ADVANCED CHARACTERIZATION OF RADIATION SENSORS AT HIGH TEMPERATURES USING THE CNA TANDEM ACCELERATOR

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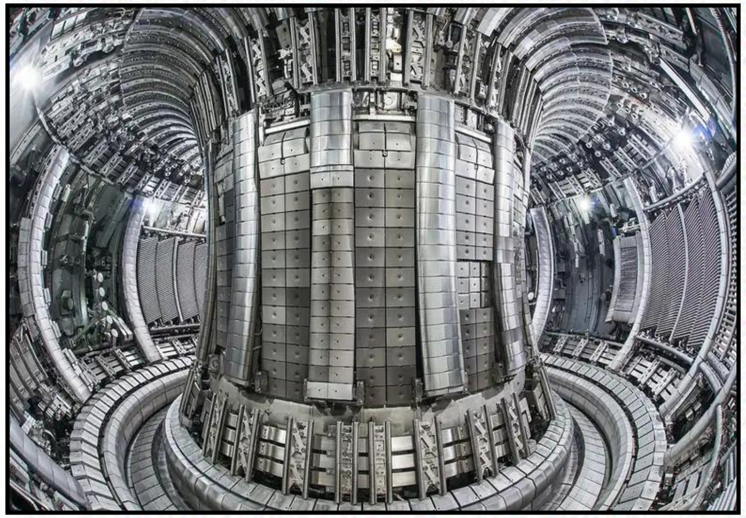
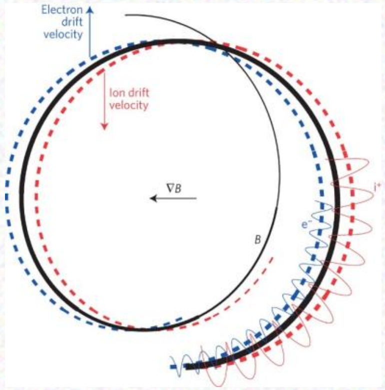
Centro Nacional de Aceleradores. Universidad de Sevilla

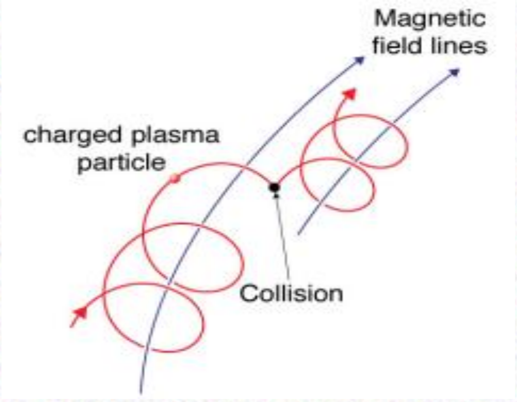
RADIATION SENSORS FOR FAST IONS IN NUCLEAR FUSION

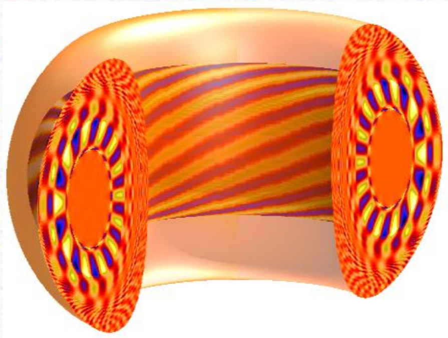
In burning plasmas losses of energetic particles can damage the device's integrity and degrade the performance of the plasma.

Diagnostic for fast ions - > Detectors based on scintillator materials.









Magnetic confinement

Coulomb Collisions

MHD Activity

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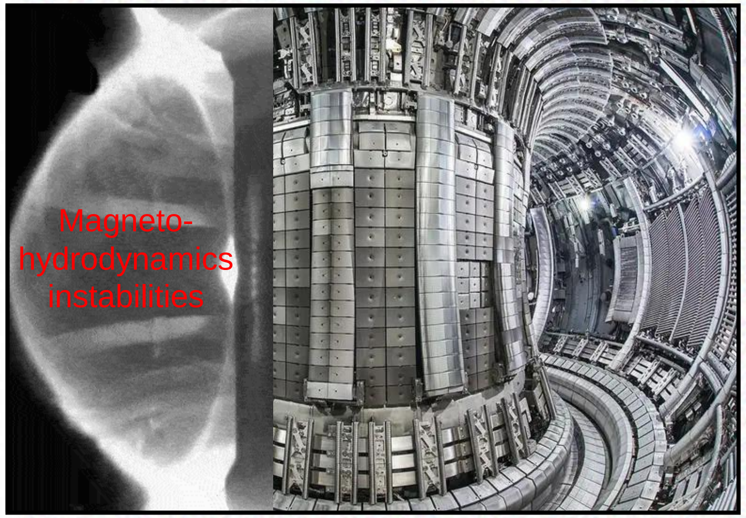

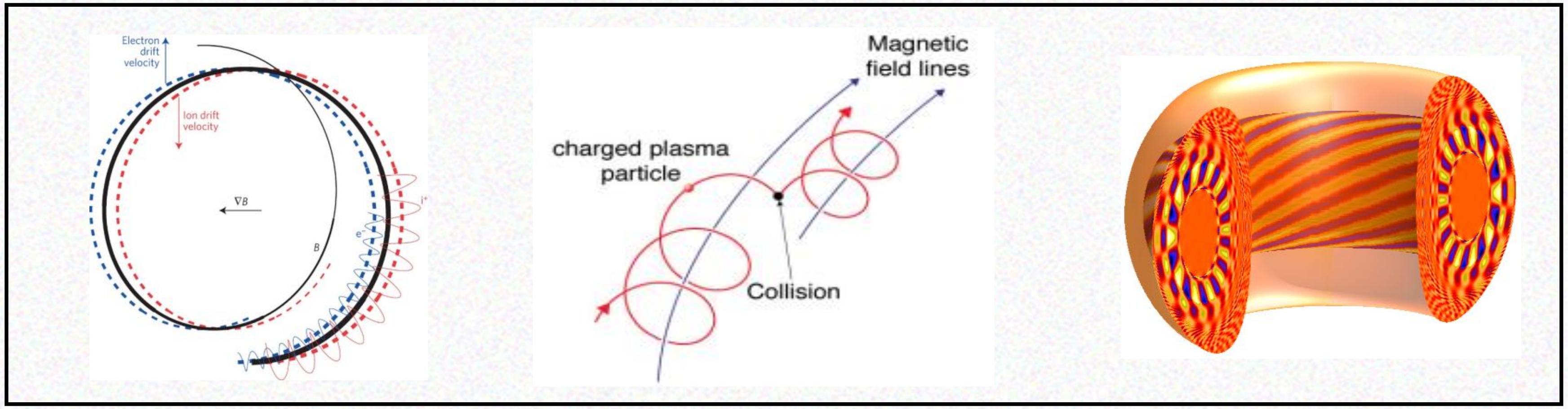

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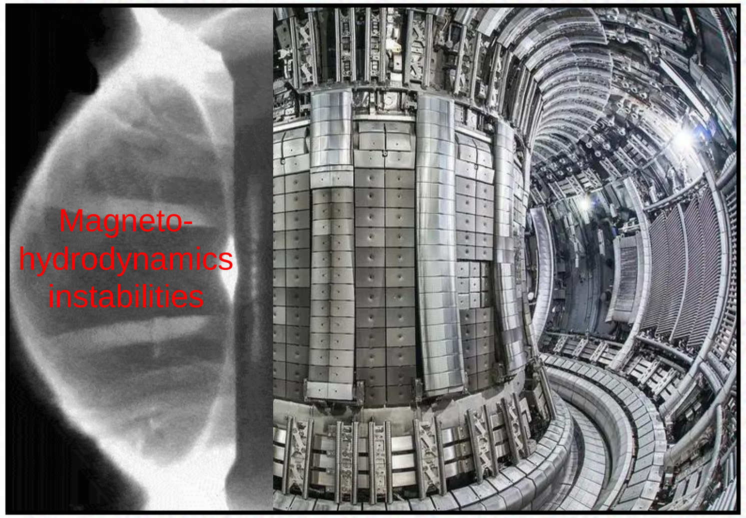

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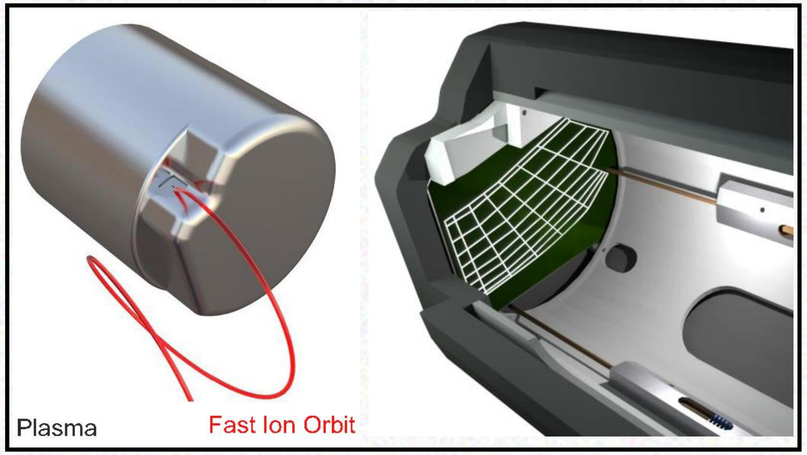

Particles enter trough the slit into chamber activating scintillator material $SrGa_2S_4:Eu^{2+}$ (TG-Green) with short decay time (490 ns) and high efficiency. (***M. Garcia-Muñoz et al, Rev. Sci. Instrum. 80, 053503 (2009)***)

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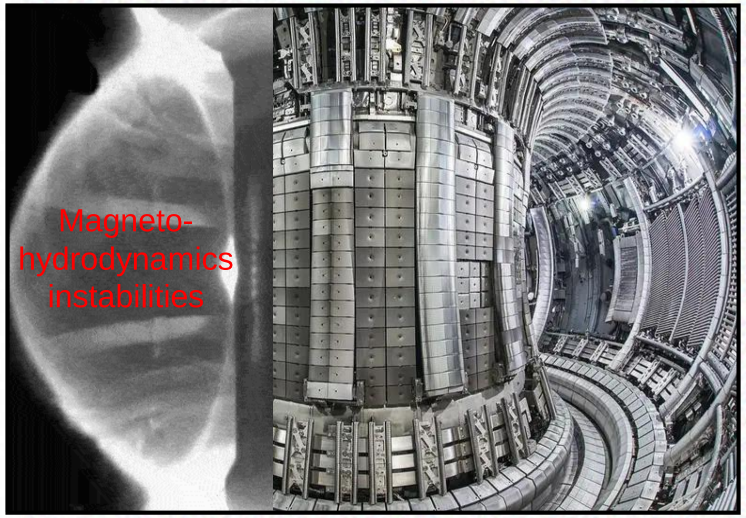

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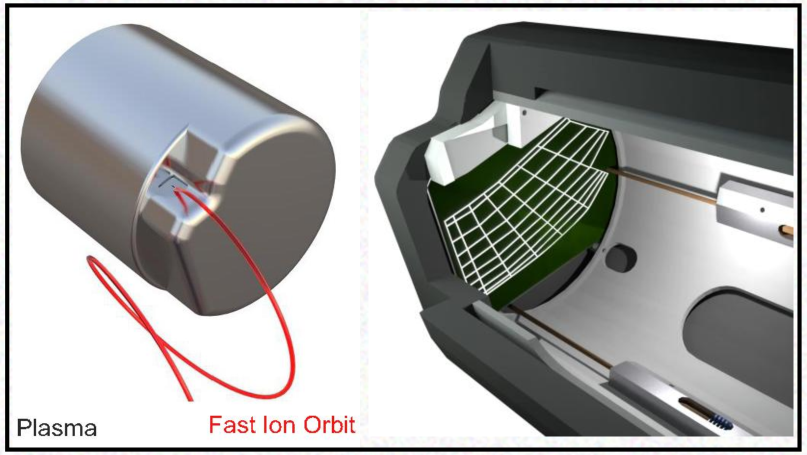

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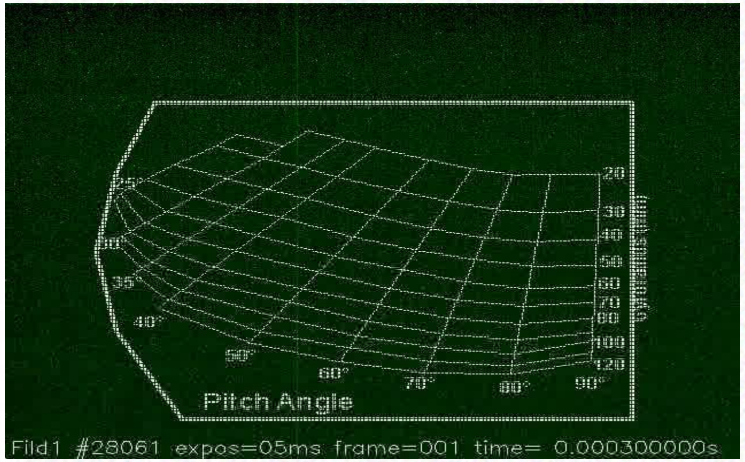

- The strike points of the ions on the scintillator plate depend on their gyroradius and pitch-angle (~ magnetic spectrometer) - > Local velocity-space ->Help to isolate fundamental mechanisms.
- **Full characterization of scintillators materials using different ion species, MeV energies, fluences and applied temperatures**.

ABSOLUTE YIELD MEASUREMENTS MADE POSSIBLE BY CNA INFRASTRUCTURE

- All stable ions available: **H - Au**
- Energy range: **600 keV - few MeV**
- Beam currents: **μA - pA**
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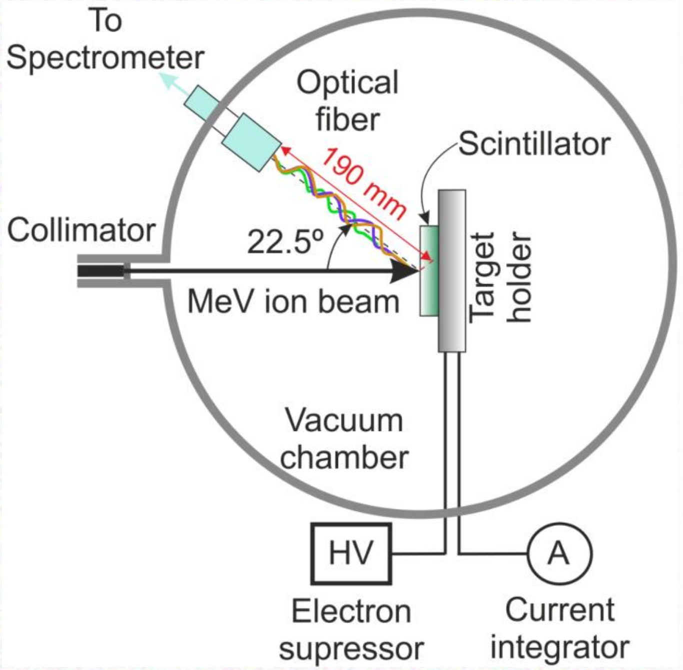
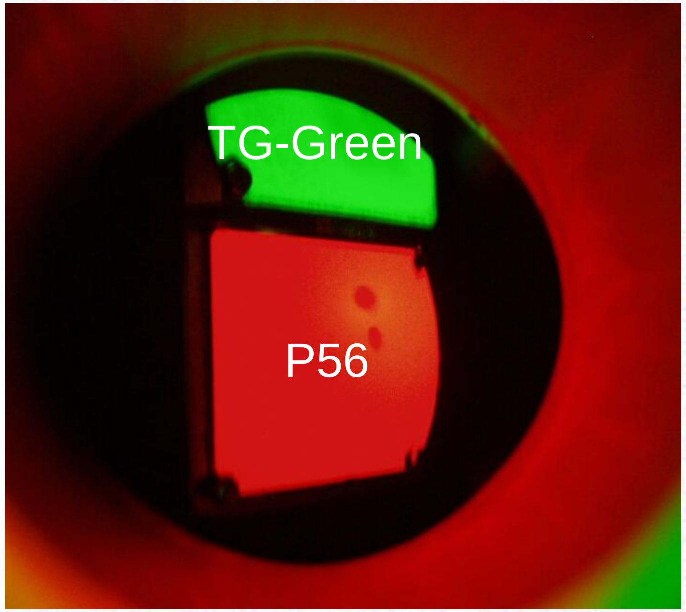


- **Photon rate**: Optical fiber for light collection connected to a calibrated spectrometer.
- **Ion rate**: Digital current integrator to monitor incoming particle flux.

ABSOLUTE ION LOSS FLUX OBTAINED FOR THE FIRST TIME IN AUG PLASMAS



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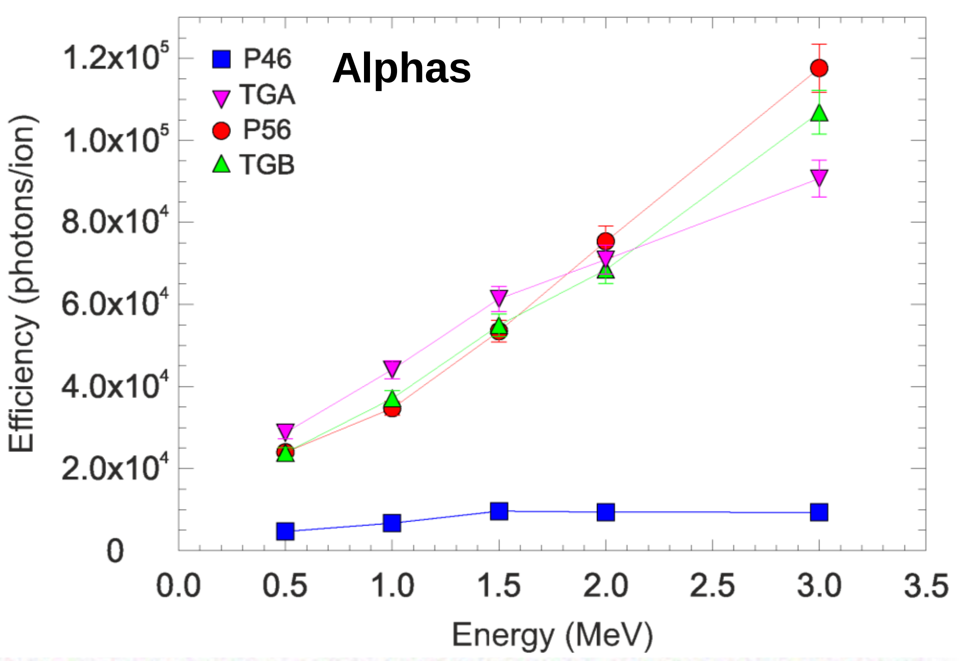
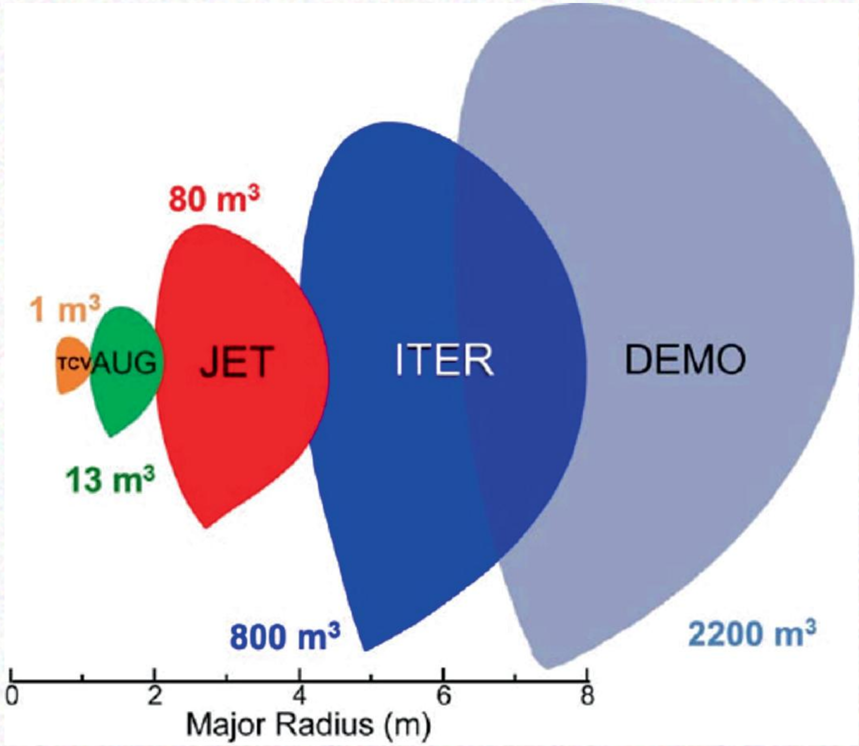
- **Ion rate**: Digital current integrator to monitor incoming particle flux.

