# Results of measuring GaAs sensor planes

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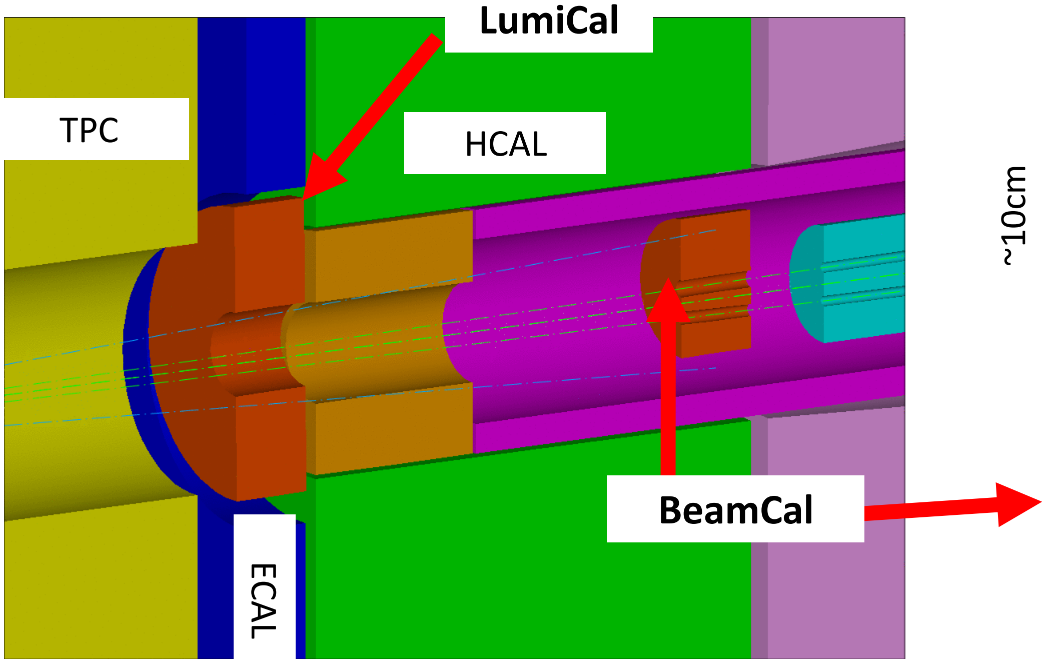
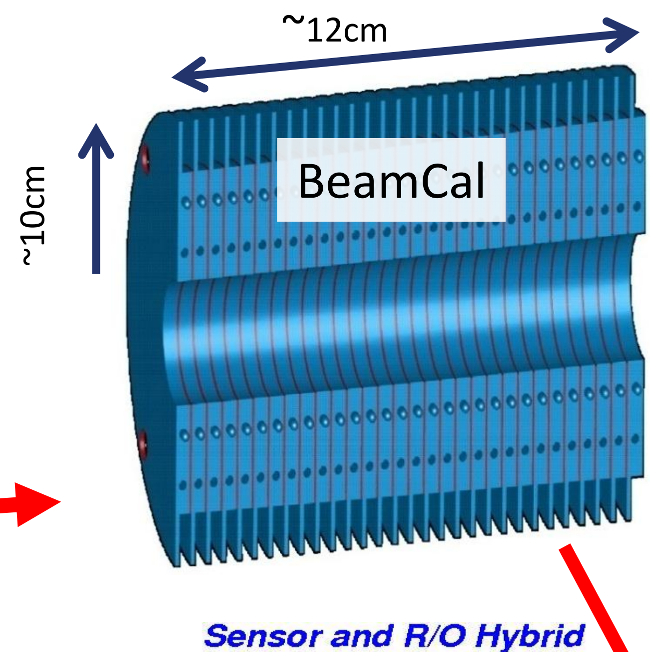
# The Beam Calorimeter - BeamCal

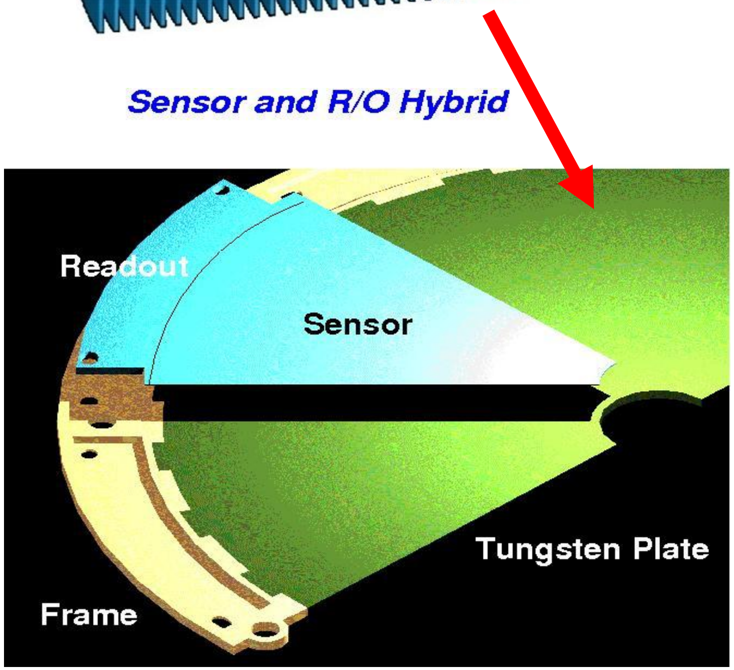



Compact EM calorimeter with sandwich structure:

- 30 layers of 1 $X_0$
  - o3.5mm W absorber and 0.3mm radiation hard sensor
- Angular coverage from 5mrad to 28 mrad (6.0 > |η| > 4.3)
- Moliére radius $R_M \approx 1$cm
- Segmentation between 0.5 and 0.8 x $R_M$

**GaAs:Cr is offered as a radiation hard sensor for Beamcal.**



# The main characteristics of semiconductor materials

| Material | Density, g/cm$^{-3}$ | Atomic number | Band gap, eV | $\mu\tau$ product, cm$^2$/V | |
|---|---|---|---|---|---|
| | | | | $\mu_n \tau_n$ | $\mu_p \tau_p$ |
| Si | 2.33 | 14 | 1.12 | ~ 1 | ~ 1 |
| GaAs | 5.32 | ~ 32 | 1.43 | ~ $10^{-4}$ | ~ $10^{-5}$ |
| CdTe | 5.85 | ~ 49 | 1.5 | $10^{-3}$ | $10^{-4}$ |
| $HgI_2$ | 6.4 | ~ 81 | 2.13 | $10^{-4}$ | $10^{-5}$ |
| $PbI_2$ | 6.16 | ~ 83 | 2.32 | $10^{-5}$ | $10^{-6}$ |

We can see that the pure (not doped) Si has the charge carriers lifetime which exceeds the lifetime for binary semiconductors by 4 orders. However, pure semiconductors (Si) have not sufficient radiation hardness and relatively small conversion efficiency for $\gamma$.

# GaAs:Cr Sensor Plane

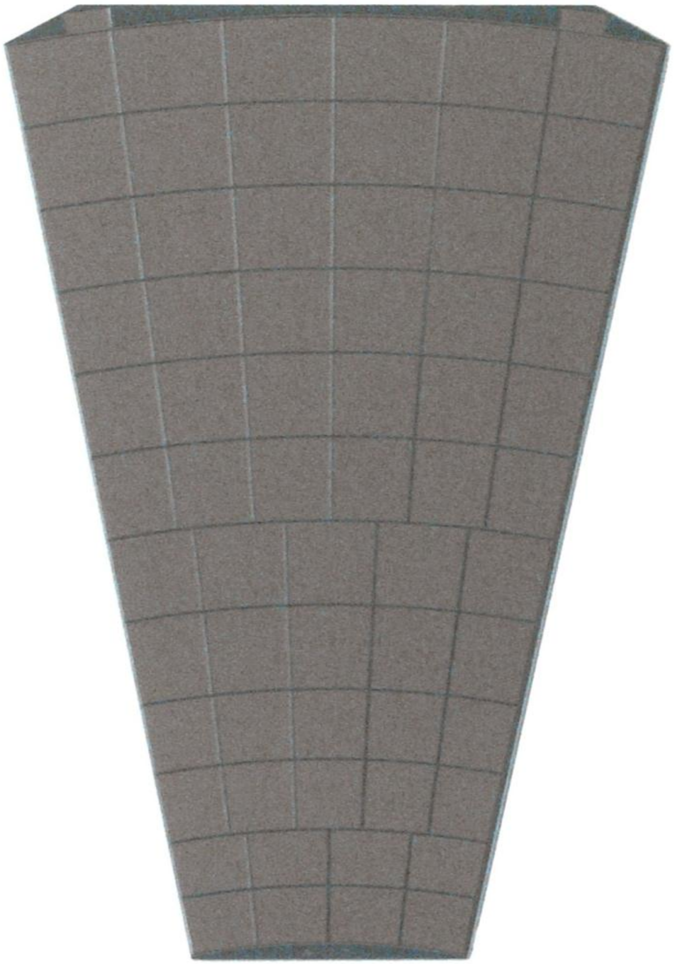
- **Produced by the Siberian Institute of Technology, Tomsk**
- **semi-insulating GaAs doped by Sn (shallow donor)**
- **compensated by Cr (deep acceptor): to compensate electron trapping centers EL2+ and provide i-type conductivity.**
- **Due to a wider band gap these samples are radiation harder and have a lower leakage current (resistivity >$10^9$ Ohm*sm)**

**BUT….**

- **Due to small holes mobility only electron charge can be collected. It limits maximum CCE to 50% for minimum ionising particles.**

# GaAs:Cr Sensor Plane

- New set of 11 sector size GaAs sensors (22 at all)
- Thickness - 500 µm
- Metallization ~1 µm Ni both sides
- 12 rings
- 64 pads from 18 to 42 $mm^2$
- Surrounded by 120 µm width guard ring

