Upgrade of CHARM beam line at CERN for VHE ion testing

HEARTS Kick-Off meeting

20-01-2023, CERN

https://indico.cern.ch/event/1216205/

Rubén García Alía, Matthew Fraser (CERN)

This project has received funding from the European Union's Horizon Europe Research and Innovation programme under GA No 101082402.

HEARTS WP7 (from project website)

Work Package 7

Upgrade of CHARM beam line at CERN for VHE ion testing

Participants

- CERN

Objectives

This work package aims at adapting the existing CHARM beam line infrastructure at CERN to accommodate very high energy (VHE) heavy ion beams for radiation effects testing on electronics. This requires the capacity of accurately tuning the beam energy and intensity in a large dynamic range and to ensure the parallelization of activities at CERN around the PS East Area. Furthermore, this WP will also tackle the definition of an adequate administrative and technical framework for external users to first validate and later regularly exploit the VHE beam for electronics testing and qualification.

Tasks

- **Task 7.1:** Methodology for extracting variable energy ion beams to ensure parallel operation of the VHE ion facility (CERN, M1-12)
- **Task 7.2:** Achievement of the required beam parameters for microelectronics SEE testing (CERN, M12-24)
- **Task 7.3:** Framework for user access (CERN, M24-48)

Deliverables

- **D7.1 (M12):** Definition of extraction methodology for parallel use of the heavy ion beamline for different energies
- **D7.2 (M24):** Demonstration of the achievements in terms of beam parameters (energy, LET, range, size)
- **D7.3 (M48):** Established framework for user access to the CHARM ion facility

Milestones

- **M20:** First external users at CHARM
- **M21:** Routine access for external users at CHARM

CHIMERA as HEARTS feasibility

Contents

CHIMERA (CHARM High-energy Ions for Microelectronics Reliability Assurance) is an ongoing working group established at CERN endorsed by the CERN management through the LHC Injectors and Experimental Facilities Committee (IEFC) and supported by ESA. Its purpose is to assess the feasibility of providing VHE ions for SEE testing in the CHARM facility and to determine the resources required to achieve the expected objectives. The working group is responsible for providing inputs that partially feed into HEARTS.

ESA Contract No. 4000134554/21/NL/KML/rk

CERN Contract No. KM5174/KT/SY/273A

with

CERN

"Development of High Energy Beam (Range and Let) for Radiation Tests of Highly Integrated Electronic Components"

ESA Contract No. 4000136601/21/NL/KML/rk

CERN Contract No. KM5450/KT/SY/276R

with

CERN

"High Energy Beam Intensity Adjustment for SEE Tests of Cots EEE Components"

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CHIMERA as HEARTS feasibility

- CHIMERA (CHARM High energy Ions for Microelectronics Reliability Assurance) is the name that we have used so far to refer to the high-energy heavy ion irradiation activity in the CHARM facility at CERN
- Currently, it can be considered to have a TRL level of 3, in compliance with CERN's commitments towards ESA in the related contracts
- Through HEARTS, the TRL will be increased to 6-7
- In practical terms, we will still need a name to describe the facility and infrastructure for heavy ion testing at CERN (now with HEARTS/EU Commission as key funding source) and, as CHIMERA is already well consolidated across the (many!) CERN groups involved in the activity, our baseline is to continue using it for this purpose → open for discussion
- Slides 10-15: pictures are from CHIMERA 2022 achievements, text in orange is expected HEARTS advancement (i.e. TRL increase)

Recent CHIMERA mini-workshop

CHIMERA mini-workshop: summary of 2022 results

Thursday Jan 19, 2023, 2:00 PM → 7:30 PM Europe/Zurich

13/2-005 (CERN)

Videoconference: CHIMERA mini-workshop: summary of 2022 results — Please log in

2:15 PM → 2:30 PM **Welcome and Introduction** — 15m — 13/2-005
Speakers: Matthew Alexander Fraser (CERN), Ruben Garcia Alia (CERN)
CHIMERA_WS_intro... CHIMERA_WS_intro...

