



Progress in low energy X-ray spectroscopy using semi-insulating GaAs detectors

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Outline

- Introduction, motivation
- Readout electronics, Peltier cooling
- Input J-FETs and PA evaluation
- **SI GaAs detector for low energy X-rays**
- Current-voltage measurement
- Detection of X and γ -rays
- Summary, conclusion

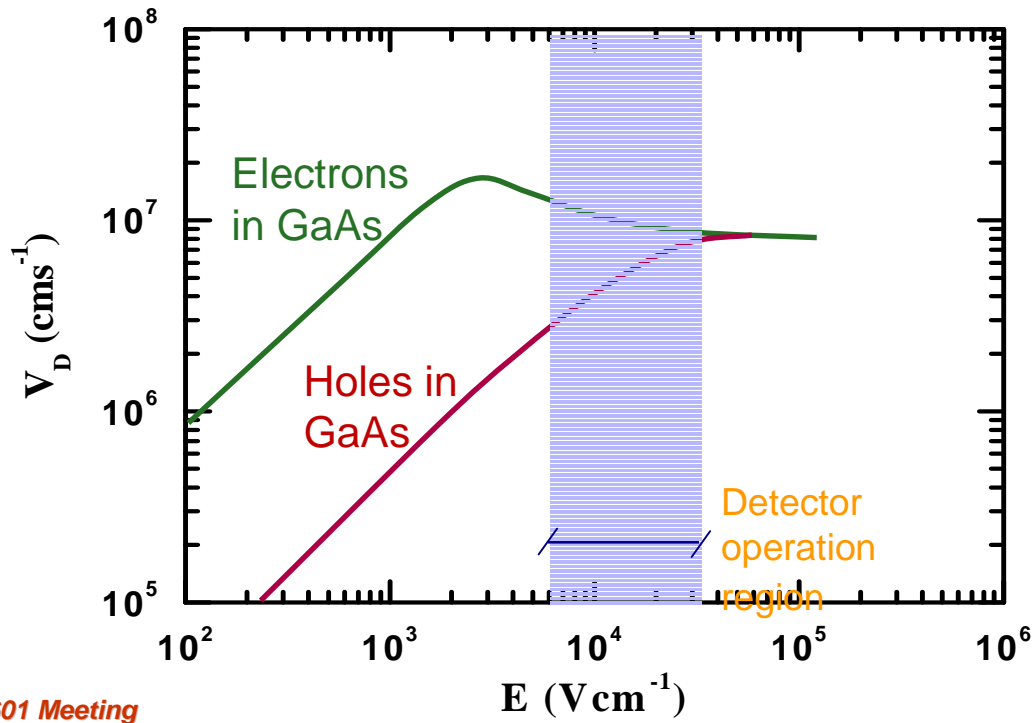
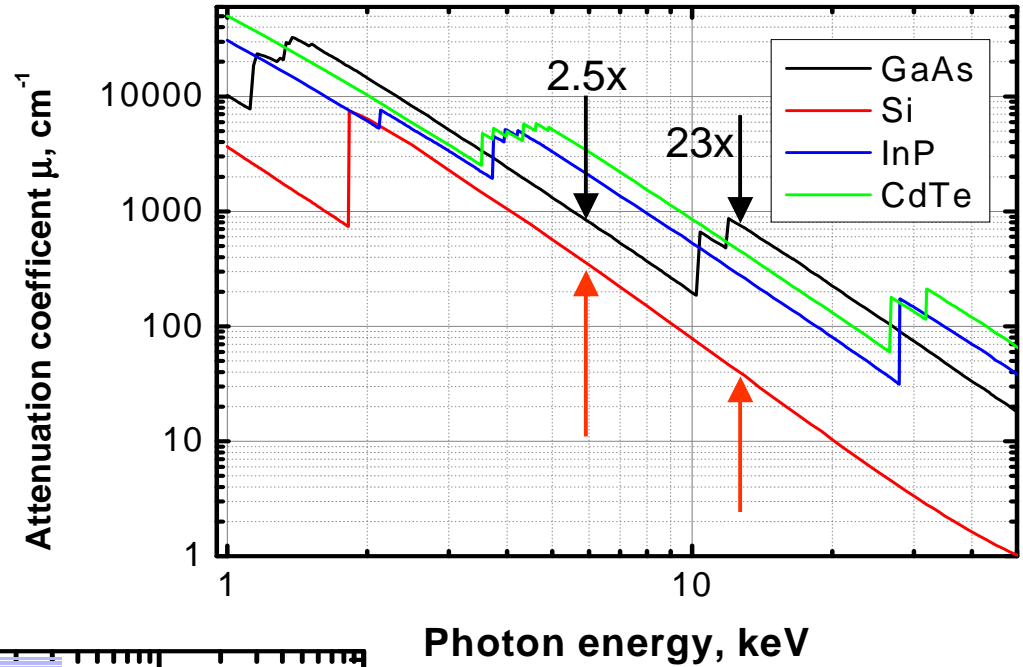
Introduction

Semi-insulating GaAs as a material of radiation detector

- Wide bandgap energy $E_g = 1.42$ eV
- Relative high atomic number 31 & 33: *efficient detection of X- and gamma rays*
- Fast reaction rate: *high drift mobility*
- High resistance to damage by irradiation
- **Drawback:** *high leakage current at RT for application in soft X-ray spectroscopy*

Motivation

- Energy gained from a fusion reaction could solve problem of energy
- Fusion has many attractive features in terms of safety, fuel reserves, and minimal damage to the environment
- The primary disadvantage being associated with difficult scientific and engineering challenges that are inherent in the fusion process
- ***Problem that must be solved: On-line hot plasma diagnostics***
- ***Application in detection of Extreme UV photons***



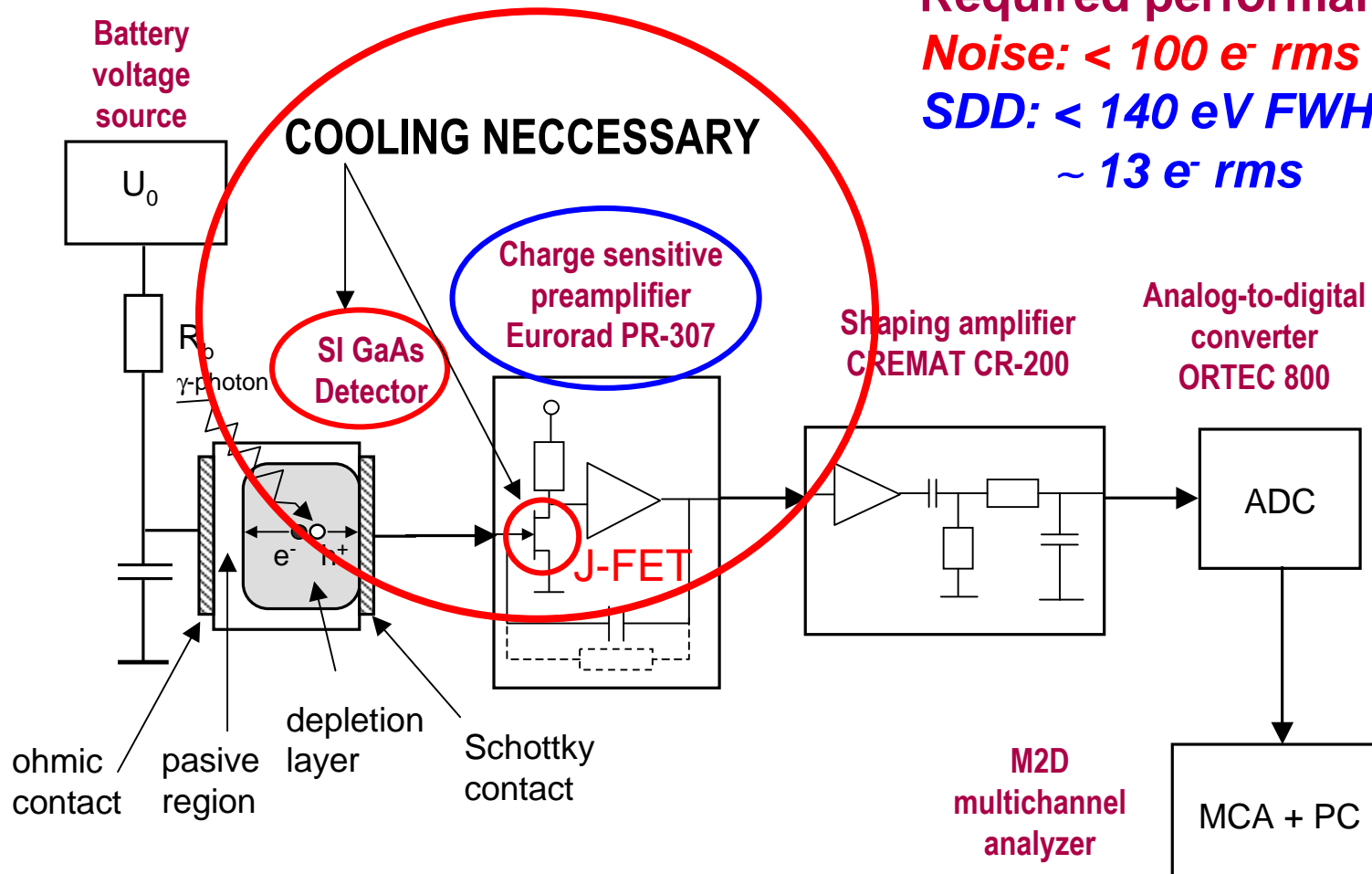
Measuring spectrometric system

Required performance:

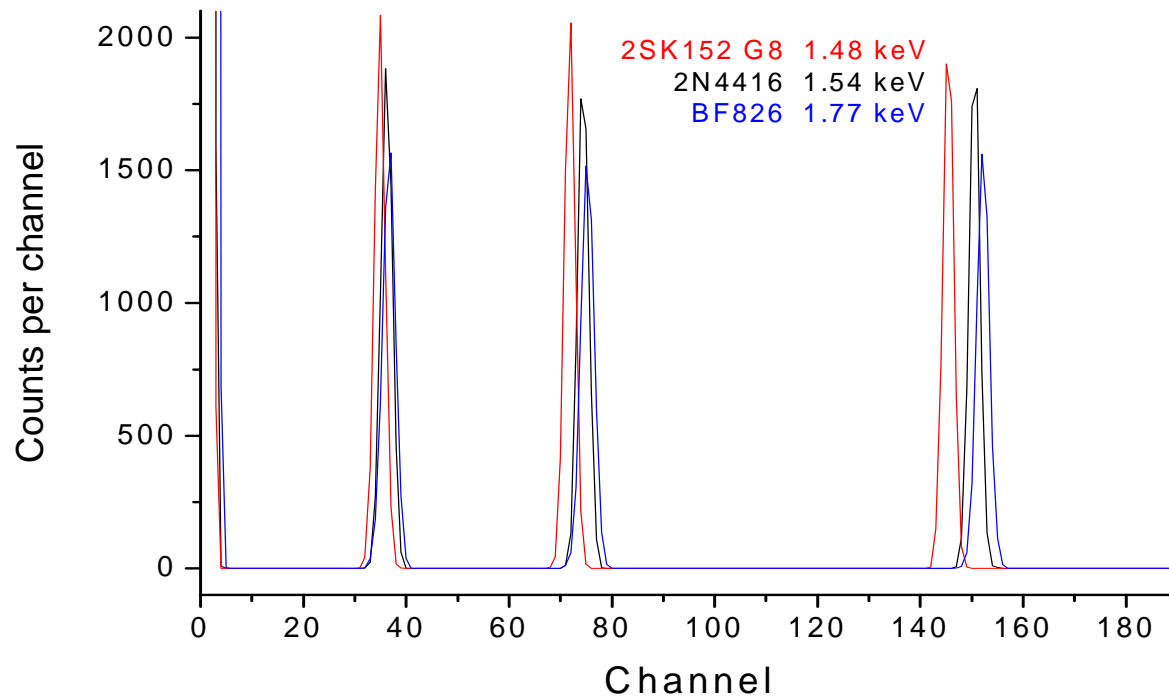
Noise: $< 100 e^- rms$

SDD: $< 140 eV FWHM$

$\sim 13 e^- rms$

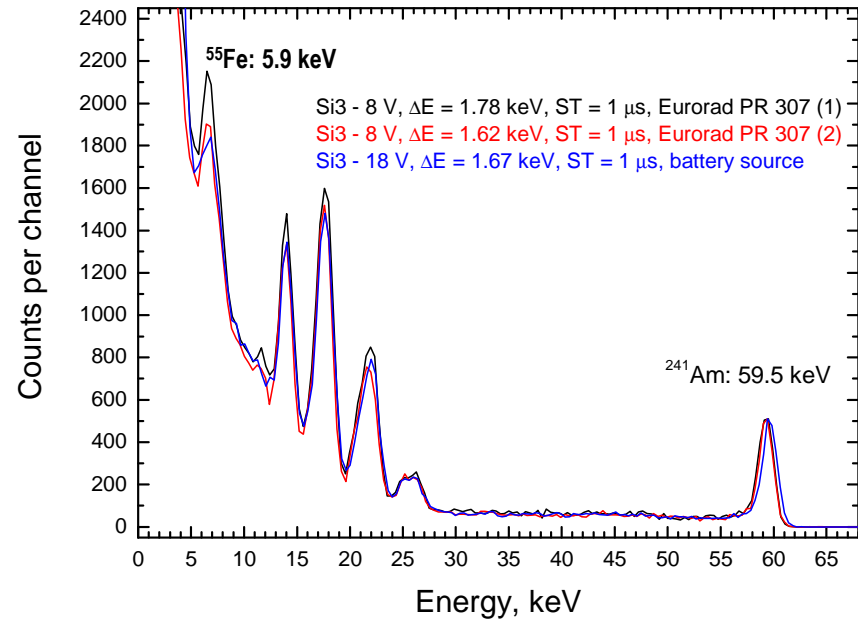
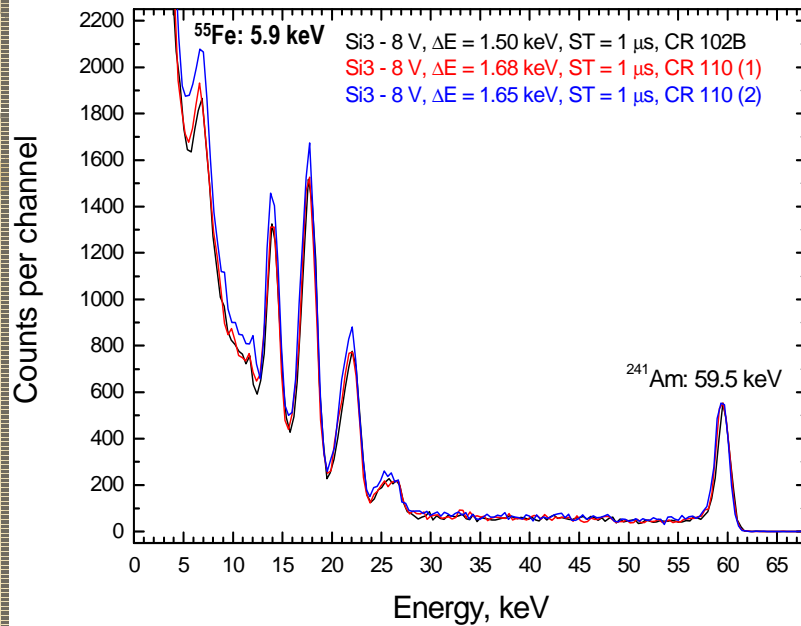


J-FETs evaluation



Transistor	Yfw, mS	Ciss, pF	Noise, nVHz-1/2	Package	Notice
● 2SK152	25	7,2	1,20	TO92	obsolete, SMD unavailable
● BF862	45	9	0,8	TO236, SOT23	Noise at 100 kHz, SMD
● 2N4416	6	2,20	6	TO72, TO236	SMD package available
MX-16	28	4	1	TO72	Chip available, Ciss at -4 V
MX-120	16	1,7	1,2	TO72	Chip available, Ciss at -4 V
NJ14AL	5,5	2,3	4	Chip	Chip
U310	17	5	10		SMD package available
SMPJ309	10	7,5	6		SMD package available
● SMPJ310	8	7,5	?		SMD package available