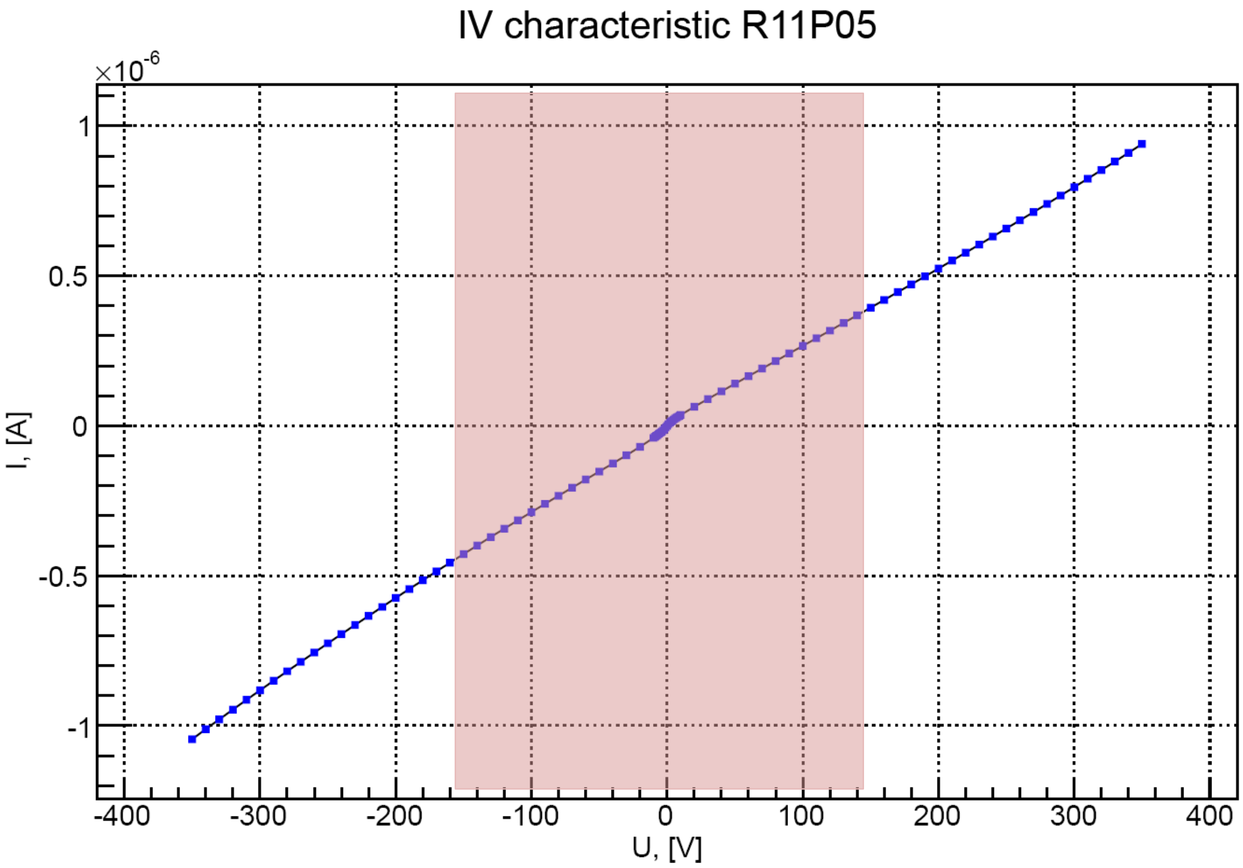


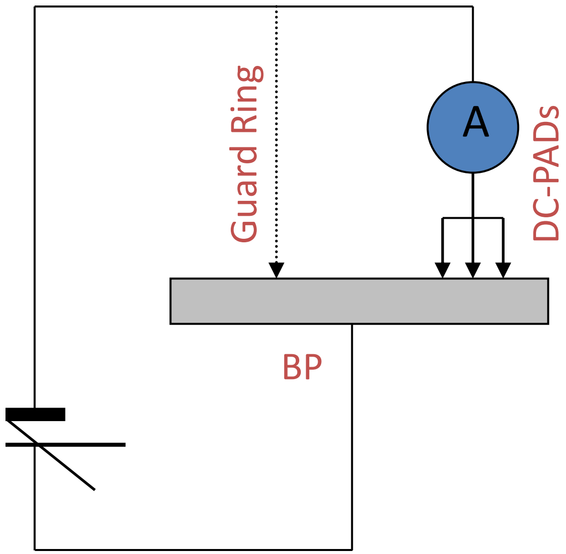
# GaAs:Cr Sensor producer data

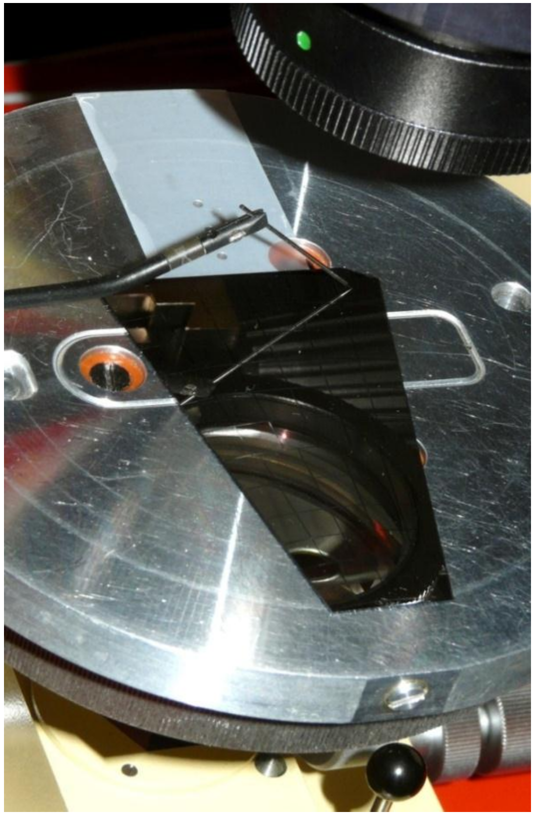
| № | Detector | thickness, um | collected charge, e* | metallization, Type of metallization | |
|---|---|---|---|---|---|
| | | | | pixels | Guard ring |
| 1 | AG-262 №1 | 506 | 40570 | Ni | Ni |
| 2 | AG-262 №3 | 512 | 41640 | Ni | Ni |
| 3 | AG-262 №4 | 509 | 42690 | Ni | Ni |
| 4 | AG-221 №6 | 498 | 37020 | Ni | Ni |
| 5 | AG-262 №12 | 504 | 35630 | Ni | Ni |
| 6 | AG-262 №13 | 517 | 37580 | Ni | Ni |
| 7 | AG-262 №15 | 518 | 39190 | Ni | Ni |
| 8 | AG-262 №16 | 509 | 37170 | Ni | Ni |
| 9 | AG-262 №19 | 507 | 34490 | Ni | Ni |
| 10 | AG 84 № 23 | 492 | 37930 | Ni | Ni |
| 11 | AG 84 №24 | 485 | 38520 | Ni | Ni |

* - $U_{bias}$= -150V, RT, β - radiation ($^{90}$Sr, mip).

