HEARTS 2nd Annual Meeting

20 January 2025

https://indico.cern.ch/event/1471638/

S. Gerardin – UniPD
on behalf of all WP5 partners

Funded by
the European Union

HEARTS is a project funded by the European Union under GA No 101082402, through the Space Work Programme of the European Commission.

Tasks & Objectives

- Project goal is to provide **>100 MeV/n heavy ion beams to space users**, to mimic the effects of Galactic Cosmic Rays (GCR) at ground level
  - penetration levels large enough to enable electronics testing in air, without the need of special preparation and at board and box level
  - essential for the exploitation of high-end microelectronics technology in space, for e.g. onboard Artificial Intelligence or Big Data processing applications
- Purpose of WP5: study of **radiation effects induced by VHE heavy ions** on a set of **technologies representative of current state-of-the-art COTS electronics**
  - Comparison with standard-energy heavy ions.
  - A hierarchical approach, based on three levels of complexity, will highlight different levels of details

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WP5 Tasks

5.1 Final review of VHE ion beam requirements for SEE testing COMPLETED

5.2 Analysis of ionization response in a PIN diode for beam quality assessments IN PROGRESS, EXTENDED

From 1st year

5.3 Suitability of the proposed VHE ion beams for 3D integrated device structures IN PROGRESS

5.4 Validation of the VHE ion beams for industrial use with TRL 6-7 achievement IN PROGRESS

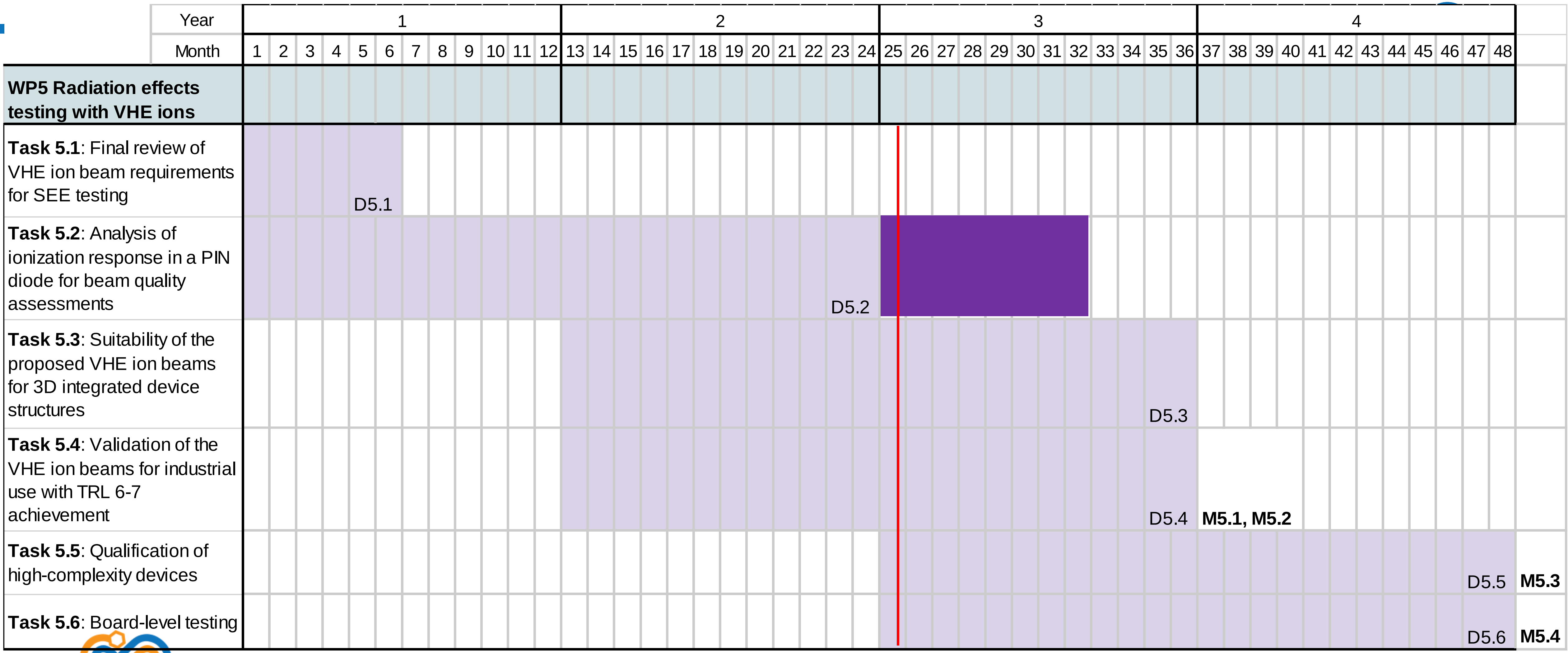
From 2nd year

5.5 Qualification of high-complexity devices IN PROGRESS

5.6 Board-level testing

From 3rd year

WP5 Timeline



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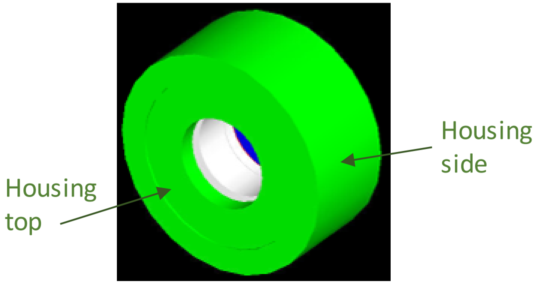
Task 5.2 - Analysis of Ionization Response in a PIN diode for Beam Quality Assessments: Description of Work

- Partners: UNIPD, M1-24
- **PiN diode**: simple and effective structure to study heavy ion beams. It provides precise measurements of energy deposition in semiconductor materials. Diagnostic tool to assess the quality of the provided beam in terms of purity and energy straggling (e.g. with degraders)



D5.2 (M24) Beam Quality

D5.5 (M48) Impact of beam energy in SEE testing

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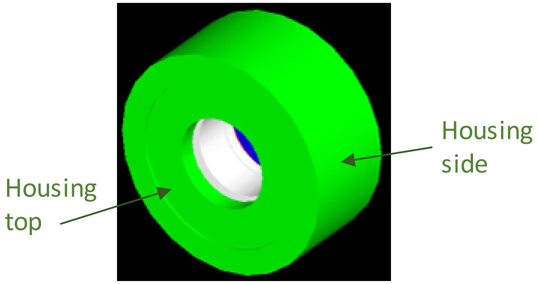
Task 5.2 - Analysis of Ionization Response in a PIN diode for Beam Quality Assessments: Status and Plans

- UniPD activity
  - Mirion diodes, CAEN charge amplifier and multi-channel analyzer
  - Measurements carried out in November 2024 @ CERN
  - **Measurements to be carried out at GSI in June 2025. Extension required to perform experiments at GSI and improve the analysis**
- **Large experimental data set is available** with standard energy heavy ion beams, mostly collected with the ESA experimental setup
  - **Monte Carlo model** of the diode is **available** (see also WP3)
- **TCAD simulations** using Sentaurus are being carried out by UniPD to study the transient currents induced by the heavy ions (see also WP3)