- First absolute efficiency obtained for fusion-relevant particles and energies at **room temperature** (**M.C. Jiménez-Ramos et al, NIMB. 332, 216-219 (2014)**).
- Enabled first absolute fast-ion flux in AUG tokamak and benchmarked transport codes like ASCOT (**M. Rodriguez-Ramos et al, Plasma Phys. Control. Fusion. 59, 105009 (2017)**).



CAN DETECTORS SURVIVE THE HEAT IN FUSION DEVICES?

- Larger plasma volumes in next-gen fusion devices will increase heat loads, forcing detectors to operate at higher temperatures.



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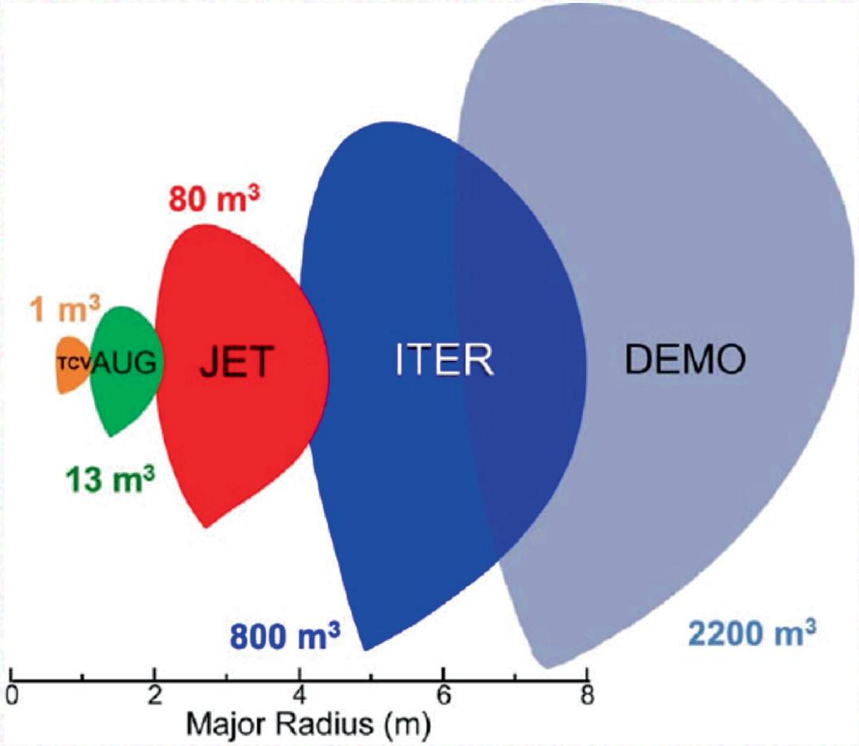

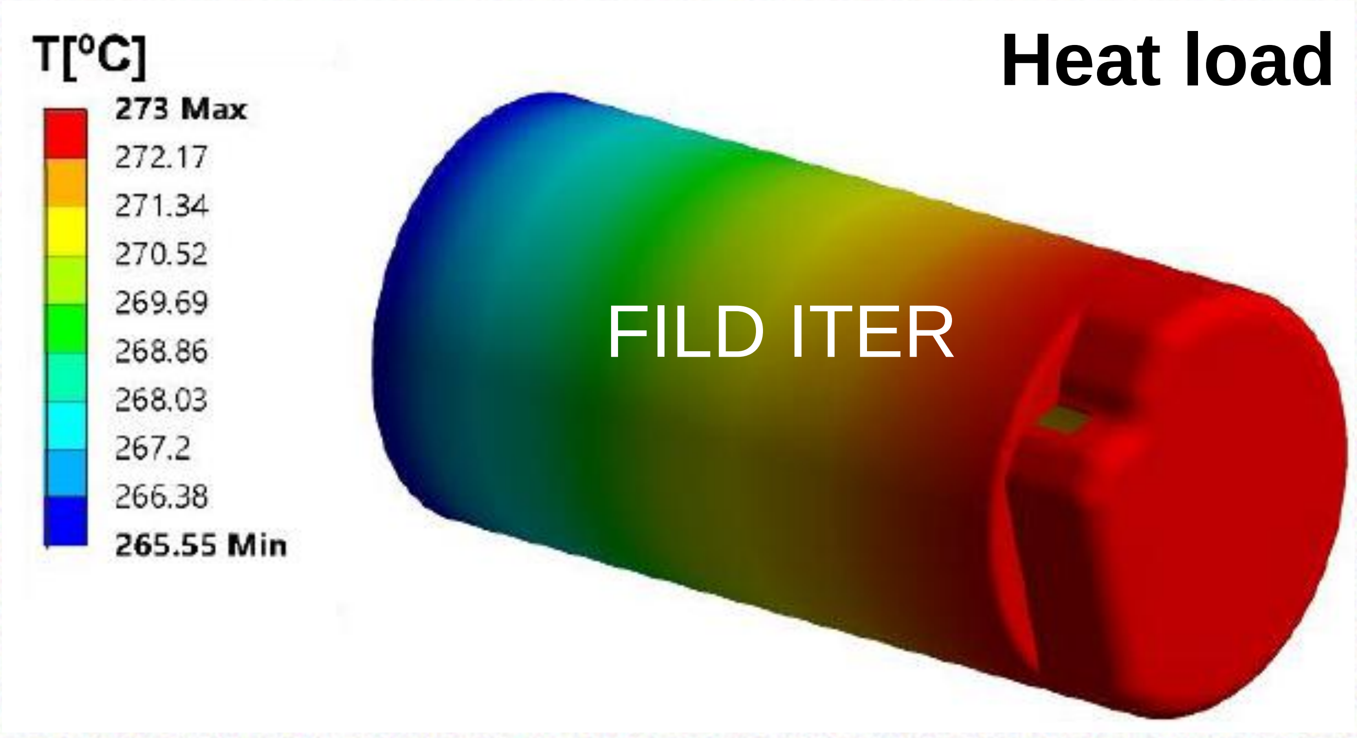

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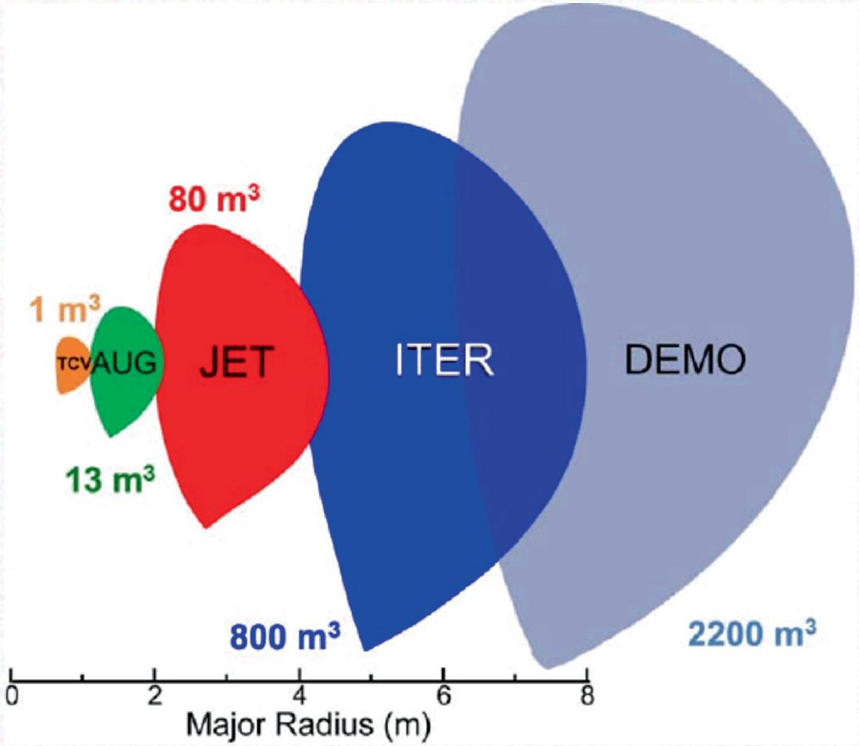
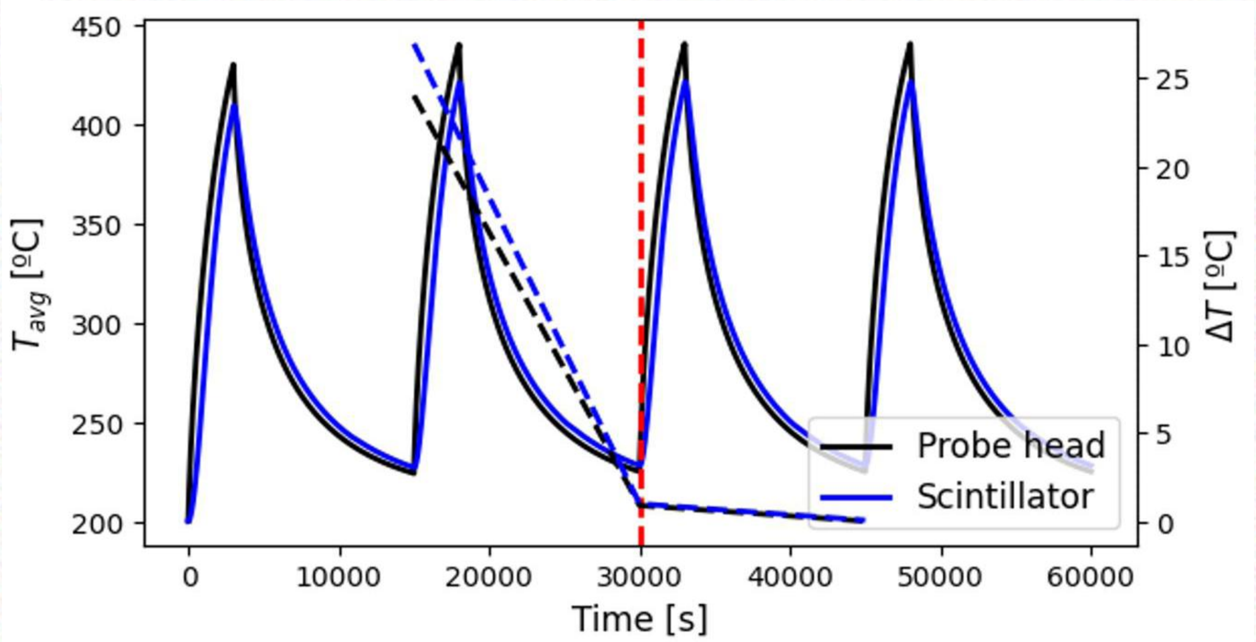


Javier Hidalgo Salaverri | ITER Loss Alpha Monitor – CDR thermomechanical assessment



Dedicated IBA chamber with calibrated detectors and temperature control to study scintillator response vs particle flux, type, energy, and temperature (RT-500 °C)

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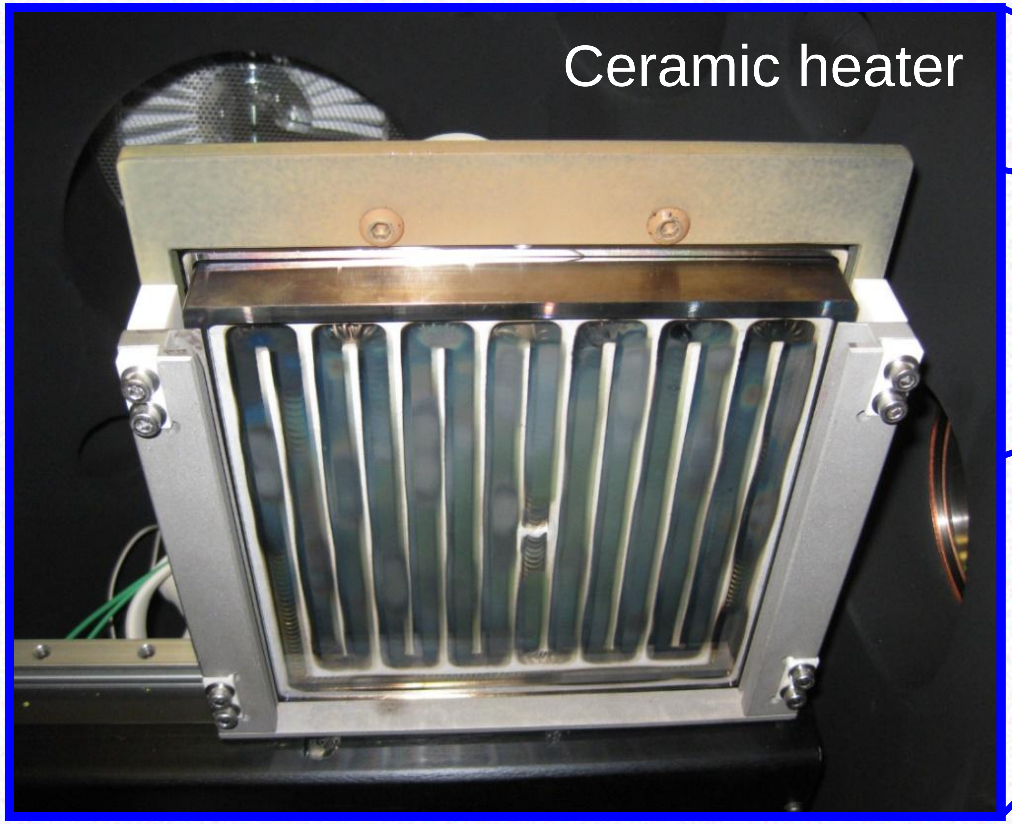

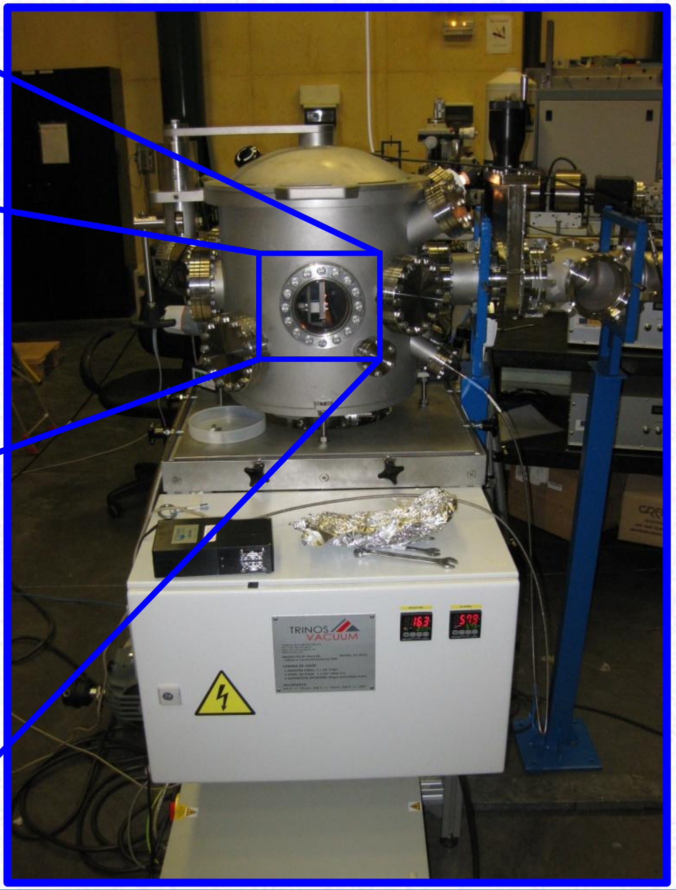

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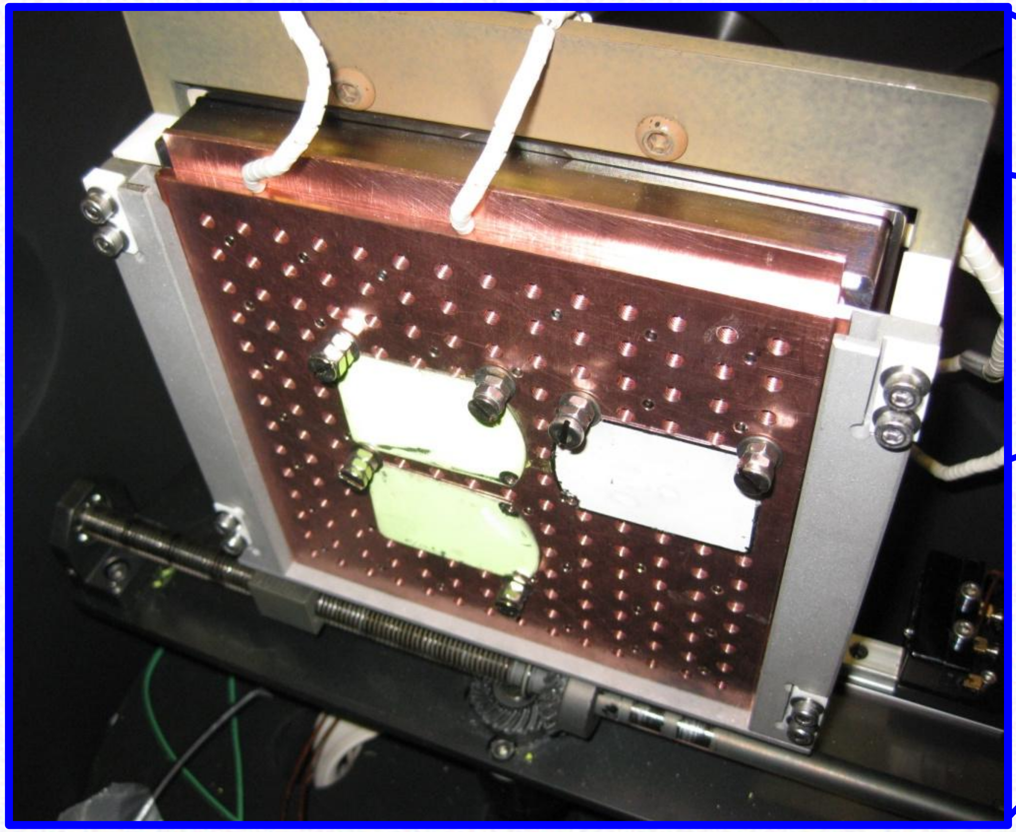

