Radiation hardness tests of GaAs and Si sensors at JINR

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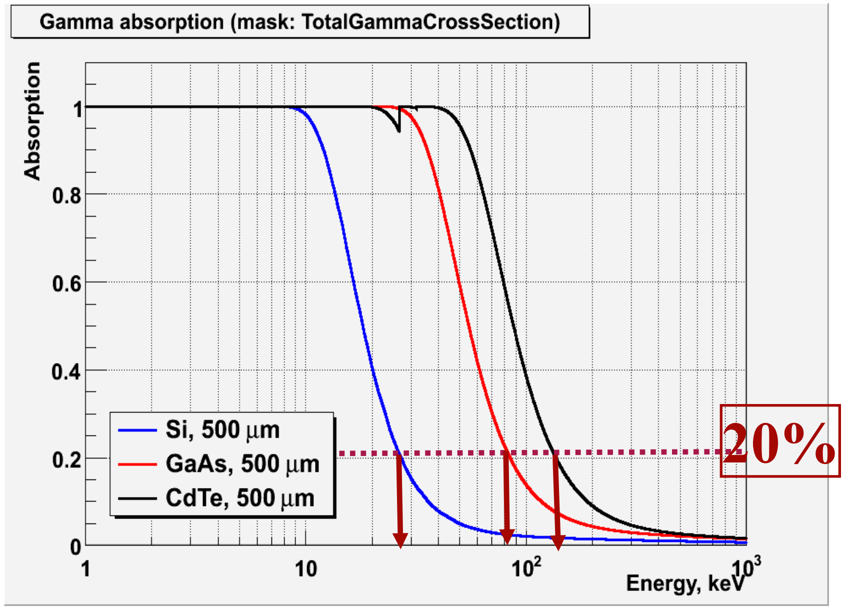
Gallium arsenide as a detector material

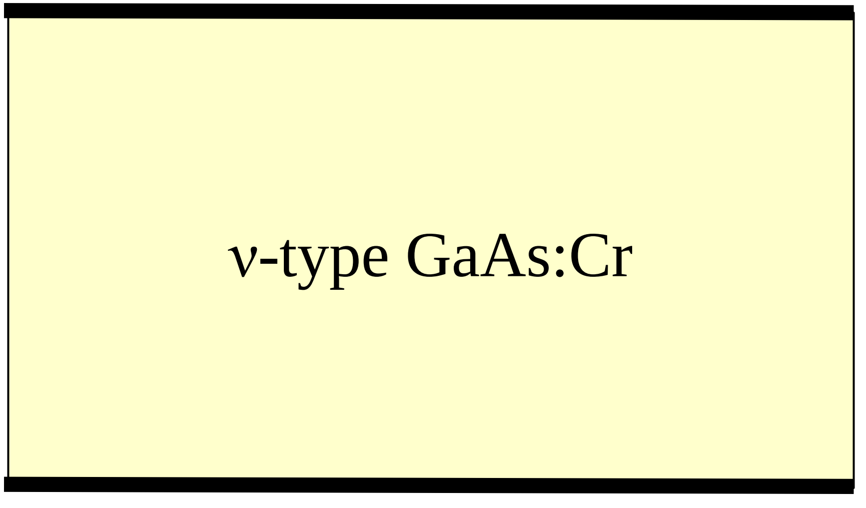
- GaAs is a well-known semiconductor, second widespread after silicon
- Limited use in particle detection because of low resistivity, low CCE and high intrinsic noise
- New modification of GaAs, compensated by Cr (GaAs:Cr), has been invented in Tomsk State University in 2000-2005
  - suitable for detector construction
  - radiation hard
  - Z(GaAs)~ 32 vs Z(Si)=14 → higher photon detection efficiency

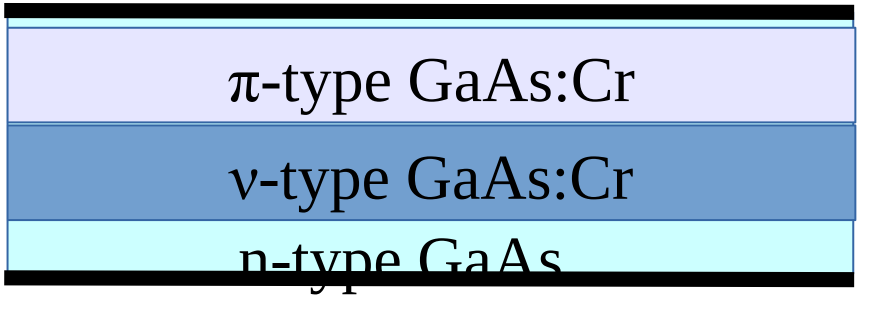


Material	main charge carriers	electron drift length	bulk resistivity	active sensor thickness	intrinsic noise
LEC SI-GaAs	holes	0.3-0.5 mm	$<2*10^8$ Ω*cm	<300 μm	high
GaAs:Cr	electrons	0.7 – 2 mm	$\sim10^9$ Ω*cm	up to 1 mm	low

Two types of GaAs:Cr detectors

- 'Resistive' GaAs:Cr
  - resistivity ~10^9 Om*cm
  - active thickness up to 1 mm
  - electron drift length up to 2 mm
- πν junction structure
  - active thickness is determined by πν junction (~0.1-0.2 mm depending on Ubias)
  - resistivity and CCE is Ok



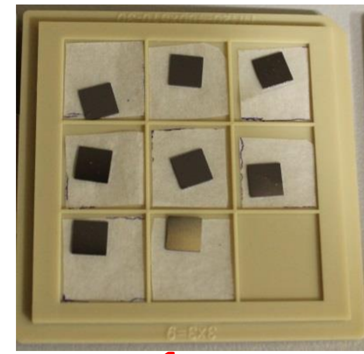


Summary of previous measurements

- GaAs:Cr detectors based on $\pi\nu$ junction structure may have the same or better radiation hardness comparing with the 'resistive' GaAs:Cr
- $\pi\nu$ junction structures were never tested systematically in electron beams.
- We never reported (= never systematically studied) the dependence of the radiation degradation on the irradiation rate

GaAs:Cr and Si sensors

N	Type	Holder	Size, x y z, mm	Sensitive area, mm^2
1	GaAs:Cr barrier, n^{+}-π-ν-n(radiation hard)	Plastic	5x5x0.3	5x5
2	GaAs:Cr high resistive	PCB	5x5x0.3	4.5x4.5
3	Si n-type	Plastic	5x5x0.3	4x4
4	Si n-type rad-hard sensor from USCS	PCB	10x10x0.4	4x4



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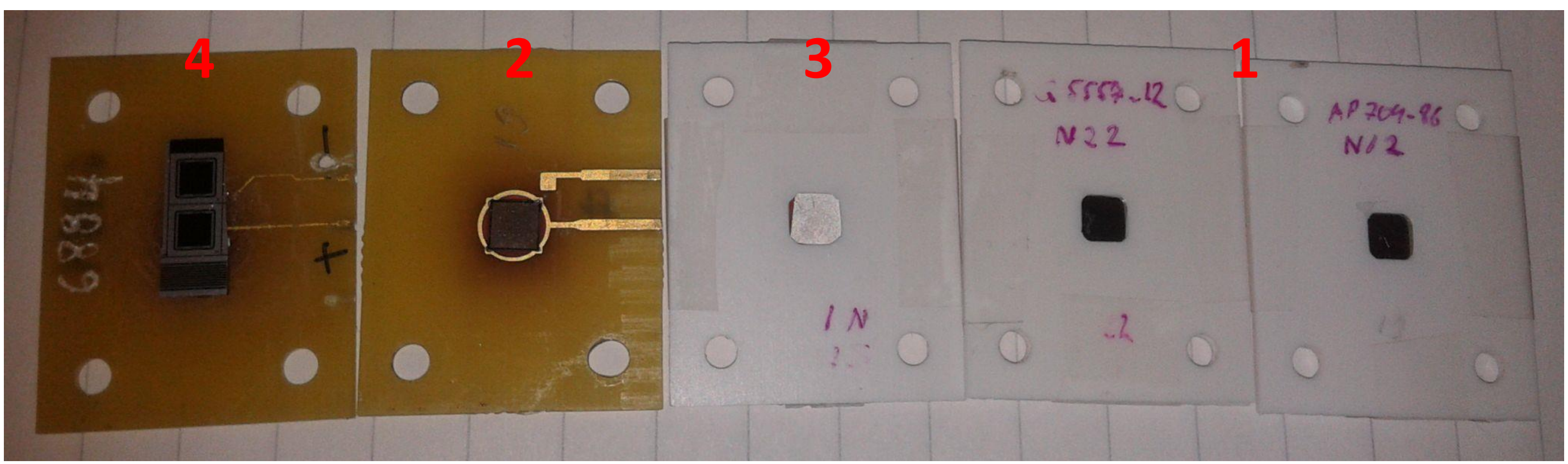
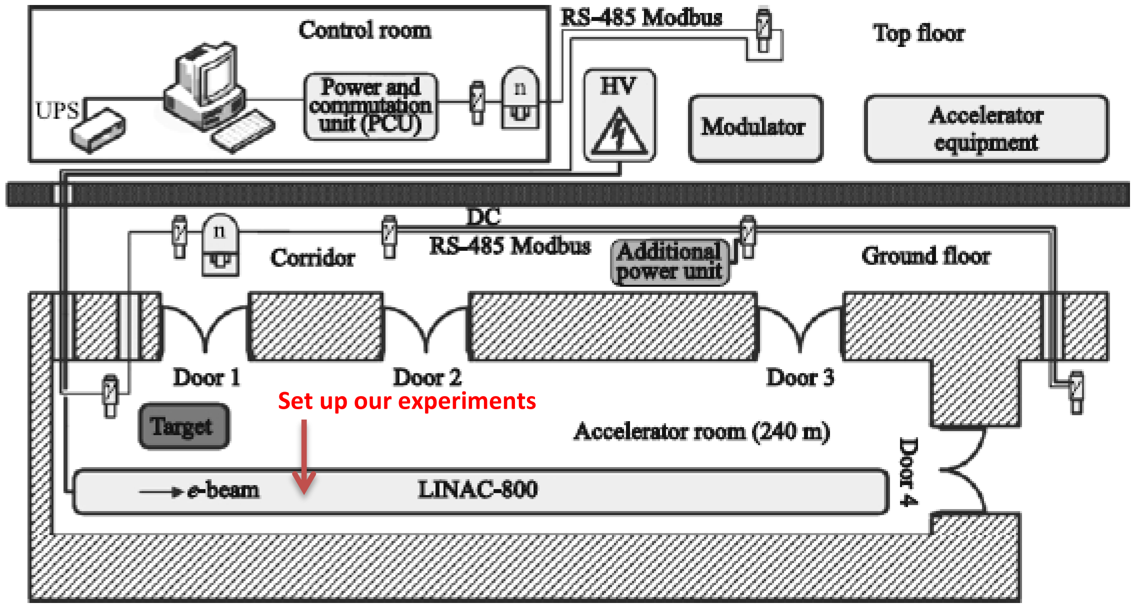


LINAC-800



800 MeV electron linear accelerator (LINAC-800) is under construction at JINR. 20 MeV beam channel was used for sensors irradiation. Beam parameters:

- bunch current up to 10 mA,
- duration 2 ms,
- frequency from 1 to 10 Hz.