# I/V pad measurements



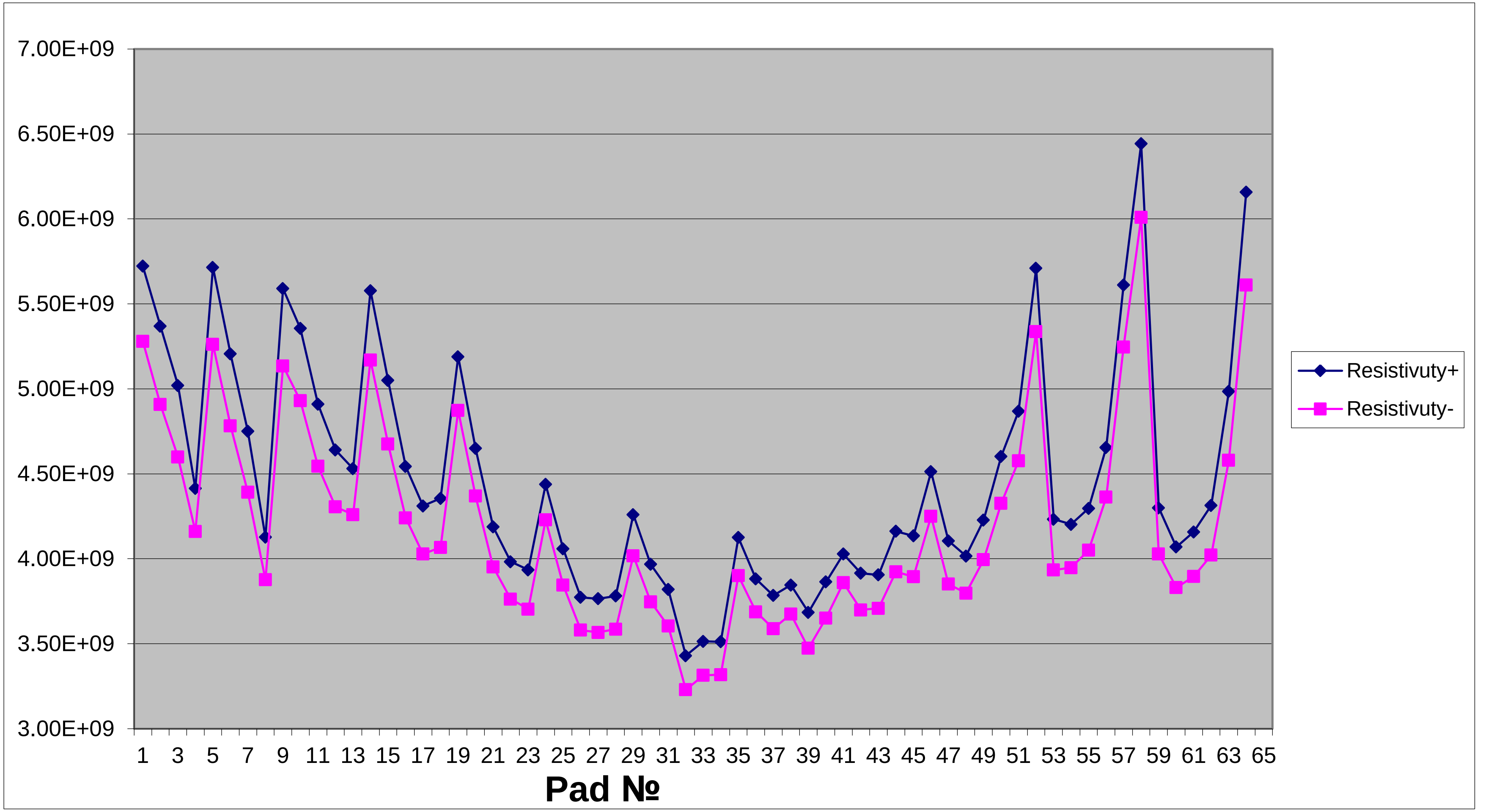



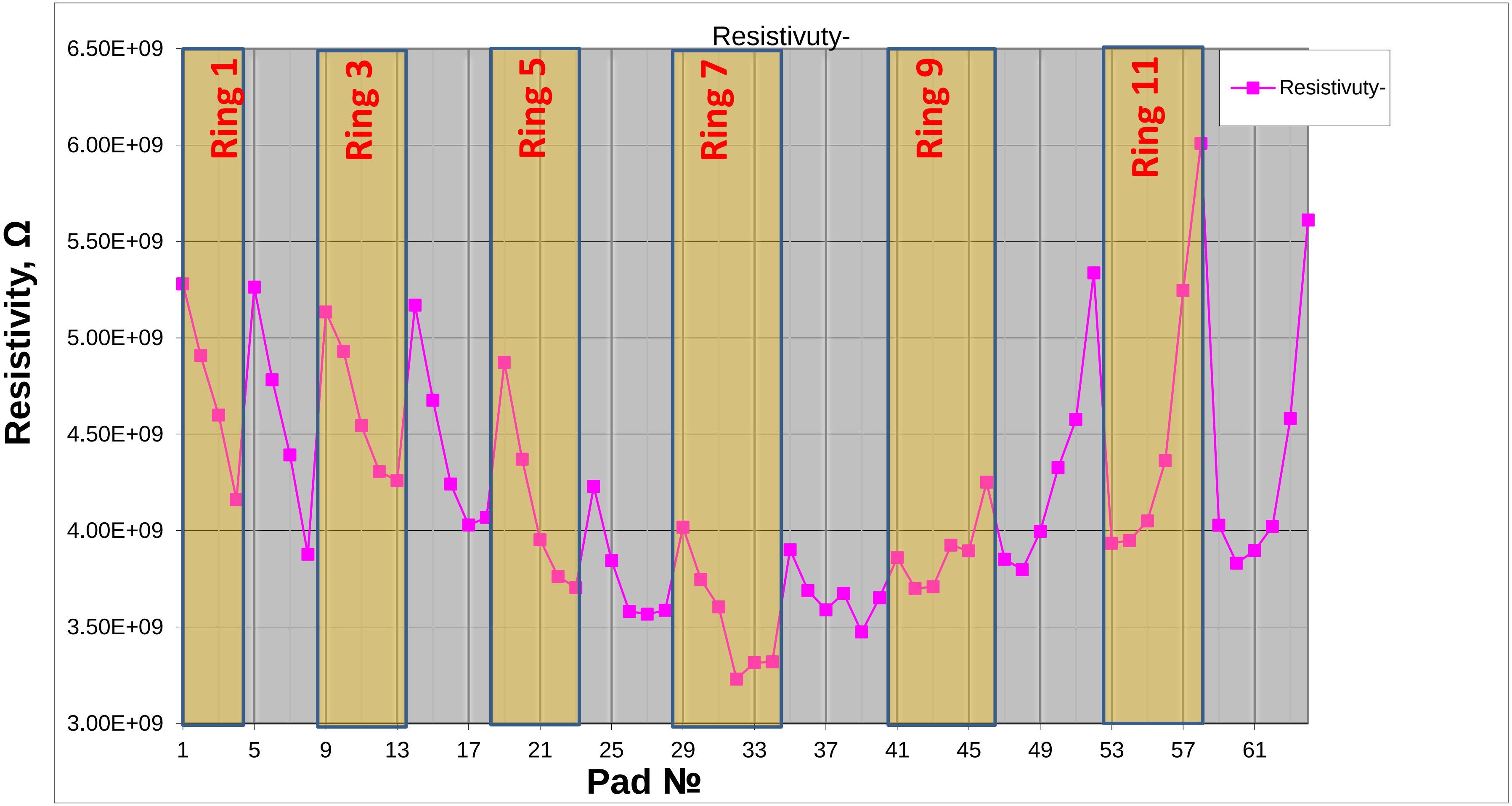
**Typical IV of one pad of AG-262№3**

- symmetric in the range +/-350V
- linear in the range +/-150V

# Resistivity pads distribution of AG221№6



# Resistivity pads distribution of AG221№6




It was found that for some sensors the ρ-, $\rho^{-}$ strongly depends on Ring №

# I-V in range +/-10V

**Parameterization of the IV curve by 4 parameters:**

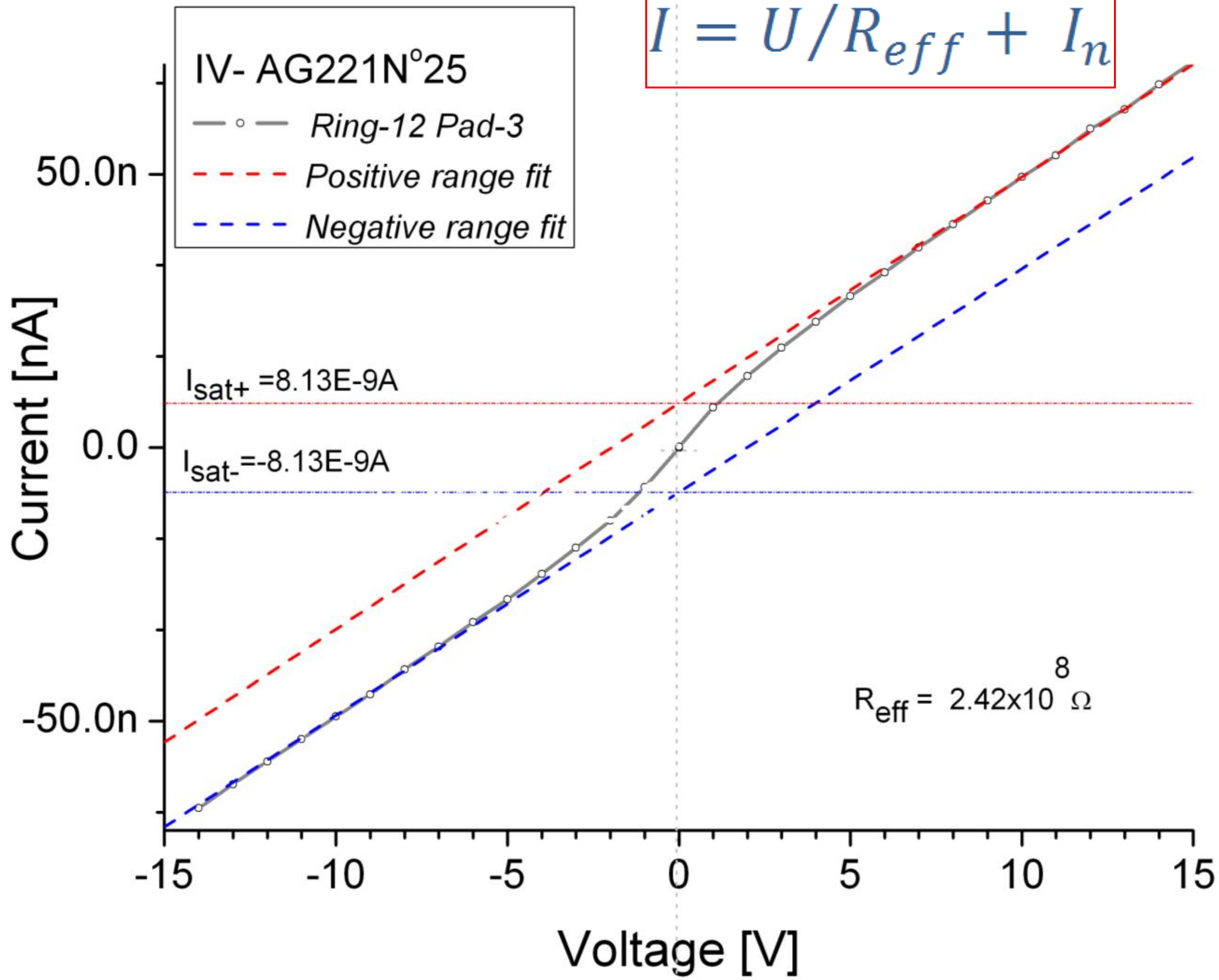
- $I_{n-}$
- $I_{n+}$
- R-
- R+

**As result of IV measurement we can get 4 parameters for each pad:**

**ρ-, ρ+**

**$\varphi^-$, $\varphi^+$**

$$I = U/R_{eff} + I_n$$



# Measurement of the barrier height on border of metal–*semiinsulating* gallium arsenide

**total current through the device**

$$I = U/R_{eff} + I_n$$

***Reff*** - effective resistance of the entire device

***In*** or ***Isat*** - Saturation current - Limiting current from metal to semiconductor

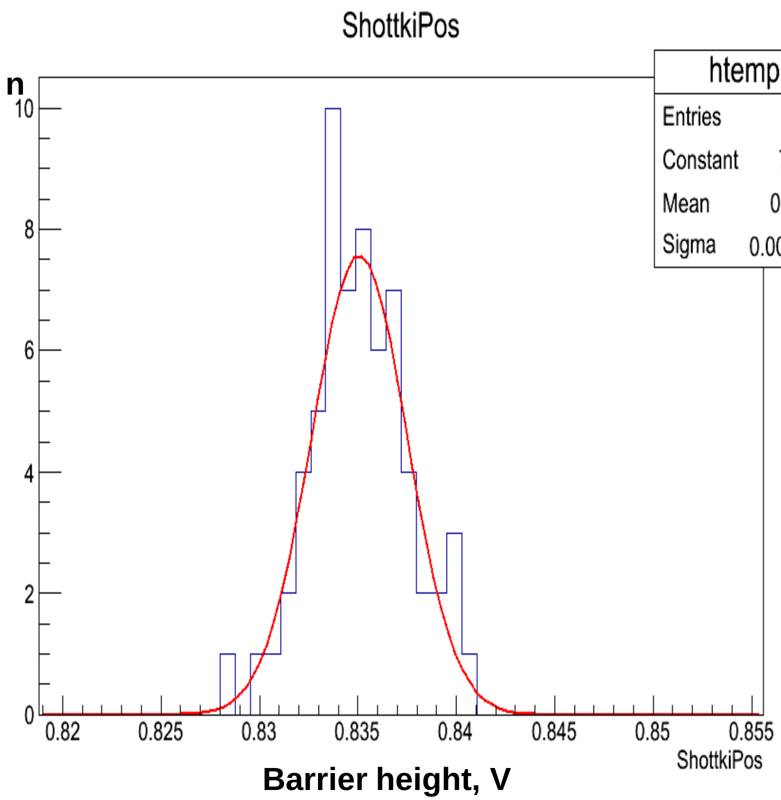
$$I_n = SA_n^* T^2 \exp\left(-\frac{q\varphi_{Bn}}{kT}\right) \qquad \textbf{[1]}$$

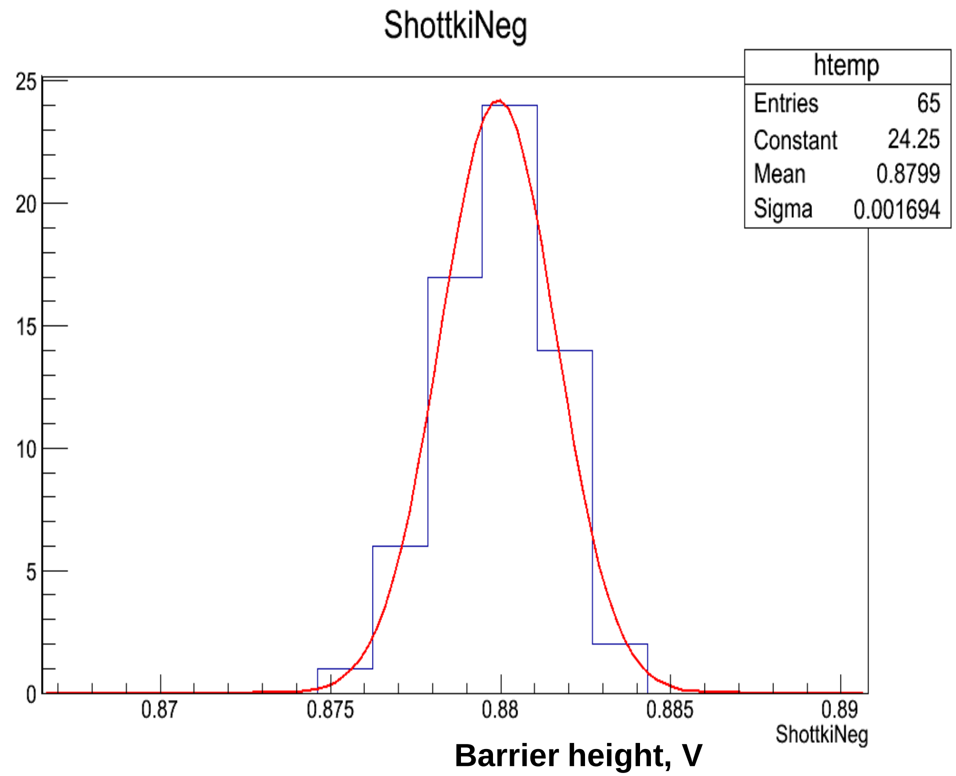
***S***- Cross-sectional area, $A^*_n$ ***= 8.16 A*cm$^{-2}$ *K$^{-2}$*** *- Richardson constant for GaAs*

***T*** *- Temperature of device,* ***q*** *- electron charge,* ***k*** *- Boltzmann constant*

$\varphi_{Bn}$ - **barrier height on border of metal–*semiinsulating* gallium arsenide**

# Shottky barrier height distribution of AG221N06

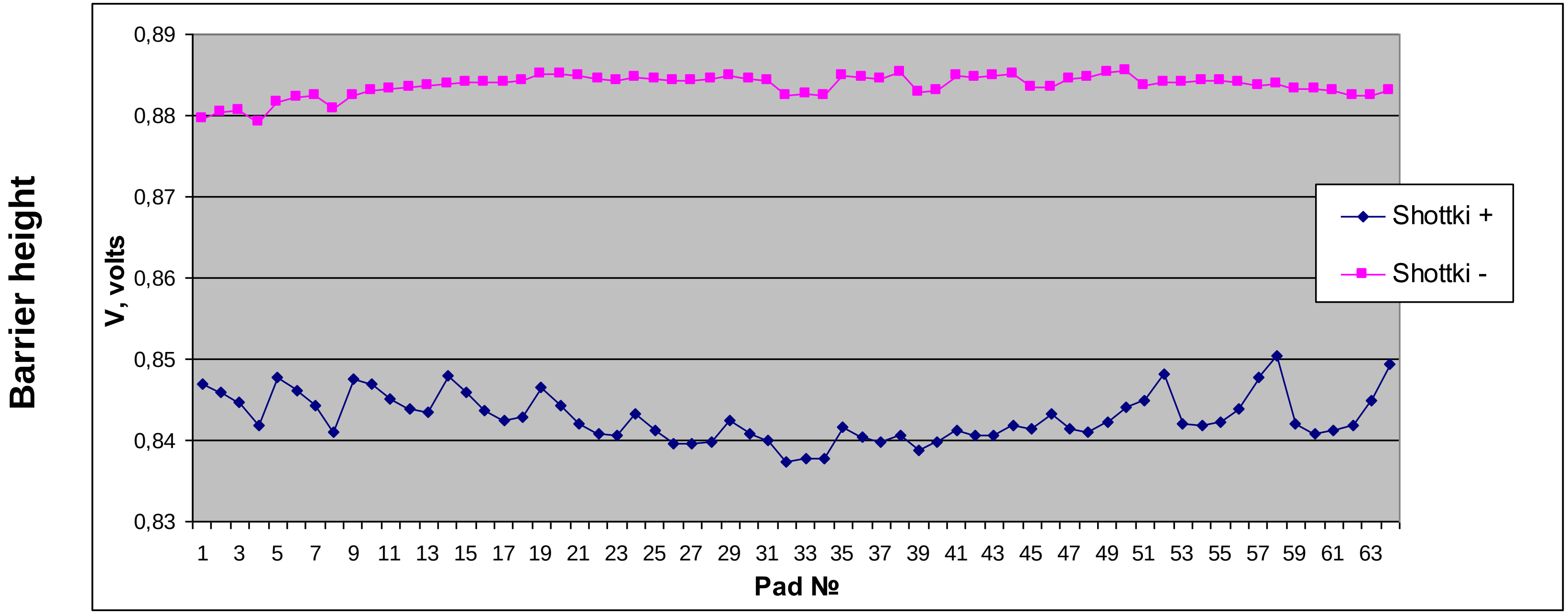



The Schottky barrier height is measured for both polarities. Positive branch corresponds to the barrier on the border Pad-GaAs, negative corresponds to the barrier on the border Backplane-GaAs.

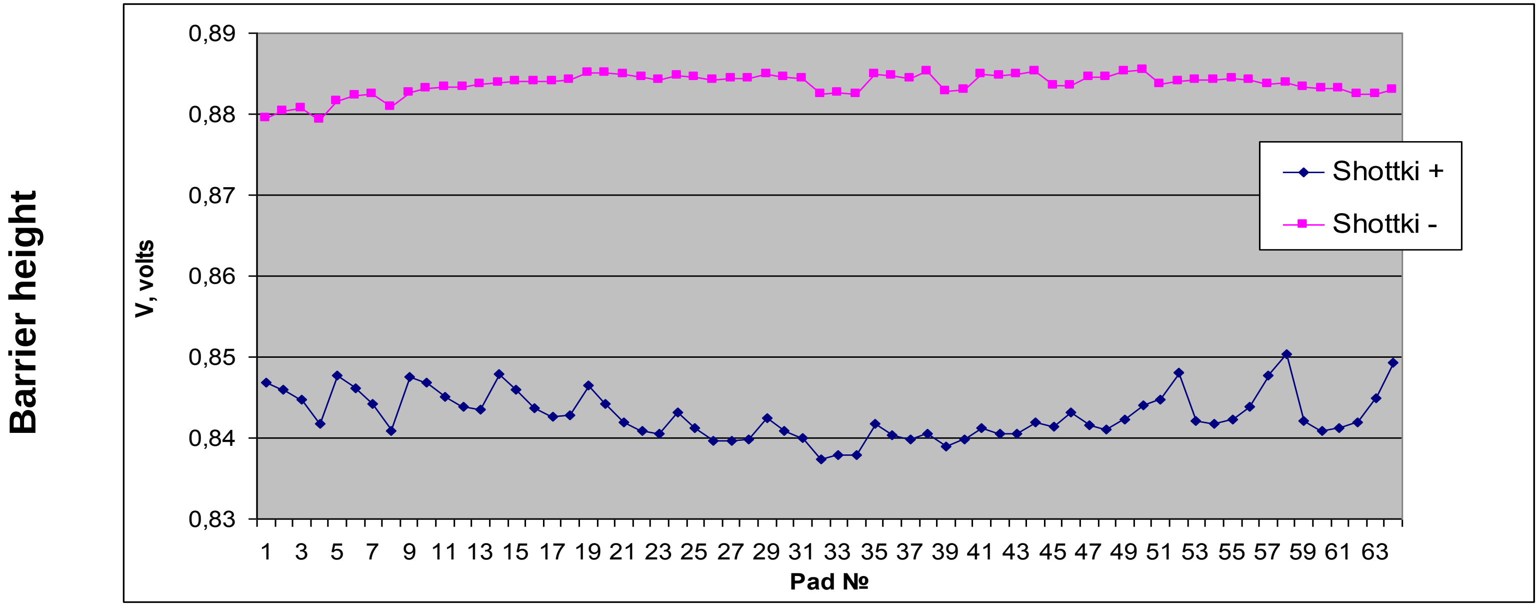
Previously measured and published value for contact based on vanadium ***0.81 ±0.02V*** [1]