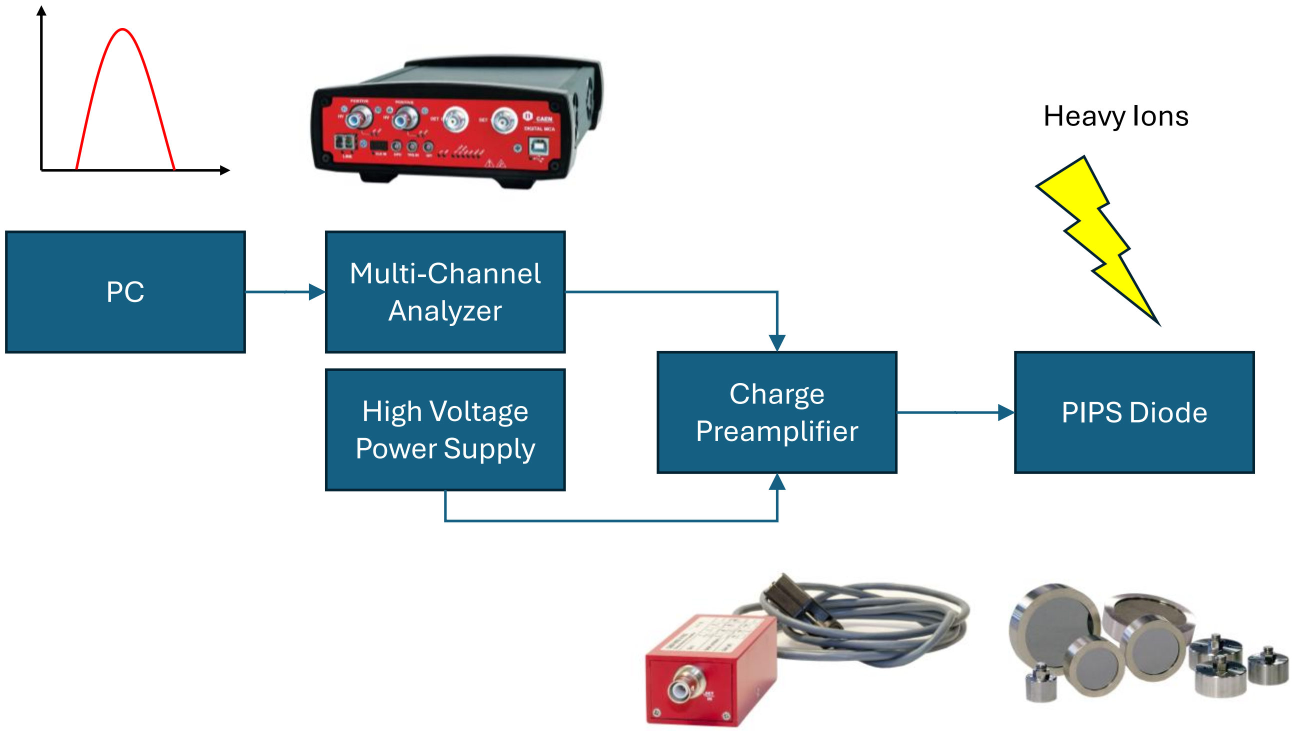


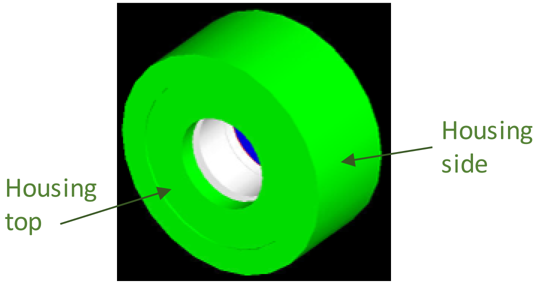
D5.2 (M24) Beam Quality

D5.5 (M48) Impact of beam energy in SEE testing

Task 5.2 - Analysis of Ionization Response in a PIN diode for Beam Quality Assessments: Status and Plans

- UniPD experimental setup: debugged at Legnaro National Labs, using low-energy ions



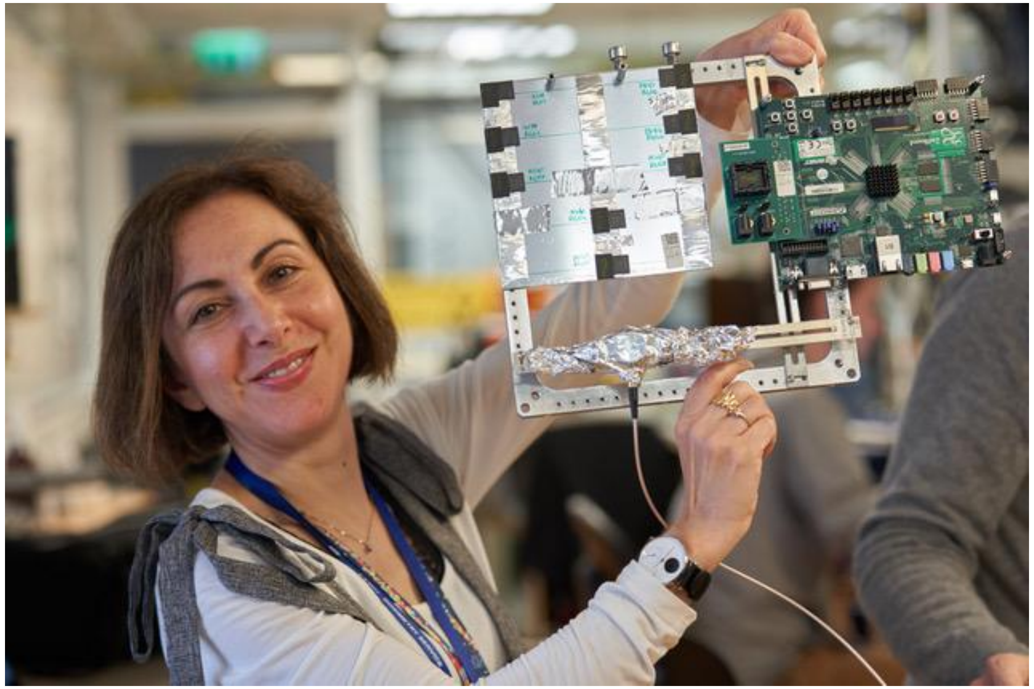


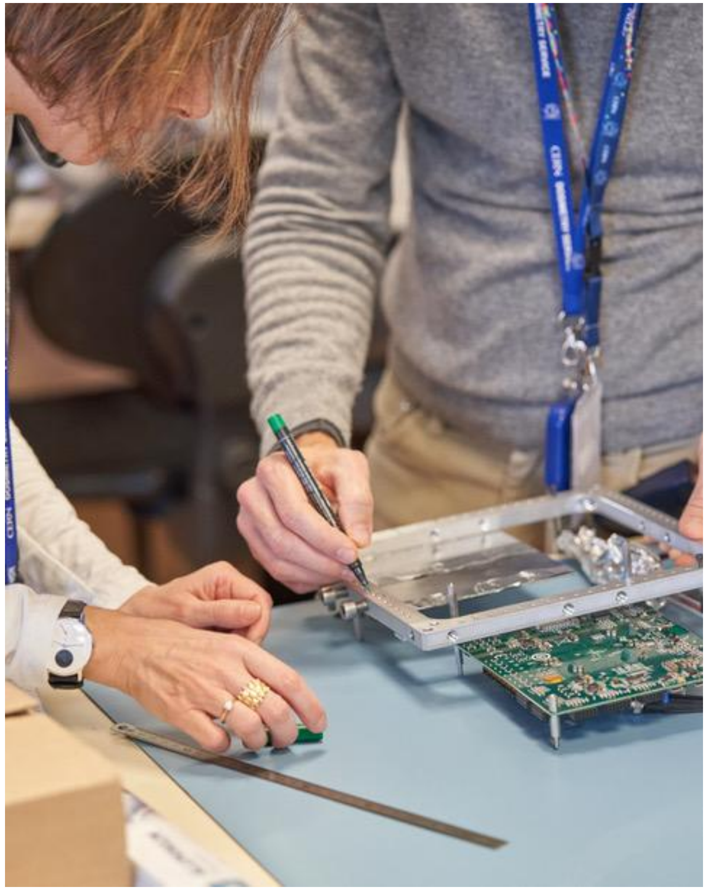
D5.2 (M24) Beam Quality

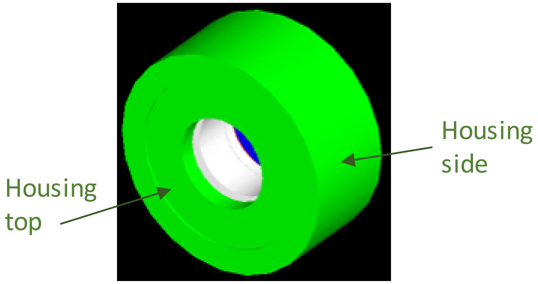
D5.5 (M48) Impact of beam energy in SEE testing

Task 5.2 – Experimental Results

- IRRAD Nov 2024 (Thanks Gerd!)







