



# HEARTS 1st Annual Meeting – WP5

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6 February 2024

<https://indico.cern.ch/event/1314502/>



**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.

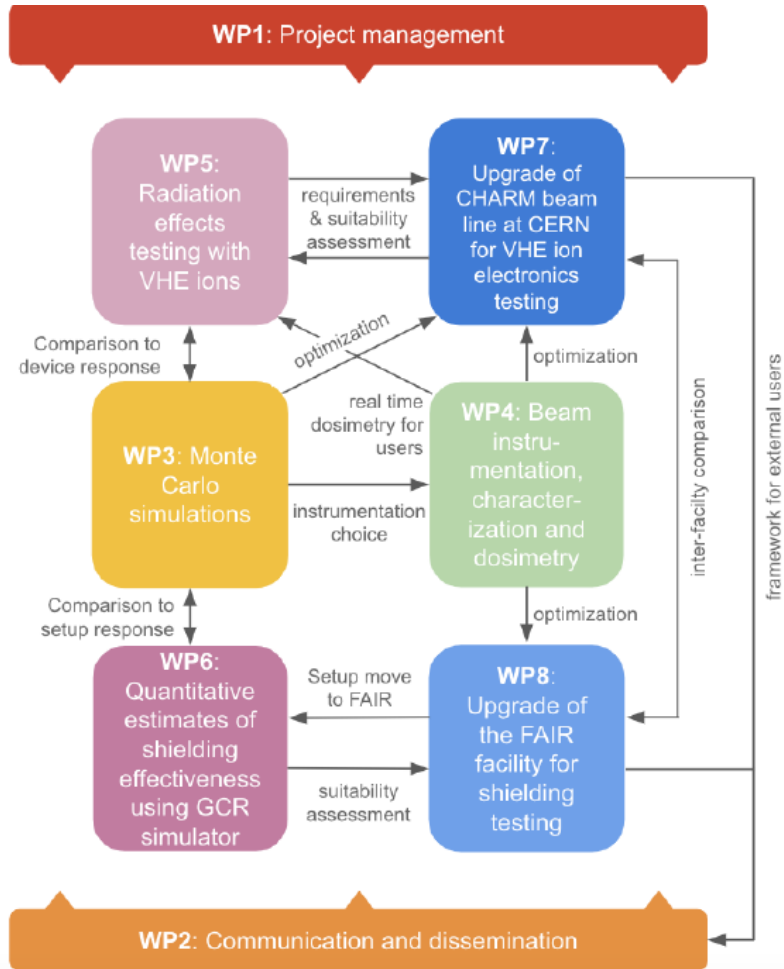


R. Mangeret - Airbus DS  
(on behalf of S. Gerardin -  
Uni. PD)

# 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
- The suitability of the **infrastructures** for the testing and qualification of EEE devices ( $\uparrow$  TRL to 6-7) and **electronic boards** is a key aspect
- 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

# WP5 in the Project



- WP5 is strongly interconnected with the other work packages
  - WP3: comparison with simulation results
  - WP4: beam dosimetry
  - WP7: facility development

# WP5 Key Personnel

- Airbus DS/TESAT:
  - R. Mangeret, M. Rostewitz
- TAS:
  - R. Mancini, S. Francola
- UniPD:
  - M. Bagatin, UniPD project leader
  - S. Gerardin, WP5 leader
  - A. Paccagnella, staff
- CERN:
  - A. Coronetti, M. Sacristan barbero

Work package number	5.	Lead beneficiary	UNIPD	
Work package title	Radiation effects testing with VHE ions			
Participant number	1	3	4	5
Short name participant	CERN	ADS	TAS	UNIPD
Person-months per participant	2	19	4	16
Start month	M1	End month	M48	

# 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**

From  
1<sup>st</sup> 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  
2<sup>nd</sup> year

5.5 Qualification of high-complexity devices **IN PROGRESS**

5.6 Board-level testing

From  
3<sup>rd</sup> year

# WP5 Timeline

	Year	1												2												3												4													
	Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48		
<b>WP5 Radiation effects testing with VHE ions</b>																																																			
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# Task 5.1 - Final review of VHE Ion Beam Requirements for SEE Testing: Description of Work