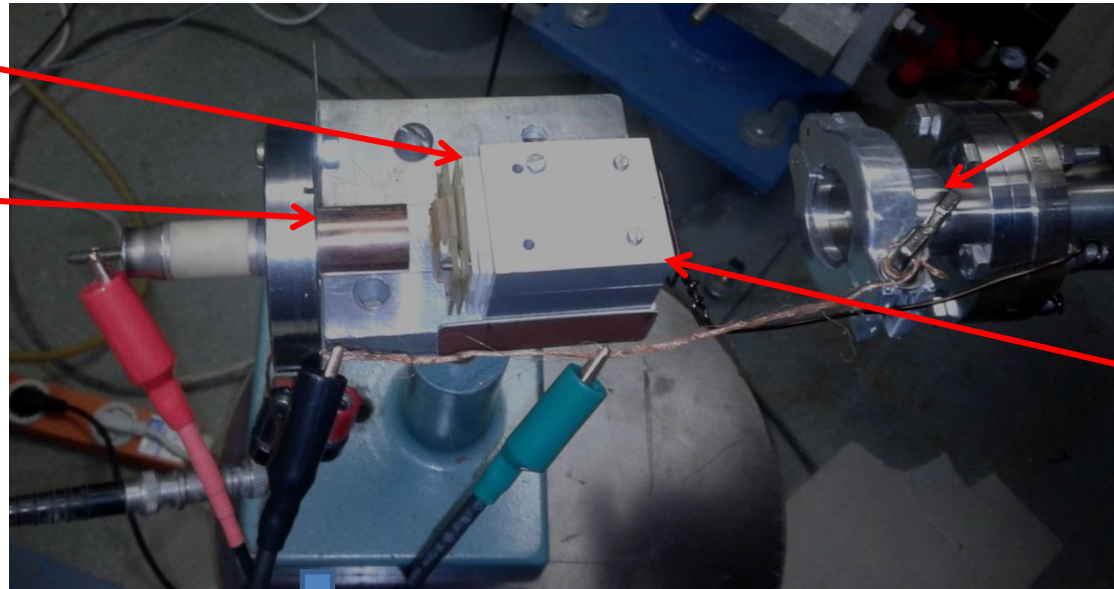
Irradiation setup

Sensors

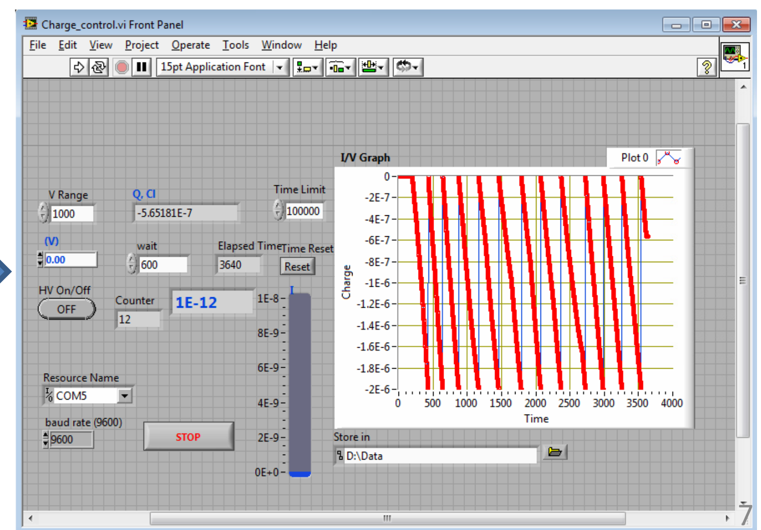
Faraday cup

Beam pipe

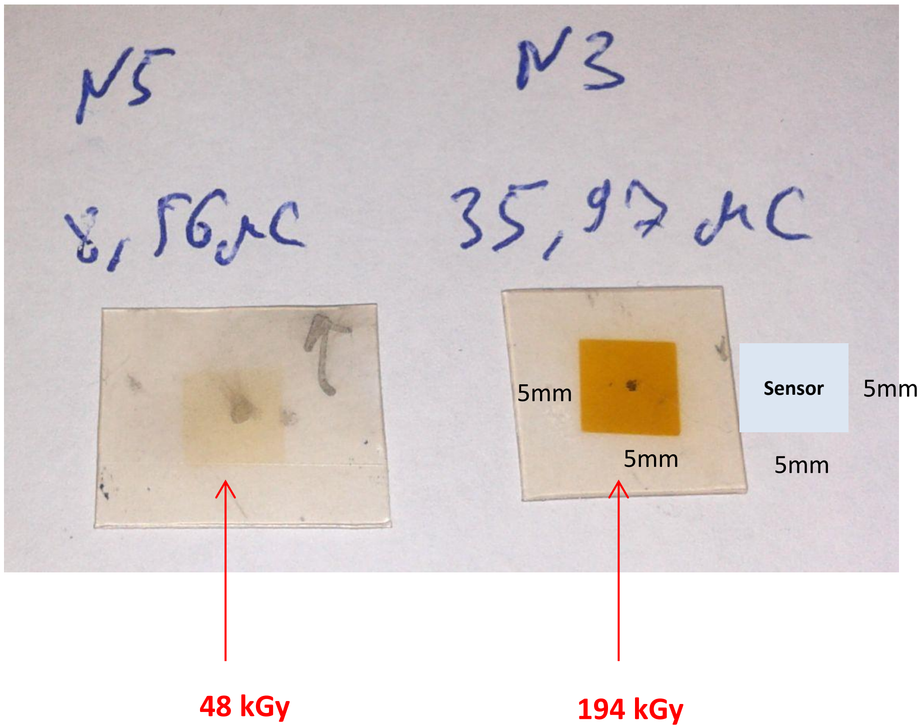
Collimator



Keithley 6517



Irradiation control



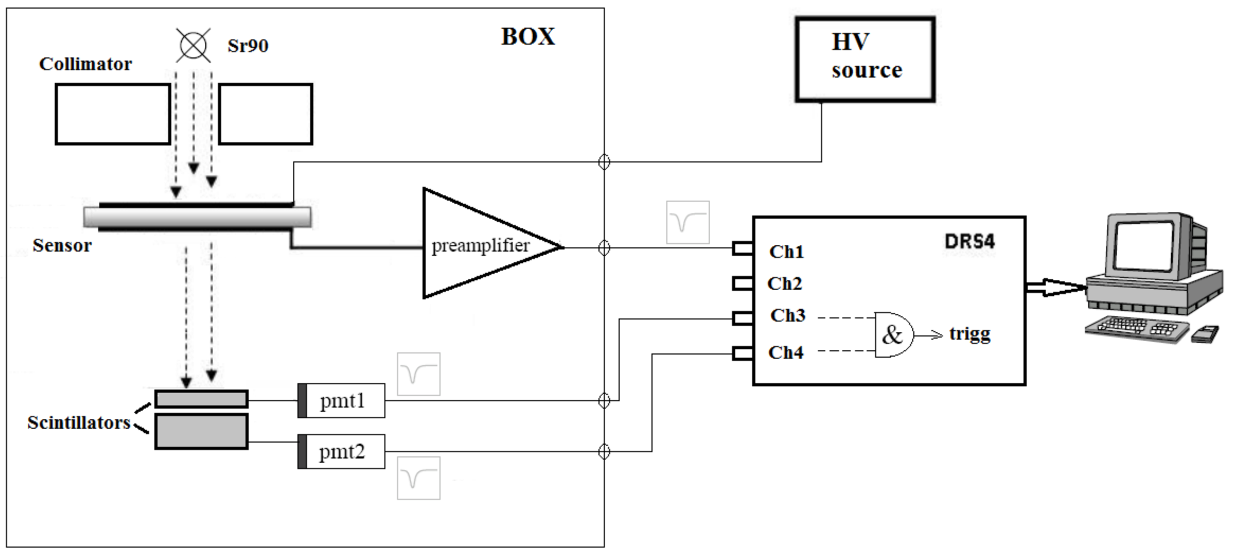
The radiation sensitive film was placed behind the sensor to control the absorbed dose, and the uniformity of electron flounce during irradiation.

GEANT 4 simulation

The electron transport through the irradiation setup was simulated by GEANT4 in order to obtain the ratio of registered by Faraday cup charge to absorbed dose in the sensor.

