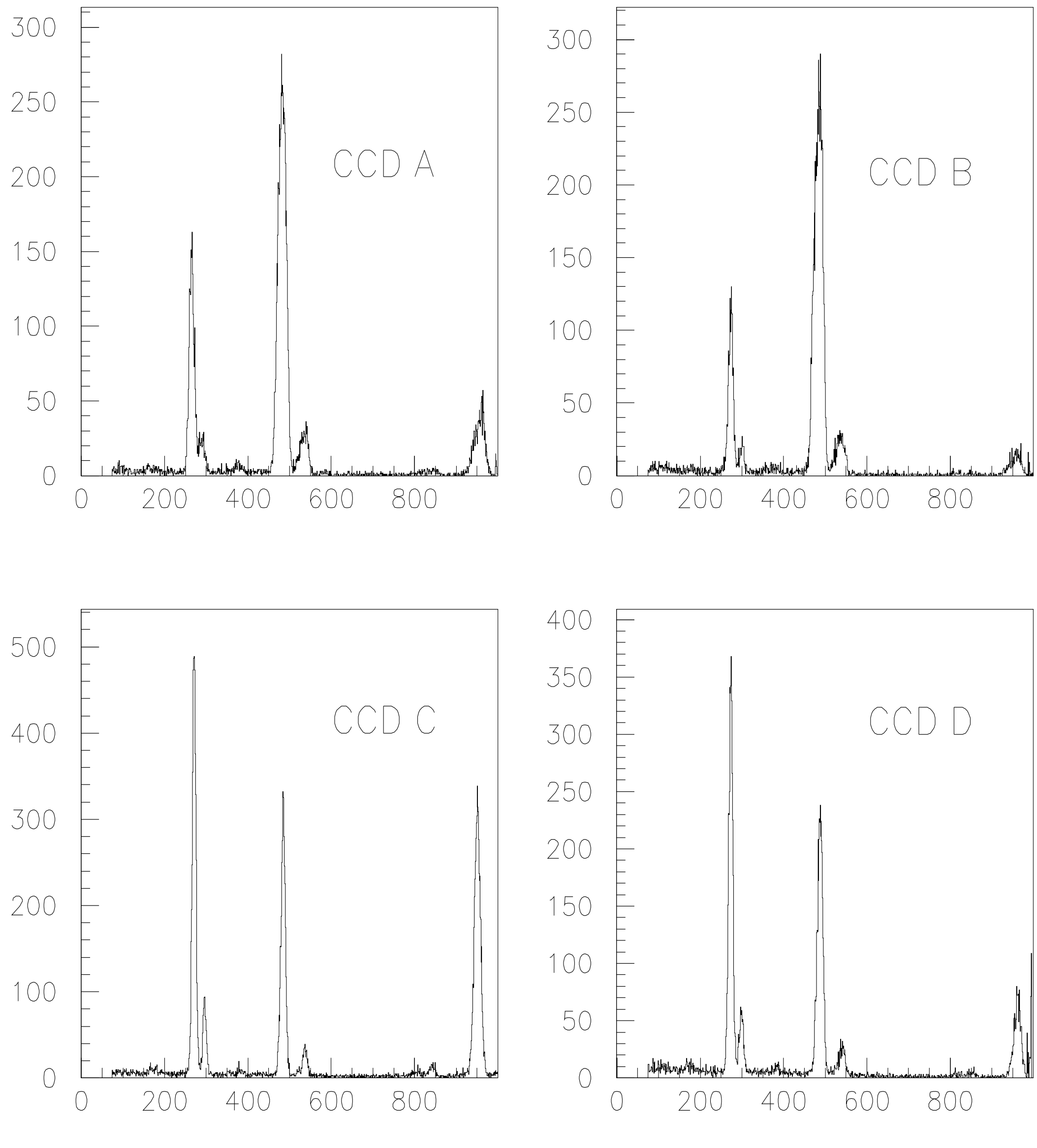

Figure 2: Spectra of the number of events versus channel number for the first 4 half-CCDs (A - D); multimaterial target run.