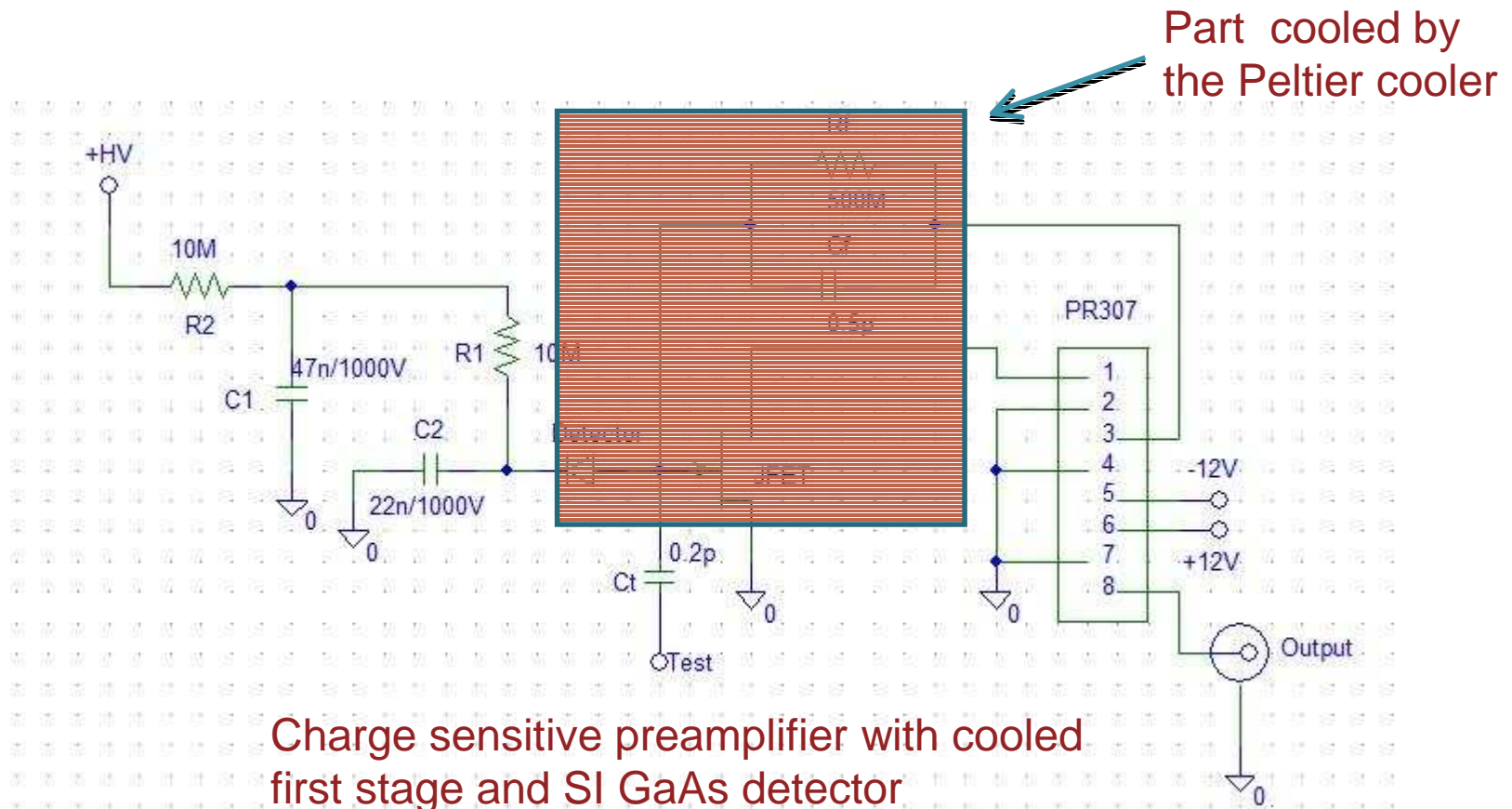
Preamplifiers testing and evaluation



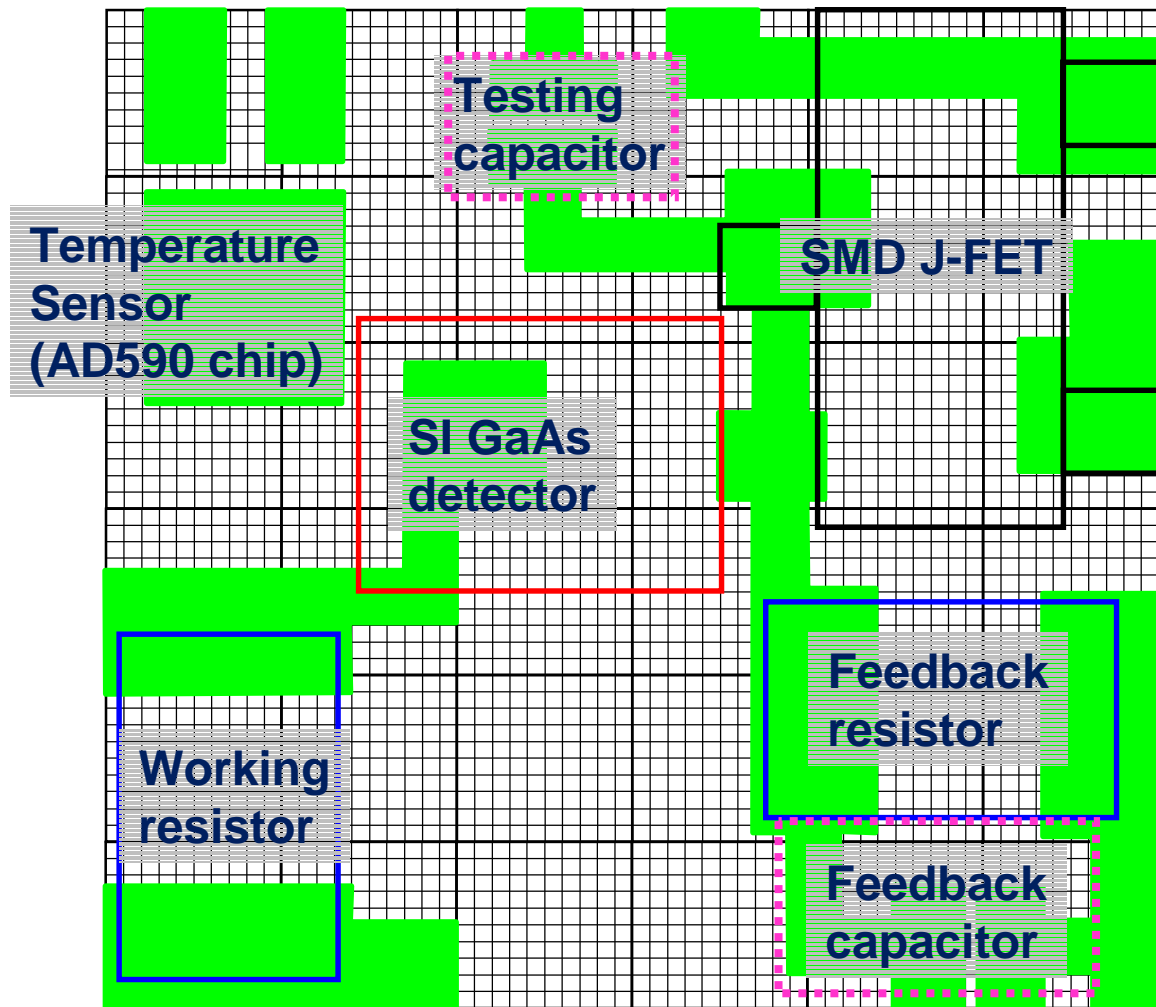
Hybride Preamp, separated FET			Noise FET dependent, @RT	
●	CR-110	CREMAT	1.5 keV	
●	CR-102B	CREMAT, obsolete	1.2 keV	
●	PR307	EURORAD	0.85 keV	
	A-250	AMPTEC	1 keV	
*	ASICS	various	< 300 eV	

e.g. Bertuccio, G., Caccia, S., NIM A 579 (2007) 243

Blocking scheme of developed charge sensitive preamplifier



Cooled stage – detailed layout



Substrate < 200 μm :

