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A Silicon Carbide Microstrip *and Pixel* Detector for Radiation Spectroscopic Imaging

G. Bertuccio, S. Caccia, D. Tosi

Politecnico di Milano and INFN, Milano, Italy

C. Lanzieri, S. Lavanga

Selex Integrated Systems, Rome, Italy

F. Nava

University of Modena and INFN, Modena, Italy

Outline

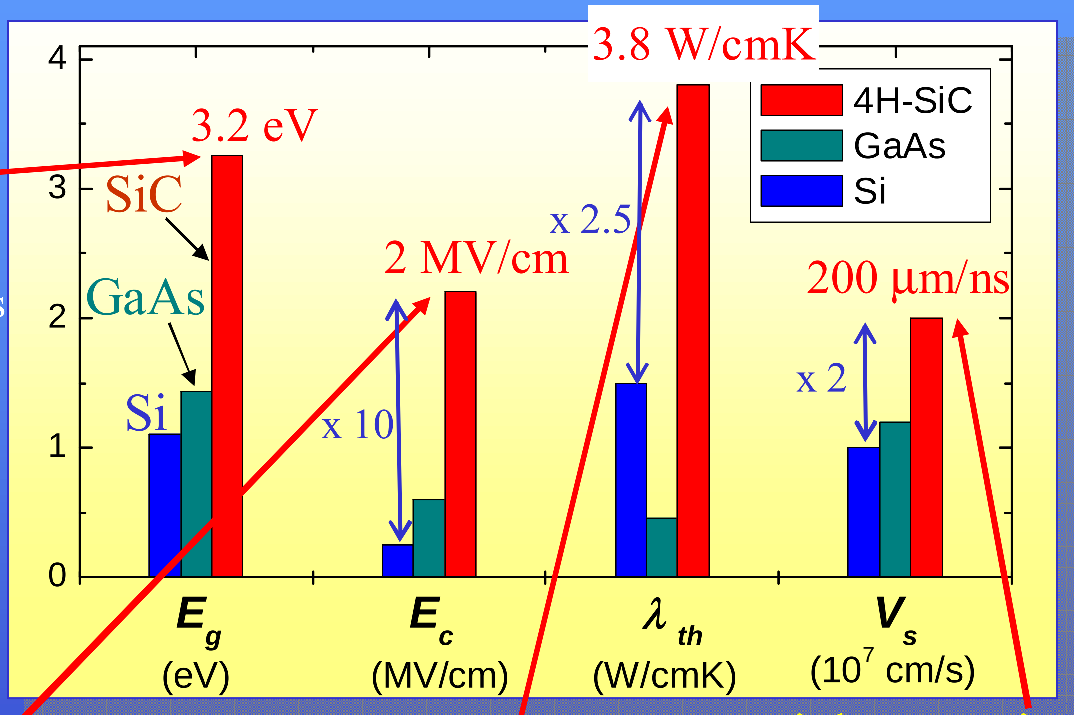
- Introduction on Silicon Carbide
  - Properties
  - Radiation detectors
- SiC Microstrip (& Pixel) detector
  - Technology
  - Junction characterization
  - Radiation spectroscopy
- Conclusions and future work

Silicon Carbide (SiC)

a brief introduction

Silicon Carbide Properties

related to radiation detectors



Wide Bandgap

- High Schottky / pn barriers
- Low thermally generated currents
- No cooling required
- High temperature operation

High Critical Field

- High bias voltage
- Reduced soft breakdown
- No guard rings necessity

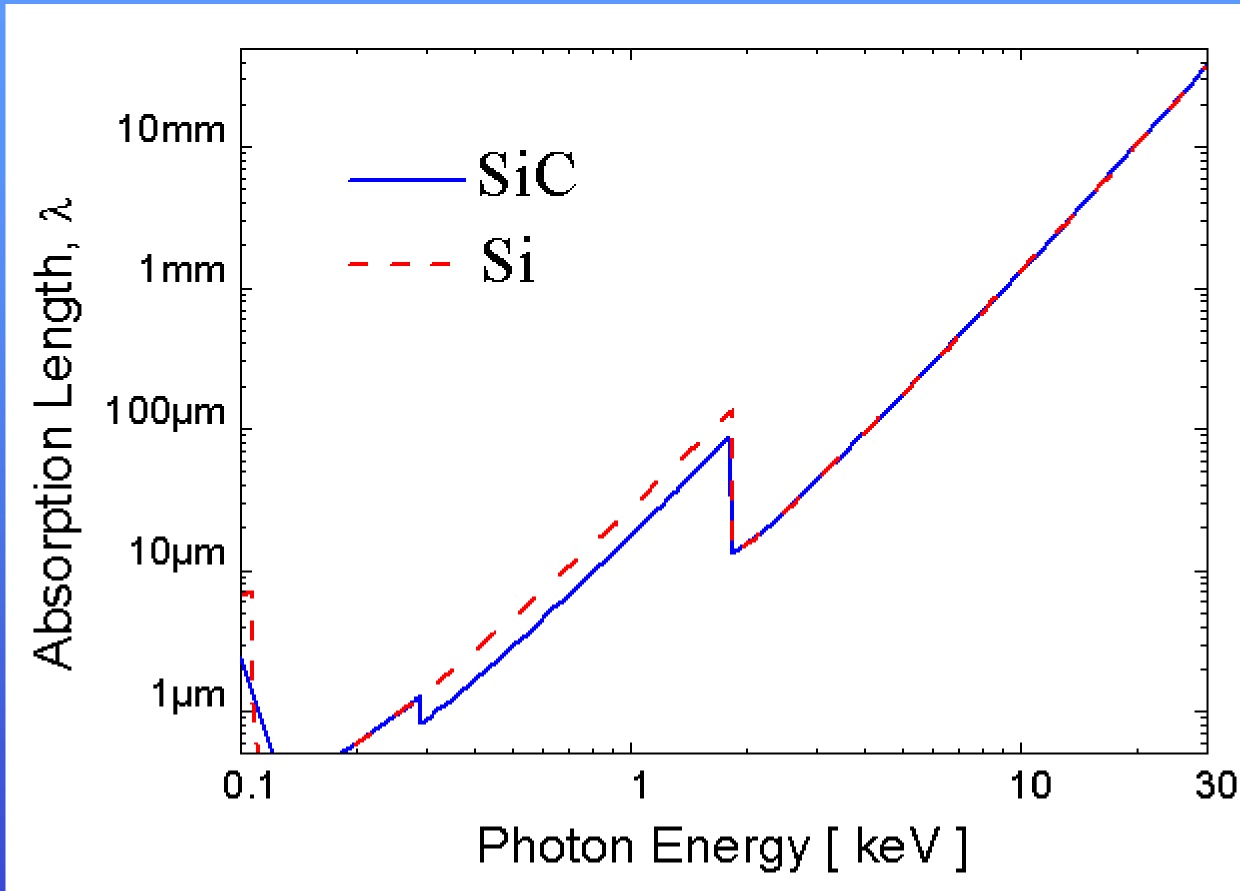
High thermal conductivity

- Easy T control
- FEE cooling

High saturation velocity

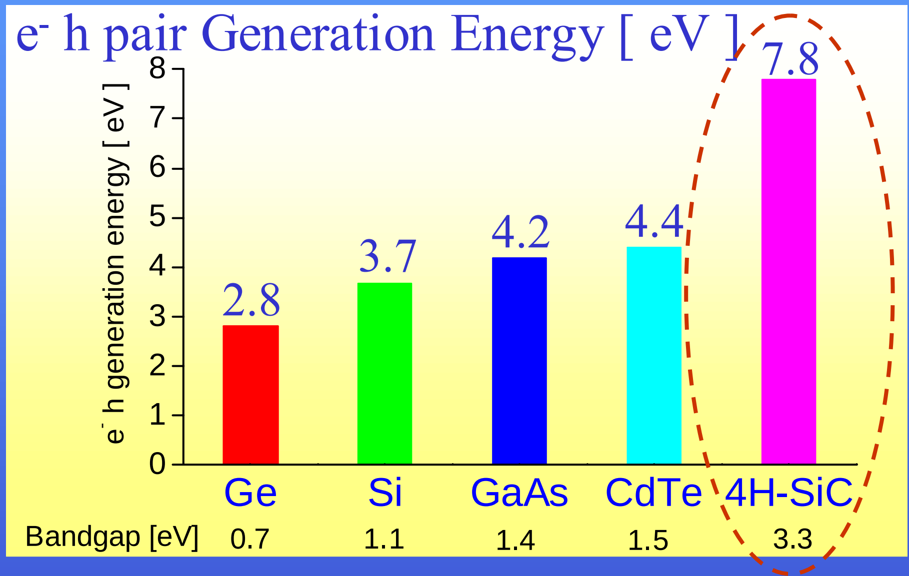
- Short transit time
- Fast signals
- Low trapping probability

Soft X-ray Absorption



SiC Detector Signal

4H-SiC bandgap: 3.3 eV

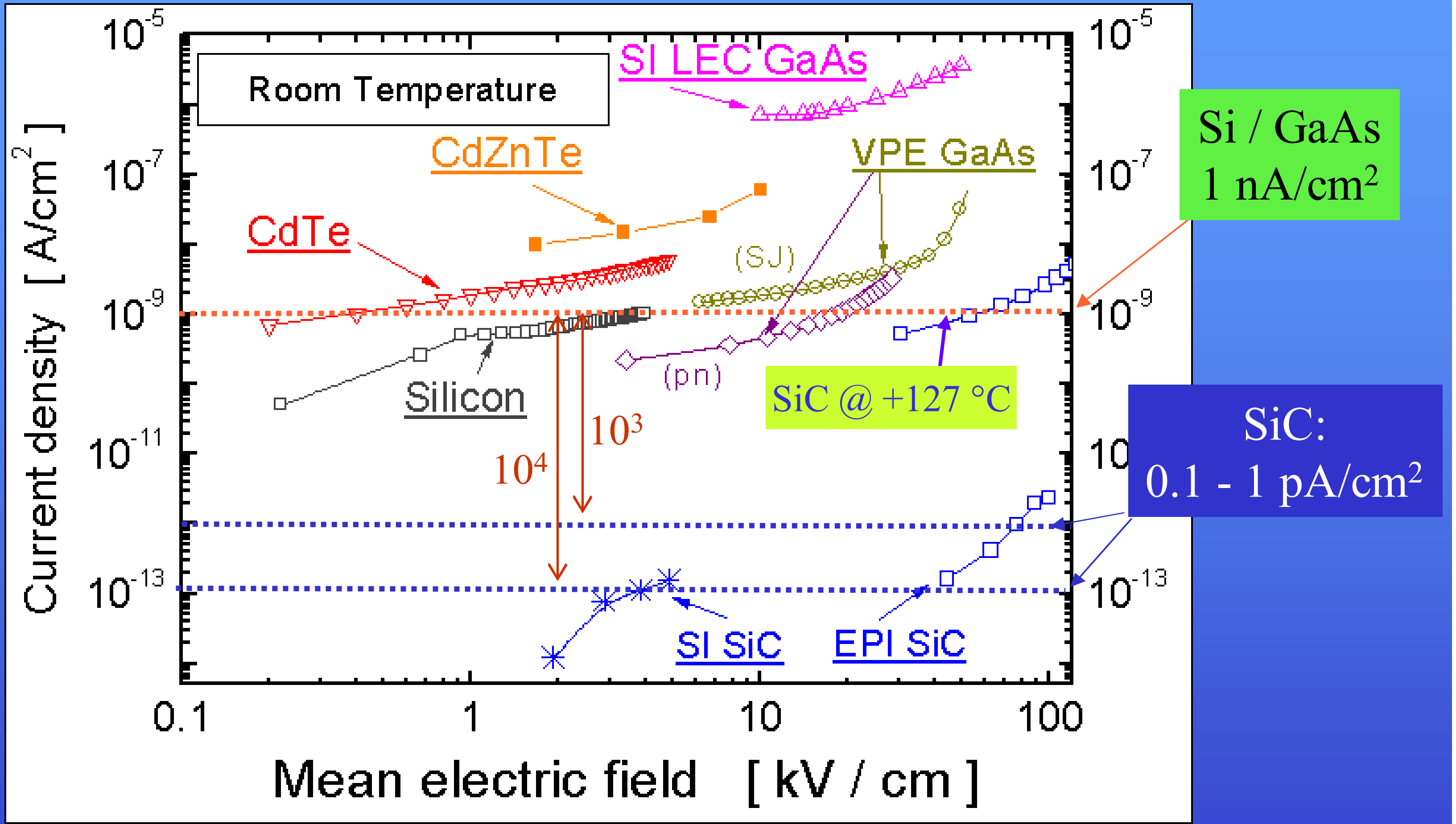


SiC detectors deliver the lowest signal !

