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Analysis of the radiation effects on some properties of GaAs:Cr and Si sensors exposed to a 22 MeV electron beam

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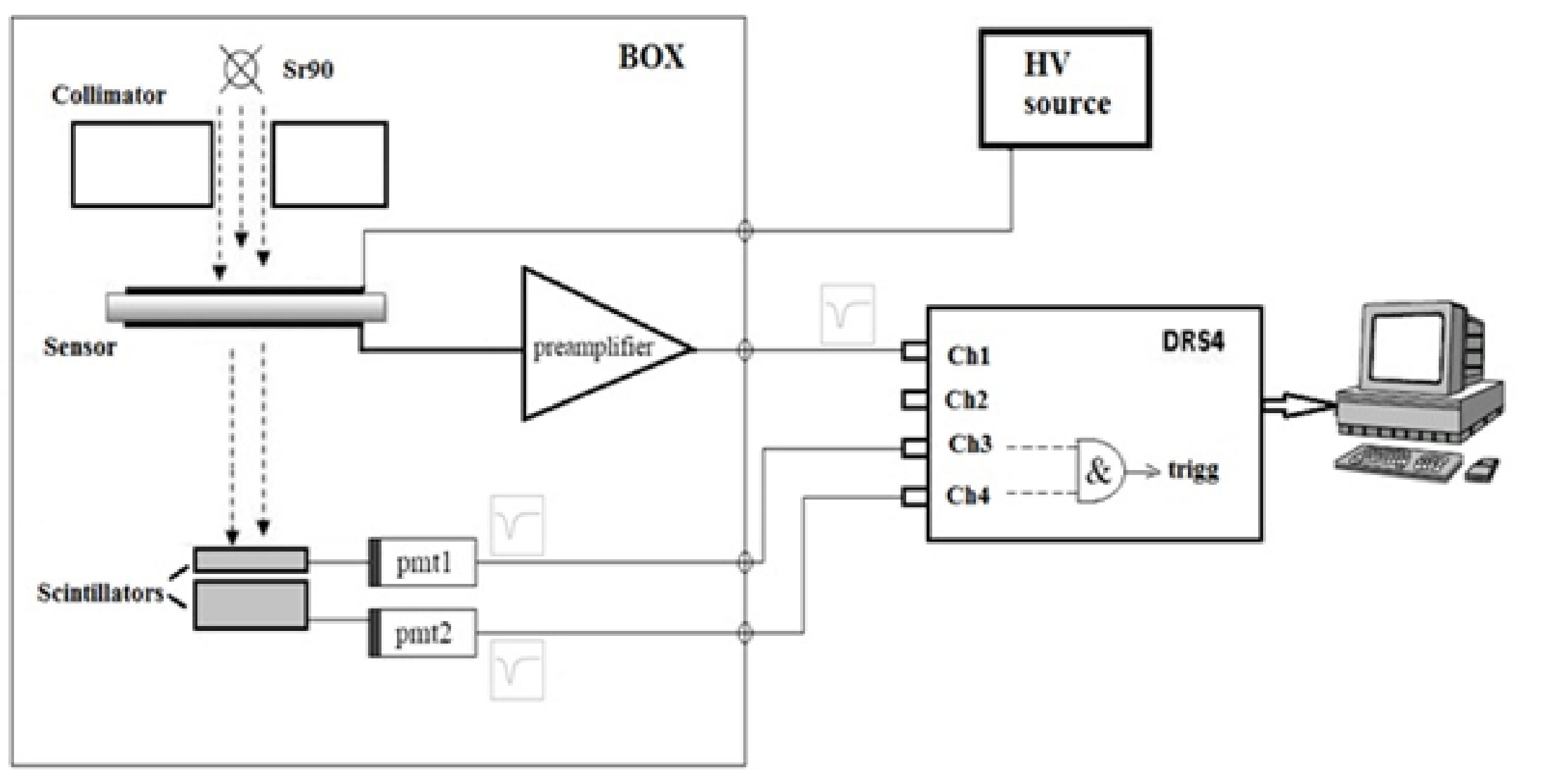
Abstract

Nowadays, the experiments related to the High Energy Physics and others fields demand the use of detectors with greater radiation resistance, and the novel material GaAs:Cr had demonstrated excellent radiation hardness compared with other semiconductors. On the basis of the evidences obtained in the JINR experiment with the use of 22 MeV electrons beam generated by the LINAC-800 accelerator, an analysis of the electron radiation effects on GaAs:Cr and Si detectors is presented. The measured I-V characteristics showed a dark current increase with dose, and an asymmetry between the two branches of the behaviors for all detectors. Analyzing the MIP spectra and CCE dose dependence measurements a deterioration process of the detectors collection capacity with the dose increase was found, although the behaviors are somewhat different according to the detector type. These effects are generally linked to the generation of atomic displacement, vacancies and other radiation defects, modifying the energy levels structure of the target material. These changes affect the lifetime and concentration of the charge carriers, and other material characteristics.

Materials and methods

Main characteristics of used sensors.

Type	Size [mm^3]	Sensitive area [mm^2]
Barrier GaAs:Cr	5x5x0.3	5x5
High resistive GaAs:Cr	5x5x0.3	4.5x4.5
Normal n-type Si	5x5x0.3	4x4
Radiation hard n-type Si from USCS	10x5x0.4	4x4



