IMPLEMENTATION OF RESILIENCE PLANS AT THE NATIONAL ACCELERATOR CENTER

M. Rodríguez-Ramos, J. García-López, C. Torres-Muñoz, M.C. Jiménez-Ramos, J. Gómez Camacho, C. Guerrero and J.M. López Gutiérrez

Centro Nacional de Aceleradores. Universidad de Sevilla

NATIONAL ACCELERATOR CENTER: FIRST ION ACCELERATOR FACILITY IN SPAIN

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Centro Nacional de Aceleradores

CSIC
Consejo Superior de Investigaciones Científicas

Junta de Andalucía

GOBIERNO DE ESPAÑA
MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES

- The **National Accelerator Center (CNA)** is a research center with particle accelerators oriented toward user service.

- It is a mix center belonging to the **University of Seville**, the **Regional Government of Andalusia**, and the **Spanish National Research Council (CSIC)**.

- Located at Parque Científico y Tecnológico Cartuja C/ Thomas Alva Edison 7 (Seville, Spain).

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INFRASTRUCTURE FOR ACCELERATOR-BASED APPLICATIONS

The CNA is part of a distributed Singular Scientific and Technical Infrastructure (**ICTS**): **IABA** together with CMAM (Autonomous University of Madrid).

- **Ion Beam Techniques (IBA)**
- **Materials Modification**
- **Low energy nuclear physics**
- **Irradiation Damage**

Six main facilities:

- 3 MV tandem accelerator
- 18 MeV proton cyclotron
- Tandetron AMS
- Compact accelerator for radiocarbon
- ^{60}Co irradiator
- PET/CT scanner

Action Line 1: Development of state-of-the-art instrumentation for future Particle and Nuclear Physics experiments

Complementary R&D&I Plan for Astrophysics and High-Energy Physics

Development of Advanced Scientific Instrumentation for National and International Infrastructures in Astrophysics and High-Energy Physics.

- Activity 1.1: **Irradiation of detectors with accelerators**.

J. García López

1.1

1.2

- Activity 1.2: **Accelerator Mass Spectrometry**.

J.M. López Gutiérrez

- Activity 1.3: **Exploitations of European Infrastructures of Nuclear Physics**.

J. Gómez Camacho

C. Guerrero Sánchez

1.3

1.4

- Activity 1.4: **Developments for ion beam therapy**.

M.C. Jiménez Ramos

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Junta de Andalucía
Financiado por la Unión Europea
Plan de Recuperación, Transformación y Resiliencia

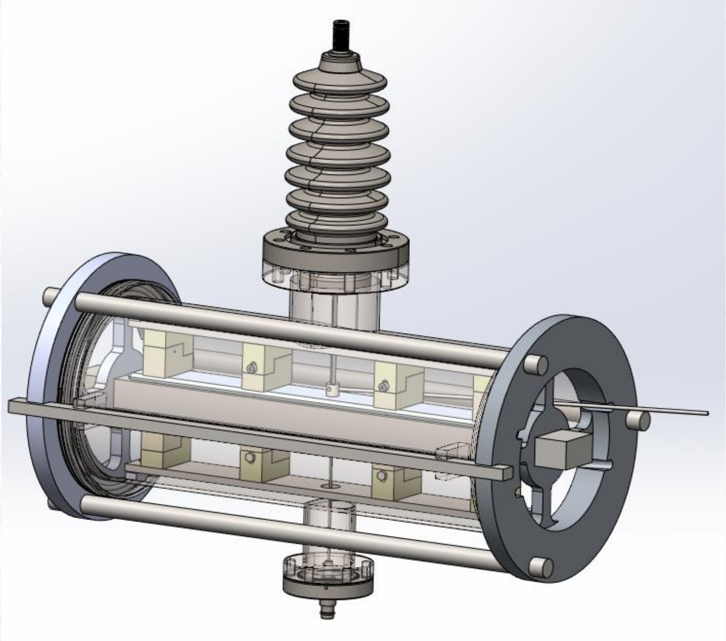
1.4: Developments for ion beam therapy

IP: M. Carmen Jiménez Ramos. Univ. de Sevilla.

Goal: Design and manufacture of a new beam pulsing system for the external line of the CNA cyclotron (for radiobiology studies in FLASH mode).

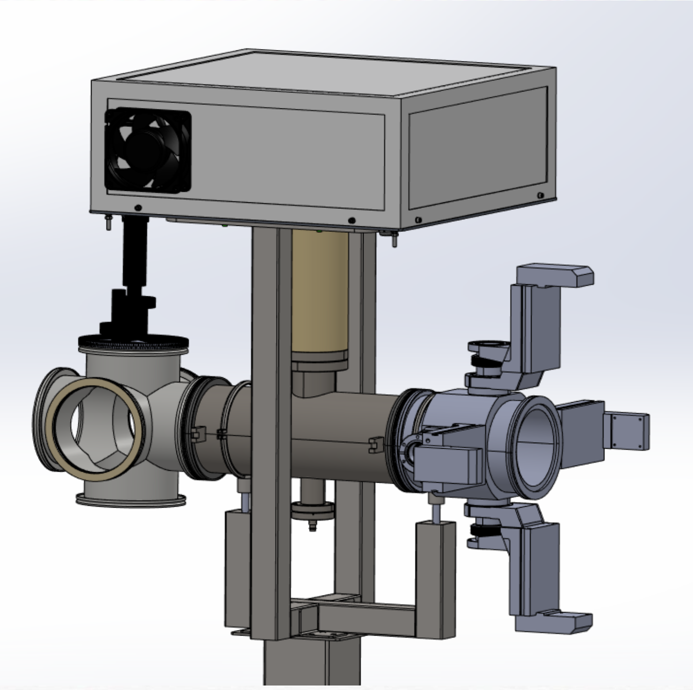
Irradiation of cell cultures in collaboration with research centers as IFIC, CABIMER & UV.

Camera design to deflect the beam. Neptury company



Collaboration with researchers from the AITANA group at IFIC.

Operating voltage: from 1 kV to 26 kV
Pulse rise and fall times: < 900 ns
Repetition rate: from 1 Hz to 1 kHz
Pulse width: from 500 ns to DC



Robot for sample replacement Mecanismos Técnicos y de Laboratorio SL

1.1: Irradiation of detectors with accelerators

IP: Javier García López. Univ. de Sevilla.

Goal: Improvement and upgrade of the 3 MV Tandem and cyclotron accelerators at the National Accelerator Center for radiation detector studies.

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New infrastructures: Sinergy with CERN DRD3 & n-ToF collaborations

Buncher for ns pulses
of H, D and He beams

Neutron spectroscopy
(See J. Bartolomé talk)

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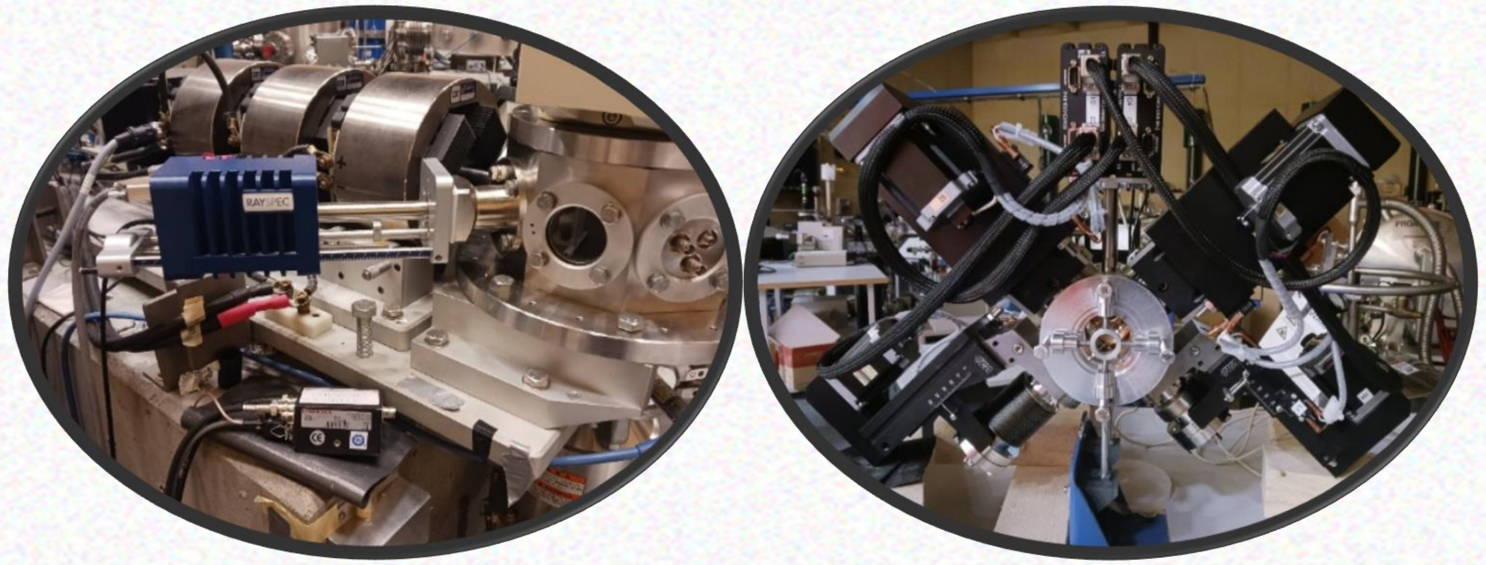
X-ray detector + Preamps

Motorized micrometric slits



Study of semiconductor detectors
(This talk)

AL 1.1: STUDY OF A NEW TYPE OF 4H-SIC SENSORS FOR NUCLEAR FUSION APPLICATIONS

Ion diagnostics must be resilient enough to operate under the harsh radiation and high temperatures of a fusion reactor.

https://static.wixstatic.com/media/8d3e15_a058e93808bc4c3f8cddbf092298a8aa~mv2.gif

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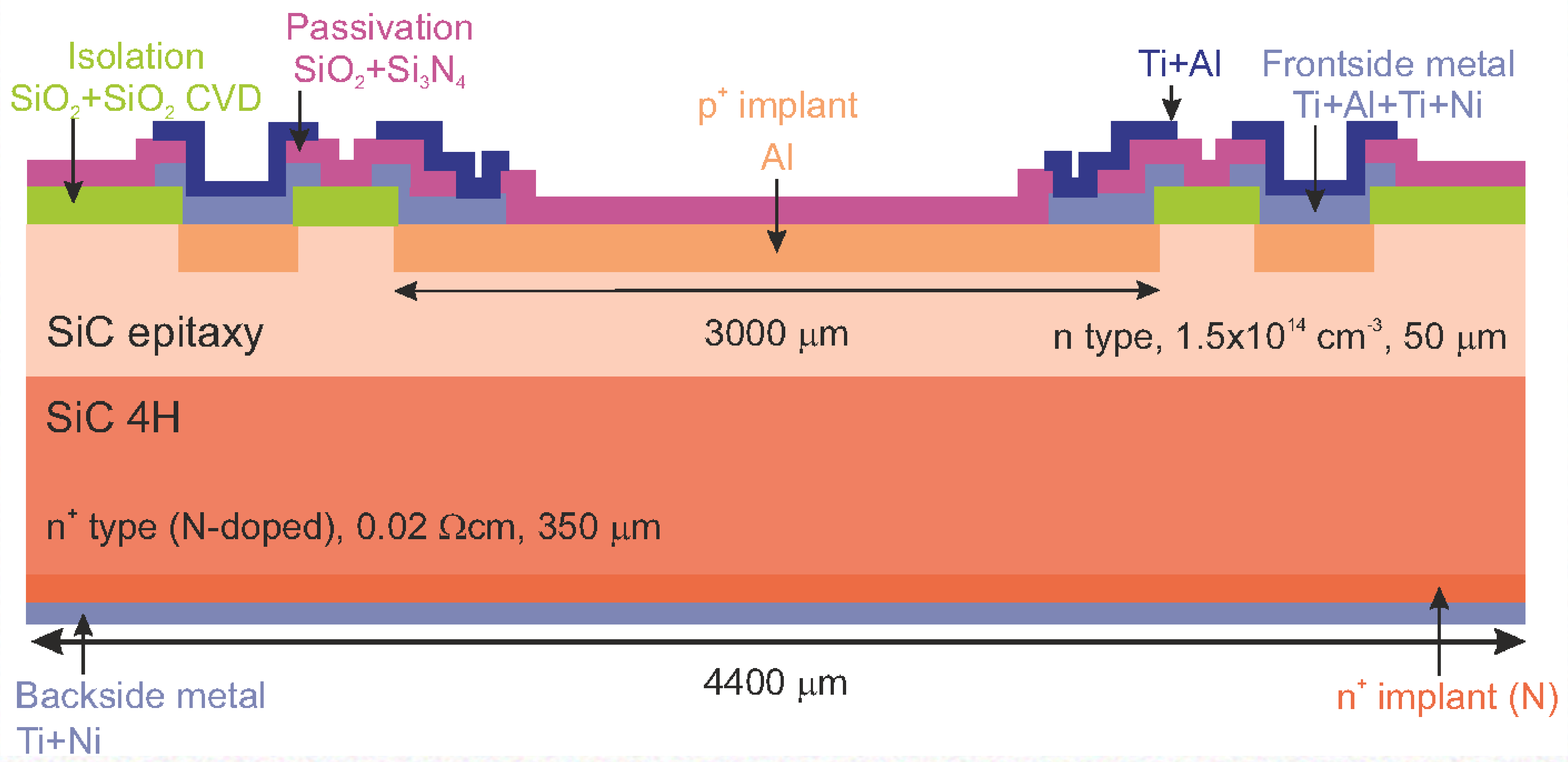

Provided by the IMB-CNM-CSIC group

- n$^+$ type 4H-SiC pn junction sensor manufactured at IMB-CNM.
- Active area of 3x3 mm^2 with ~50 mm active region.
- Non-metalized surface, with only a guard ring structure.