But the Signal/Noise ratio is important !

…What about noise ?

Detector leakage current (J vs. E_{field})



noise due to the current

$$ENC_I \div \sqrt{I_{DET}} \quad \Rightarrow \quad ENC_I(SiC) < \frac{1}{30}\left[ENC_I(Si/GaAs/CdTe/CZT)\right]$$

SiC Microstrip detectors

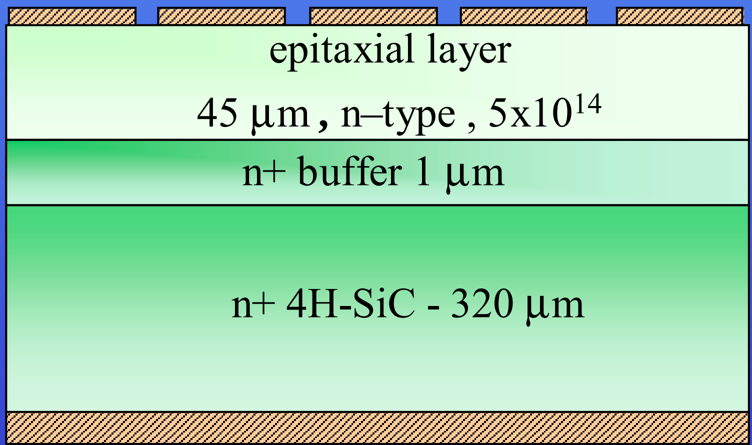
Starting Material & Technology

Undoped epitaxial 4H-SiC wafers : 2'' CREE USA ; 3'' LPE S.p.A. ITALY

SiC Technology : SELEX Sistemi Integrati ITALY

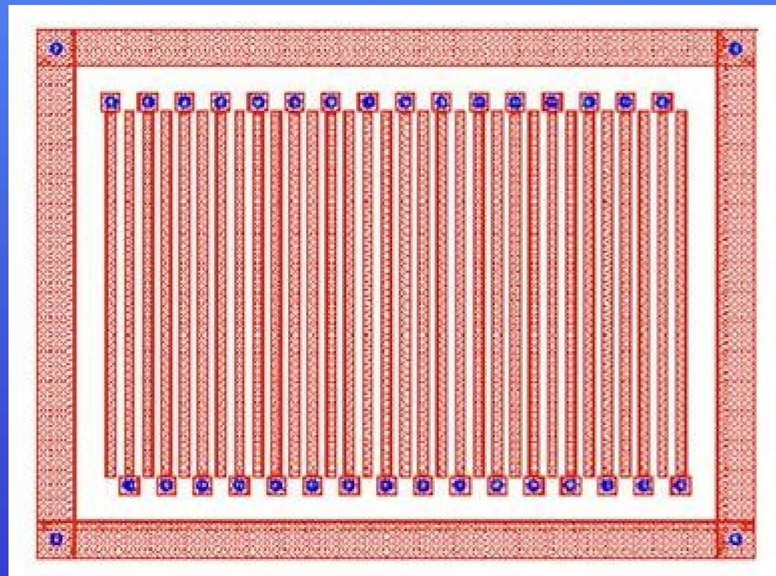
Structure (section)

Schottky contact : Ni_2Si, 0.1µm Ni - 700°C



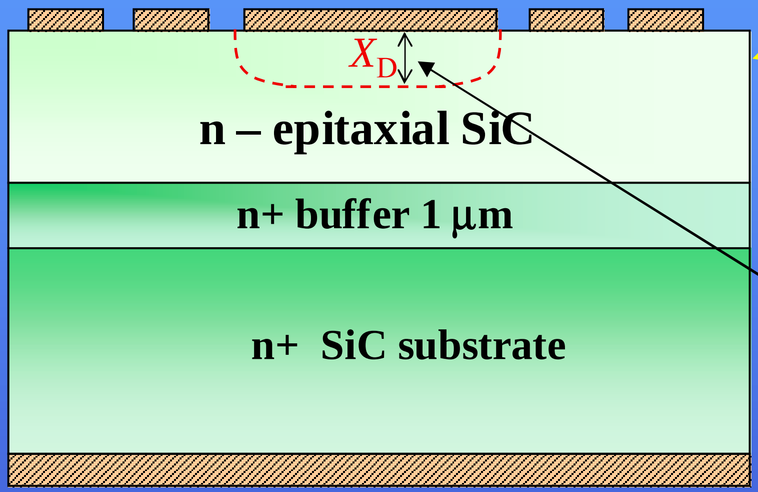
ohmic contact : Ti/Pt at 950°C , 30s

Microstrip Detector Layout



Present Limit of SiC detectors

Schottky contact



ohmic contact

Epitaxial layer

- thickness: ≤ 100 μm
- Residual (unintentional) doping: ≥ 10^{14} cm^{-3}

⇓

Depletion (active) layer thickness X_D

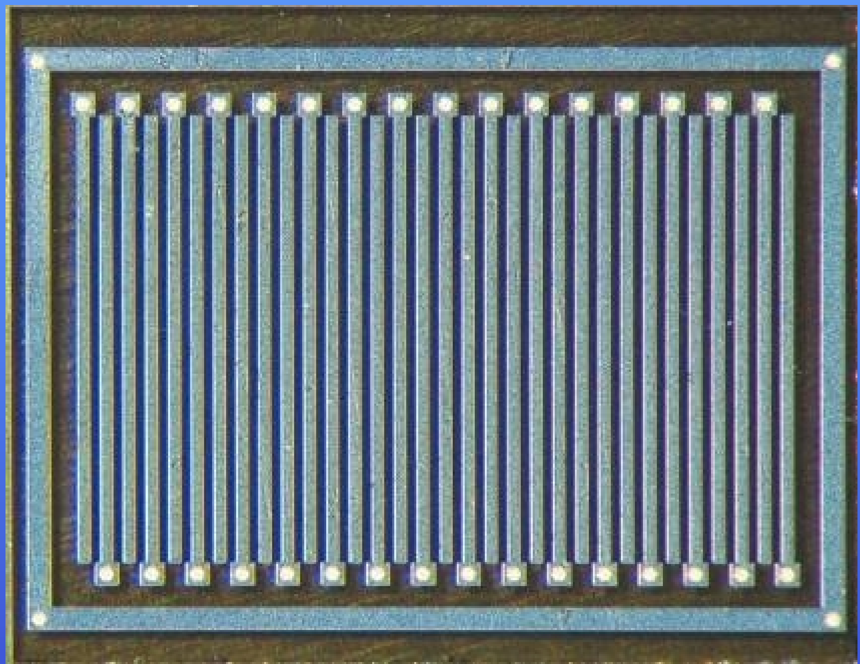
$N_d = 10^{14}$, $V_R = 300$ V → $X_D = 55$ μm