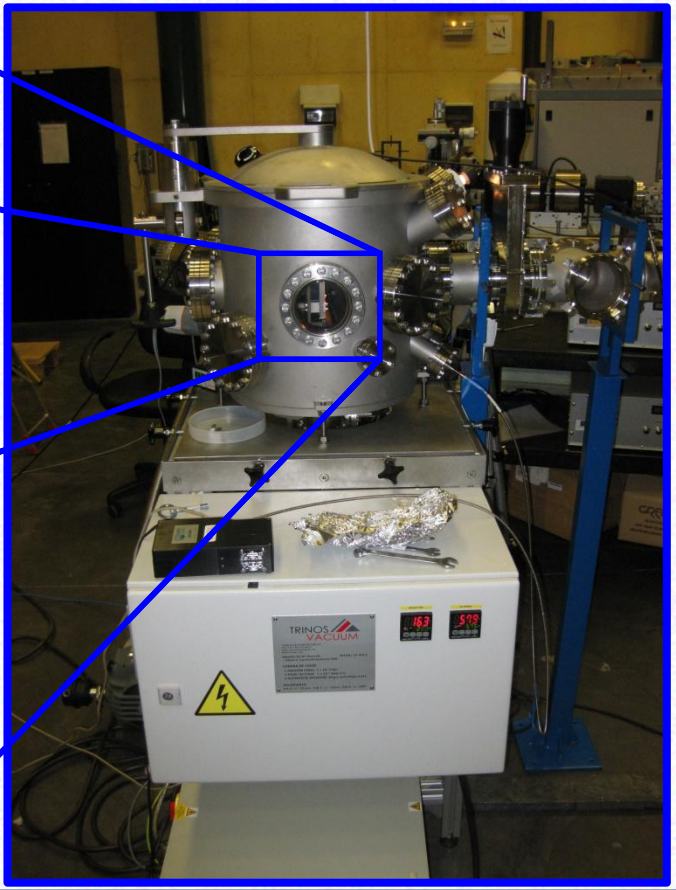

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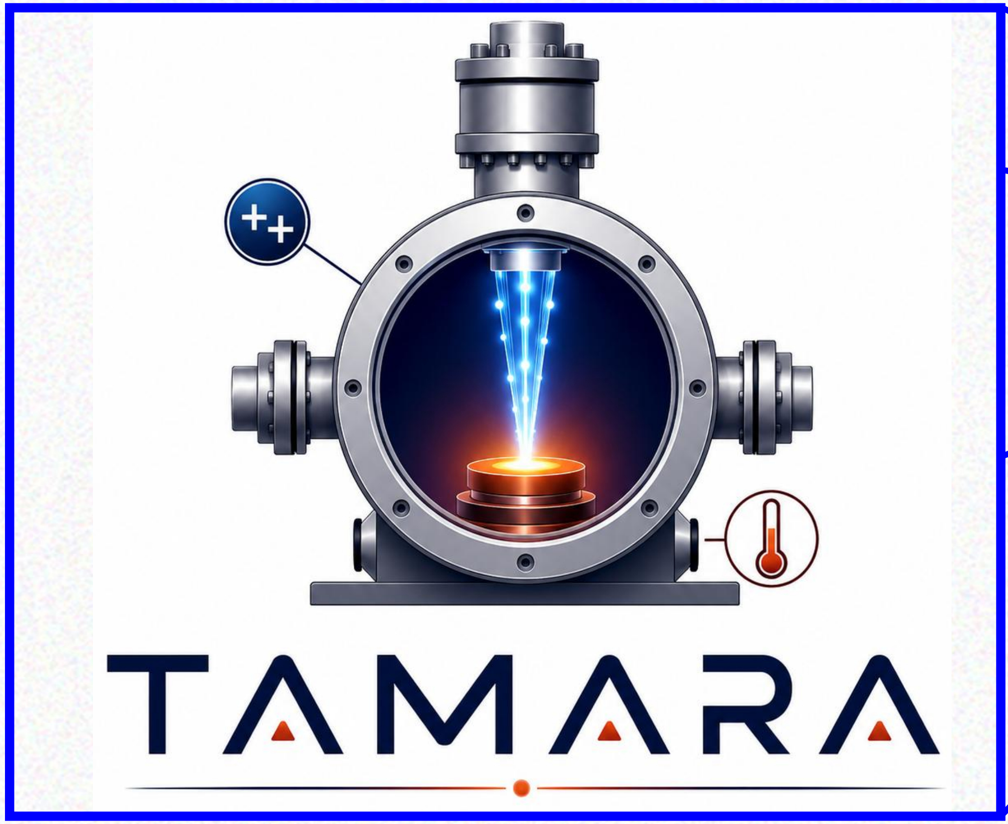
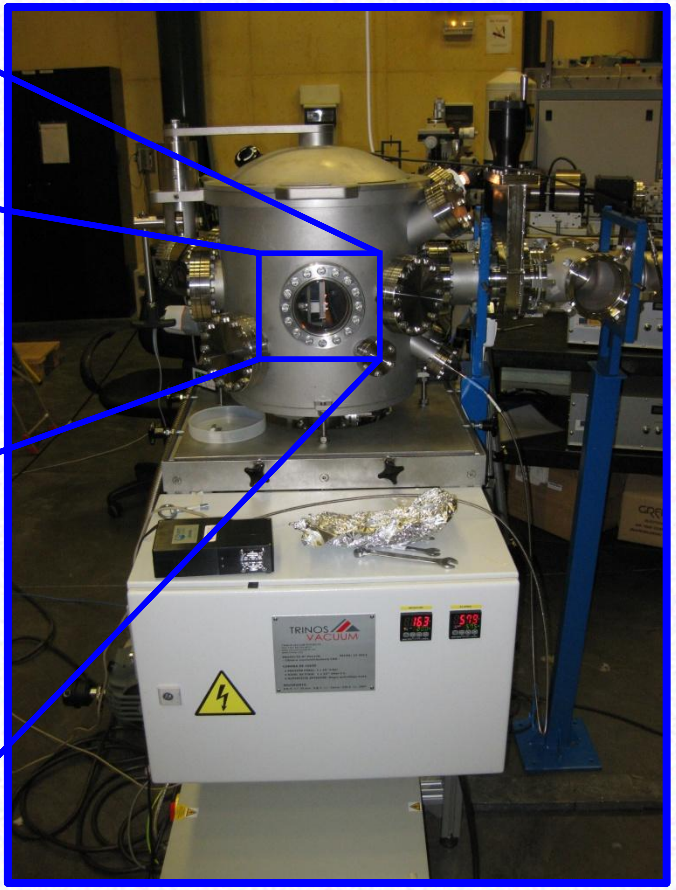
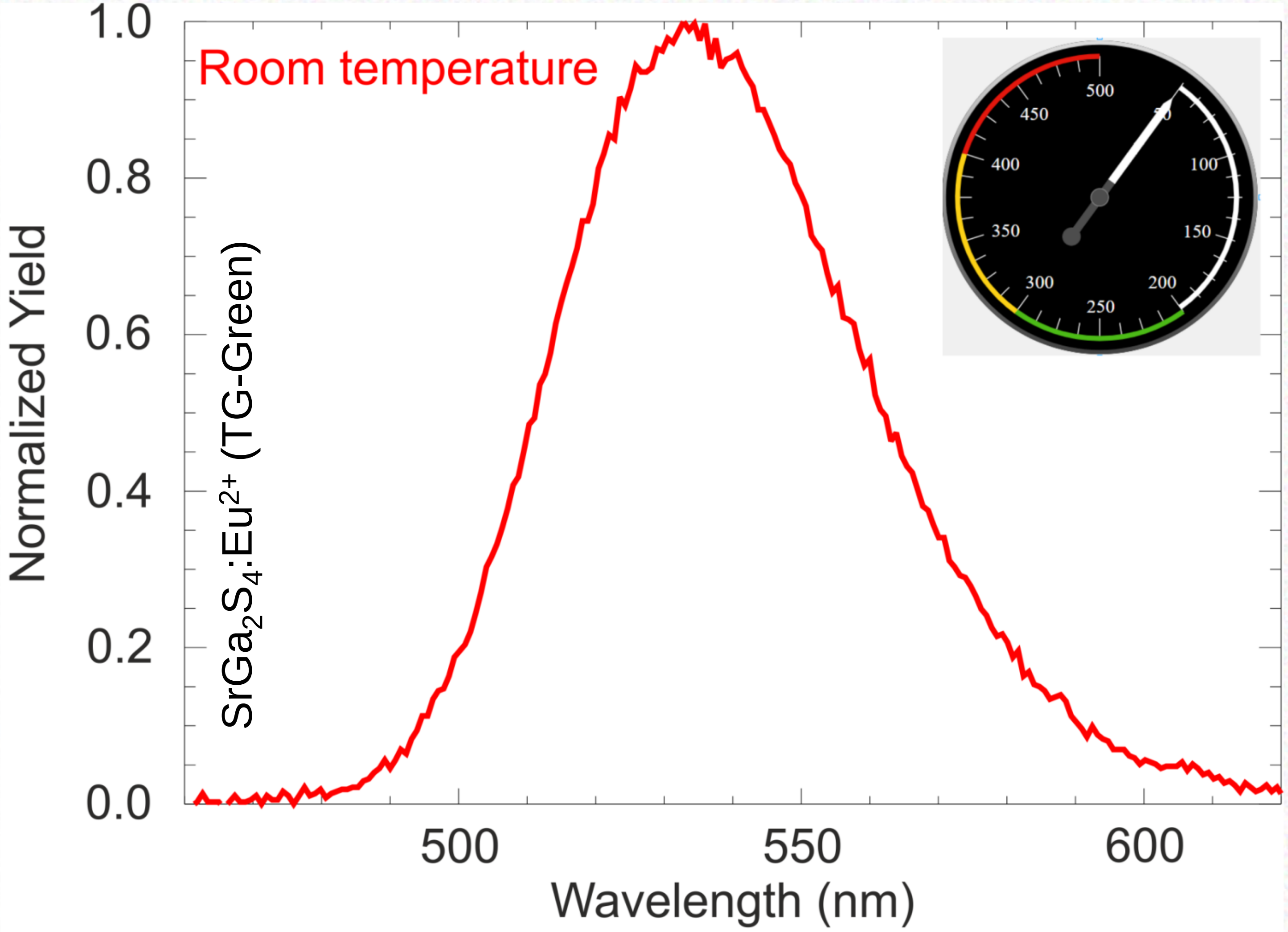
Temperature
Analysis
Measurements
And
Radiation
Applications







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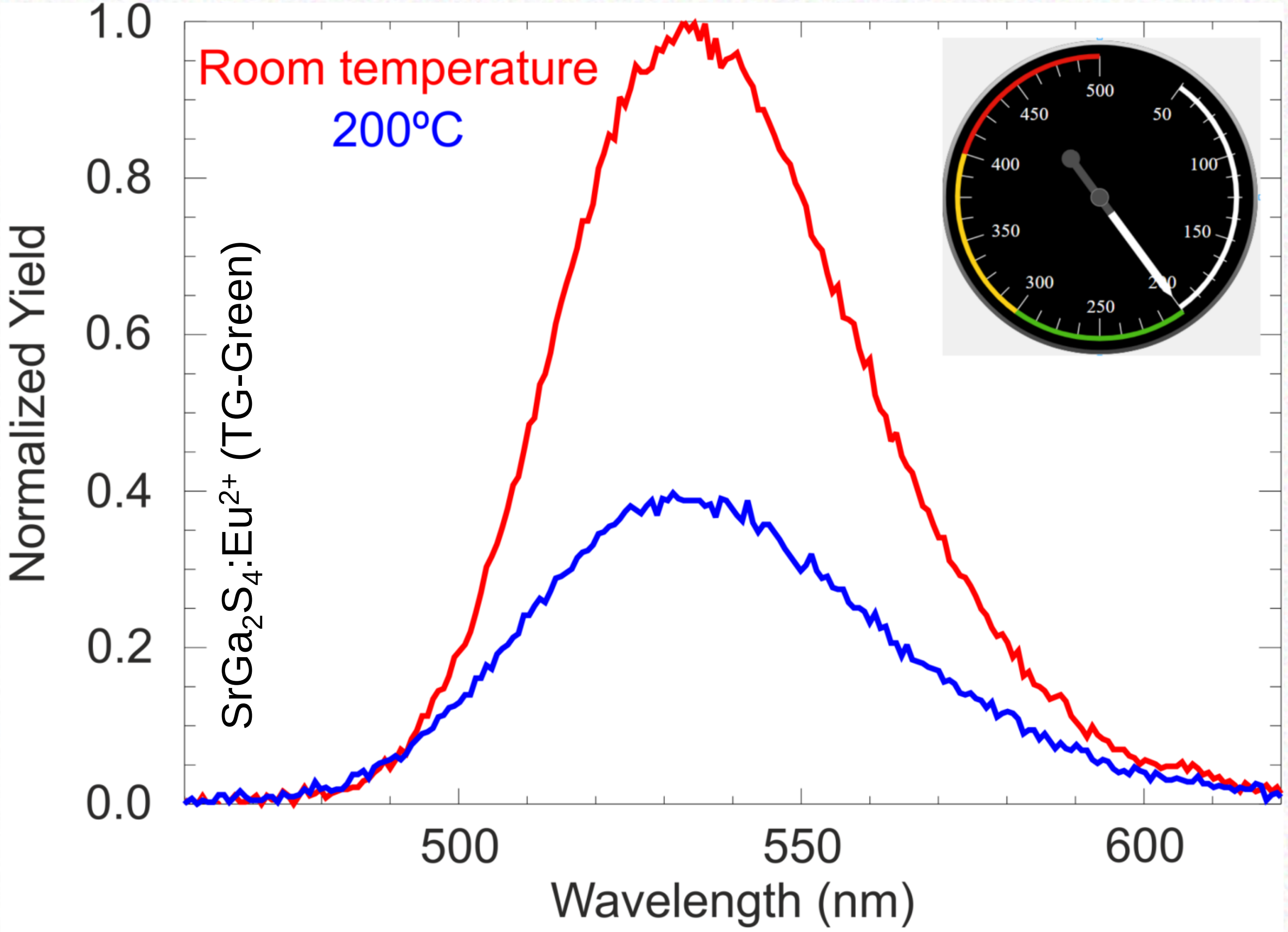
M. Rodriguez-Ramos *et al.* *NIMB.* 403, 7-12 (2017).

THE PHOTON EFFICIENCY DECREASES WITH OPERATION TEMPERATURE



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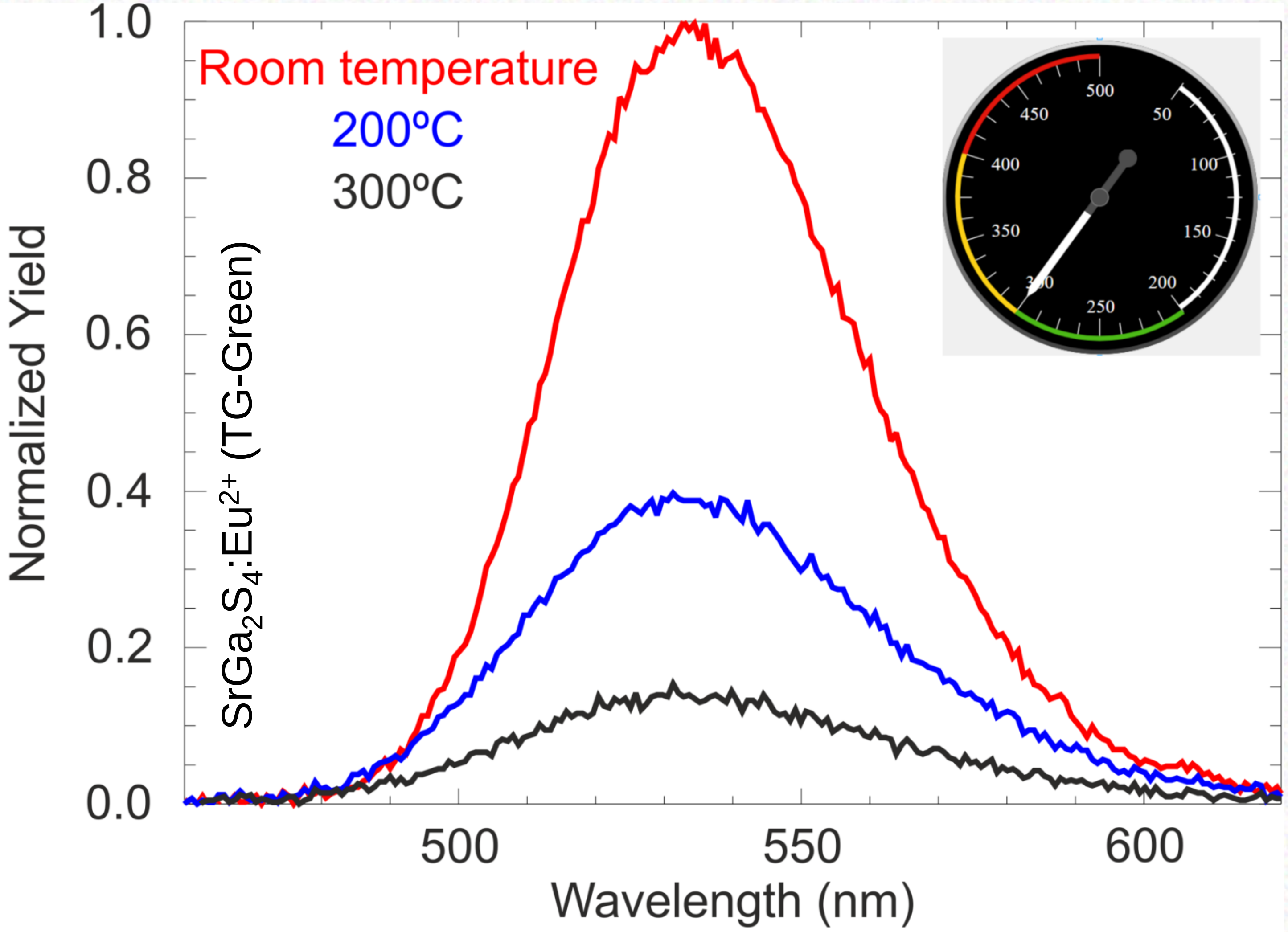

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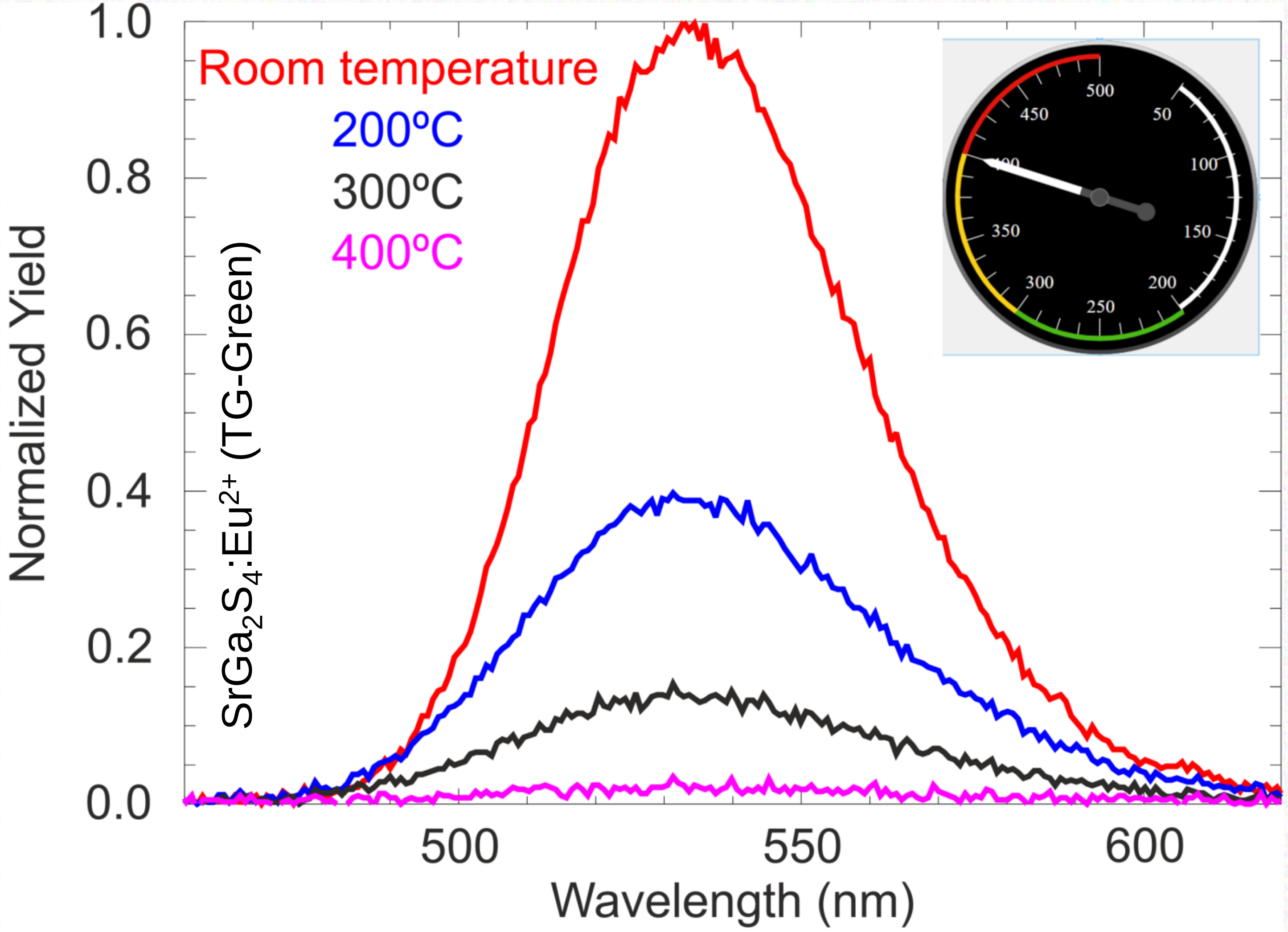