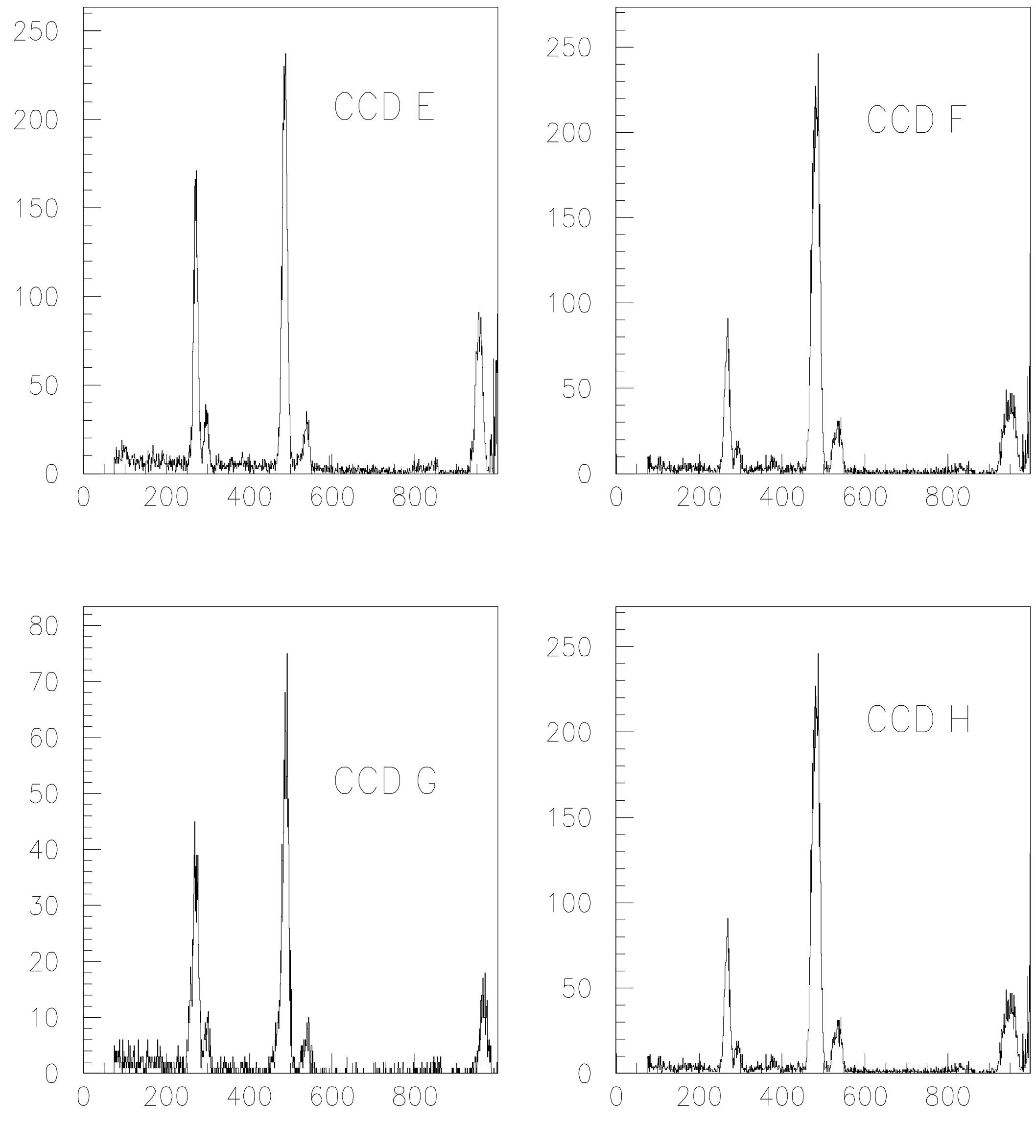

Figure 3: Spectra of the number of events versus channel number for the second 4 half-CCDs (E - H); multimaterial target run.