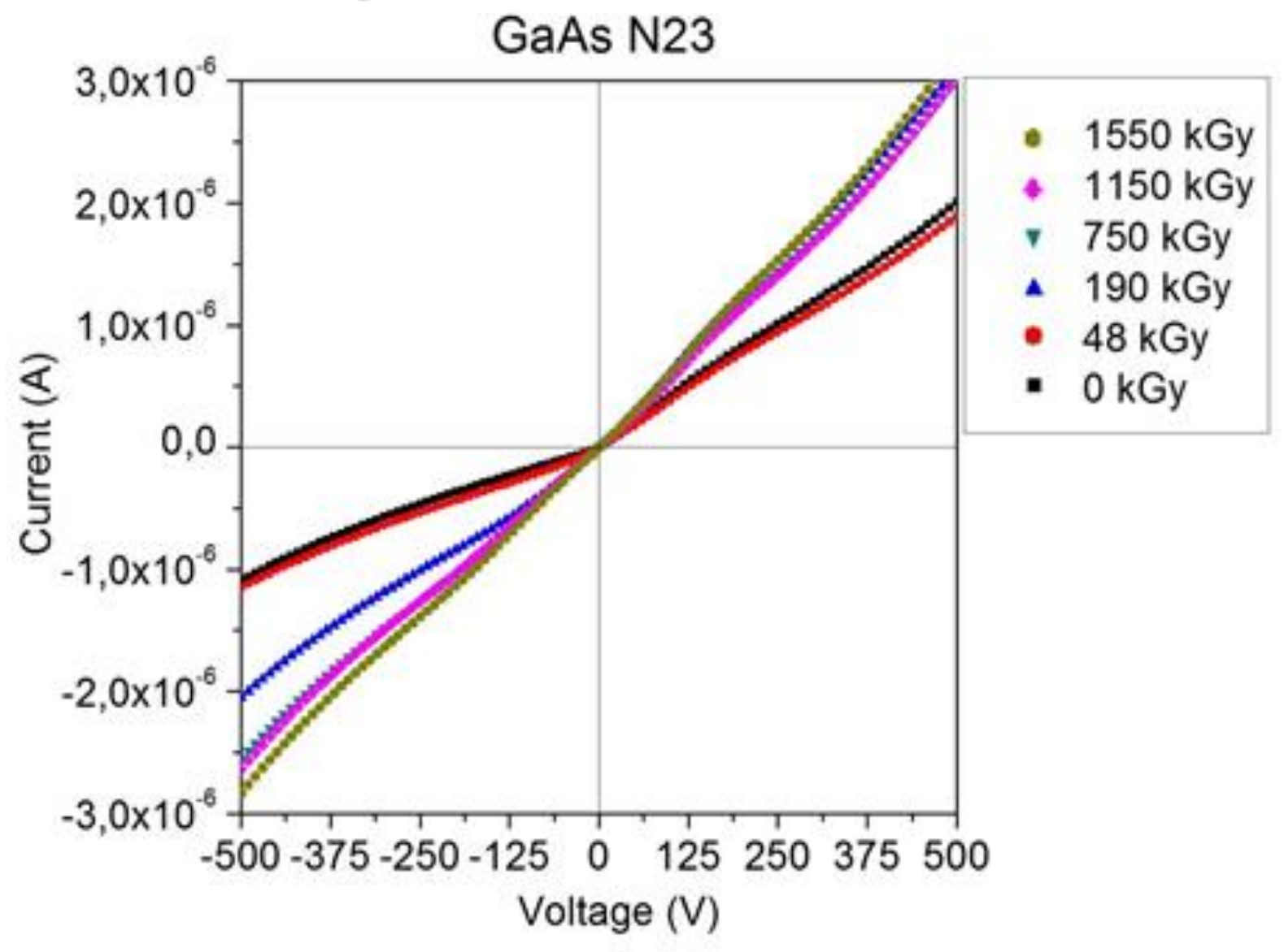
Block-scheme of CCE measurement.

- ❖ The electron irradiation was performed at the LINAC-800 accelerator using the 22 MeV beam channel.
- ❖ Charge collection efficiency was measured by using a 90Sr ß-source. After each dose step the CCE for at least 2 bias voltages and the I-V dependences were measured.
- ❖ Measurement temperature = 21ºC.