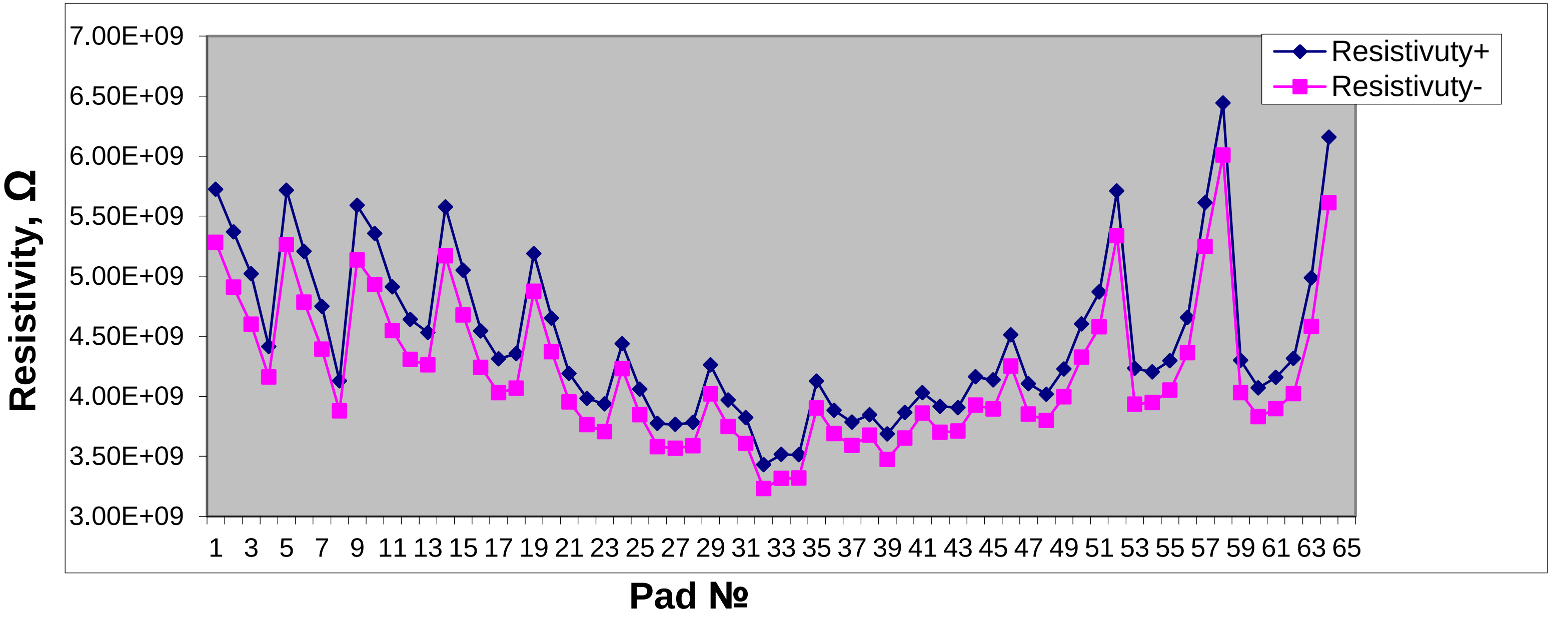
# Barrier height distribution of AG221№6




The sensors with **ρ+, ρ⁻** dependence on Ring №
have similar behavior for **φ⁺**, but not for **φ⁻**

# Barrier height distribution of AG221№6



# Average resistivity and barrier height of 11 sensors

| № | Detector | Thickness, um | Resistivity, Ohm*cm | | Barrier height, volts | |
|---|---|---|---|---|---|---|
| | | | $\rho^+$ | $\rho^-$ | $\varphi^+$ | $\varphi^-$ |
| 1 | AG-262 №1 | 506 | 3,27E+009 | 3,05E+009 | 0,835 | 0,880 |
| 2 | AG-262 №3 | 512 | 3,10E+009 | 2,90E+009 | 0,835 | 0,880 |
| 3 | AG-262 №4 | 509 | 3,25E+009 | 3,09E+009 | 0,837 | 0,884 |
| 4 | AG-221 №6 | 498 | 4,47E+009 | 4,19E+009 | 0,843 | 0,884 |
| 5 | AG-262 №12 | 504 | 3,38E+009 | 3,26E+009 | 0,838 | 0,884 |
| 6 | AG-262 №13 | 517 | 2,72E+009 | 2,58E+009 | 0,833 | 0,883 |
| 7 | AG-262 №15 | 518 | 3,22E+009 | 3,06E+009 | 0,837 | 0,884 |
| 8 | AG-262 №16 | 509 | 3,63E+009 | 3,49E+009 | 0,839 | 0,885 |
| 9 | AG-262 №19 | 507 | 3,25E+009 | 3,08E+009 | 0,836 | 0,884 |
| 10 | AG 84 № 23 | 492 | 2,92E+009 | 2,78E+009 | 0,833 | 0,880 |
| 11 | AG 84 №24 | 485 | 3,08E+009 | 2,93E+009 | 0,834 | 0,881 |
| Average ± Sigma | | | 3,30±0,45 E+09 | 3,13±0,43 E+09 | 0,836±0,003 | 0,883±0,002 |

# Defects found

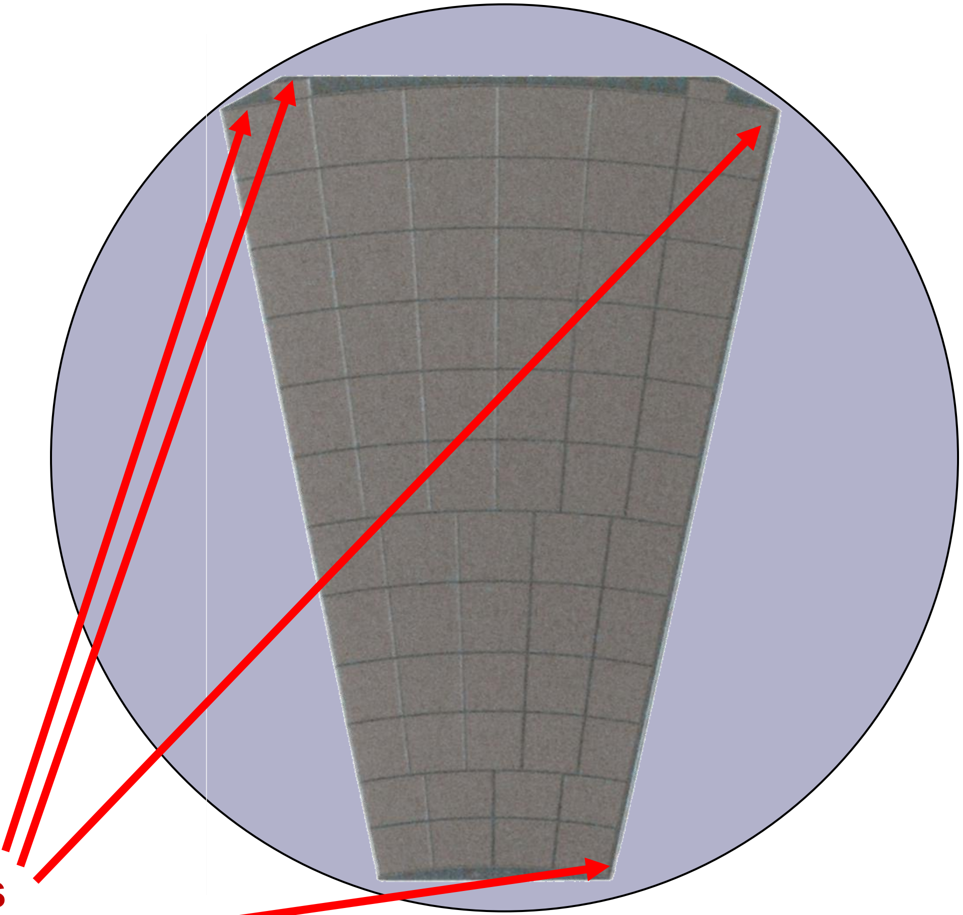
The criteria for a pad accepted as good:

$\rho > 10e9\ \Omega{*}cm$

Some pads or guard rings have untypical behavior.

8 of 22 sensors have deflection Guard ring and one pad: that may be related internal structure injury. It appear on the crystal boundary for all cases.

All 8 sensors are made of the same crystal AG84!

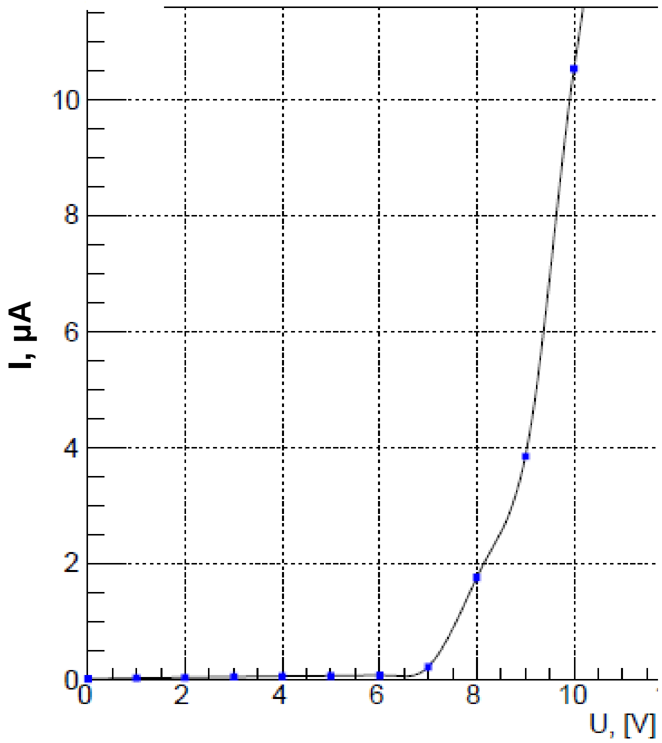


**Unusual pads**

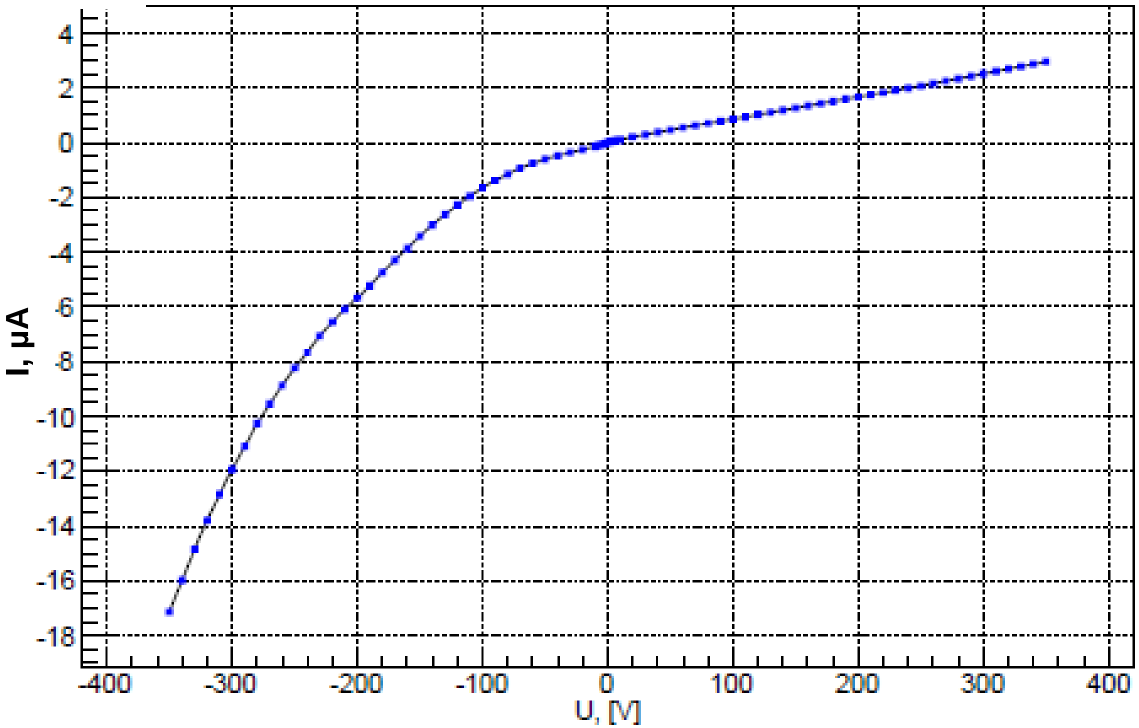
Guard ring +

Ring1-Pad4; Ring12-Pad1; Ring12-Pad6;

