24th iWoRiD International Workshop on Radiation Imaging Detectors

Spreading of an active region of semi-insulating GaAs detectors after radiation degradation #212

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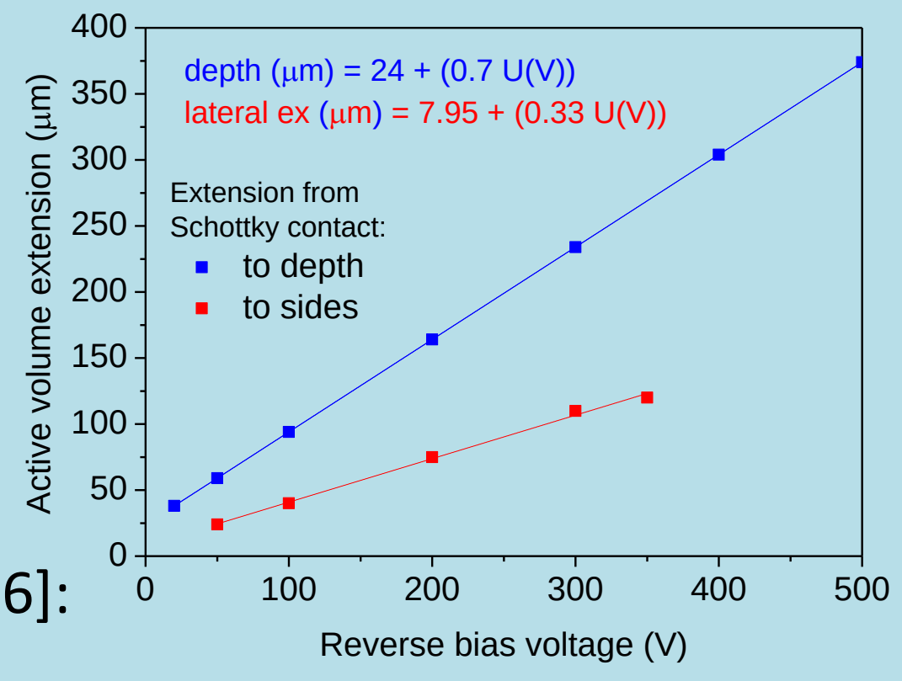
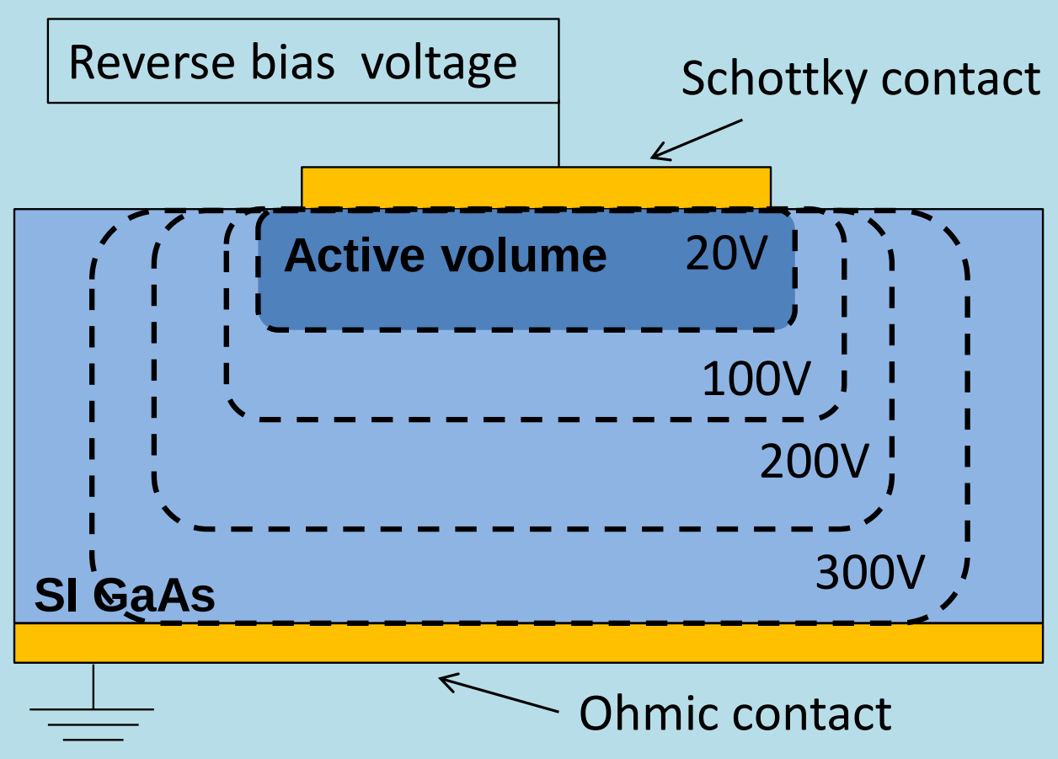
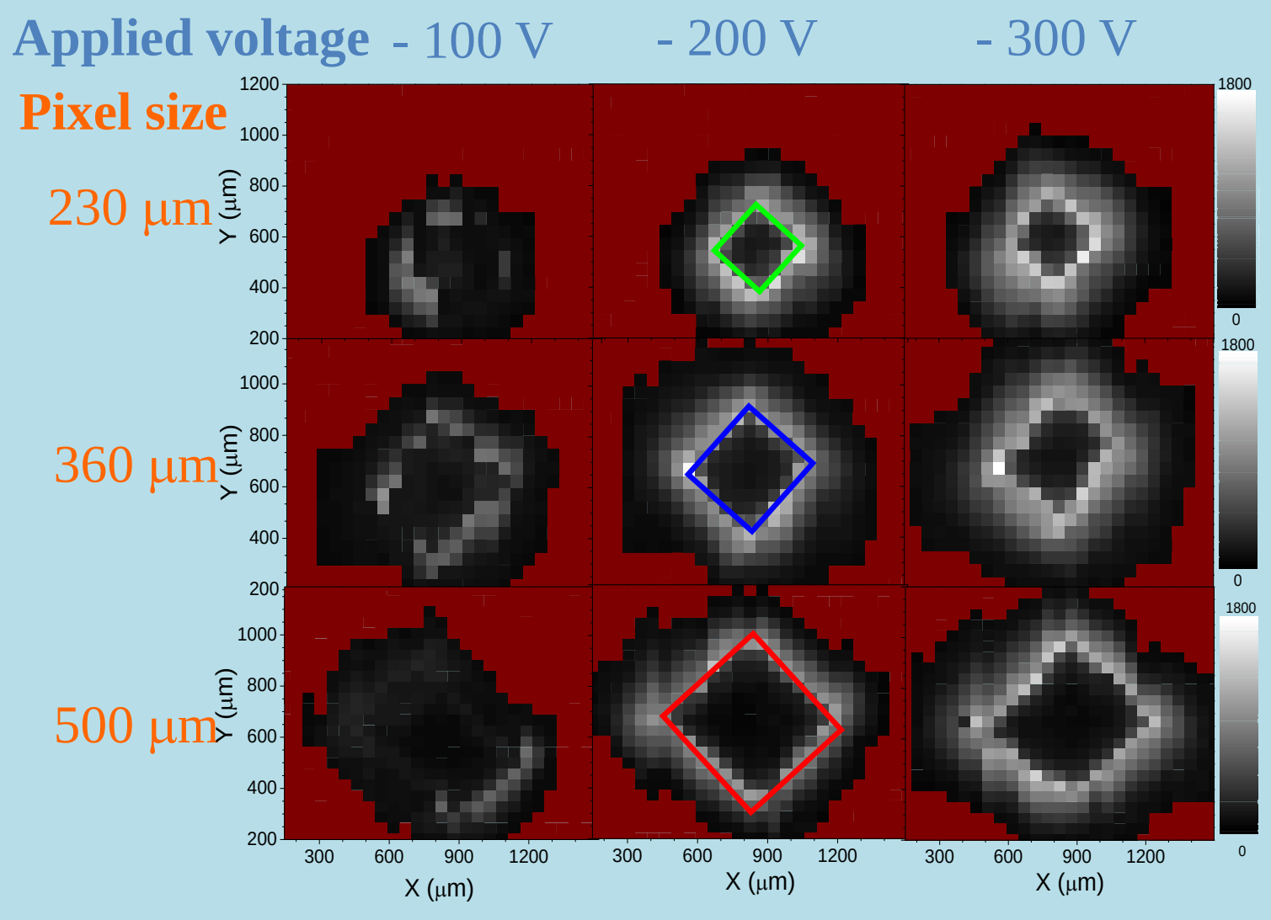
Introduction