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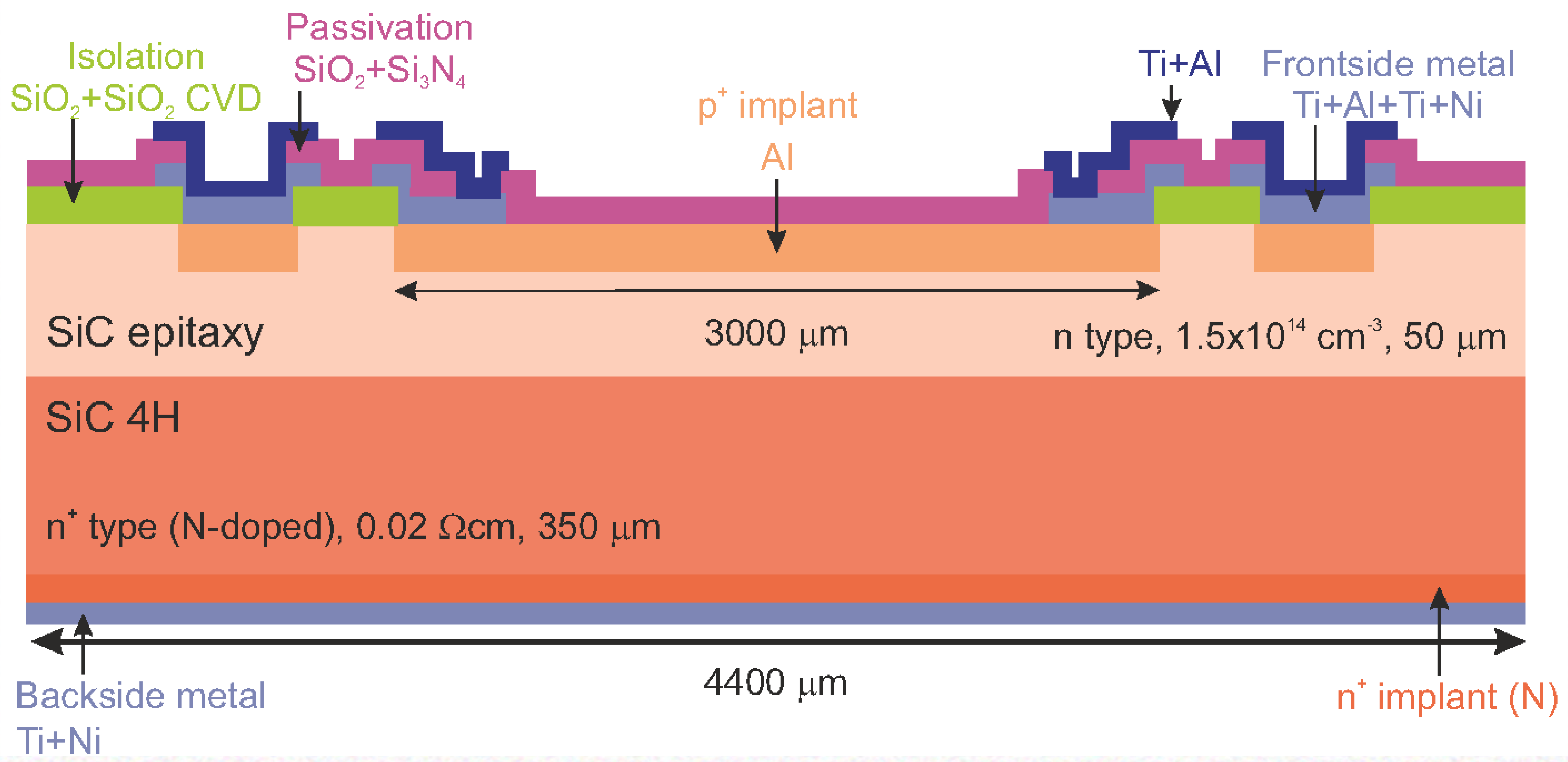

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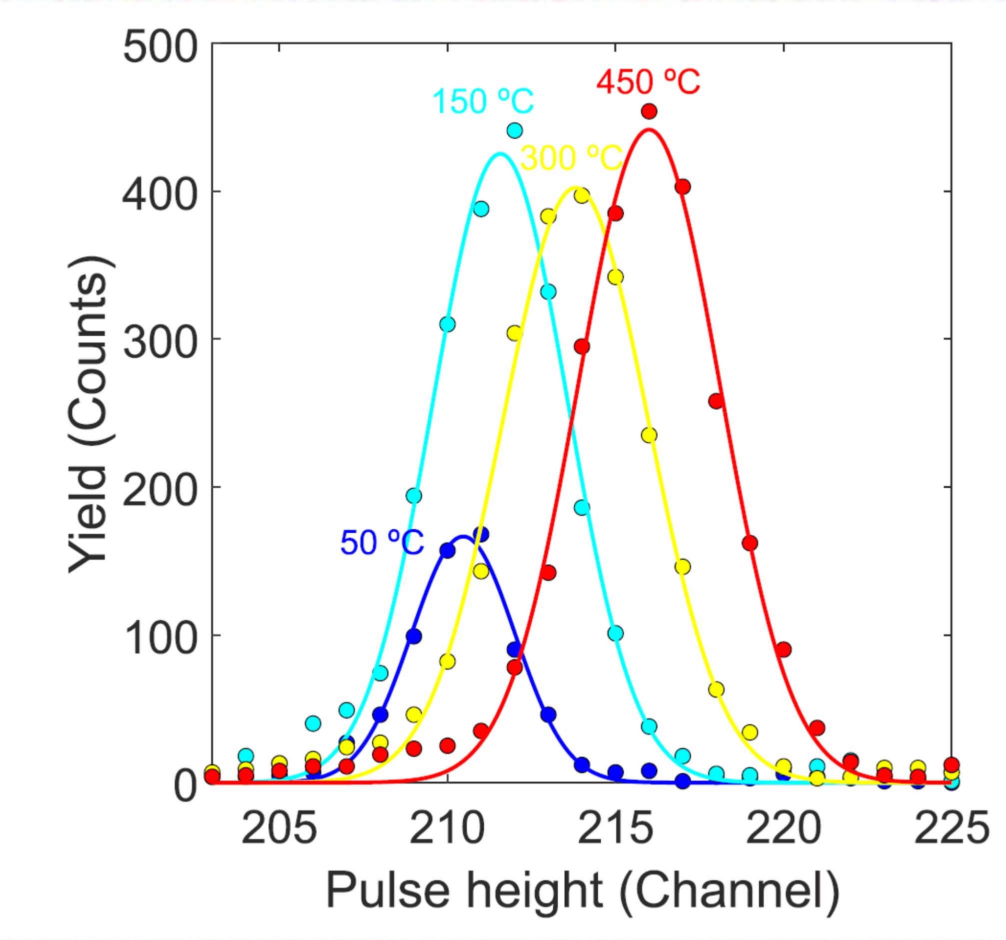

- 4H-SiC detectors operate up to 450 °C with excellent energy resolution (≲2%) (*J. Radiat. Phys. Chem. 2024, 214, 111283*).

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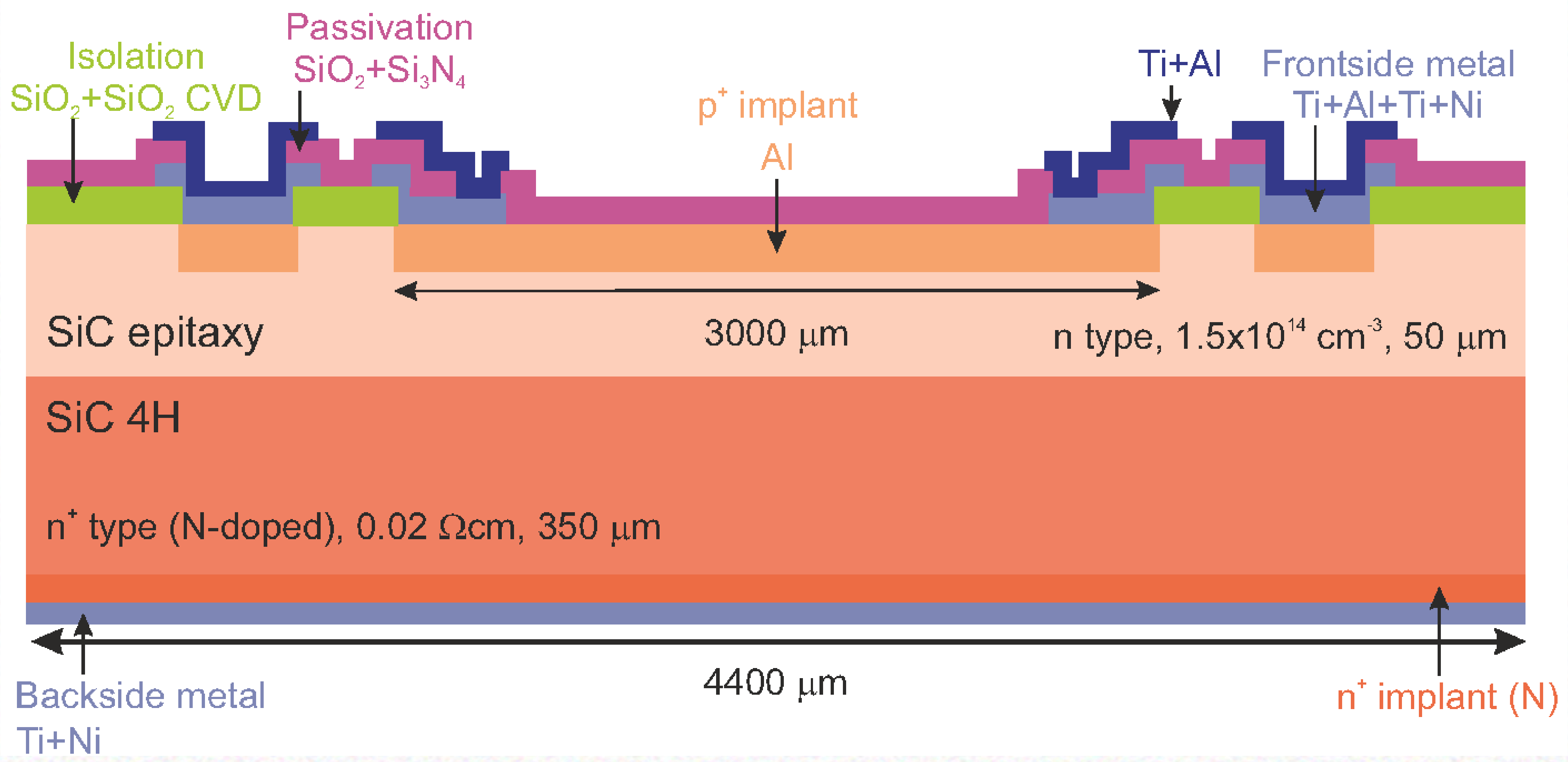

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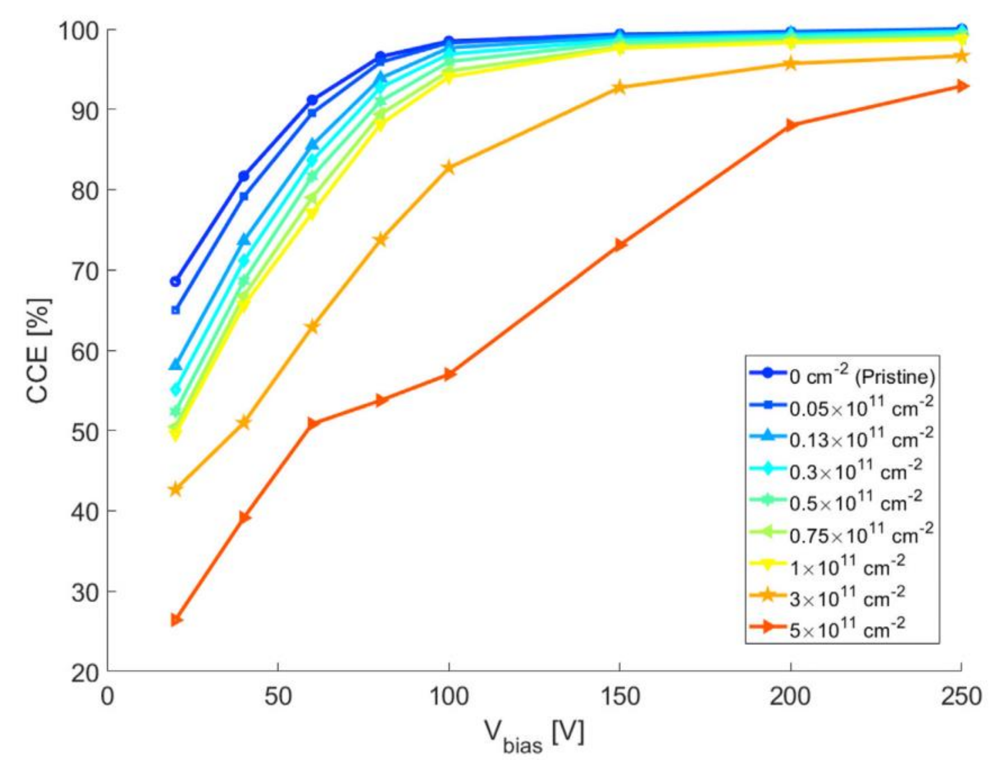
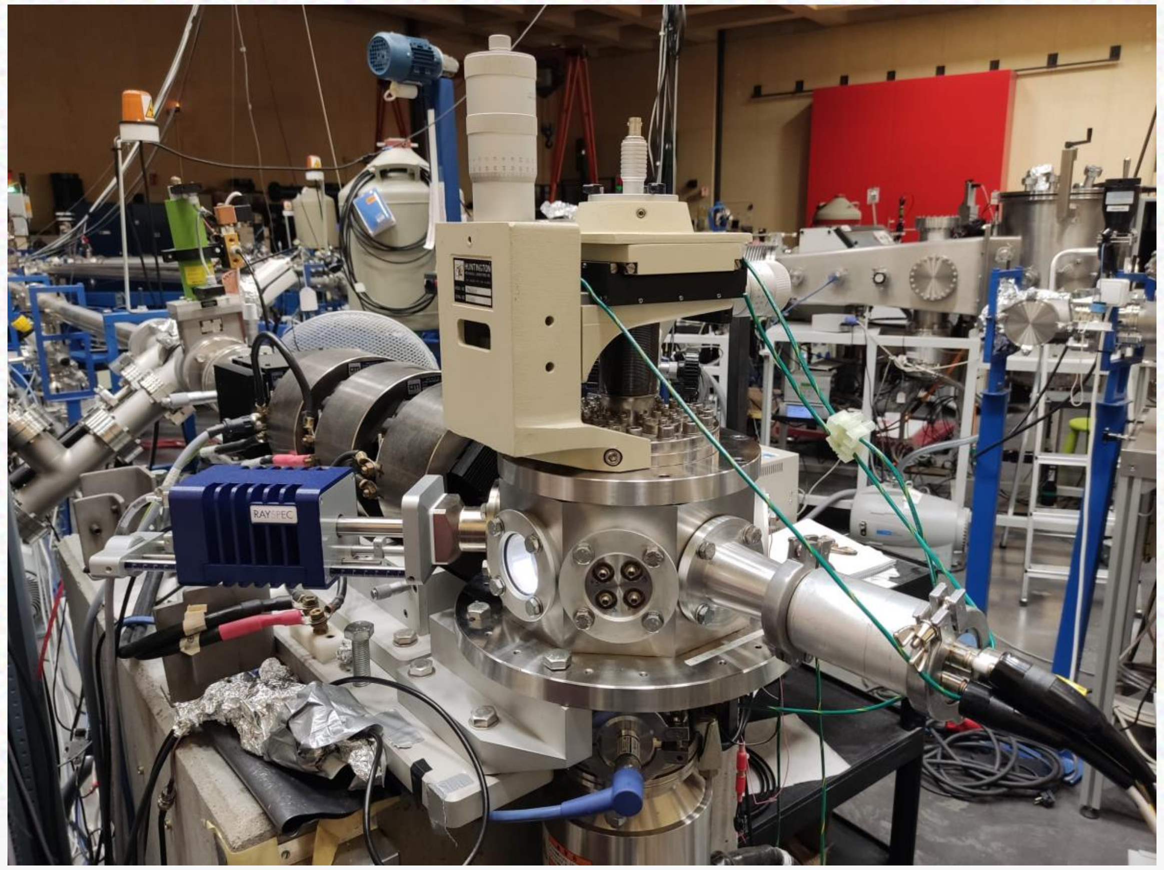


- Detector **radiation hardness** was studied **at room temperature** up to fluences of 5×10^{11} ions/cm^2, showing a significant decrease in charge collection with increasing fluence (*J. Radiat. Phys. Chem 2020, 177, 190100*

ACCELERATORS FOR STUDYING RADIATION INDUCED DEFECTS IN DETECTORS

- The ion beam microprobe linked to a particle accelerator constitutes an powerful tool to characterize radiation detectors.

- Focusing the beam down to **micrometer dimensions**, which enables localized irradiation on small-scale devices.
- Controlled beam rate using **micrometric slits** to avoid additional damage during characterization.
- **Tunable particle energy** within the MeV range (3.5 MeV He^{++}).
- New **ceramic heater** installed, capable of heating samples up to 1200 °C.


Nuclear Microprobe line

PIXE AS AN EFFECTIVE METHOD TO MEASURE ACCUMULATED ION DOSE

- The ceramic heater generates electronic noise, making direct measurement impossible.

- An indirect system is used to determine the accumulated fluence during controlled high-temperature damage.