- Partners: UNIPD, ADS, TAS, CERN M1-6
- Academic and industrial partners will review the goals in terms of **VHE ion beam parameters** to be reached with the CHARM and GSI-FAIR upgrade (WP7-8)
- Other than parameters such as ion type, energy, LET and range (and related accuracy), **beam time availability** (facility usable/bookable with reasonable delays) and **commercial conditions of access** (competitive with respect to European standard-energy ion facilities) will be included. Optimal trade-offs will be identified and submitted to the facilities

**DELIVERED**

D5.1 (M6) Beam Requirements

# Deliverable 5.1: Structure

## D5.1 FINALISED LIST OF BEAM PARAMETER REQUIREMENTS CONCURRING TO ESTABLISH A TRL 6-7 FOR THE HEARTS FACILITIES

- 2. SOURCE
  - 2.1. HEAVY-ION BEAMS
  - 2.2. BEAM FLUX, FLUENCES AND TEMPORAL STRUCTURE
  - 2.3. BEAM SIZE AND SPATIAL UNIFORMITY
  - 2.4. SAMPLE HOLDER AND USER SETUP
- 3. CONDITIONS FOR ACCESS
- The document is organized as a set of requirements and reflects users' perspective!



# Deliverable 5.1: Beam Requirements

## D5.1 FINALISED LIST OF BEAM PARAMETER REQUIREMENTS CONCURRING TO ESTABLISH A TRL 6-7 FOR THE HEARTS FACILITIES

### SOURCE

- Req. 2.1.a: the LETs of the available beams shall range from  $\sim 0.1$  to  $\geq 60 \text{ MeV} \cdot \text{mg}^{-1} \cdot \text{cm}^2$   
[...] **Low-LET** beams are very important, because the long range of very-high energy heavy-ion facilities will be used to test advanced components with low LET threshold, and because of the abundance of low-LET particles in space.
- Req. 2.1.d: the particle range shall exceed **500  $\mu\text{m}$**  in Silicon for the full LET range. In addition, several use cases require significantly longer ranges [heat spreader  $> 3 \text{ mm}$ ].
- Req. 2.2.a: the heavy ion accelerator shall be capable of delivering ions with variable flux ranging from a few (10) ions/cm<sup>2</sup>/s to at least **10<sup>6</sup> ions/cm<sup>2</sup>/s** on the device under test.

# Deliverable 5.1: Access Requirements

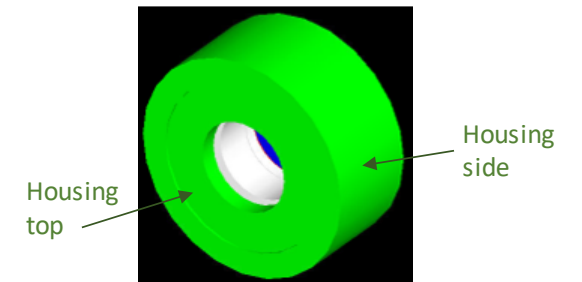
## D5.1 FINALISED LIST OF BEAM PARAMETER REQUIREMENTS CONCURRING TO ESTABLISH A TRL 6-7 FOR THE HEARTS FACILITIES

### CONDITIONS FOR ACCESS

- Req. 3.a: a schedule with weeks of beam time availability should be ready 6 months before the first testing period. The user should have the possibility of giving the **final confirmation 3 weeks in advance**.
- Req. 3.b: the cost for beam should be less than **3000€ per hour**. The invoiced time should include only hours that can be effectively used (beam preparation should not be included, but ion energy changes should be).

# 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)

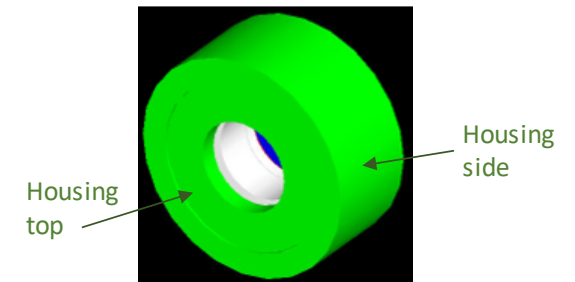


D5.2 (M24) Beam Quality

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

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

- UniPD is working with ESA and CERN to define the best experimental setup
  - Possible ESA involvement through a “Third part activity” (<https://technology.esa.int/page/consultancy-testing>), which should be the best option for EU projects
- **Large experimental data set is available** with standard energy heavy ion beams, mostly collected with the ESA experimental setup
  - One of the key reason to use the ESA system in HEARTS
  - **Monte Carlo model** of the diode is **available** (see also WP3)
- Measurements are expected in the second half of 2024