2:30 PM → 3:00 PM **PS beam manipulation: energy, intensity and spill profile (25' + 5')** — 30m — 13/2-005
Speaker: Eliott Philippe Johnson (CERN)
E_Johnson_CHIME... E_Johnson_CHIME...

3:00 PM → 3:20 PM **T8 beam characterization: spatial profile and intensity (15' + 5')** — 20m — 13/2-005
Speakers: Kacper Bilko (CERN - Universite Jean Monnet (FR)), Ruben Garcia Alia (CERN)
2023-01_CHIMERA_...

3:20 PM → 3:45 PM **T8 beam characterization: energy, through measurements and simulations (20' + 5')** — 25m — 13/2-005
Speaker: Andreas Waets (University of Zurich (CH))
CHIMERA_1901222...

3:45 PM → 4:00 PM **Coffee break** — 15m — 13/2-005

16:00 → 16:20 **Integration of test setups in CHIMERA (15' + 5')** — 20m — 13/2-005
Speakers: Jerome Lendaro (CERN), Dr Natalia Emriskova (CERN)
230119_CHIMERA_...

16:20 → 16:40 **Radiation effects experiments: CERN (15' + 5')** — 20m — 13/2-005
Speaker: Andrea Coronetti (CERN - University of Montpellier (FR))
Radiation effects ex... Radiation effects ex...

16:40 → 17:05 **Complementary beam characterization and radiation effects experiments: ESA (20'+ 5')** — 25m — 13/2-005
Speaker: Alessandra Costantino
2022_Chimera cam...

17:05 → 17:25 **A glimpse into the North Area heavy ion R2E results (15' + 5')** — 20m — 13/2-005
Speaker: Mario Sacristan Barbero (Univ. Montpellier - CERN)
CHIMERA workshop...

17:25 → 17:45 **Future outlook and plans (15' + 5')** — 20m — 13/2-005
Speakers: Matthew Alexander Fraser (CERN), Ruben Garcia Alia (CERN)
2023-01_CHIMERA_...

17:45 → 19:30 **CHIMERA "apero" in R1** — 1h 45m — Restaurant 2

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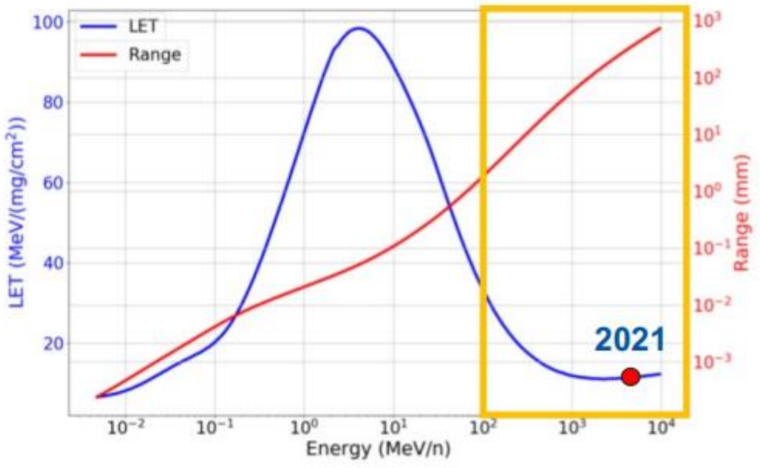
CHIMERA: a steep 2022 learning curve

- Can we send beams safely at low energy to CHARM in parallel to EA operation?



- Can we send beams safely at low energy to CHARM in parallel to EA operation?
- Why is the PS slow extraction so non-linear ?
- How do we accelerate and extract very, very low intensities ?
- How do we ease the CHIMERA overhead for the PS OP team with our requests inc. multiple beam energies and intensities ?
- How do we model the optics and transfer different beam energies along the T8 line… in presence of beam intercepting instrumentation, air, etc. ?
- How can we measure, control and manipulate the beam profile at CHARM ?
- How many ions do with have at CHARM? Can we measure and calibrate the intenisty/flux of low intensity ion beams ?
- How do integrate and exchange multiple test setups in CHARM ?