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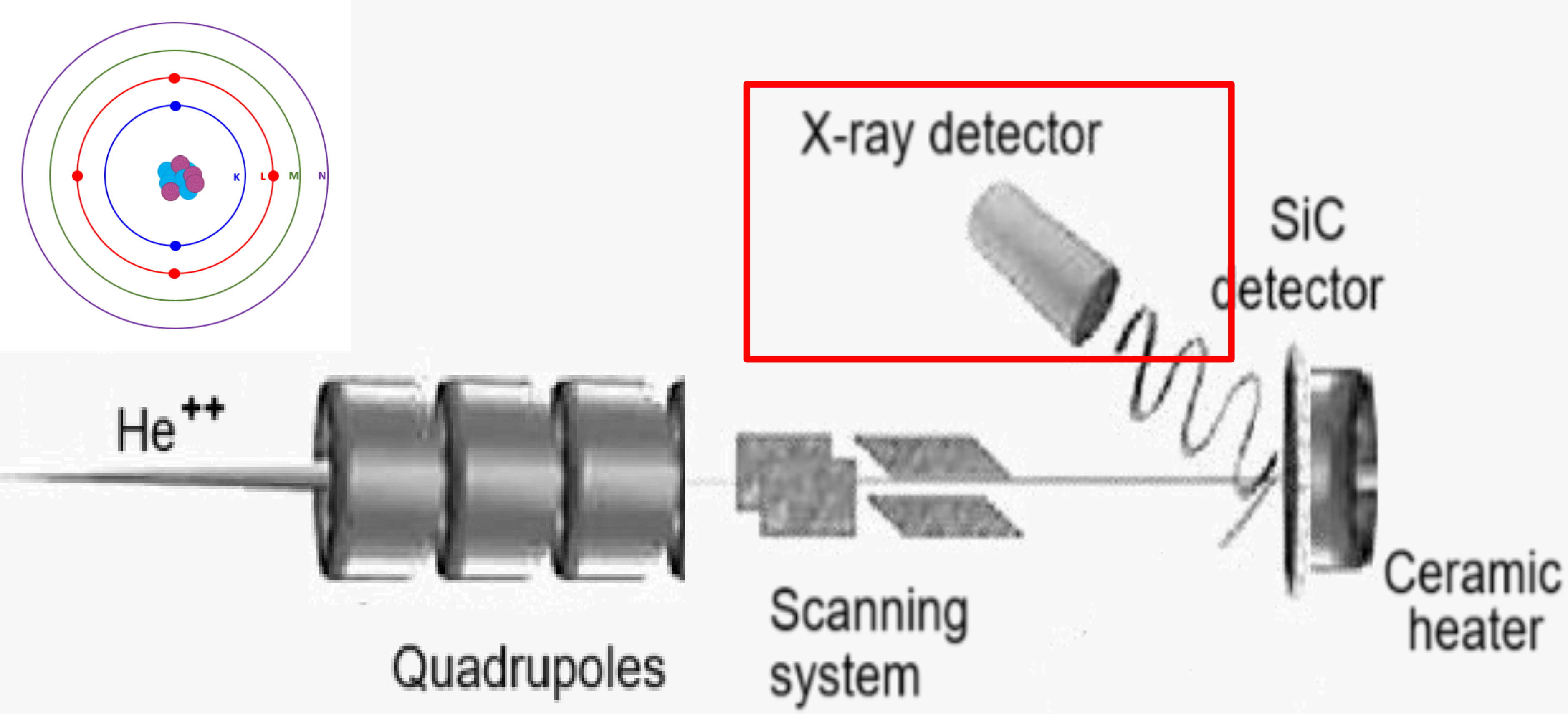

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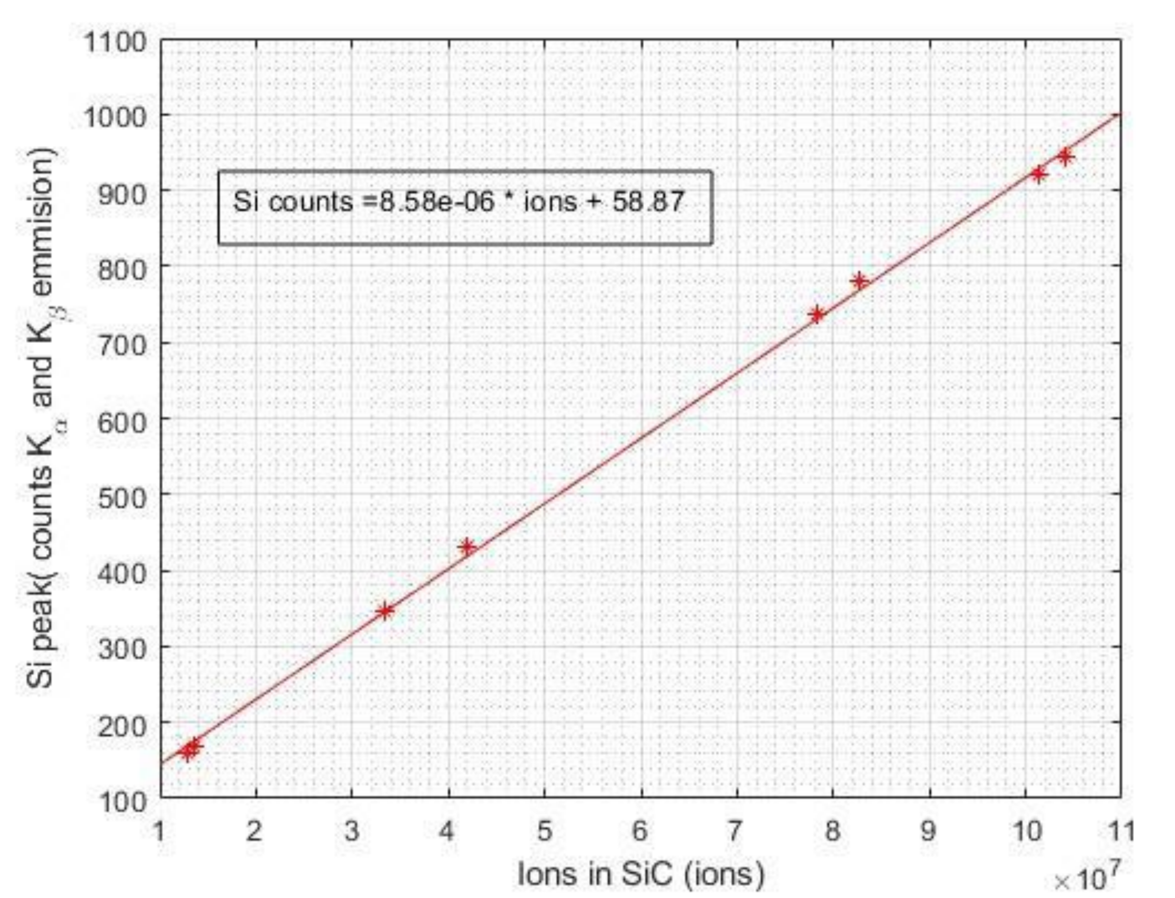
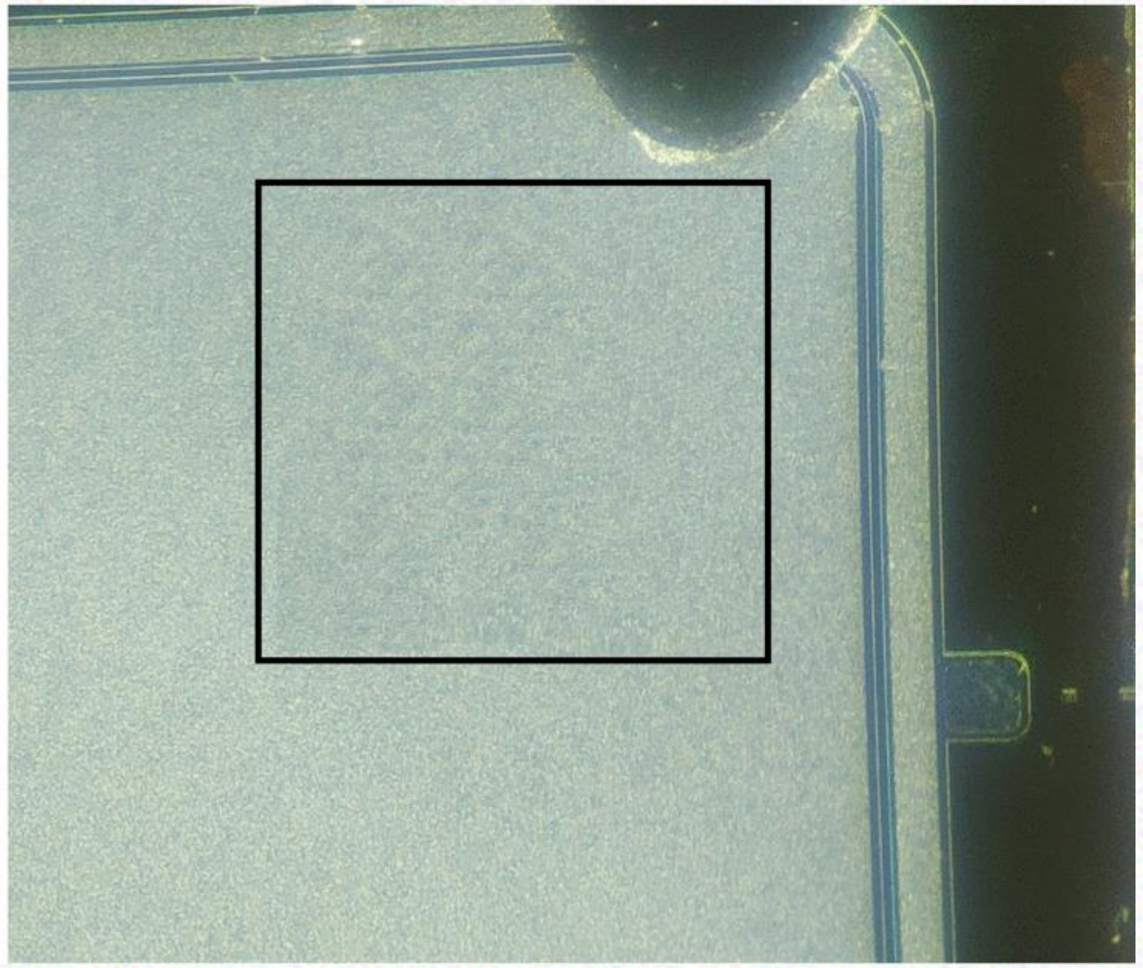
- **X-ray detector** installed at the ion beam microprobe.
- PIXE detects X-rays generated in the SiC detector during alpha particle exposure.
- **X-ray yield is proportional to ion fluence**.
- Enables real-time monitoring of delivered fluence.



RADIATION HARDNESS: ION BEAM–INDUCED DEFECTS AT DIFFERENT TEMPERATURES



- The scanning system allows controlled damage using the focused ion beam.

- Ten 100 × 100 µm² areas with different fluences, first at 400ºC and room temperature.

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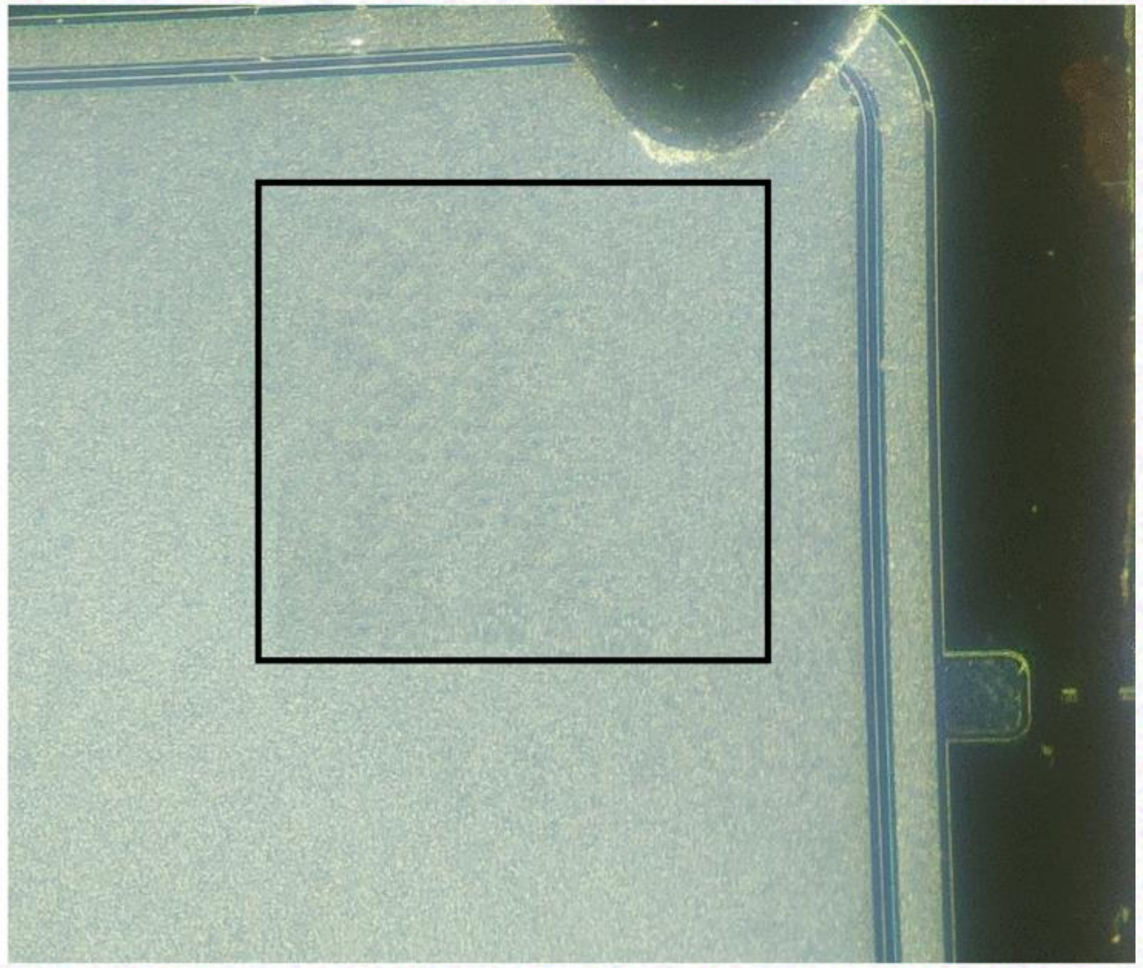