D5.2 (M24) Beam Quality

D5.5 (M48) Impact of beam energy in SEE testing

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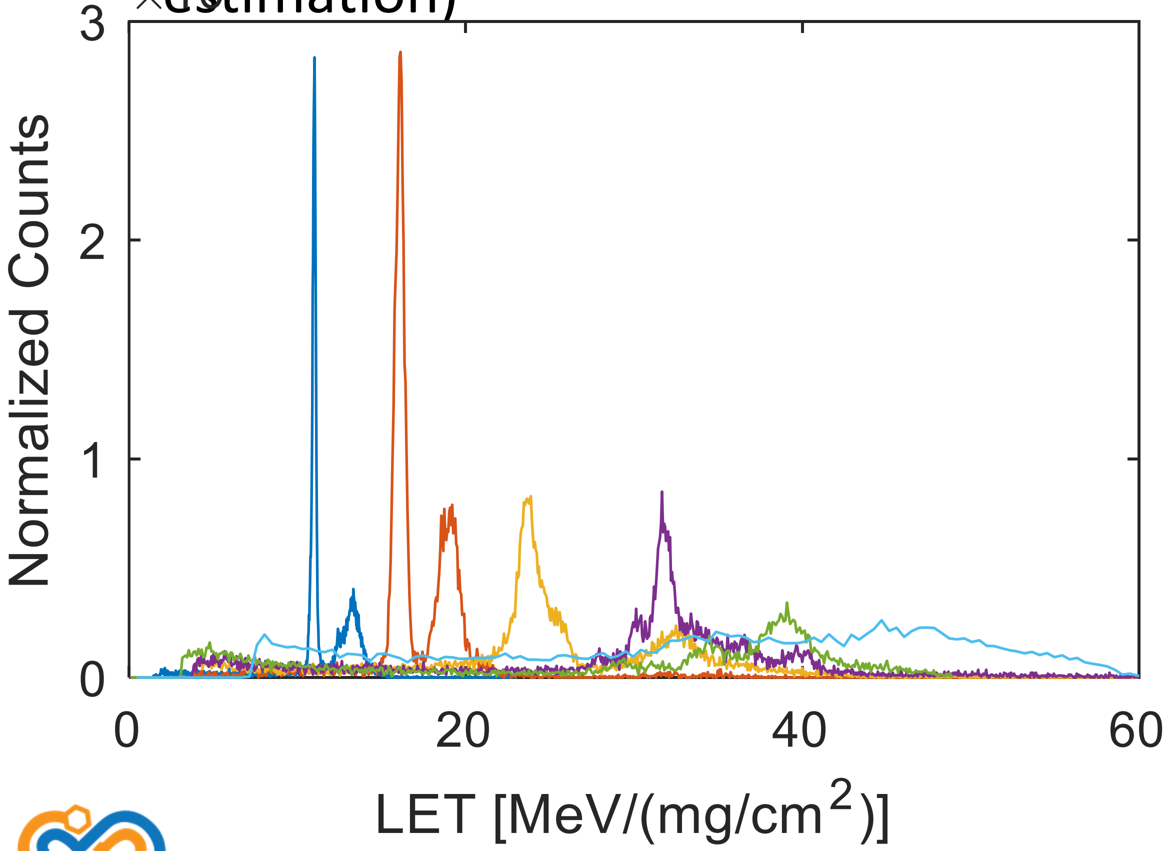
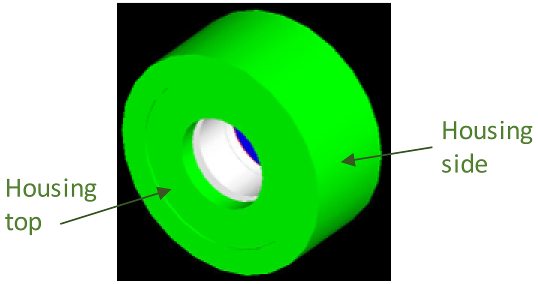
Task 5.2 – Experimental Results

- IRRAD Nov 2024: First LET Spectra @ IRRAD (LET is first estimation)



Energy in accelerator (MeV/u)	Energy At DUT (MeV/u)		LET at DUT (MeV cm2/mg)	PMMA_thickness (mm)
1000	908	188864	12.3	0
500	387	80496	16.5	0
500	210	43680	22.2	13
500	153	31824	26.6	16.5
500	113	23504	31.7	18.5
500	88	18304	36.3	19.5



D5.2 (M24) Beam Quality

D5.5 (M48) Impact of beam energy in SEE testing

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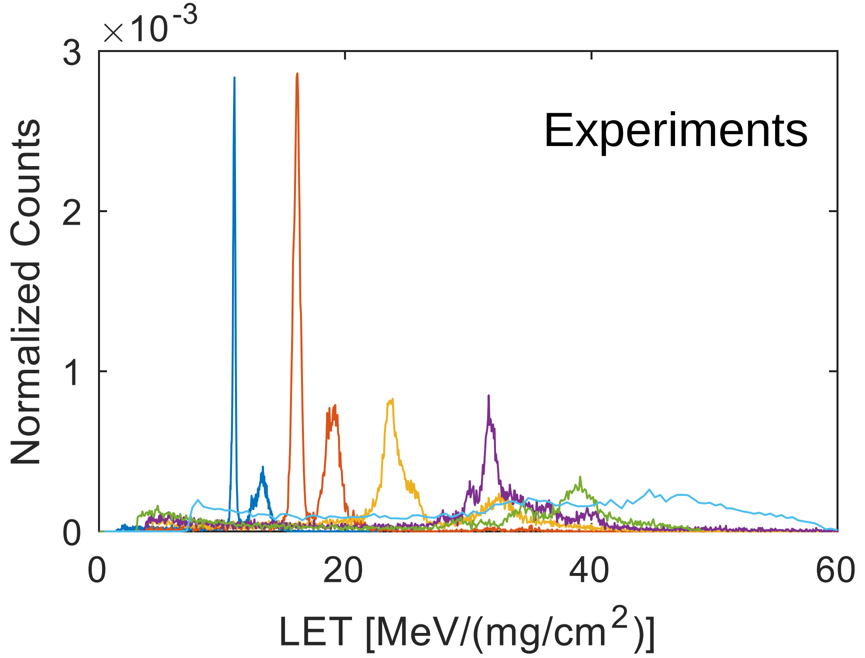
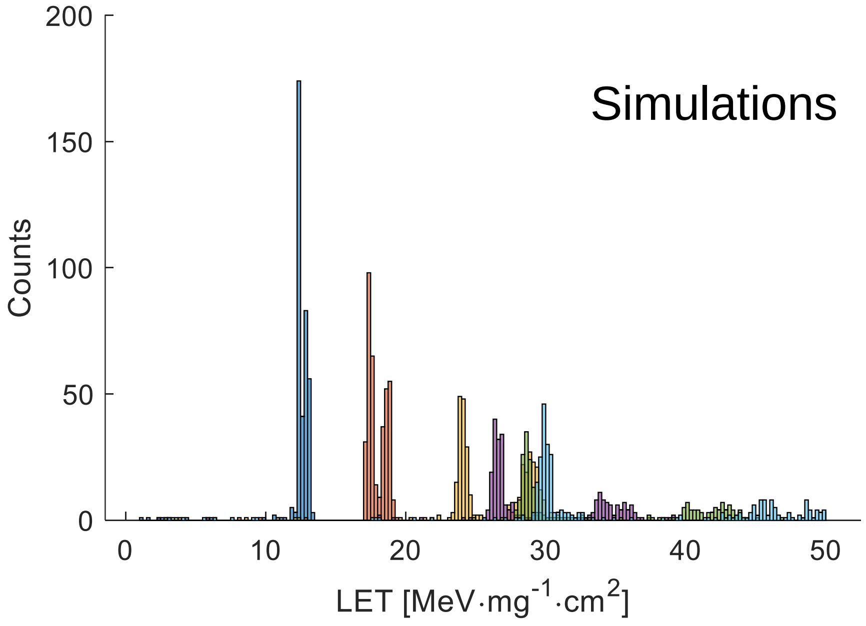
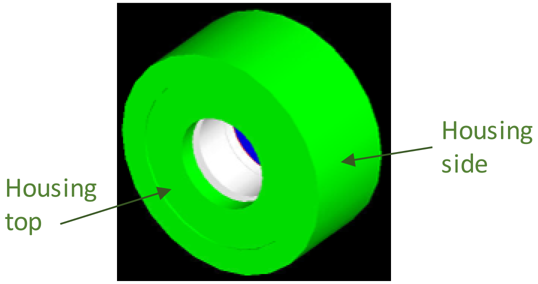
Task 5.2 – Experimental Results

- Using simplified Geant4-based simulations to understand the measurements (WP3): energy before degraders given by CERN + PMMA + diode in air