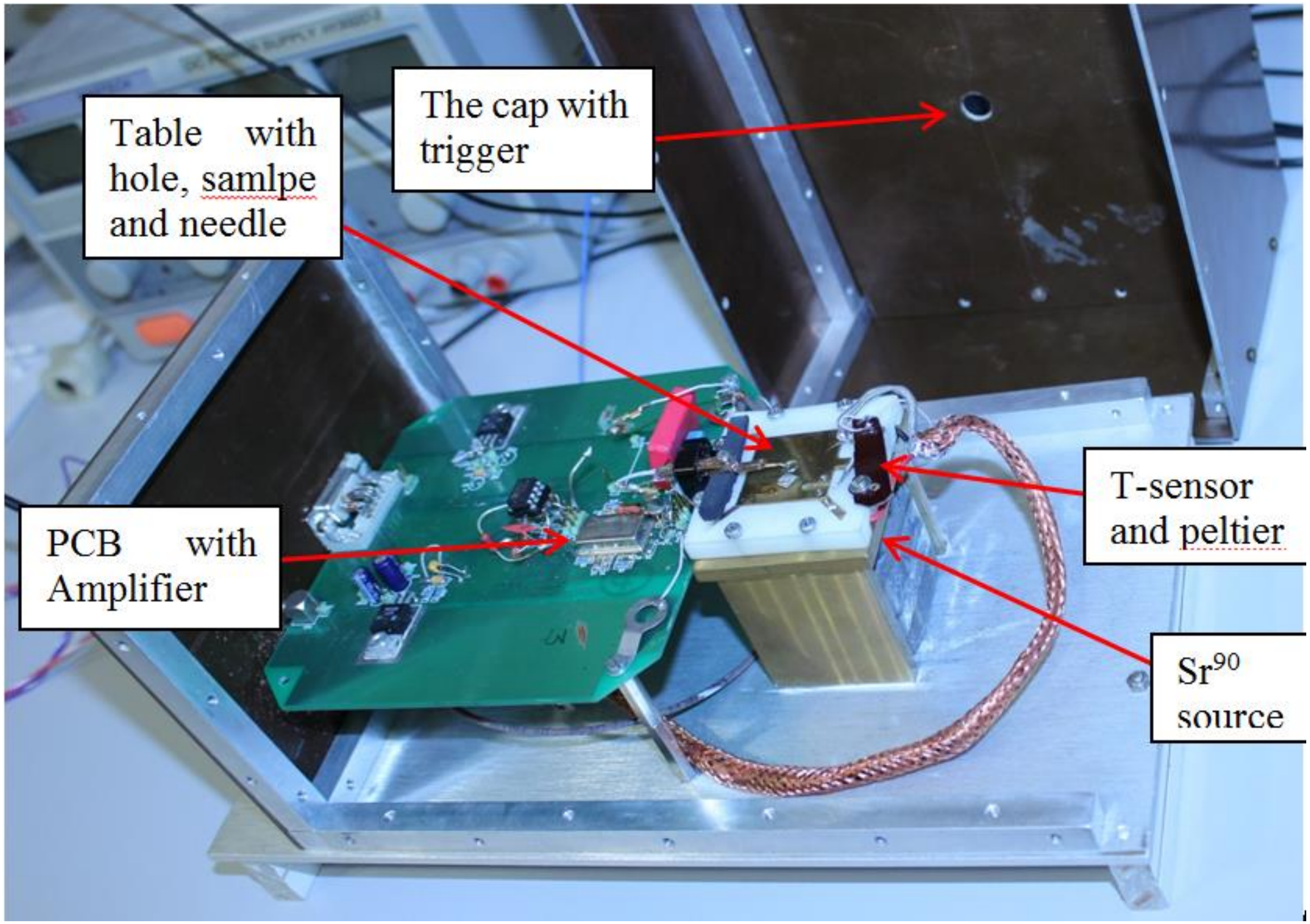
Sensor	Holder	Thickness, um	Energy deposit by one e, MeV	Absorbed dose to charge in Faraday cap, kGy/uC	Error
GaAs	Plastic	300	0.2218	5.56	0.04
GaAs	PCB	300	0.2238	5.61	0.04
Si	Plastic	300	0.1064	6.09	0.06
Si	PCB	300	0.1066	6.10	0.06

CCE(Charge collection efficiency) measurement set up



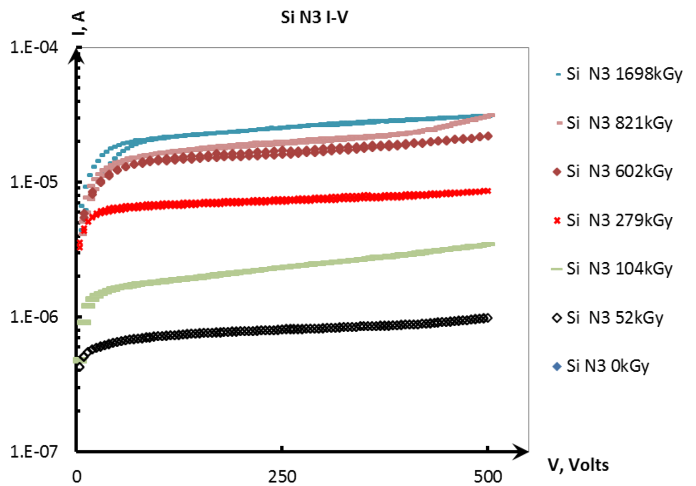
electrons from Sr^{90} source well collimated and triggered by 2 scintillators. It allows to cut and measure signal only from electrons passed throw the sensor with energy from 1 to 2.2 MeV which is close to MIP electrons

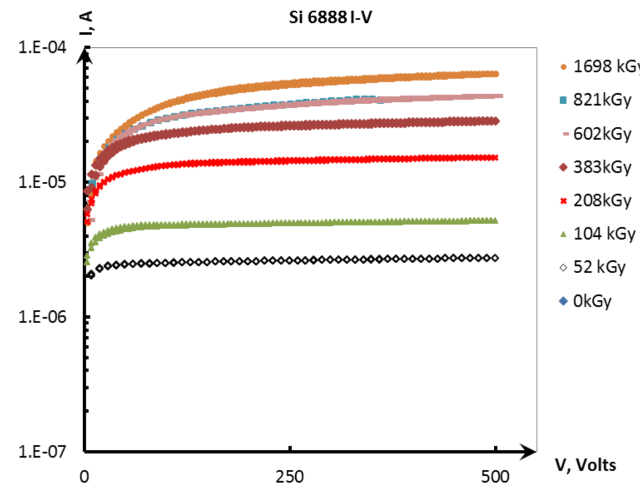
Installation for CCE and I-V(Volt - Ampere) measurement

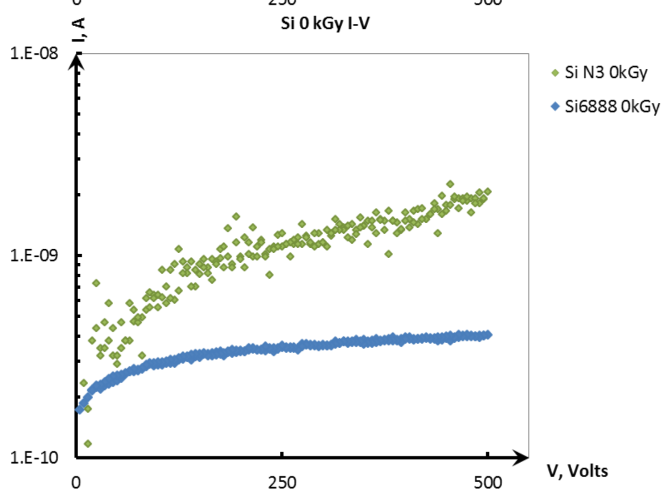


All the sensors measured at room temperature, except some measurements at low temperature for Si

Results I-V Si

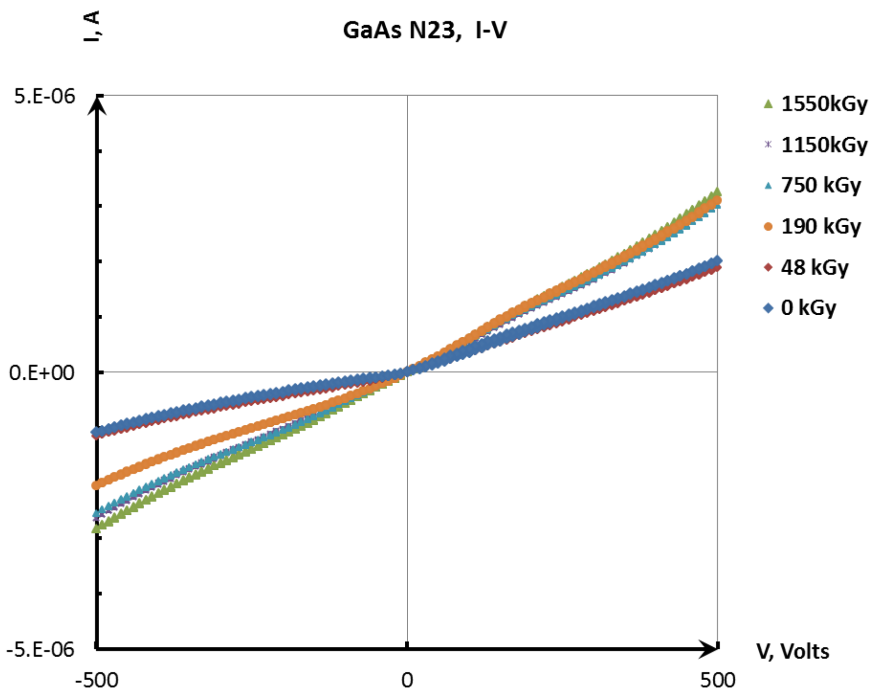


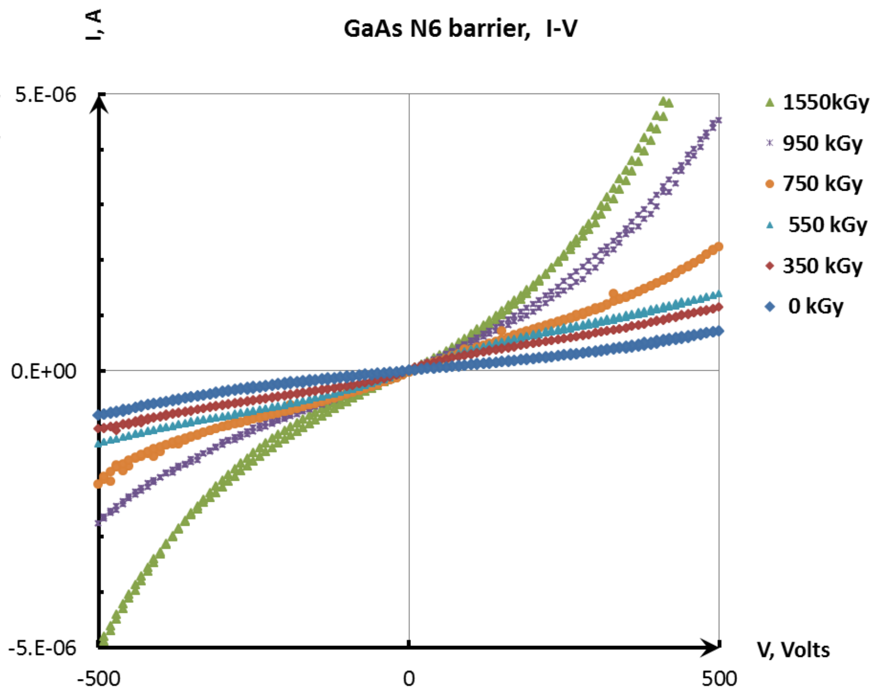




I-V characteristics of the normal n-type Si (N3) and radiation hard USCS Si (6888).
The dark current increased almost 4 orders of magnitude after the absorbed dose of 1.5 MGy