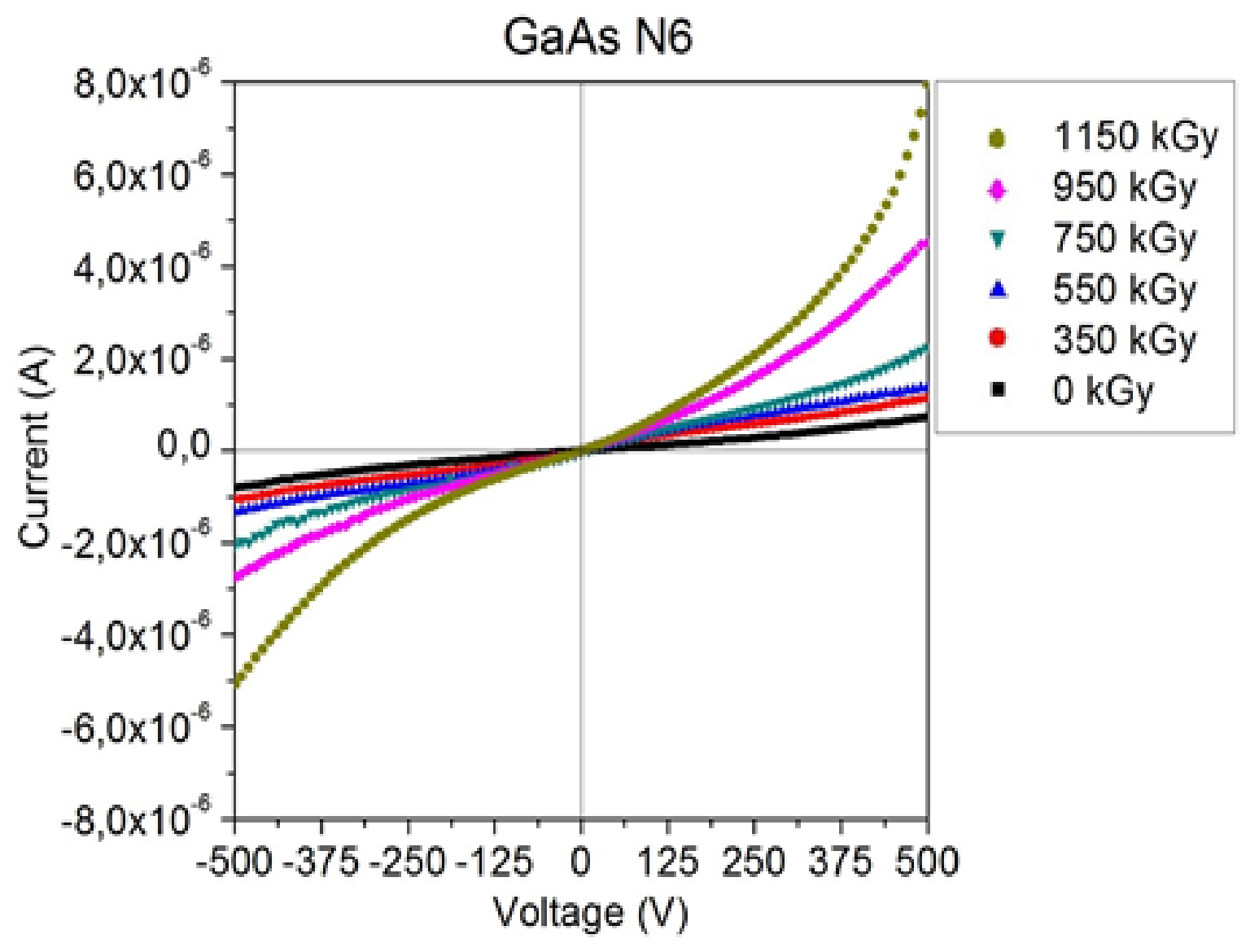
Results

I-V measurements for different doses

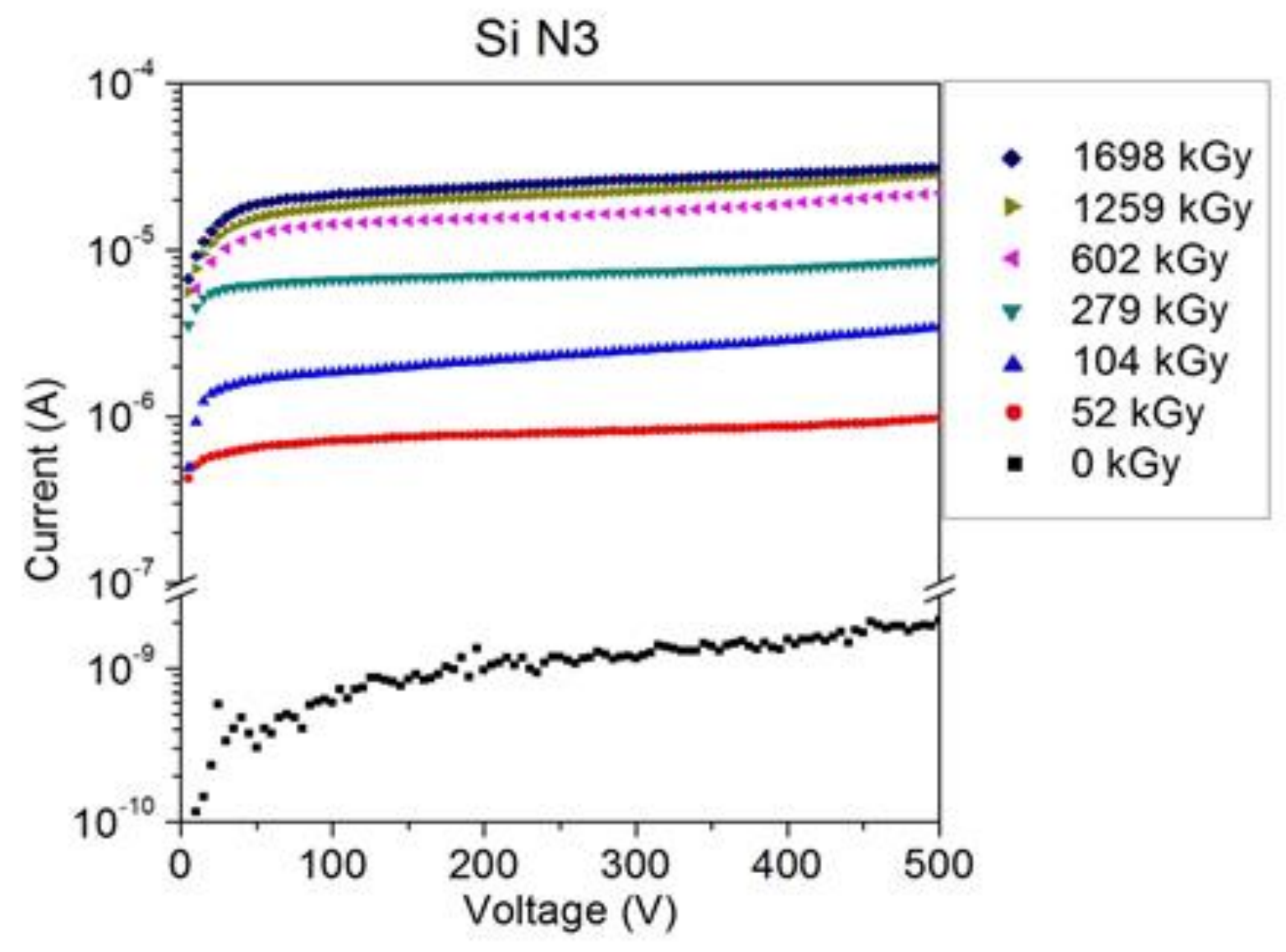
High resistive GaAs:Cr