4 Analysis

In order to check the CCD response in function of energy, we must compare to peaks of well-known energy. Some transitions are too close together to resolve with our detectors, so we use the intensity-weighted average of the transition energies as the assumed mean of a single Gaussian. The energies of the peaks in the energetical range of interest are presented in table 1 [2].

Table 1: Energies of the electromagnetic transitions used for the study of CCD linearity

Material	Peak	Energy (keV)	Intensity	Weighted-average (keV)
Ti	KL_{II}	4.50486	0.51	
Ti	KL_{III}	4.51084	1.00	4.508
Ti	$KM_{II,III}$			4.932
Cu	KL_{II}	8.02783	0.50	
Cu	KL_{III}	8.04778	1.00	8.041
Cu	$KM_{II,III}$			8.905
Zr	KL_{II}	15.6909	0.50	
Zr	KL_{III}	15.7751	1.00	15.747

The spectrum was analyzed within the PAW software environment. The results of the fits to the CCD C spectrum, using Gaussian signal peaks plus a polynomial background function, are presented in table 2.

Table 2: Results of the fit of the spectra corresponding to CCD C

Energy (keV)	Nr. of events in the peak	Fit peak position (channel)	Error in the peak position (channel)
4.508	5412	270.72	.06
4.932	980	295.93	.16
8.041	4071	484.50	.09
8.905	575	537.15	.33
15.747	5727	950.95	.10

Similar results, but with larger errors (due to a poorer statistics) were obtained for the other half-CCDs (A,B,D,E,F,G,H).

The CCD C spectrum is reproduced and the fit peak mean channel as function of energy is presented in figure 4.

The results presented in table 2 were analysed in terms of the linearity of the energy as function of the channel number. In order to perform this study, various fits were performed (using the MINUIT software package).

A fit with a linear dependence of the channel number as function of energy was performed, yielding the following results:

- a fit with 3 points (Ti-K_α, Cu-K_α, Zr-K_α) gave a χ^2/NDF=0.25;
- a fit with 4 points (Ti-K_α, Ti-K_β Cu-K_α, Zr-K_α) gave a χ^2/NDF=0.6;
- a fit with all 5 points gave a χ^2/NDF=2.7.

A fit with a quadratic dependence of the channel number as function of energy was as well performed, yielding the following results:

- a fit with 3 points (Ti-K_α, Cu-K_α, Zr-K_α) gave a quadratic term contribution at 6.5 keV of (1.3 ± 2.7) eV, where no χ^2/NDF could be defined;
- a fit with 4 points (Ti-K_α, Ti-K_β Cu-K_α, Zr-K_α) gave a quadratic term contribution at 6.5 keV of (0.7 ± 2.6) eV and a χ^2/NDF=1.1;
- a fit with all 5 points gave a quadratic term contribution at 6.5 keV of (0.3 ± 2.6) eV and a χ^2/NDF=4.0.

5 Conclusions

From the results presented in the preceding section, one can observe:

- the fit quadratic term is always consistent with zero;
- for any given number of points, the χ^2/NDF for the linear fit is "better" (smaller) than the one for the quadratic fit;
- the quadratic term contribution in energy at 6.5 keV (our region of interest) is less than 1 eV for the fits with 4 and 5 points considered;
- the error on the quadratic term contribution is about 3 eV.