Results I-V: πν junction structure and HR GaAs:Cr

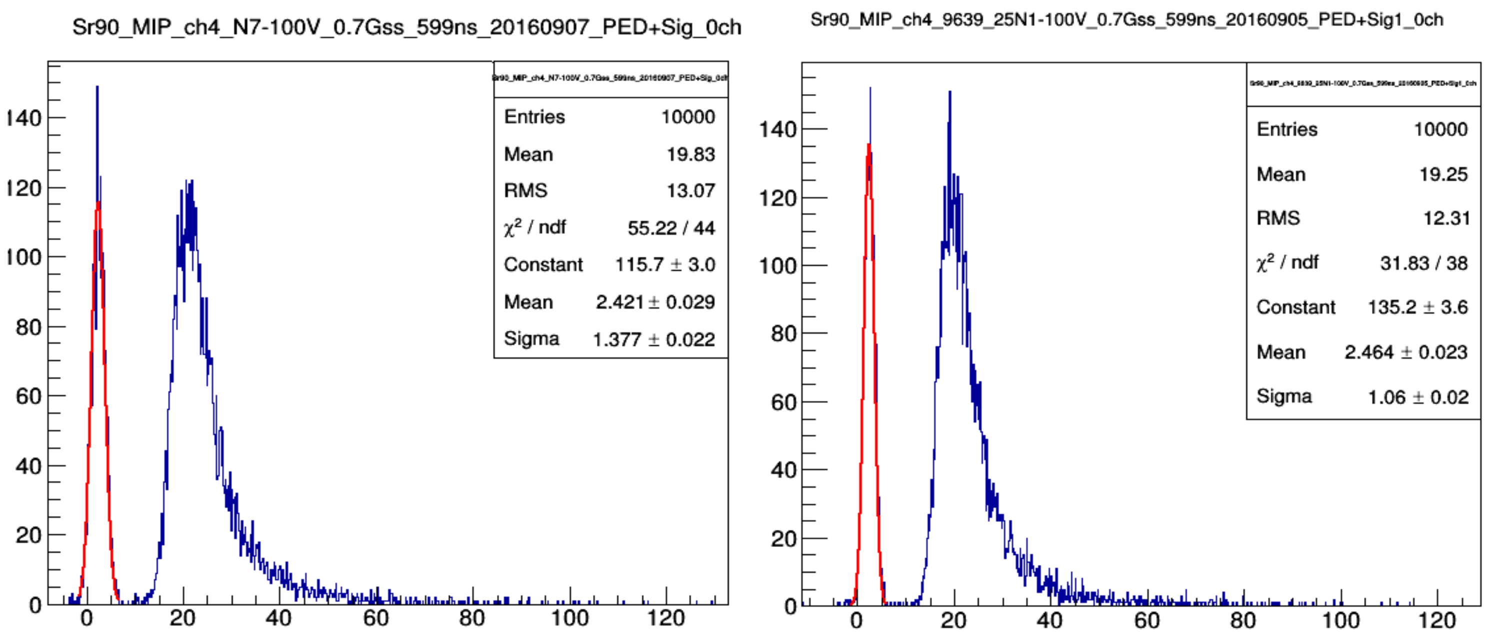




I-V characteristics of the sensors: high resistive GaAs:Cr (left), πν junction structure GaAs:Cr(right)

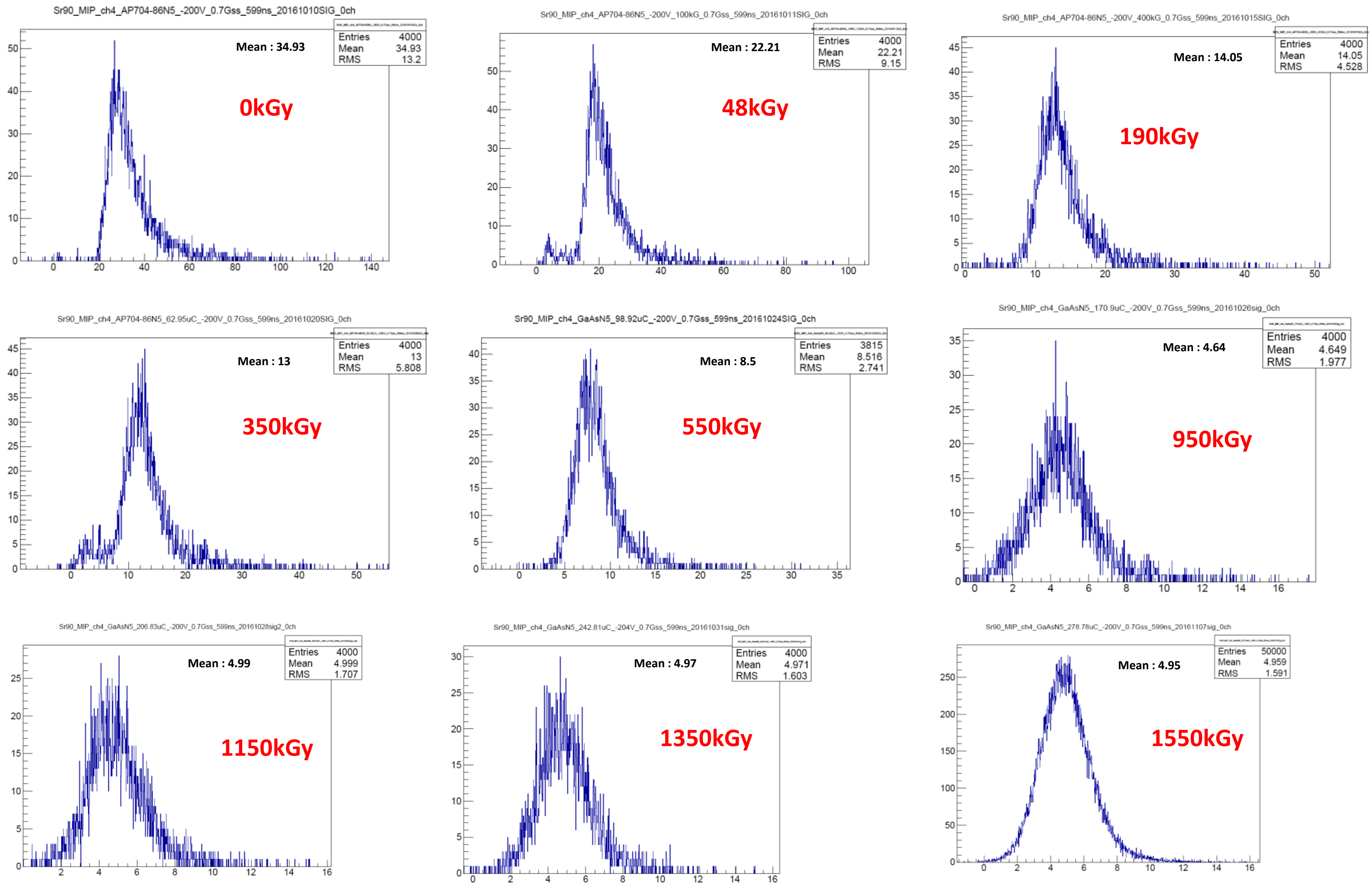
Resistivity of GaAs:Cr sensors is about 2-5*10^9 Ohm*cm, the dark current increased only 3 times for the high resistive and 4-5 times for the barrier GaAs:Cr.

MIP of non irradiated GaAs:Cr sensors

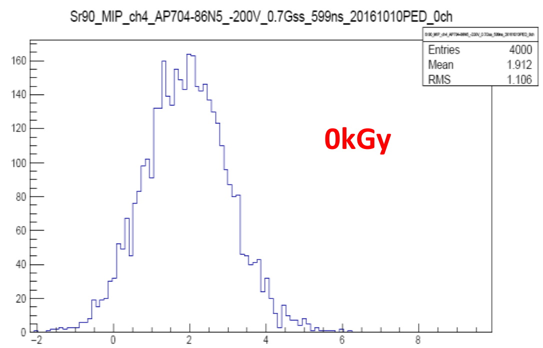


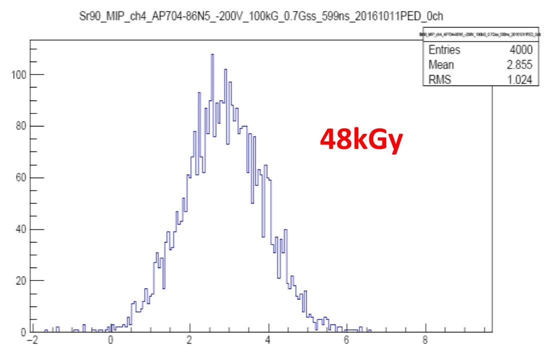
MIP spectrum from Sr^{90} of the HR GaAs (left) and πν junction structure *GaAs sensors (right)*