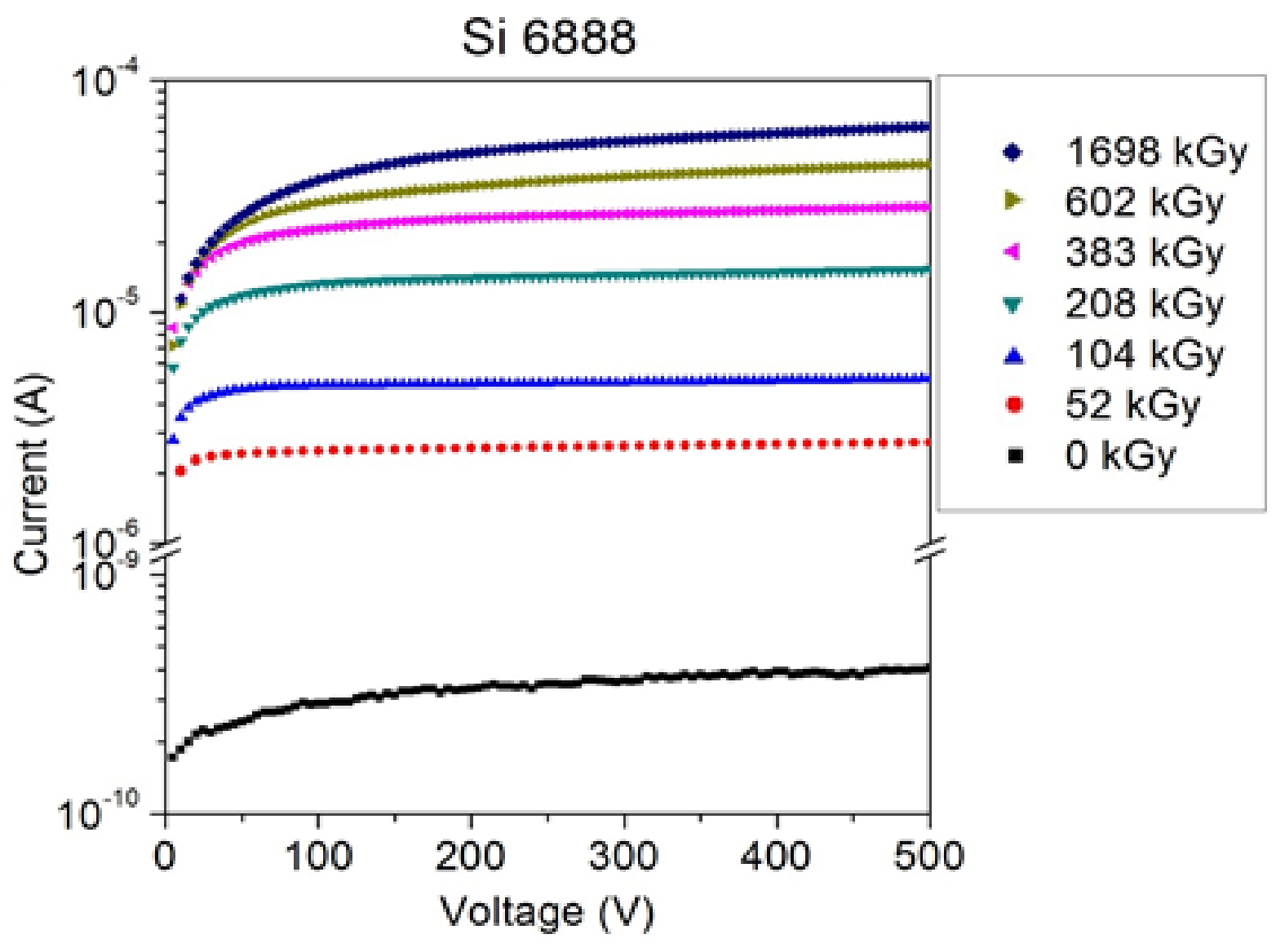
Barrier GaAs:Cr



Normal n-type Si

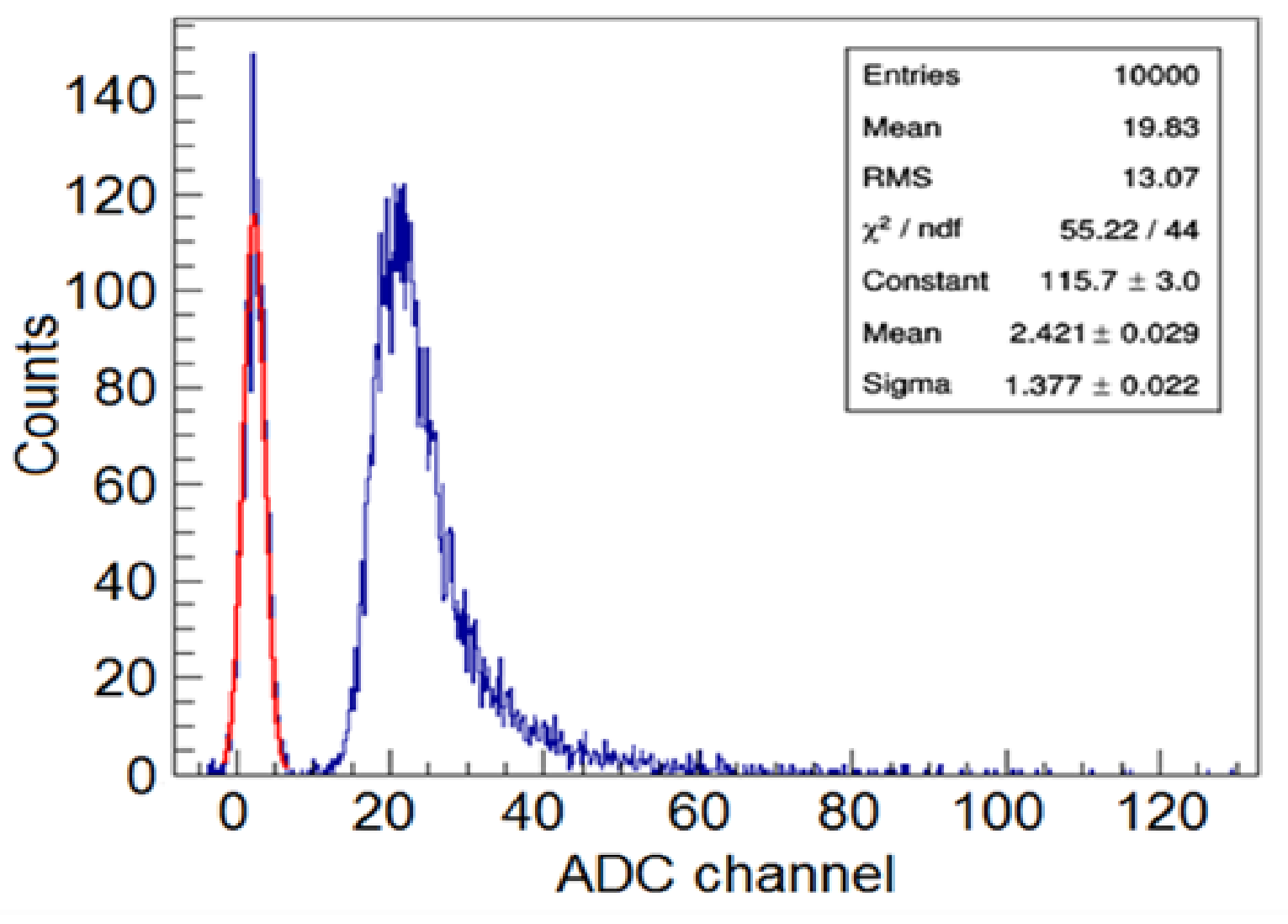


USCS radiation

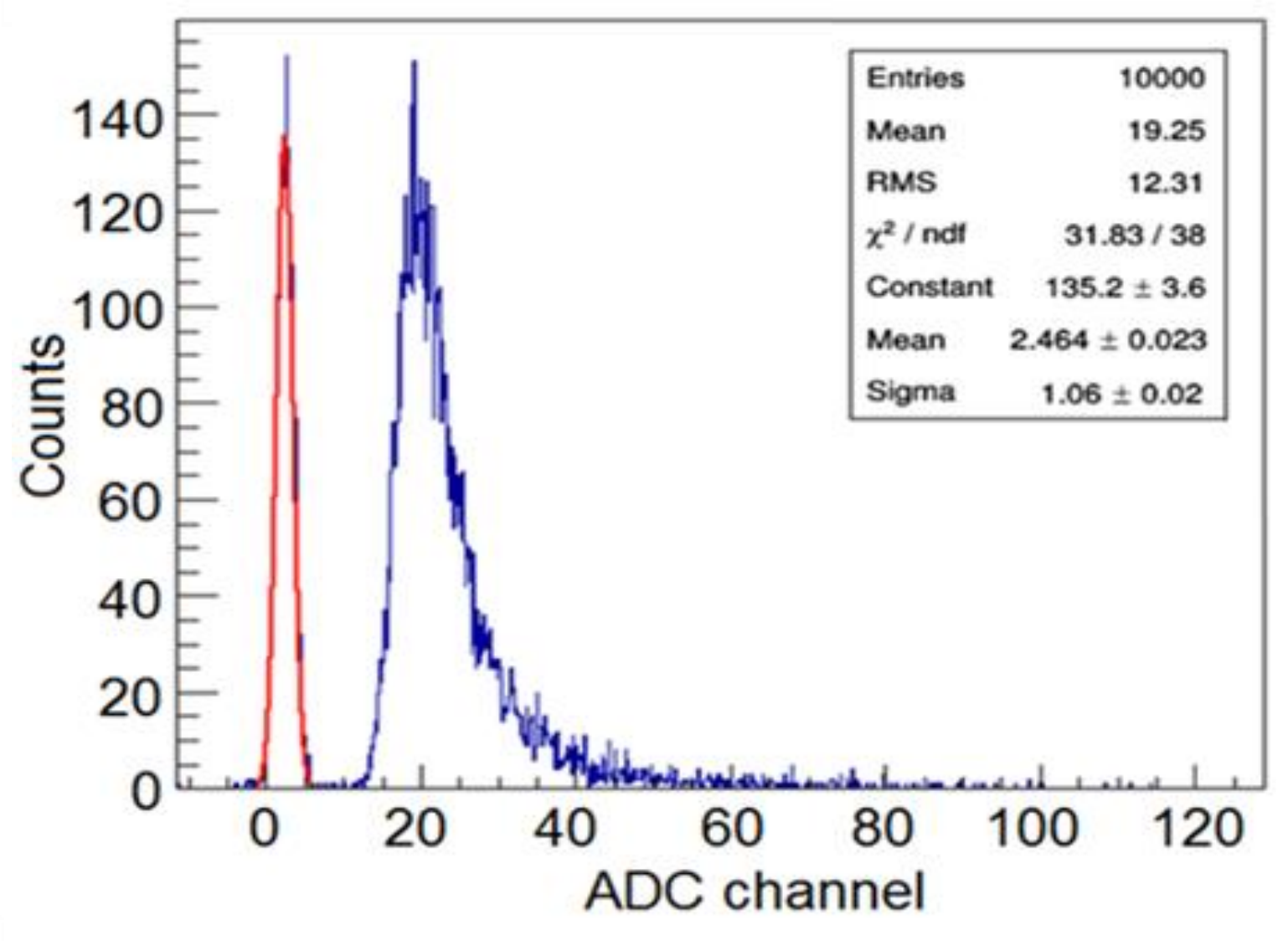