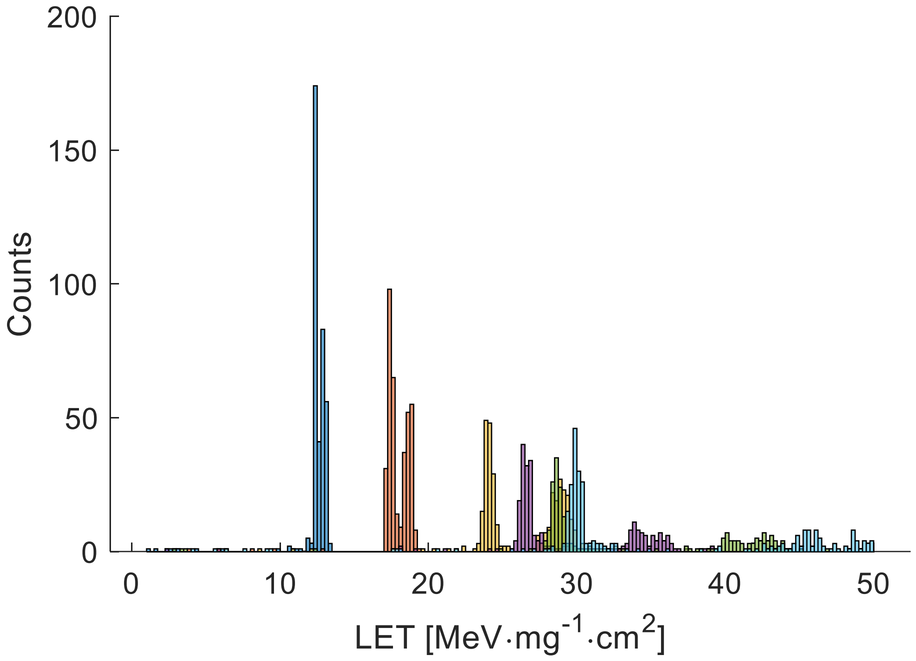


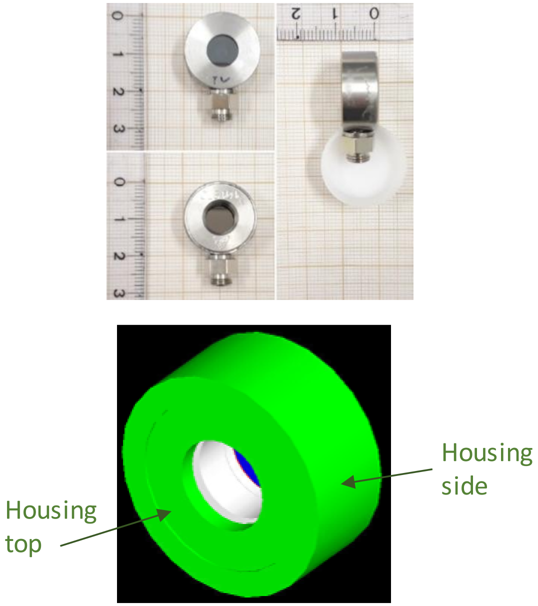
D5.2 (M24) Beam Quality

D5.5 (M48) Impact of beam energy in SEE testing

Task 5.2 – Experimental Results

- Issues with the simulations
  - Shown results are with the standard electromagnetic model
  - The low electromagnetic package (which includes the best model for the VHE ions we are using) has some convergence problems ("time goes back" errors")
- Ions go through the diode package and create a secondary peak (simulations with narrow beam do not show secondary peak)
- Broadening of the response
- Quantitative agreement to be improved



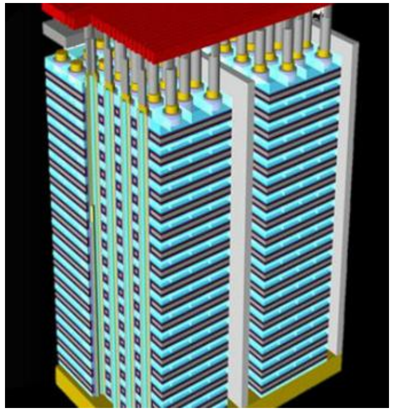


D5.2 (M24) Beam Quality

D5.5 (M48) Impact of beam energy in SEE testing

Task 5.3 - Suitability of the Proposed VHE Ion Beams for 3D Integrated Device Structures: Description of Work

- Partners: UNIPD, M12-36
- **3D NAND Flash memories,** the first and most successful example of 3D integration in the semiconductor industry, are an ideal test vehicle
- Devices with **hundreds of layers** are now available and increasing, reaching tens of microns of thicknesss.
- VHE heavy ions are extremely useful for these technologies



D5.3 (M36) Beam suitability for 3D structures

D5.5 (M48) Impact of beam energy in SEE testing

D5.6 (M48) SEE qualification guidelines for high complexity devices and board level testing

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Task 5.3 - Suitability of the Proposed VHE Ion Beams for 3D Integrated Device Structures: Experimental Campaign

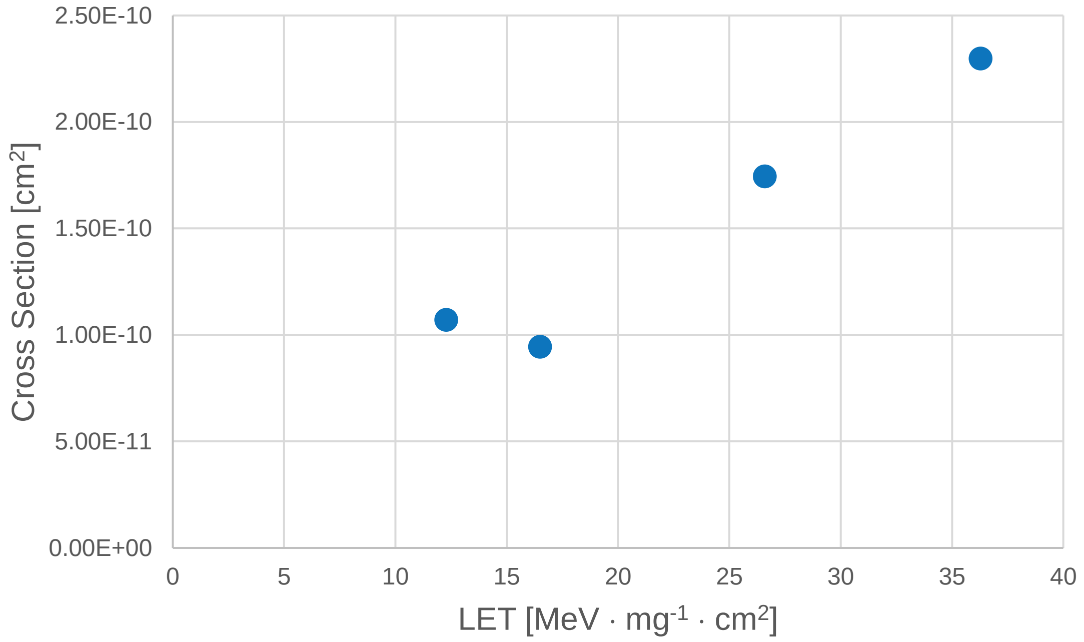
Experimental Campaign at CERN

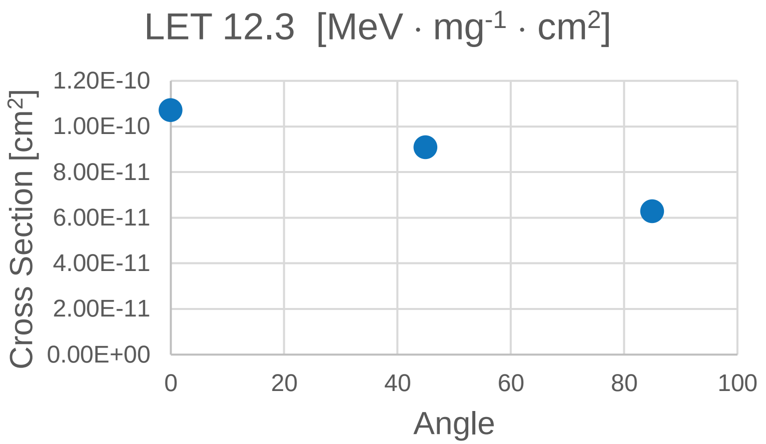
- Carried out a full irradiation campaign in November 2024
  - 8 Floating Gate Devices irradiated at 3 LET and 3 angles (0, 45°, 85°)
    - Post-rad measurements completed
  - 8 Replacement Gate Devices irradiated at 3 LET and 3 angles (0, 45°, 85°)
    - Post-rad measurements ongoing
  - 1 Active FG Device irradiated at multiple LET and angles
- Data are being analyzed

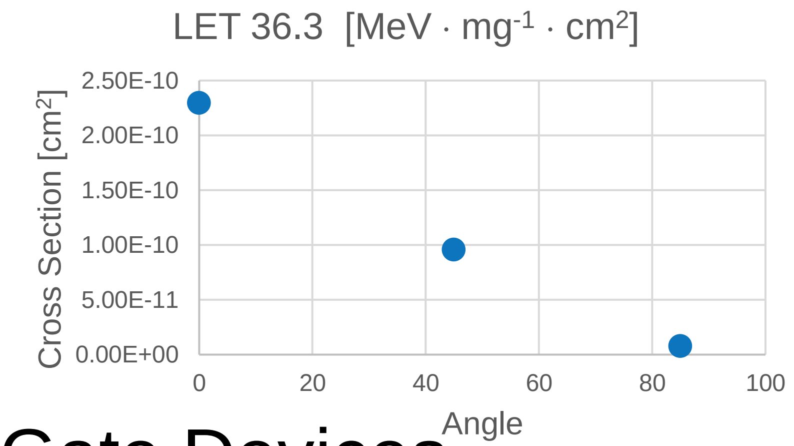
Task 5.3 - Suitability of the Proposed VHE Ion Beams for 3D Integrated Device Structures: Experimental Campaign