# Untypical IV behavior




Ag84N24 Guard ring

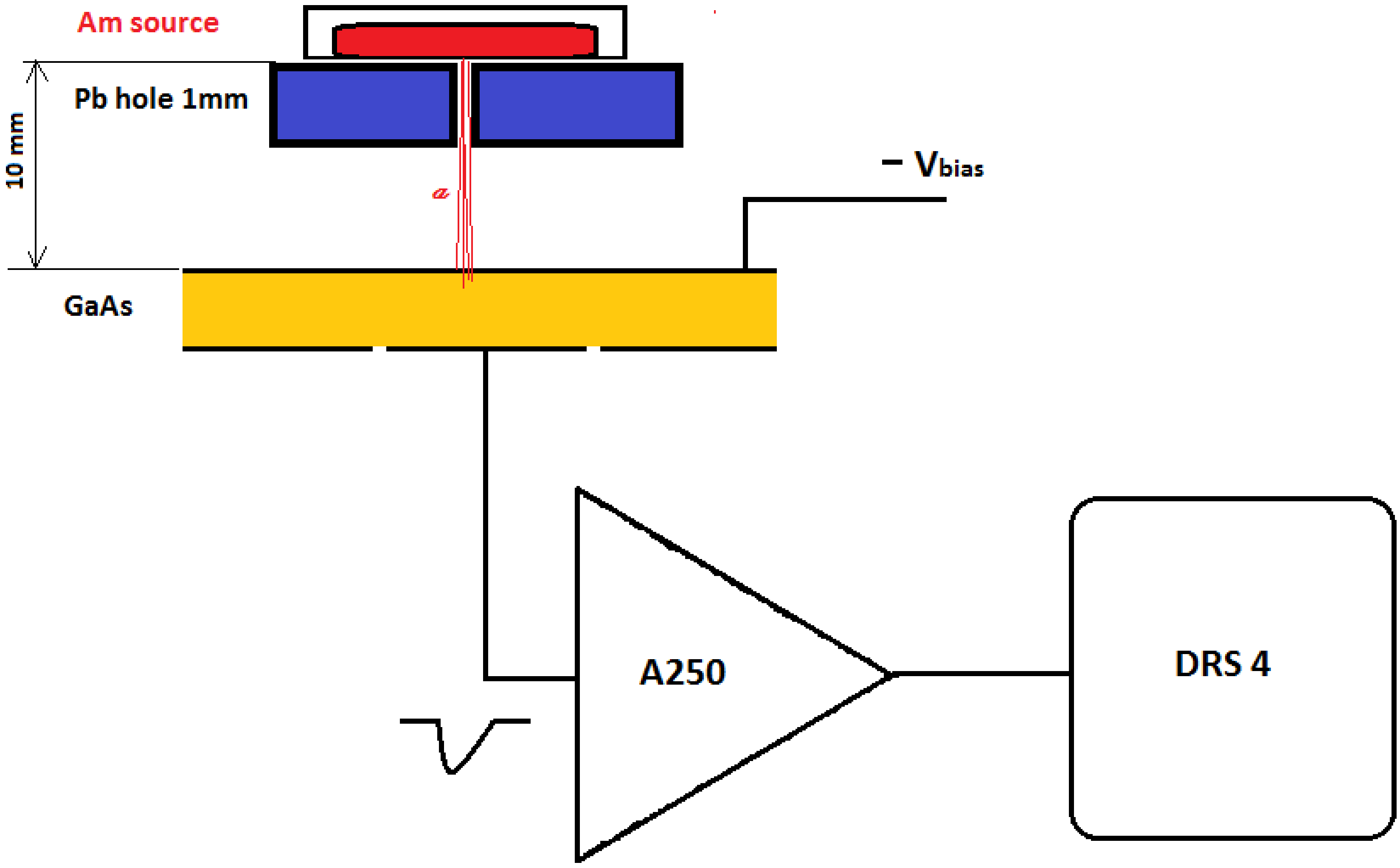



Ag84N23 Ring 1 Pad 4

# 8 of 22 planes have 1 unusual pad and GR (All 8 of 12 ϵ AG84)

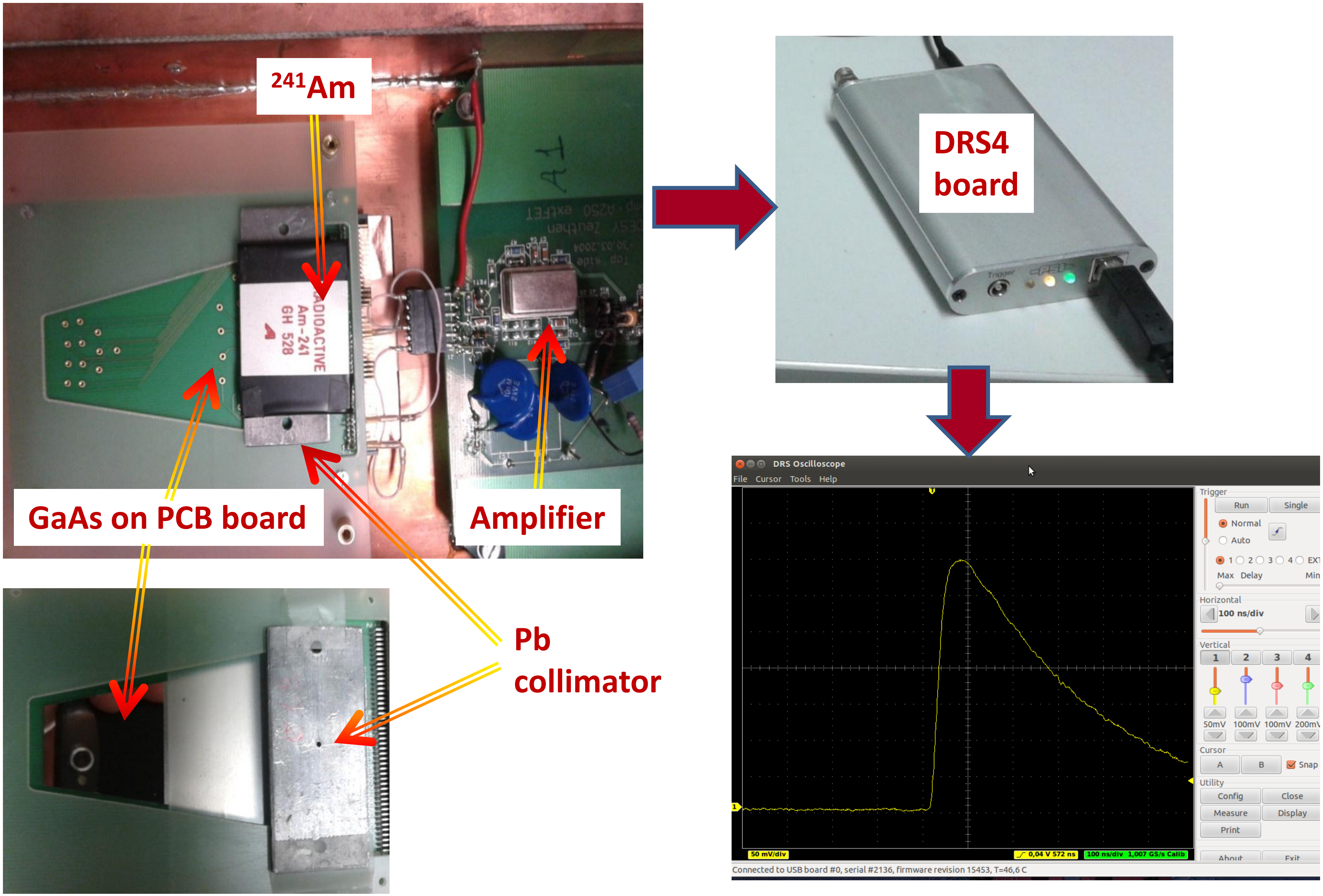
| Nº | Pad Nº | Breakdown voltage, V |
|---|---|---|
| AsGa84N7 | Guard ring | -330 |
| AsGa84N7 | Ring12-Pad1 | -310 |
| AsGa84N13 | Guard ring | -160; +200 |
| AsGa84N13 | Ring12-Pad6 | -280 |
| AsGa84N21 | Guard ring | +30 |
| AsGa84N21 | Ring1-Pad4 | +50 |
| AsGa84N26 | Guard ring | -110; +230 |
| AsGa84N26 | Ring12-Pad1 | -210 |
| AsGa84N28 | Guard ring | -300 |
| AsGa84N28 | Ring12-Pad6 | +330 |
| AsGa84N41 | Guard ring | +110 |
| AsGa84N41 | Ring12-Pad6 | +110 |
| AsGa84N23 | Guard ring | ρ- < 1E08 |
| AsGa84N23 | Ring1-Pad4 | ρ- < 1E08 |
| AsGa84N24 | Guard ring | +10 |
| AsGa84N24 | Ring1-Pad4 | +10 |
| AsGa84N24 | Ring12-Pad6 | +30 |

# α-spectra $^{241}$Am experimental setup.

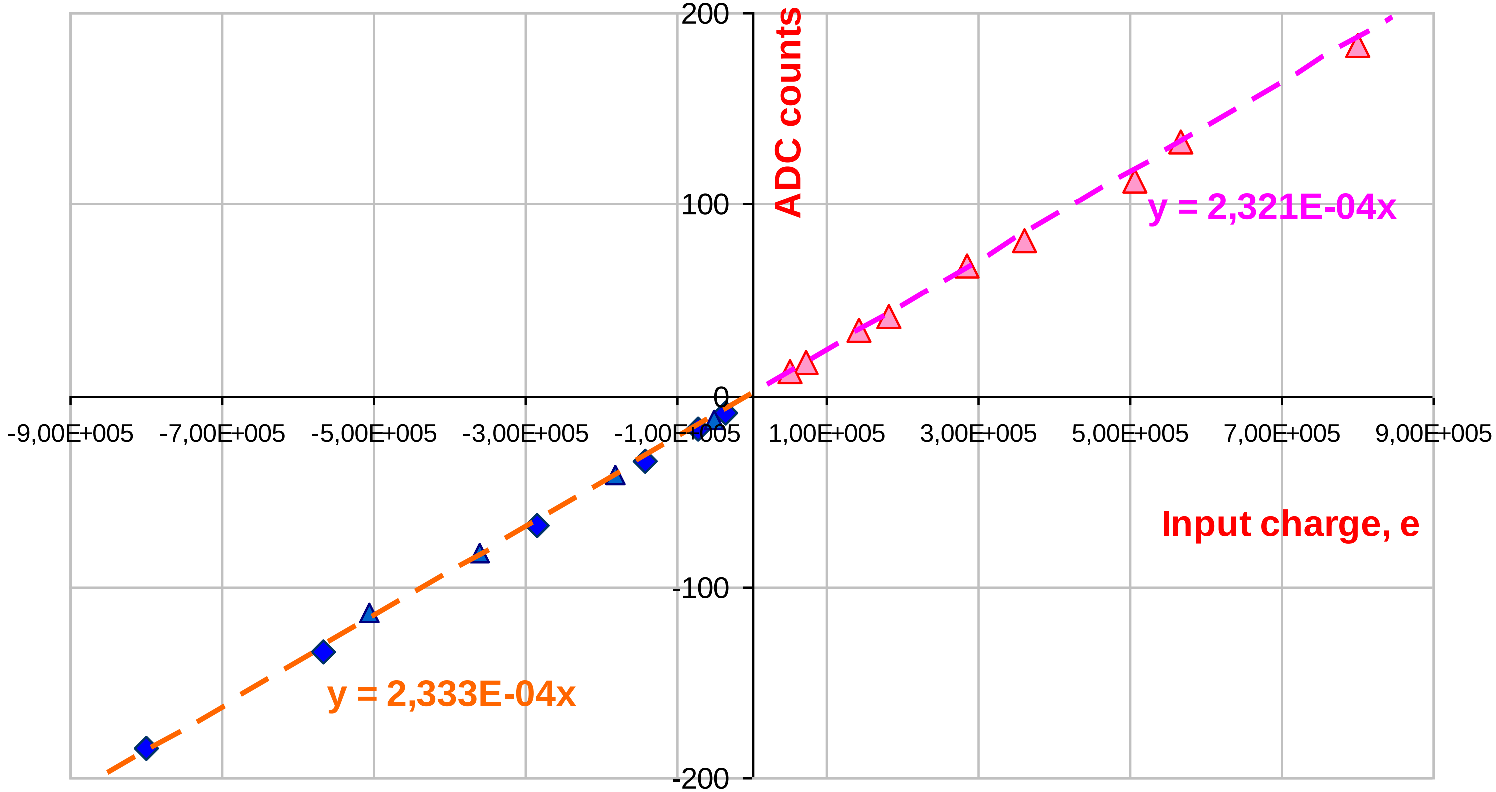



Sensor **AG84N13** has several bonded pads, Ring 12 Pad 3 was connected for measurement.

# α-spectra of $^{241}$Am experimental setup.



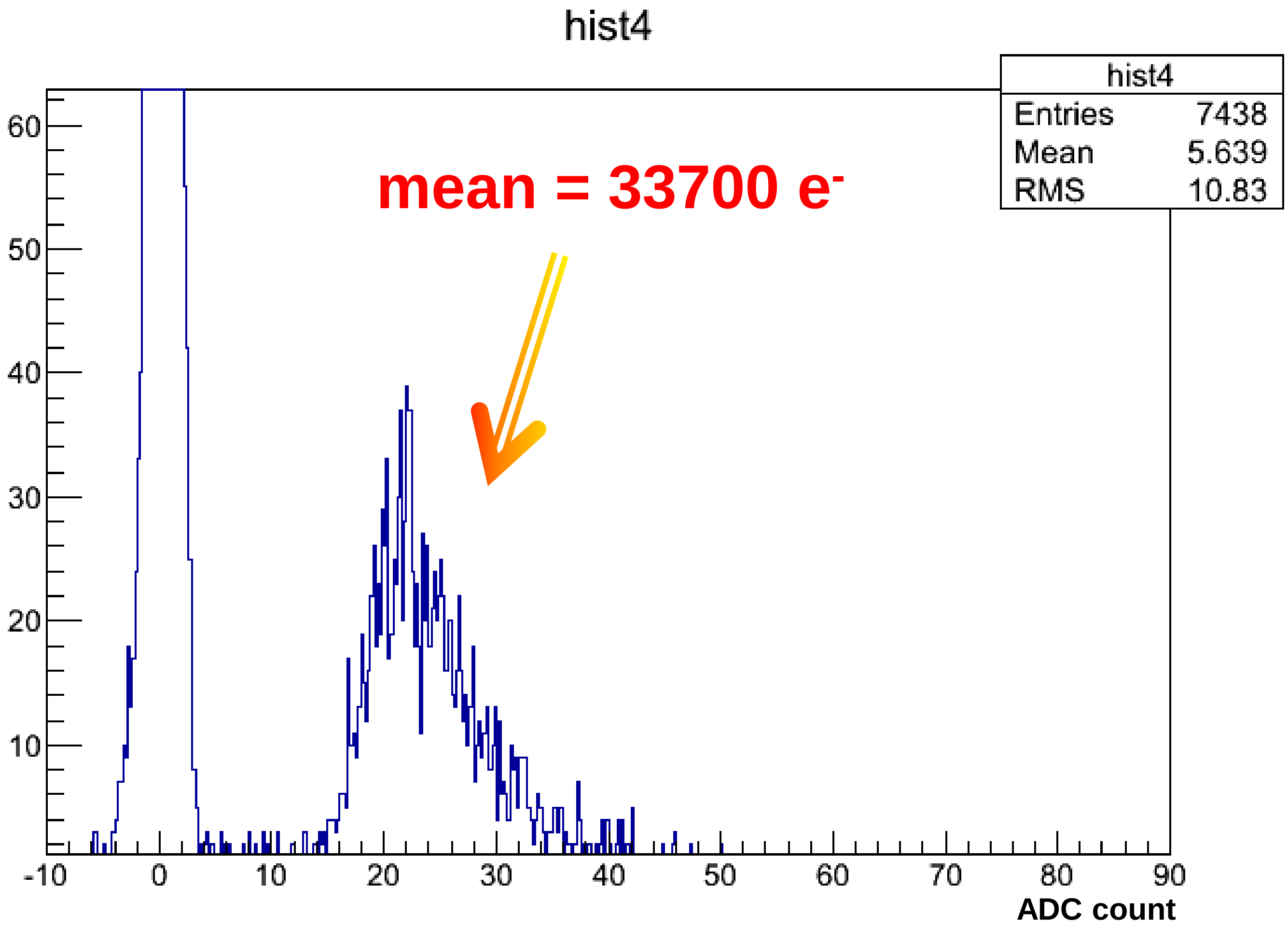
# Amplifier & readout calibration.