CCE Measurements

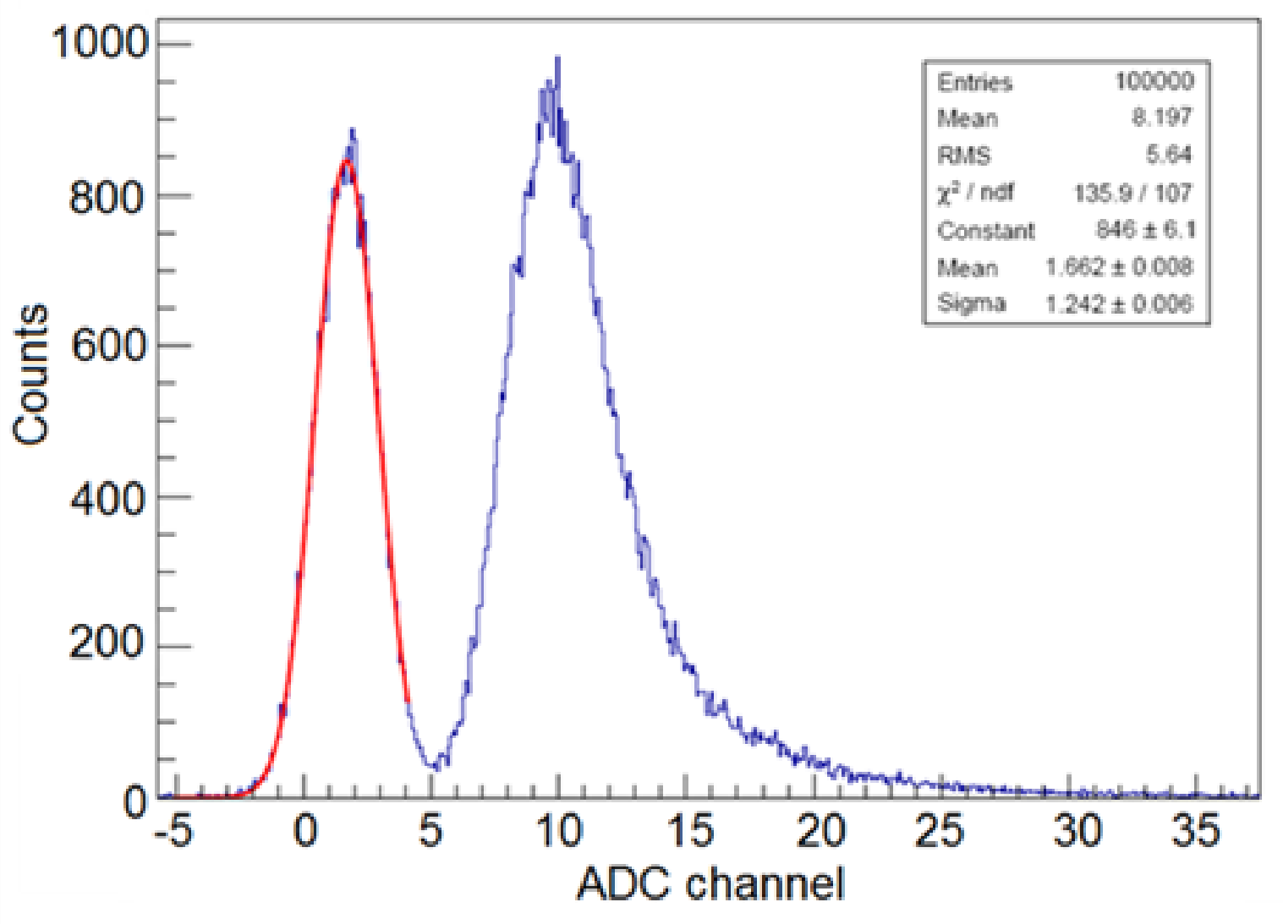
MIP spectra ➡ High resistive GaAs:Cr (0 kGy)



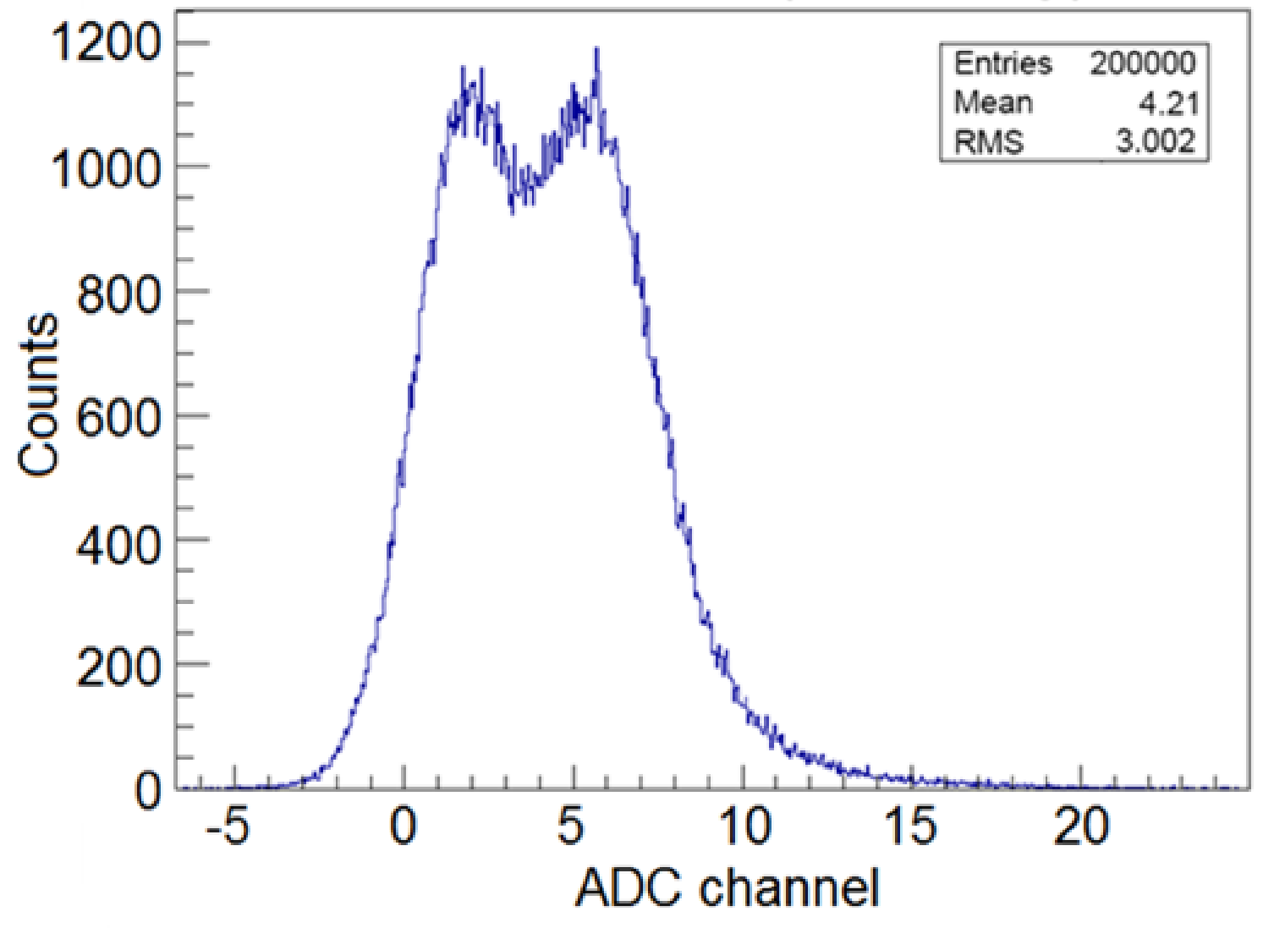
Barrier GaAs:Cr (0 kGy)