Experimental Campaign at CERN:

- LET and angle dependence: comparing with previous data







Unbiased Floating Gate Devices

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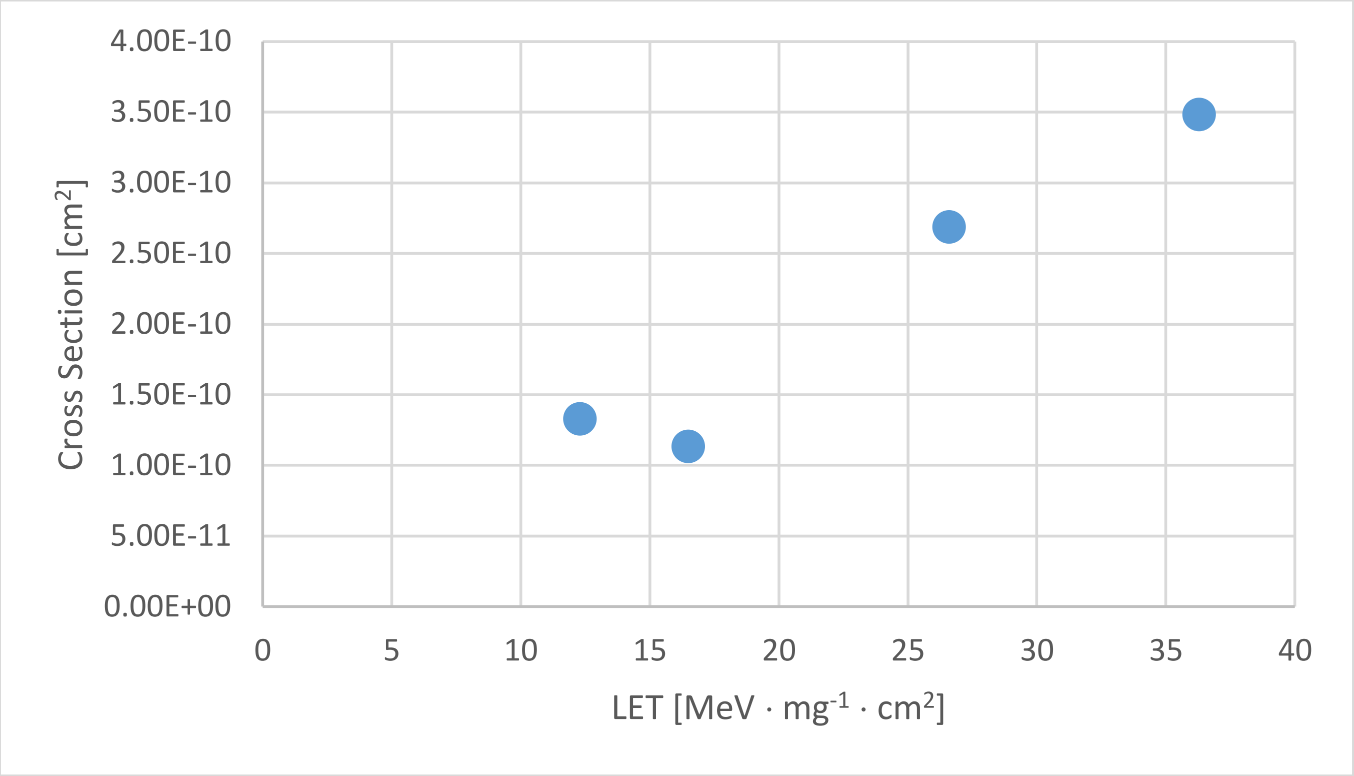
Task 5.3 - Suitability of the Proposed VHE Ion Beams for 3D Integrated Device Structures: Experimental Campaign

Experimental Campaign at CERN:

Analysis ongoing, together with simulations

Experimental conditions (e.g. fluence) need to be double checked



Active Floating Gate Devices

Task 5.4 - Validation of the VHE Ion Beams for Industrial use with TRL 6-7 Achievement: Description of work

- Partners: Airbus DS/TESAT, CERN, M-12-36
- **VHE SEE testing on devices which have already been characterized** by the ADS or CERN **at standard-energy heavy ion test facilities** (e.g., UCL, RADEF)
- Previous tests carried out according to ESCC 25100 (package lid removal)
- Broad range of technologies have been tested or will be tested:
  - Benchmark SRAMs
  - High power diodes (Silicon or SiC)
  - High power MOSFETs (Silicon or SiC)
  - A stacked memory
    - all the dies will be tested as opposed to only the top die as customary with standard energy ions
  - High-complexity device

D5.4 (M36) Verification of beam parameter requirements

D5.5 (M48) Impact of beam energy in SEE testing

D5.6 (M48) SEE qualification guidelines for high complexity devices and board level testing

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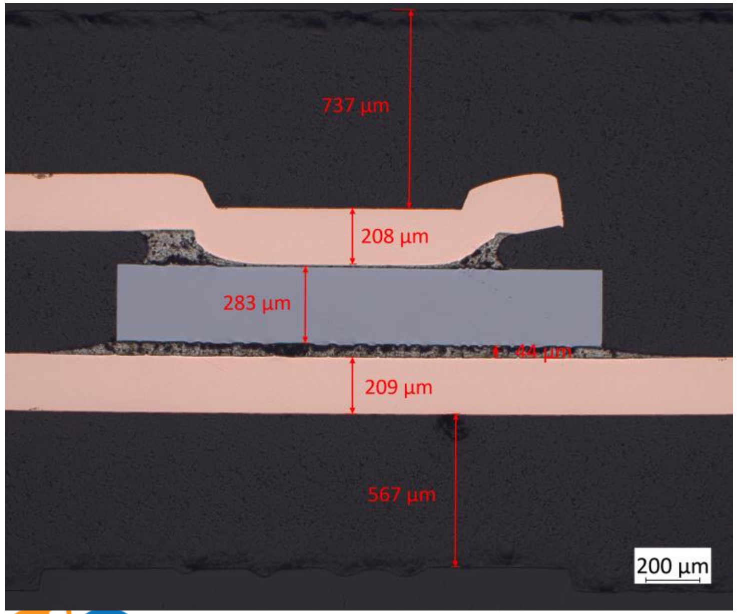
Task 5.4 - Validation of the VHE Ion Beams for Industrial use with TRL 6-7 Achievement : Status and Plans

- First “family” addressed power devices and SEB/SEGR
  - 200V Si Schottky Diode NRVBS4201 (ON SEMI) tested for destructive SEE



Used Ion (lead) as per table:

FLUKA				SRIM
LET [MeVcm^2/mg]		Kinetic energy/nucleon [MeV/n]		Range [mm]
Mean	*FWHM*	*Mean*	*FWHM*	
12.3	0.1	**908**	10	**50.0**
16.5	0.1	**387**	10	**14.5**
22.2	0.5	**210**	12	**6.0**
26.6	1.1	**153**	14	**3.5**
31.7	2.2	**113**	14	**2.3**
36.3	3.3	**88**	16	**1.5**

D5.4 (M36) Verification of beam parameter requirements

D5.5 (M48) Impact of beam energy in SEE testing

D5.6 (M48) SEE qualification guidelines for high complexity devices and board level testing