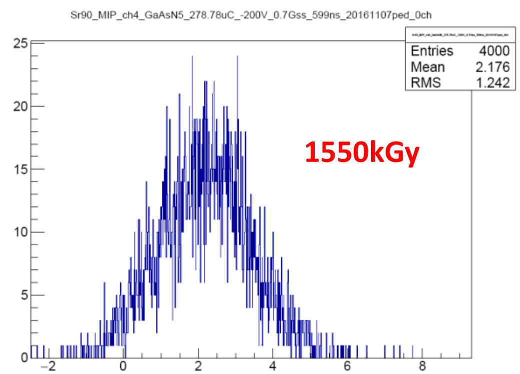
GaAs MIP signal vs Dose



GaAs pedestal vs Dose

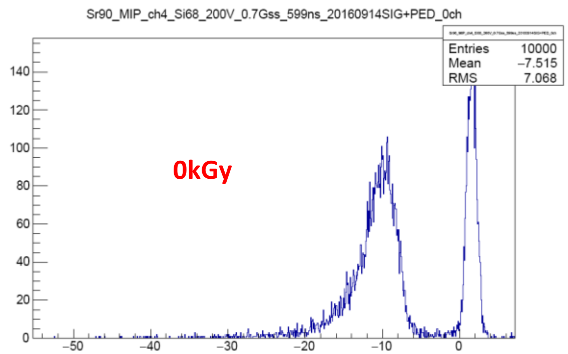


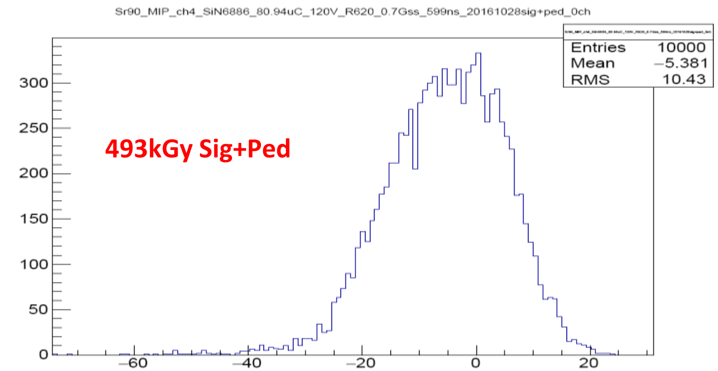


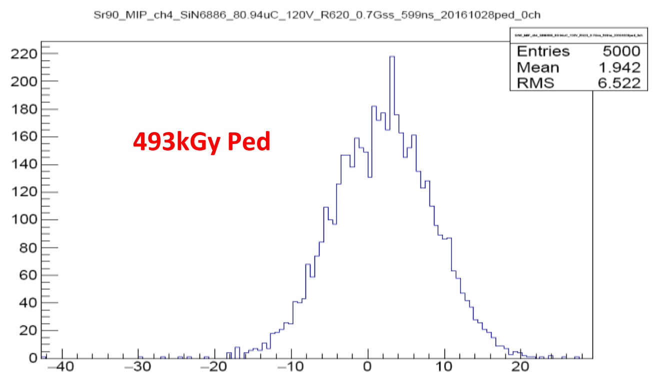


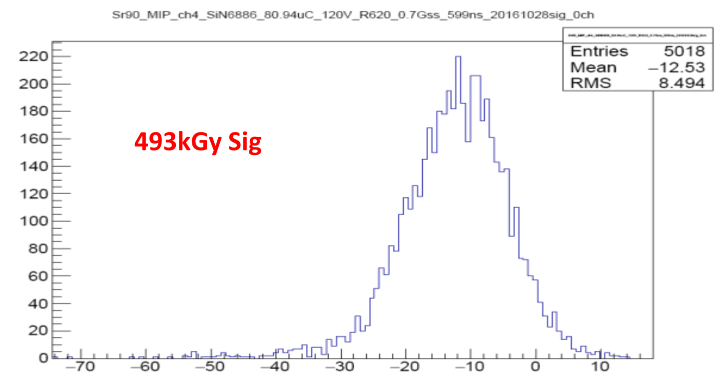
In GaAs:Cr the CCE drops 5 times even at a dose 0.5 MGy, but then it decreases slowly, keeping about 10% of the initial CCE after dose 1.5 MGy. The width of the pedestal in a GaAs remains practically unchanged.

UCSC Si 6886 MIP vs Dose



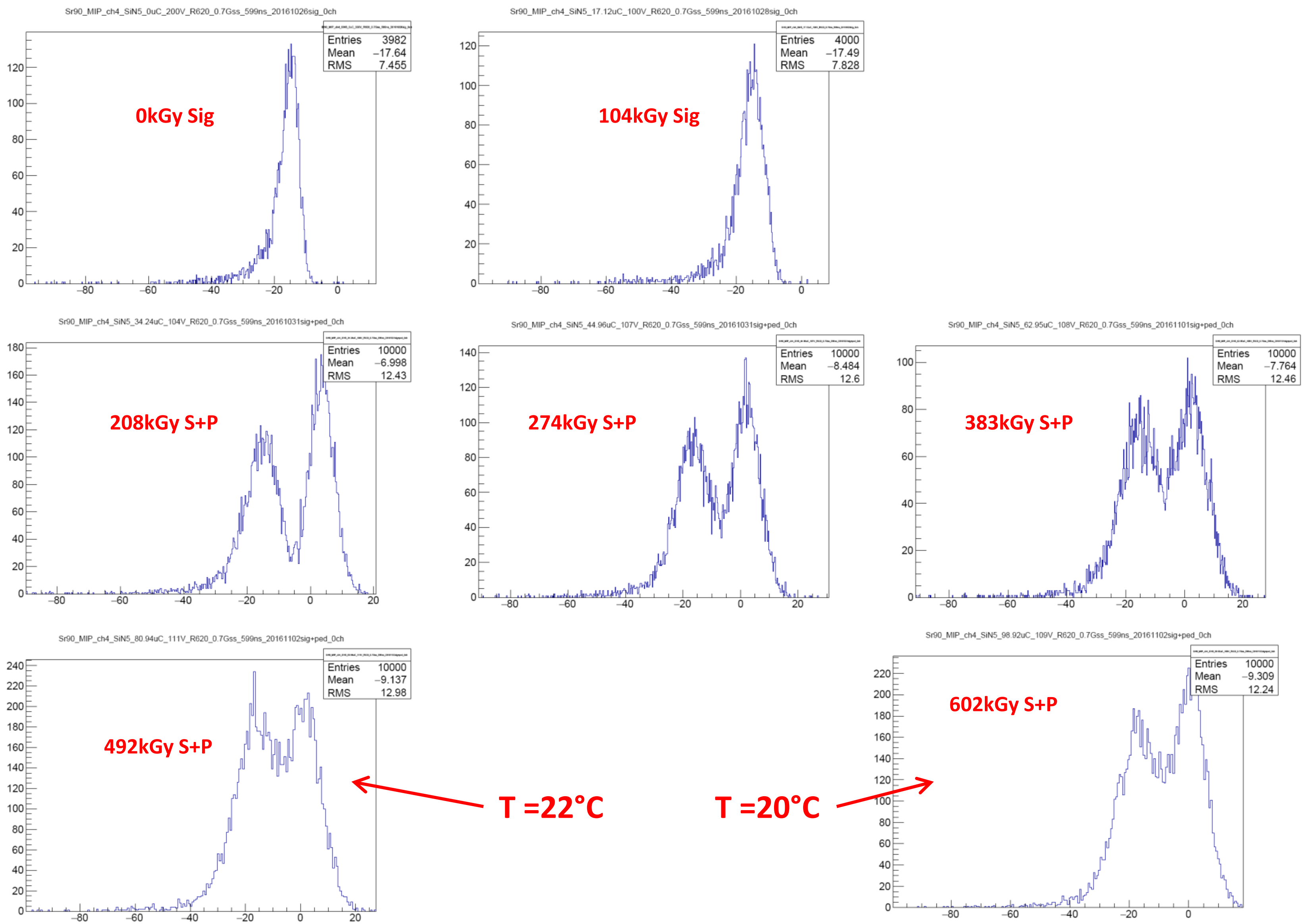






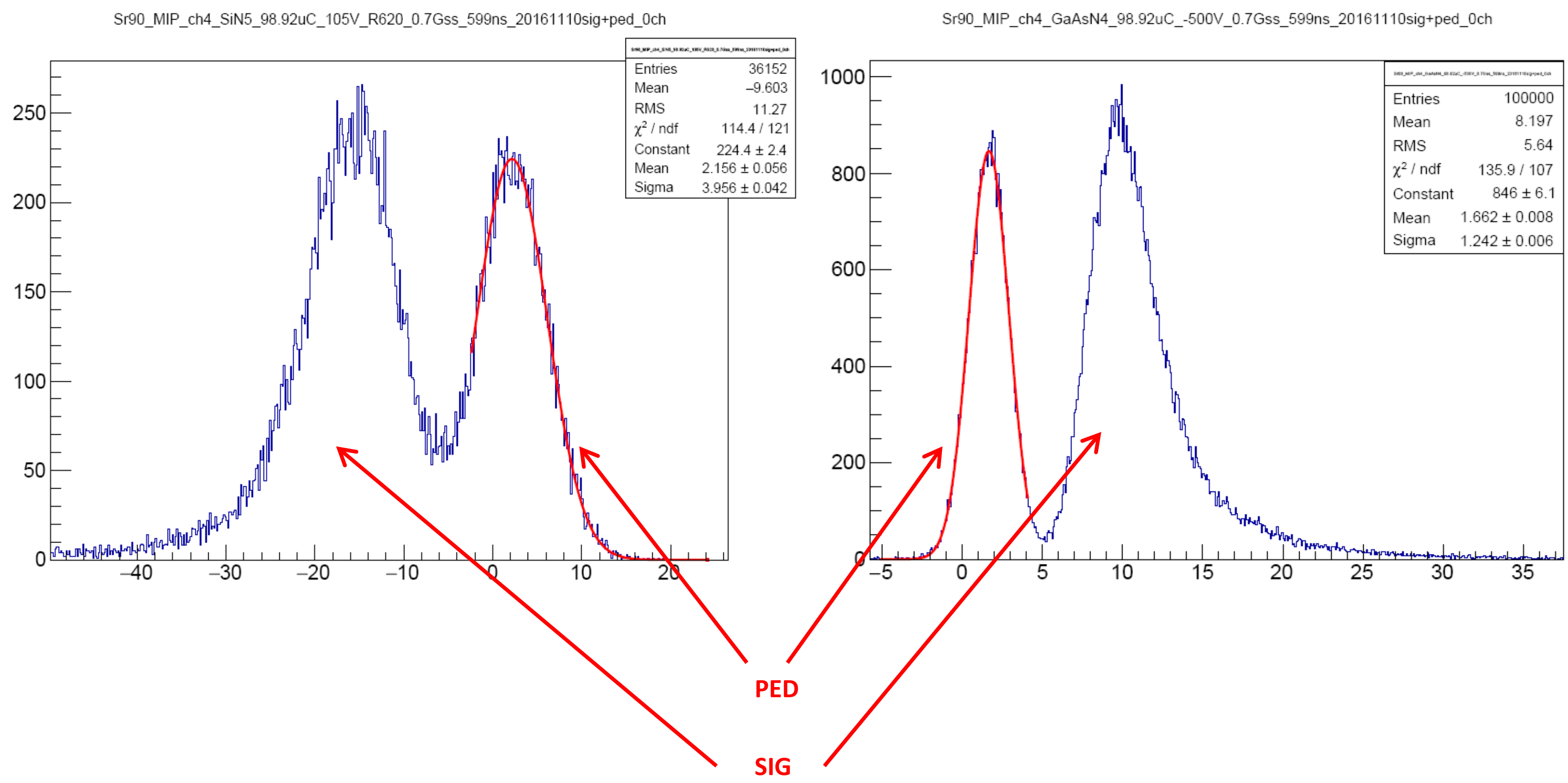
The pedestal expands and the signal from pedestal separation becomes difficult after doses 0.5MGy