- ❖ Recent progress in radiation technology applications (nuclear power plants, hadron therapy, space applications, research accelerators) brings new requirements for the radiation hardness of used devices:
  - Electronics in the spacecraft is exposed to electrons with energies of a few MeV and fluences up to 10^{10} cm^{-2}day^{-1}sr^{-1} [1].
  - The future electron-positron collider planned in Europe [2] will be exposed to electron-positron pairs from bremsstrahlung of a dose of about 1 MGy per year.
- ❖ We have studied the effect of 5 MeV electrons on properties of SI (semi-insulating) GaAs detectors [3]:
  - We observed that the registered number of counts in photo-peak during measuring gamma spectra of ^{241}Am increases with cumulative dose induced by high energy electrons.
  - We assumed that it is only an apparent increase of detection efficiency in fact caused by the enlargement of detector active area caused by radiation induce defects in GaAs material leading to problems with collecting field distribution.
  - Alpha particles are ideal particles for proof of our theory, the are absorbed in the surface layer (17 μm) of detector substrate. The collecting field spreading should be observed as an increase of detected counts in alpha spectrum.
  - The spreading of collecting field in non-degraded SI GaAs with REVERSE APPLIED VOLTAGE was observed to be linear both to depth and to the sides [4-6]:





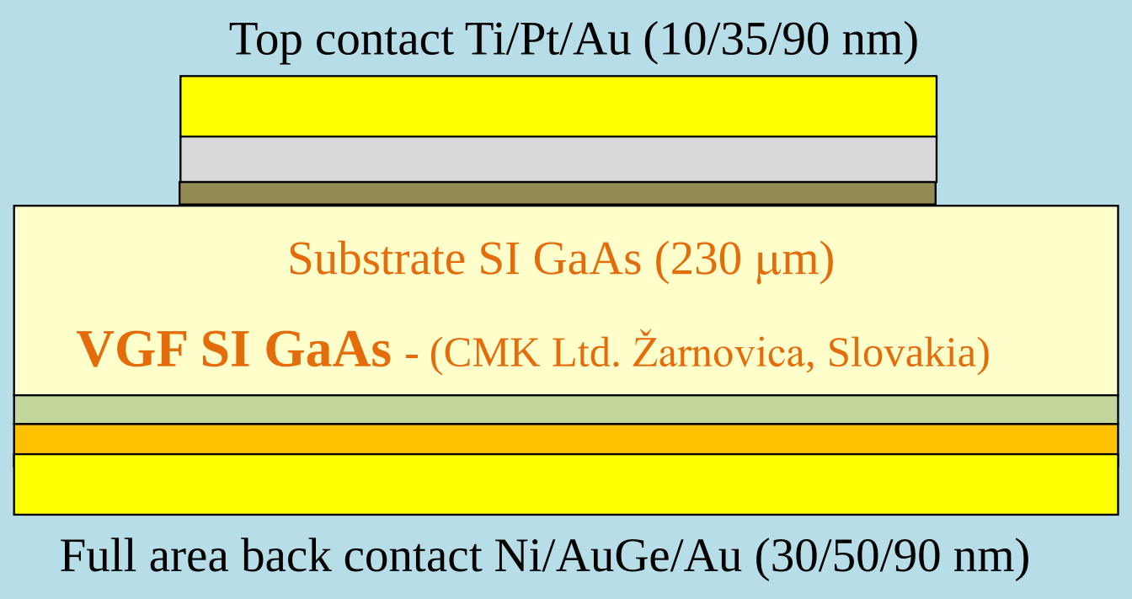
- Does the collecting field spreading occur also with APPLIED DOSE?



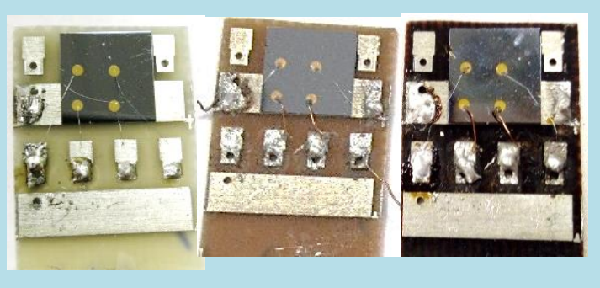
Lateral spreading observed by laser with ∅50μm spot [6]:

SI GaAs Detectors

DETECTOR CROSS-SECTION VIEW

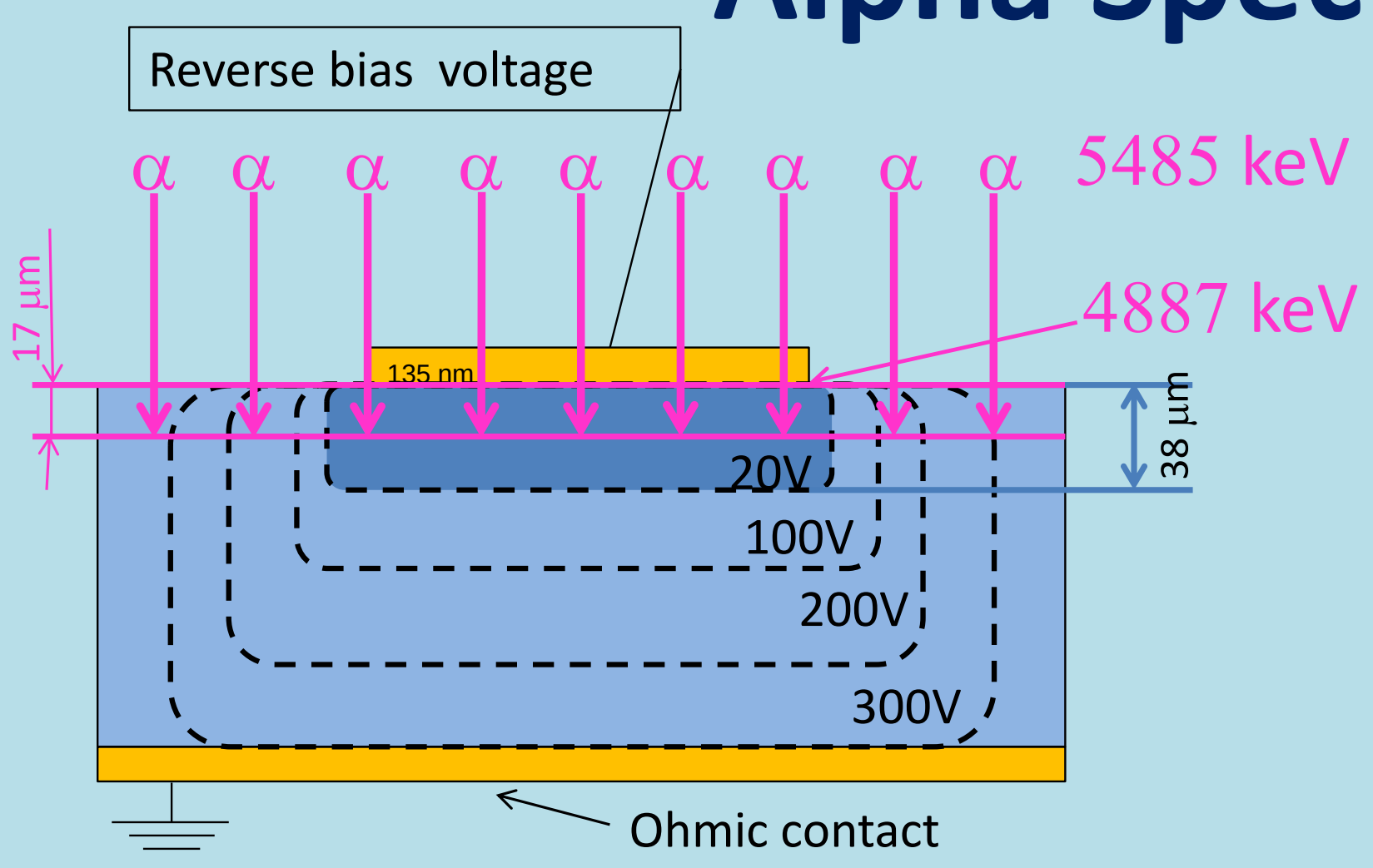


PHOTOGRAPH



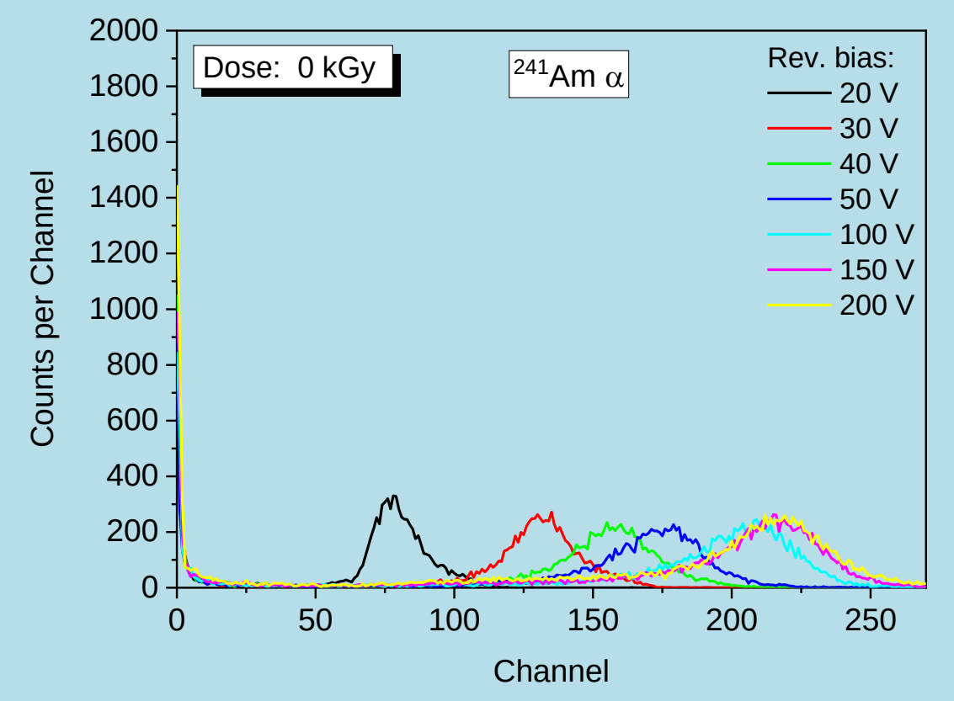
- VGF SI GaAs substrate made by CMK Ltd. Žarnovica, Slovakia
  Resistivity @ 300K: 2 × 10^7 Ωcm
  Hall mobility @ 300K: 7219 cm^2/Vs
- *Top Schottky contact:*
  circle: ∅ 1 mm: Ti/Pt/Au
- *Back ohmic contact:*
  full-back-side: Ni/AuGe/Au *Prepared at:*
  Institute of Electrical Engineering SAS in Bratislava, Slovakia