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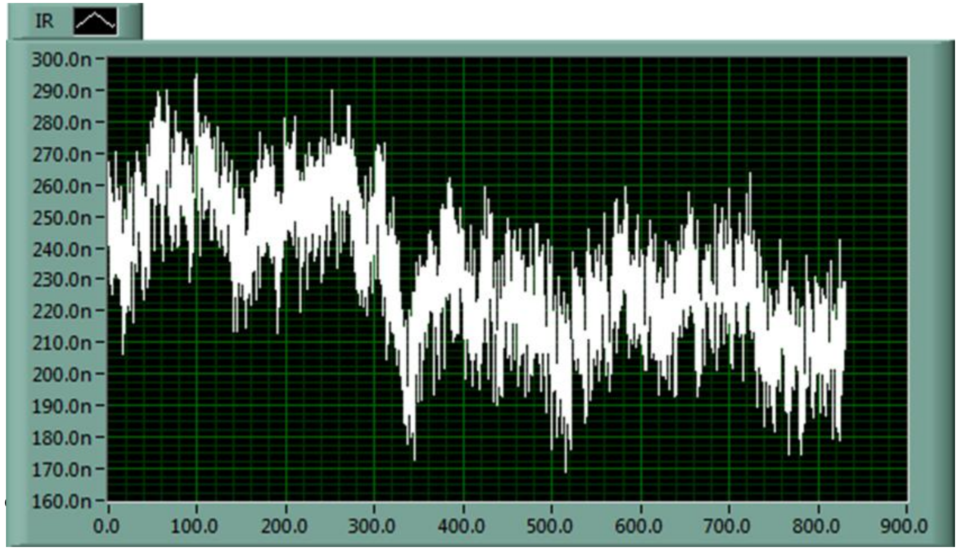
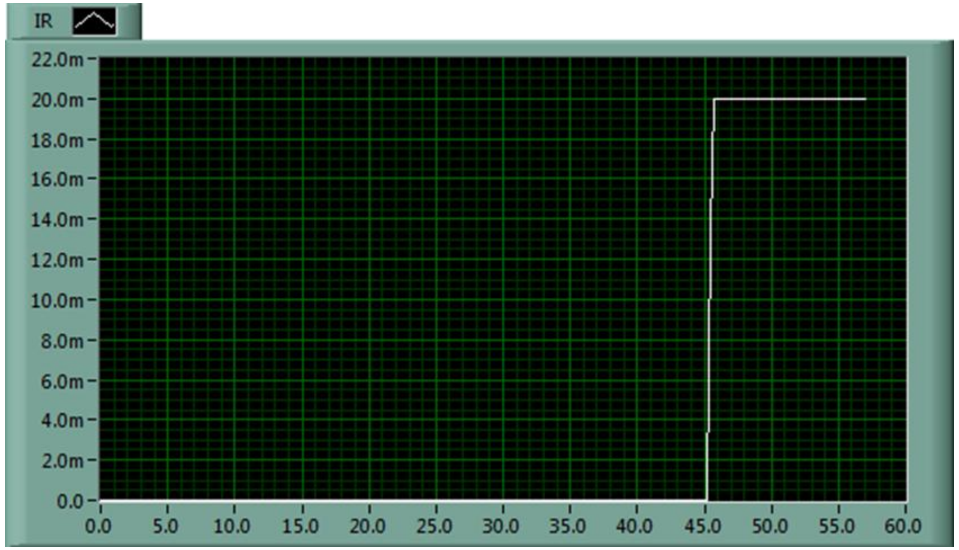
Task 5.4 - Validation of the VHE Ion Beams for Industrial use with TRL 6-7 Achievement : Status and Plans

- 200V Si Schottky Diode NRVBS4201 (ON SEMI)
  - Voltage increased step by step until failure
  - Example @ LET=36 MeV.cm^2/mg, sample 1

Vr=130V



Vr=140V



D5.4 (M36) Verification of beam parameter requirements

D5.5 (M48) Impact of beam energy in SEE testing

D5.6 (M48) SEE qualification guidelines for high complexity devices and board level testing

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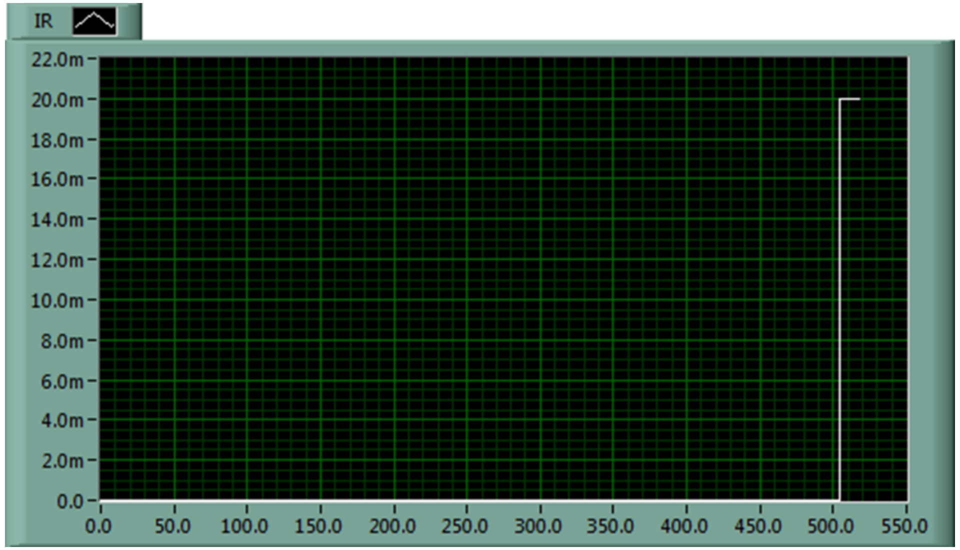
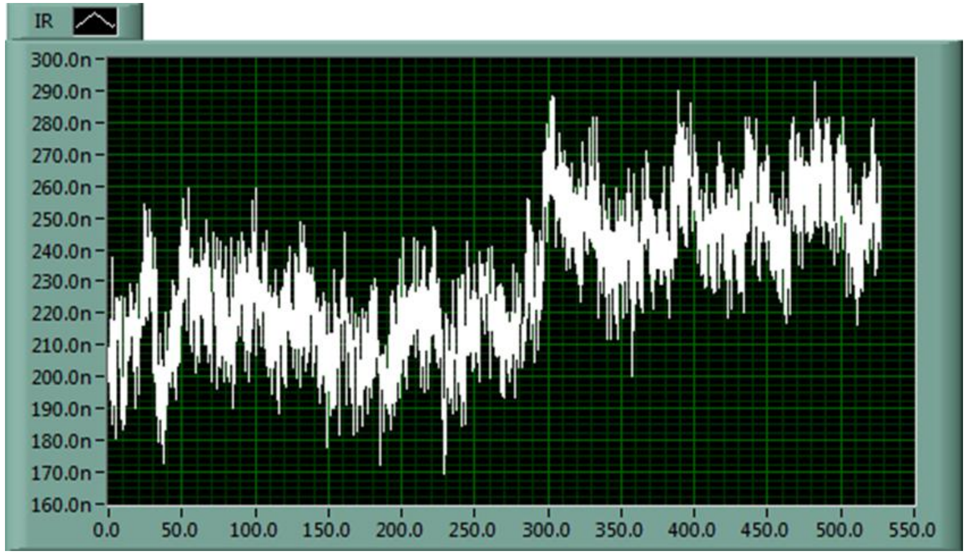
Task 5.4 - Validation of the VHE Ion Beams for Industrial use with TRL 6-7 Achievement : Status and Plans

- 200V Si Schottky Diode NRVBS4201 (ON SEMI)
  - Example @ LET=12 MeV.cm^2/mg

sample 12 - Vr=165V



Samples 7 & 11 Vr up to 200V



D5.4 (M36) Verification of beam parameter requirements

D5.5 (M48) Impact of beam energy in SEE testing

D5.6 (M48) SEE qualification guidelines for high complexity devices and board level testing

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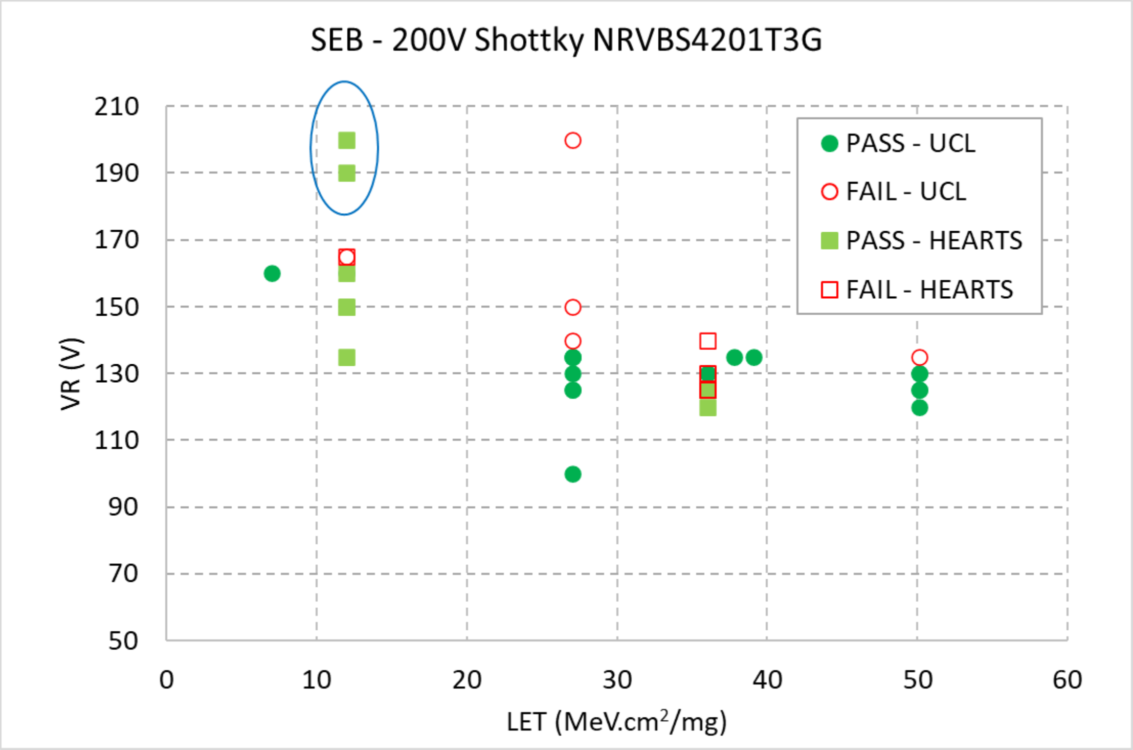
Task 5.4 - Validation of the VHE Ion Beams for Industrial use with TRL 6-7 Achievement : Status and Plans