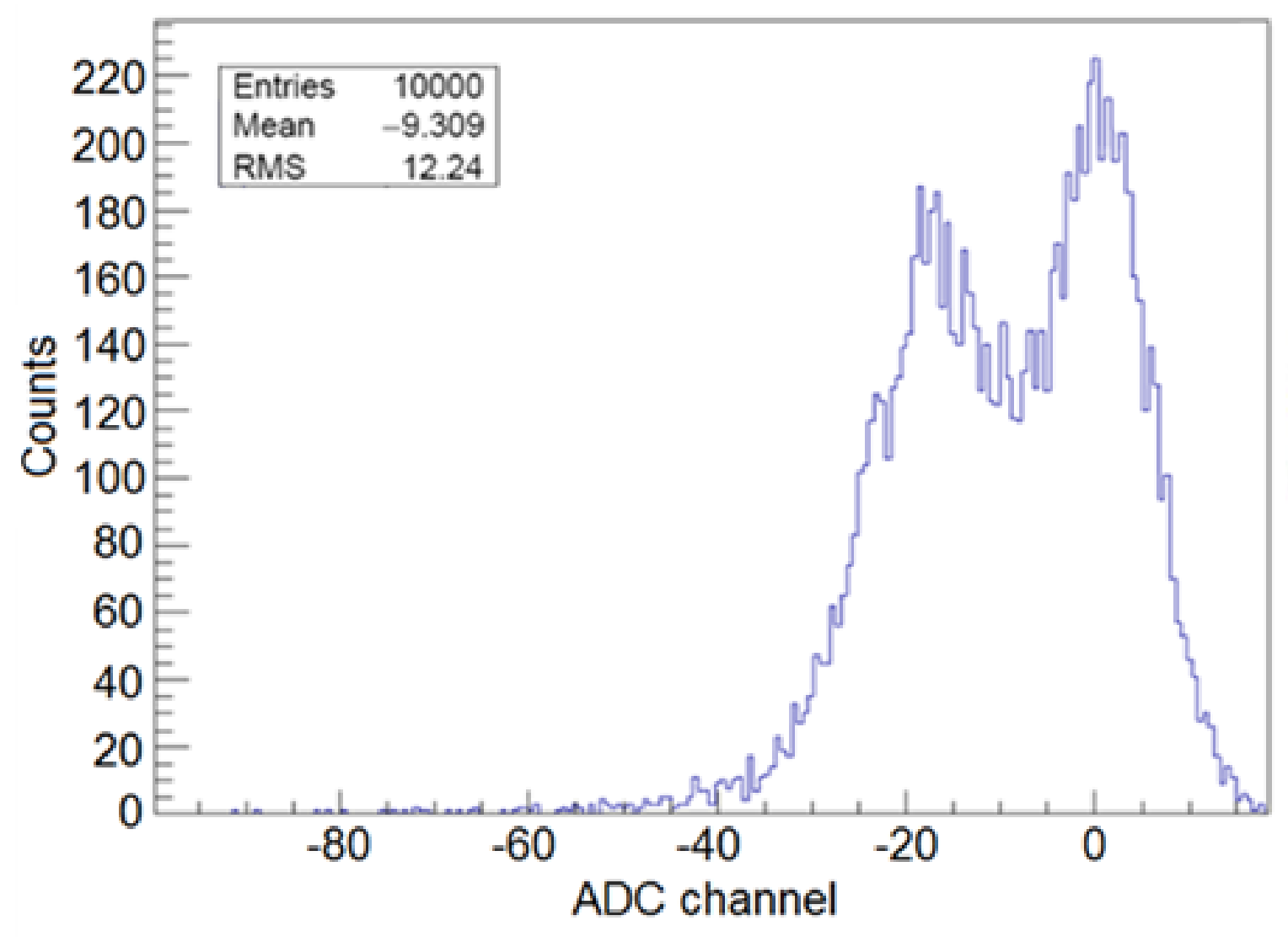
Barrier GaAs:Cr (550 kGy)



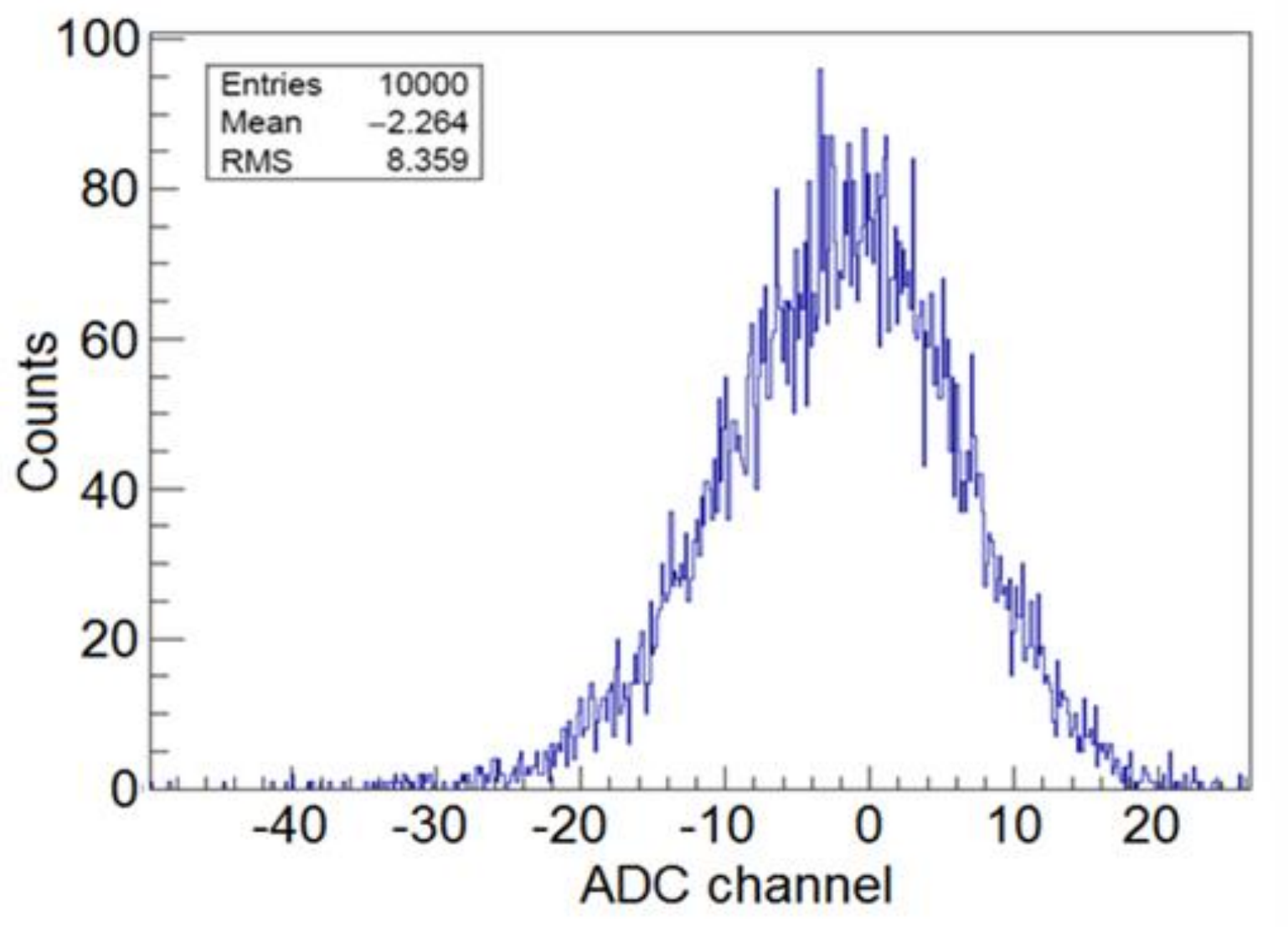
Barrier GaAs:Cr (1550 kGy)