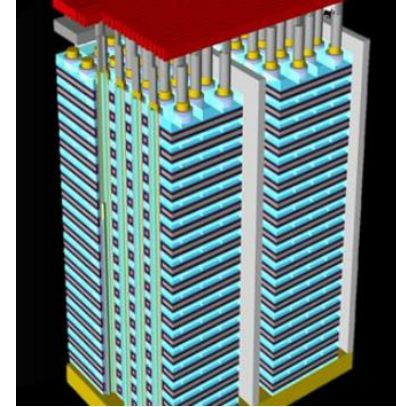


D5.2 (M24) Beam Quality

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 thickness.
- 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

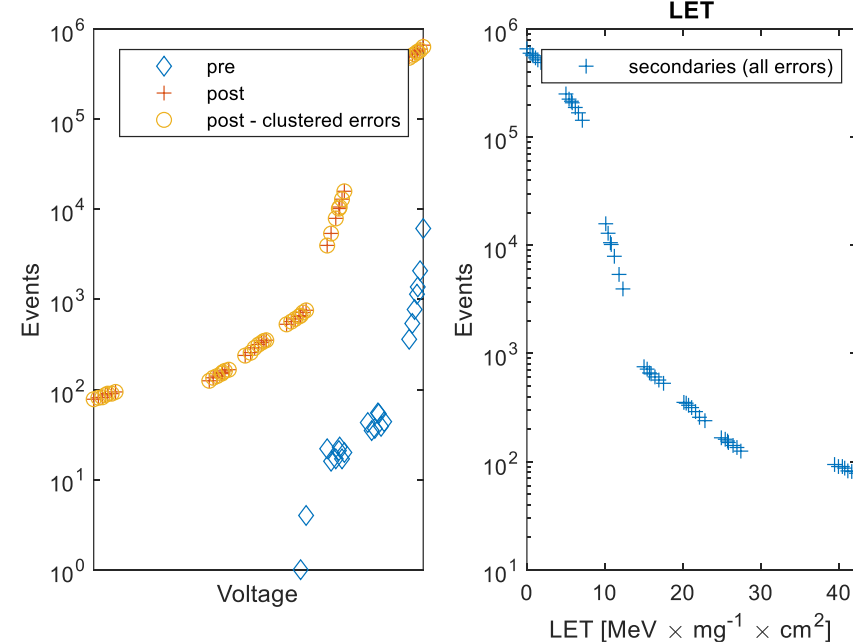
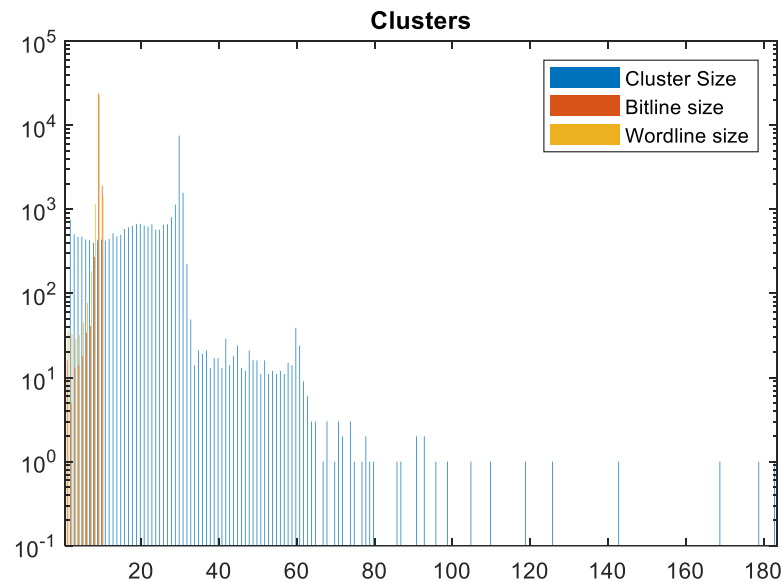
# Task 5.3 - Suitability of the Proposed VHE Ion Beams for 3D Integrated Device Structures: Status