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Teamwork: CHIMERA working group

- CHIMERA activies highlight the multifaceted nature of the project with multiphysics and engineering problems being tackled together
- We have achieved a lot whilst exploiting existing infrastructure… thanks to all the usual suspects for impressive contributions: **presentations to follow!**
- **Transverse Feedback Excitation:** thanks to Pablo Arrutia & Thomas Bass (ABT), Gert Kotzian (RF) and Tom Levens (BI) for joining the effort and helping us apply TFB excitation to control the extraction
- **Slow extraction cycle development:** thanks to Marc Delrieux (OP) for driving the effort and creative ideas for simplifying the PS cycles
- **Beam instrumentation:** thanks to the various experts for helping us debug live during MD's to collect important data using instrumenation design for protons: Inaki, Stephane, Stephen, Joe …
- **Thanks to PS-OP, RF, STI, Linac3 and LEIR teams, IRRAD and RP for their support**

+ R2E project for radiation effects expertise and CHARM team for smooth integration

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Beam development and operation: work ahead

- **Slow extraction driven by noise:** RF Knock-out is commonly used to control extractions from synchrotrons (e.g. medical & irradiation facilities), demonstrated for CHIMERA in 2022, **to be studied by TECH & DOCT studies, improved and optimised at the PS in the coming years.**
- **Beam instrumentation:** impressive progress made as part of CHIMERA, keep momentum: absolute calibration techniques, beam profiles
- **Beam transfer and delivery:** transfer line optics now well understood, interaction with air problematic, techniques to homogenise the Gaussian distribution of the beam (installation of octupoles, collimators) needed
- **Beam operation:** RFKO simplifies operation, future development of tools to help scale energy and intenisty of PS machine for complex operation demanded by a VHE ion electronics testing facility like CHIMERA