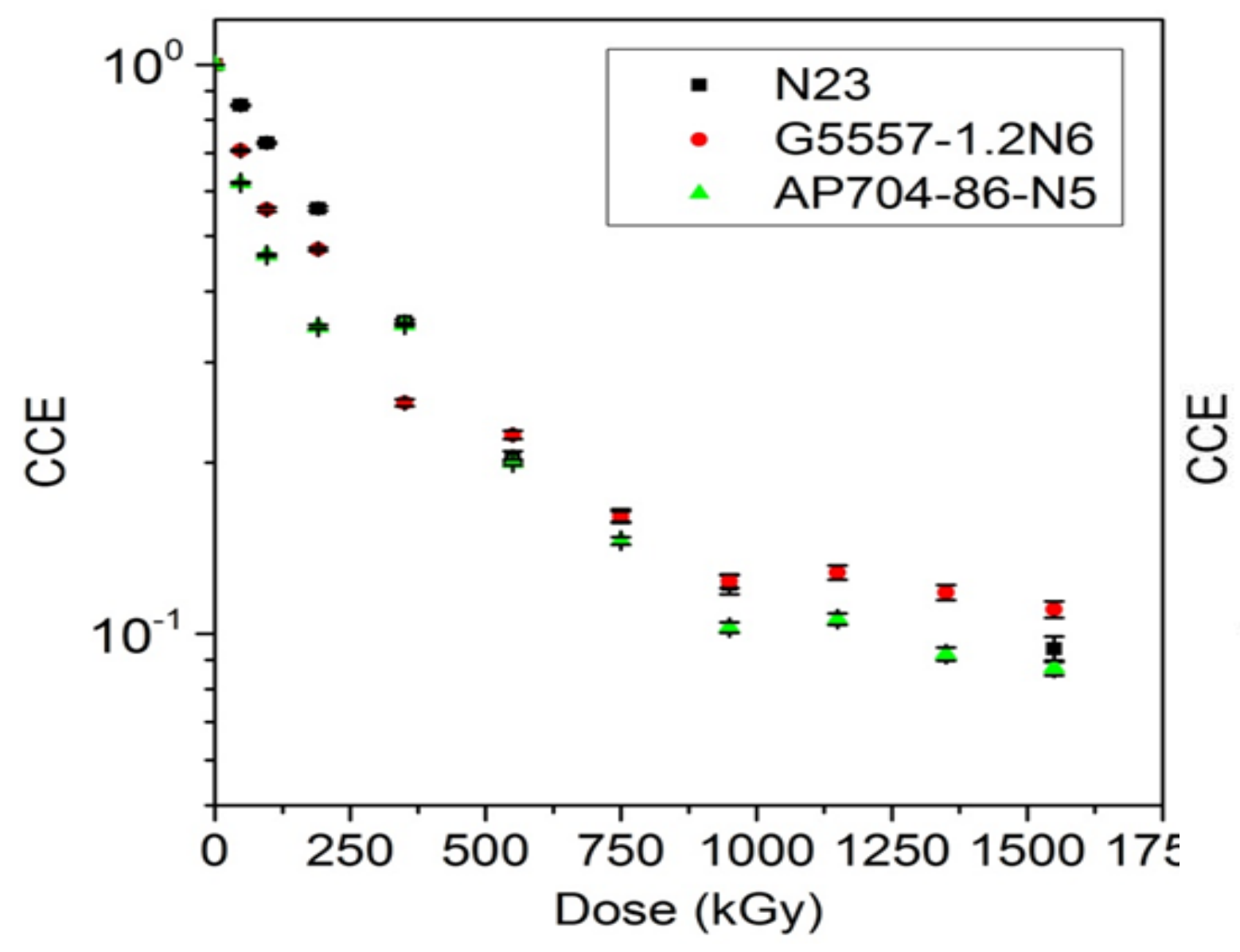
MIP spectra ➡ Si (493 kGy)



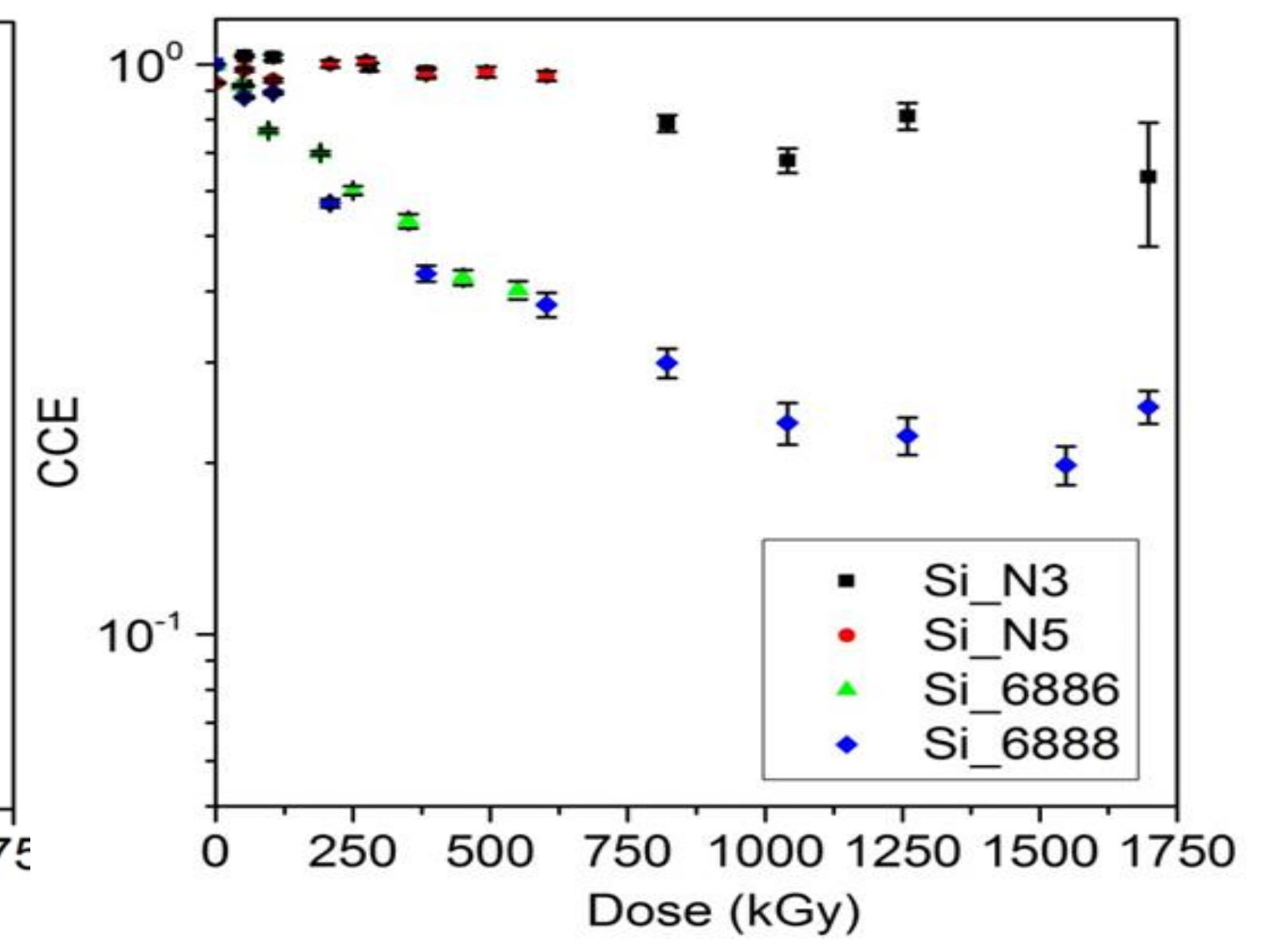
Si (260kGy)