Al_2O_3

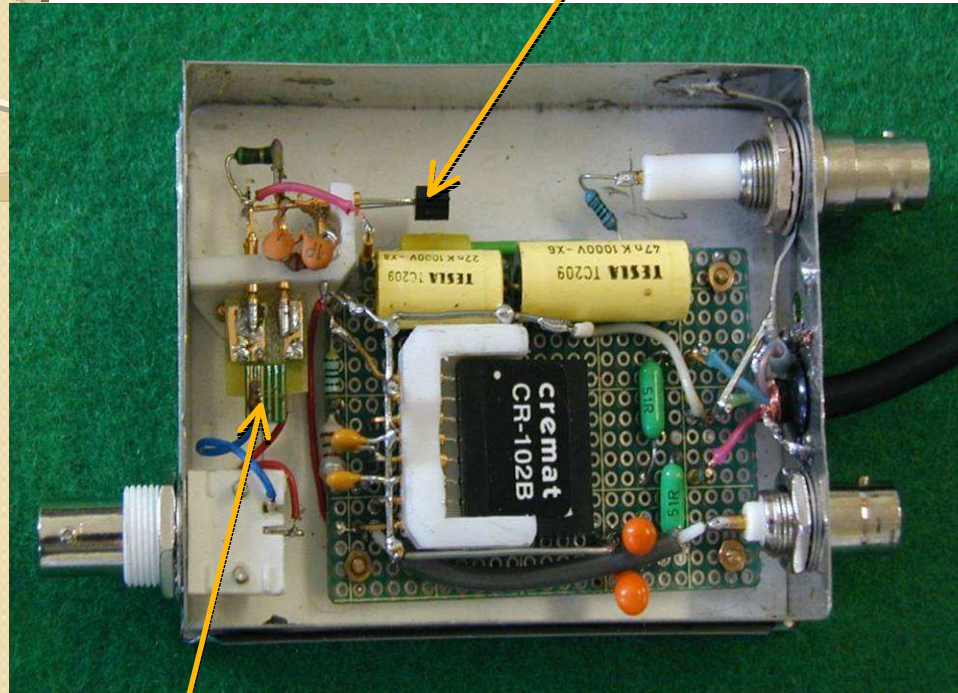
AlN

Be-based ceramic

~ 6x6 mm²

Developed low noise preamplifiers

Input J-FET



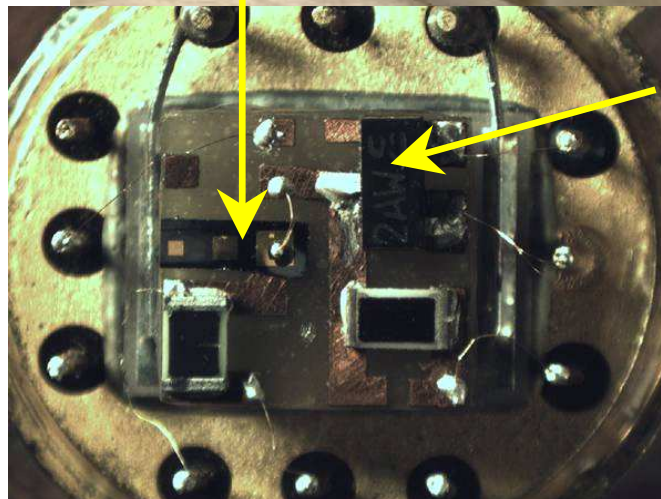
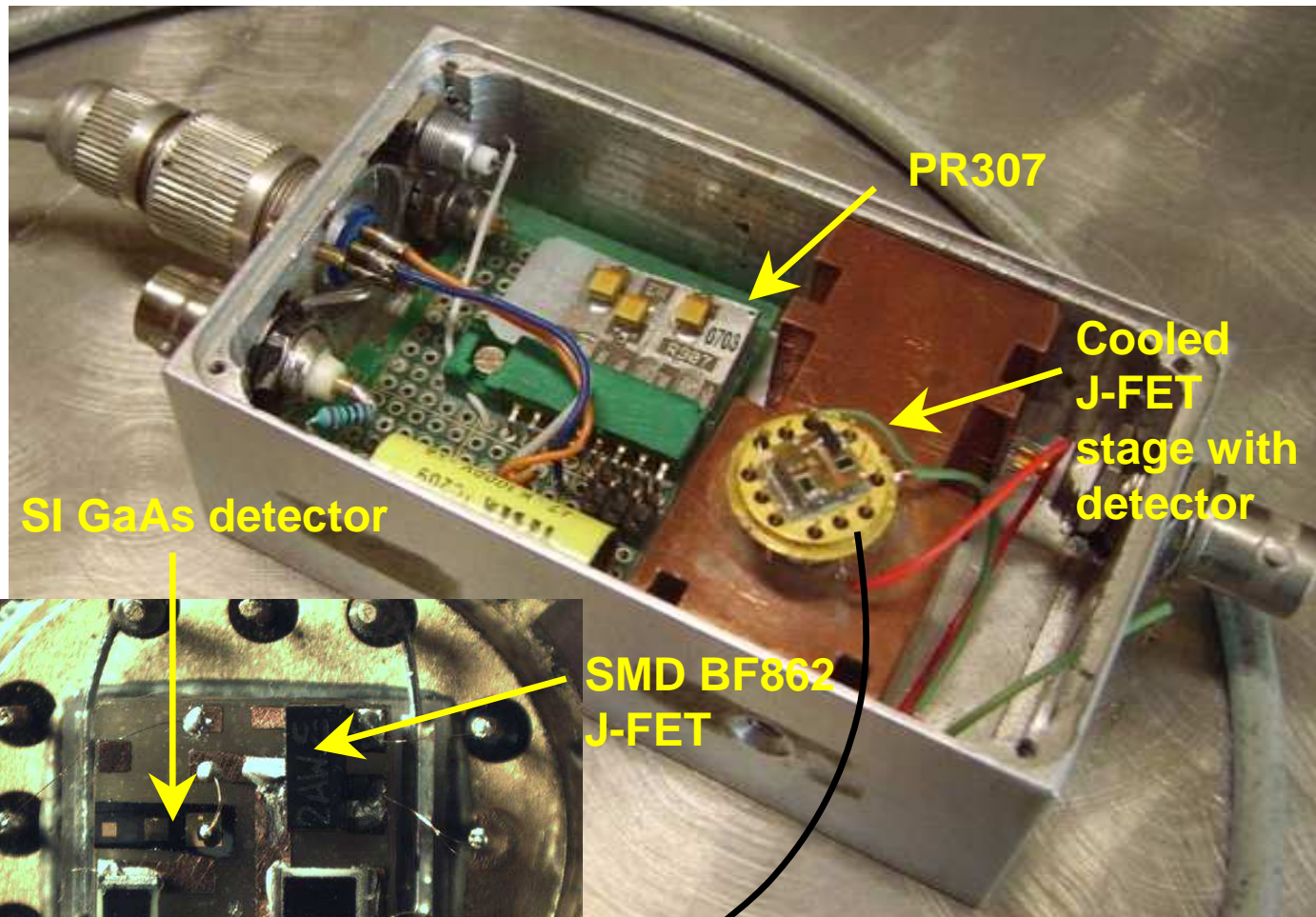
Detector

Charge sensitive preamplifier based on CR-102B hybrid circuit and external input J-FET 2SK152

Noise: 135 e⁻ rms at RT

SI GaAs detector is directly coupled to the input of the charge sensitive preamplifier

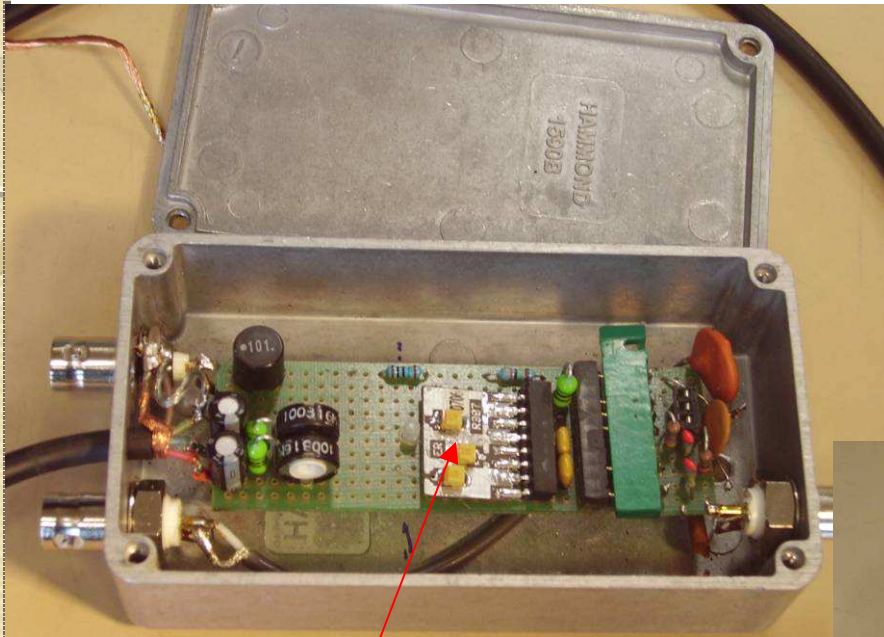
Charge sensitive preamplifier with Peltier cooler



New solution: 3 stage Peltier cooler

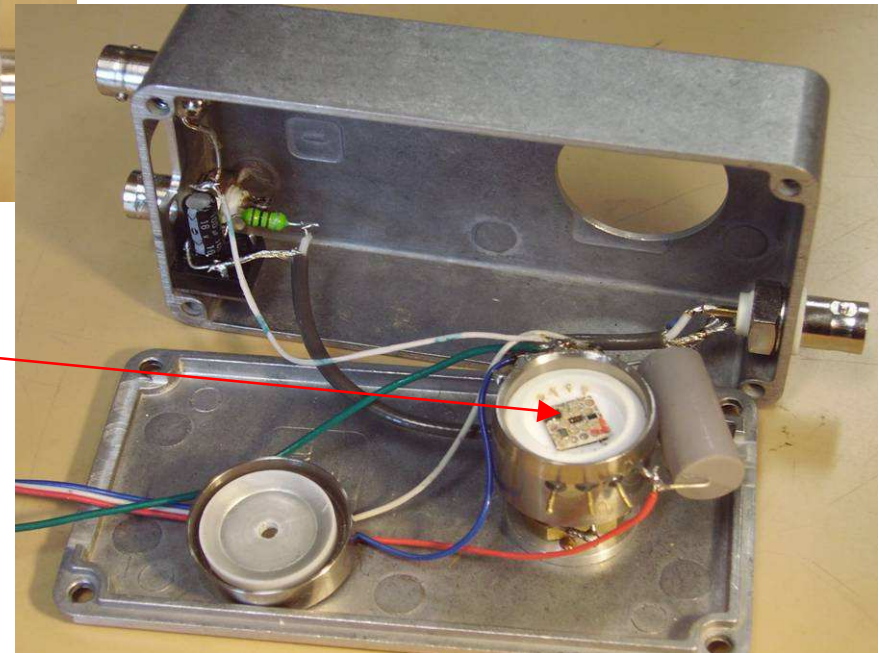
Additional tasks necessary to solve:

- *input thin window with a low absorption*
- *collimator*
- *micro-temperature sensor*
- *efficient cooling of the heat sink*
- *compact bias source*
- *improvement of detector radiation and neutron damage resistance*