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Probably will not work in future tokamaks like ITER

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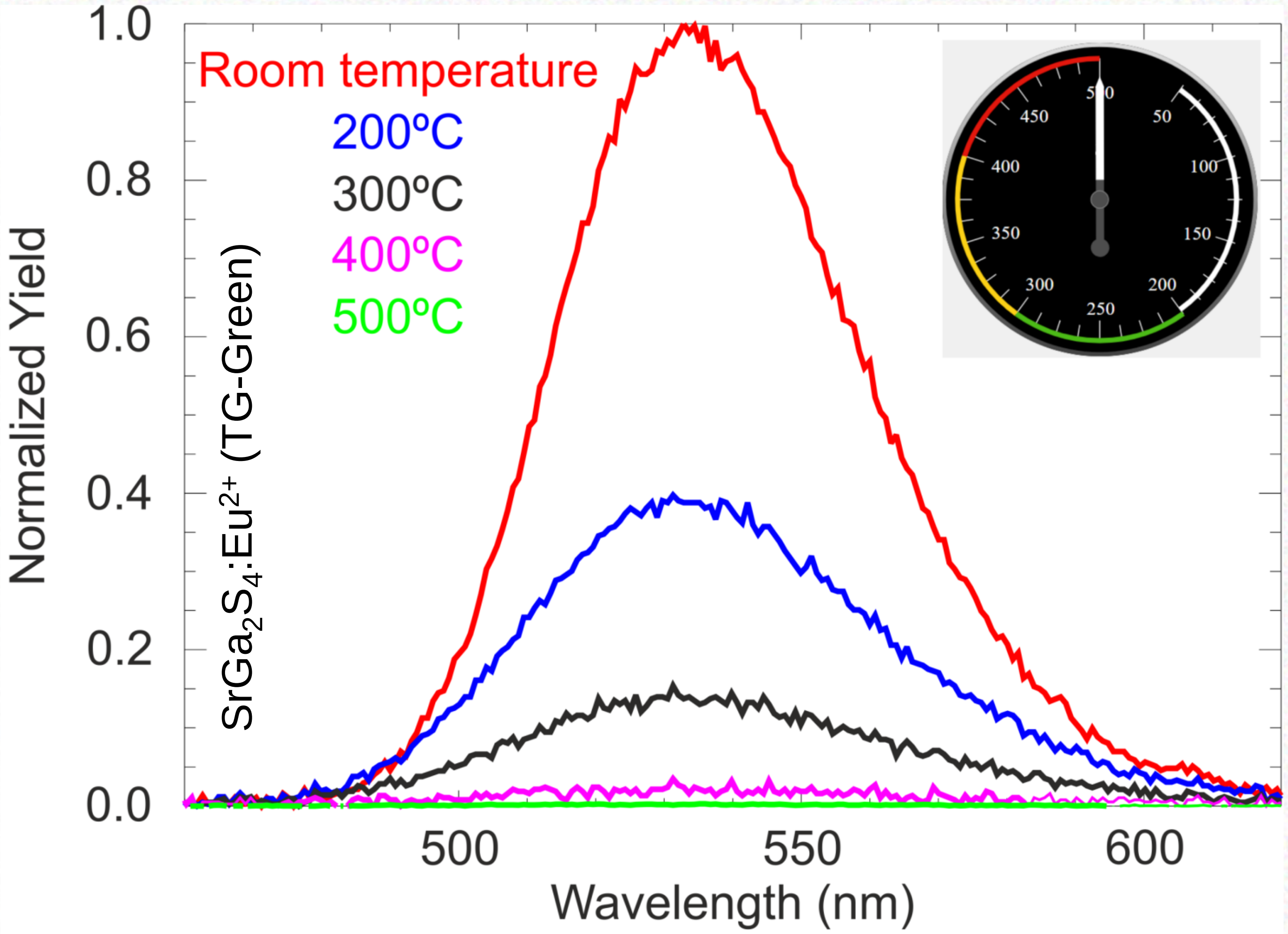

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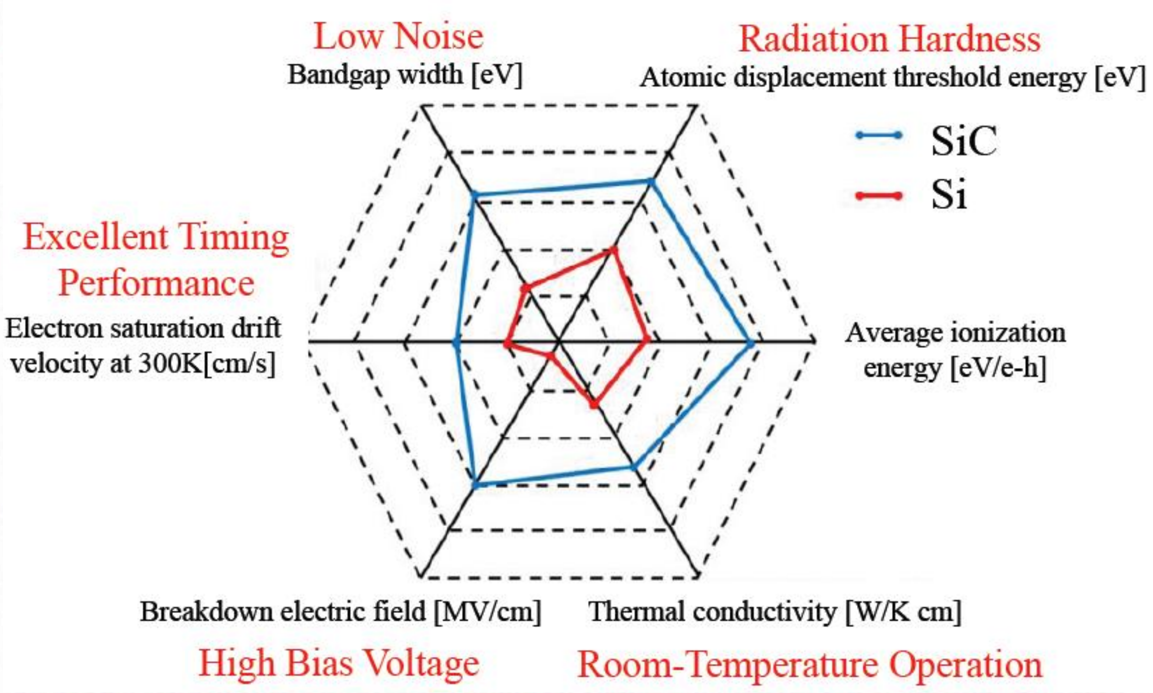
Alternatives for FILD operation at high temperature:

- **New scintillator materials**
- **Semiconductor materials**

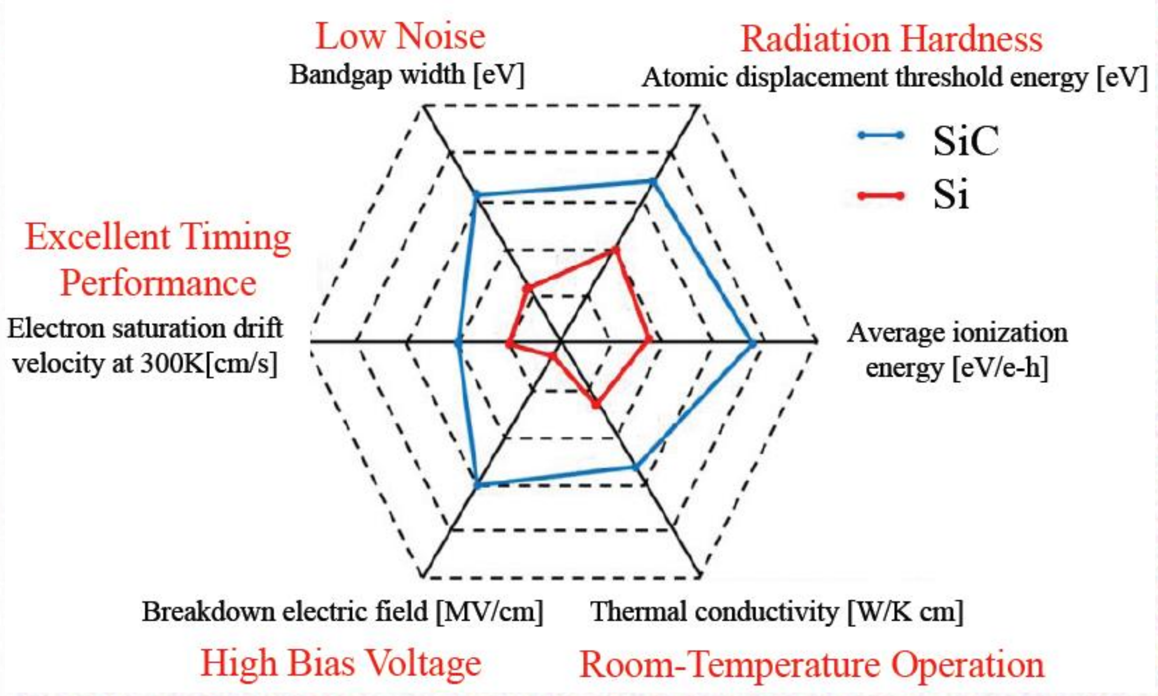
NEW TYPE OF 4H-SiC SENSOR FOR APPLICATIONS AT HIGH TEMPERATURES

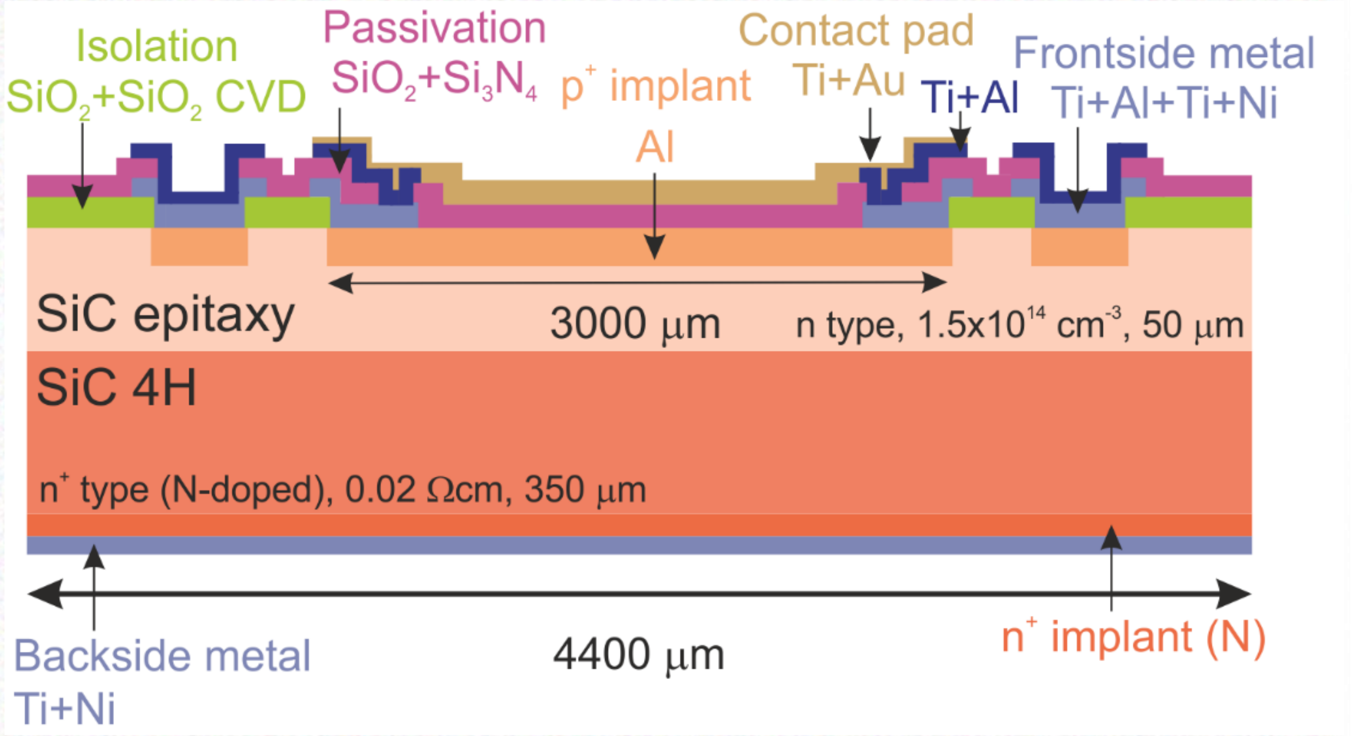
- **Limitations of conventional semiconductors (Si,Ge)**: Performance degrades sharply under high temperatures and intense radiation fields.

- **Path to novel detectors**: Research must focus on materials with a higher atomic displacement threshold and a wider bandgap.



Project RETOS-EMPRESA:
RTC-2017-6369-3





Provided by the IMB-CNM-CSIC group

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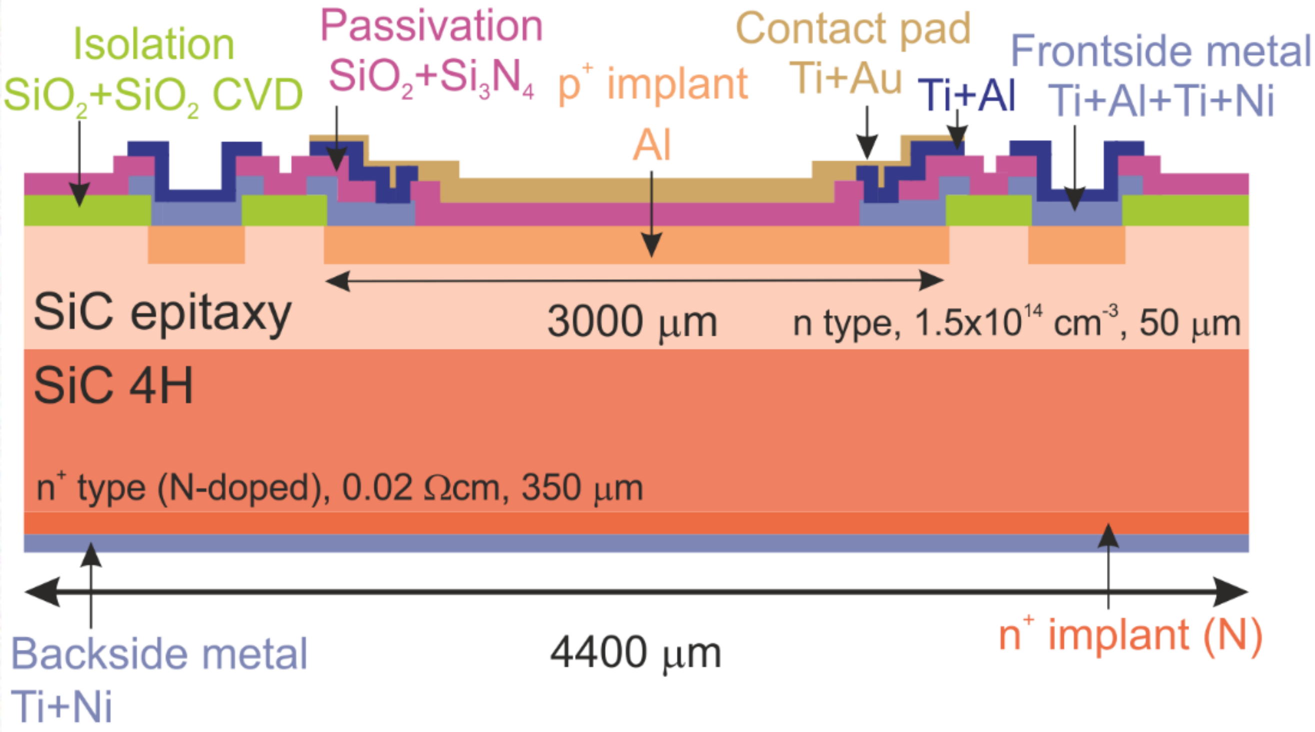