- **Four 3D NAND FG devices have been irradiated at CERN in October/November 2023**
  - Exposure in passive mode, possible thanks to the non-volatility of the memories
  - Two LETs and two fluences
    - MS33:  $E = 2\text{GeV}/n$ ,  $\text{LET} = 11\text{ MeV}/(\text{mg}/\text{cm}^2)$ , Fluence  $5\text{E}6\text{ ions}/\text{cm}^2$
    - MS34:  $E = 2\text{GeV}/n$ ,  $\text{LET} = 11\text{ MeV}/(\text{mg}/\text{cm}^2)$ , Fluence  $1\text{E}7\text{ ions}/\text{cm}^2$
    - MS35:  $E = 750\text{ MeV}/n + 15\text{ mm PMMA degradation}$ ,  $\text{LET} = 30\text{ MeV}/(\text{mg}/\text{cm}^2)$ , Fluence  $5\text{E}6\text{ ions}/\text{cm}^2$
    - MS36:  $E = 750\text{ MeV}/n + 15\text{ mm PMMA degradation}$ ,  $\text{LET} = 30\text{ MeV}/(\text{mg}/\text{cm}^2)$ , Fluence  $1\text{E}7\text{ ions}/\text{cm}^2$



# Task 5.3 - Suitability of the Proposed VHE Ion Beams for 3D Integrated Device Structures: Status (2)

- Analysis of the four 3D NAND FG devices irradiated at CERN is ongoing
- Error data track LET and fluence very well
- Preliminary results on clusters and secondaries generated by VHE ions are available (examples below)



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

## Next steps

- Complete analysis on irradiated FG 3D NAND devices and compare experimental results with simulations (see WP3)
- Carry out a full irradiation campaign in the second half of 2024
  - 3D NAND Devices with Floating gate and Replacement Gate Technologies will be used
  - Exposure to different LETs



# 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 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 will be tested:
  - 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
  - Benchmark SRAMs from CERN
  - 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

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



- Device types are to be selected according to HEARTS objectives, and, both heritage testing and device stock availability at Airbus DS and TESAT.
- Device type selection aims at
  - Covering different families, different Single Event Effect natures and different potential issues
  - Allowing test results comparison between high energy and traditional SEE test facilities
  - Allowing testing of “untestable” device reference
  - Supporting test analysis guideline
- Multiple test campaigns will be needed

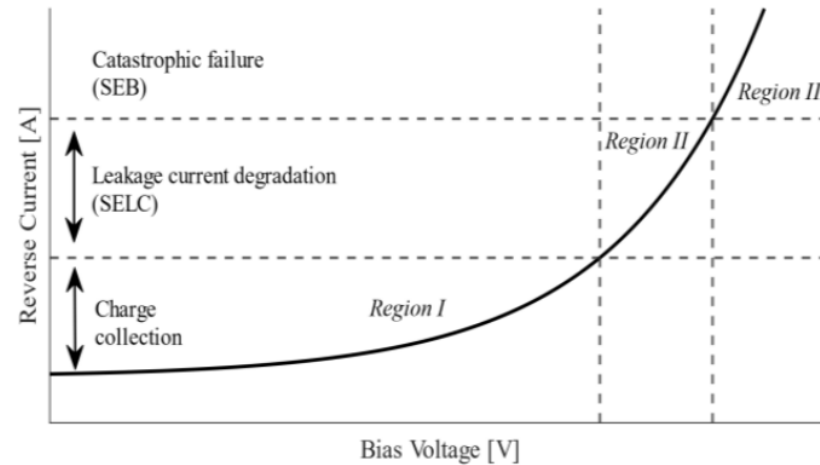
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testing

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

- First “family” will address power devices and SEB/SEGR
  - Two different power device types and SEE mechanisms are planned to be tested
    - SiC Diode
    - Si/SiC Power Mosfet
  - SiC diode is of particular interest since exhibiting a very specific behavior under HI exposure