N-type Si N5 MIP vs Dose



Si vs GaAs 550 kGy

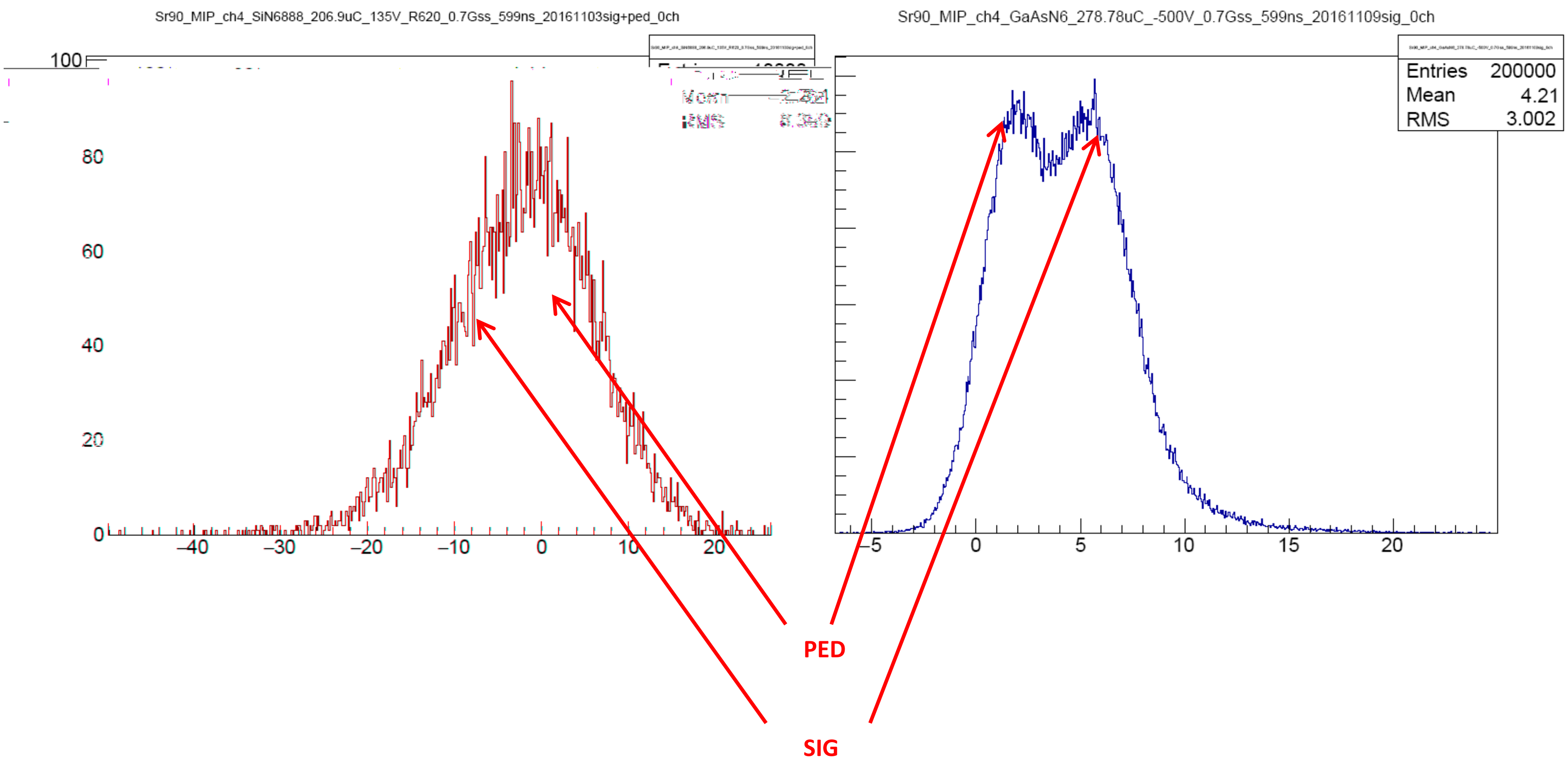
Si N5; 492kGy ; T= 16°C **GaAs N4 barrier; 550kGy ; T =22°C**



A slight cooling of the sensor Si for 5°C significantly improves the MIP-signal and pedestal separation, but it is still worse than GaAs:Cr.

Si vs GaAs 1550 kGy

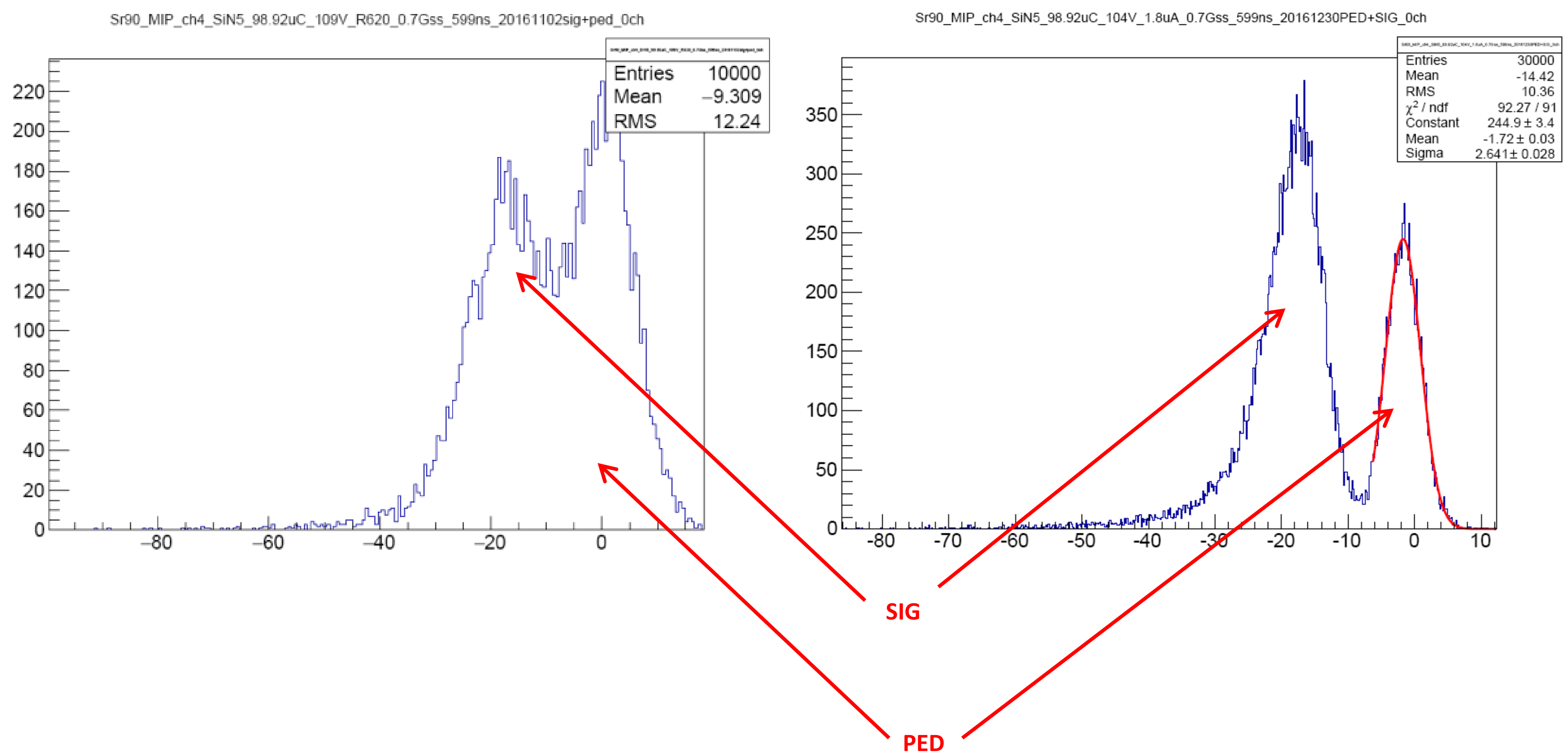
Si 1260 kGy ; T =22°C **GaAs 1550 kGy ; T =22°C**