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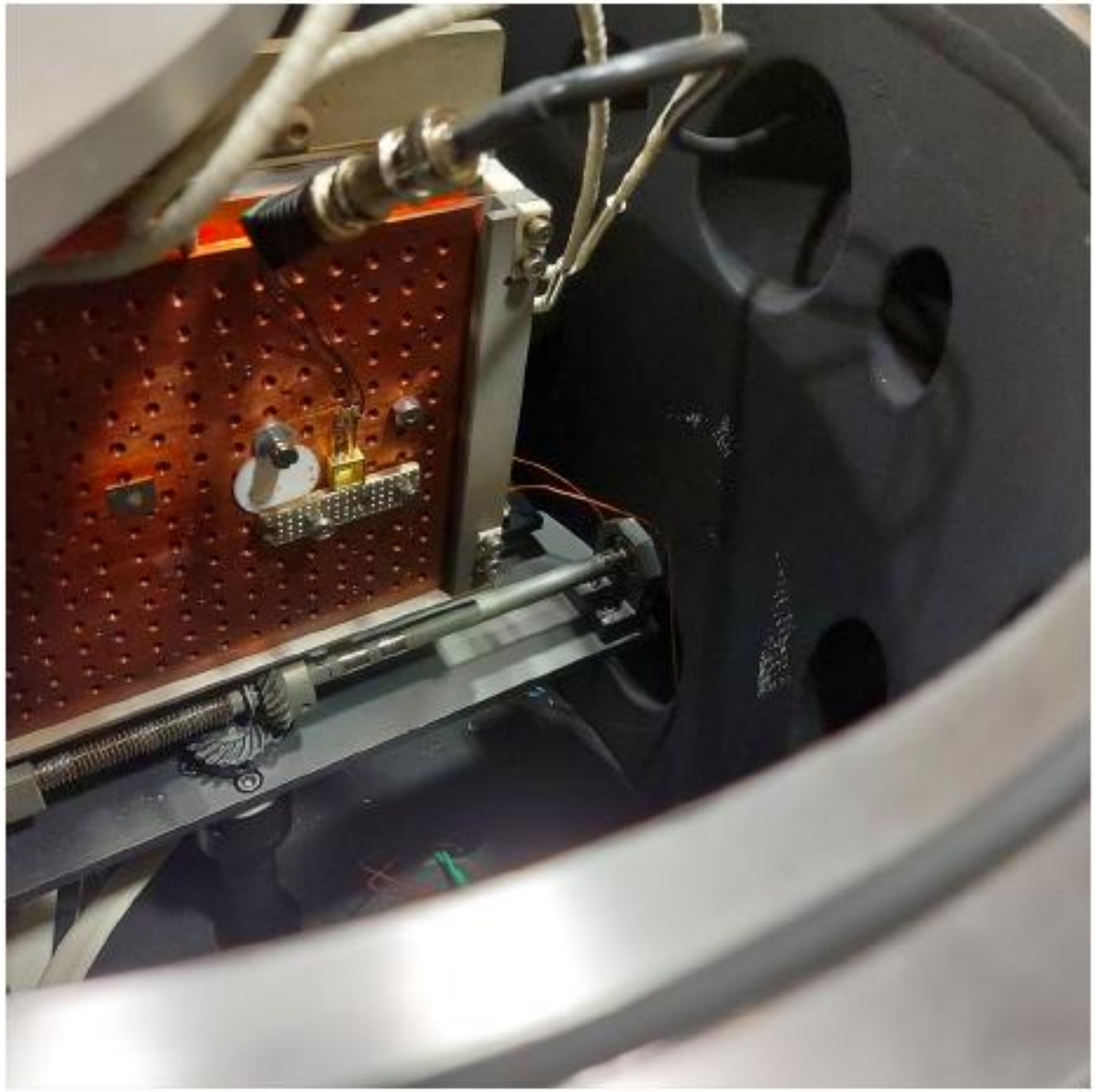
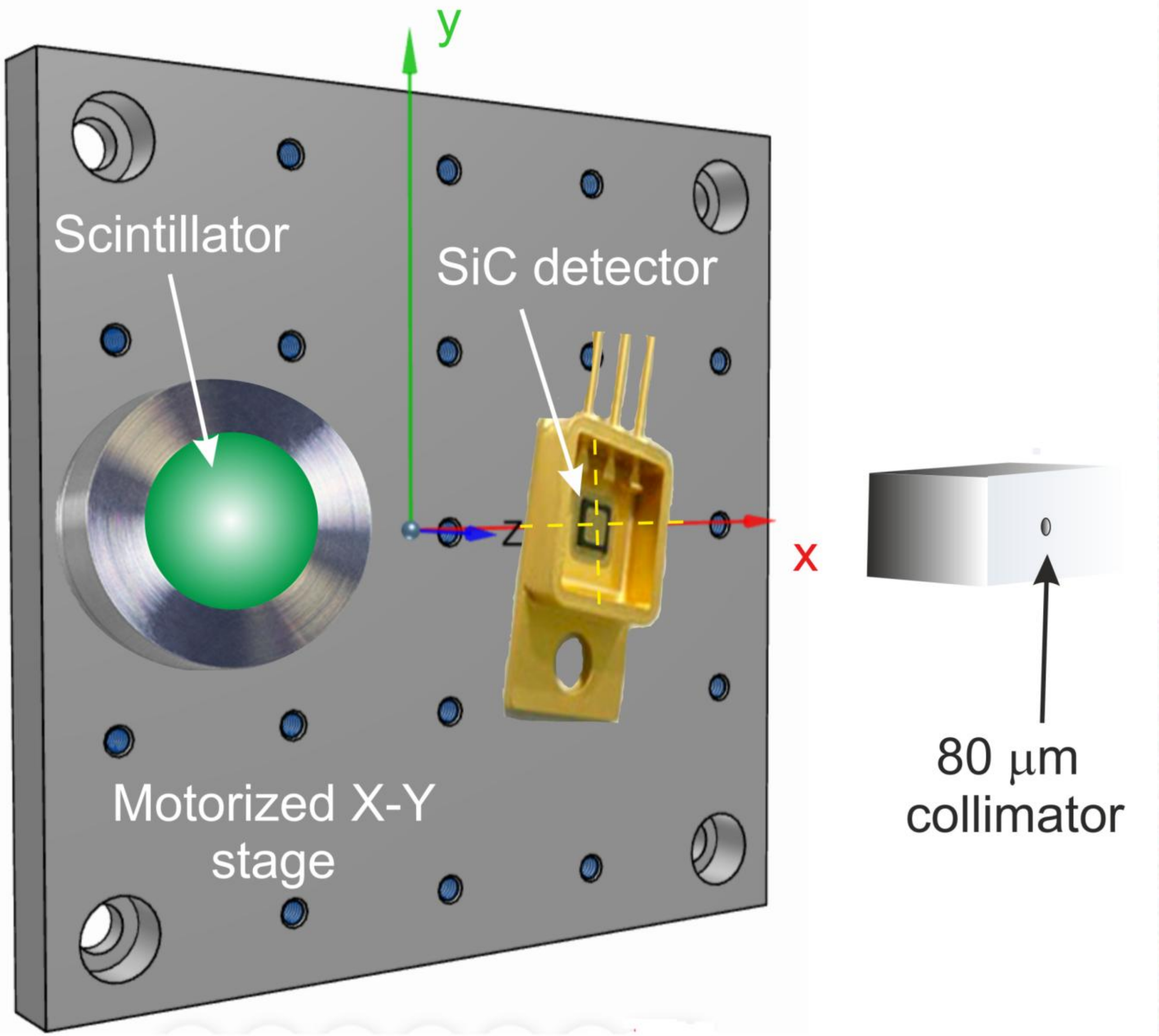
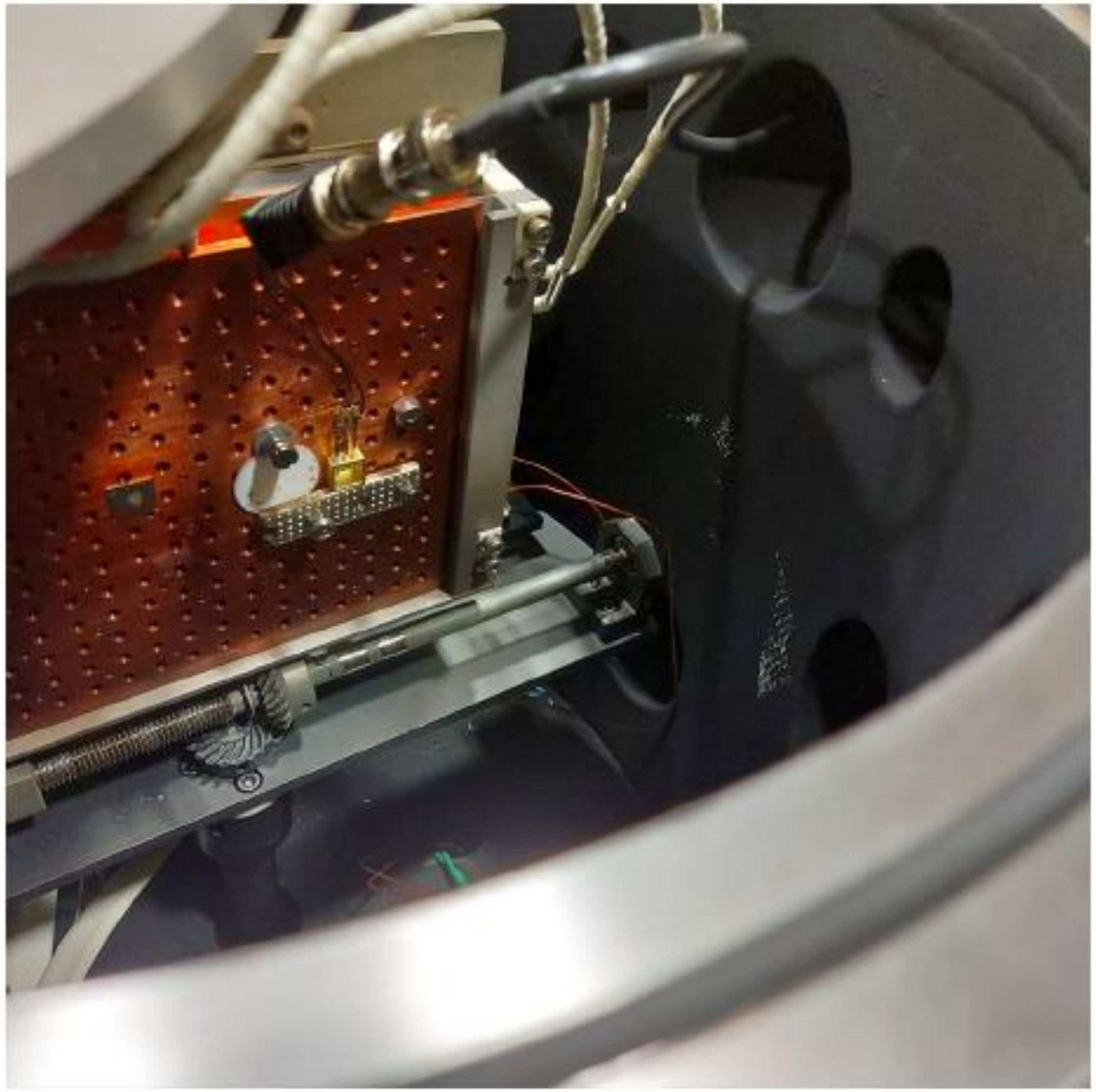
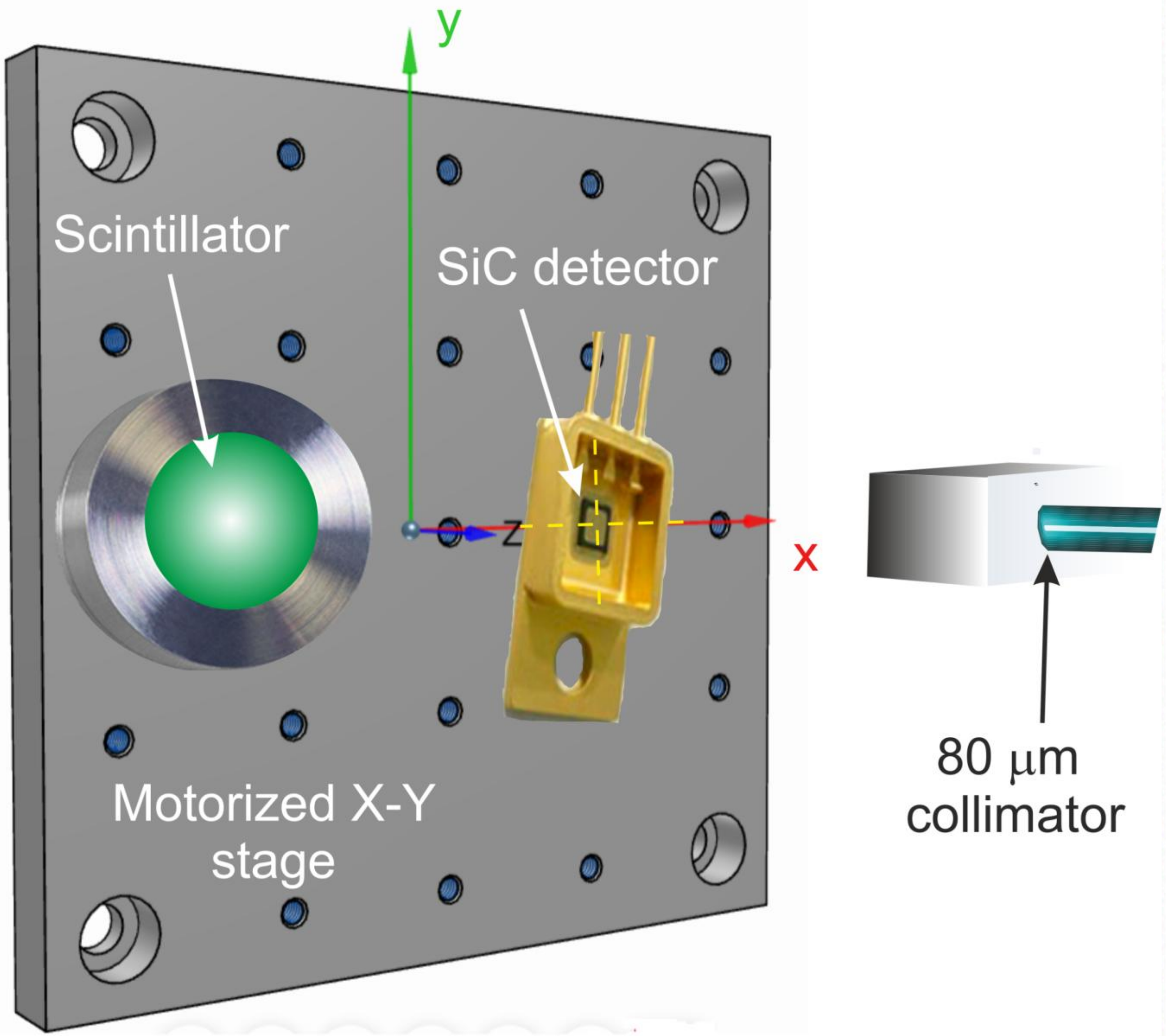
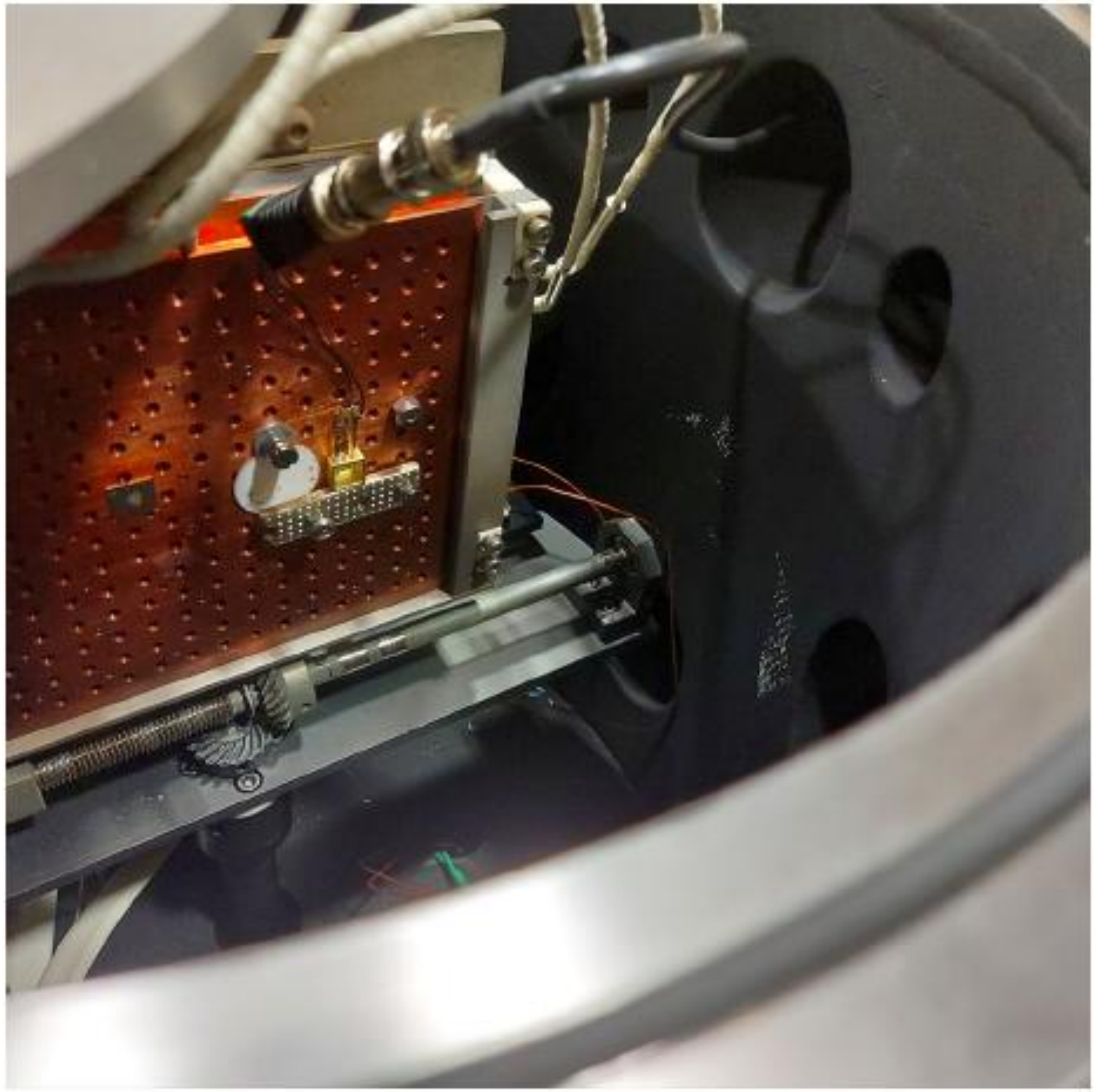
EXPERIMENTAL SETUP FOR SPECTROSCOPY AT HIGH TEMPERATURE

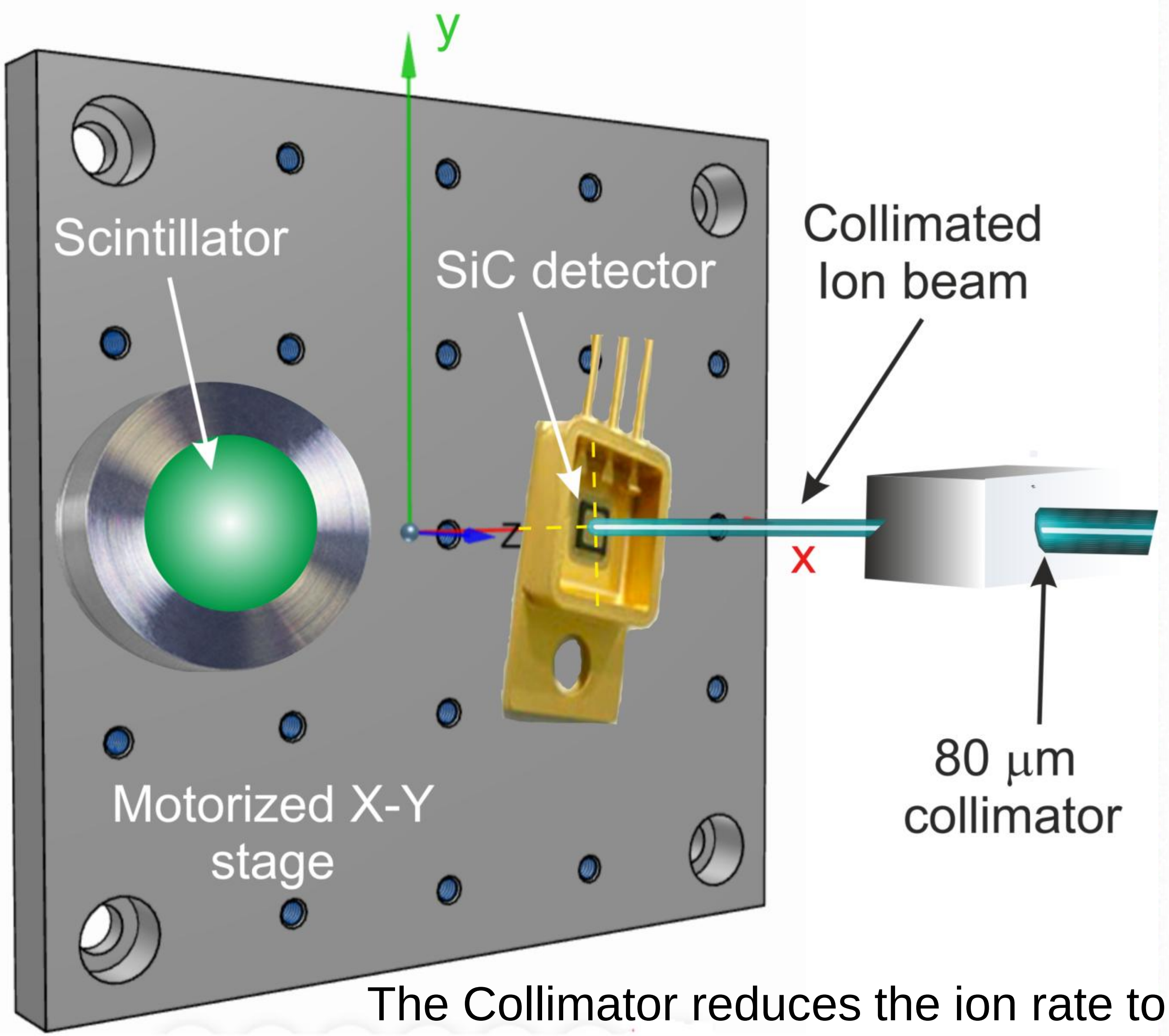







y
Scintillator
SiC detector
z
x
Motorized X-Y stage
80 μm collimator

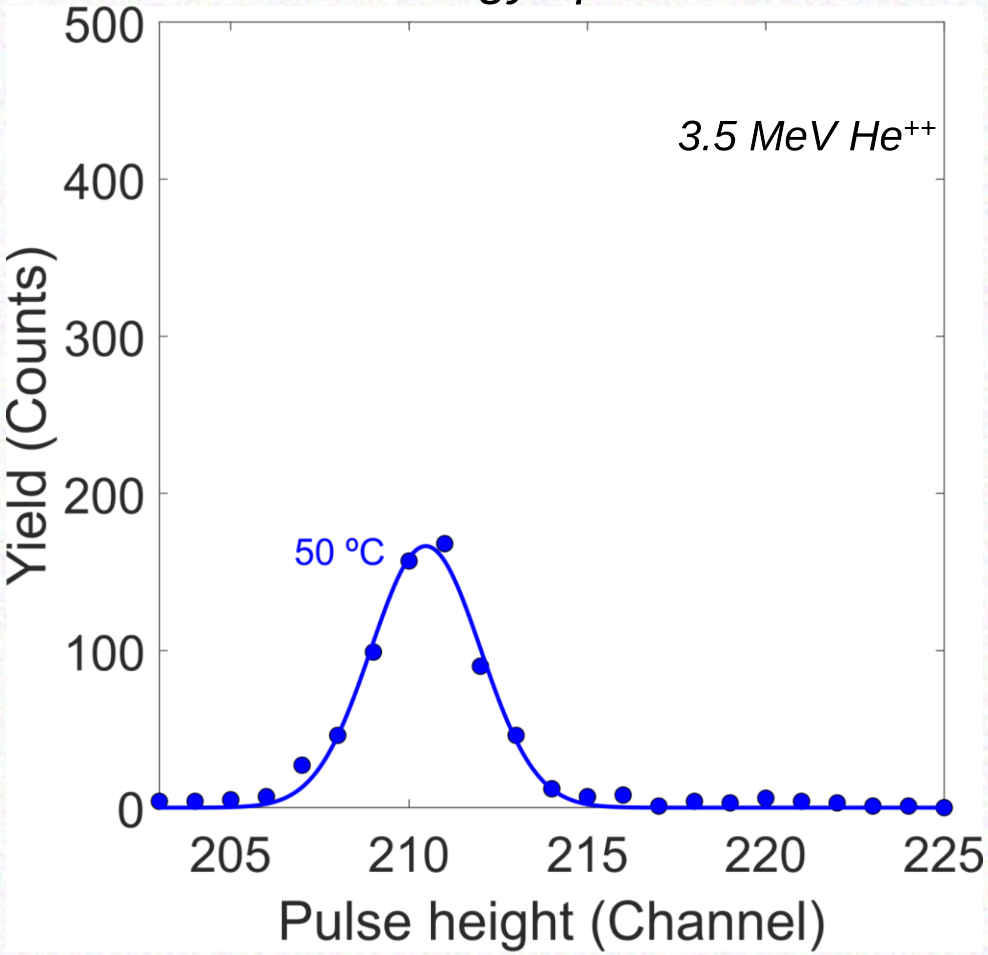




The Collimator reduces the ion rate to avoid damage.