Started R&D to reduce residual doping down to 10^{12} cm^{-3}

in collaboration with LPE S.p.A. ITALY

SiC Microstrip prototype SCM1

32 strips – 2 mm length

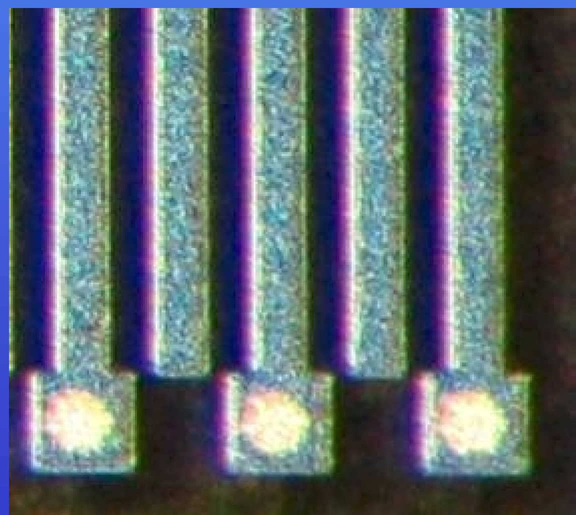


2 mm

3.35 mm

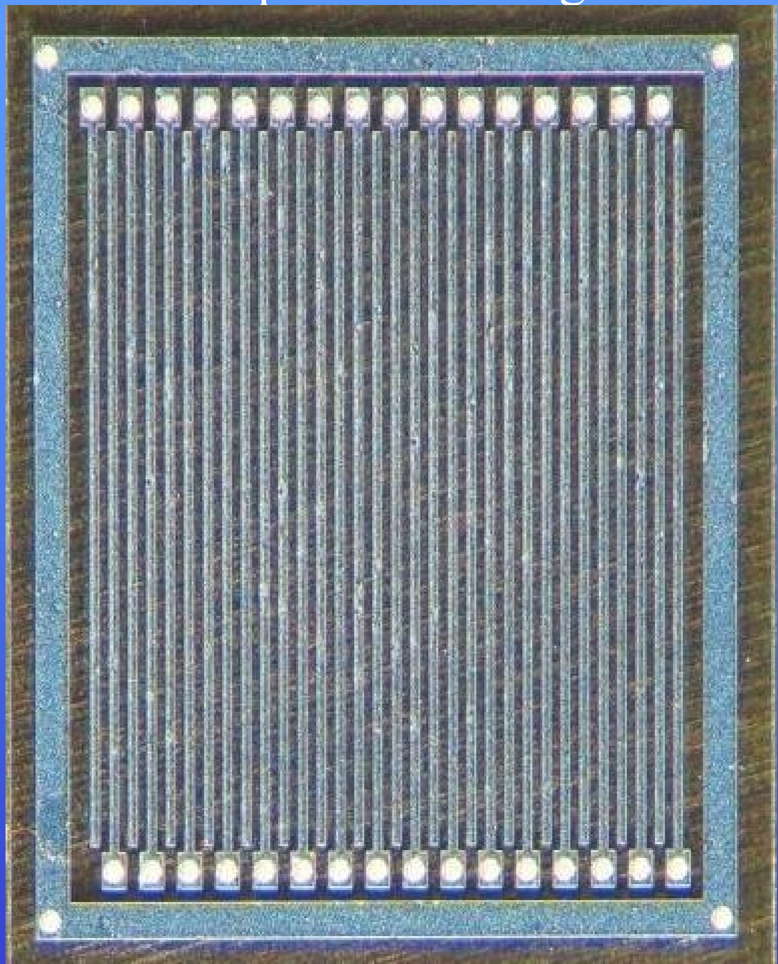
Width 50 µm

Pitch 100 µm



SiC Microstrip prototype SCM2

32 strips – 2 mm length



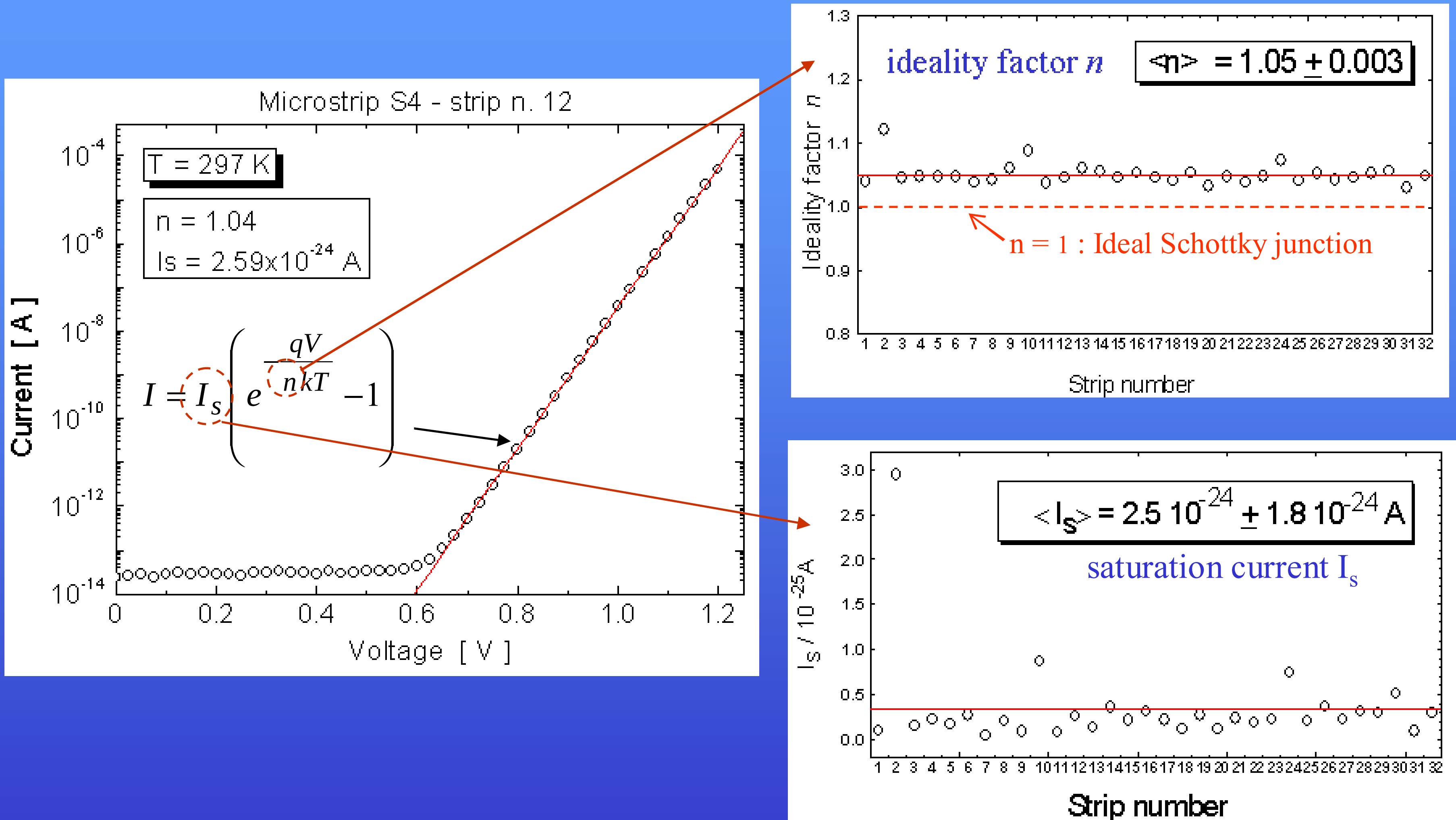
2 mm

1.84 mm

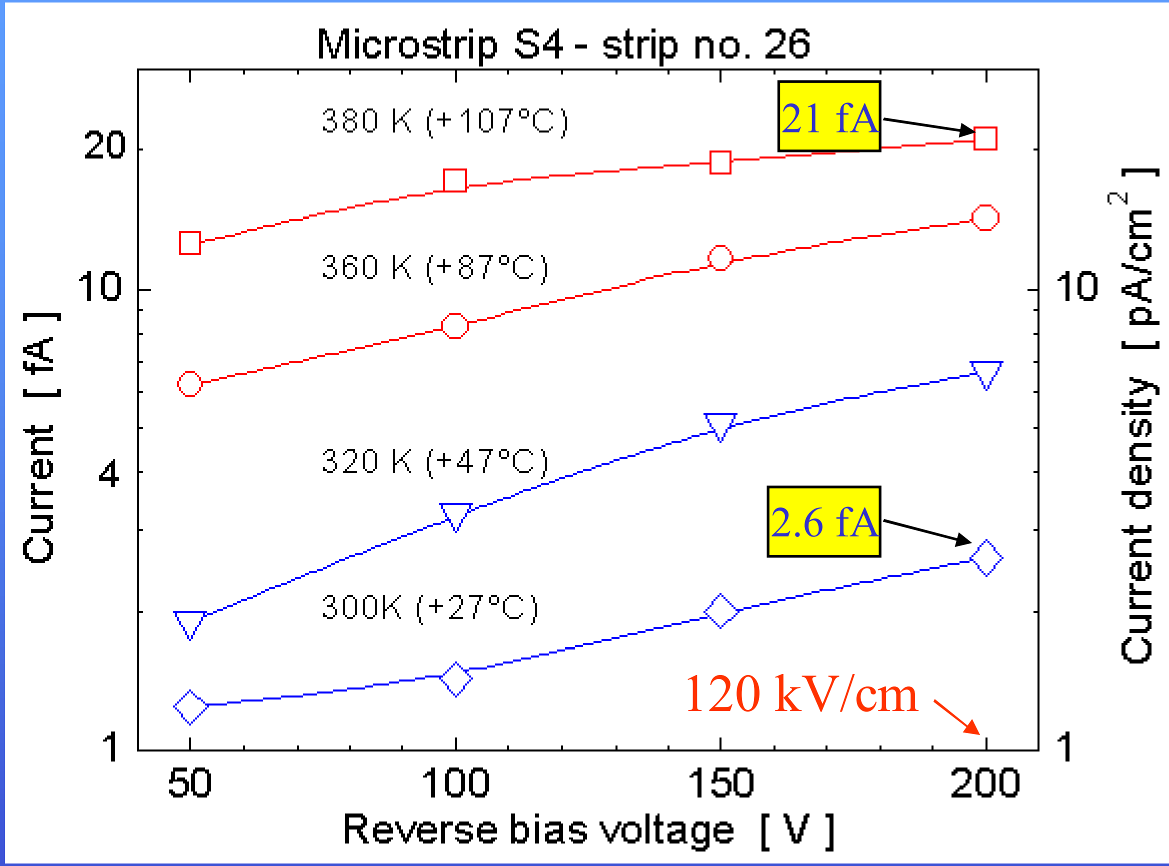
Width
25 µm

Pitch
55 µm

Schottky junction (I-V forward bias)



Reverse I-V characteristic

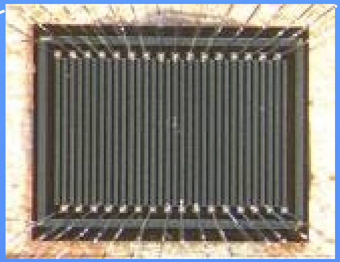


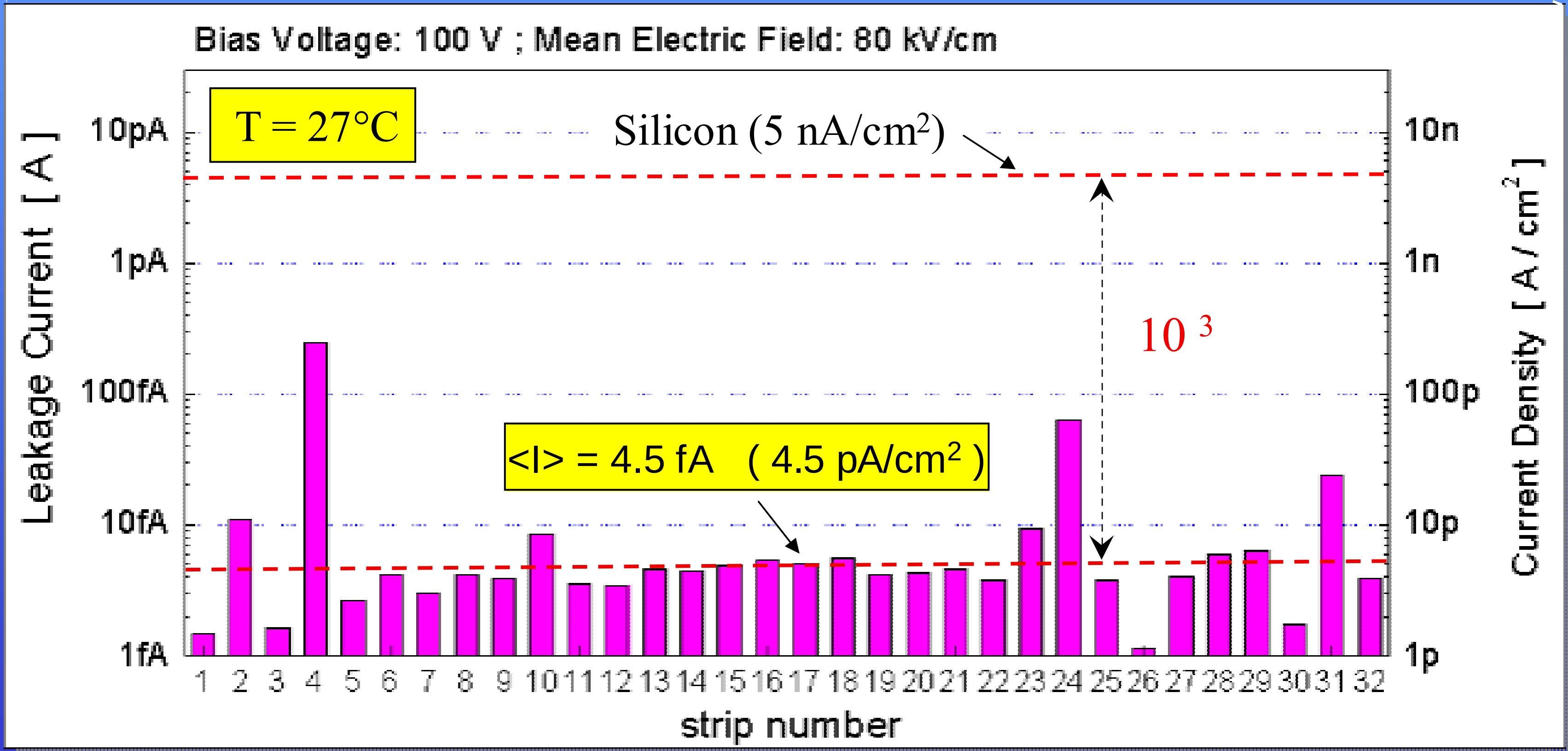
Wide bandgap (3.3 eV) : Ultra–low current by thermal generation