Alpha Spectra Measurements

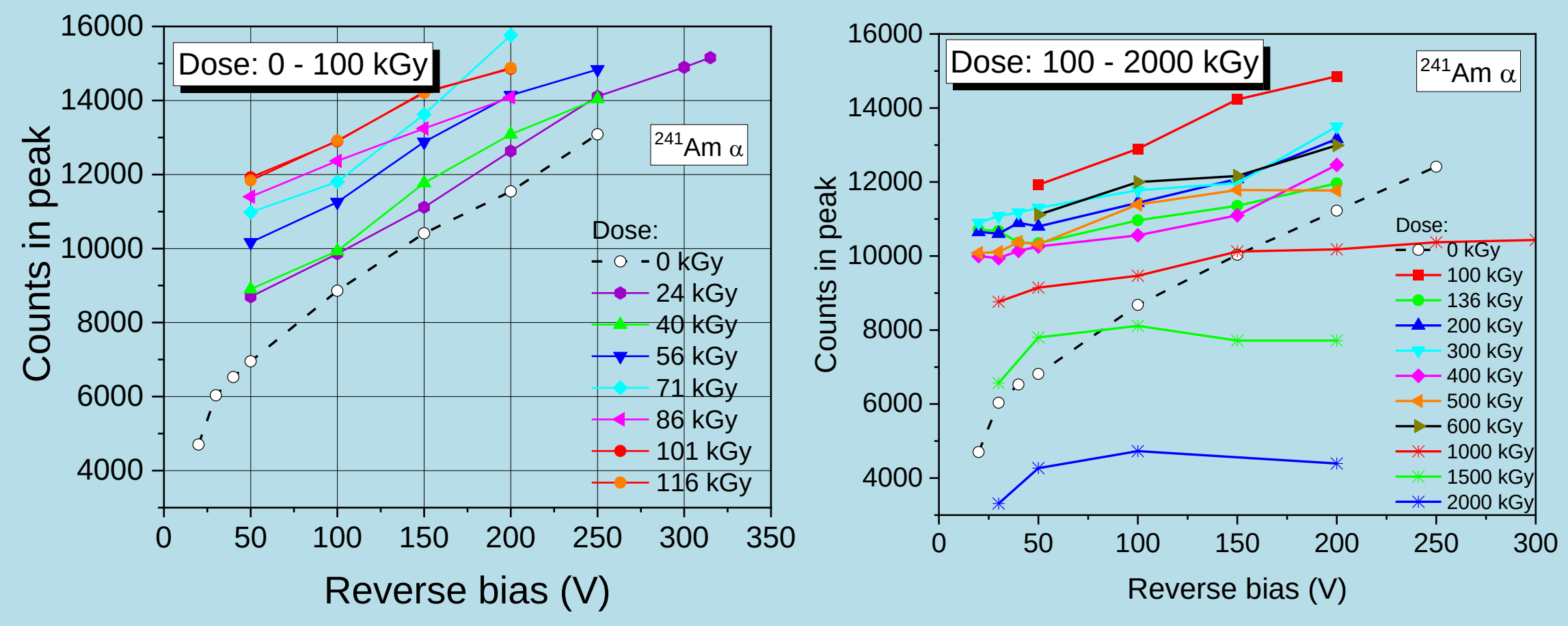


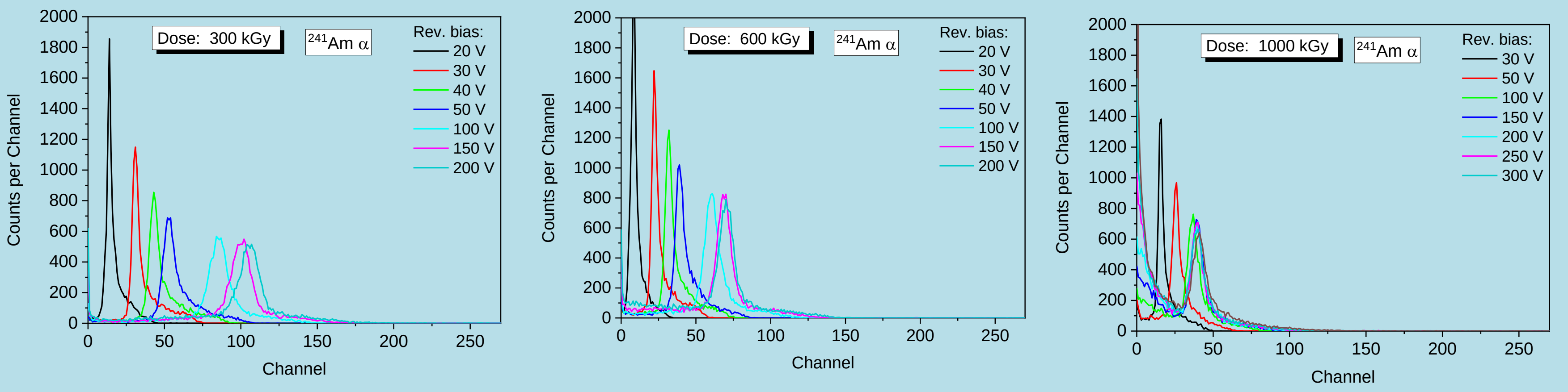
The alfa spectra measurements were performed with an ^{241}Am alpha source with 5.5 MeV alpha particles after irradiation to doses of 24-2000 kGy.

- With increasing voltage higher charge collection efficiency and better homogeneity of collecting field were observed.
- With increasing dose the charge collection efficiency decreases but the number of detected counts rises up to 100 kGy.



Integrated counts in peak of alpha spectra as a function of reverse bias voltage for different cumulative doses:

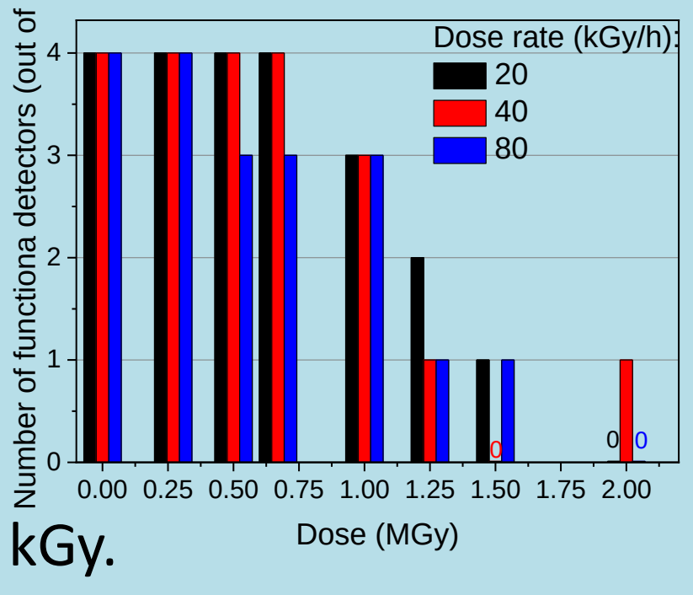


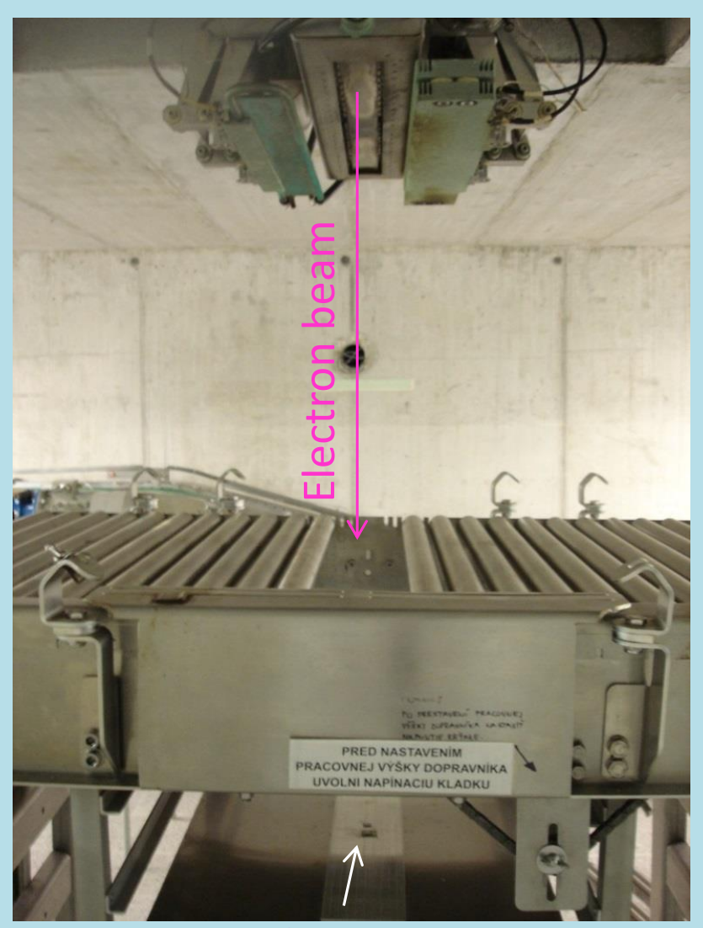


Radiation Degradation by Electrons

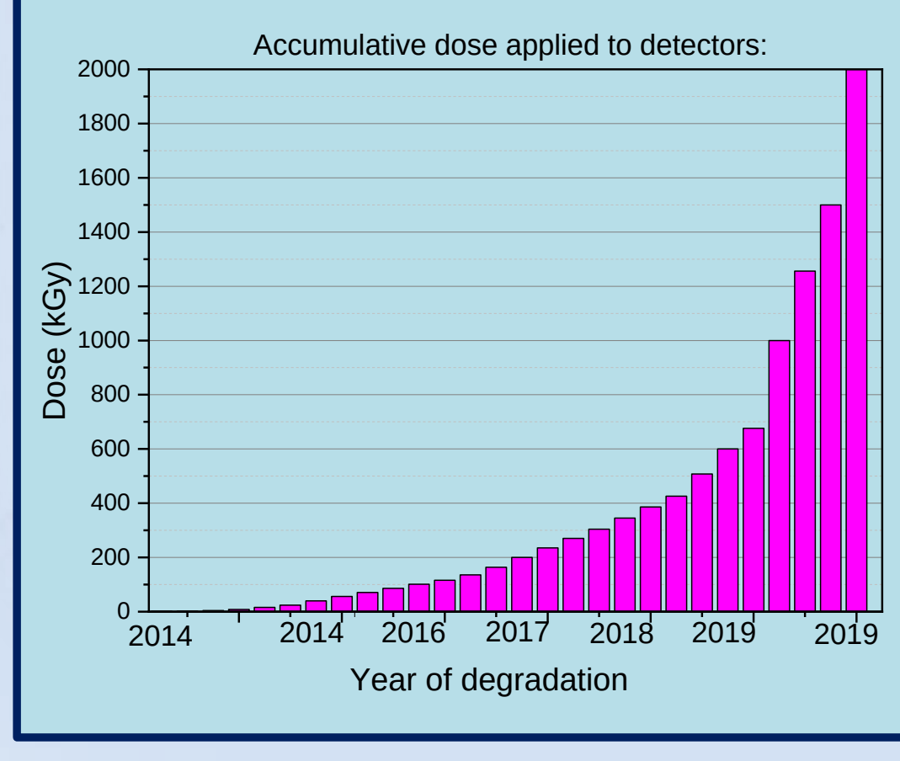
At University Centre of Electron Accelerators in Trenčín, Slovakia by 5 MeV electrons:

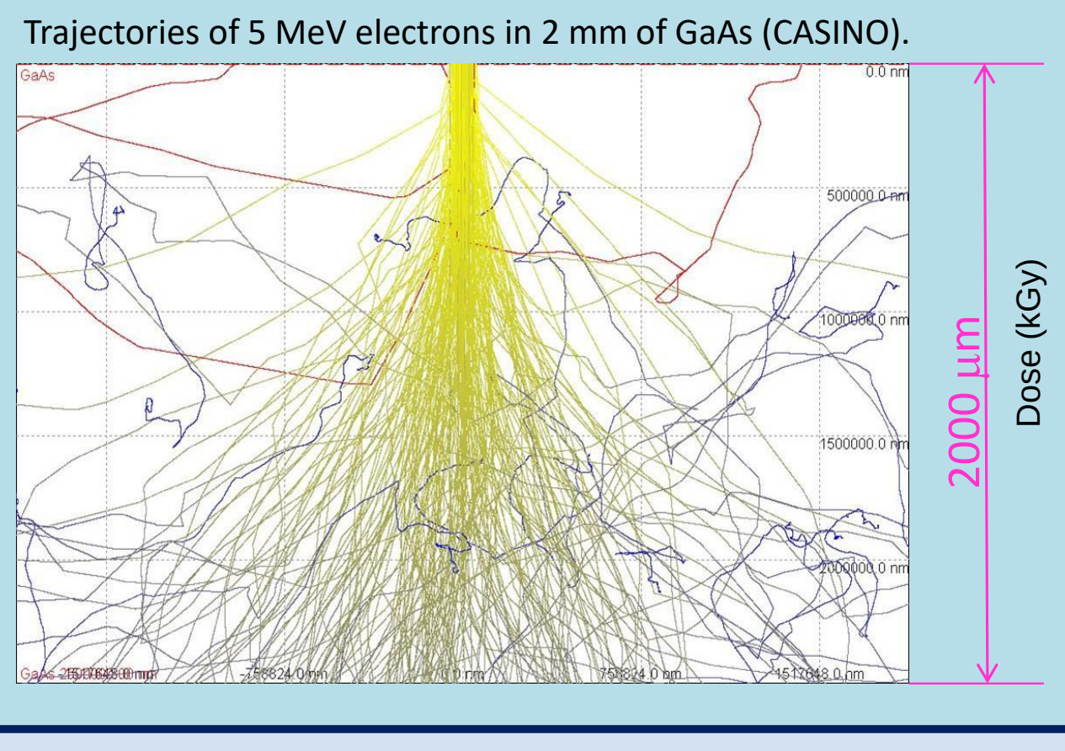
- ❖ Detector distance from accelerator window: 95 cm
- ❖ Beam scanning width: 40 cm
- ❖ Beam scanning frequency: 0.25 Hz
- ❖ Beam diameter at sample: 8 cm
- ❖ Beam repetition rate 10 Hz
- ❖ Average beam current 8 μA
- ❖ Base: 1 cm thick aluminum board
- ❖ Irradiated in thirteen steps to a cummulative surface dose of 2000 kGy.