After 1.5 MGy the MIP-signal and the pedestal still separated for GaAs:Cr

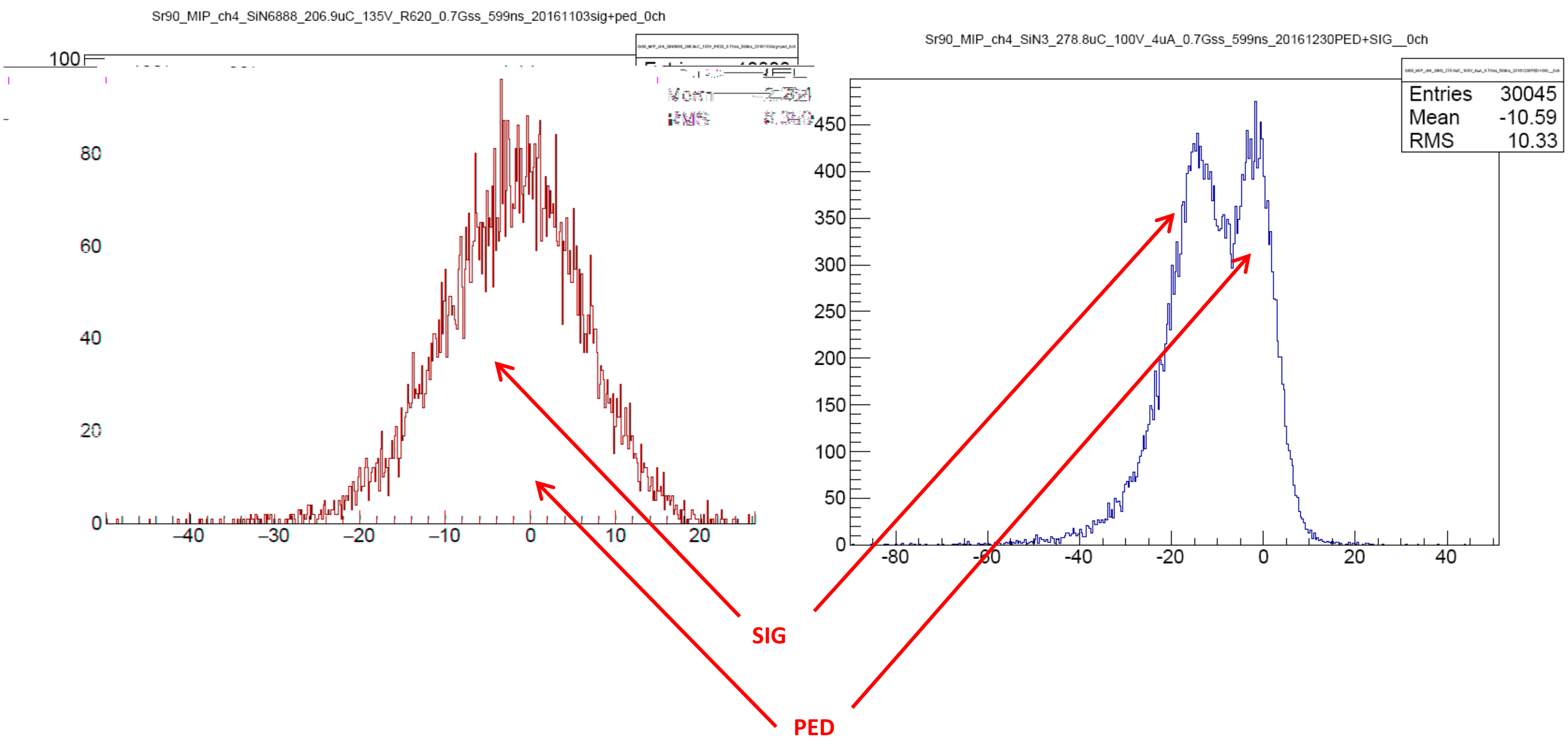
Si cooling

Si 602 kGy ; T =20°C **Si 602 kGy ; T =-1°C**

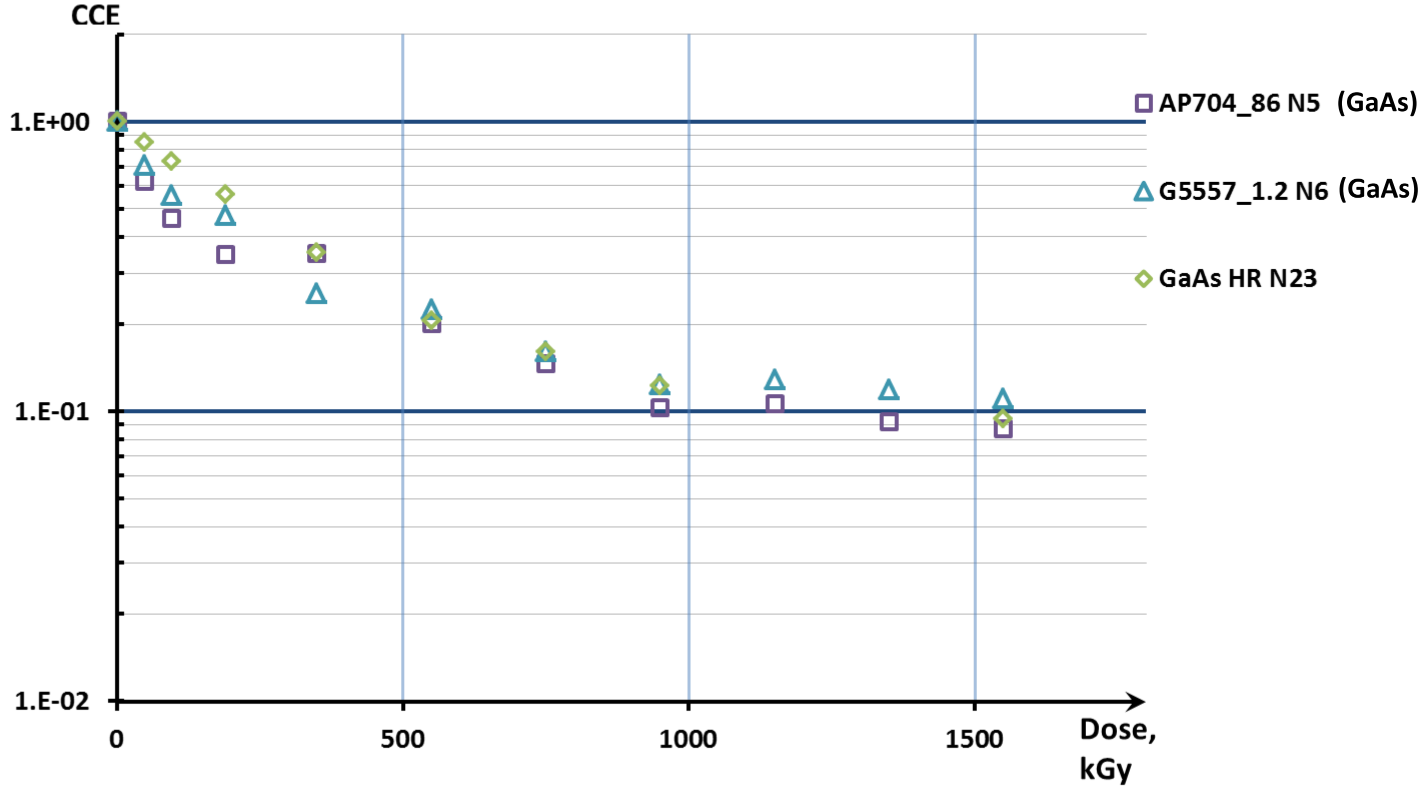


Si cooling

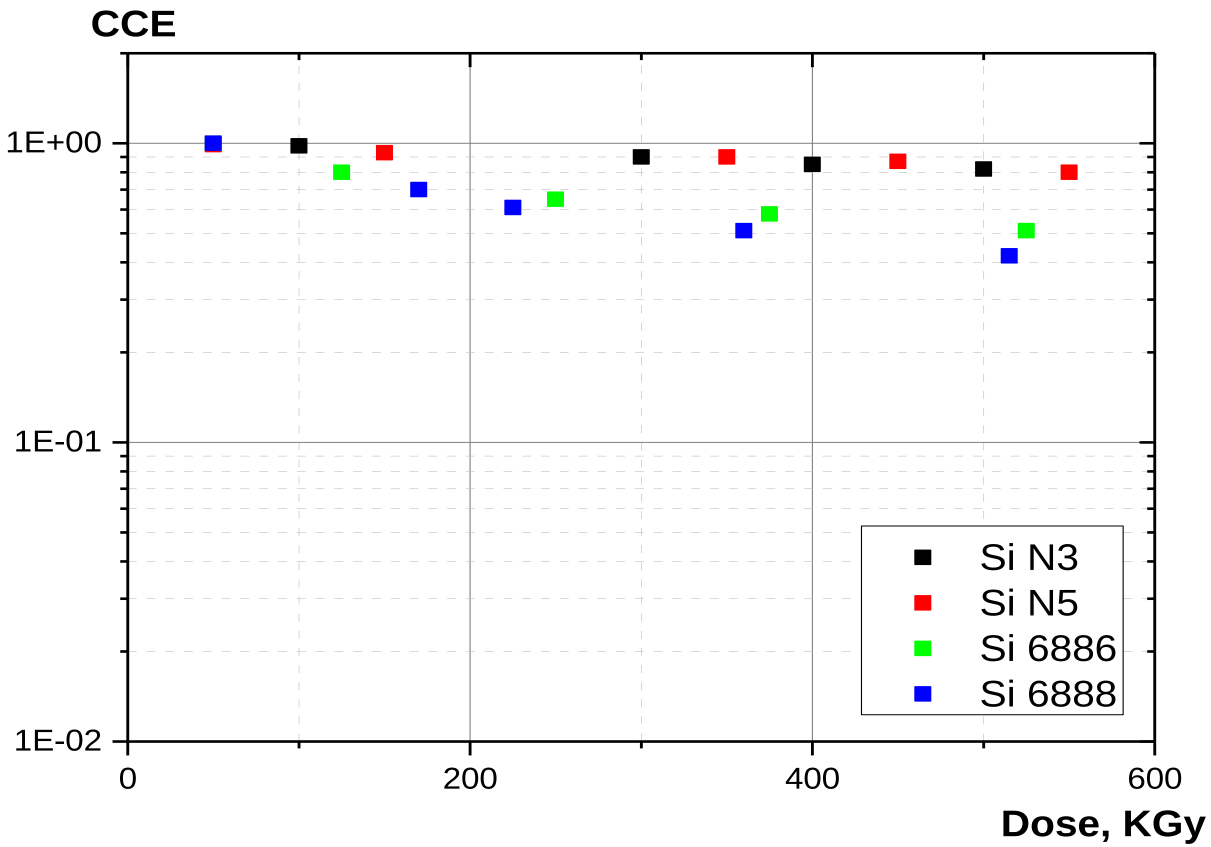
Si 1260 kGy ; T =22°C **Si 1698 kGy ; T =-0.7°C**