**For both positive and negative signal polarity calibration gives same value:**

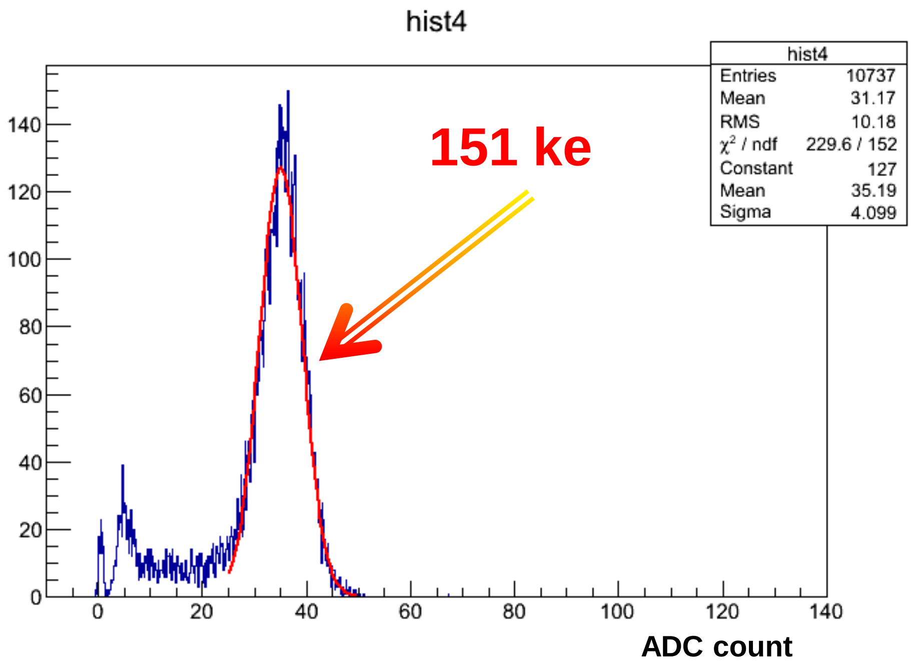
**1count = 4,29E03 $e^-$**

# MIP -spectrum of $^{90}Sr$

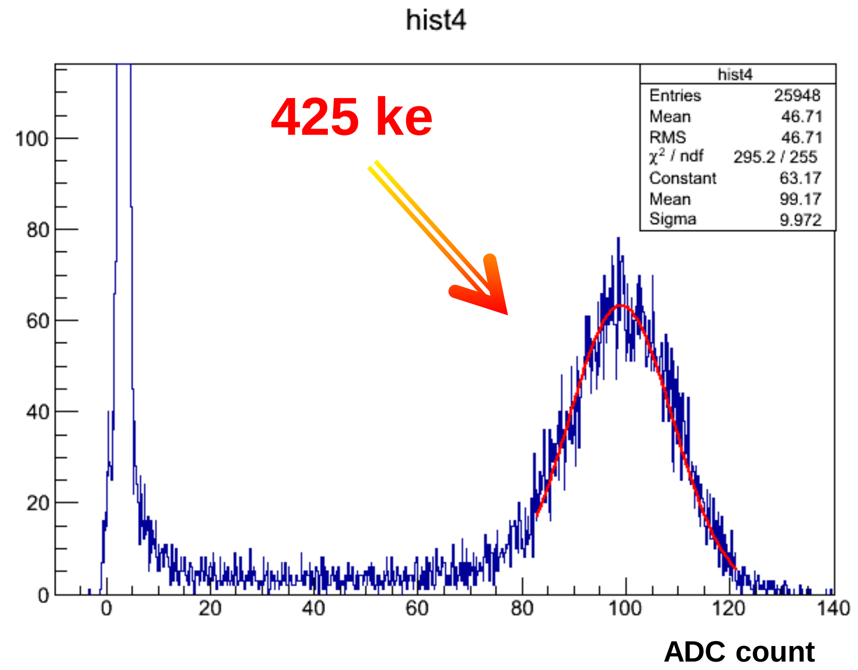



**Sr MIP measured with Vbias = -400V gives the signal 33700**
**MIP produces ~150 e/h pairs per 1um,**
**it corresponds CCE ~ 45% or 90 % for electron collection only.**

# α-spectra of $^{241}$Am



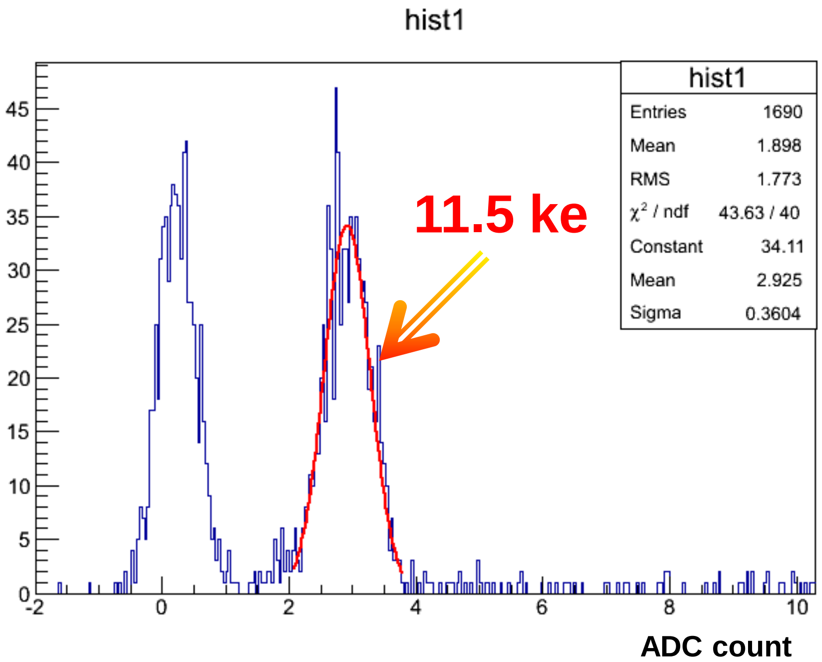

Vbias = -50V



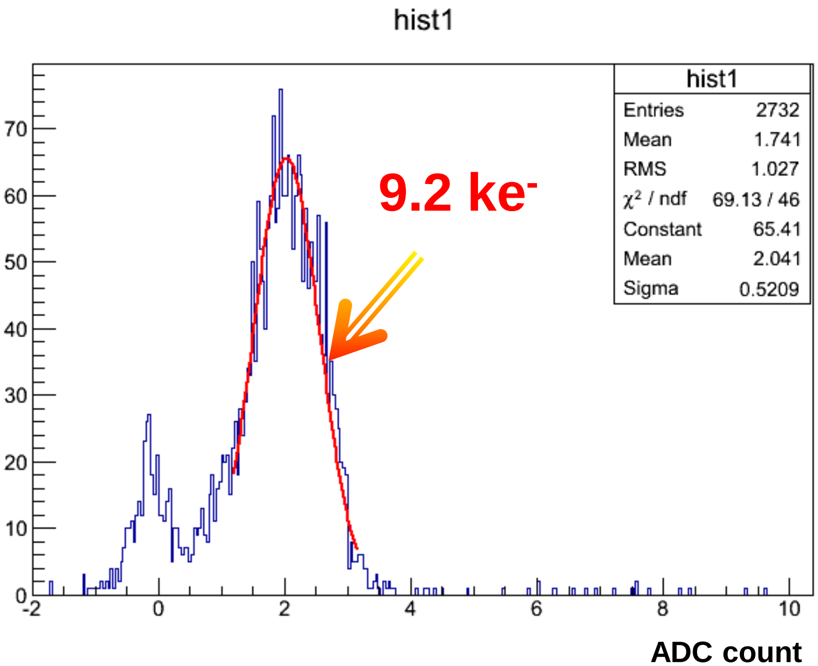

Vbias = -300V

Am from BP, Vth = 10mV, Gauss fit.
Signal from α is rising with $V_{bias}$, but Signal/Sigma rate is not so critical: 8.8 for -50V, 9.9 for -300V.

# α-spectra of $^{241}$Am




**Vbias = -400V**

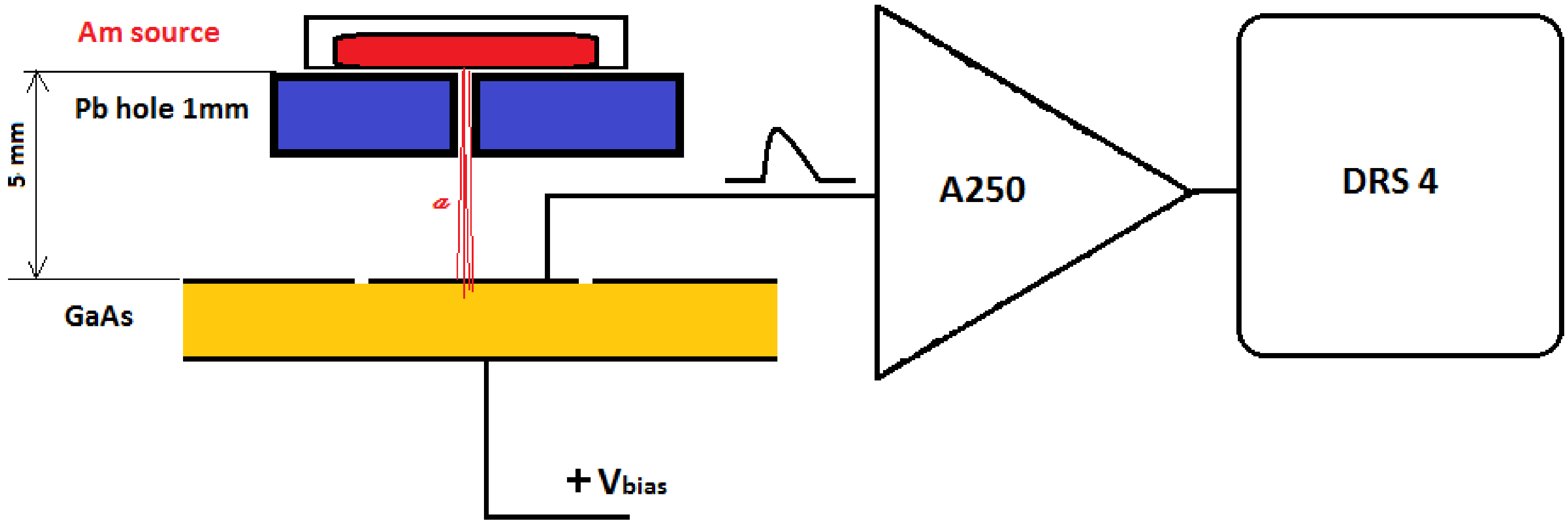



**Vbias = +300V**

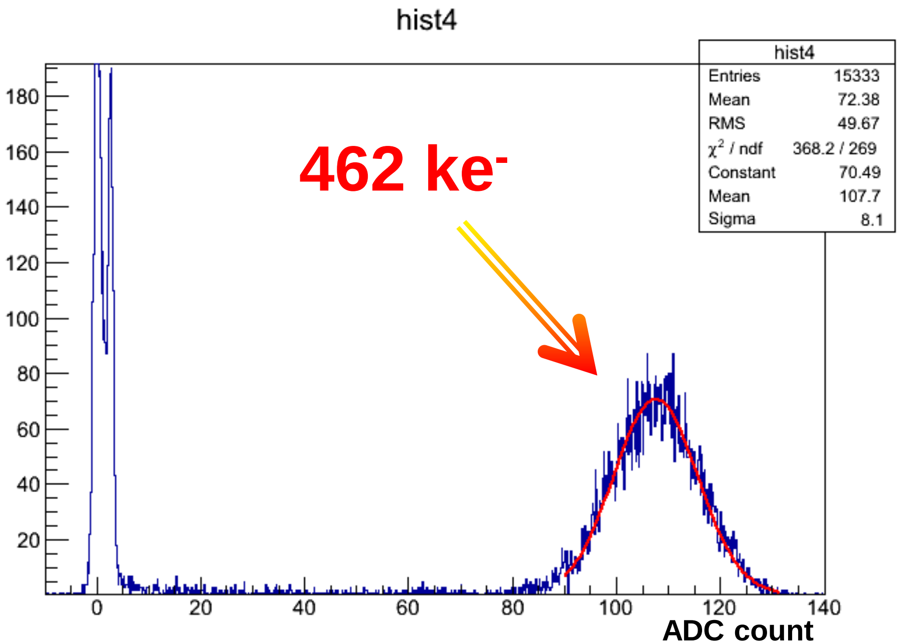
Am source closed by the 50um Cu foil to kill alpha. All big signals escaped and rate dropped from 300Hz to ~2Hz. About 12ke signal may be part of Am 60keV.