- 200V Si Schottky Diode NRVBS4201 (ON SEMI)
  - Comparison with previous data



D5.4 (M36) Verification of beam parameter requirements

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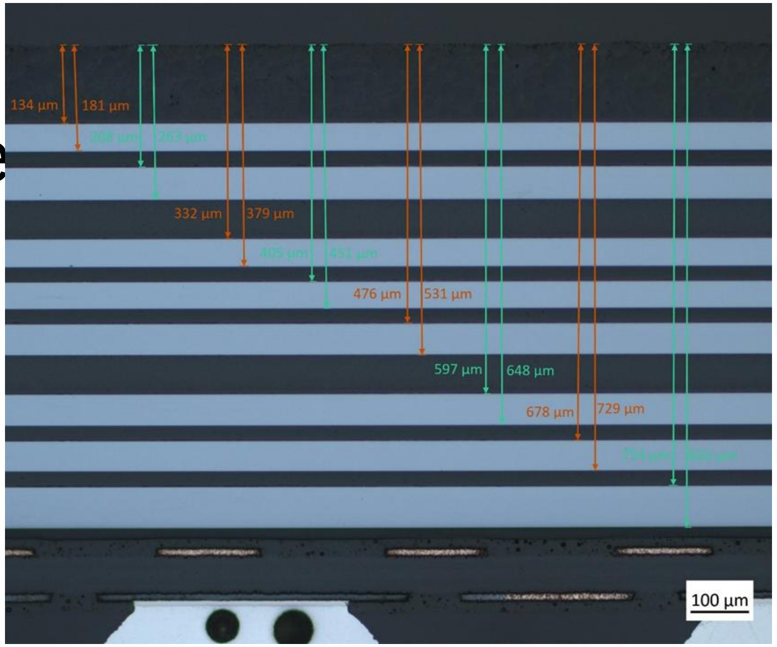
Task 5.4 - Validation of the VHE Ion Beams for Industrial use with TRL 6-7 Achievement : Status and Plans

- Second “family” is memory
- NAND flash MT29F256G08AUCAB

- Same LETs used as for diode

- Two devices tested per LET



D5.4 (M36) Verification of beam parameter requirements

D5.5 (M48) Impact of beam energy in SEE testing

D5.6 (M48) SEE qualification guidelines for high complexity devices and board level testing

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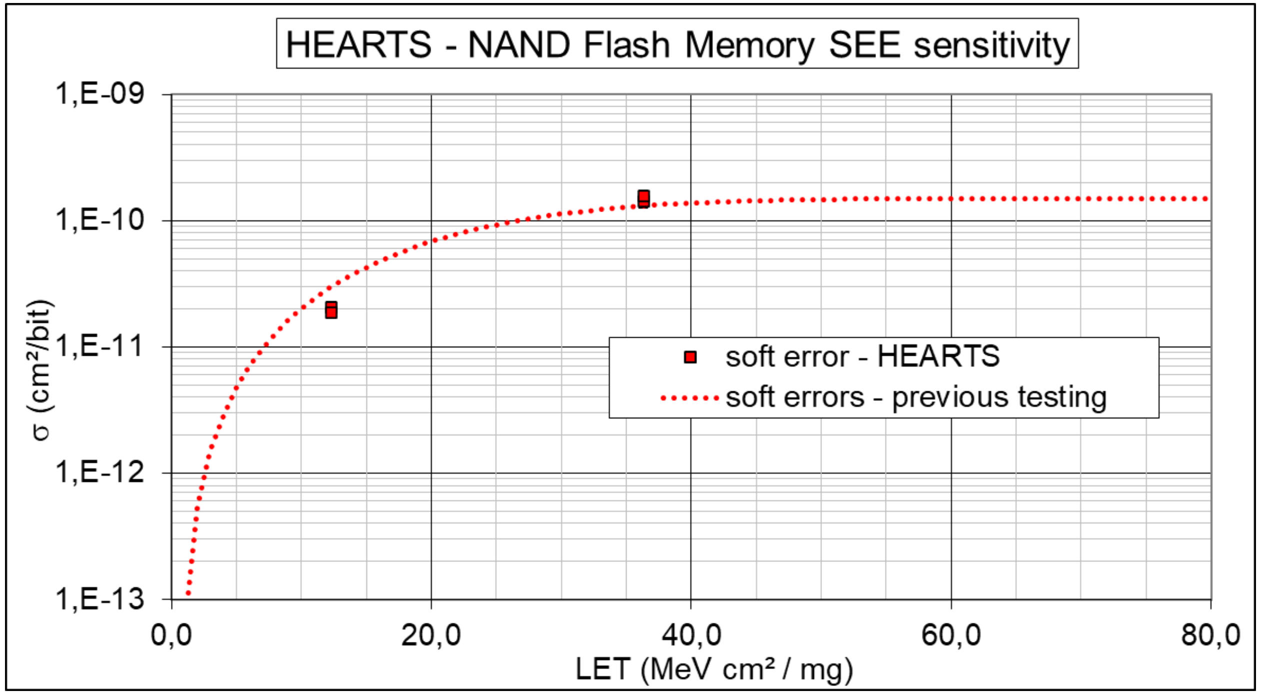
Task 5.4 - Validation of the VHE Ion Beams for Industrial use with TRL 6-7 Achievement : Status and Plans

- NAND flash MT29F256G08AUCAB
- SEE originates from the 8 memory dies



- Test results definitely need more in-depth analysis however global SEE cross section fitting well with previous characterization

D5.4 (M36) Verification of beam parameter requirements

D5.5 (M48) Impact of beam energy in SEE testing

D5.6 (M48) SEE qualification guidelines for high complexity devices and board level testing

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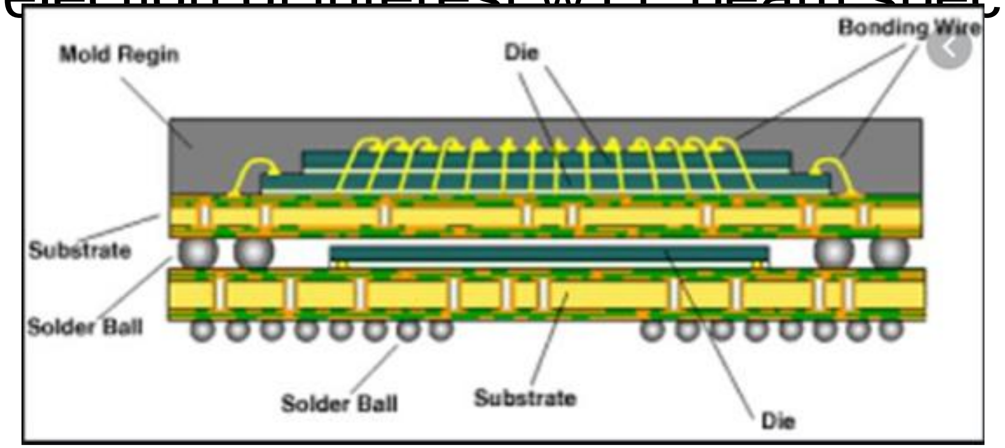
Task 5.4 - Validation of the VHE Ion Beams for Industrial use with TRL 6-7 Achievement : Status and Plans