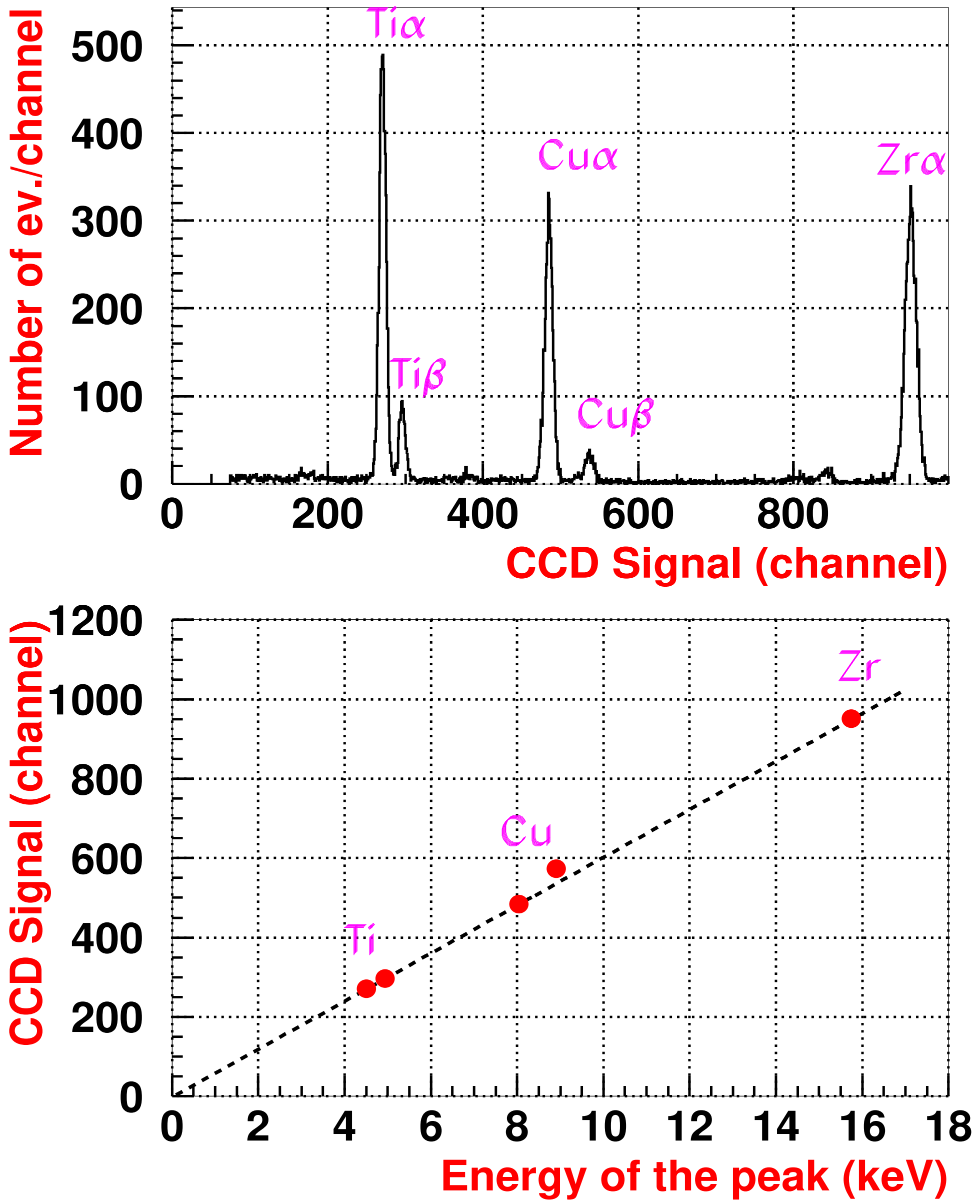

Figure 4: The number of events versus channel number for CCD C and the CCD C signal (fit peak mean channel) versus energy

We conclude that the CCD response is linear in the region of interest, within the limits of our observations. Conservatively, we estimate this limit to the contribution of the *uncertainty* of the quadratic term (and not the quadratic term itself) to the evaluation of the expected kaonic hydrogen K_α energy (6.4 keV), that is, to about 3 eV.

It is therefore clear that similar CCD linearity studies must be carried out for each half-CCD (and its corresponding electronics) as it will be used in the final setup. With further measurements and higher statistics, we should be able to reduce this number to below 2 eV, that is, to the level required by a 1% precision measurement.

References

[1] T.M. Ito and R. King,
"Summary of foil measurements, foil Monte Carlo, and recommendations for the long-term calibration",
DEAR Technical Note IR-2, 1998.

[2] J.A. Bearden, Rev. Mod. Phys. 39 (1967) 78.
J.A. Bearden and A.F. Burr, Rev. Mod. Phys. 39 (1967) 125.