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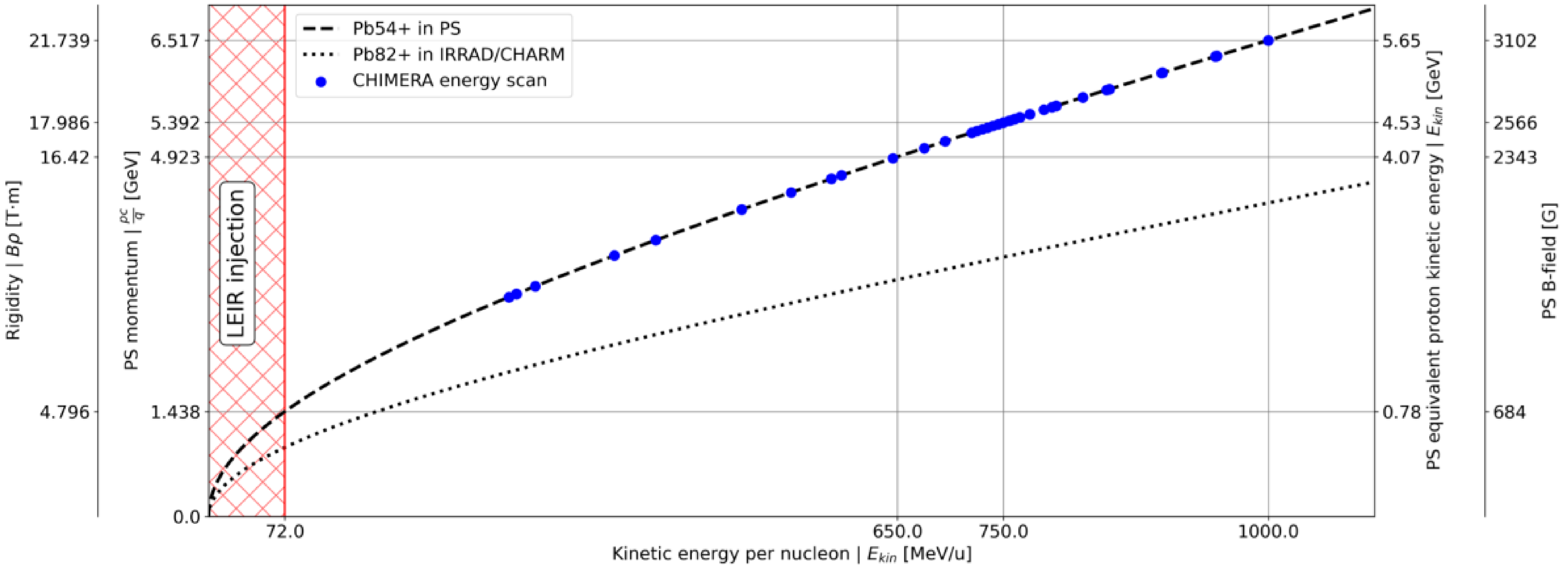
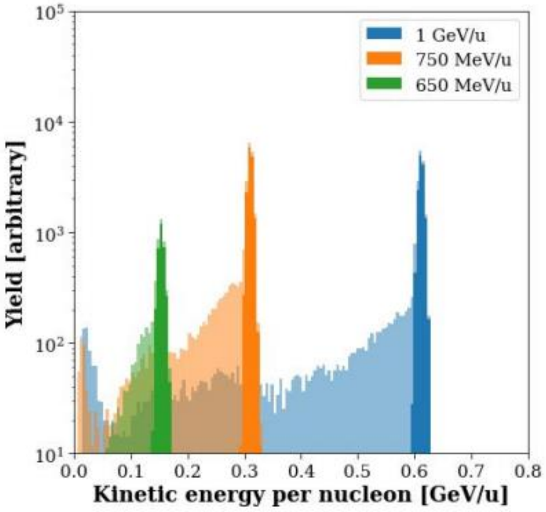
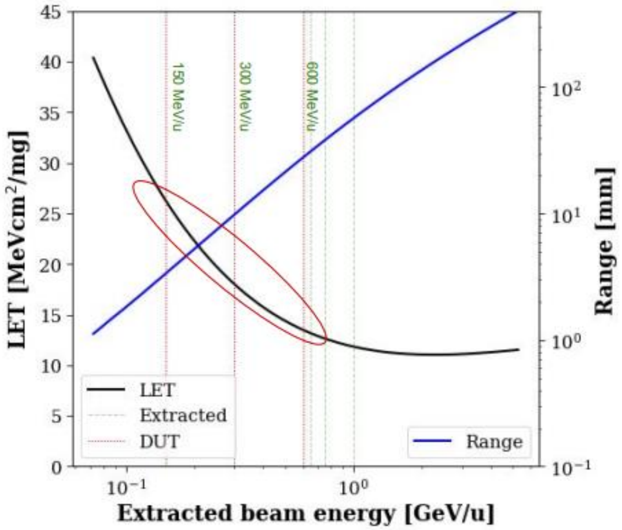
2022 achievements and starting point for HEARTS: energy