High Schottky barrier (1.6 eV) : Ultra-low current by thermionic emission

Low doping (<10^{15} cm^{-3}): Ultra-low current by barrier tunneling

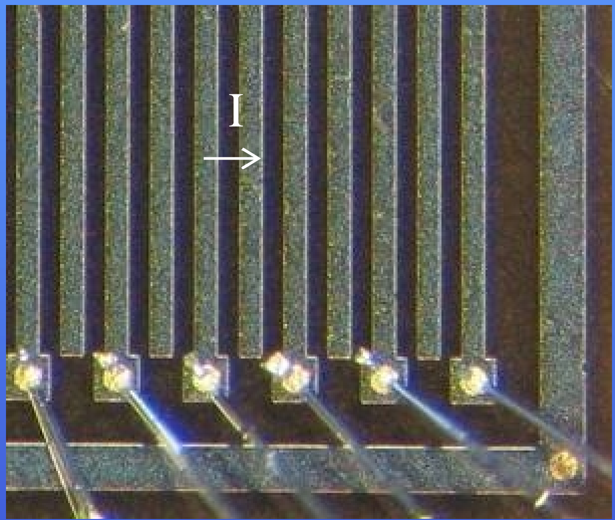
Leakage current mapping

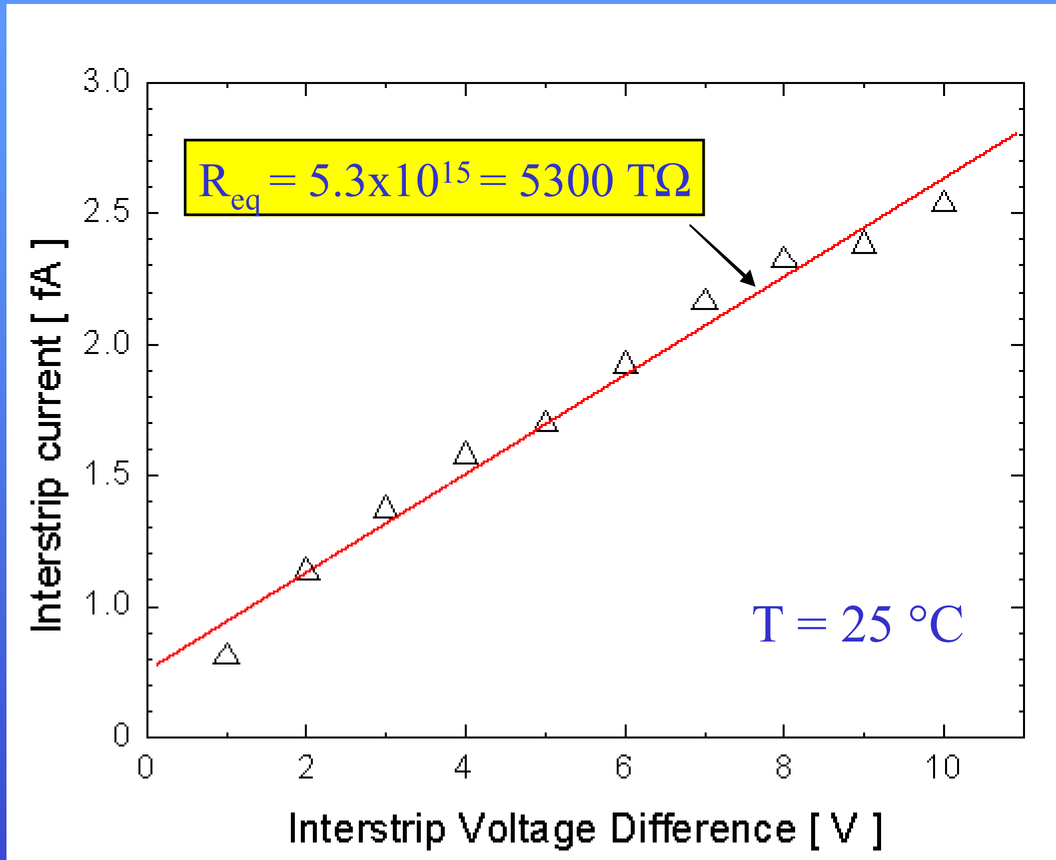




Interstrip current / resistance

ΔV ←

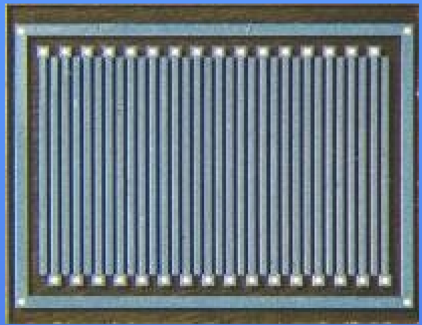


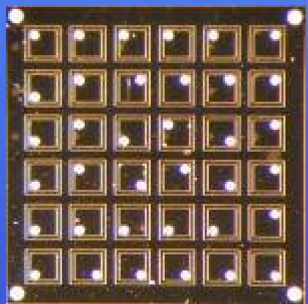


ΔV<1V ⟹ I<< 1fA

SiC Microstrip & Pixel Detectors

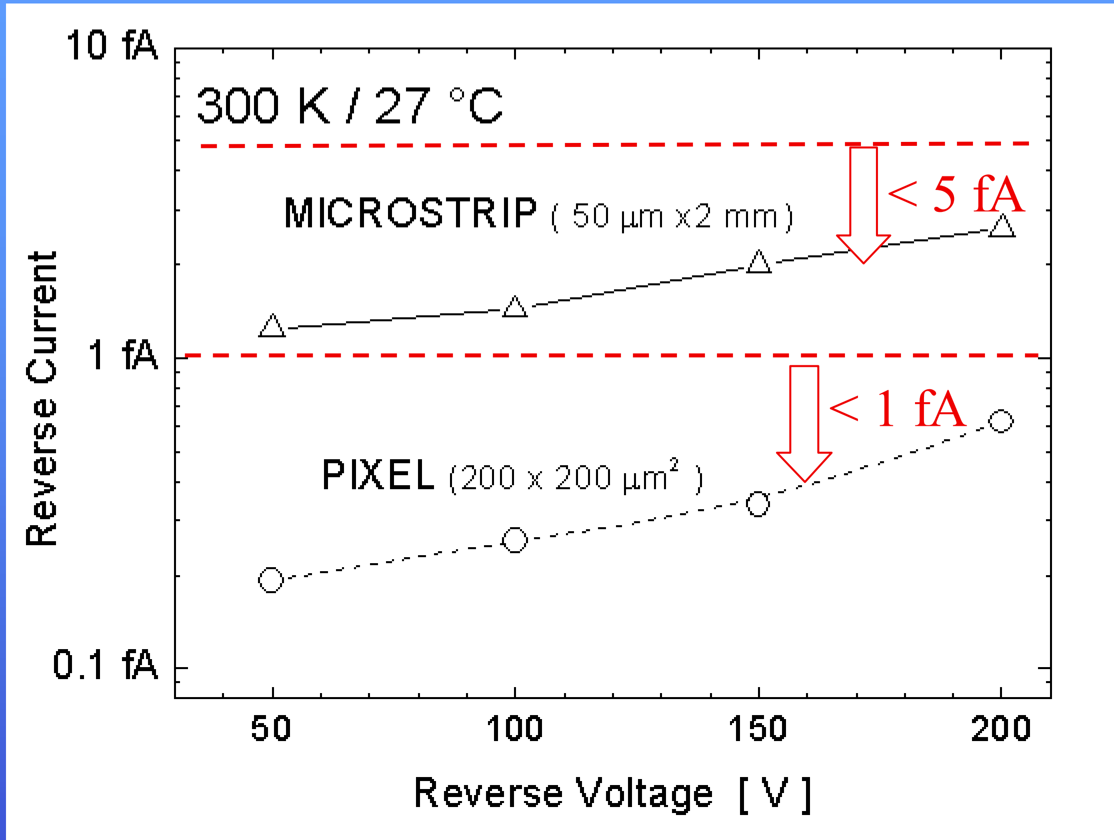
SiC Microstrip





SiC Pixel (6 x 6 prototype)

pixel size: 200μm x 200μm

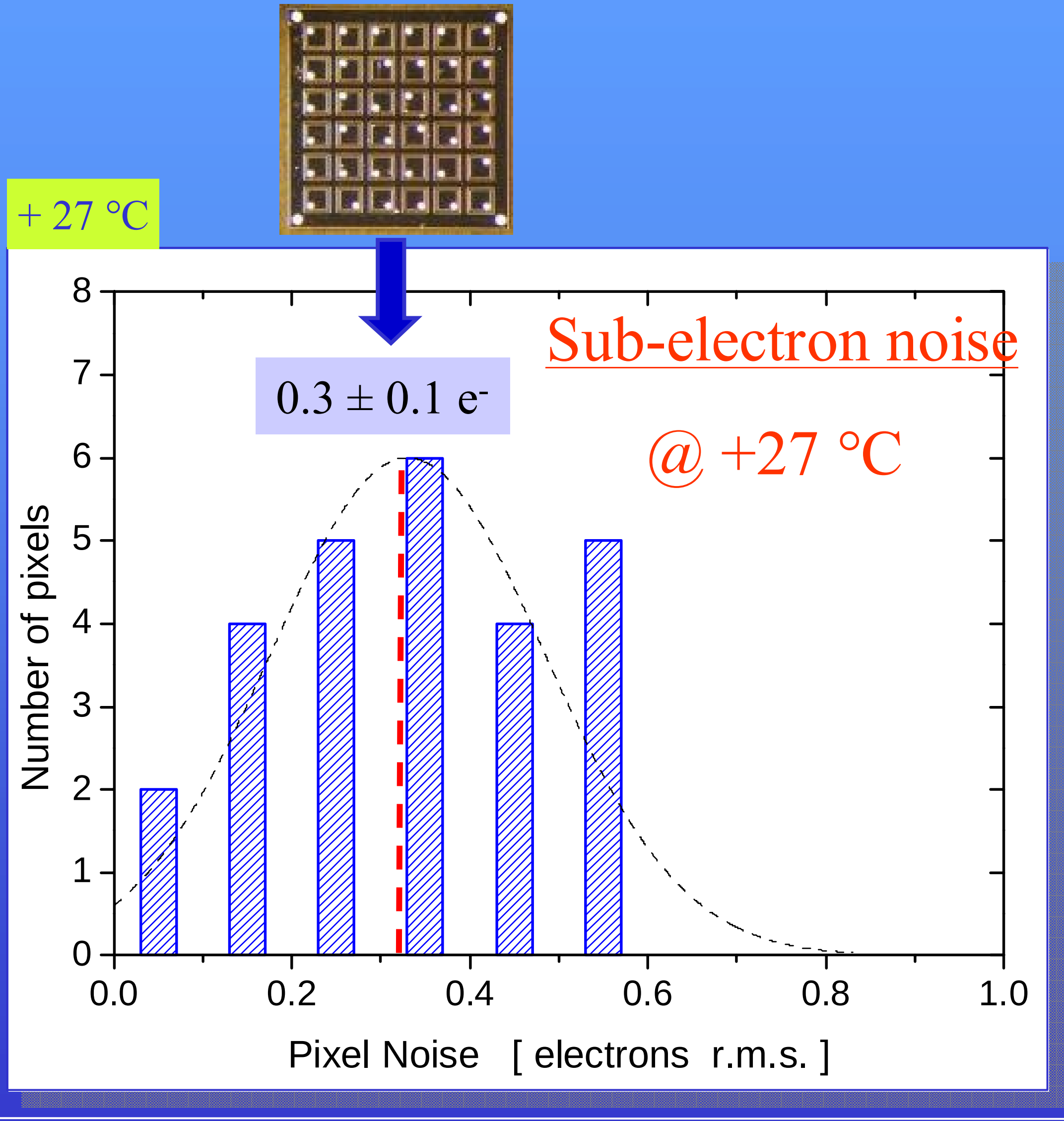


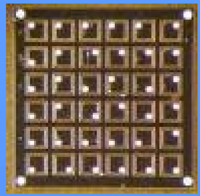
$$ENC_I = 0.065\sqrt{I \quad [fA]}\sqrt{\tau_{peak} \quad [\mu s]} \quad [e^- \, r.m.s.]$$