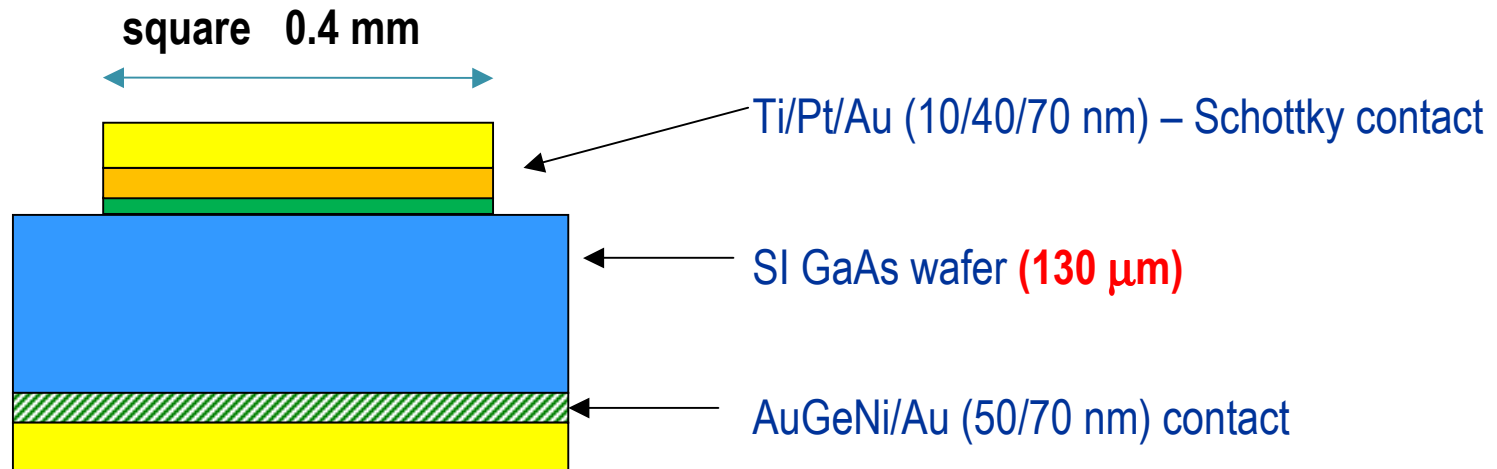


PR-307

**CERAMIC SUPPORT
with detector and J-FET**

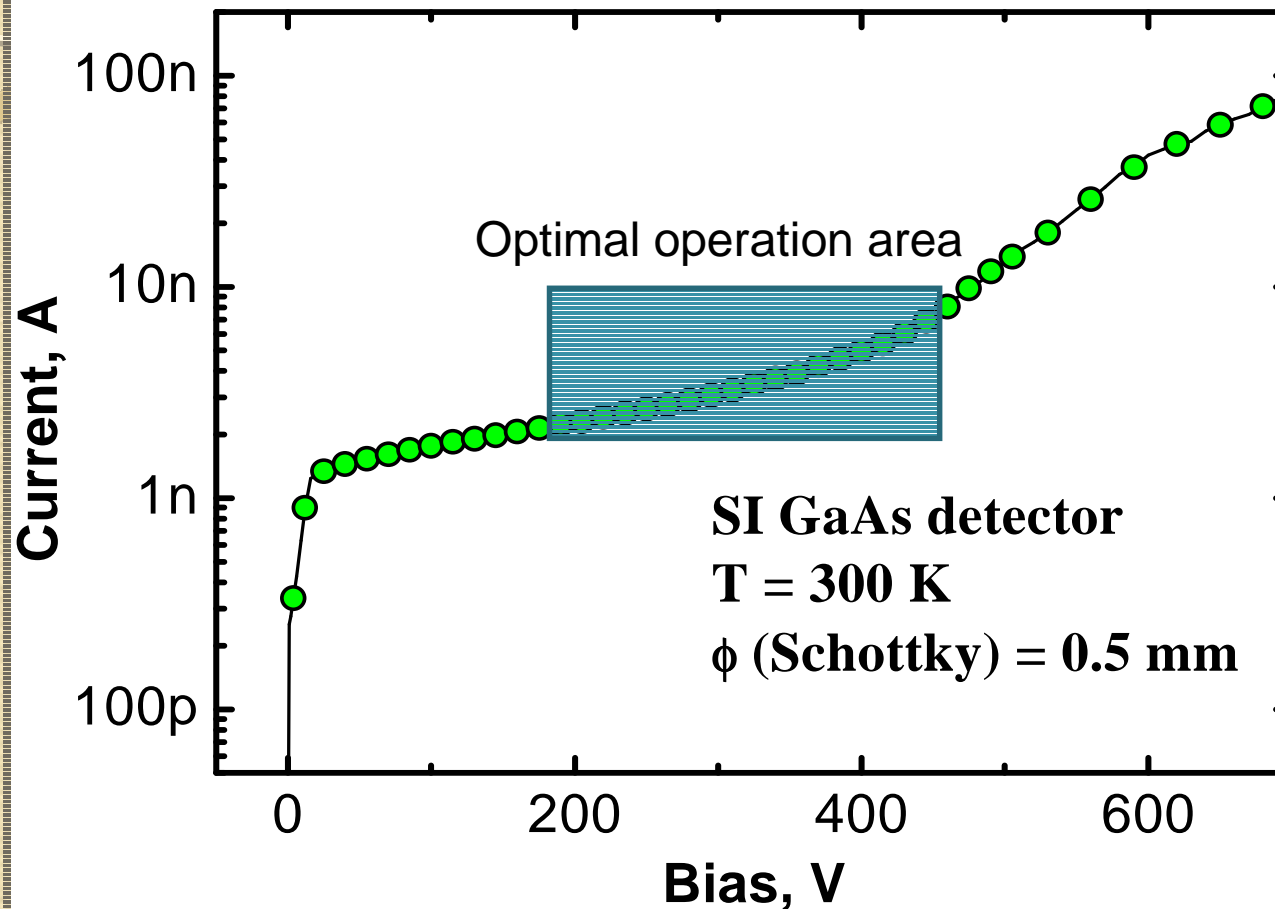


Simple SI GaAs detector for low energy X-rays



- bulk VGF SI GaAs wafer (100) - „*detector grade*“
- producer: *CMK Ltd. Žarovica, Slovakia*
- RT resistivity: $1.8 \times 10^7 \Omega\text{cm}$
- RT Hall mobility: $7060 \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$

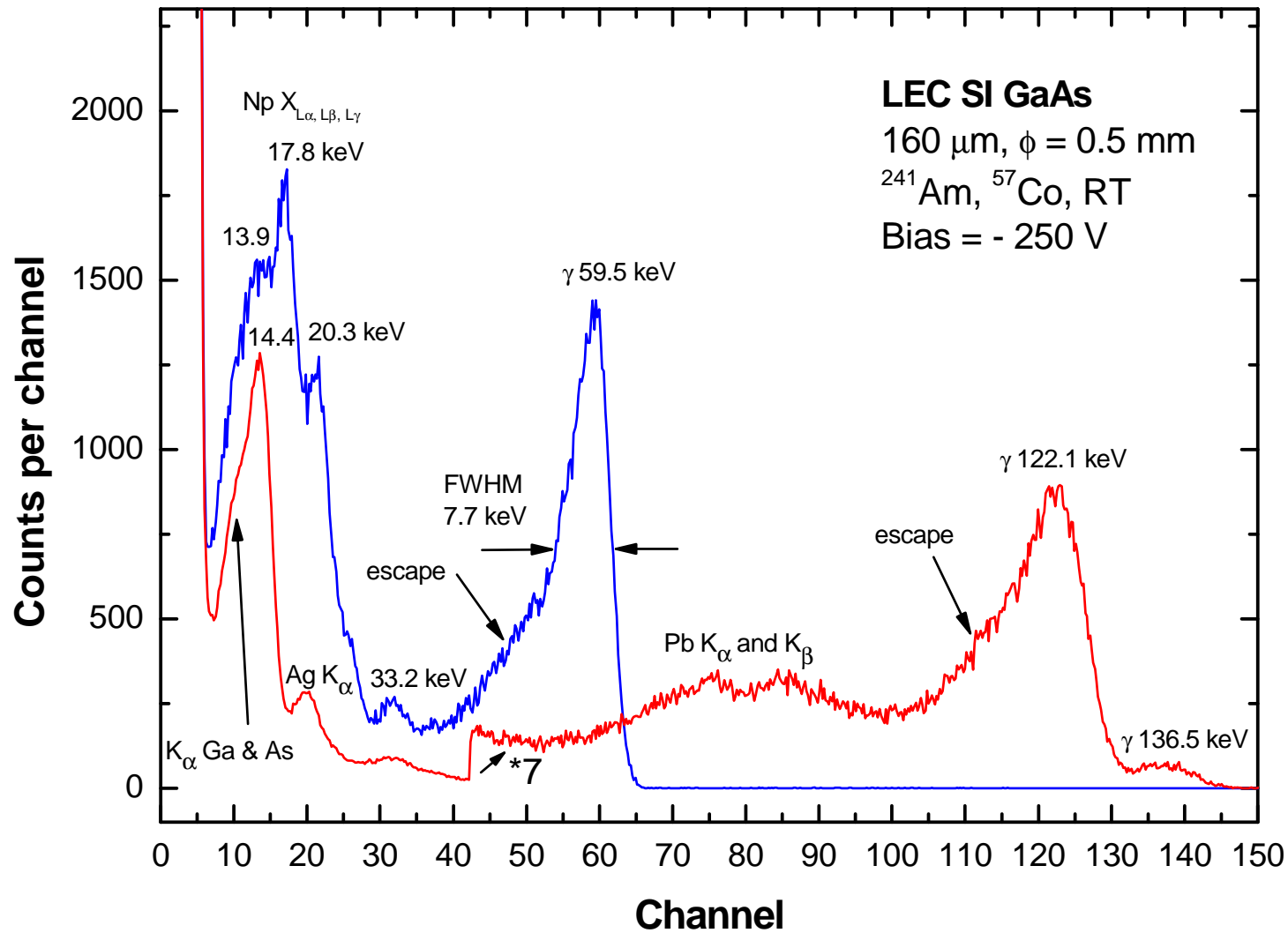
Current-voltage characteristic of SI GaAs detector @ RT



DC current decrease:
*10× with each 20 deg.
of temperature lowering:*
e.g. @ 260 K $I_{sat} \approx 10$ pA