Reversing Vbias = +300V gives only 9.8 ke signal mean and rate dropped from 300Hz to ~6 Hz.
It proves only electron charge collection for GaAs:Cr.

# α-spectra of $^{241}$Am from Pad.

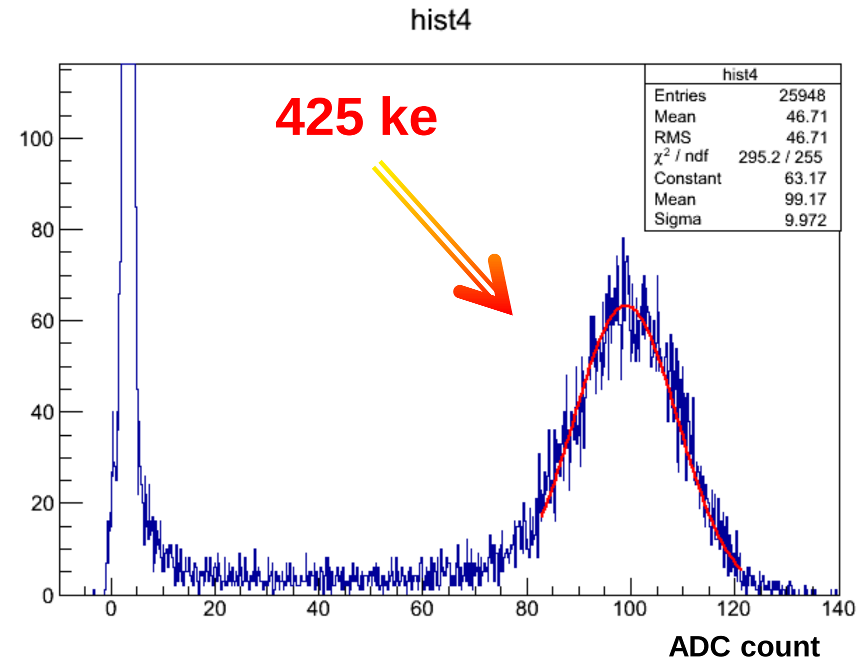


# α-spectra of $^{241}$Am




**Vbias = +300V**

**Am from Pad**

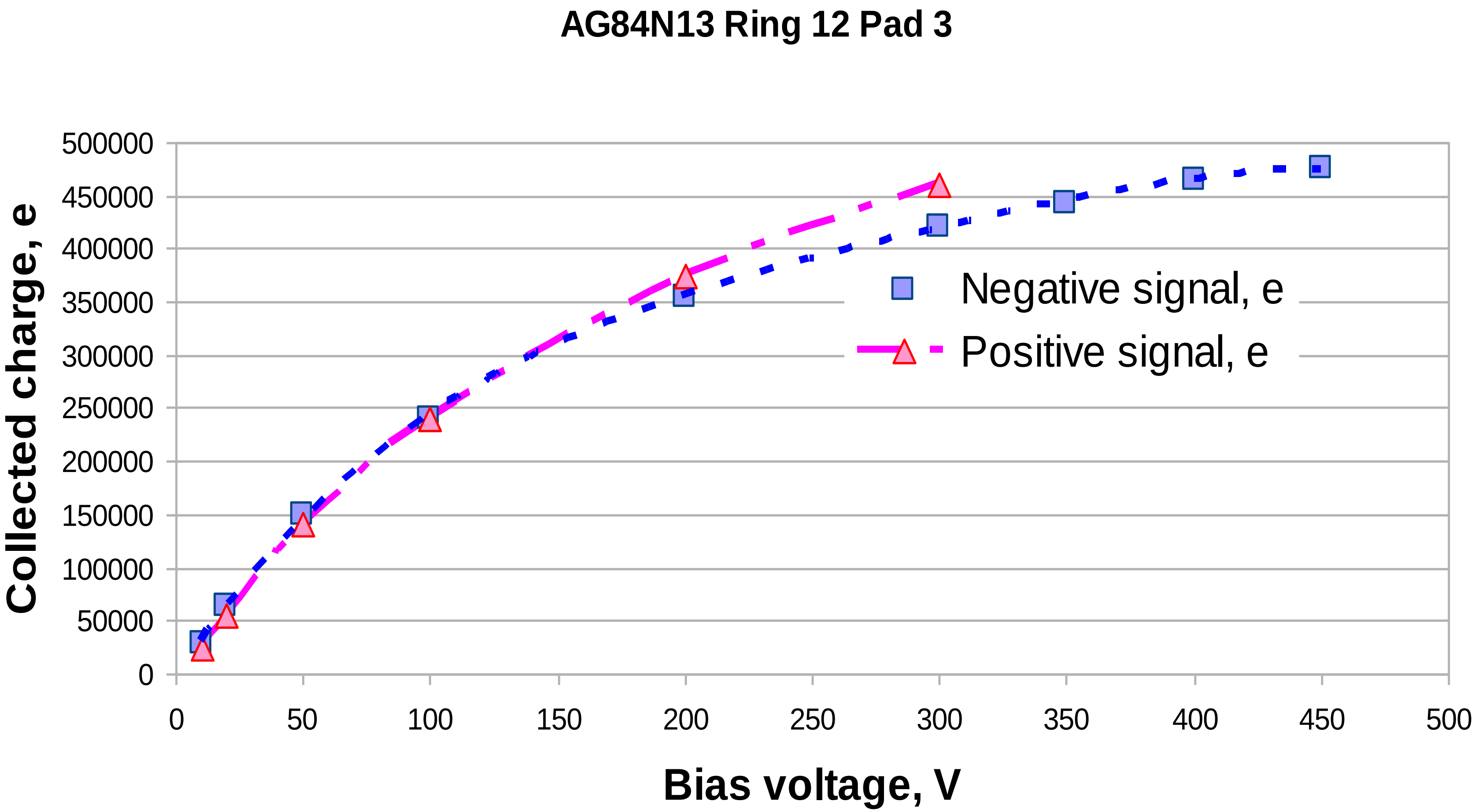



**Vbias = -300V**

**Am from BP**

When **α** comes from pad, the signal a bit higher(8% for $\mathbf{V_{bias}}$=300V),
Also signal/noise ratio is better : 13 vs 10.
This can be explained by the fact that the distance from the source to the pad was in the first case 5mm, the second 10 mm.

# α-spectra of $^{241}$Am charge collection vs $V_{bias}$




Charge collection was measured at different $\mathbf{V_{bias}}$ up to 1V/um. There is a tendency to saturation.

For the positive $\mathbf{V_{bias}}$ is limited to 310V due to noise.

# Summary

**DESY's experimental set-up has been applied for measurement of I/V and temperature dependence of GaAs sector sensors (I-V, ρ, $\varphi_{Bn}$ )**

## The results are:

- ✓ **I-V of 11 new sensors was measured**
- ✓ **I-V behavior is well consistent with previous results and theoretical calculations.**
- ✓ **The resistivity and the barrier heigh on the border metal-semiinsulating GaAs was measured for all pads.**
- ✓ **Together with previous measurements now all 22 sector size sensors are certified:**
  - **14 were recognized as completely good,**
  - **for all pad ρ>10e9 GOhm*cm, $0.8V < \phi_{Bn} < 0.9$ V.**
  - **7 has defects the current exceed the limit for one polarity in Guard ring and one pad. 1 sensor has GR resistivity ~ 10e08 for negative polarity.**
- ✓ **α-spectra of $^{241}$Am were measured for different Bias voltages, polarity, geometry.**
- ✓ **only electron charge collection approved.**
- ✓ **collected charge slightly depends on the bias voltage polarity, but strongly depends on ist value and the interaction depth in the detector.**

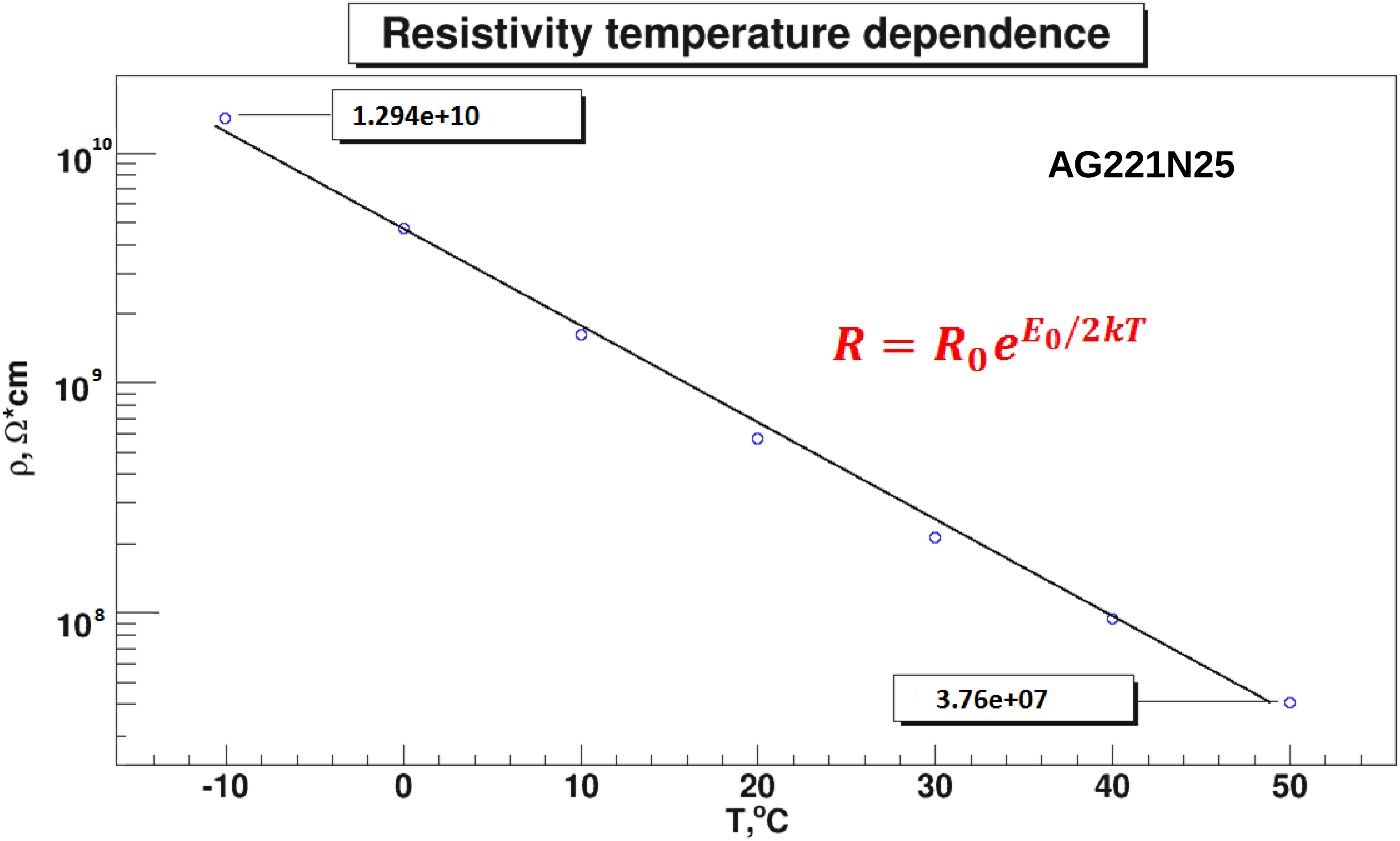
## We have all 22 sensors tested.

# *References*

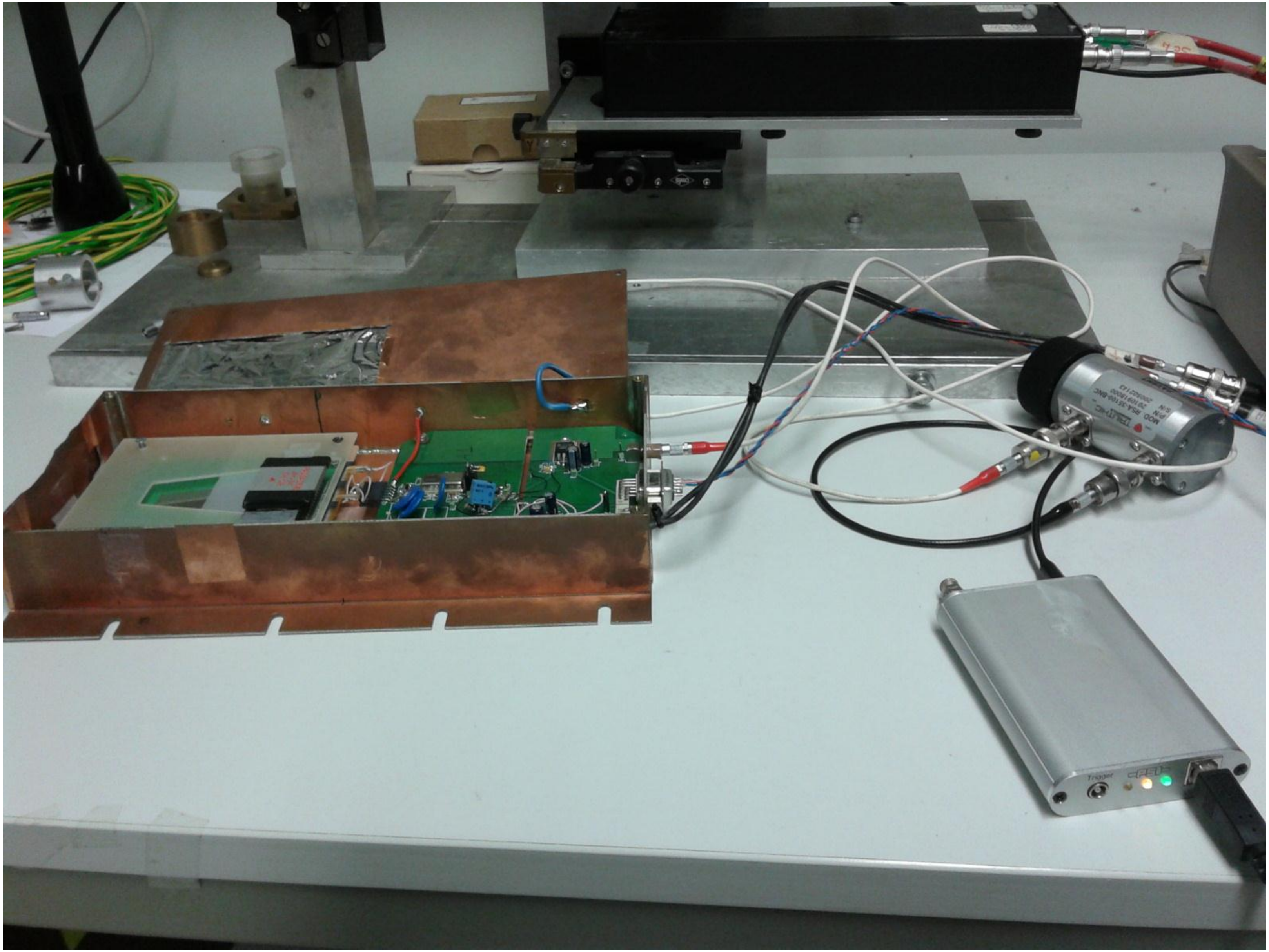

1. **Measurement of the barrier height on border of metal–semiinsulating gallium arsenide.** *G.I. Ayzenshtat, M.A. Lelekov, O.P. Tolbanov. Физика и техника полупроводников , 2007, том 41, вып. 11*
2. **Current transport in gallium arsenide detector compensated by chromium**
   *G.I. Ayzenshtat, M.A. Lelekov, V.A. Novikov, L.S. Okaevitch, O.P. Tolbanov. Физика и техника полупроводников , 2007, том 41, вып.5*