$I \leq 10$ fA $\rightarrow ENC_I$ (τ_{peak}=20μs) < 1 e^- rms

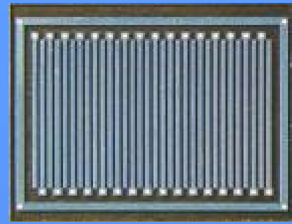
sub-electron parallel noise

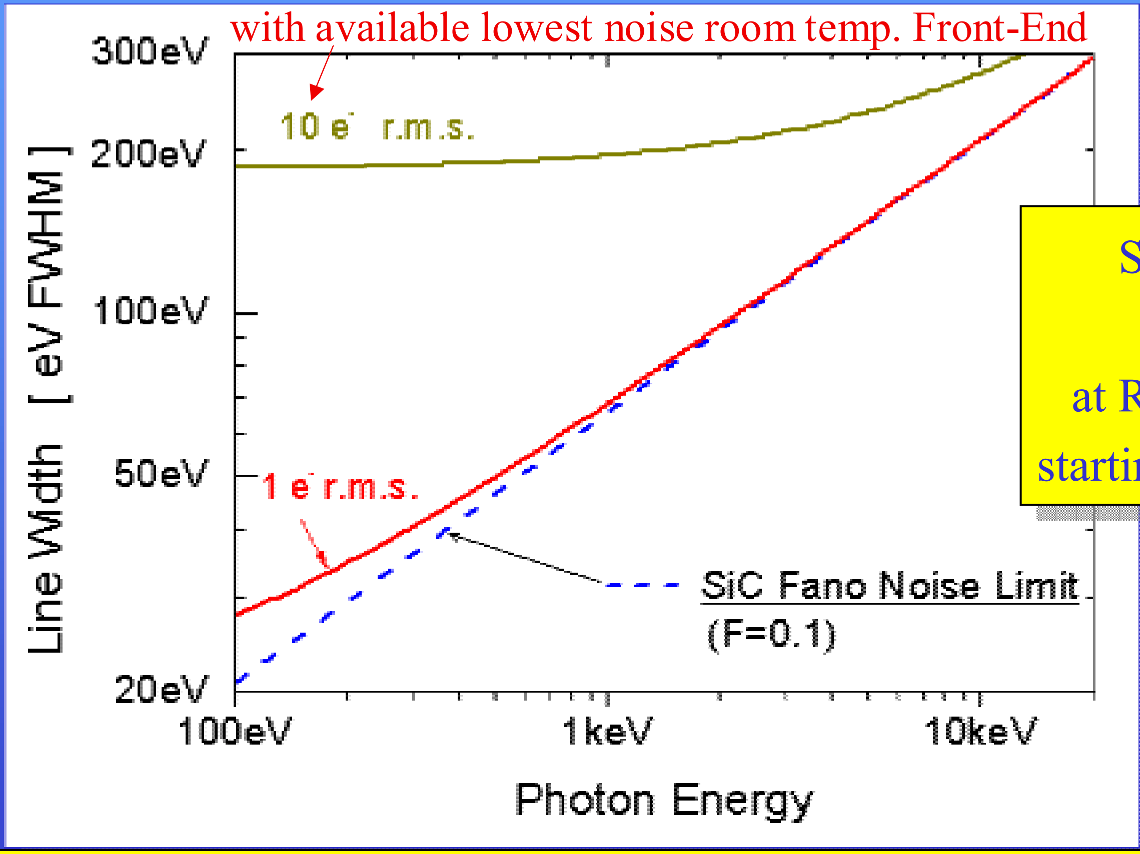
Map of Pixel Noise due to Leakage Current





SiC Detectors possibilities…

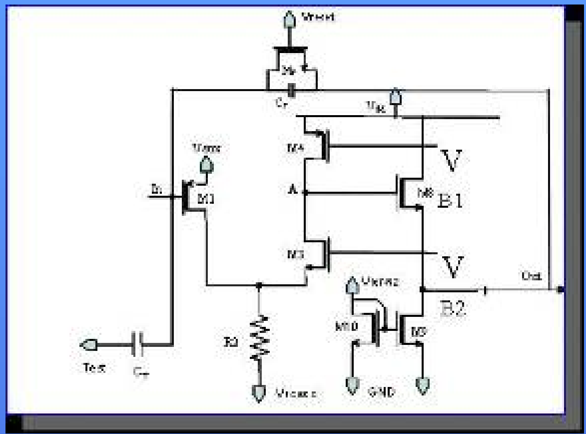




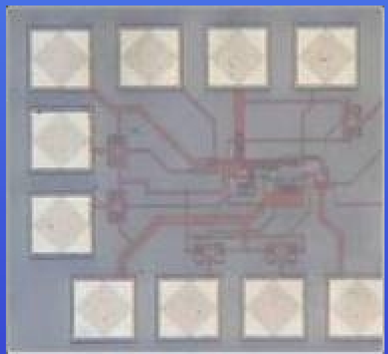
SiC detectors are
"Fano limited"
at Room Temperature
starting from E_{ph}=100 eV