- Third “family” prone to a different approach
- Device type will be selected according to the Airbus DS project needs (and stock availability)
  - Device won’t necessarily benefit of previous SEE testing
  - Device selection of interest w.r.t. beam specificities



D5.4 (M36) Verification of beam parameter requirements

D5.5 (M48) Impact of beam energy in SEE testing

D5.6 (M48) SEE qualification guidelines for high complexity devices and board level testing

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Tested DUTs at HEARTS@CERN

- List of devices tested at HEARTS@CERN
  - These have also been tested at other facilities, either at **RADEF** (using heavy-ion cocktail cyclotron beams with energies up to 16.3 MeV/n), at **NSRL** (with high-energy ions from a synchrotron, comparable to HEARTS@CERN), or both of these facilities
  - Results are currently being analyzed and are intended to be submitted as a Data Workshop contribution for NSREC

Device type	Reference	SEE type investigated
ADC	AD7291BCPZ	SEL
ADC	ADS8320	SEL
DAC	AD7801	SEL
LDO	LT3083EQ#PBF	SEL
Op-amp	OPA2192	SEL
GaN FET	GS61008P	SEB
GaN FET	GS66516B	SEB

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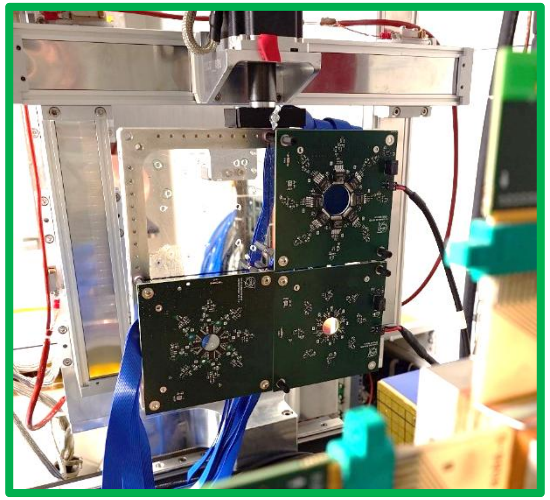
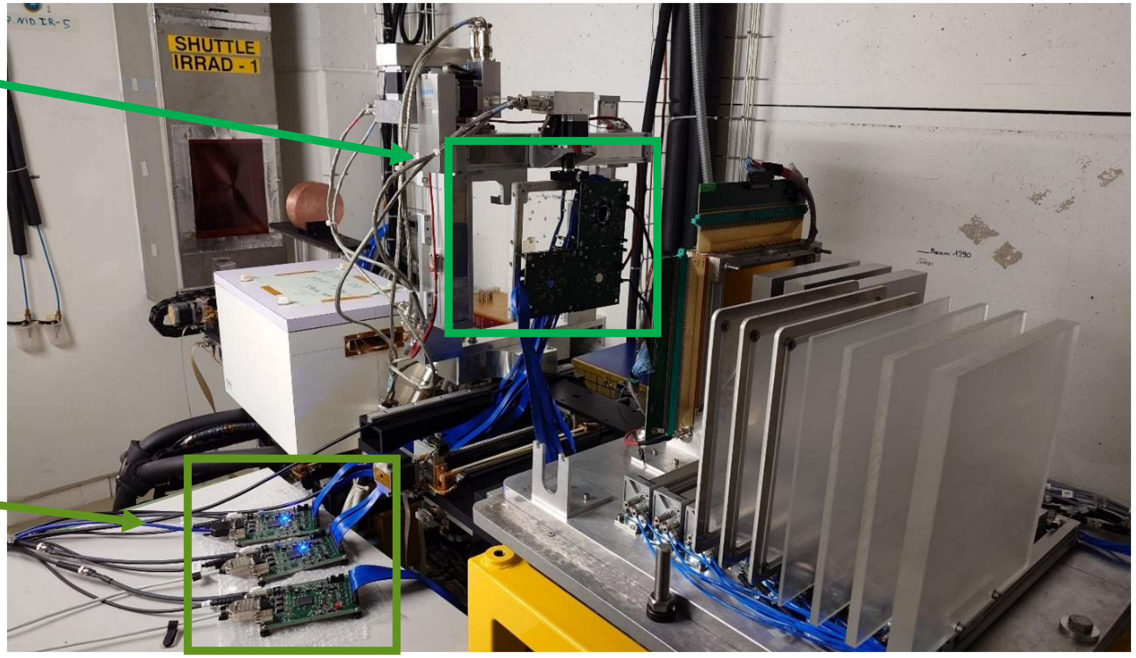
Experimental setups for SEL testing

- Multiple DUTs (8 or 9) of some of the tested references were irradiated in parallel, using dedicated daughter boards.
- SELs identified through current threshold crossing monitoring with independent detection of SELs in the DUTs on the daughter boards. The power-cycling of the components is performed from a SmartFusion2 SoC embedded on the test control boards by switching off and on the embedded power regulator.



Daughter boards

Test control boards



Task 5.5 - Qualification of High-complexity Devices: Description of Work

- Partners: UNIPD, TAS, M24-48
- **Graphical Processing Units** (GPUs) and **Field Programmable Gate Arrays** (FPGAs) are two key enablers for on-board **artificial intelligence**
- Heavy-ion SEE qualification is very complex because of the very high power-consumption (standard energy ions require in-vacuum irradiations) -> in air irradiation is key
- UNIPD will perform a test campaign on a GPU
- TAS will perform a test campaign on a FPGA
- The results will be used together to compile recommendations and guidelines about SEE testing with very high energy ion beams

D5.5 (M48) Impact of beam energy in SEE testing

D5.6 (M48) SEE qualification guidelines for high complexity devices and board level testing

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Task 5.5 - Qualification of High-complexity Devices: Status and Plans

- Device is to be chosen according to the need and availability of TAS projects.

- Trade-off is between:
  - High performance System-On-Chip (backside irradiation with fan-based cooling system).

- A device from AMD VERSAL ACAP family is the most rated candidate.

- A PhD student is joining TAS Radiation team and will take care of this testing activity in the next months

D5.5 (M48) Impact of beam energy in SEE testing

D5.6 (M48) SEE qualification guidelines for high complexity devices and board level testing

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Task 5.6 - Board-level testing: Description of Work

- Partners: TAS, M24-48
- Board-level testing can enable the qualification of several devices by irradiating them simultaneously under the same beam.
- In some cases, and thanks to the properties of VHE ion beams, it can even be envisaged to test more complex systems that are made of a few electronic boards stacked on top of one another.
- The task will consist of testing electronic boards enabling power conditioning functionalities, which may be particularly sensitive to radiation.
- The objective of the task will be that of defining a methodology for testing these kinds of boards with a VHE ion beam that will be integrated in the guideline.

D5.6 (M48) SEE qualification guidelines for high complexity devices and board level testing

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Task 5.6 - Board-level testing: Status and Plans

- Device under trade-off for testing are DC/DC converters.
- DC/DC converter with high power density w.r.t. footprint are not so common in the space market.
- On the other hand they are a need in payload architecture where the same module type is implemented recursively to build large structures (like SAR for earth observation).
- The first choice for this application are commercial DC/DC converters available in TAS:
  - All DC/DC are Si based
  - Standard brick dimension
  - 6 part number selected available with high voltage input:
    - 34V / 75V Vin, 28V Vout, 1.8 A and 21.5 A.
    - 34V / 75V Vin, 3.3V Vout, 30 A.
    - 48V Vin, 24V Vout, 350 W.
    - 24V Vin, 100W.
    - 24V Vin, 400W.

D5.6 (M48) SEE qualification guidelines for high complexity devices and board level testing

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Conclusions

Task	Status
~~5.1: Final review of VHE ion beam requirements for SEE testing~~	~~Beam requirements have been discussed. Task has been completed with deliverable D5.1.~~
5.2: Analysis of Ionization Response in a PIN diode for Beam Quality Assessment	PIN diode setup has been used to assess beam quality at CERN IRRAD. Results interpretation is ongoing, using simulations. GSI measurements to be done in June 2025. An extension has been required and granted to 31/8/2025.
5.3: Suitability of the Proposed VHE Ion Beams for 3D Integrated Device Structures	In progress. Second set of high-energy heavy ion experiments on 3D NAND Flash have been carried out.
5.4: Validation of the VHE Ion Beams for Industrial use with TRL 6-7 Achievement	ADS has tested diodes and NAND Flash at IRRAD.
5.5: Qualification of High-complexity Devices	TAS is identifying test vehicles. A Ph.D. student is joining the team.
5.6: Board-level testing	TAS is identifying test vehicles.

Funded by the European Union

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