# Backup slides

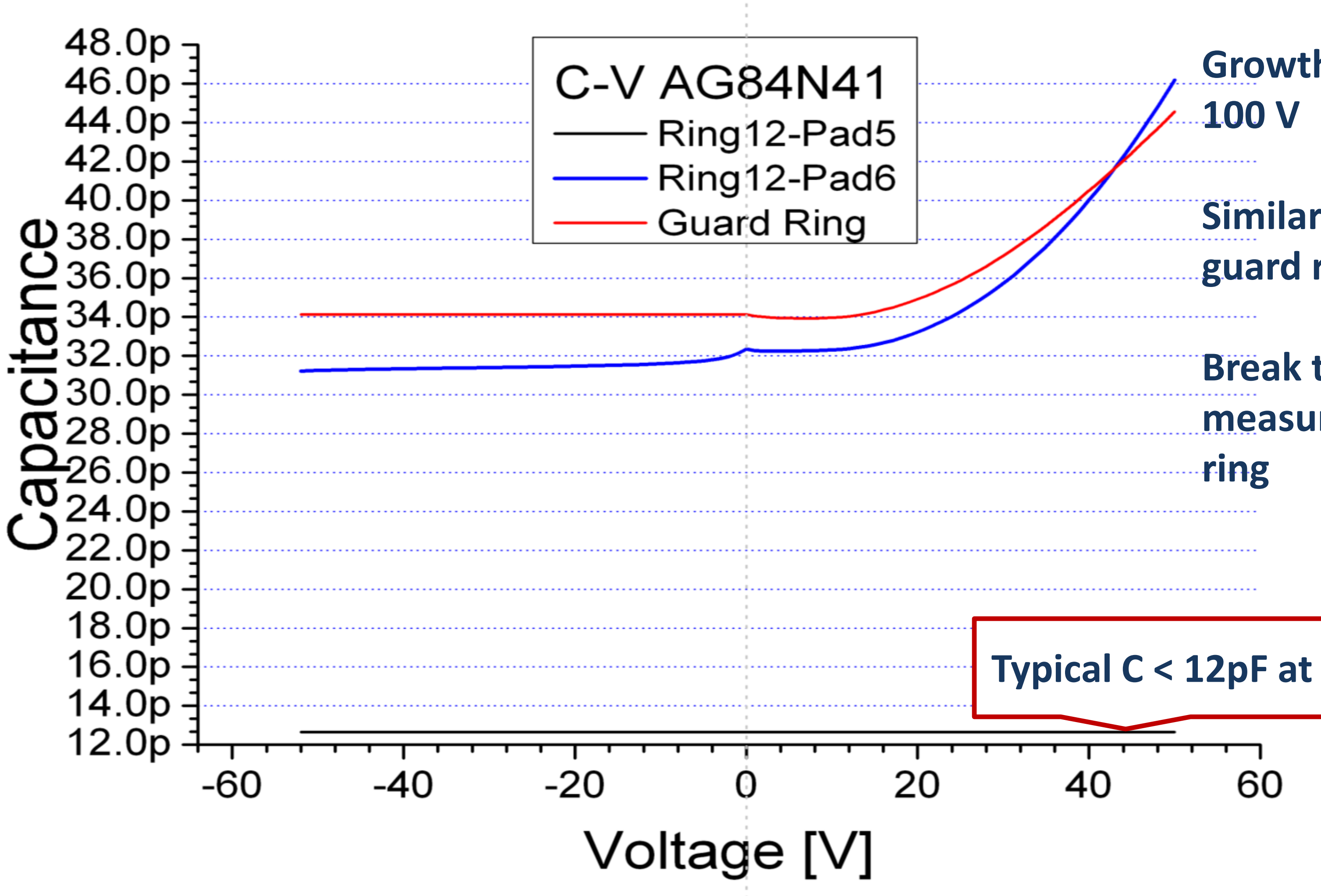
# Temperature dependence of the resistivity



# α-spectra of $^{241}$Am experimental setup.



# Unusual pad, unusual guardring and normal pad C-V



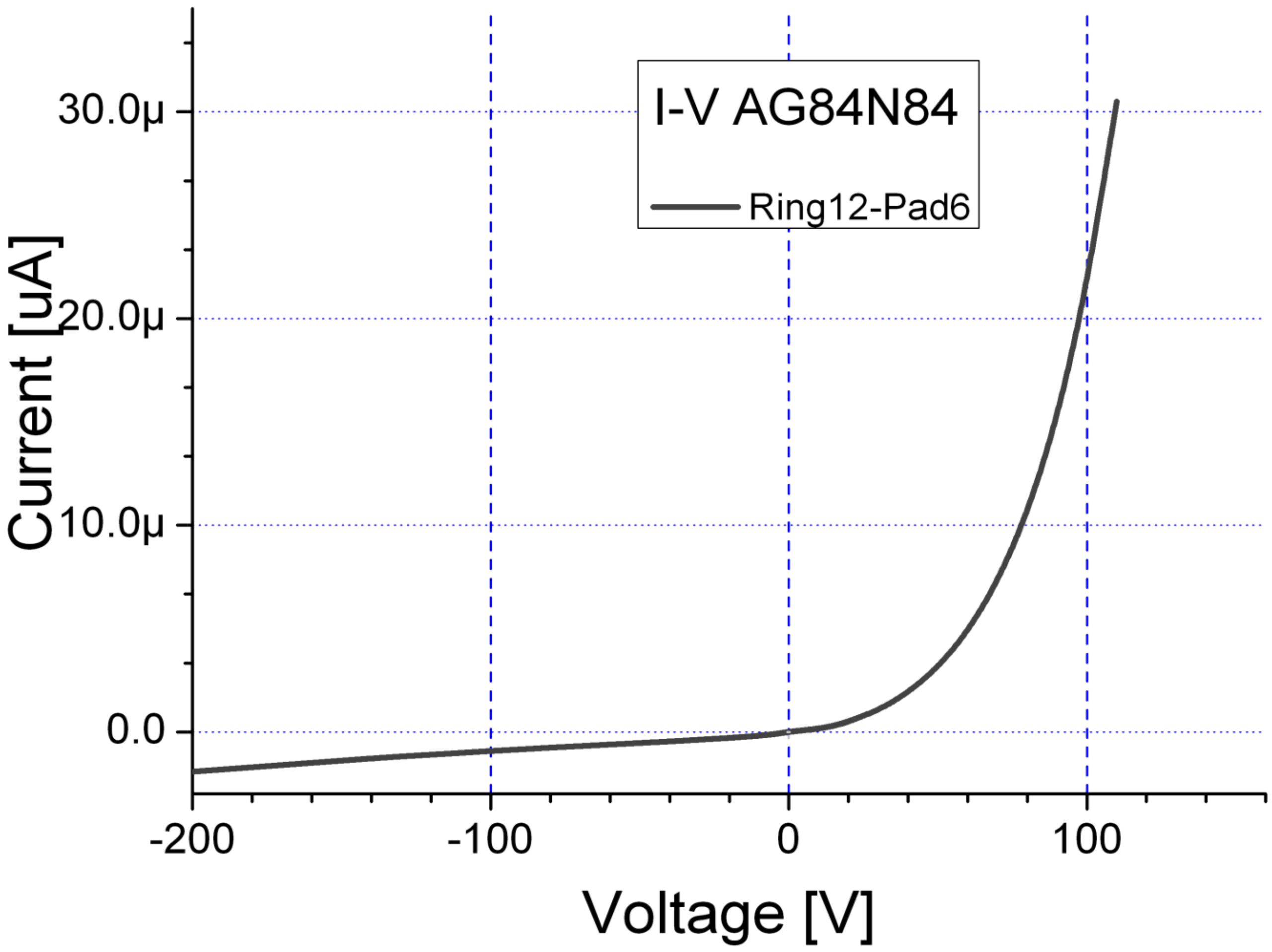

Growth up to 110pF at 100 V

Similar behavior with guard ring

Break through while measuring with guard ring

Typical C < 12pF at 10kHz

# Unusual pad I-V




**Growth up for positive Vbias**

**Normal behavior in negative area**

**Similar behavior with guard ring**

# Average resistivity and barrier height of 11 sensors

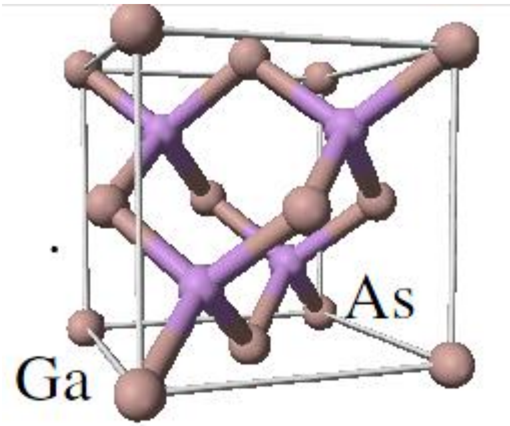
| № | Detector | thickness, um | Resistivity, Ohm*cm | | Darrier height, volts | |
|---|---|---|---|---|---|---|
| | | | $\rho^+$ | $\rho^-$ | $\varphi^+$ | $\varphi^-$ |
| 1 | AG-84 №13 | 498 | Not processed | Not processed | Not processed | Not processed |
| 2 | AG 84 № 26 | 502 | 1.20E9 | 1.10E9 | 0.75 | 0.74 |
| 3 | AG 84 № 7 | 490 | 2.25E9 | 2.18E9 | 0.78 | 0.79 |
| 4 | AG 84 № 19 | 495 | 3.00E9 | 2.79E9 | 0.78 | 0.78 |
| 5 | AG 84 № 21 | 492 | 2.42E9 | 2.37E9 | 0.76 | 0.76 |
| 6 | AG 84 № 32 | 502 | 3.20E9 | 3.04E9 | 0.78 | 0.77 |
| 7 | AG 84 № 39 | 495 | 3.71E9 | 3.48E9 | 0.79 | 0.76 |
| 8 | AG 84 № 41 | 487 | 4.07E9 | 3.84E9 | 0.76 | 0.75 |
| 9 | AG 84 № 29 | 487 | 3.67E9 | 3.23E9 | 0.78 | 0.81 |
| 10 | AG 84 № 28 | 500 | 2.09E9 | 1.92E9 | 0.76 | 0.77 |
| 11 | AG 221 №25 | 492 | 2.49E9 | 2.42E9 | 0.79 | 0.81 |

# Forward region of the ILC

**Beam calorimeter (BeamCal)** - monitor the beam parameters at the interaction point; adjacent to the beampipe.

**Luminosity detector (LumiCal)** – covers larger polar angles; luminometer of the detector.

**The gamma detector (GamCal)** – together with BeamCal, measures beamstrahlung photons, which are very collinear to the beam.




# Gallium arsenide (GaAs)

Compound semiconductor, direct bandgap
Two sublattices of face centered cubic lattice (zinc-blende type)

GaAs grown by Liquid Encapsulated Czochralski (LEC).
doped by Te or Sn (shallow donor) to fill EL2+ trapping centers.
Compensated by Cr (deep acceptor) to high-ohmic intrinsic material.
Compensation is temperature controlled

Semi-insulating - no p-n junction

Signal charge transport mainly by electrons

Structure provided by metallisation (similar to diamond)

| | |
|---|---|
| ❑ Density | 5.32 g/cm3 |
| ❑ Pair creation E | 4.3 eV/pair |
| ❑ **Band gap** | **1.42 eV** |
| ❑ **Electron mobility** | **8500 cm2/Vs** |
| ❑ Hole mobility | 400 cm2/Vs |
| ❑ Dielectric const. | 12.85 |
| ❑ Radiation length | 2.3 cm |
| ❑ Ave. Edep/100 µm (by 10 MeV e-) | 69.7 keV |
| ❑ Ave. pairs/100 µm | 13000 |
| ❑ Structure | p-n or insul |