The Front-End Electronics issue is critical…

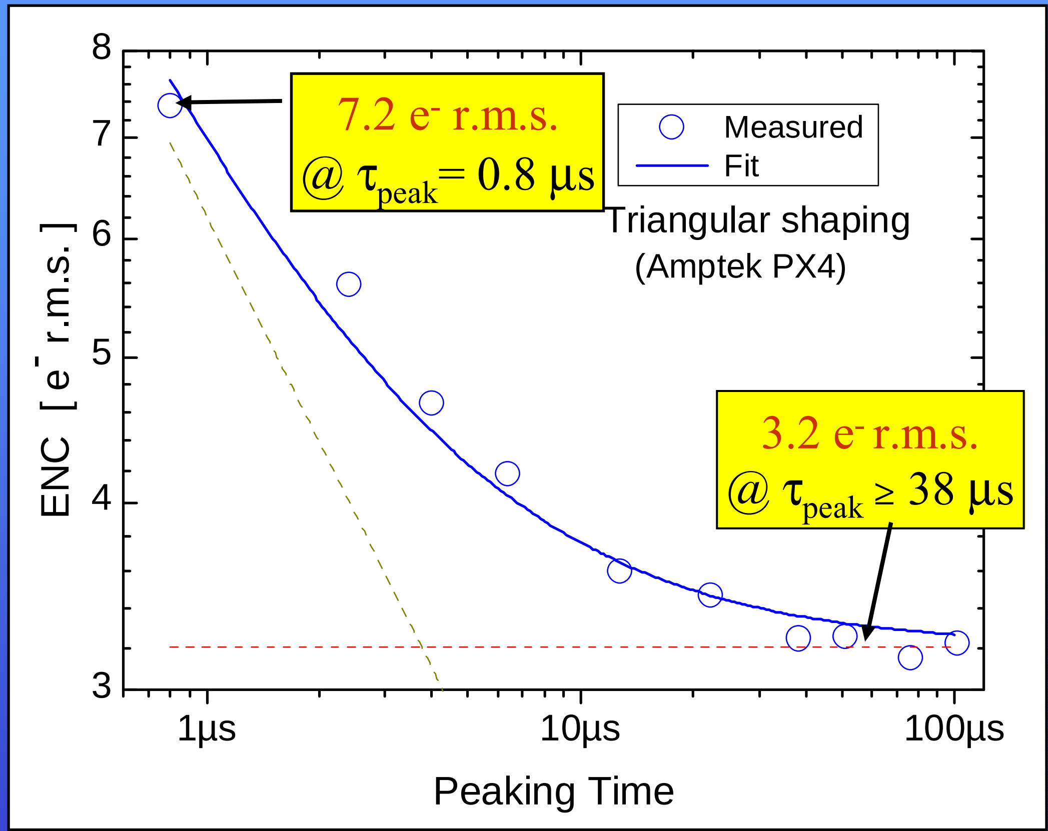
Ultra low noise CMOS Charge Amplifier



Preamp. chip

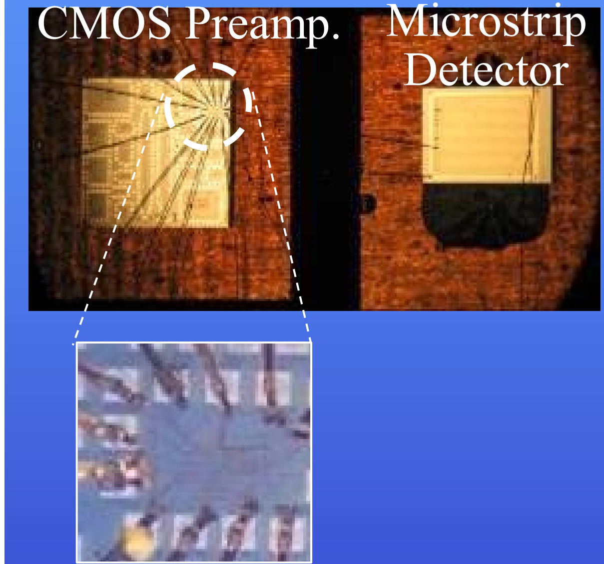


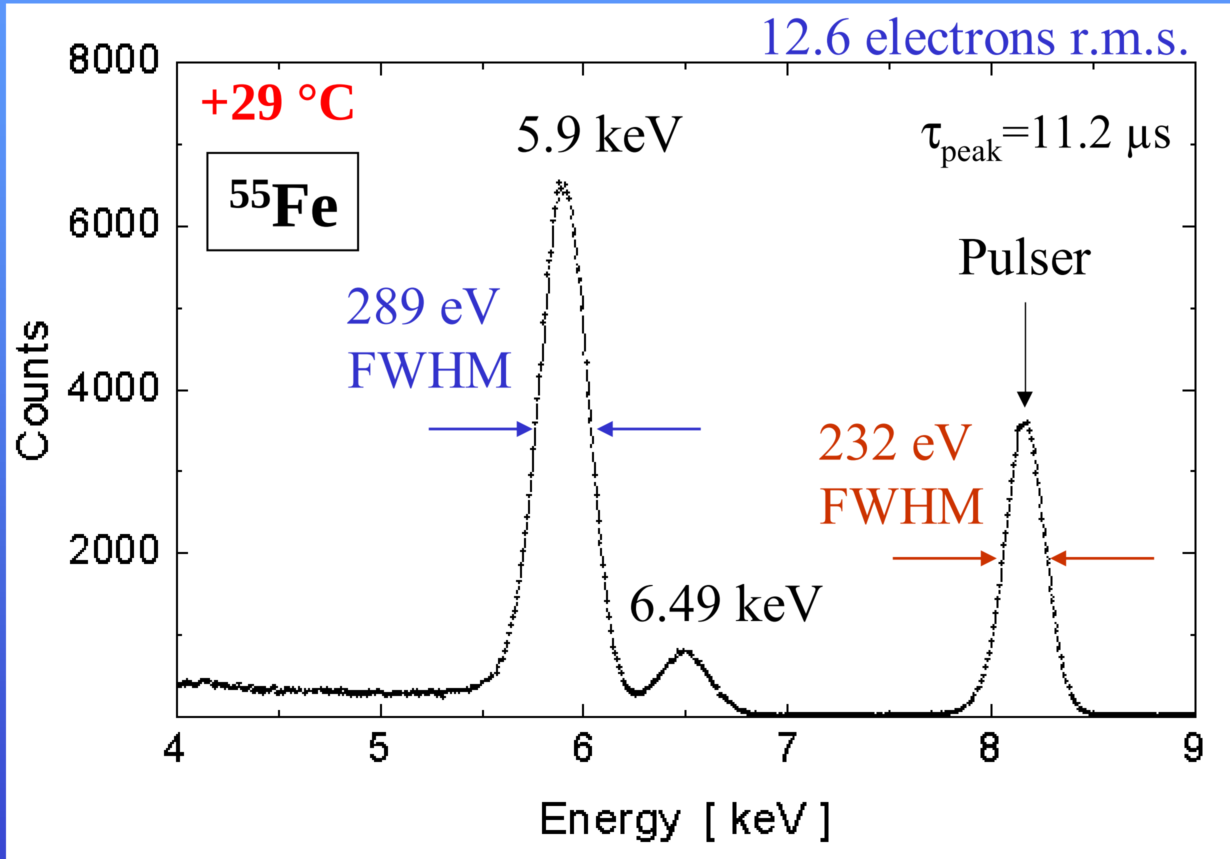
Designed at Politecnico di Milano



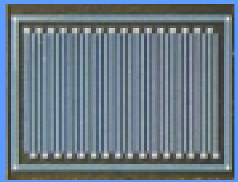
input leakage current < 1fA

SiC Microstrip detector & CMOS Preamplifier



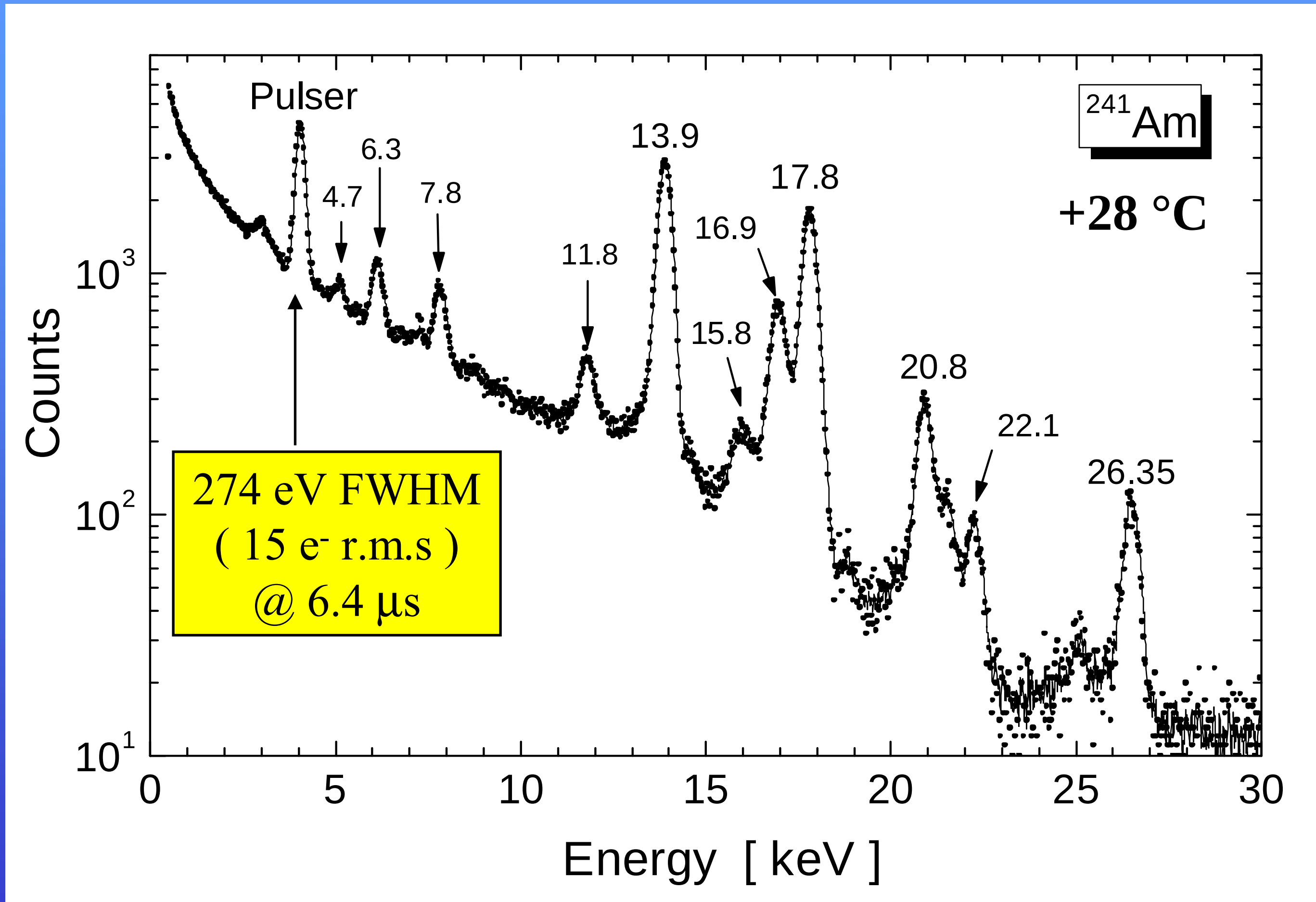


'High' noise due to anomalous leakage of 0.5 pA

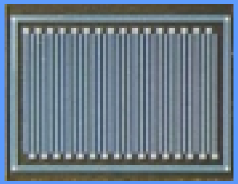


SiC Microstrip/CMOS Preamplifier

at +28°C