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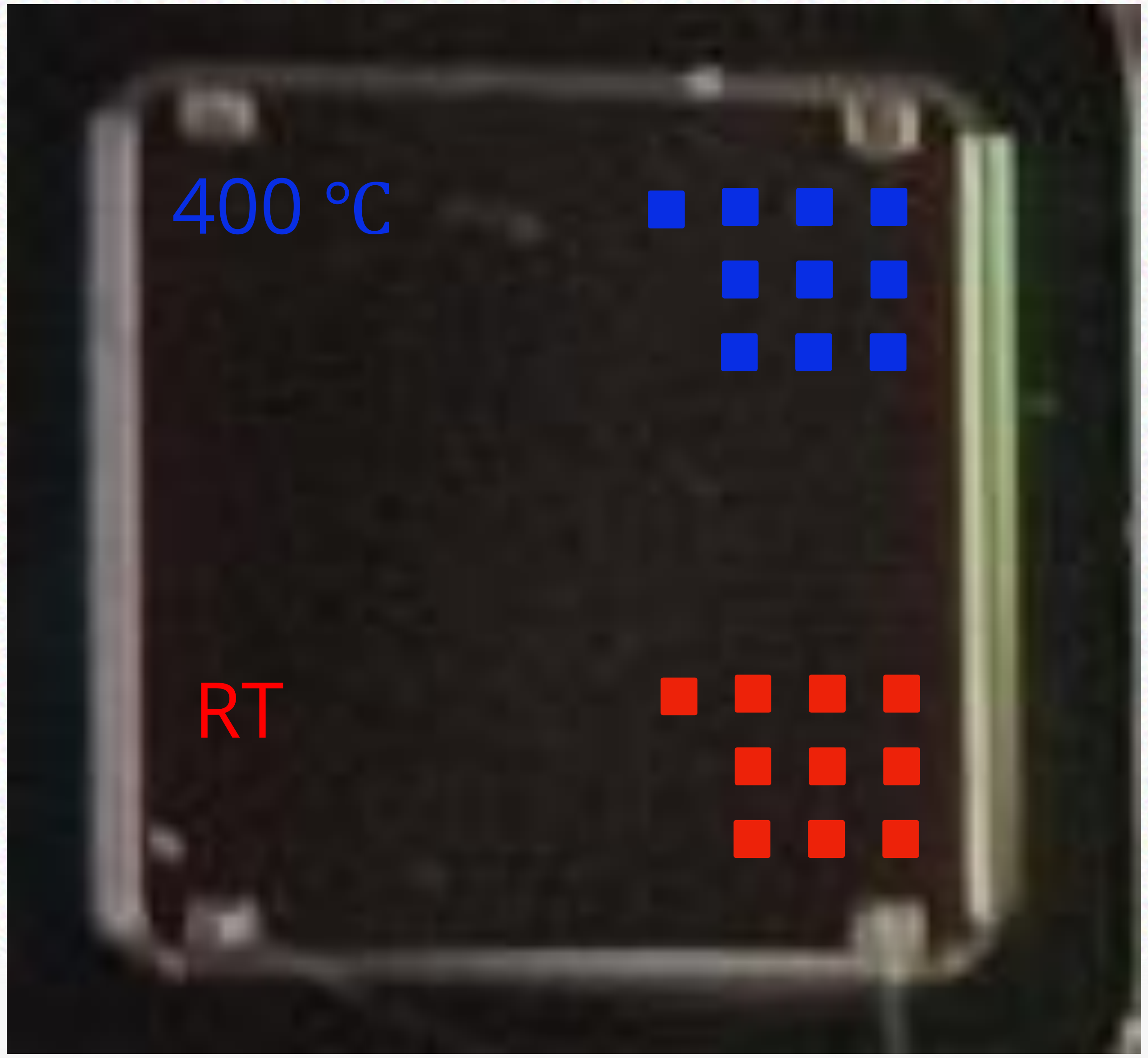
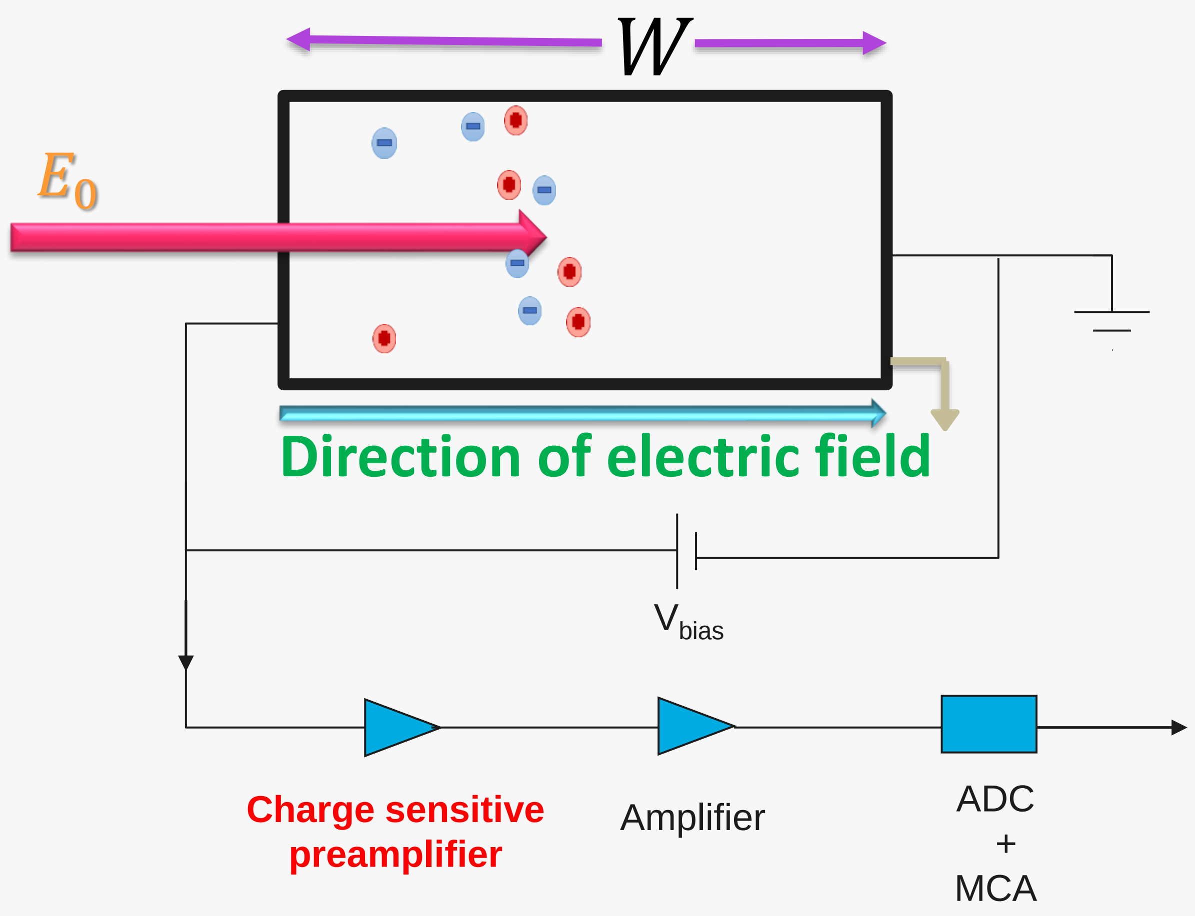
Fluence (ions/cm²)	Fluence (ions/cm²)
1×10^{11}	**3×10^{12}**
3×10^{11}	**5×10^{12}**
5×10^{11}	**8×10^{12}**
8×10^{11}	**1×10^{13}**
1×10^{12}	**Pristine**

- **Post-irradiation analysis via IBIC to assess charge collection efficiency.**



RADIATION HARDNESS: ION BEAM–INDUCED DEFECTS AT DIFFERENT TEMPERATURES

IBIC technique is an analytical tool based on the creation of electrons/holes by ionizing radiation using single ions.



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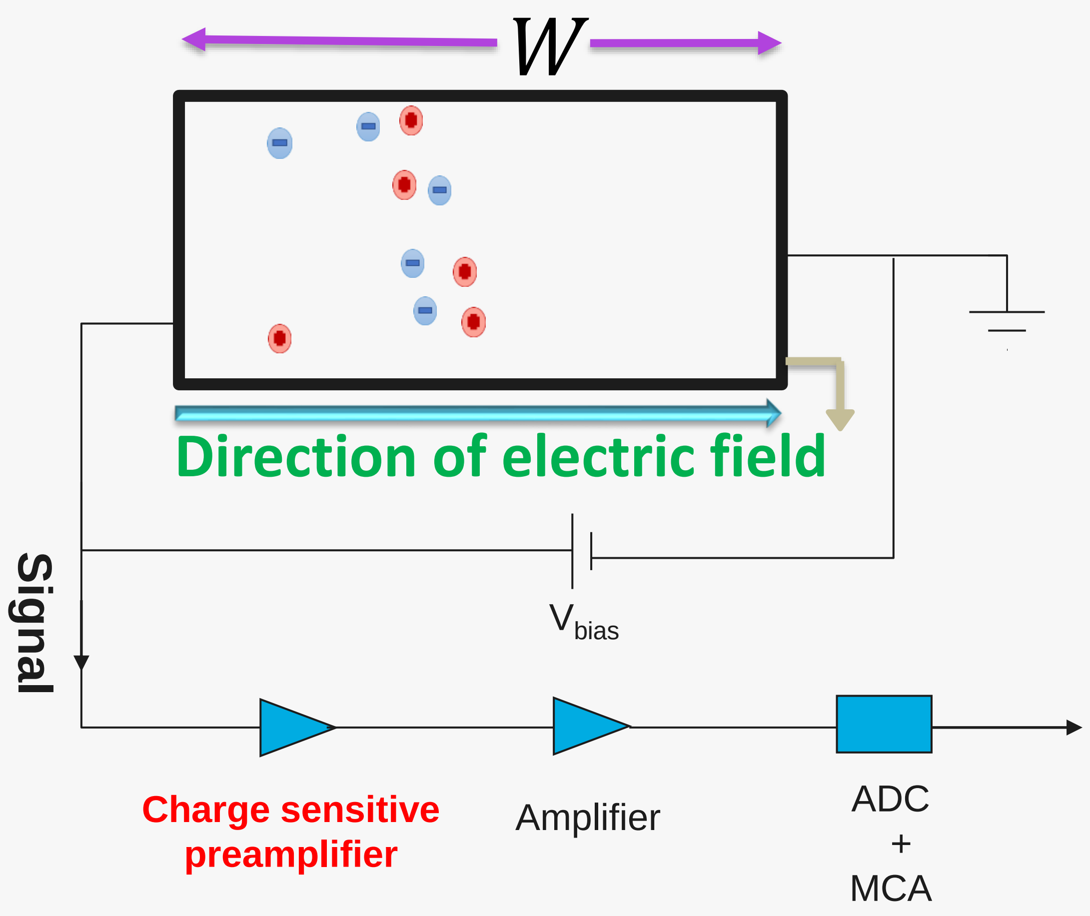

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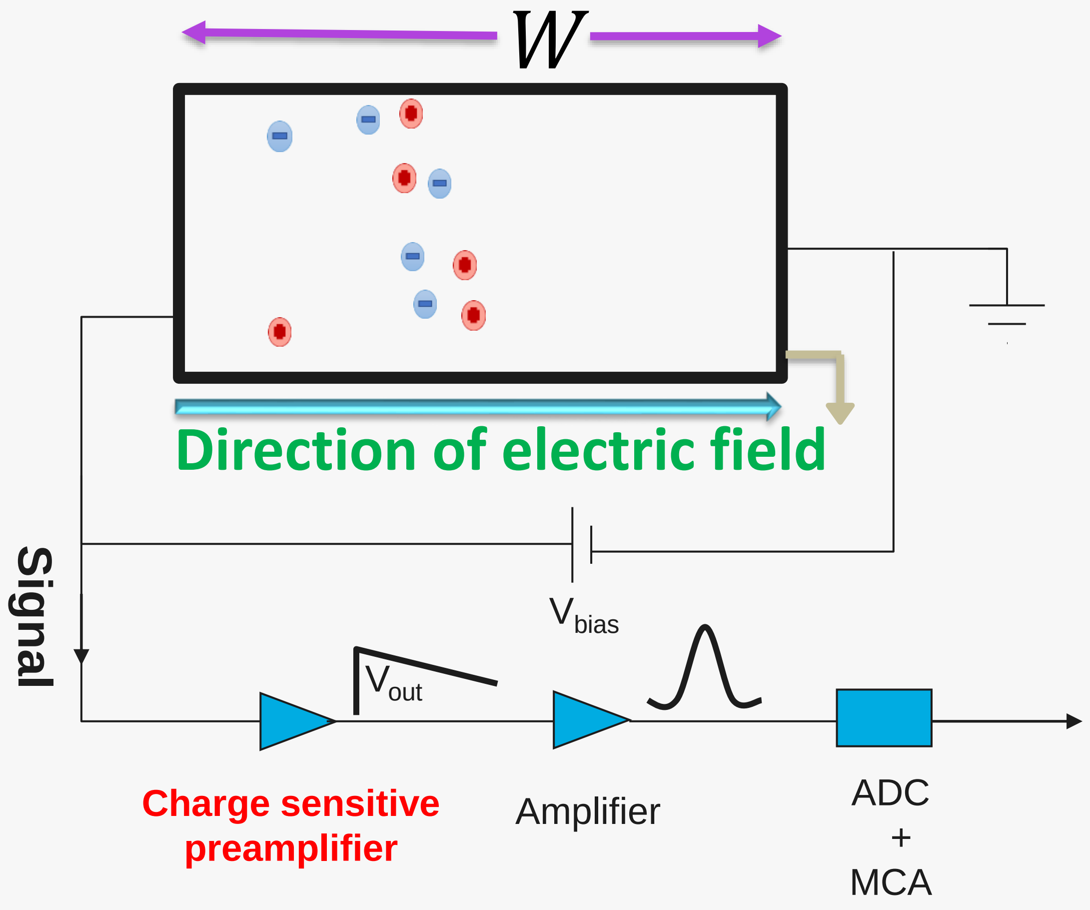

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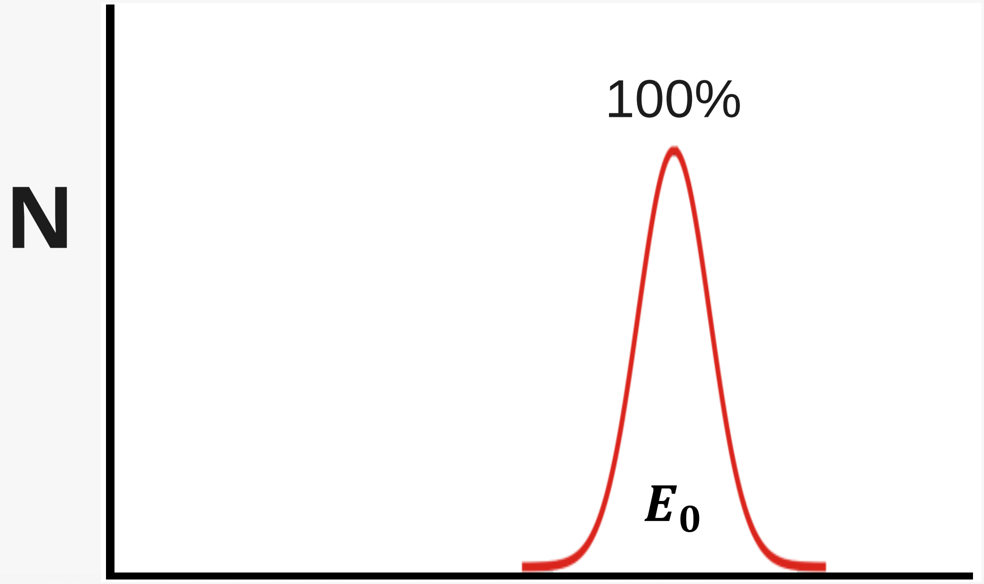

$$CCE = \frac{\text{Charge measured}}{\text{Charge generated}} = 100\%$$

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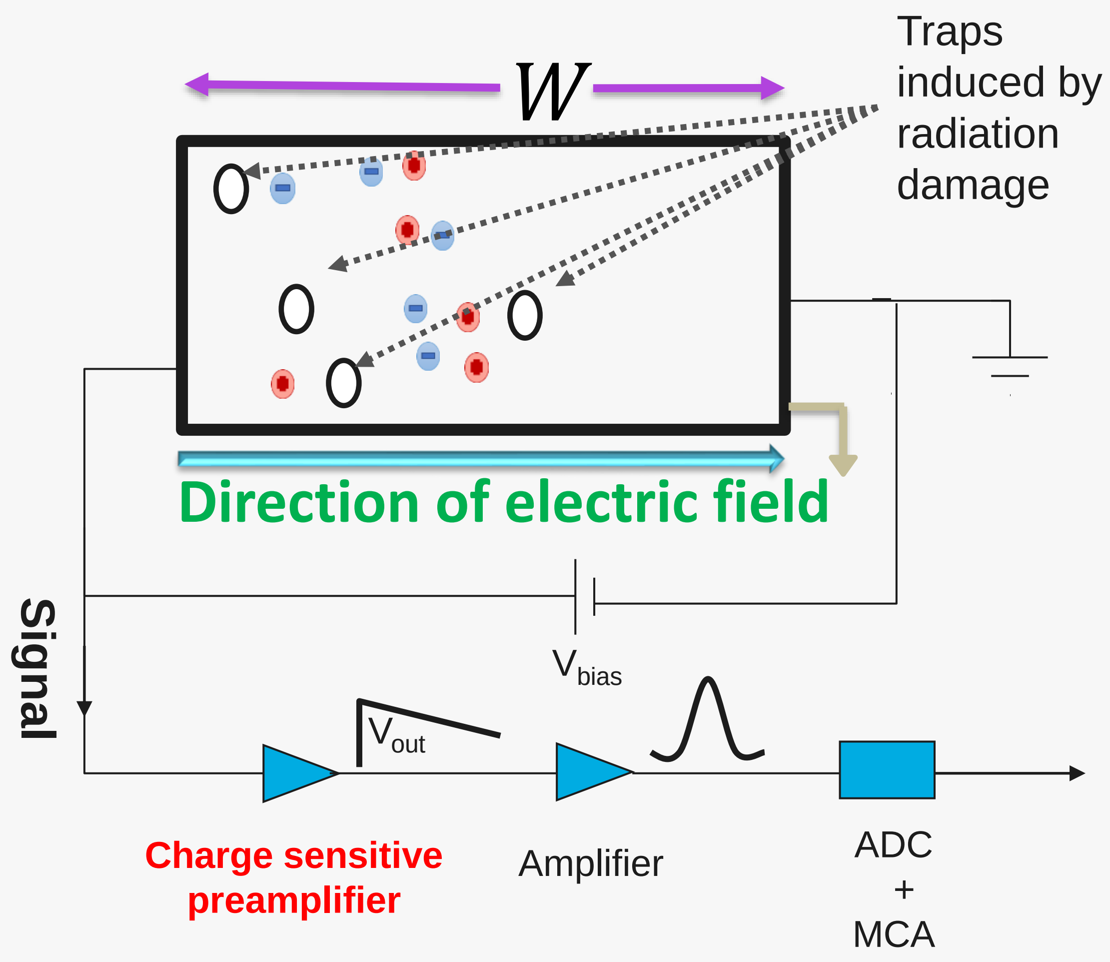
Presence of defects, impurities or recombination centers affect the collection of carriers and hence the current.