Spectroscopy results demonstrate reliable operation in high-temperature environments like nuclear fusion reactors or outer space.

Energy spectra



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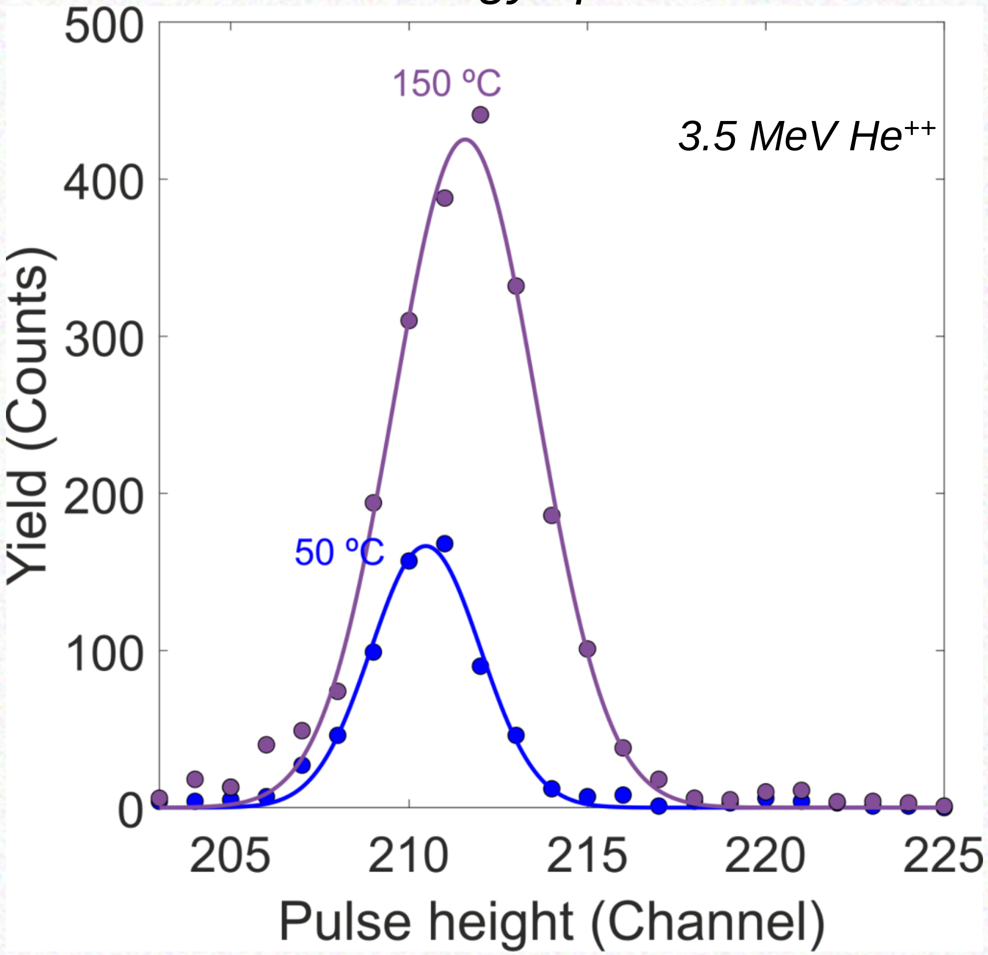

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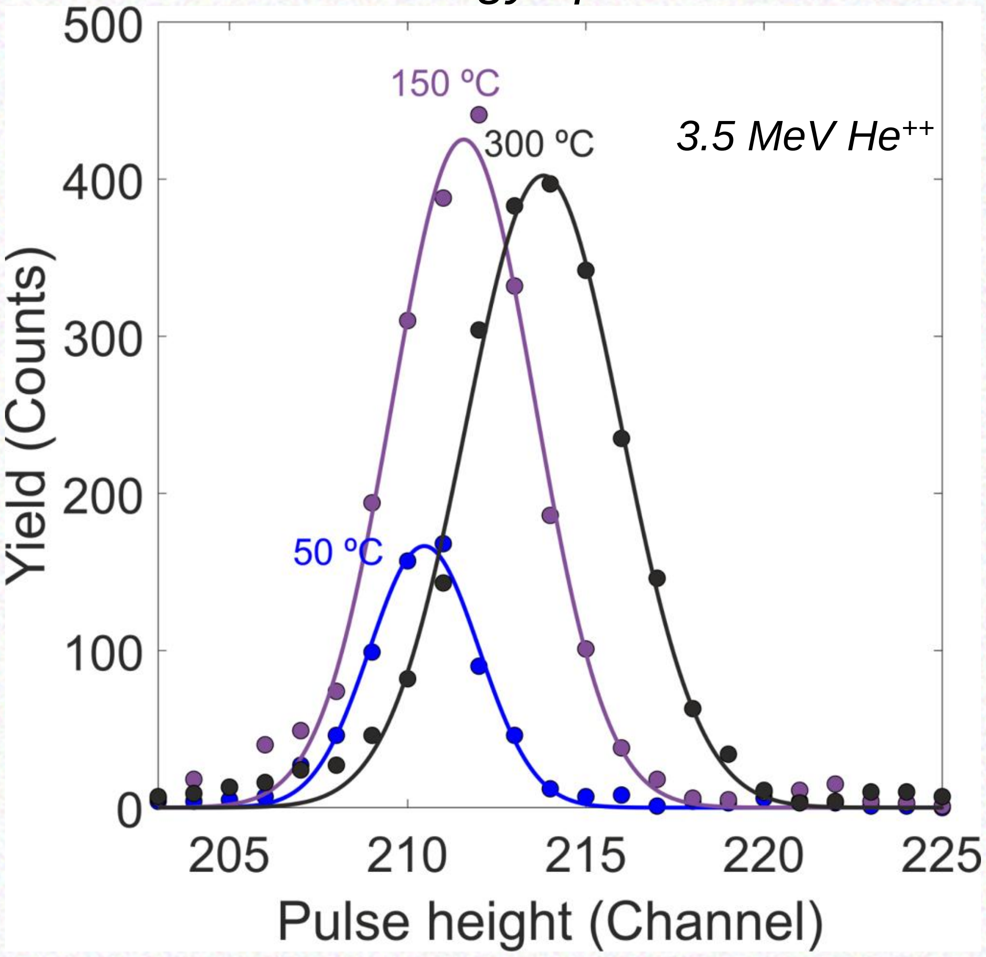

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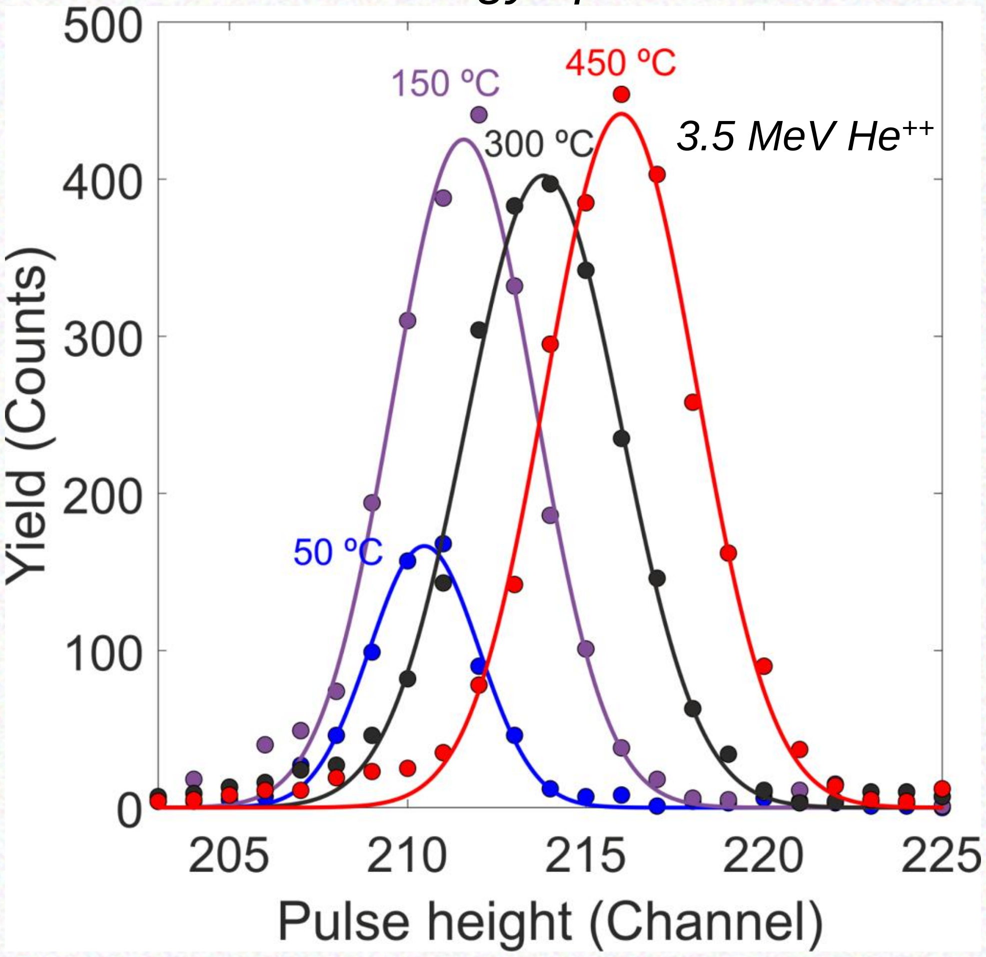

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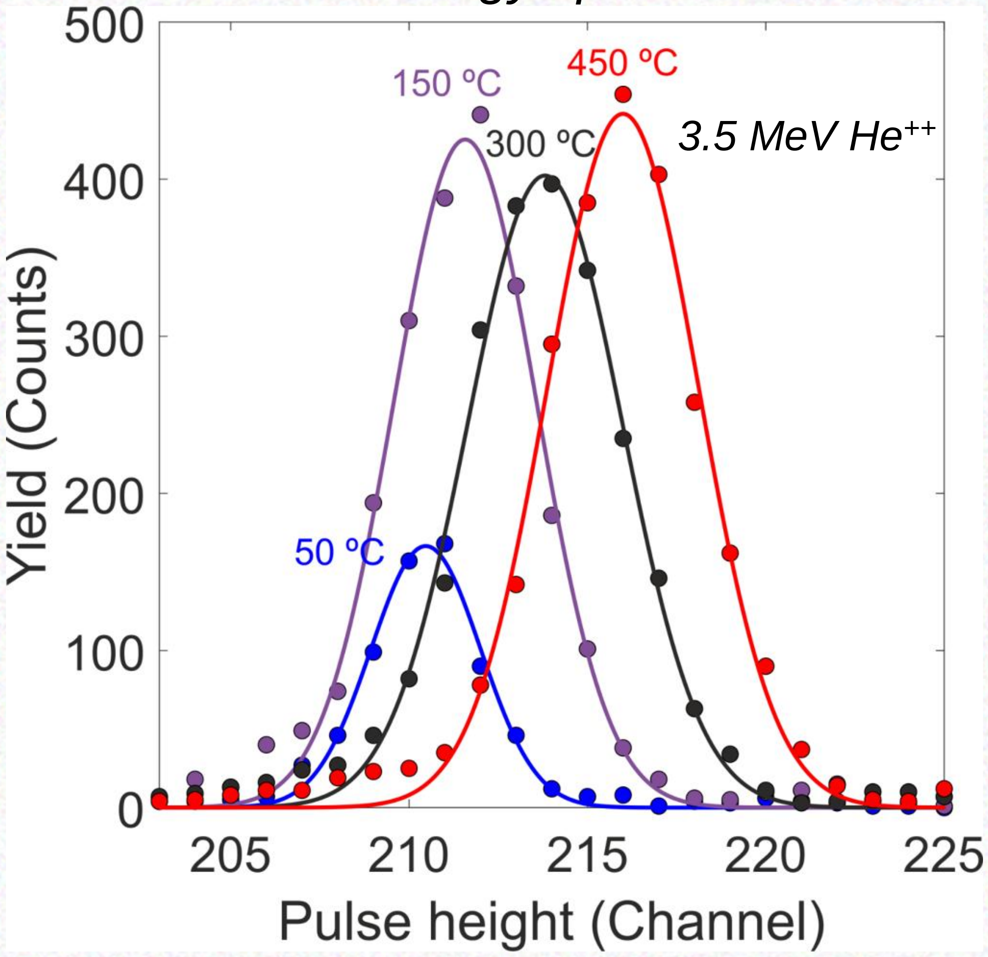

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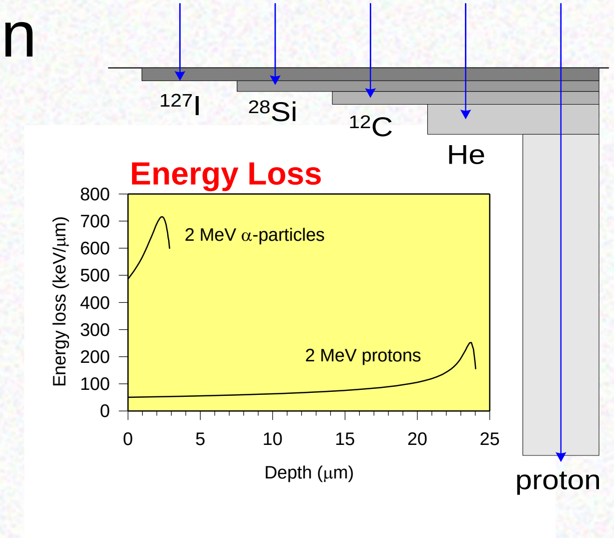
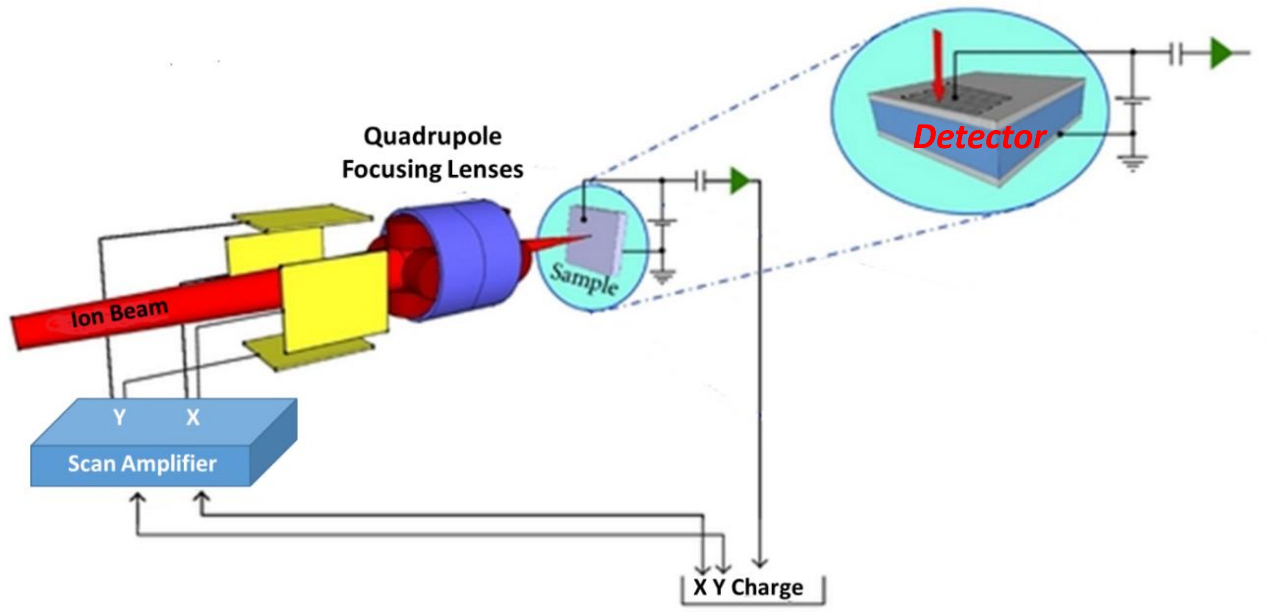
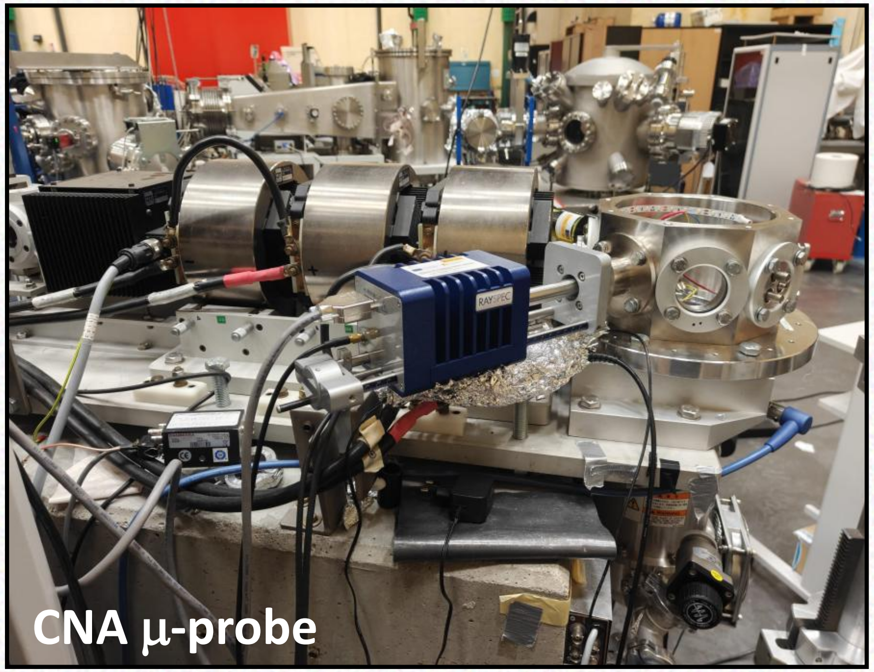
How can we induce controlled damage at high temperatures?

- Tunable penetration depth (E~MeV).
- Good selection of ion species and ionization profiles.



- Ion beam focusing to the μm scale using a magnetic quadrupole triplet.
- Scanning system: few mm^2.
- Synchronous signal acquisition system with scanning: mappings.