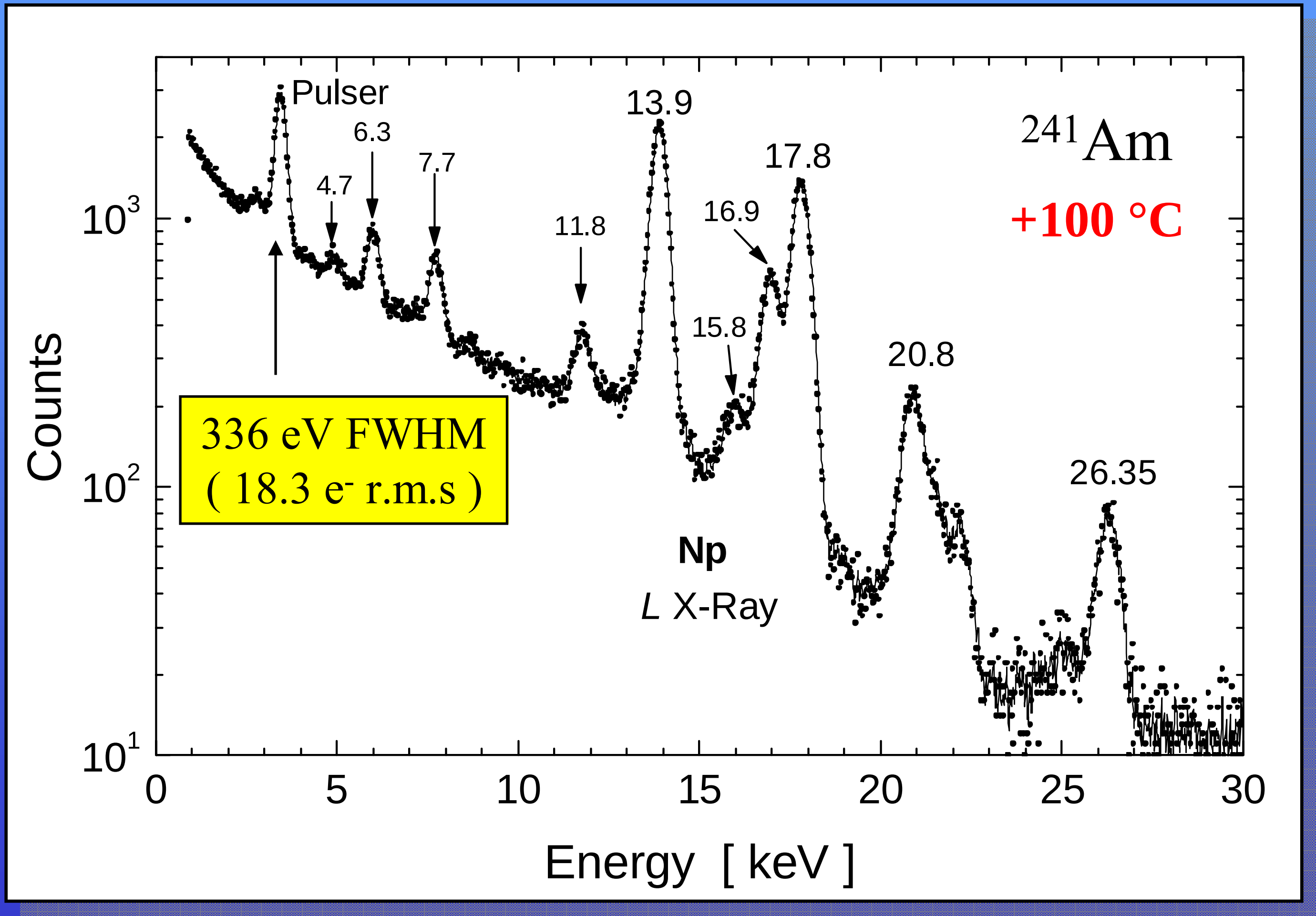


POLITECNICO DI MILANO



SiC Microstrip/CMOS Preamplifier

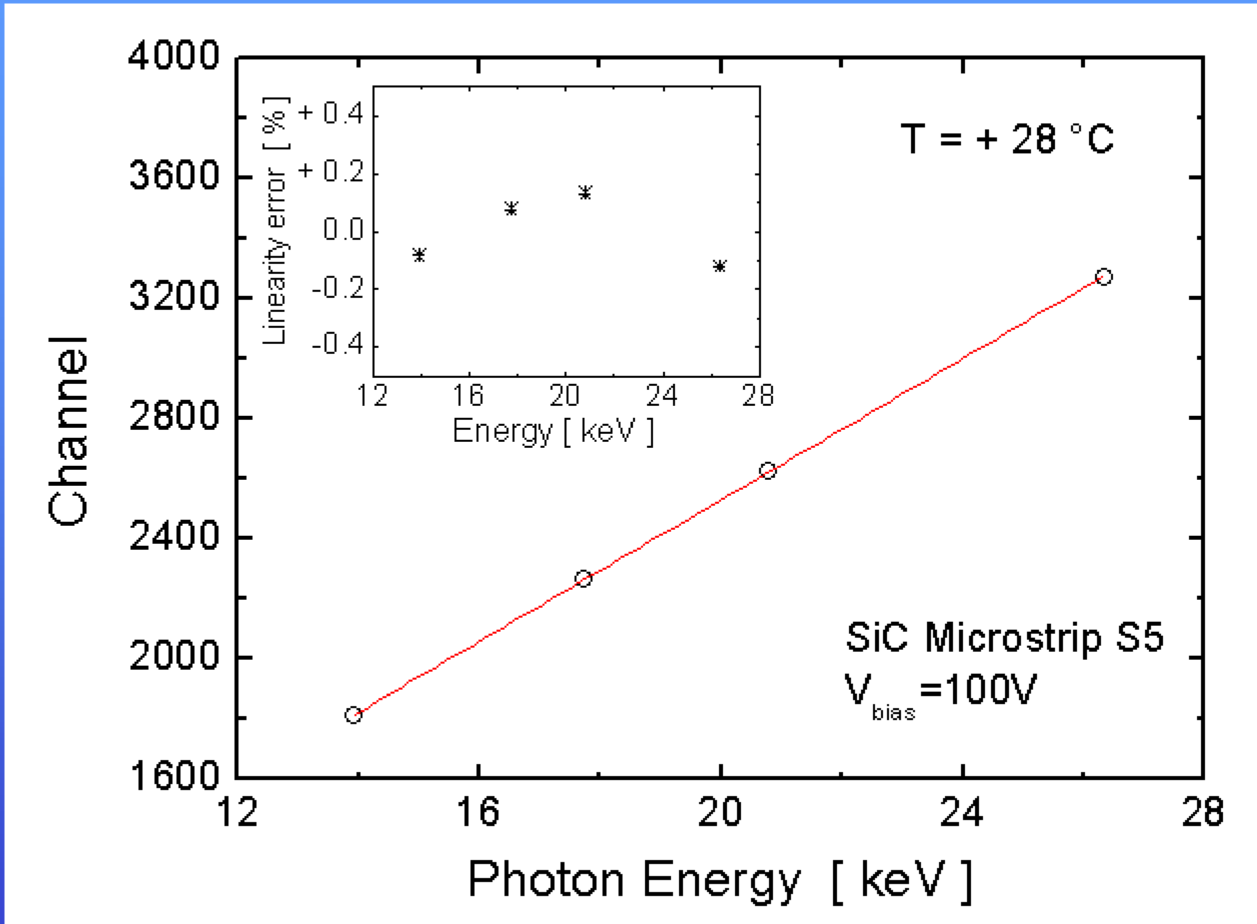
at +100°C



G. Bertuccio et al. "A Silicon Carbide Microstrip Detector for Radiation Spectroscopic Imaging"
9th International Workshop on Radiation Imaging Detectors, July 22-26, 2007, Erlangen, Germany

Spectra linearity

T = + 28 °C

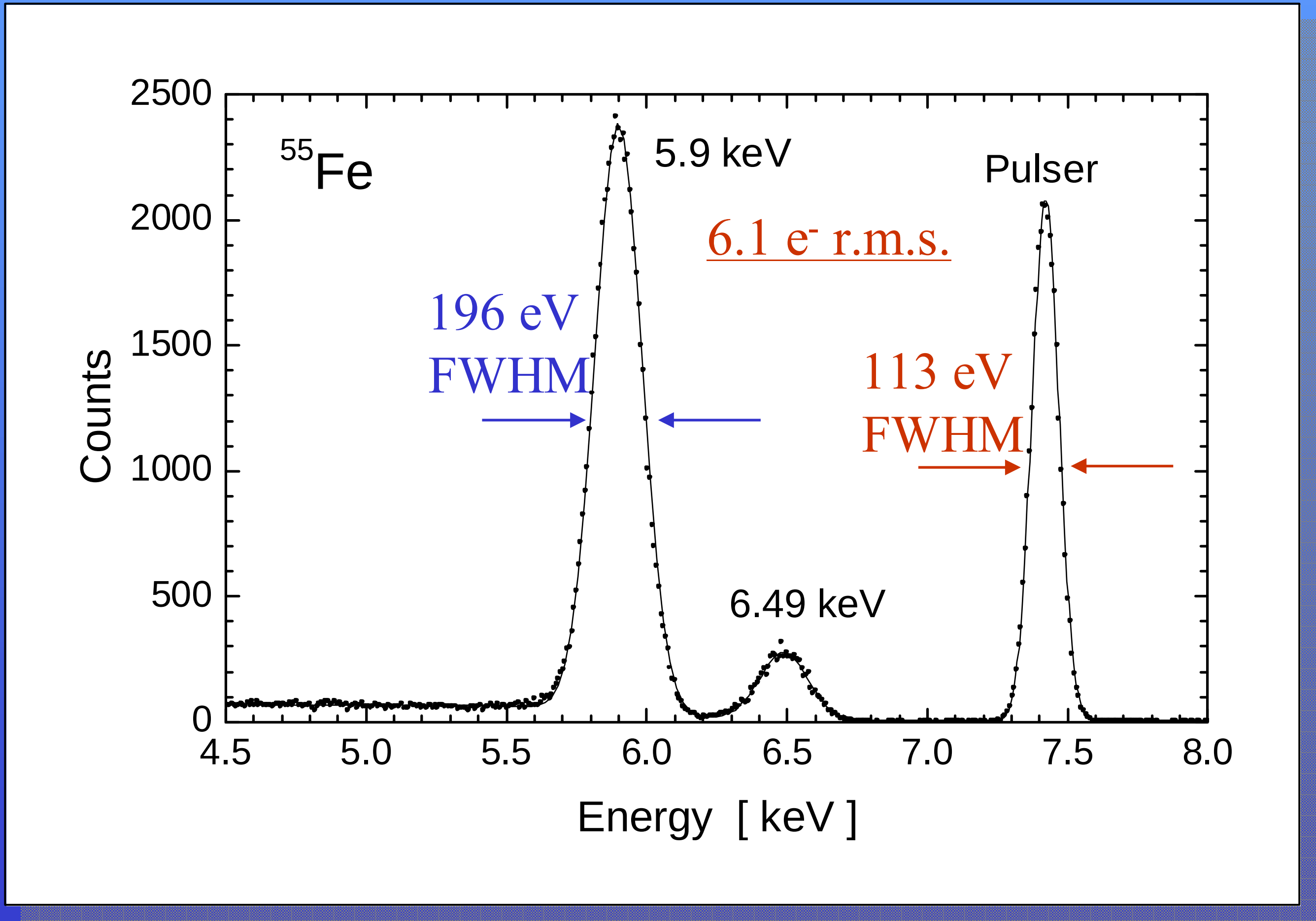


linearity errors within ± 0.2 % (± 0.4 % @ 100°C)

Results with a SiC Pixel detector

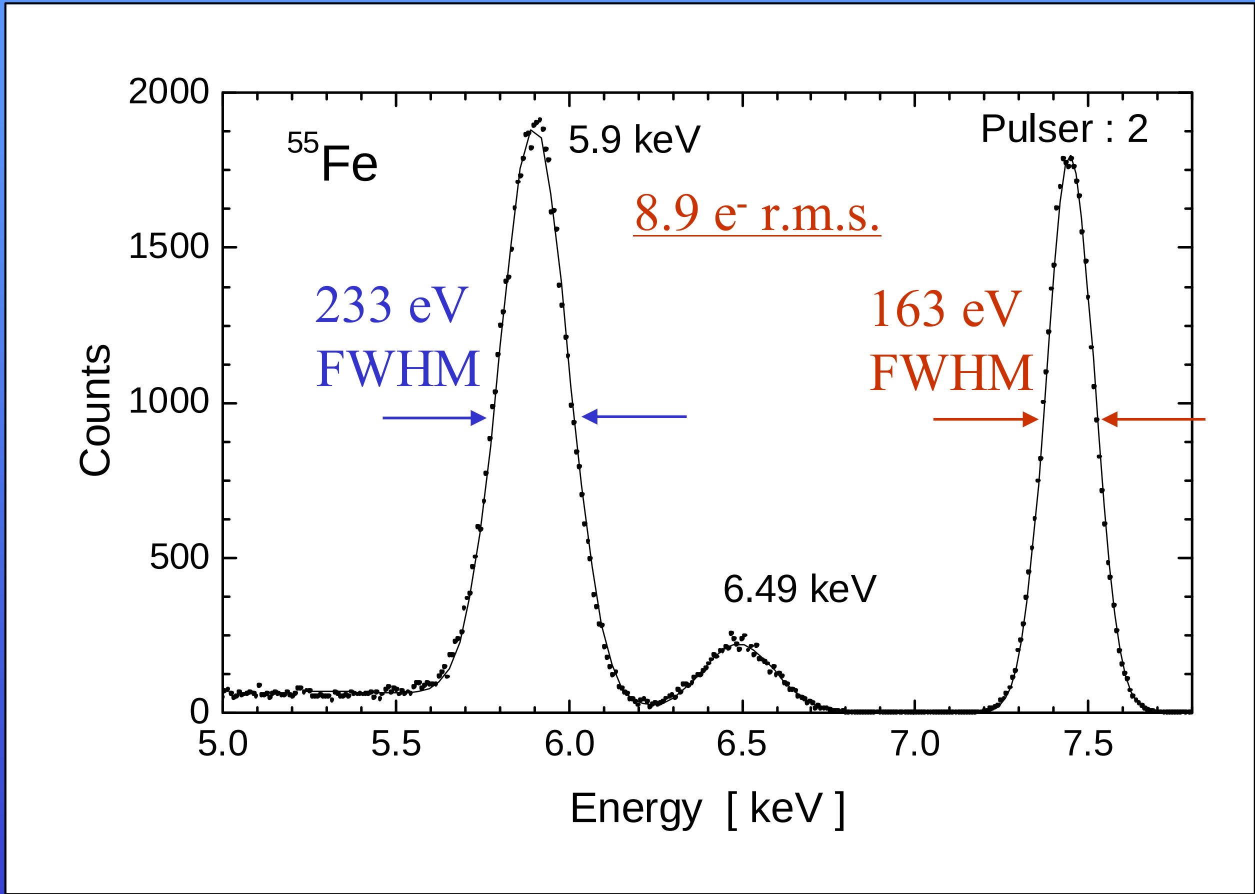
SiC Pixel detector/CMOS Preamp.