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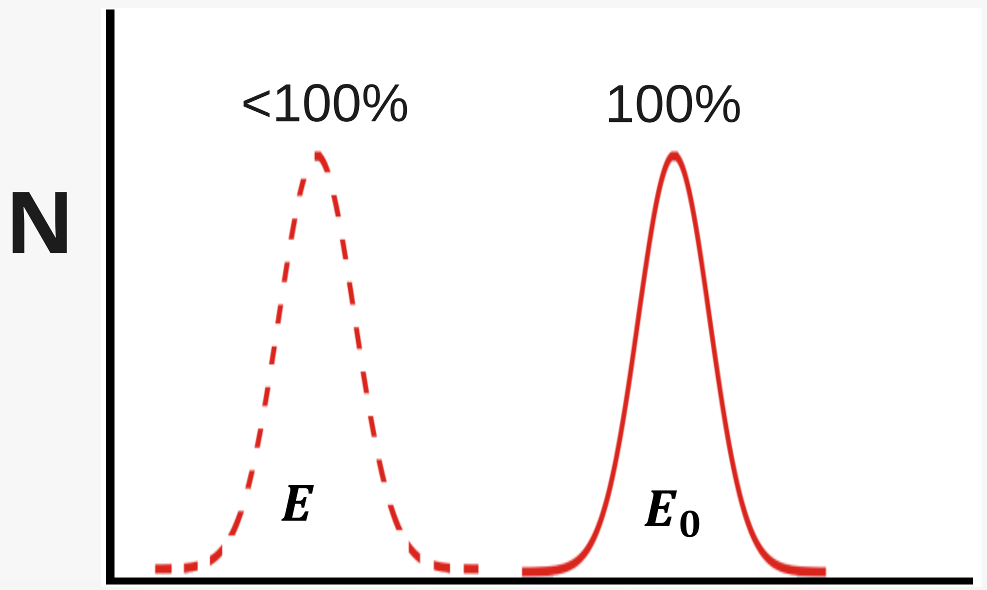

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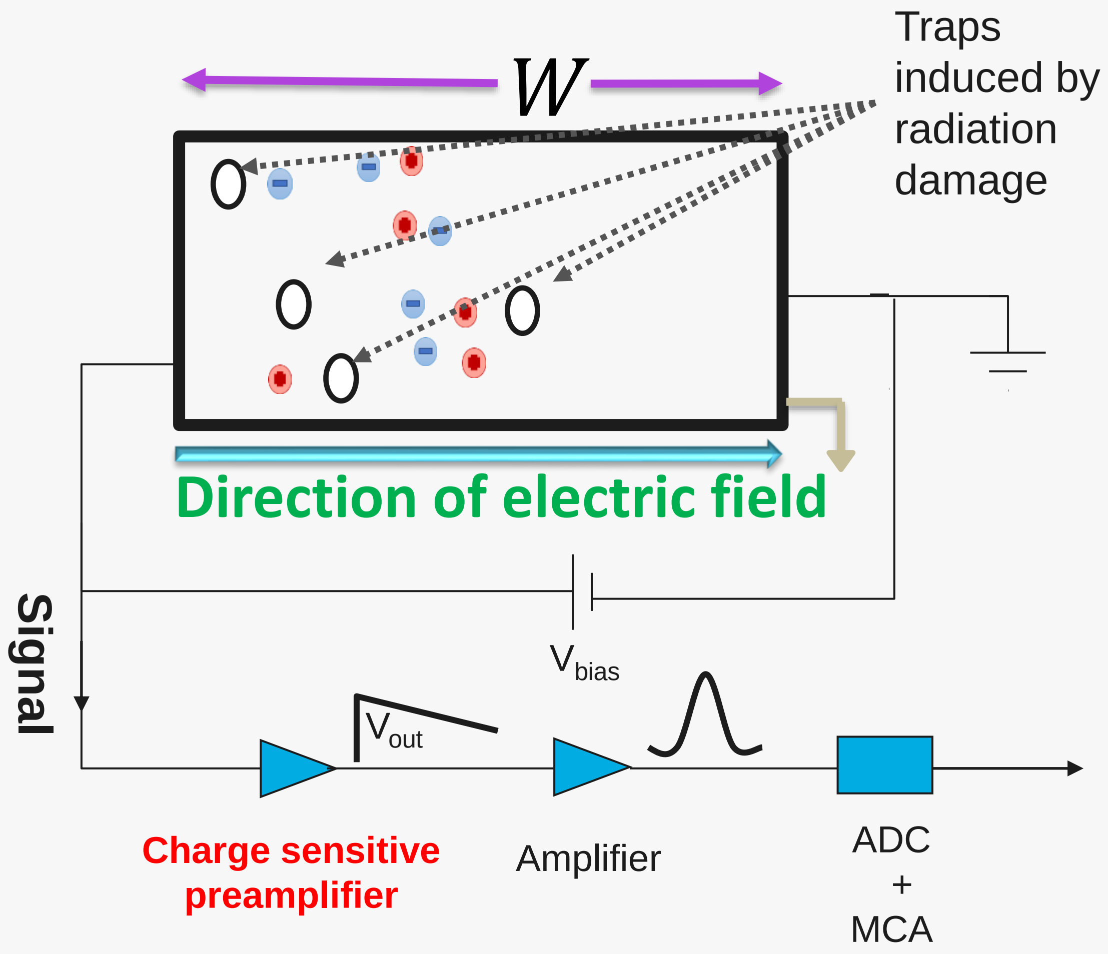

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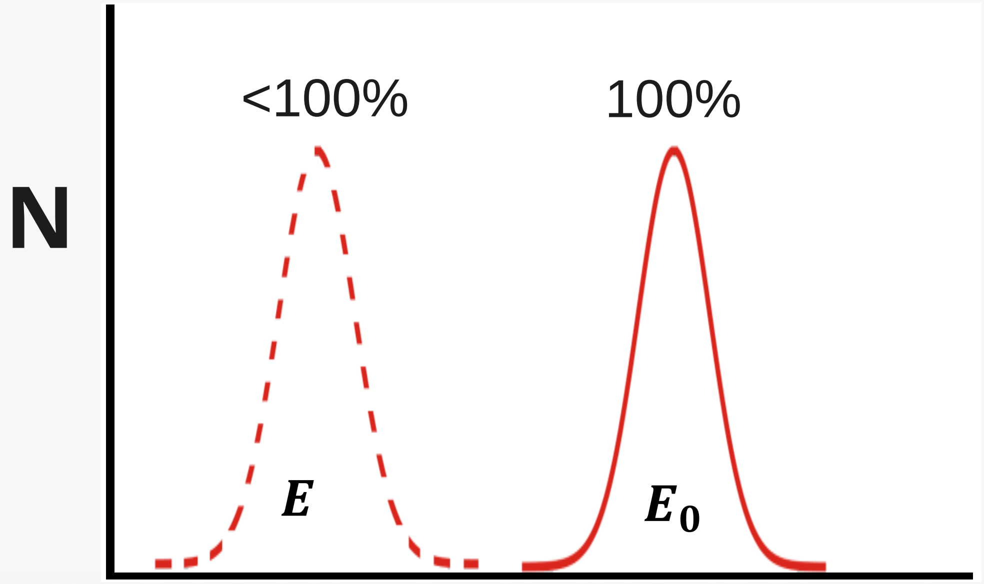
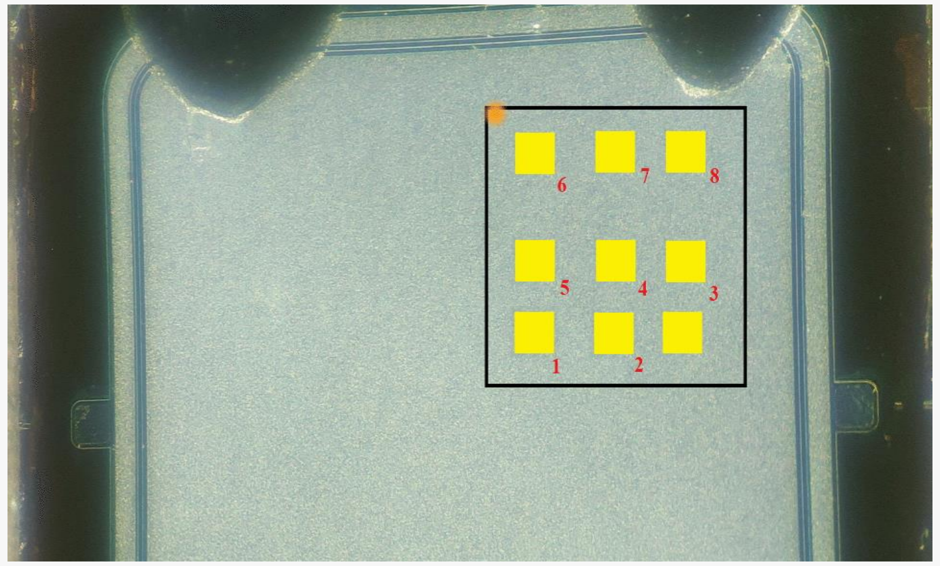


Synchronization of the scanning system with the DAQ enables the creation of 2D maps, allowing precise localization of the damaged areas.



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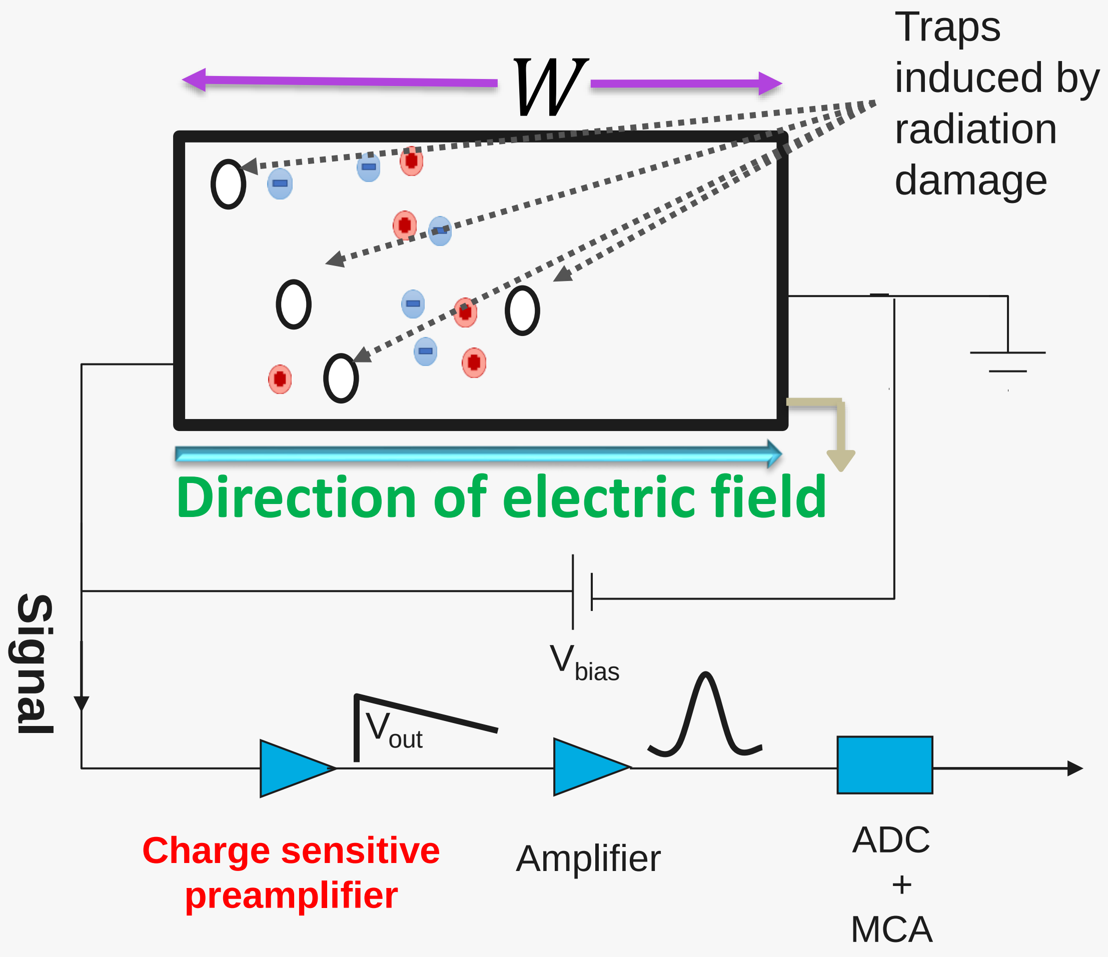

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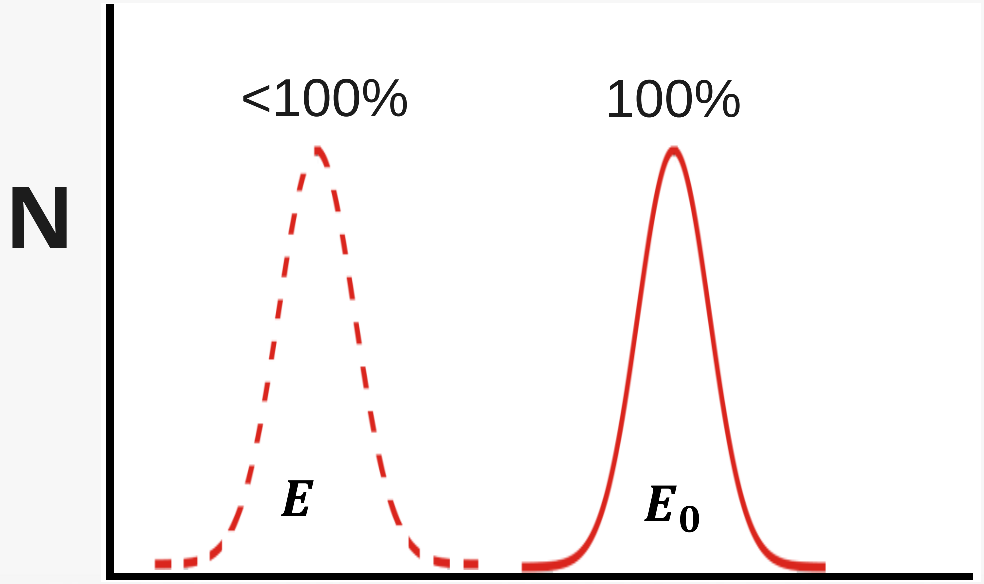