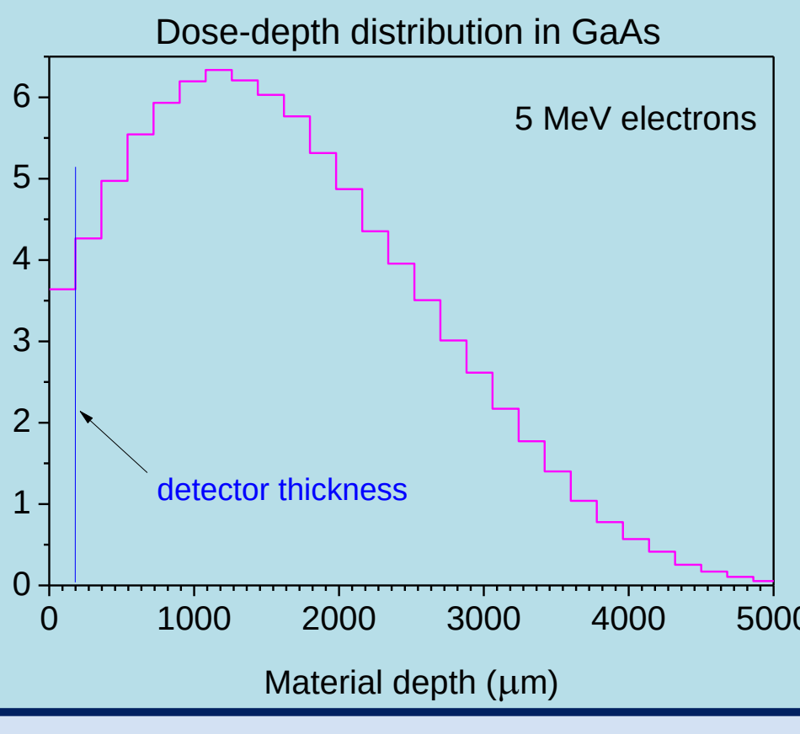




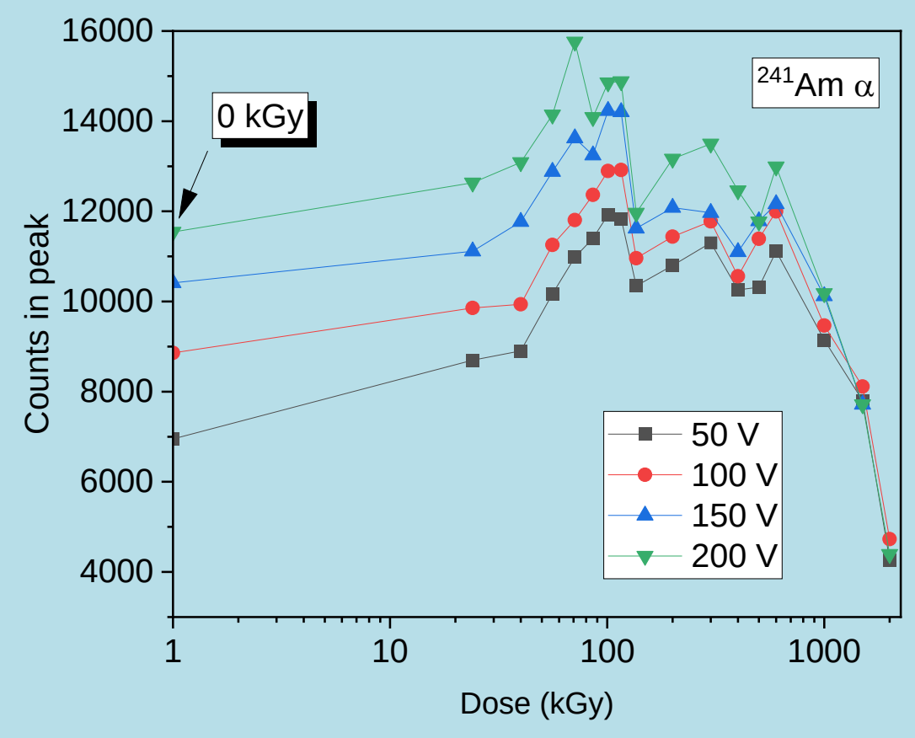
detector



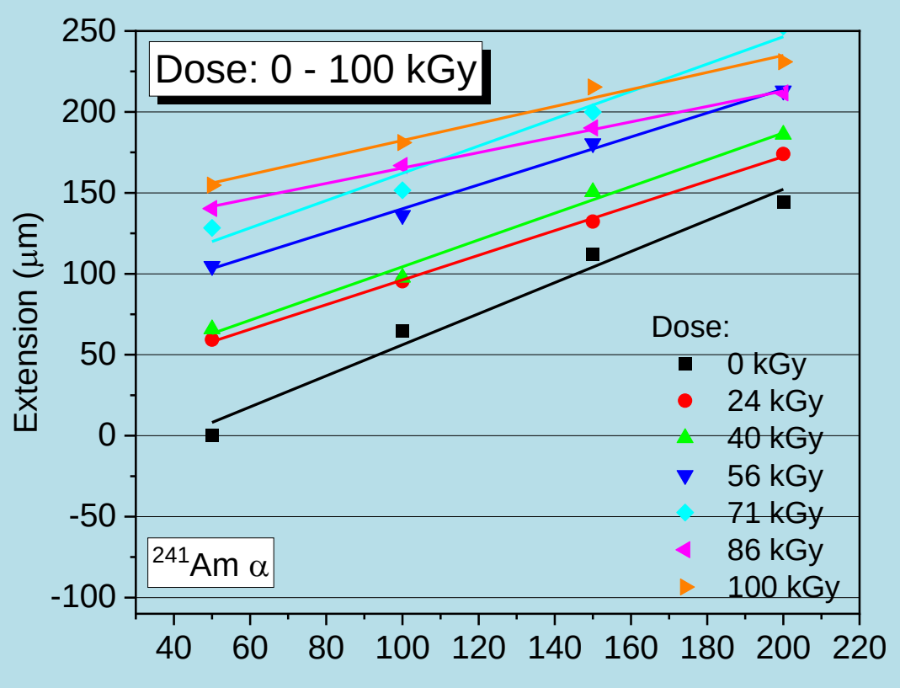




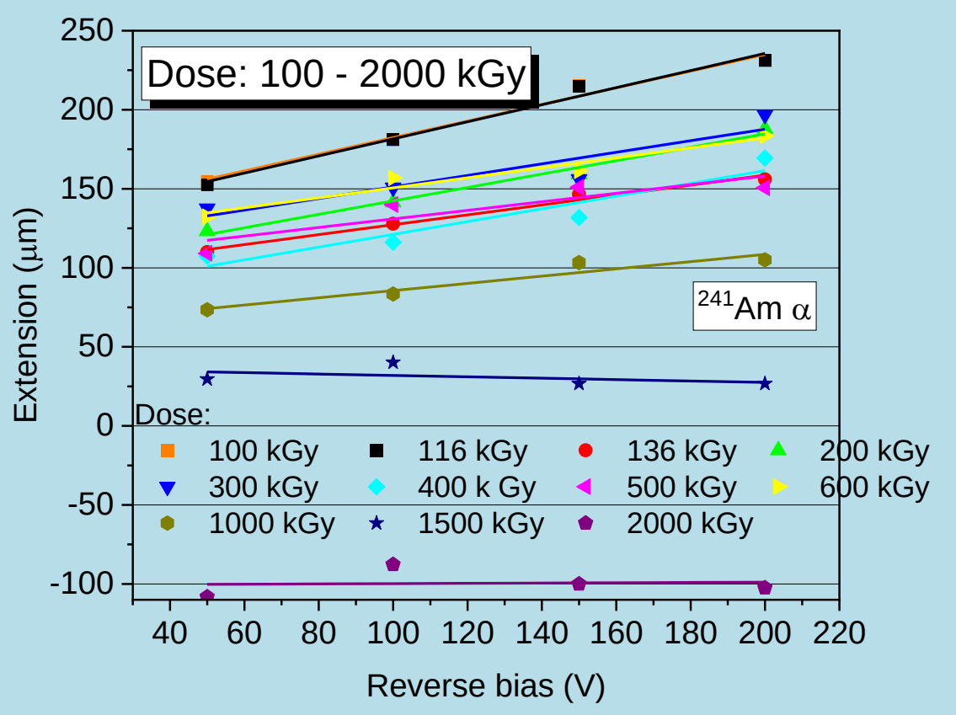
Results and Discussion



Integrated counts in peak of alpha spectra as a function of applied cumulative dose for different reverse voltages applied (50 to 200 V).

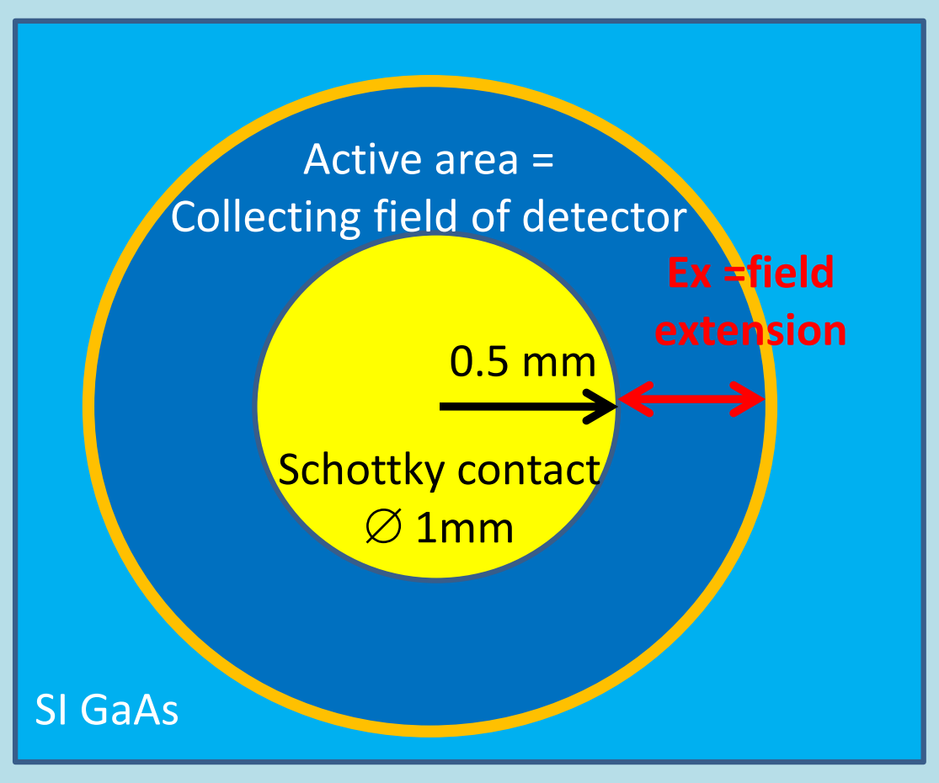