2022 achievements and starting point for HEARTS: energy

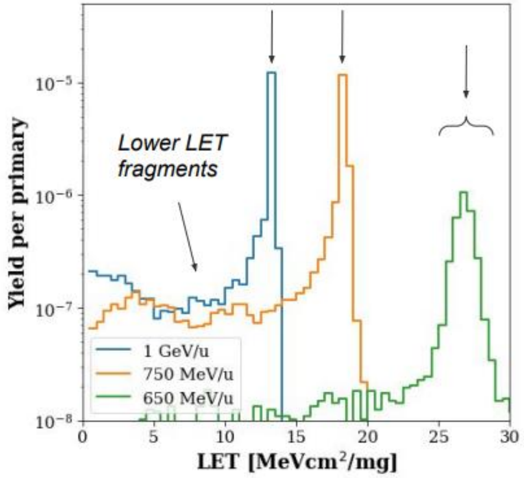


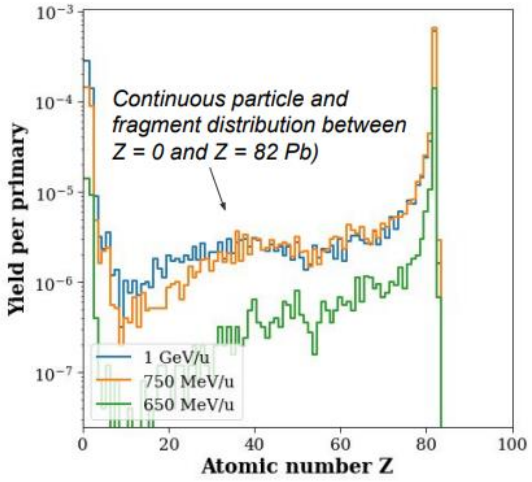


Routine definition of energy and LET values at DUT

Beam energy stability, logging and definition by users

Characterization and reduction of energy and LET spread





FLUKA

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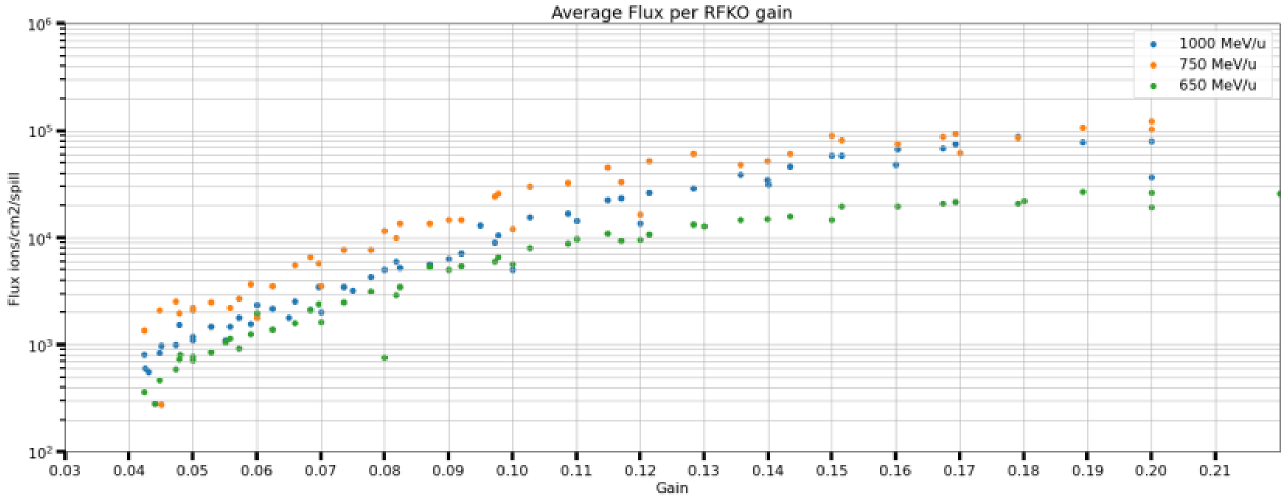
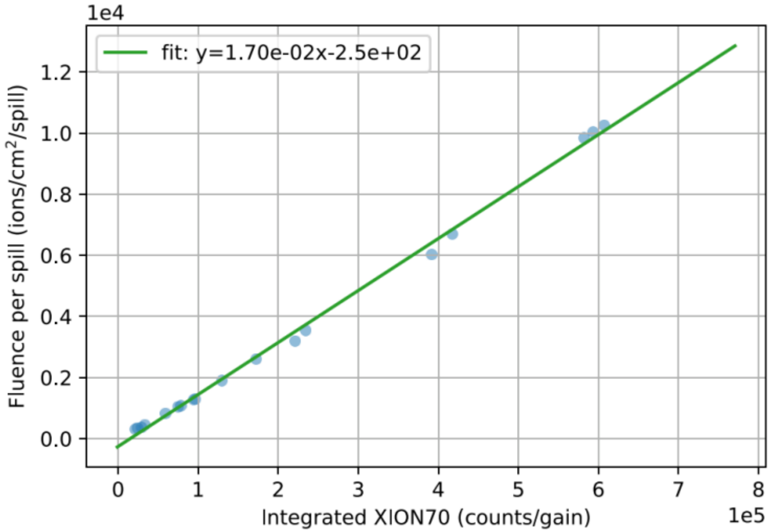
2022 achievements and starting point for HEARTS: intensity



650 MeV/n, XION



Beam intensity repeatability (spill-to-spill, run-to-run)