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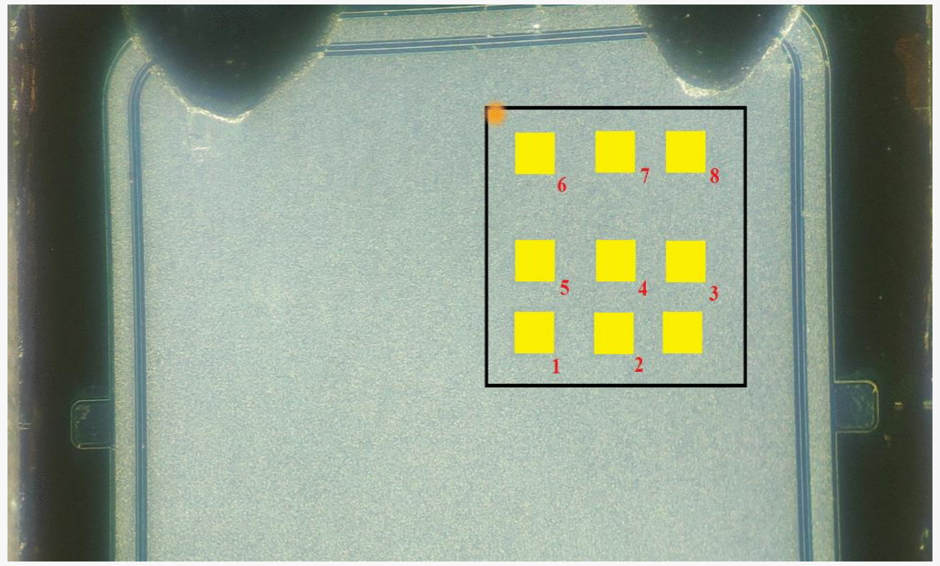

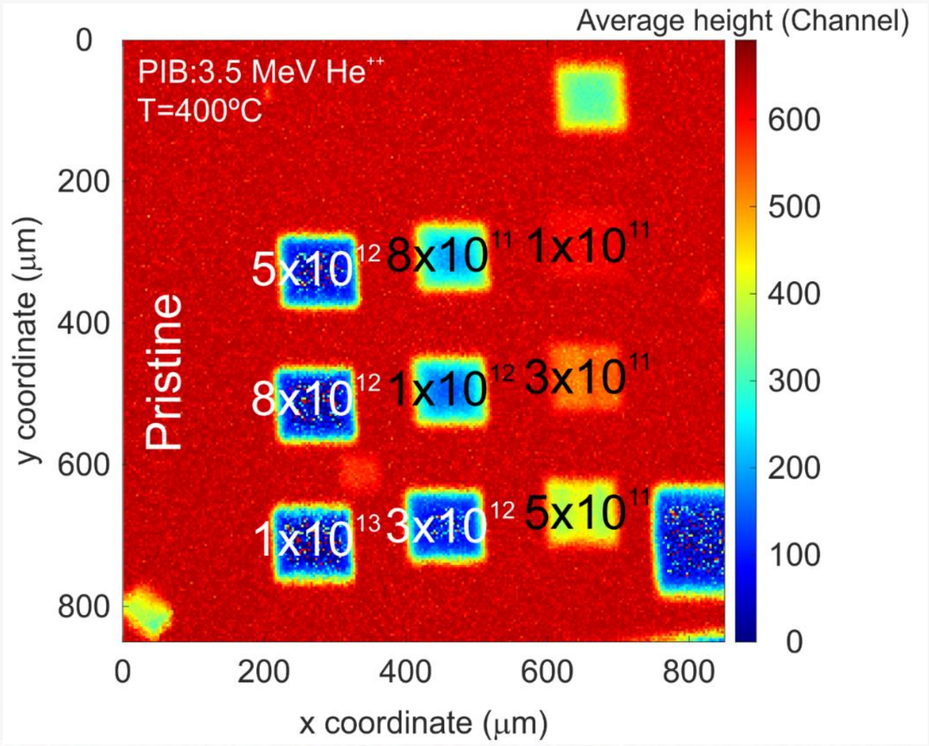

DAMAGE AT HIGH TEMPERATURE ENHANCES THE RESPONSE OF THE DETECTOR

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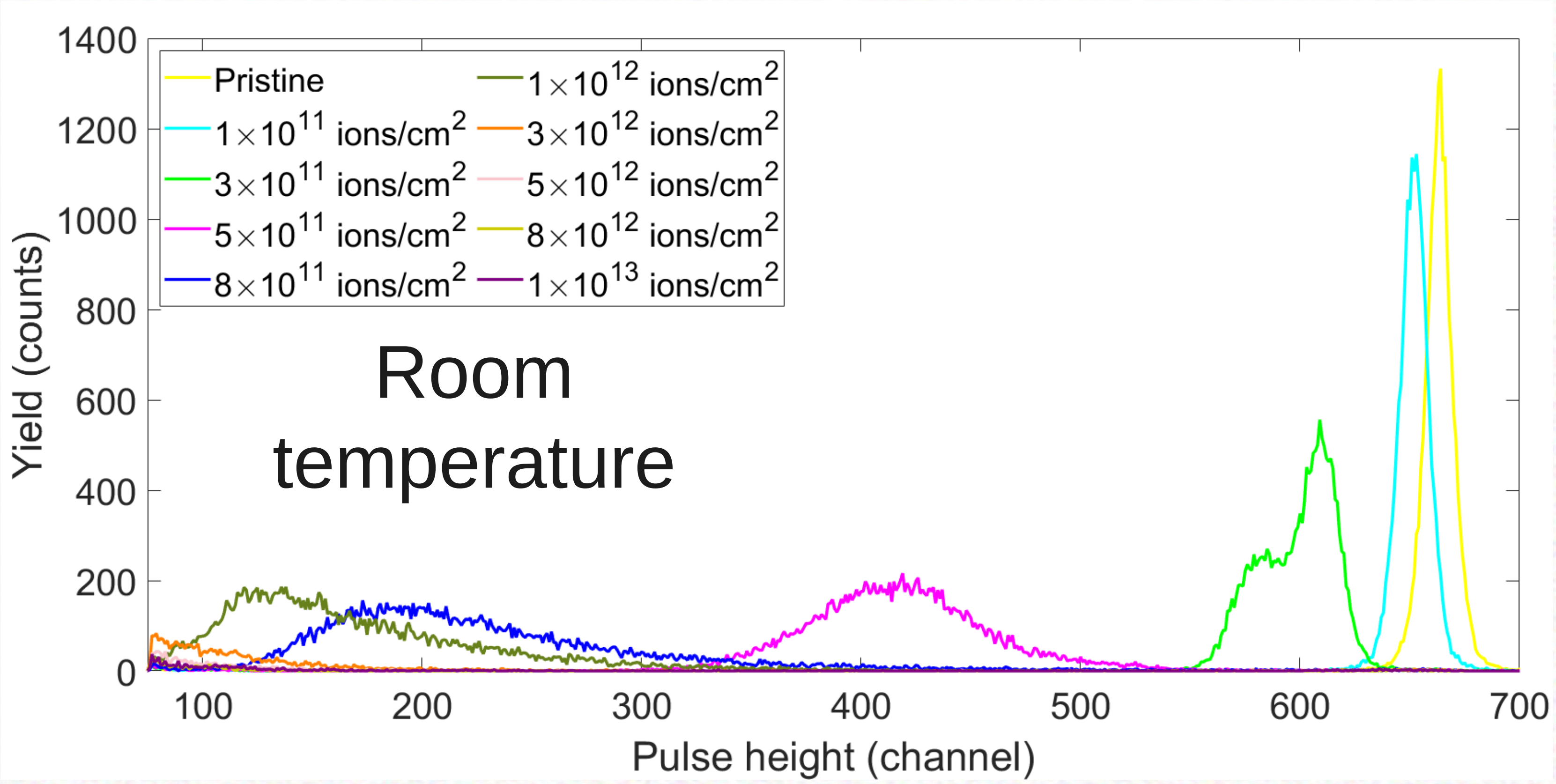

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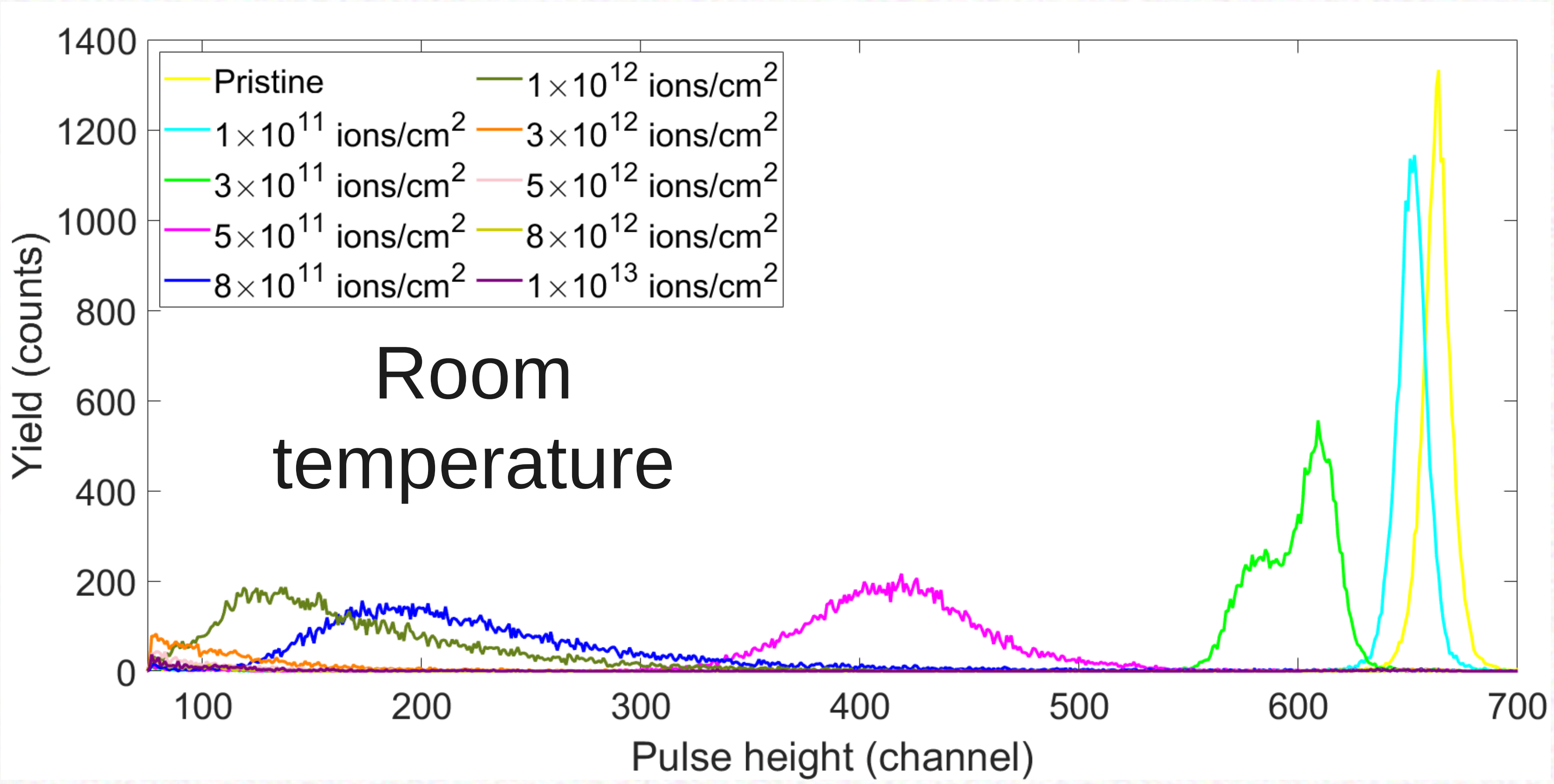