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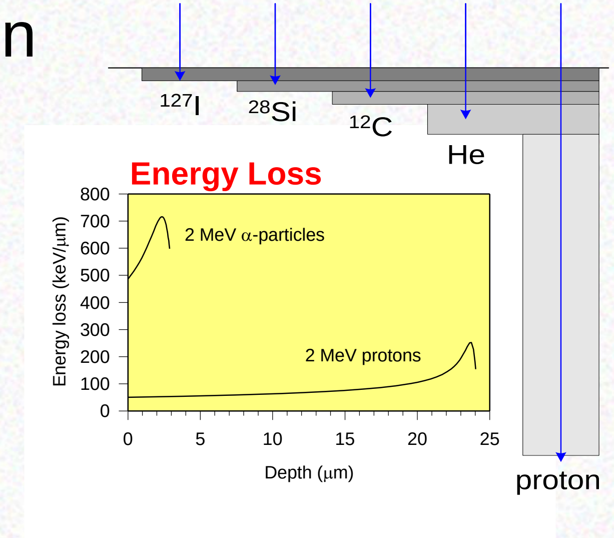

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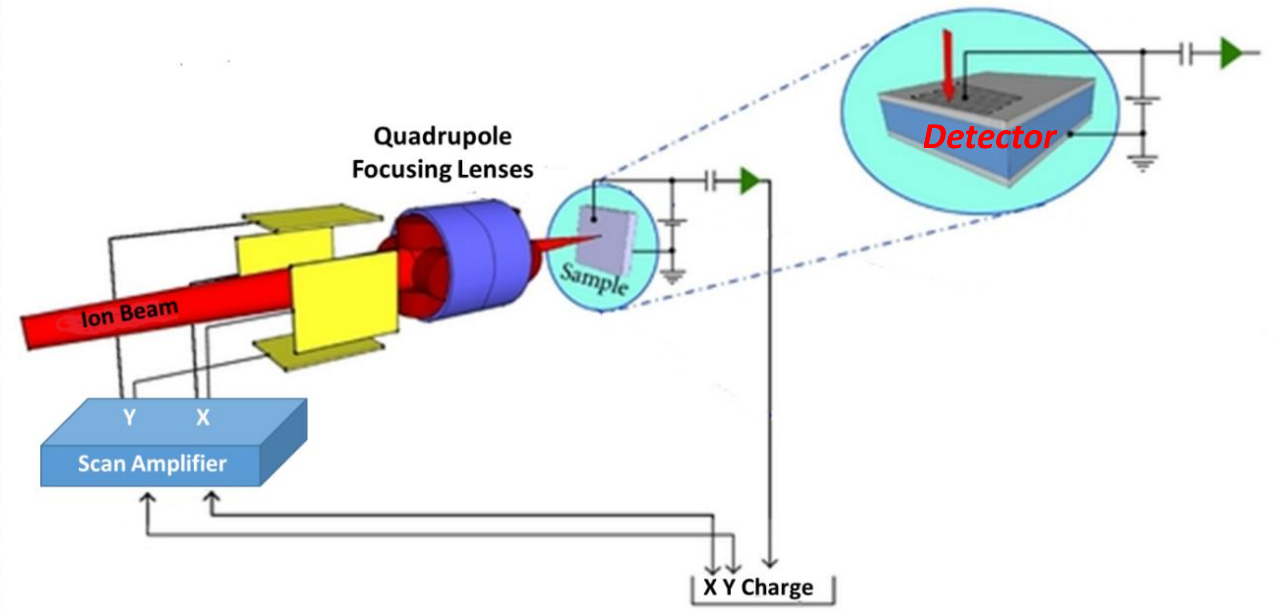

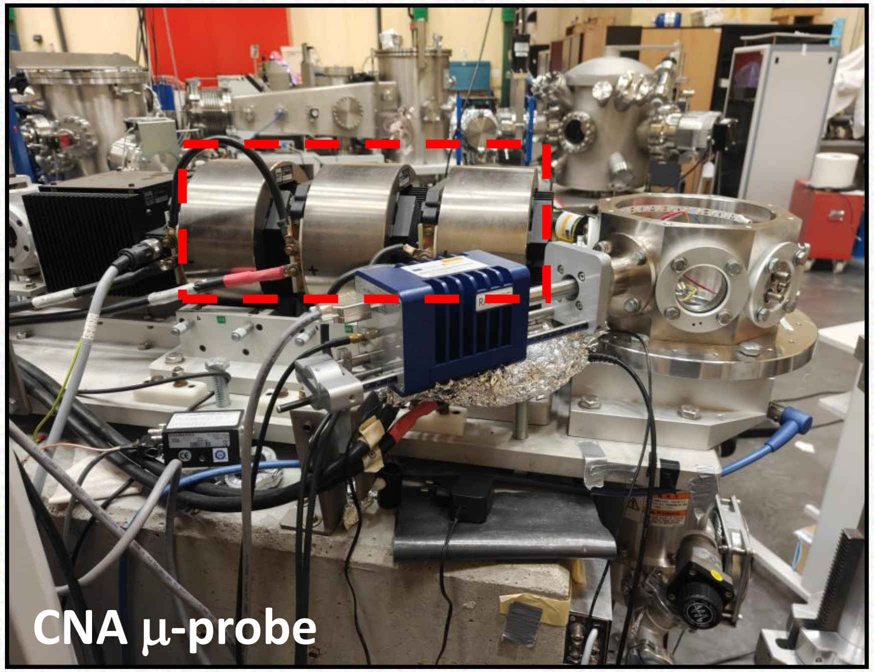

ION BEAM MICROPROBE FOR SEMICONDUCTOR CHARACTERIZATION

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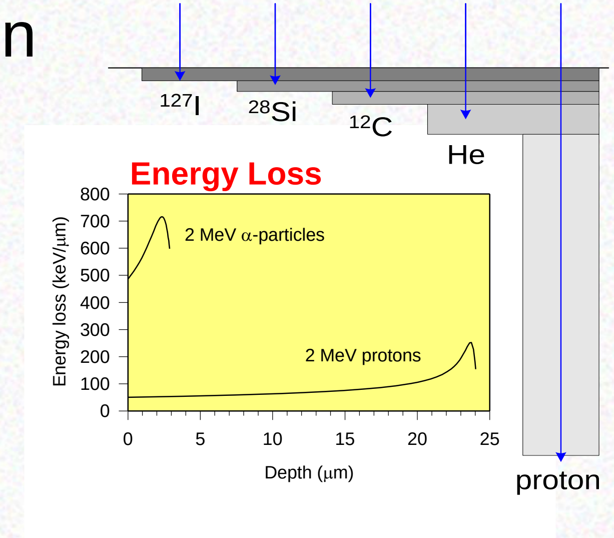

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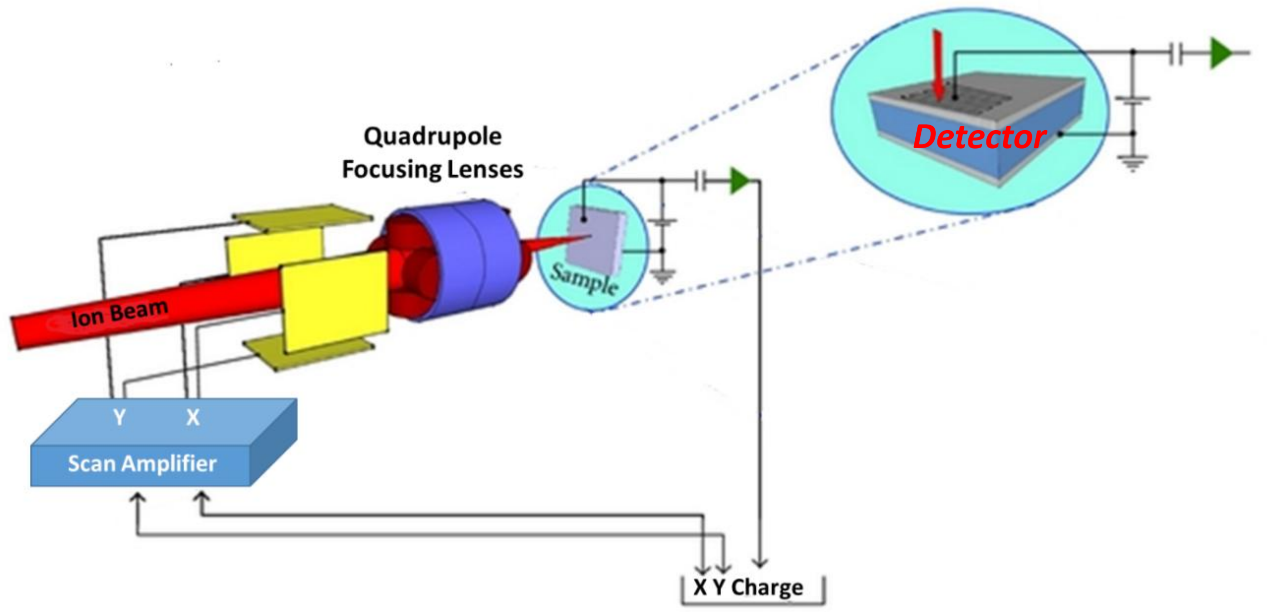

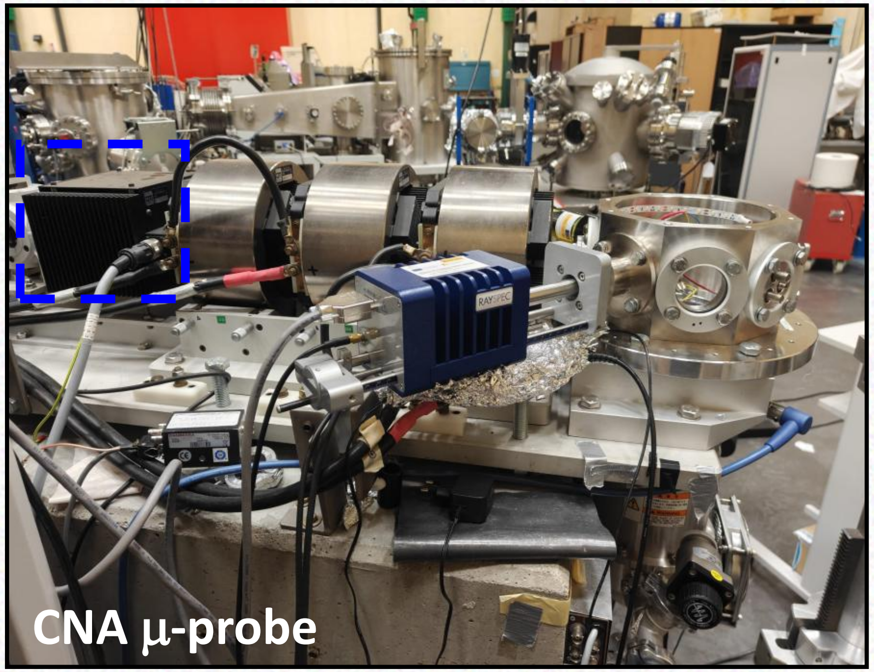

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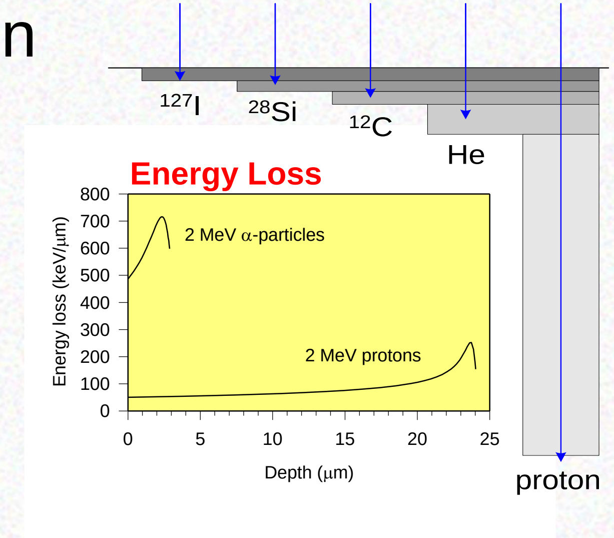
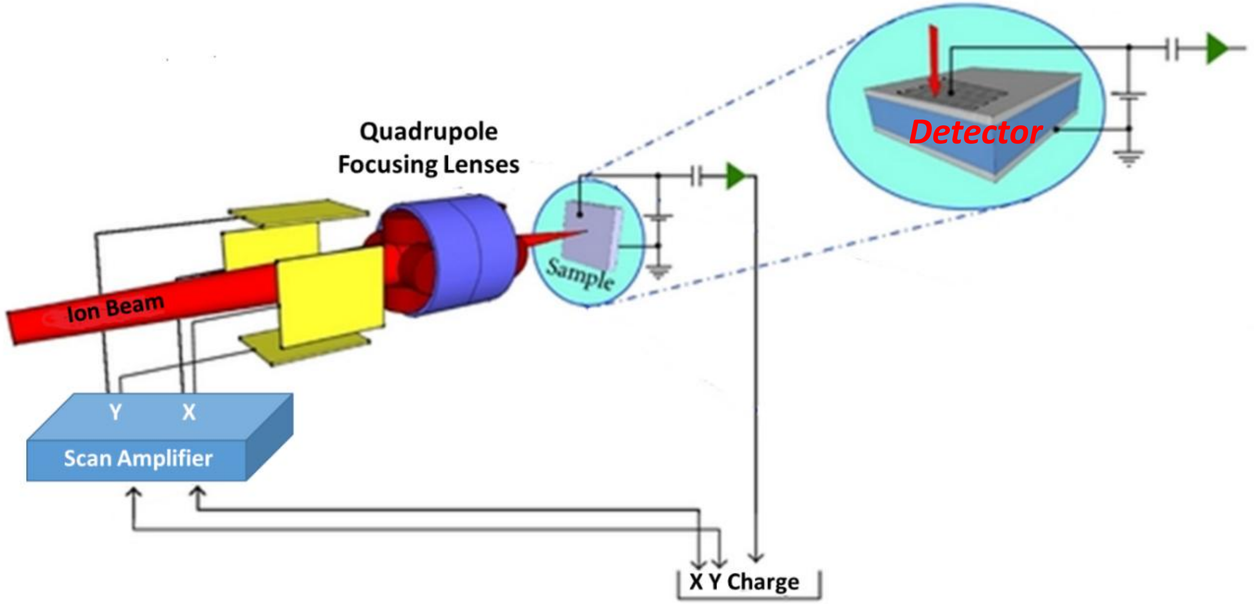
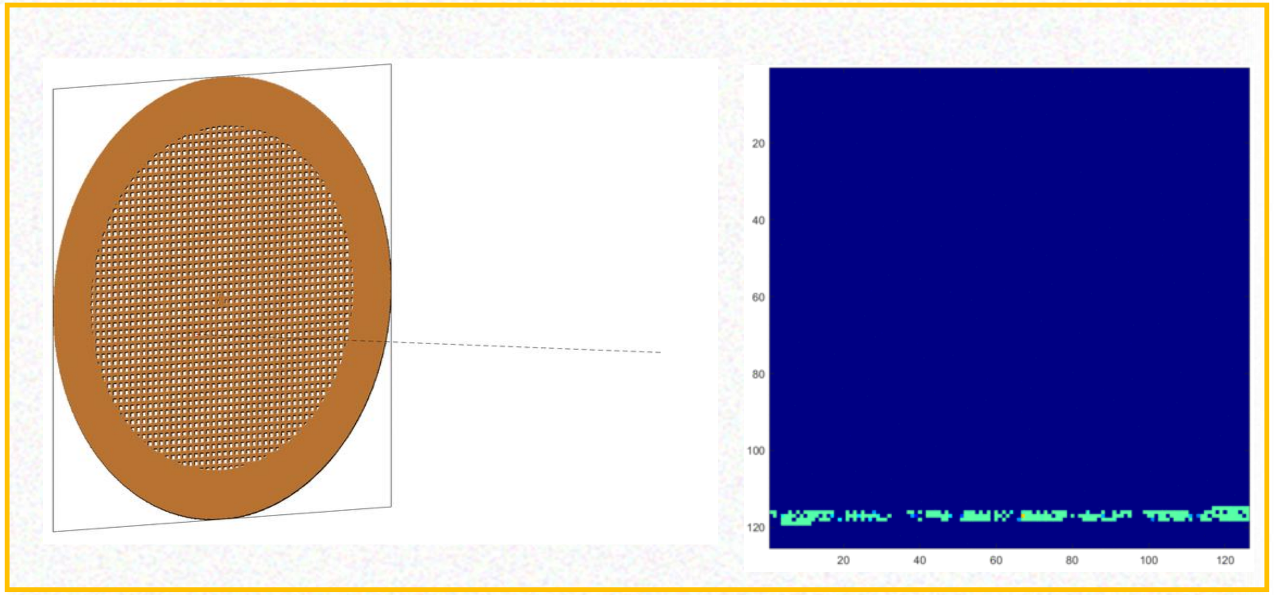


- Ion beam focusing to the μm scale using a magnetic quadrupole triplet.
- Scanning system: few mm^2.
- **Synchronous signal acquisition system with scanning: mappings**.





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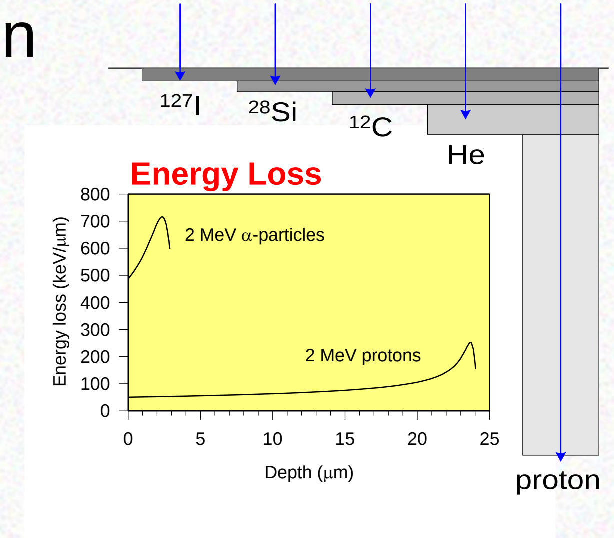