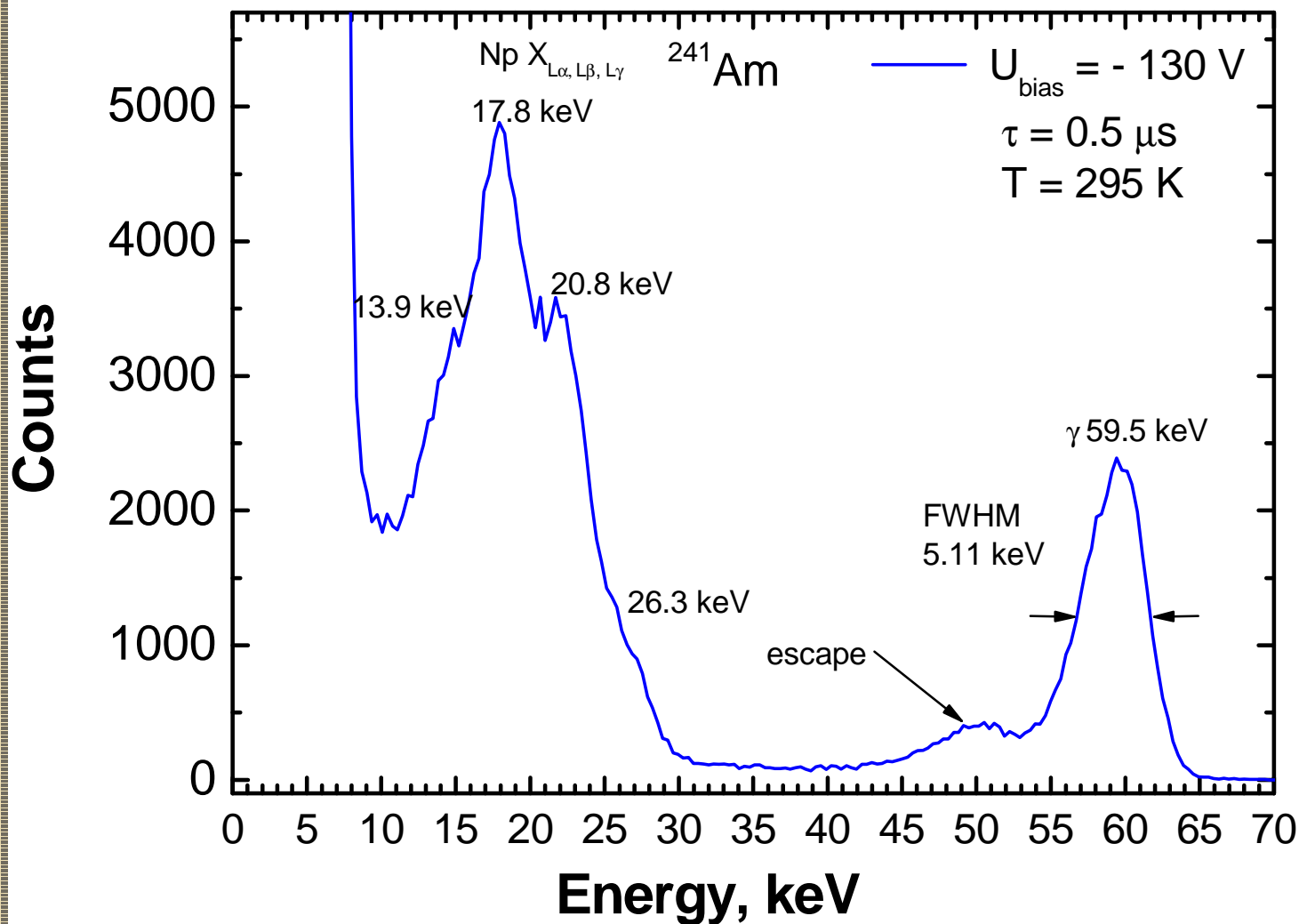
Detection of X- and γ -rays: @ RT

160 μm

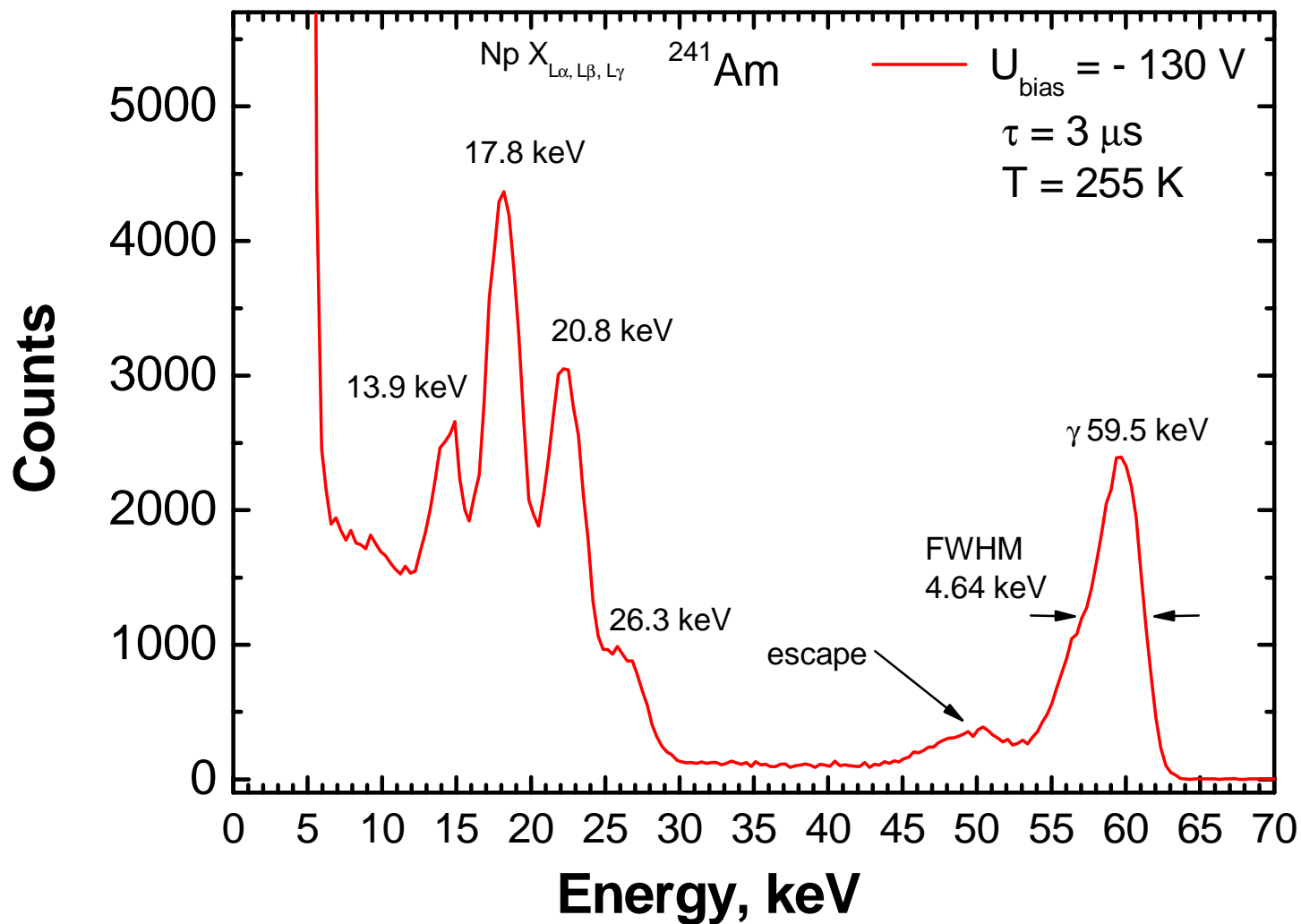


RT pulse-height spectrum of ^{241}Am

130 μm



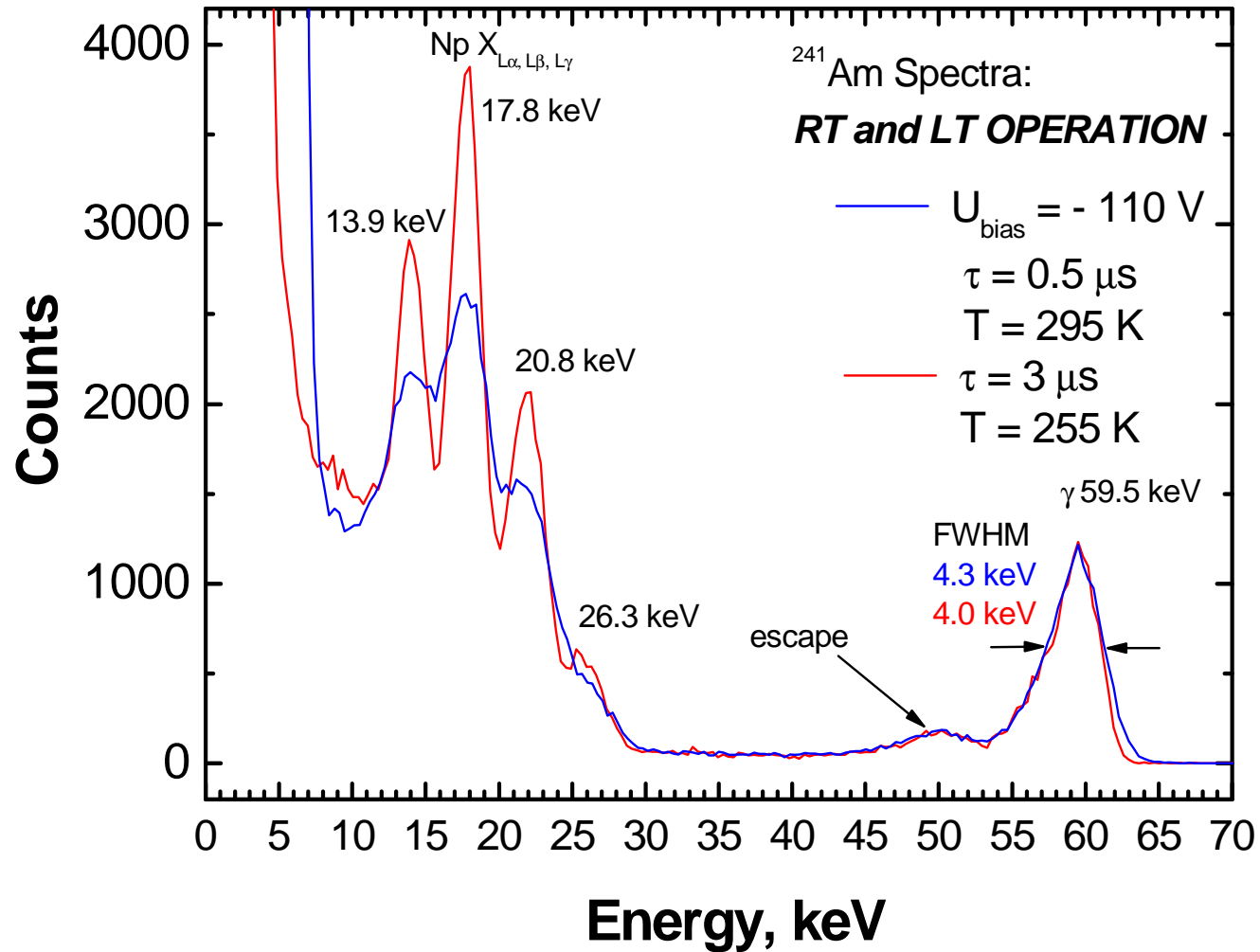
LT: Pulse-height spectrum of ^{241}Am



130 μm

RT<: Pulse-height spectrum of ^{241}Am using optimized electronics

130 μm

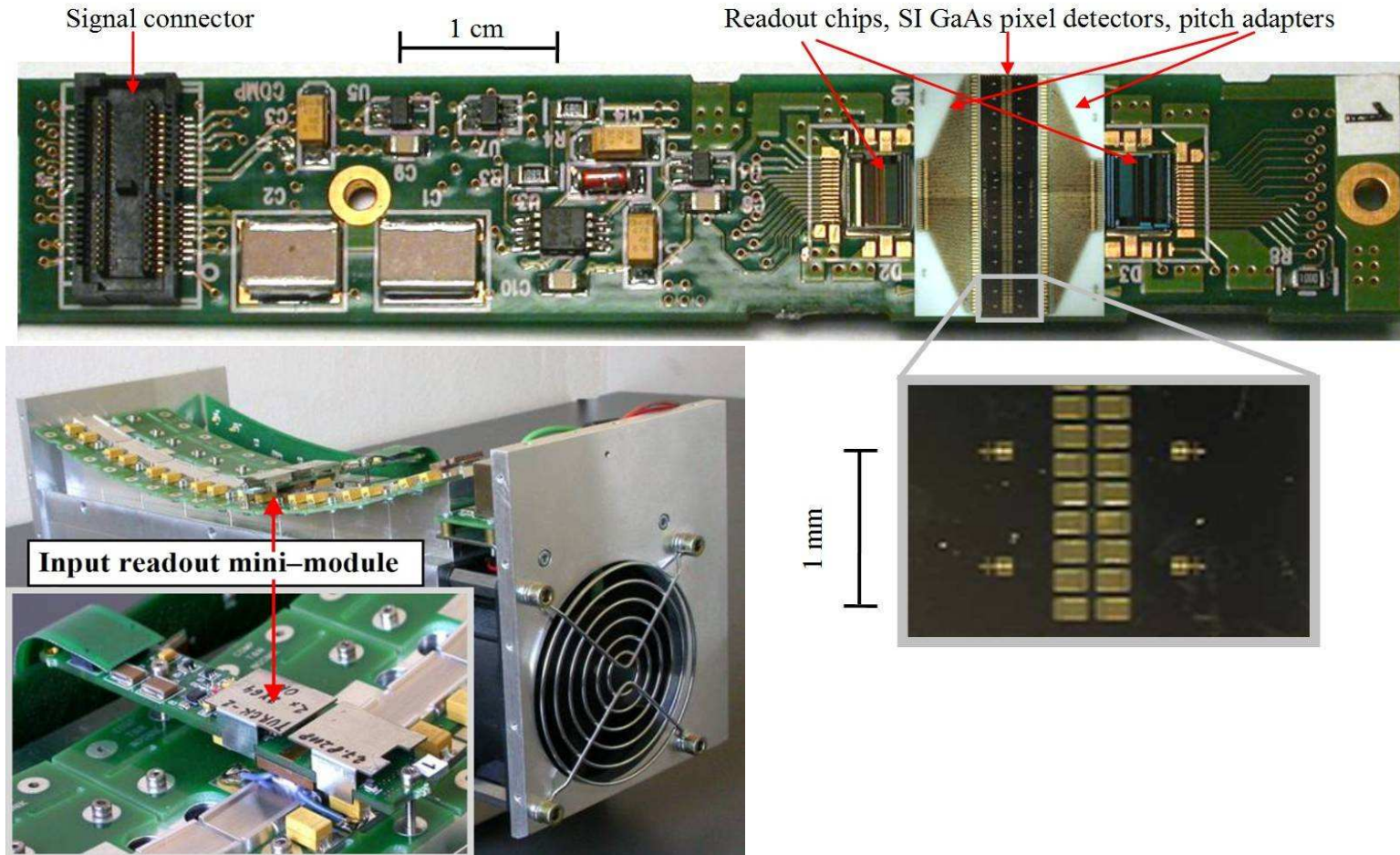


Energy resolution

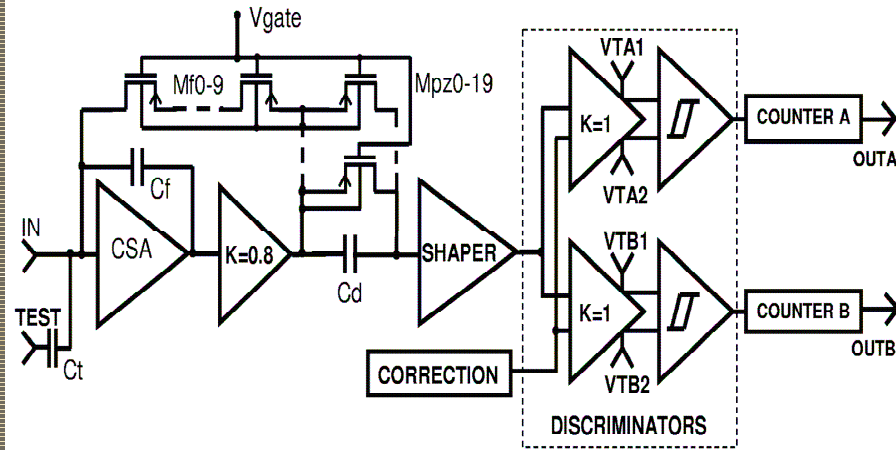
Temperature, K	Energy resolution, % FWHM (keV)	
	17.8 keV peak	59.5 keV peak
295	< 25 (< 4.5)	8.6 (5.0)
295	< 23 (< 4.2)	12.9 (7.7)
improved	< 22 (3.9)	7.2 (4.3)
265	< 19 (< 3.6)	7.8 (4.6)
265	< 16 (< 3.0)	7.2 (4.3)