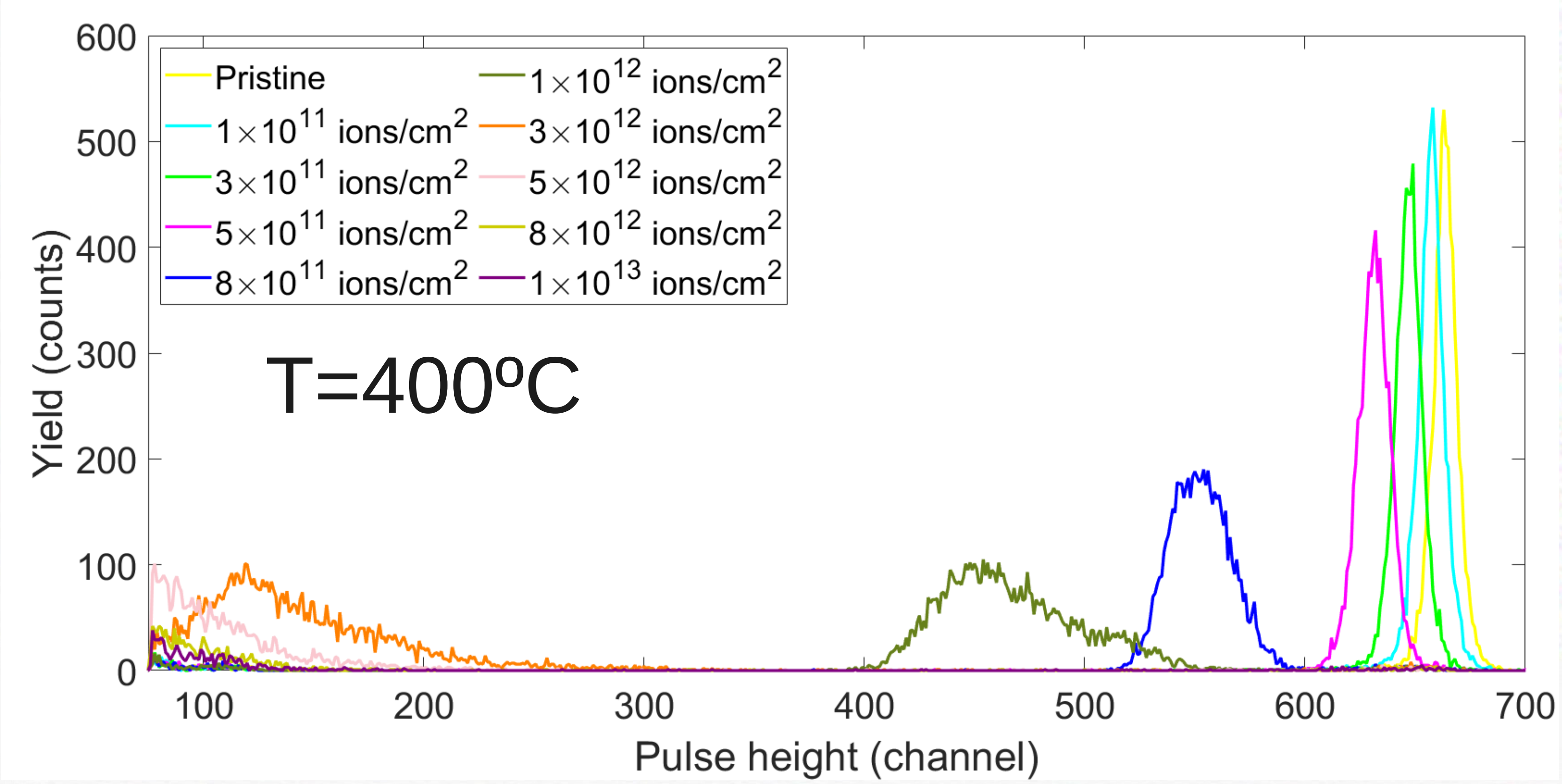

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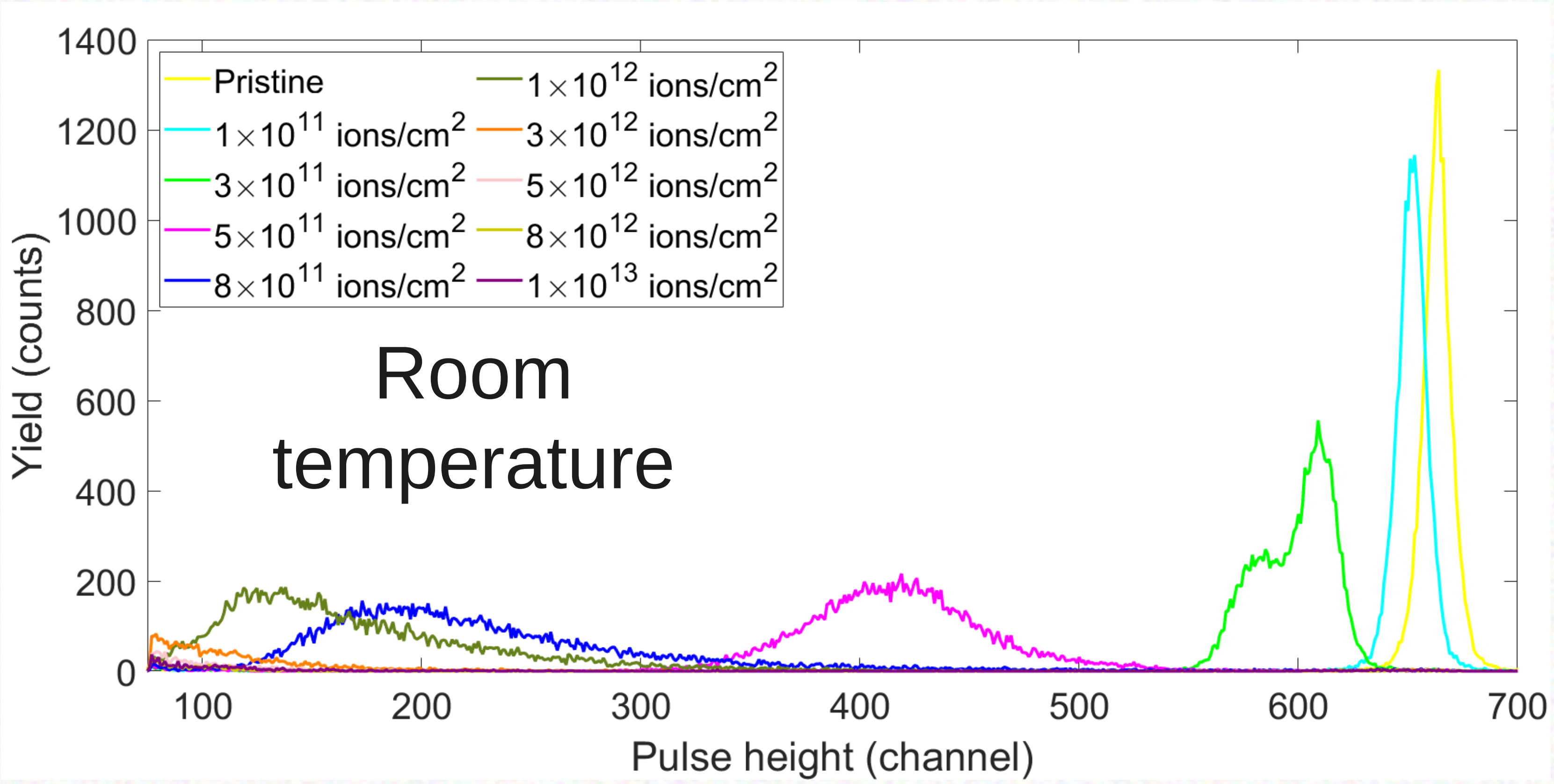
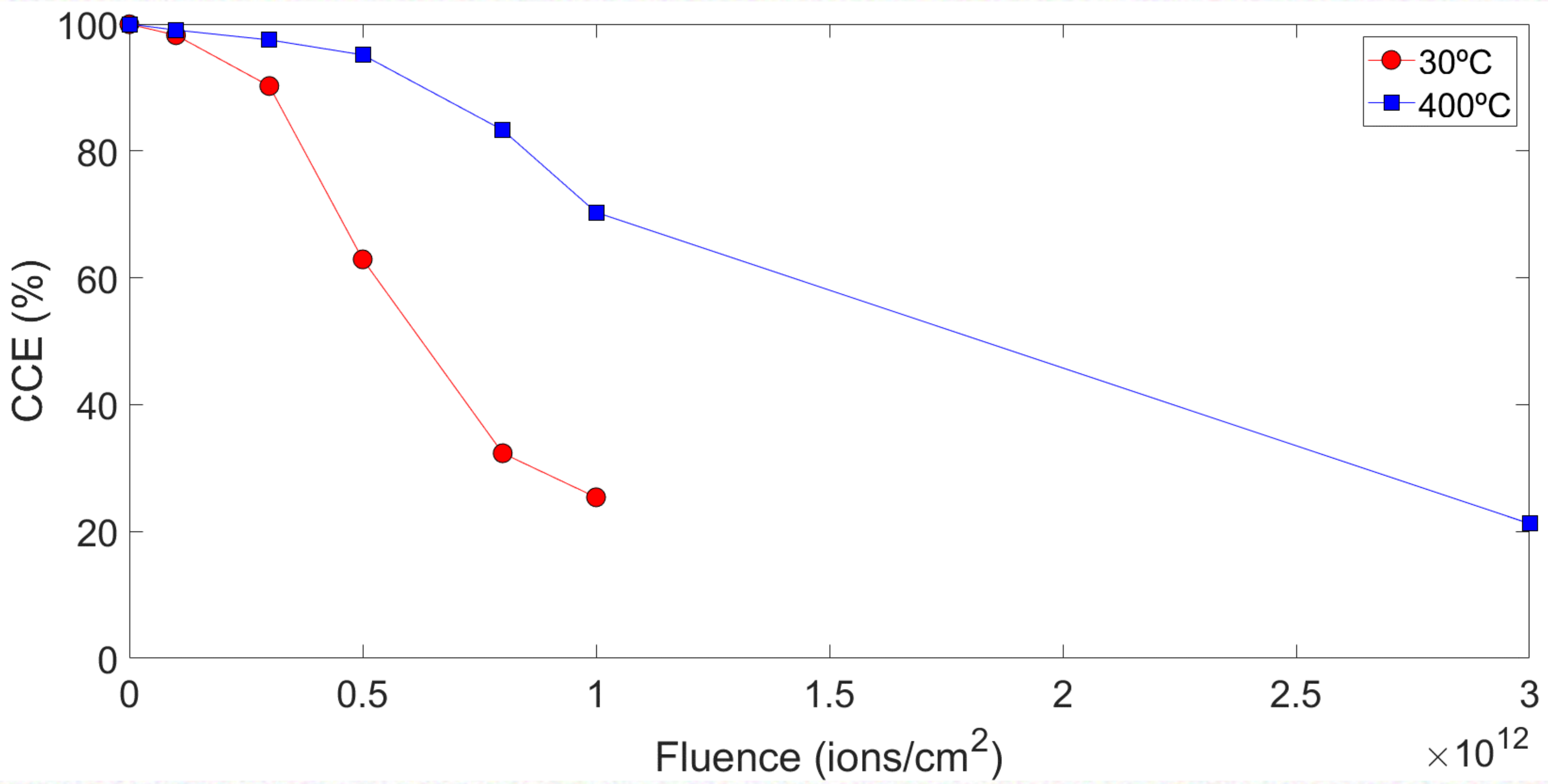
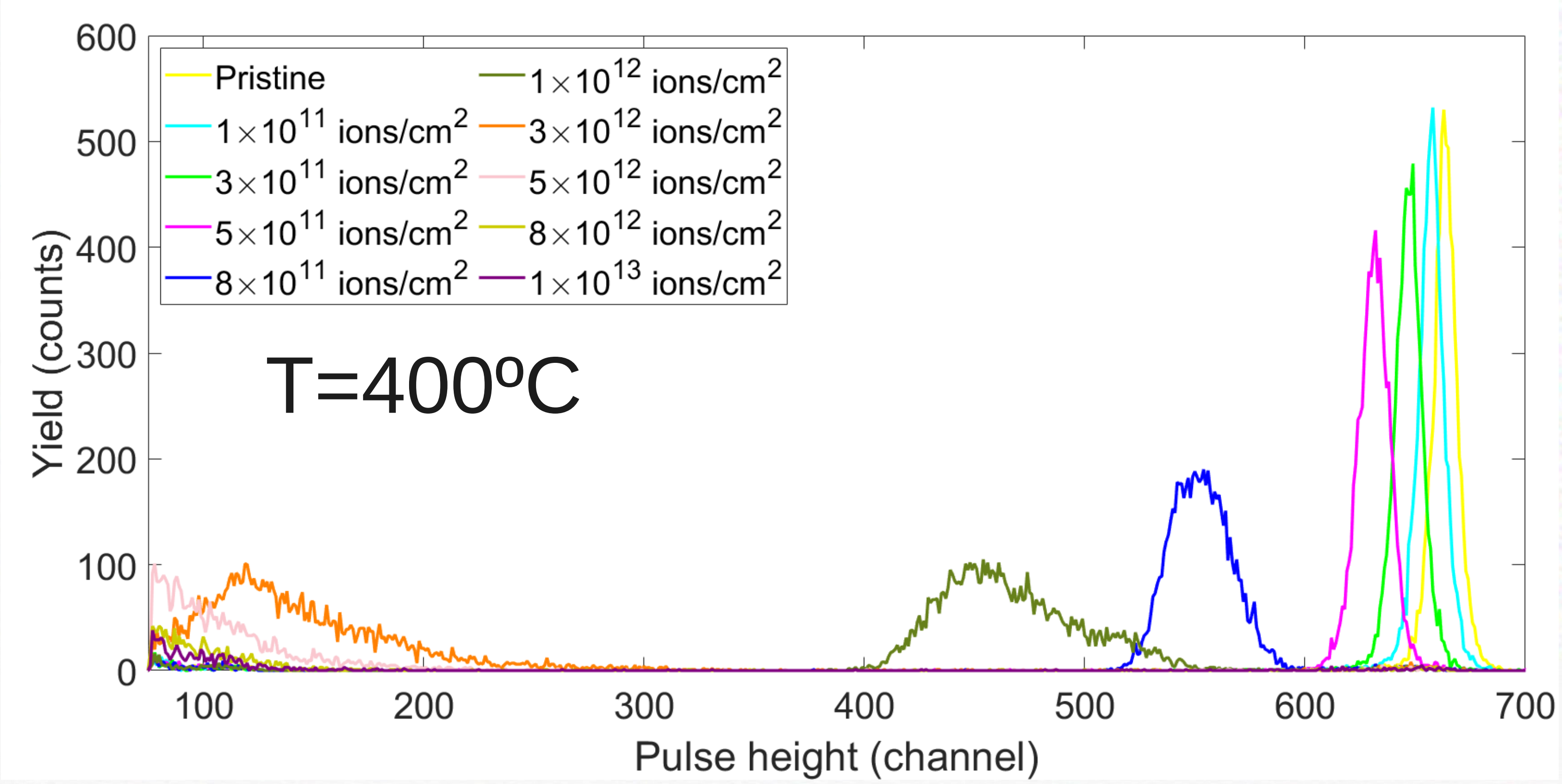




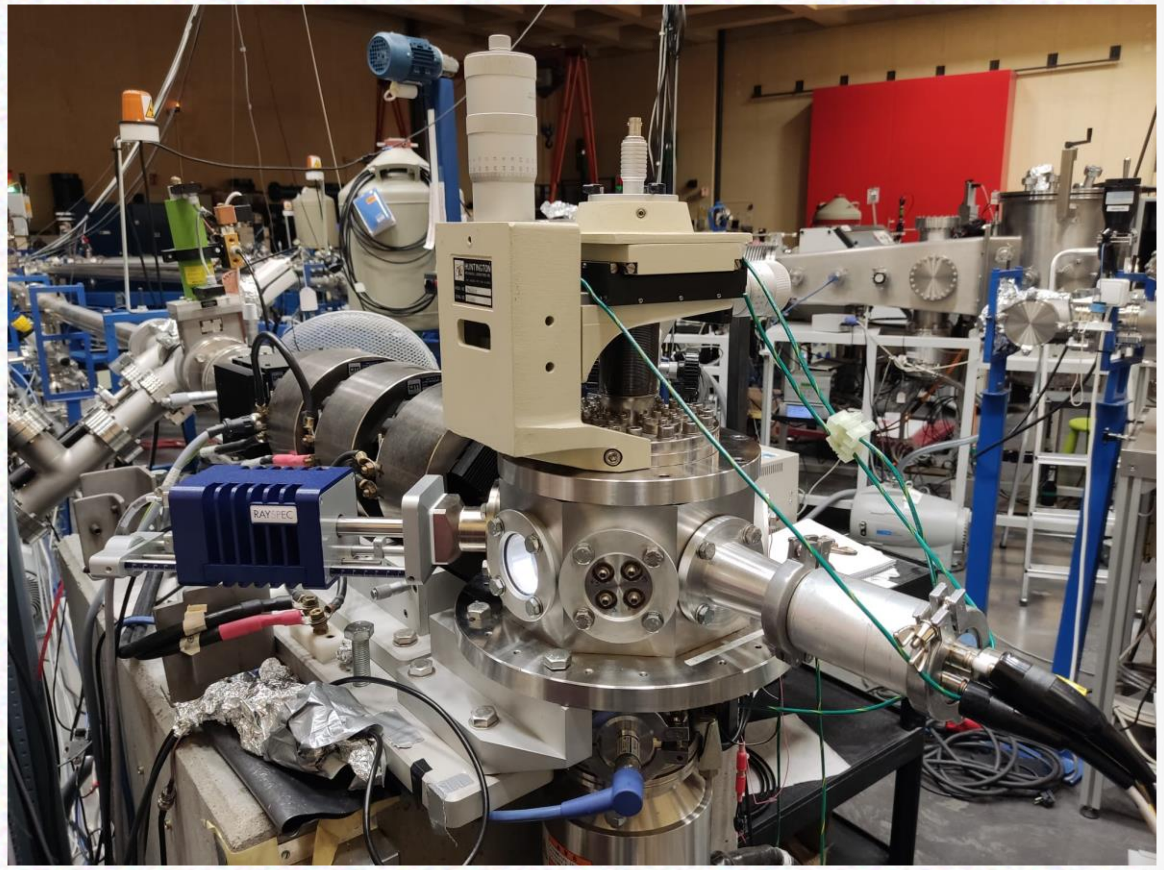


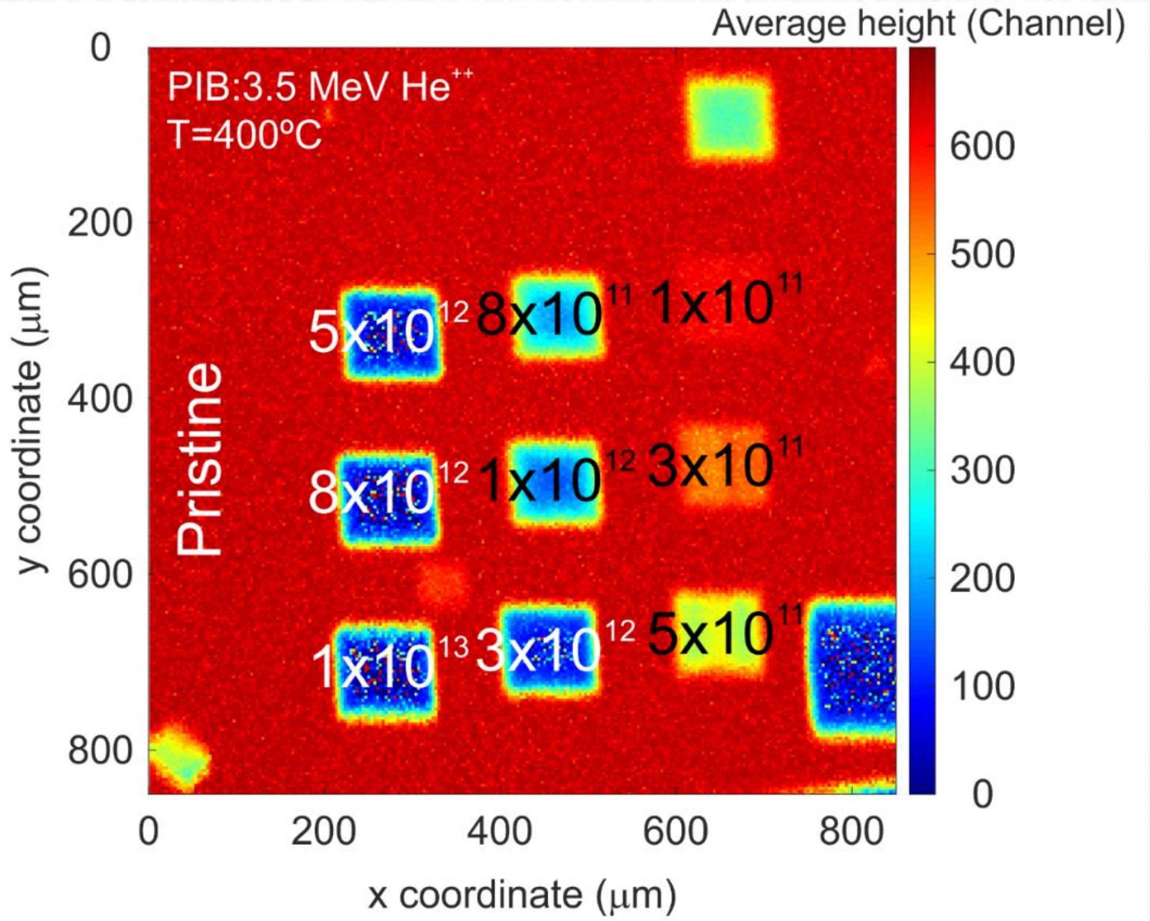
- The CCE decreases with fluence, making some damaged regions inaccessible.