The absolute field extension (Ex) of active detector area behind the Schottky contact edge as a function of applied reverse voltage for various degradation doses of electrons.

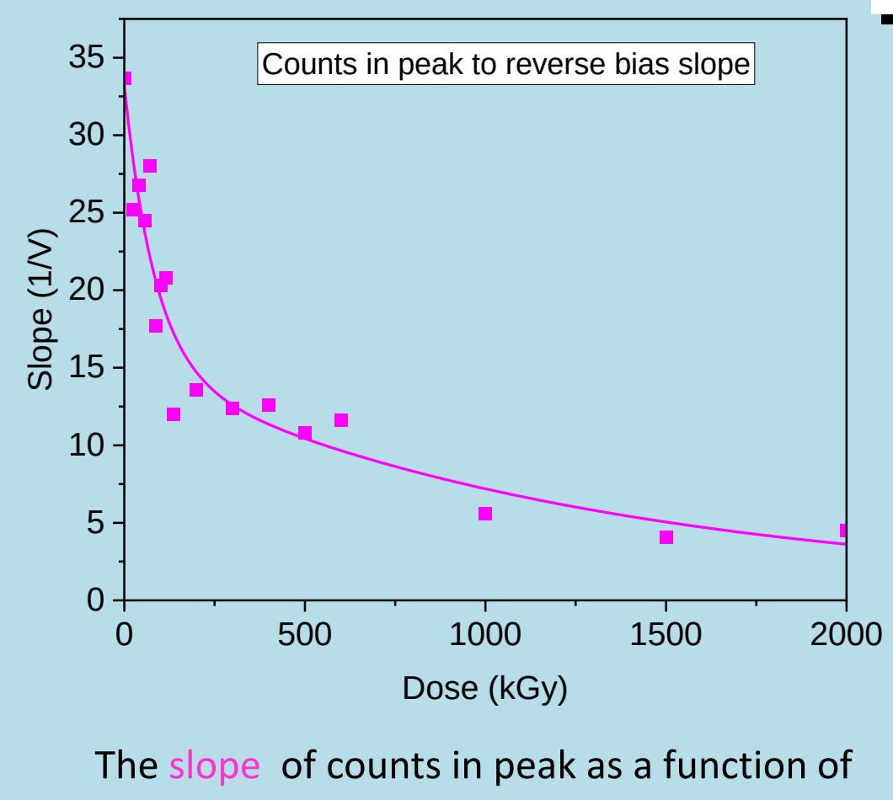


The absolute field extension (Ex) of active detector area behind the Schottky contact edge as a function of applied reverse voltage for various degradation doses of electrons.