303 K (+30°C)



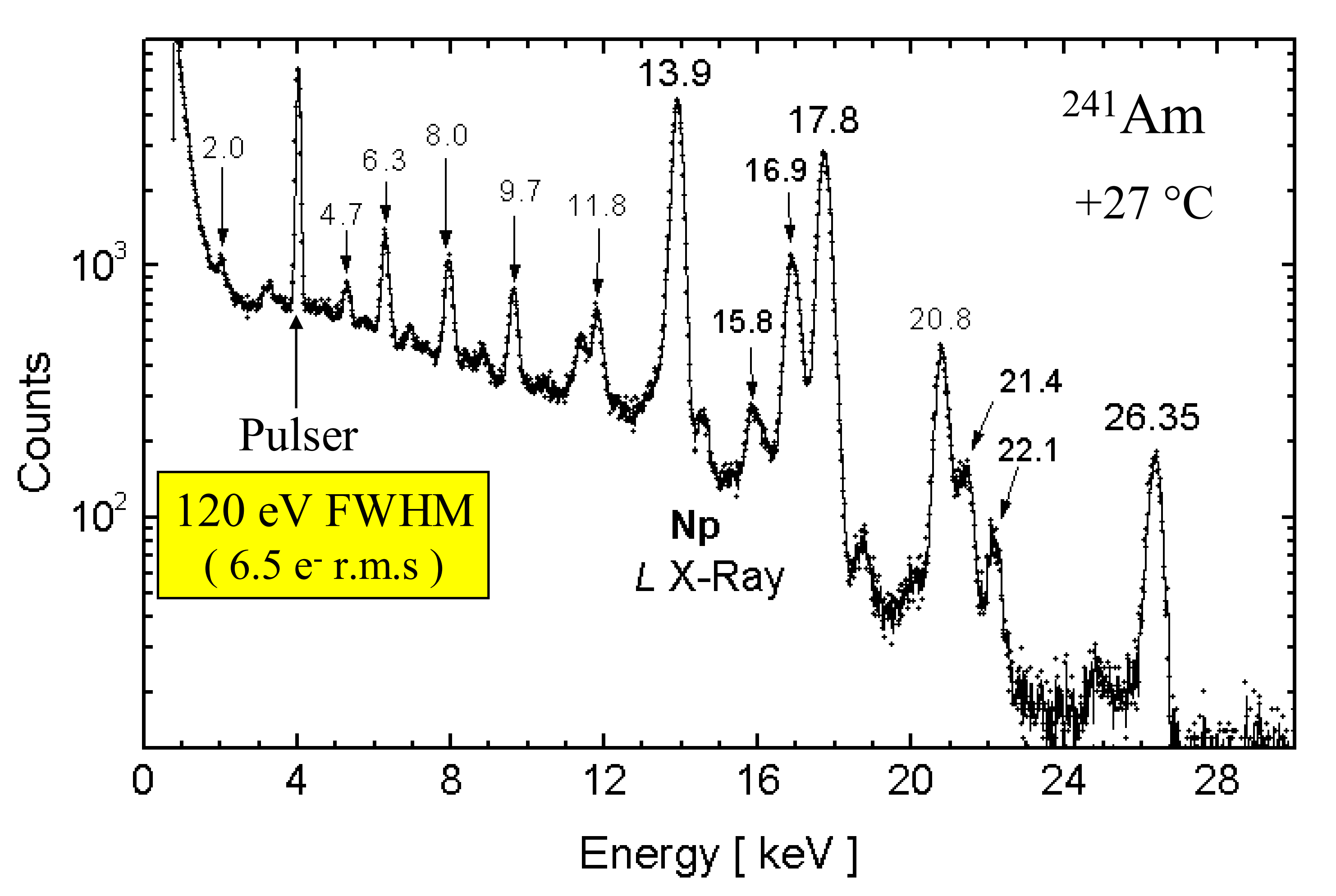
SiC Pixel detector/CMOS Preamp.

373 K (+100°C)



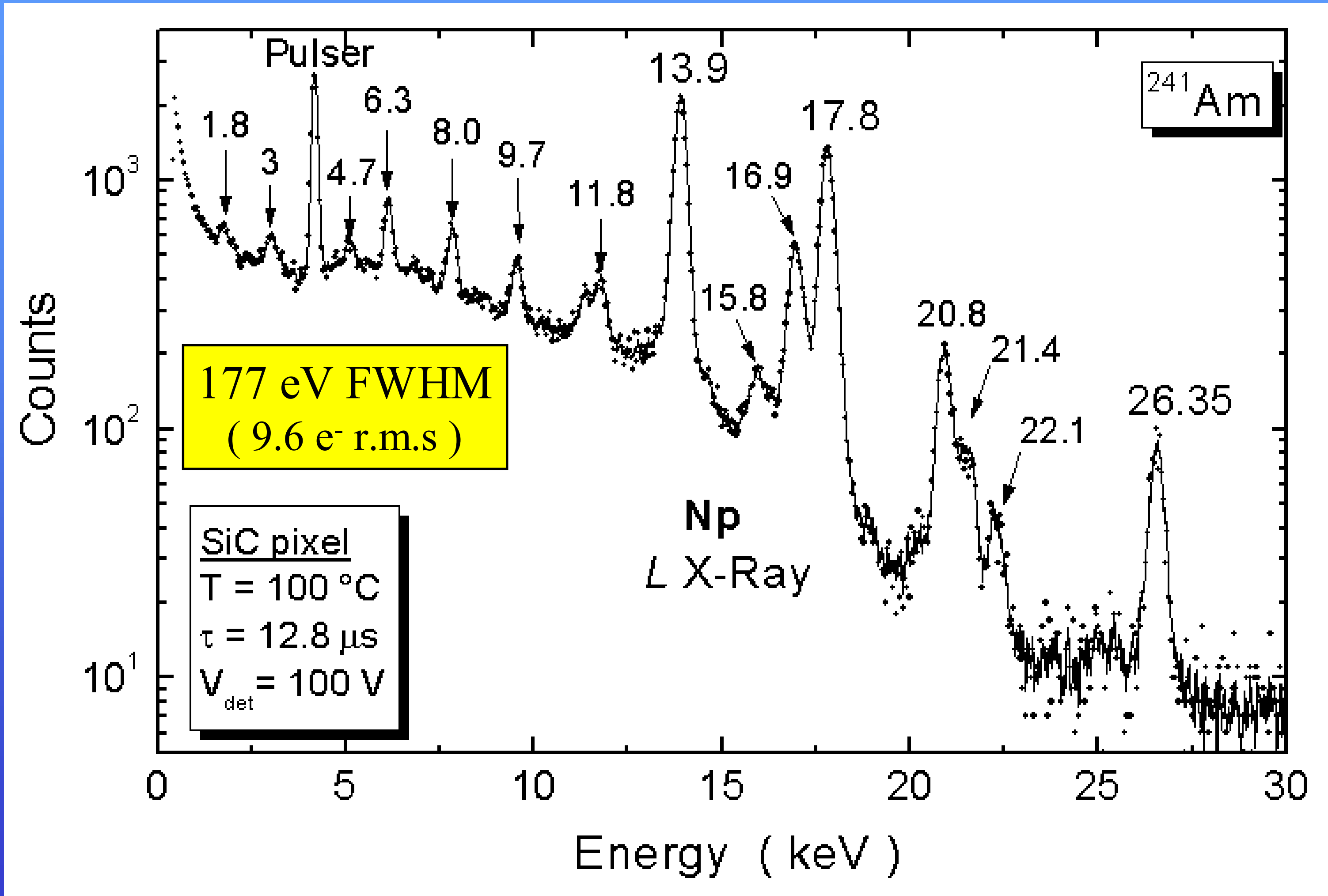
SiC pixel – CMOS IC at +27 °C

^{241}Am Spectrum



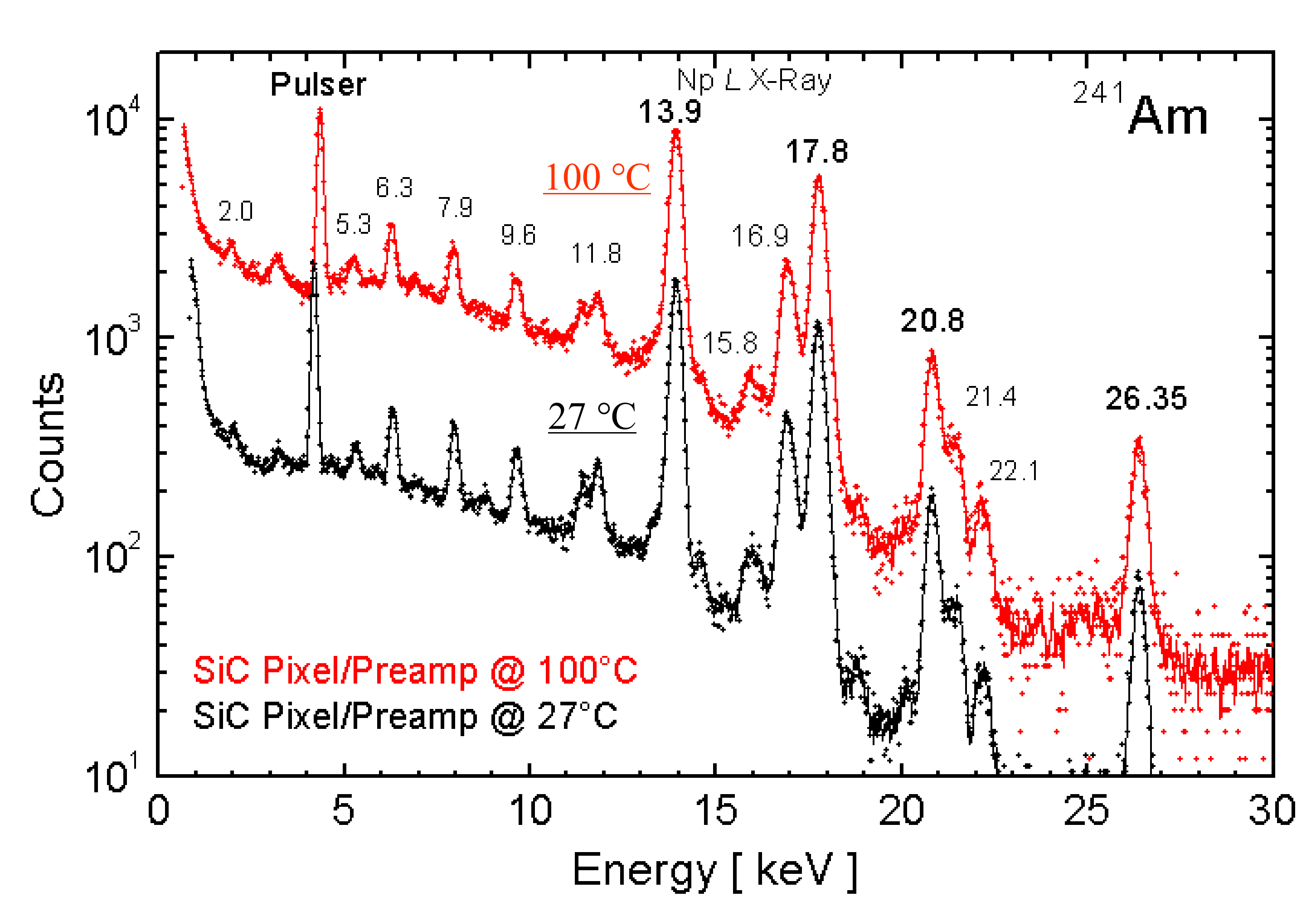
SiC Pixel/CMOS Preamplifier

at +100°C



SiC Pixel/CMOS Preamplifier

27°C vs. +100°C



Summary

1. SiC microstrip & pixel detectors with femptoampere leakage

2. Good uniformity of the junction's parameters

3. Ultra low noise CMOS Preamp. required
   - 3.2 e^- r.m.s. @ 1.3 mW
   - 5.0 e^- r.m.s. @ 39 µW

4. High Resolution – Wide T Soft X-ray spectroscopy
   - 232 eV (µstrip) & 113 eV (pixel) FWHM @ +30°C
   - 336 eV (µstrip) & 163 eV (pixel) FWHM @ +30°C

5. R&D on: Thick/Low doped epi-SiC; Semi-Insulating SiC

Acknowledgements

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