- The CCE is better preserved at high temperatures due to the dynamic annealing mechanism.

CONCLUSIONS

- The new infrastructures acquired through **Action Plan 1.1** enhance CNA's capabilities for radiation-detection studies.
- A new thermal heater installed at the microprobe helps to investigate detector behavior at high temperatures.
- The 4H-SiC CCE decreases with increasing fluence at all temperatures.
- Operating the device at high temperatures reduces spectrometric degradation and extends its lifetime.





ACKNOWLEDGEMENTS

- Activity 1.1: Irradiation of detectors with accelerators. **(ASTRO21/1.1/1).**
- Actuación 1.2 Accelerator Mass Spectrometry. **(ASTRO21/1.2/2).**
- Actuación 1.3 Exploitations of European Infrastructures of Nuclear Physics. **(ASTRO21/1.3/3).**
- Actuación 1.4 Developments for ion beam therapy. **(ASTRO21/1.4/4).**

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MINISTERIO DE CIENCIA E INNOVACIÓN

Plan de Recuperación, Transformación y Resiliencia

Junta de Andalucía
Consejería de Universidad, Investigación e Innovación

- Actividades del CNA para los "upgrades" de alta luminosidad de CMS y DRDs del ECFA **(PID2023-148418NB-C44).**

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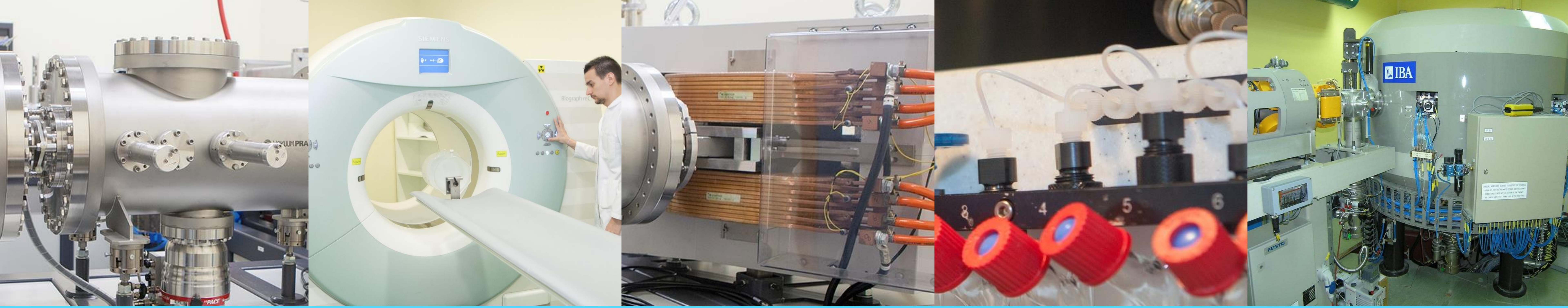
AGENCIA ESTATAL DE INVESTIGACIÓN



Thank you for your attention

BACKUP

1.2: Accelerator Mass Spectrometry

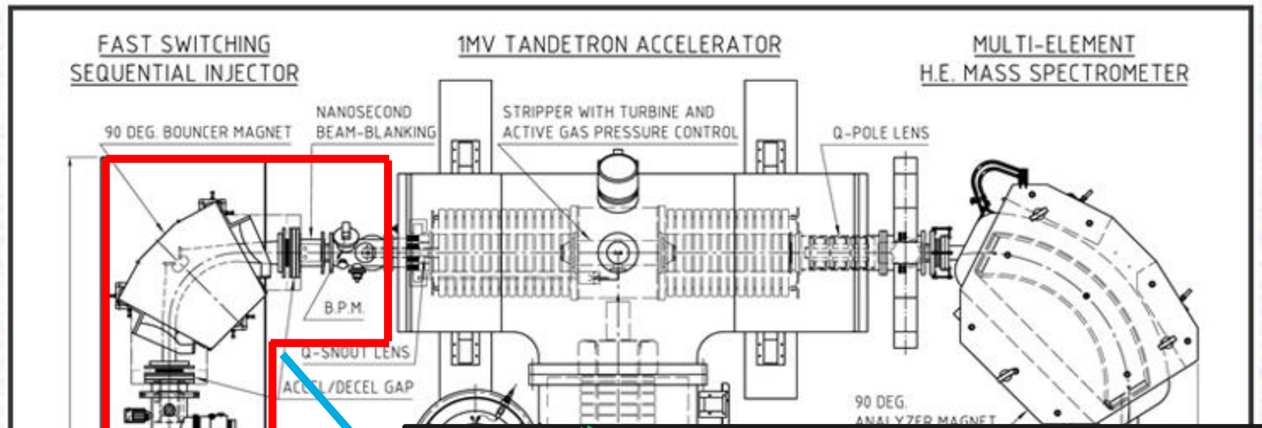
IP: José María López Gutiérrez. Univ. de Sevilla.

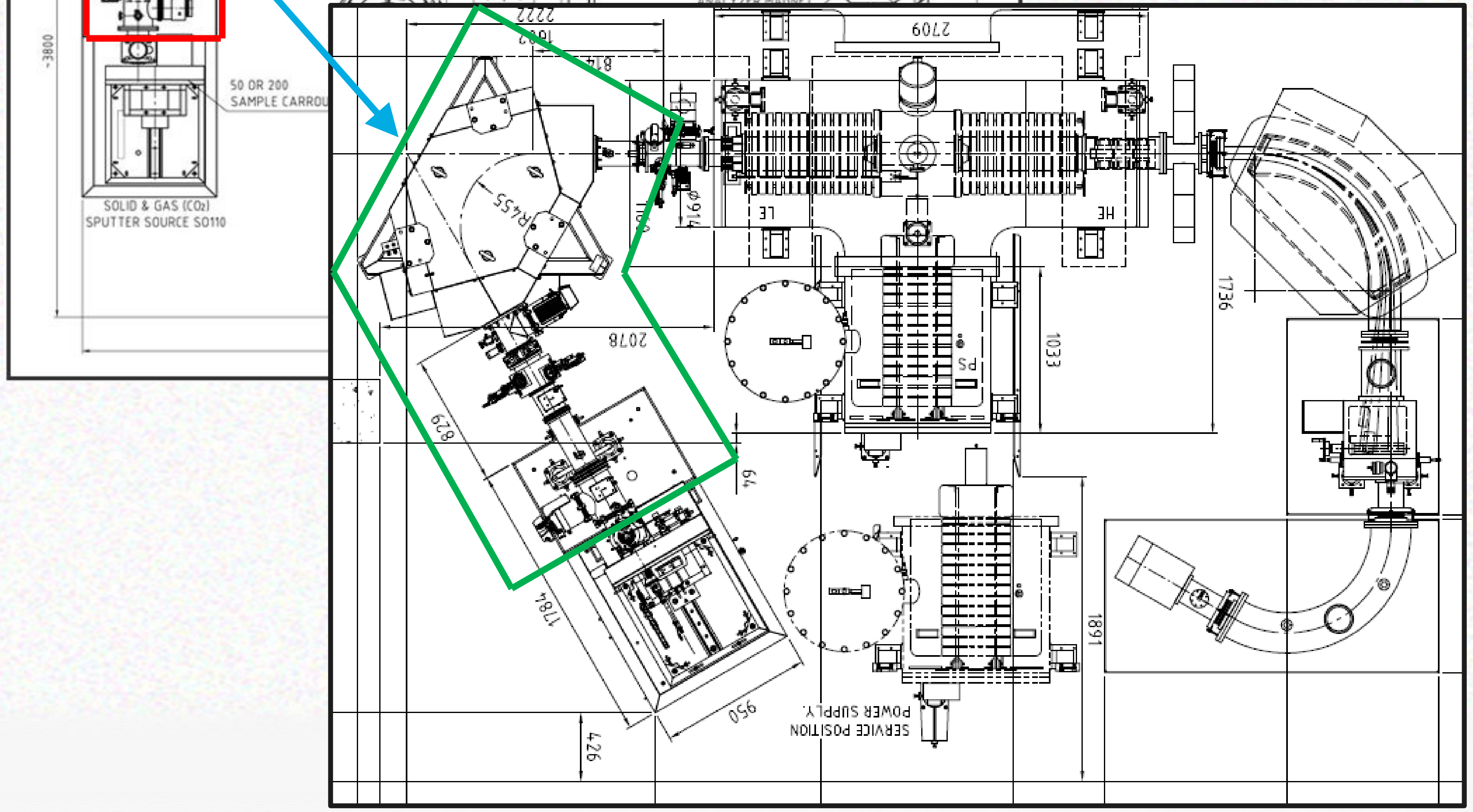
Goal: Improvement of the 1 MV Accelerator Mass Spectrometry (AMS) system for astrophysics experiments.

- **Main action:** Installation of a new 120º injector to enhance resolution and consequently reduce measurement background.

- **Studies to be applied to:** Meteorite dating, cosmic rays, nucleosynthesis, isotopic anomalies…

SARA: *Spanish Accelerator for Radionuclide Analysis*





1.3. Exploitations of European Infrastructures of Nuclear Physics

IPs: Carlos Guerrero, J. Gomez-Camacho. Univ. de Sevilla.

Goal: Improvement and upgrade of the 3 MV Tandem and cyclotron accelerators at the National Accelerator Center for radiation detector studies.

Instrumentation

Magnetron Sputtering chamber to produce targets to be used in radioactive beam experiments at CERN-ISOLDE and LNS-Catania

Moderators and shielding to improve the HISPANOS neutrón Beam Line , to complement the measurements done at CERN-nTOF.

KEY INFRASTRUCTURE ACQUIRED

magnetrón-*sputtering chamber*: 128.000 €

Charge preamplifiers: 34.000 €

Injector for AMS: 430.000 €

Buncher for pulsed H, D and He beams: 94.000 €

Switched HV power supply: 64.000 €

Motorized micrometric slits: 184.000 €

High-resolution X-ray detector: 24.000 €

The total investment in infrastructure at the CNA has been **1095049.40** €.

CNA Centro Nacional de Aceleradores
Universidad de Sevilla
CSIC Consejo Superior de Investigaciones Científicas
Junta de Andalucía
Financiado por la Unión Europea
Plan de Recuperación, Transformación y Resiliencia

CONCLUSIONS: OBJETIVES OF THE COMPLEMENTARY PLAN AT THE CNA

- Improvement and upgrade of the 3 MV Tandem and cyclotron accelerators at the National Accelerator Center for radiation detector studies

- Accelerator Mass Spectrometry

HiSPANoS

- Exploitation of European infrastructures in nuclear physics

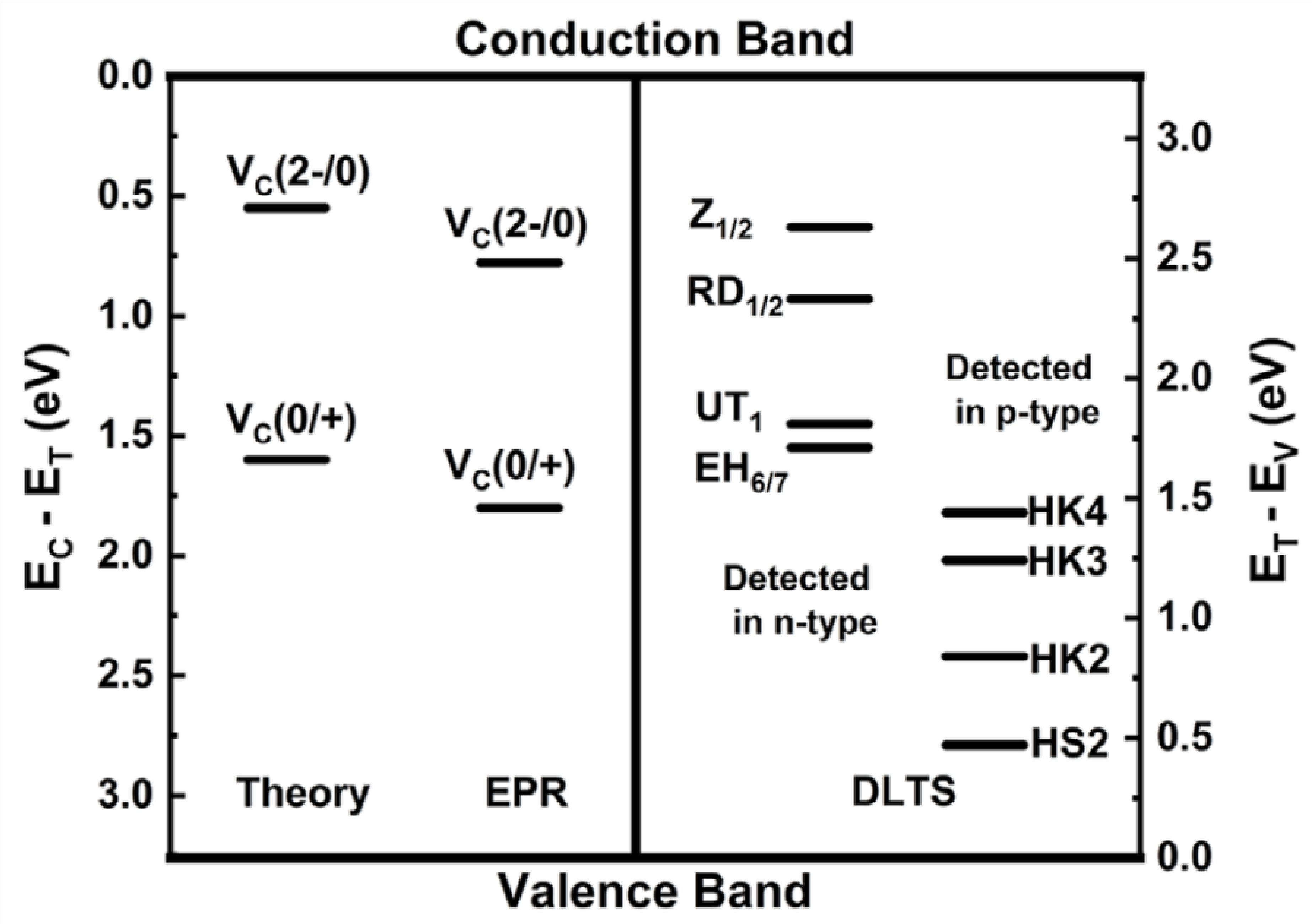
- Developments for ion beam therapy

Financiado por la Unión Europea

Plan de Recuperación, Transformación y Resiliencia

IMPROVING DETECTOR PERFORMANCE THROUGH DIFFERENT MECHANISMS

Intrinsic or radiation-induced trapping centers (defects, impurities, …) in the lattice structure can capture free charge carriers, leading to signal degradation.



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- Dynamic annealing: defect recombination during irradiation at high temperature that mitigates damage accumulation.
- Trap filling: Illumination fills active traps, reducing carrier trapping and improving charge collection.
- Photo-detrapping: Illumination with a light source can release trapped carriers by exciting them with photons.