Flux measurement accuracy

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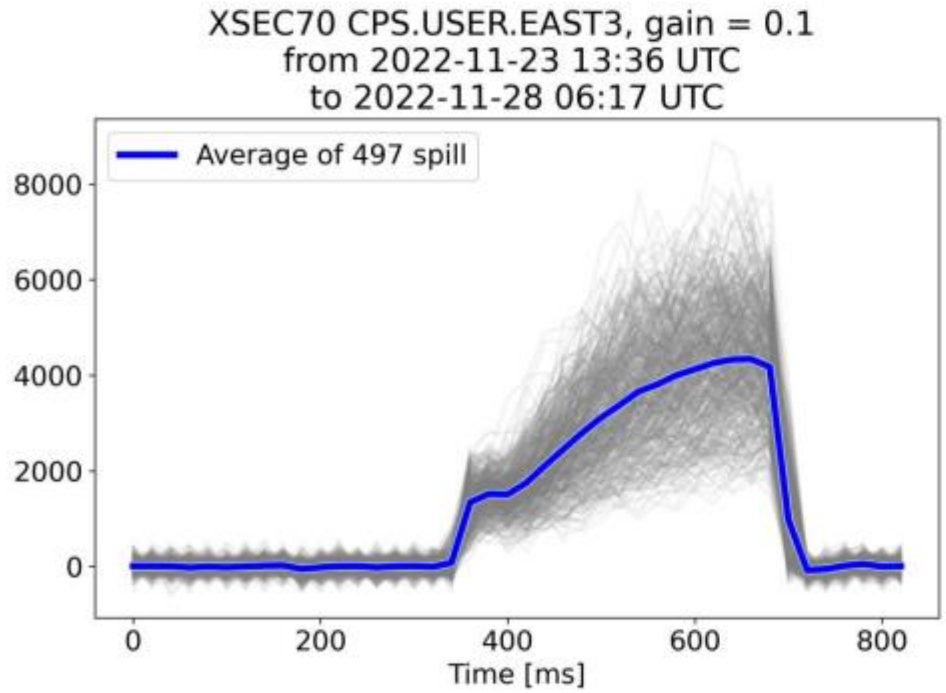
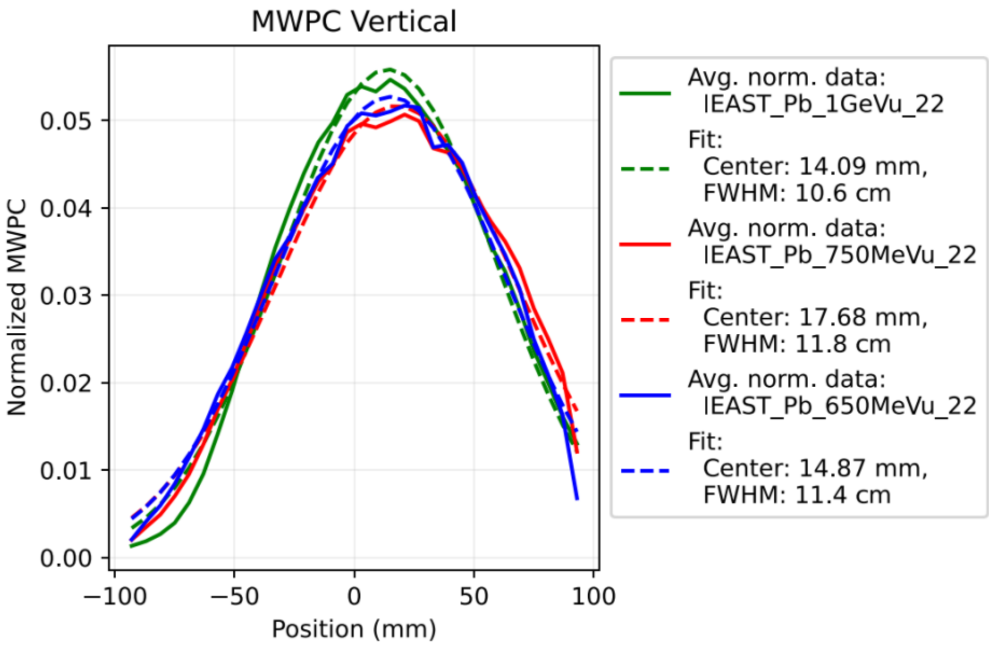
2022 achievements and starting point for HEARTS: spill time and spatial profiles