GaAs CCE vs Dose

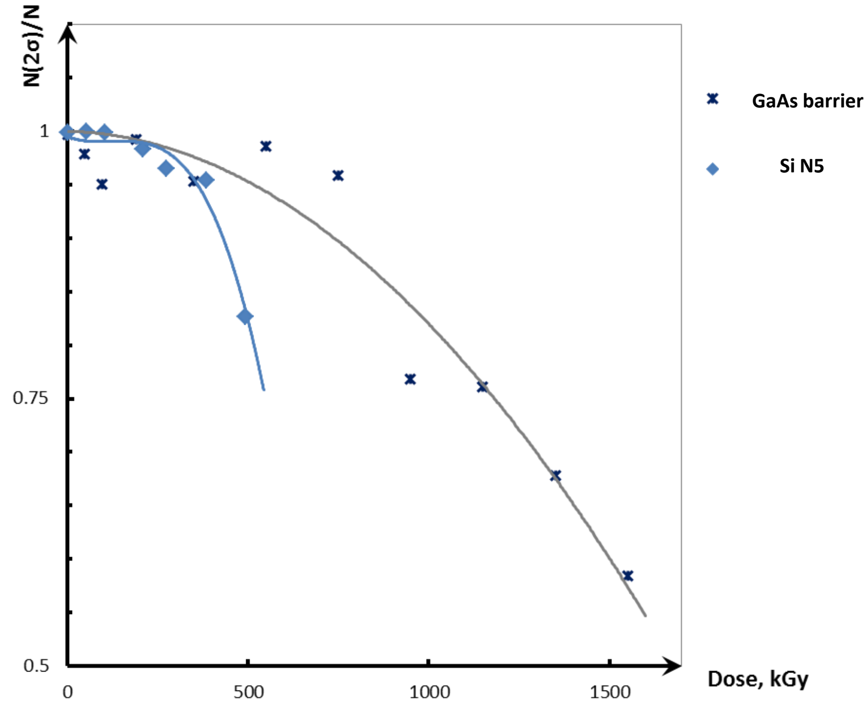


Si CCE vs Dose



Due to increasing of the dark current the pedestal considerably broadened and the measurement becomes difficult for doses higher 0.5 MGy.

GaAs:Cr and Si sensor resolution.



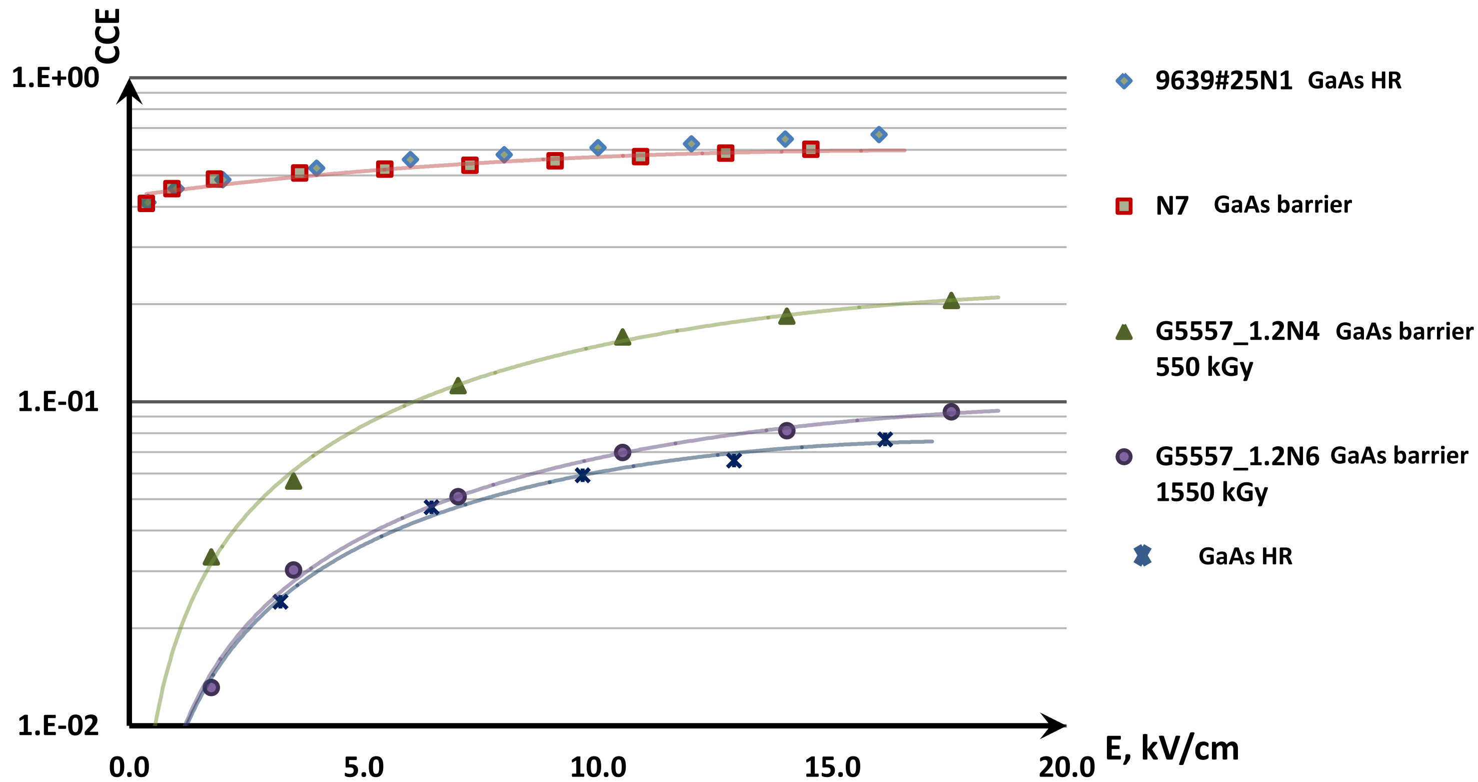
$$K = \frac{N_{2\sigma}}{N_{total}}$$

2σ-criterion was applied for a correct comparison of Si and GaAs sensor performance.

K is the ratio of events departed greater than the total number 2σ from pedestal to the total number of events in MIP-spectrum.

The greater ***K***, the better the signal and pedestal are separated in the spectrum.

GaAs CCE-Vbias dependence.

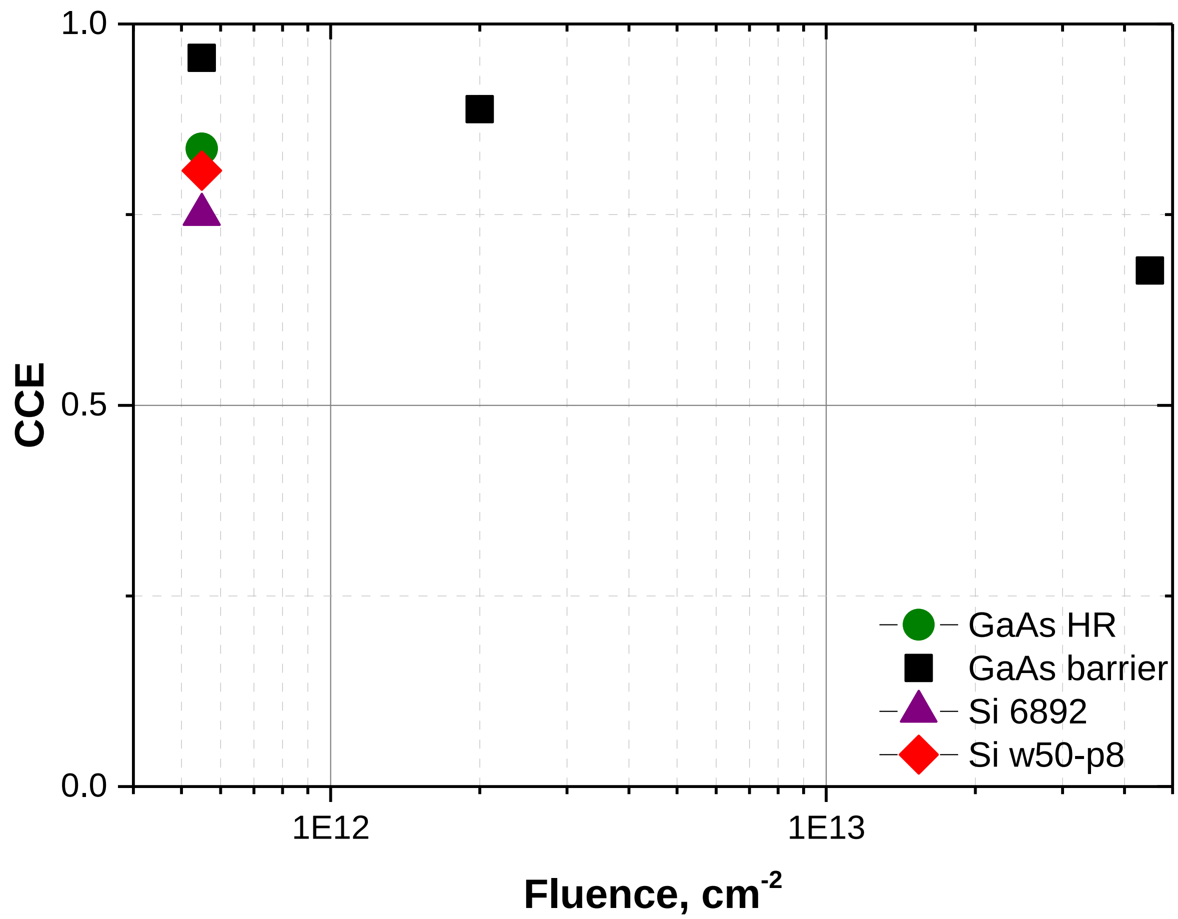


For the irradiated GaAs sensors CCE increases significant with the field strength

up to **20 kV / cm**,

while in the non-irradiated sensors saturation begins at **1 kV/cm**

CCE measurements for GaAs and Si under neutron irradiation from IBR 2



Summary

- Irradiation of the high-resistive and barrier GaAs:Cr sensors and the normal and radiation-resistant n-type Si sensors by 20 MeV electron beam of was performed.
- Radiation damage in GaAs and Si are different: increasing of the dark current in Si and dropping signal in GaAs.
- A significant difference between two types of GaAs:Cr sensors and two types of Si is not found.
- 2-σ criterion was applied to separate the signal from the pedestal.
- After dose 1.5 Mgy in GaAs:Cr signal magnitude remains about 10% of initial, when Si is not possible to use at room temperature.