D5.4 (M36)  
Verification of  
beam parameter  
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D5.6 (M48) SEE  
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testing

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



- Second “family” oriented towards a memory
- Device type not fully selected, could be NAND flash or DDR memory
  - Will depend on available stock
- Different type of SEE to be investigated since those devices exhibit sensitivity to multiple SEE
  - SEL, SEU, MBU, row event, column event, SEFIs, stuck/weak bits

D5.4 (M36)  
Verification of  
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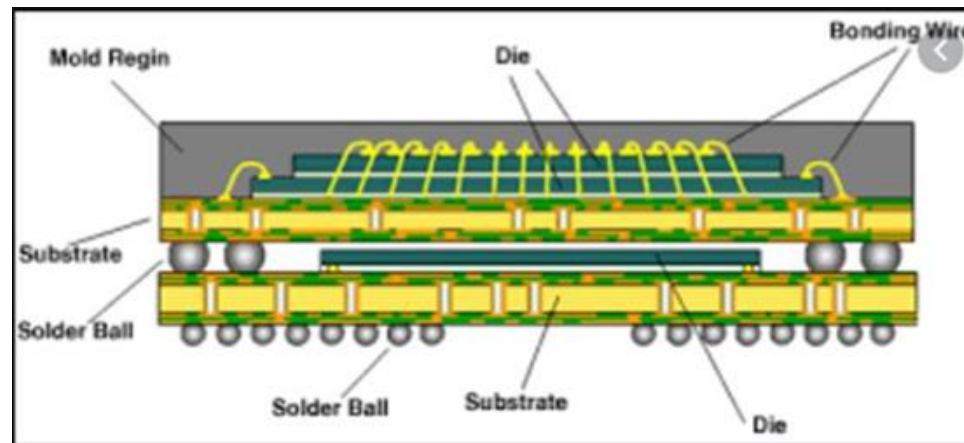
# Task 5.4 - Validation of the VHE Ion Beams for Industrial use with TRL 6-7 Achievement : Status and Plans

- 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

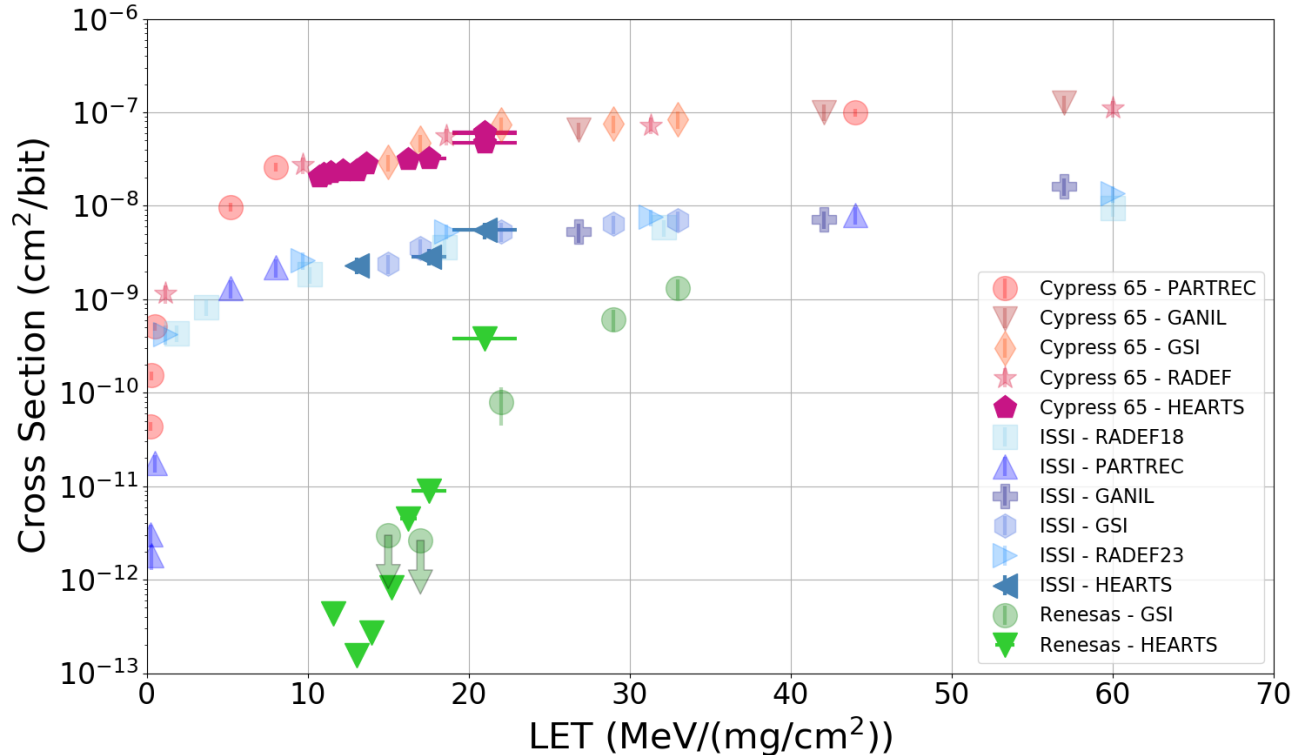
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# Task 5.4 - Validation of the VHE Ion Beams for Industrial use with TRL 6-7 Achievement : Status and Plans