improved	< 14 (< 2.8)	6.8 (4.0)

Two-line SI GaAs detector module

One detection mini-module with 2×64 pixel detectors

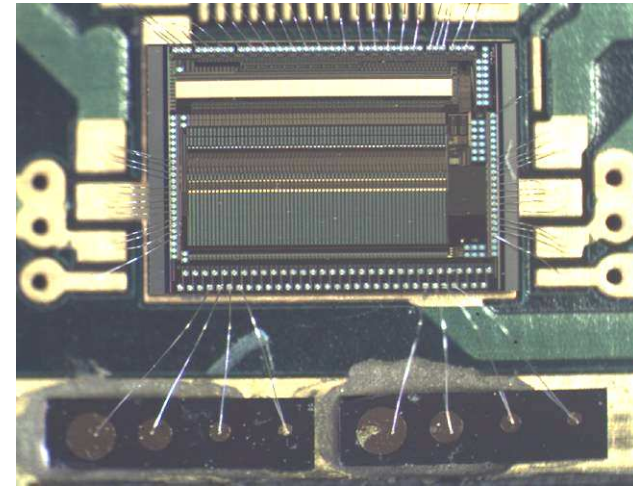


Zařko, B., Dubecký, F., Přibil, J., Boháček, P., Frollo, I., Ščepko, P., Mudroň, J., Grybos, P., and Nečas, V.:
On the development of portable X-ray CT mini-system using semi-insulating GaAs radiation imaging detectors,
Nuclear Instr. and Methods in Phys. Res. A **607** (2009) 67-70. IF: 1.019

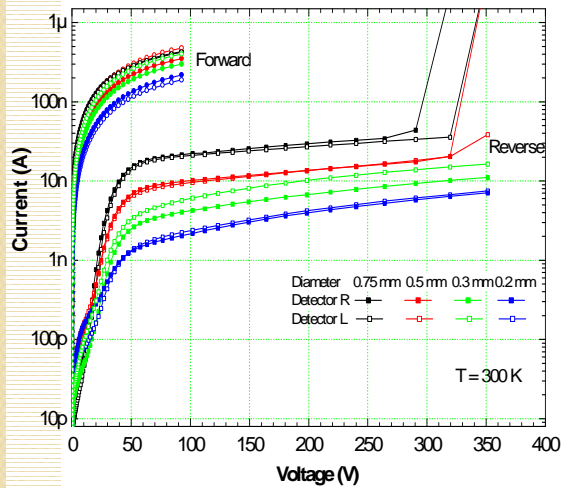


Block diagram of single channel

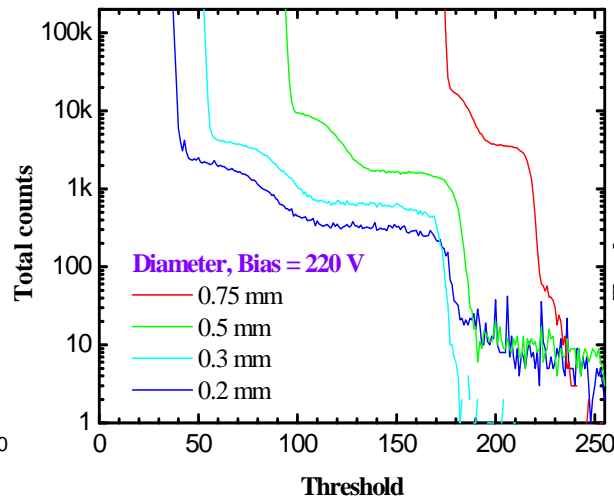
Grybos et al.: *IEEE Nucl. Sci. Sym. Conf. Record* (2006) 693.