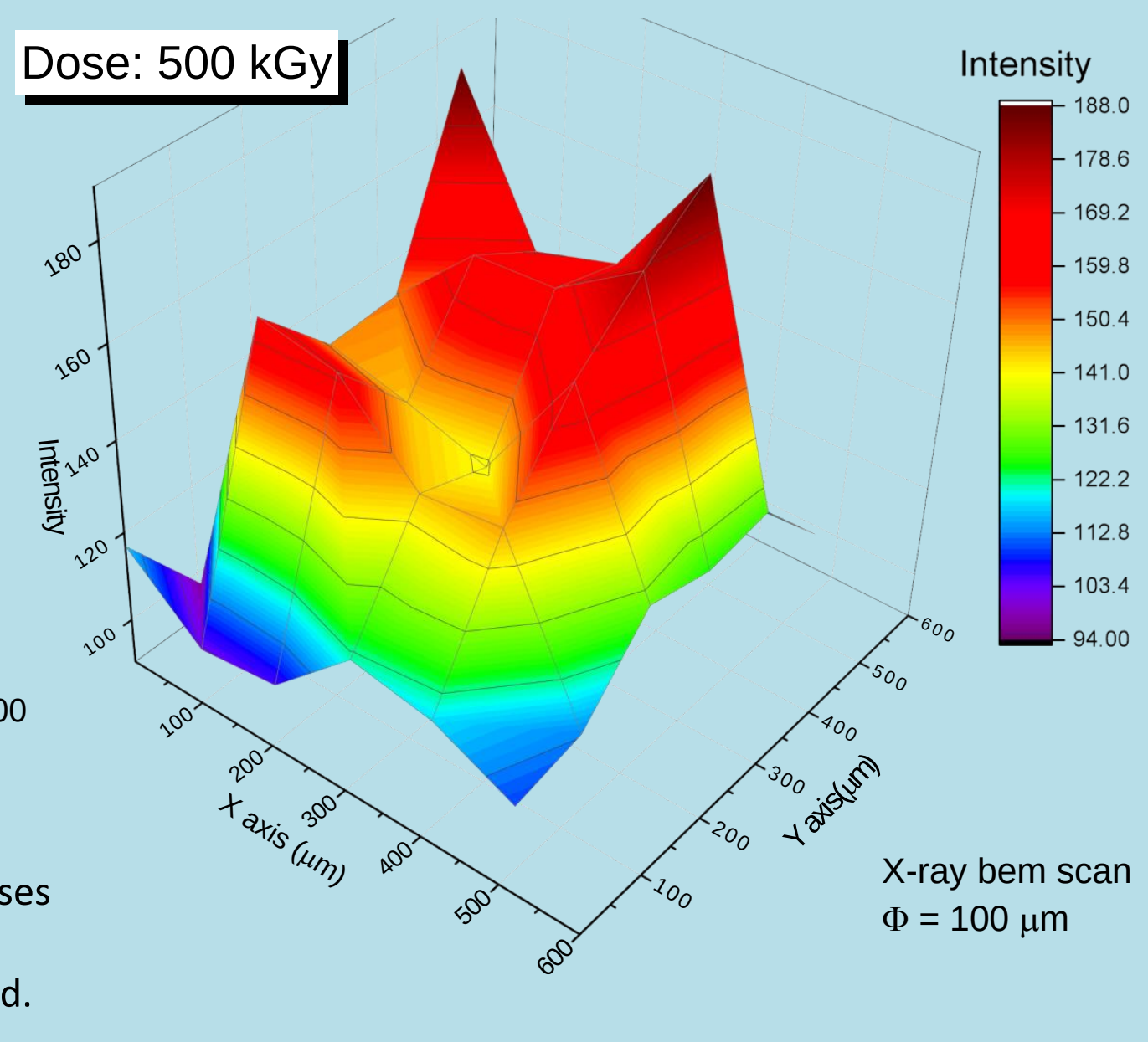
- Number of registered counts in peak increases with both applied reverse bias and the cumulative dose (up to 100 kGy).
- At low reverse voltage (50 V) the number of counts in peak rises with dose more steeply than at higher reverse bias.
- For doses in the range 100 – 600 kGy the number of counts in peak decreases but still is higher than initial value before degradation.
- For doses in the range 600 – 2000 kGy the number of counts in peak decreases mor intensively and is below the initial value before degradation.



Top view at the SI GaAs detector with Schottky contact on GaAs substrate with field extension display.



The slope of counts in peak as a function of applied reverse bias for various degradation doses of electrons, representing improvement of detection efficiency with increased bias applied.



X-ray bem scan
Φ = 100 μm

Conclusions

- We have employed the alpha spectrometry to reveal the behaviour of SI GaAs detectors after radiation degradation by 5 MeV electrons to reveal the electric field distribution in detector substrate.
- The electric field spreads behind the Schottky contact edges not only with increasing applied reverse bias but also with rising cumulative dose of radiation degradation up to 100 kGy.
- The collecting field extension (Ex) is larger for doses up to 600 kGy than before degradation and for doses over 1000 kGy, the field is smaller than initial before degradation.

$$Ex = \frac{D_a - D}{2} \qquad D_a = \sqrt{\frac{N}{N_R}}\, D$$

D_a-diameter of the active area of the detector, D -physical diameter of the top Schottky contact
N - total count in peak, N_R - total count in peak at 50 V before degradation (reference value)

References:
[1] Ts. P. Dachev et al.: *J. Atmos. Sol.-Terr. Phys.* **99,** 150 (2013).
[2]International Linear Collider, *ILC reference design report. Volume 4 — Detectors*, http://www.linearcollider.org/about/Publications/Reference-Design-Report
[3] A. Šagátová et al.: *JINST* **11,** C12078 (2016).
[4] A. Castaldini et al.: *Nucl. Instr. and Meth.* **A410,** 79 (1998).
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[6] A. Perďochová-Šagátová: *Nucl. Instr. and Meth.* **A563,** 187 (2006).