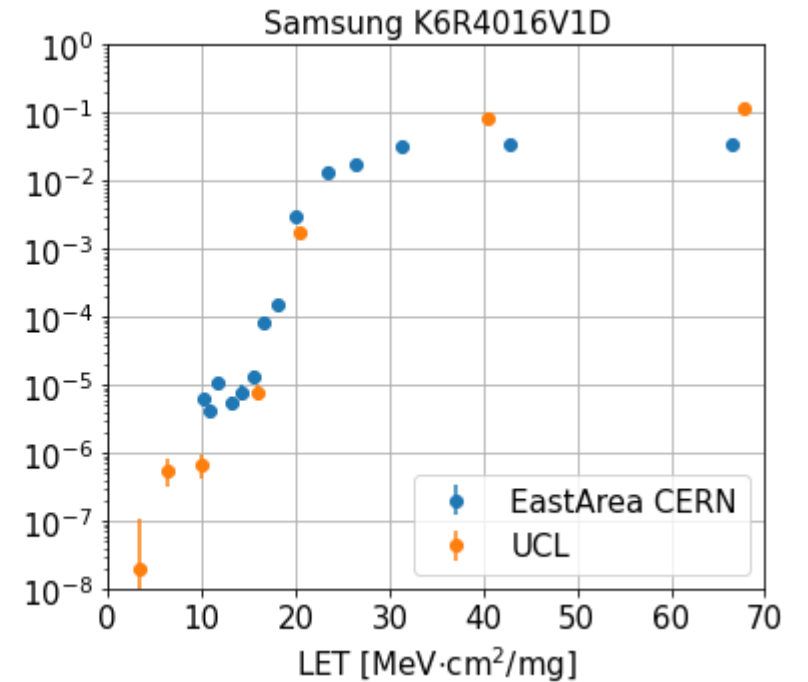
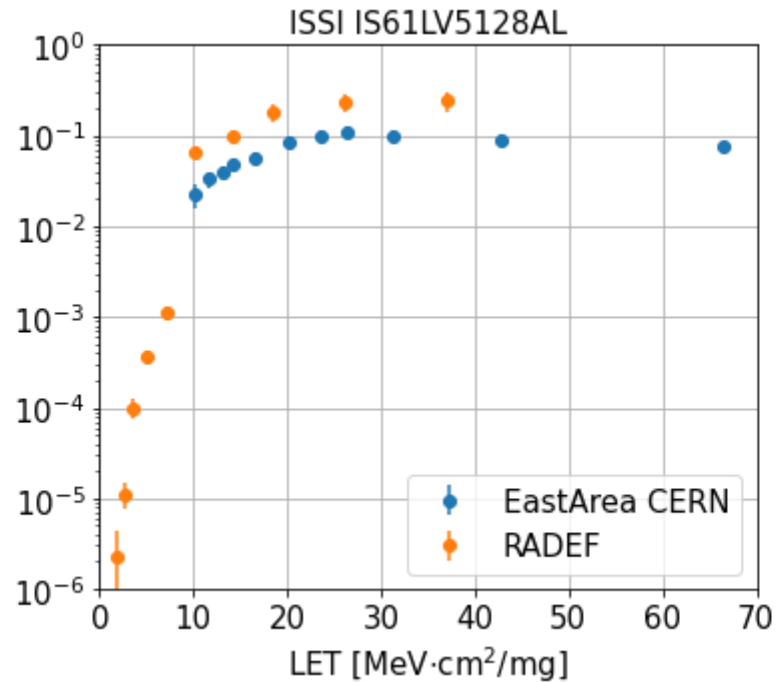
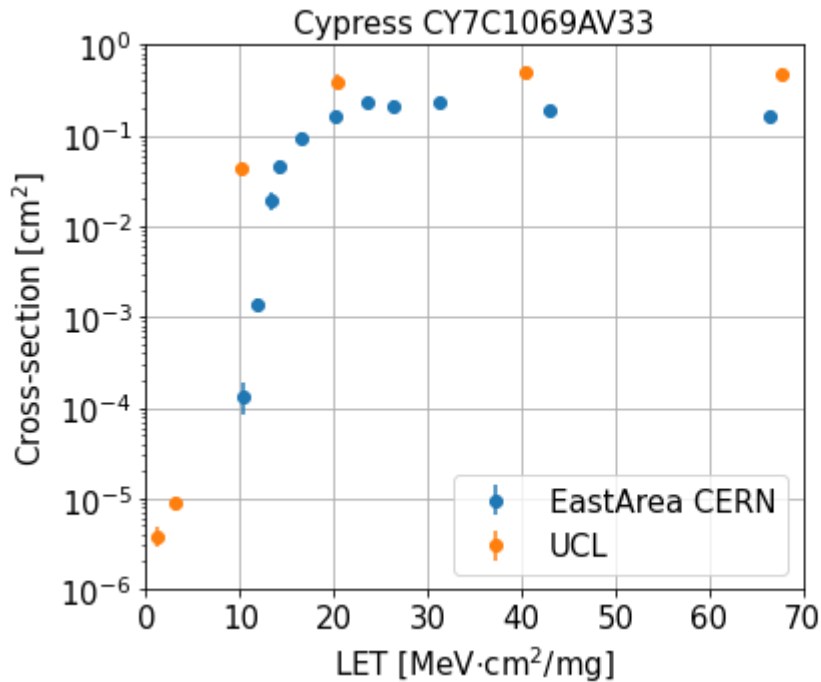