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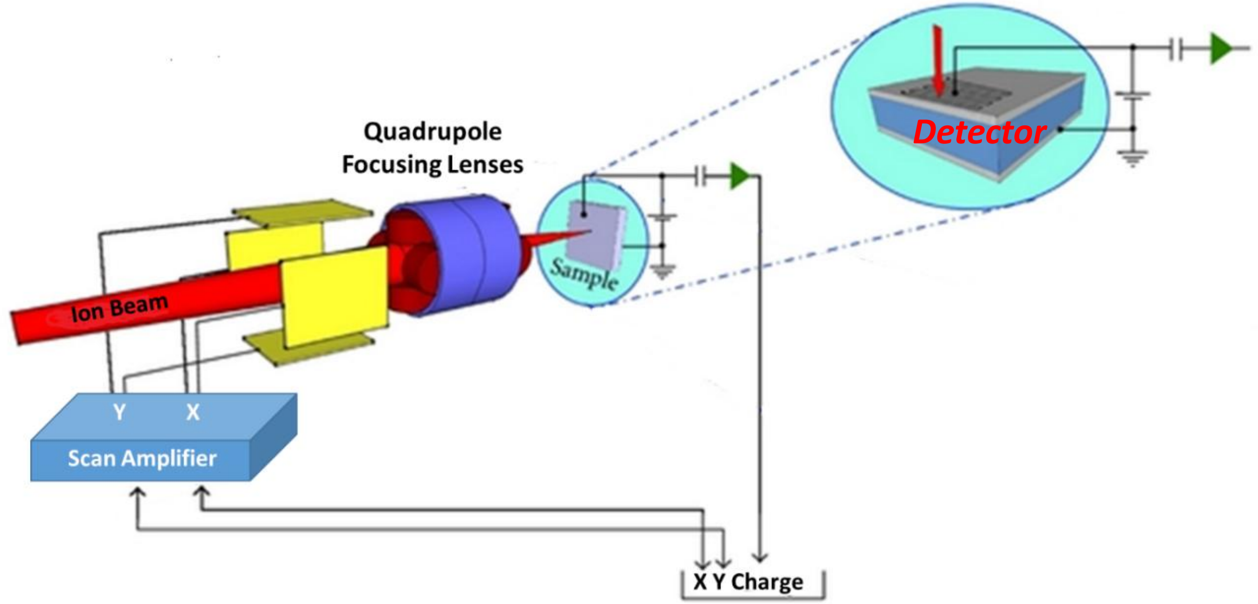
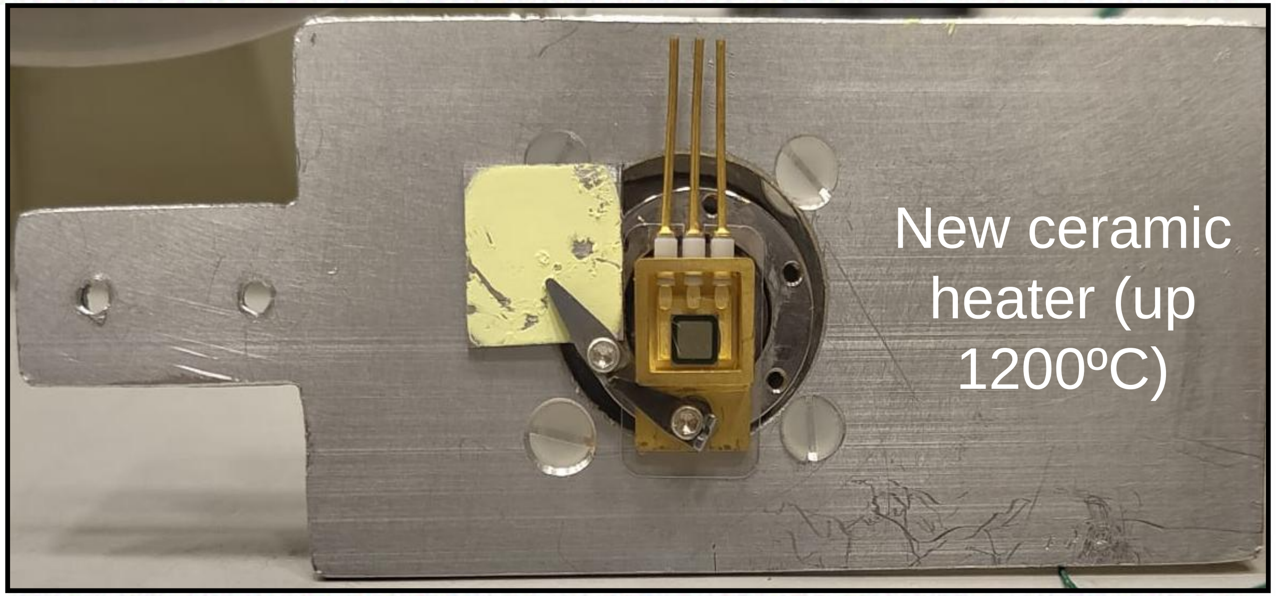
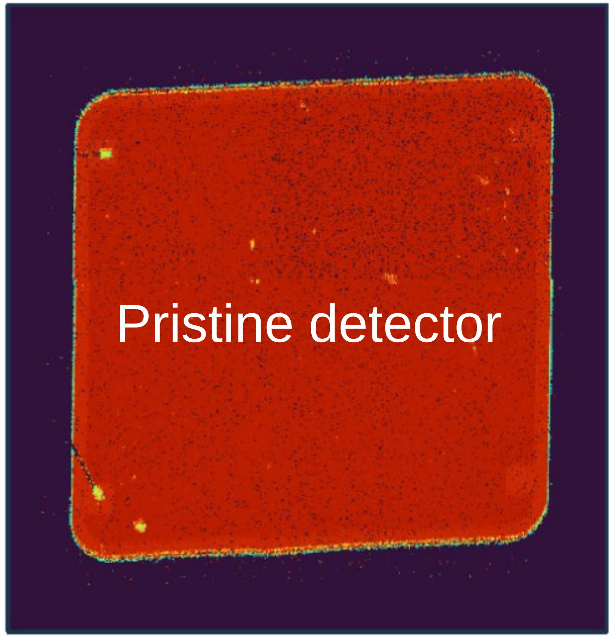
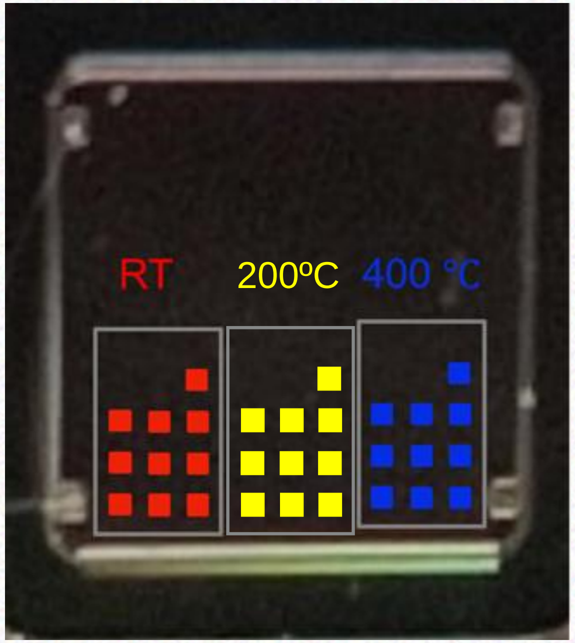




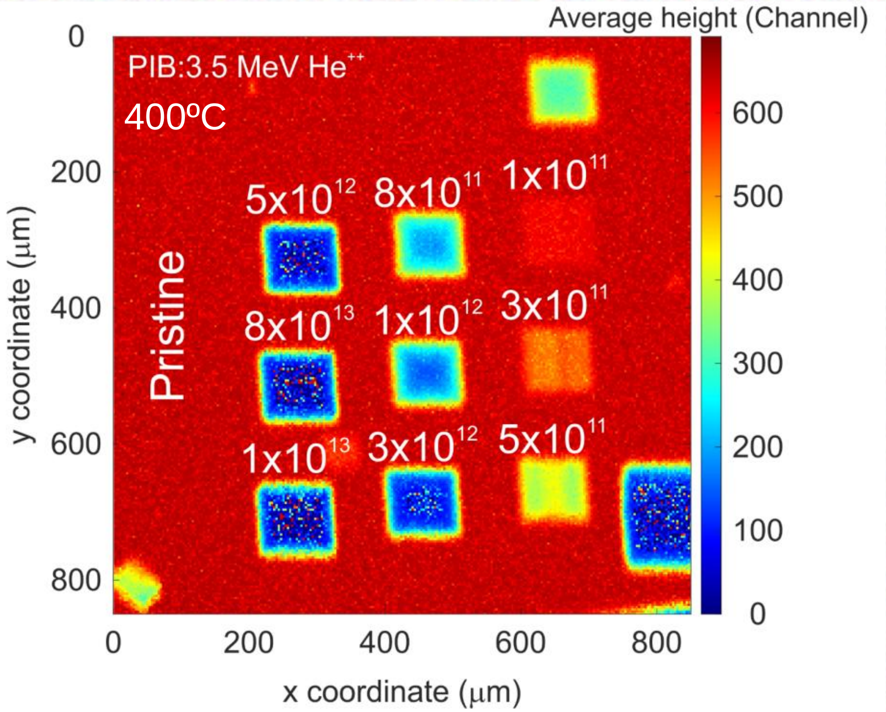


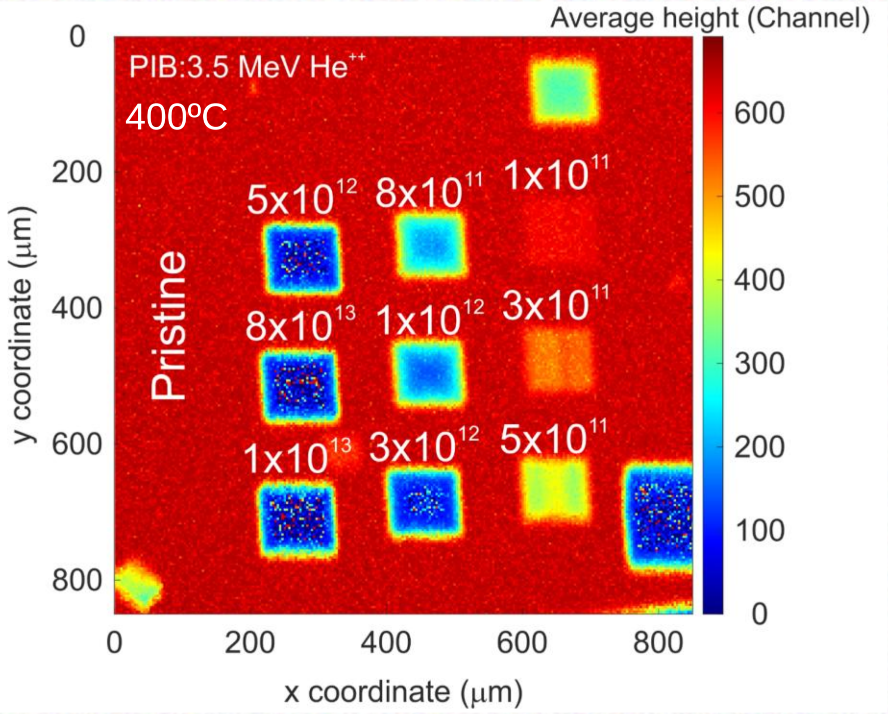


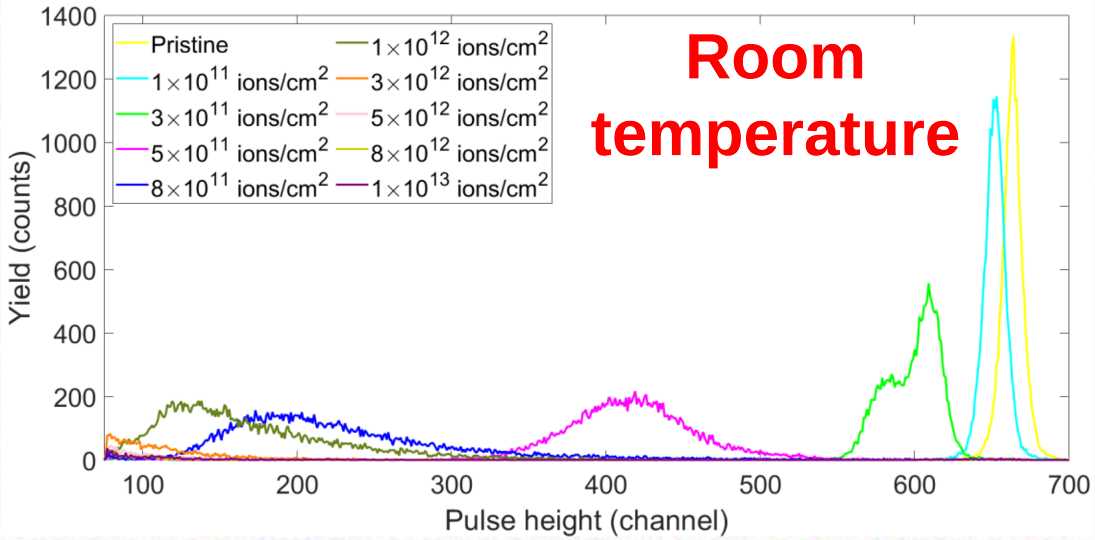
- 2D map revealed high homogeneity in detector's response.

- Ten different regions (100x100 μm^2) were damaged at different doses (ranging from 1×10^{11} to 1×10^{13} ions/cm^2) for each temperature.

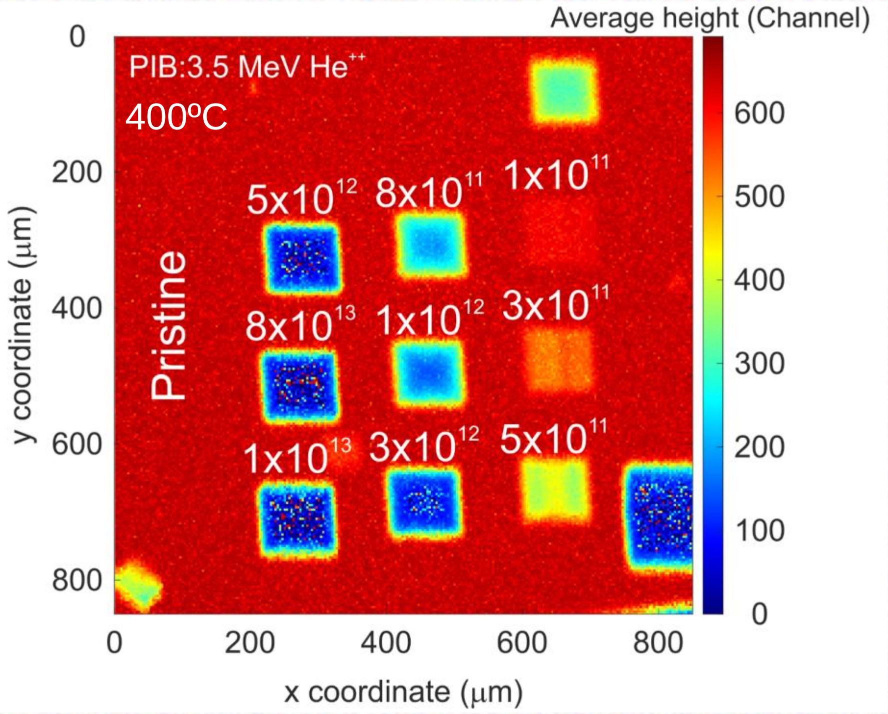
DAMAGE UNDER HEAT IMPROVES RESPONSE







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



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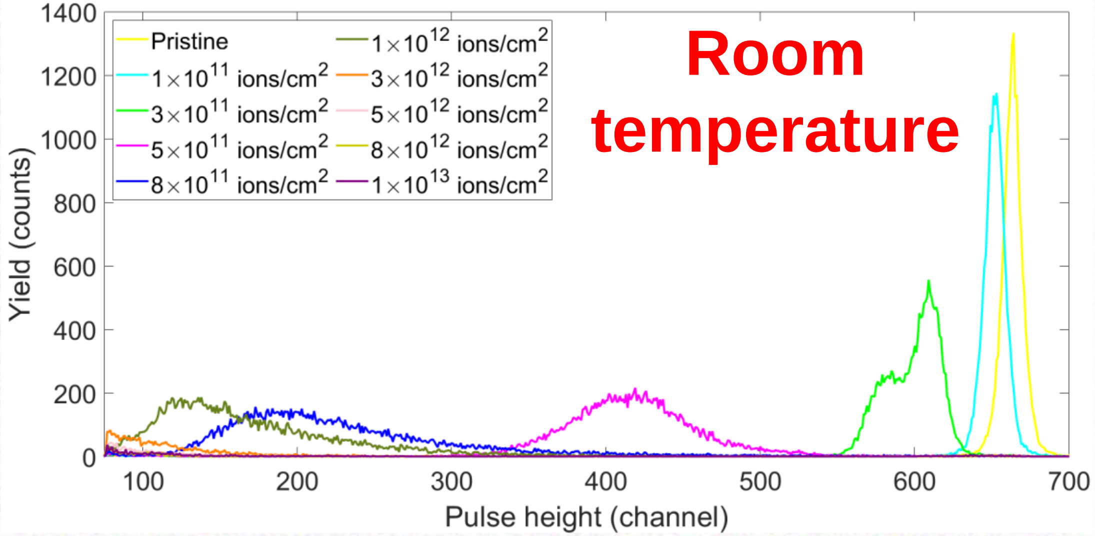
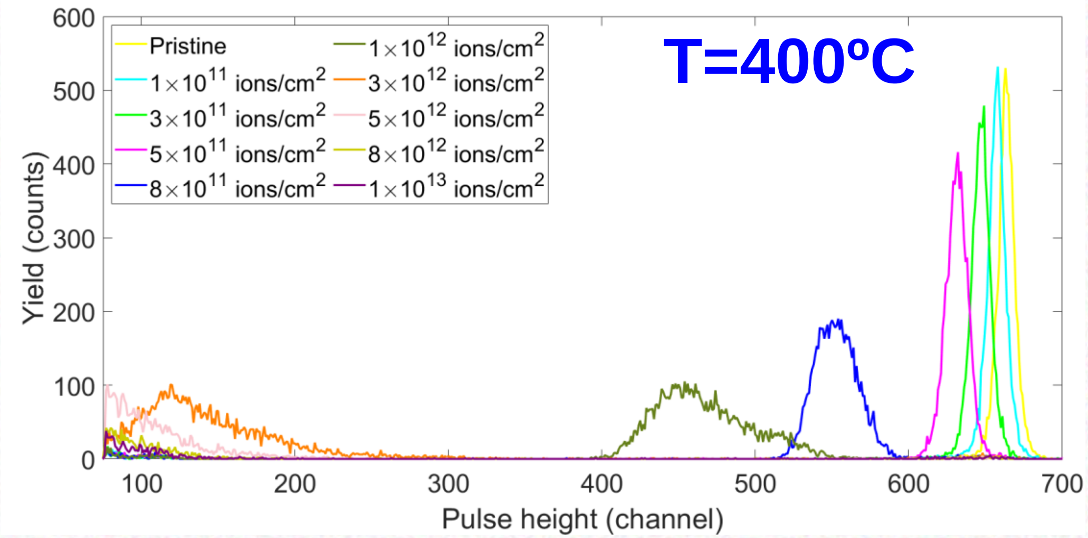
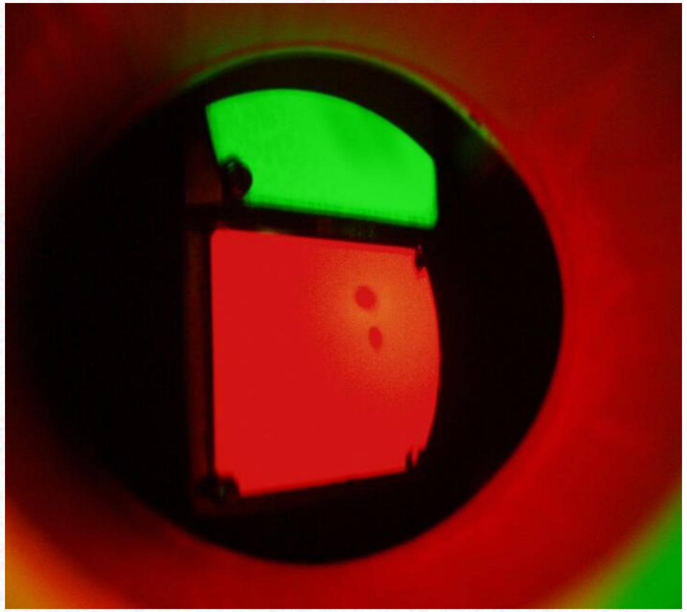
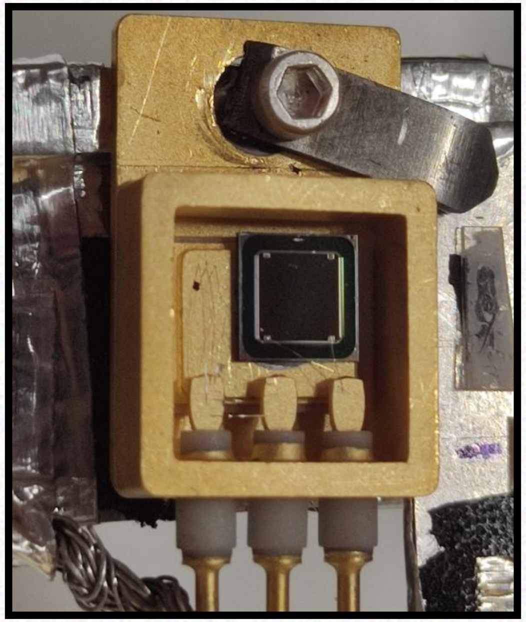
- The signal is better preserved at high temperatures due to the **dynamic annealing mechanism (****Torres, C et al. IEEE Trans. Instrum. Meas. Under revision (2026)****)**.





- The CNA facility utilizes IBA techniques to study both scintillator materials and semiconductor detectors for nuclear fusion.
- Standard fusion scintillators suffer from severe thermal quenching at next-generation reactor operating temperatures.
- The 4H-SiC detectors measure suprathermal ions effectively up to 450 °C with excellent energy resolution.





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- Standard fusion scintillators suffer from severe thermal quenching at next-generation reactor operating temperatures.
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- **Future work** involves finding new heat-resistant scintillators and exploring techniques to enhance the response of damaged 4H-SiC detectors at high temperatures.

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

Actuación 1.1 Irradiación de detectores con aceleradores. **(<u>ASTRO21/1.1/1</u>).**


Thank you for your
attention

Six main facilities:

- 3MV Tandem Accelerator
- 18 MeV proton cyclotron
- Tandetron AMS
- Compact accelerator for radiocarbon
- ^{60}Co Irradiator
- PET/CT Scanner