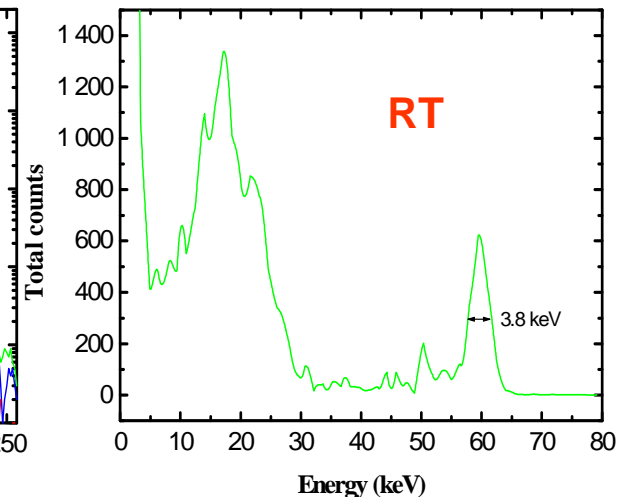
Photograph of **SI GaAs** radiation detectors coupled to ASIC DX64 readout chip.



I-V characteristics of **SI GaAs** detectors measured at RT.

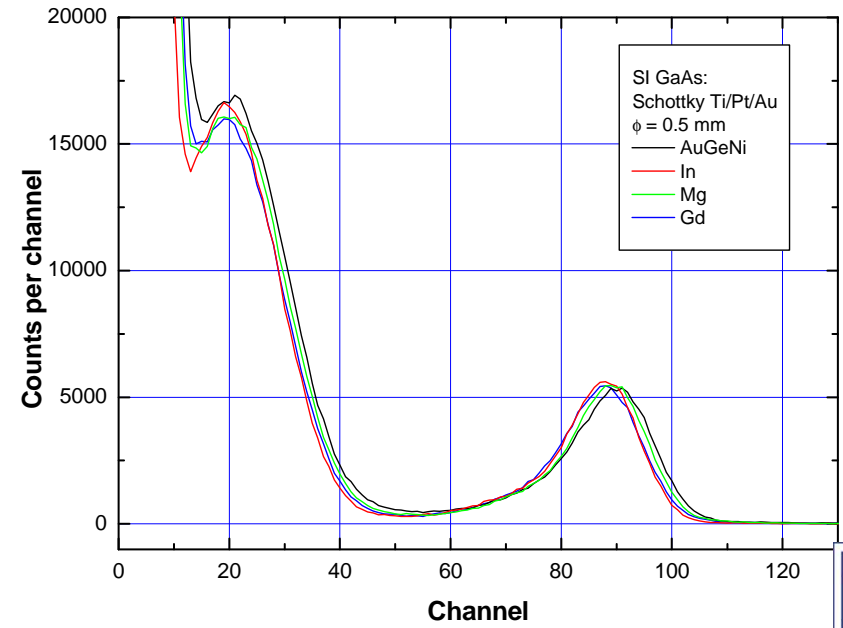
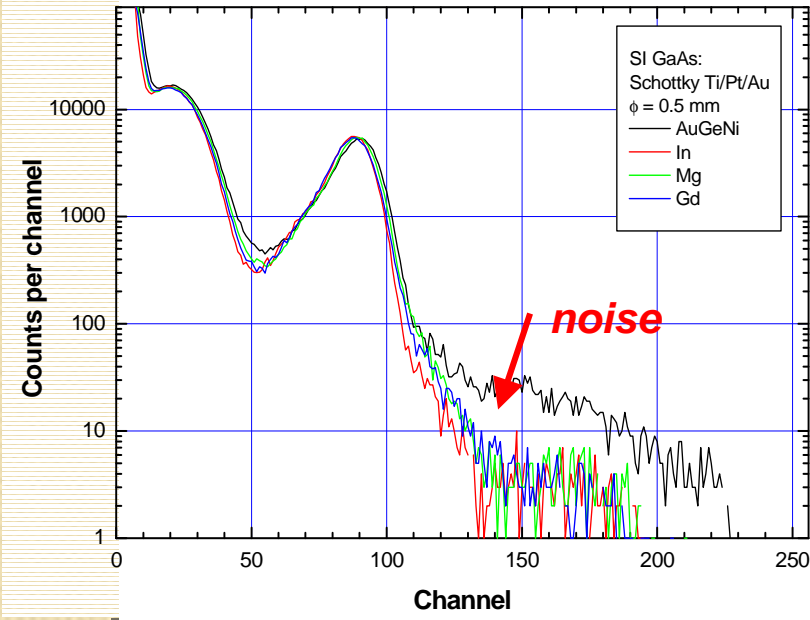
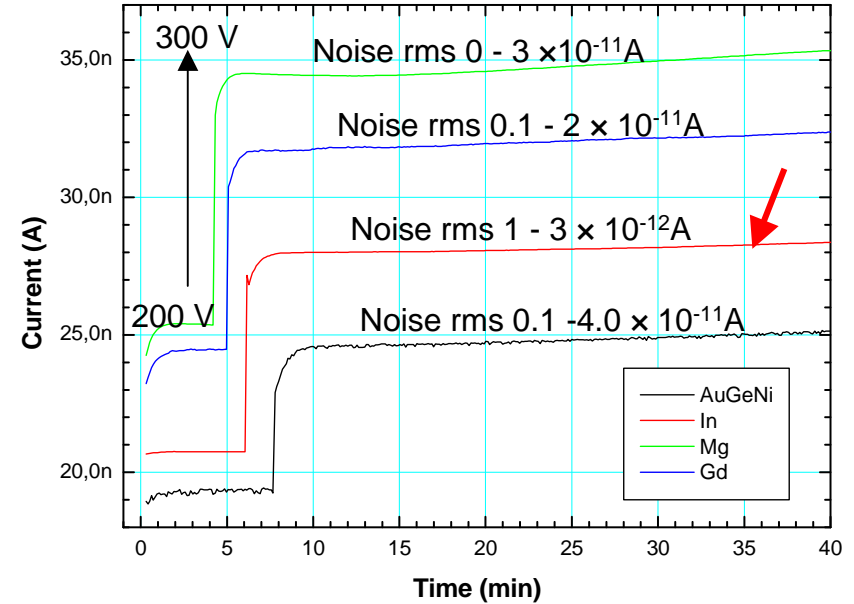
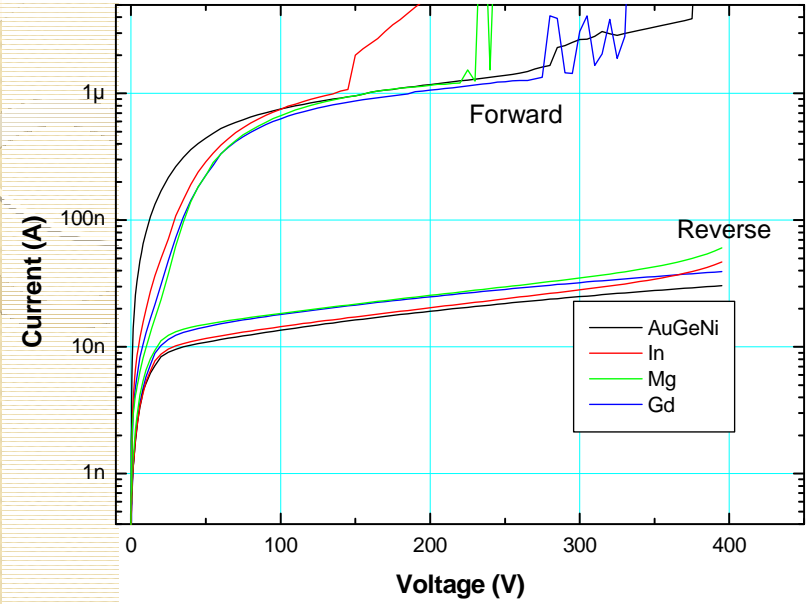
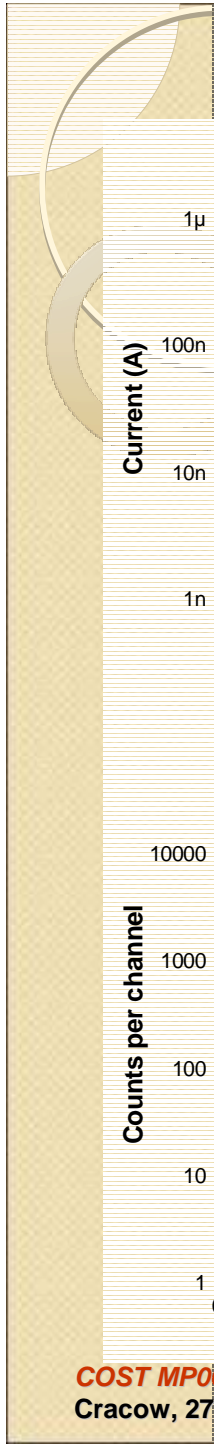


Integral spectra of **SI GaAs** detectors measured using ASIC DX-64 readout chip.



Calculated differential spectra of ^{241}Am measured using ASIC DX-64 with **SI GaAs** detector 0.3 mm in diameter

New choice: electrodes technology



Conclusions

- We developed and tested charge sensitive preamplifiers with external J-FET operated at RT and lowered temperature.
- **SI GaAs** detector *dc* coupled to the developed front-end electronics gives detectable energy threshold of 4.5 keV at 295 K and < 3 keV at 265 K.
- Fabricated and evaluated surface **SI GaAs** Schottky barrier detector has an active base width of 130 μm and gives energy resolution of about **2.8 keV FWHM for 17.8 keV** peak from ^{241}Am source at 265 K.
- The results show that first of all the ***noise of the front-end electronics chain must be reduced to <100 e⁻ rms.***
- Future plan toward spectrometric detector technology: ***electrodes, topology, material aspects, neutron damage...***

Acknowledgements

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***THANK YOU FOR YOUR
ATTENTION***