CERN measured the SEU cross section of three benchmark SRAMs from Cypress, ISSI, and Renesas during the October 2023 run

A large amount of experimental data at other facilities is available for these samples

The data taken at HEARTS include only primary beam energies and no degradation runs, for which the LET is still to be determined

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



Single Event Latchup has been measured as well for three 3 SRAMs (Cypress, ISSI and Samsung) during the same test campaign

# 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



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

- UNIPD is selecting a suitable platform and perform preliminary test campaigns (using neutrons)
  - NVIDIA Jetson line of AI accelerators appears as the most promising candidate
    - CPU + GPU in one chip, with full framework for AI computing
  - Preliminary tests carried out at ChiPr (UK) on some Jetson Nano boards



Jetson Nano board



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

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

# 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).
  - Optoelectronics that cannot be «opened» in the traditional way to be tested.
- Device will be chosen during 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

# 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

# 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.



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

# Conclusions

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- Task 5.1 “Final review of VHE ion beam requirements for SEE testing” has been completed with delivery of 5.1
- Tasks 5.2 “Analysis of ionization response in a PIN diode for beam quality assessments” is in line with planning and in the setup definition phase
- Task 5.3 “Suitability of the proposed VHE ion beams for 3D integrated device structures” is ahead of schedule with some measurements already carried out
- Task 5.4 “Validation of the VHE ion beams for industrial use with TRL 6-7 achievement” is ongoing. Data have been collected on benchmark SRAMs and device selection and plans are being finalized for new experiments
- Task 5.5 “Qualification of high-complexity devices” is in the preparation stage
- Task 5.6 “Board-level testing” is ongoing. Devices are being selected and test plans finalized



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