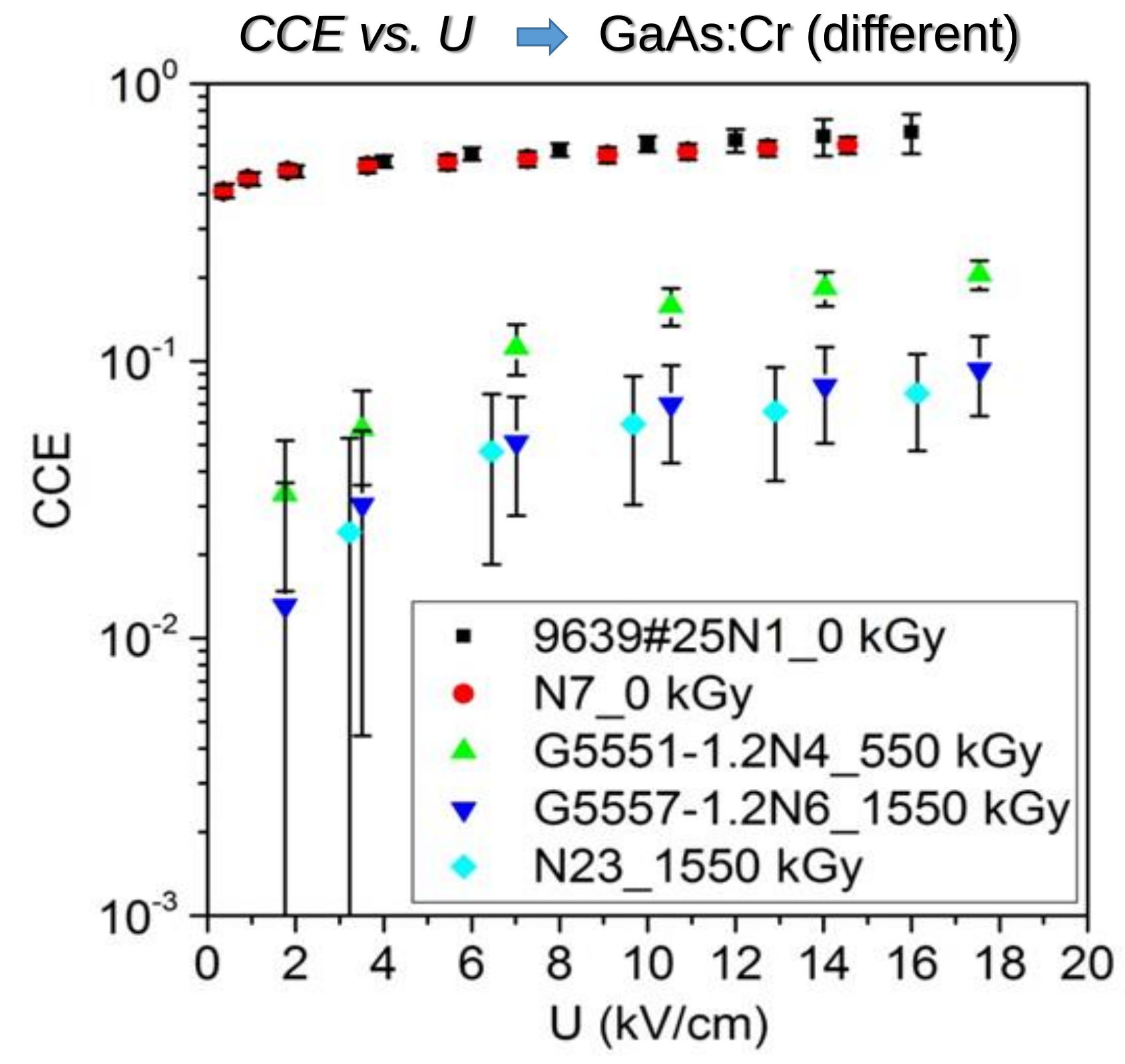
CCE vs. Dose ➡ GaAs:Cr



Si



CCE vs. U ➡ GaAs:Cr (different)



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Conclusions

- The dark current increased in 3-7 times for GaAs:Cr detectors with the maximum doses, due to the introduction of displacement damages in the material, corresponding to primary and complex defects, leading to formation of energetic states in the band gap and an easier electrons transition from the valence band to the conduction band, generating current in the depletion region.
- The presence of a slight asymmetry between the two branches of the I-V characteristic related to the asymmetric potential distribution within the device was observed.
- For Si sensors, the increase in the leakage current by almost 4 orders of magnitude confirms that in Si the radiation effects are stronger than in GaAs detectors.
- Pedestal width in GaAs:Cr remains practically unchanged in all irradiation process, while for Si, due to increasing of the dark current, the pedestal considerably broadens and the measurement becomes difficult for doses higher 493 kGy.
- The overlapping between signal and pedestal is the result of the depression of the sensor charge collection capacity with irradiation, product the increase of traps concentration and decrease of free carriers mobility and their lifetime, leading to the drift length diminution.
- CCE deterioration with the dose increase in the GaAs:Cr detectors responds to the creation of new EL2 traps in the bulk material as result of the electron irradiation. Also, it is possible that the radiation may activate a number of previously compensated EL2 traps. This limits the average free path of carriers, leading to a deficit in charge detection.
- For Si sensors the collecting properties reduction was slightly lower than for GaAs:Cr ones.
- For GaAs:Cr sensors the electric field intensity increase leads to the carriers speed growth, achieving a less diffusion, reducing the possibility of being trapped by the defects, and then improving the charges collection.