Spill duration and structure/uniformity at different time scales



Tunable rectangular beam shape, from small components to full boards

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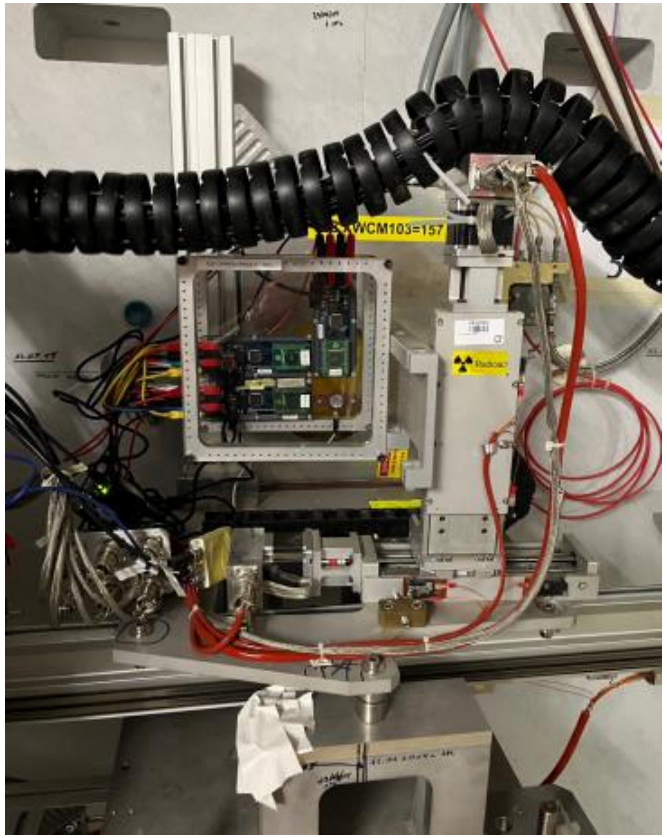
2022 achievements and starting point for HEARTS: integration of radiation effects experiments

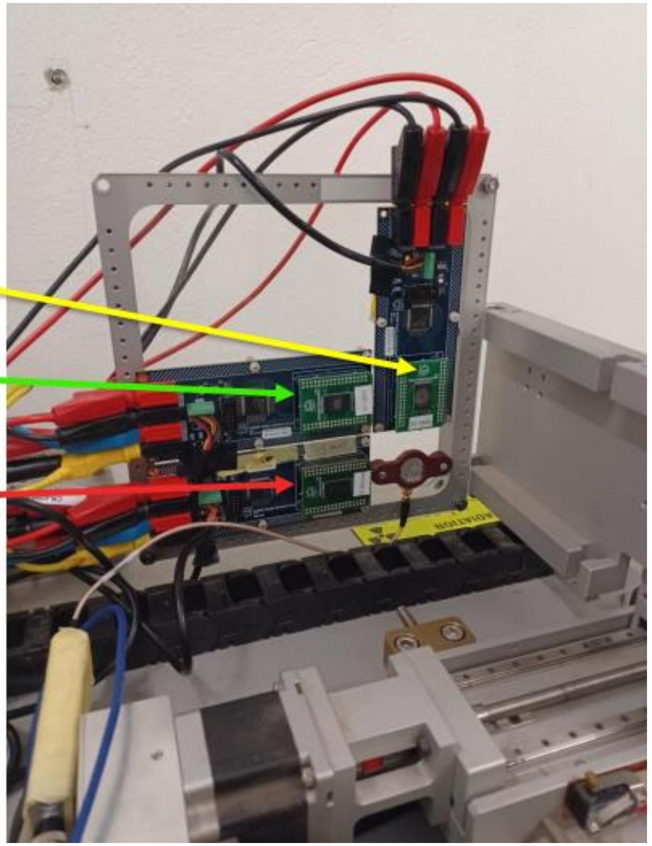


Setup integration for electronics testing users

2022 achievements and starting point for HEARTS: integration of radiation effects experiments

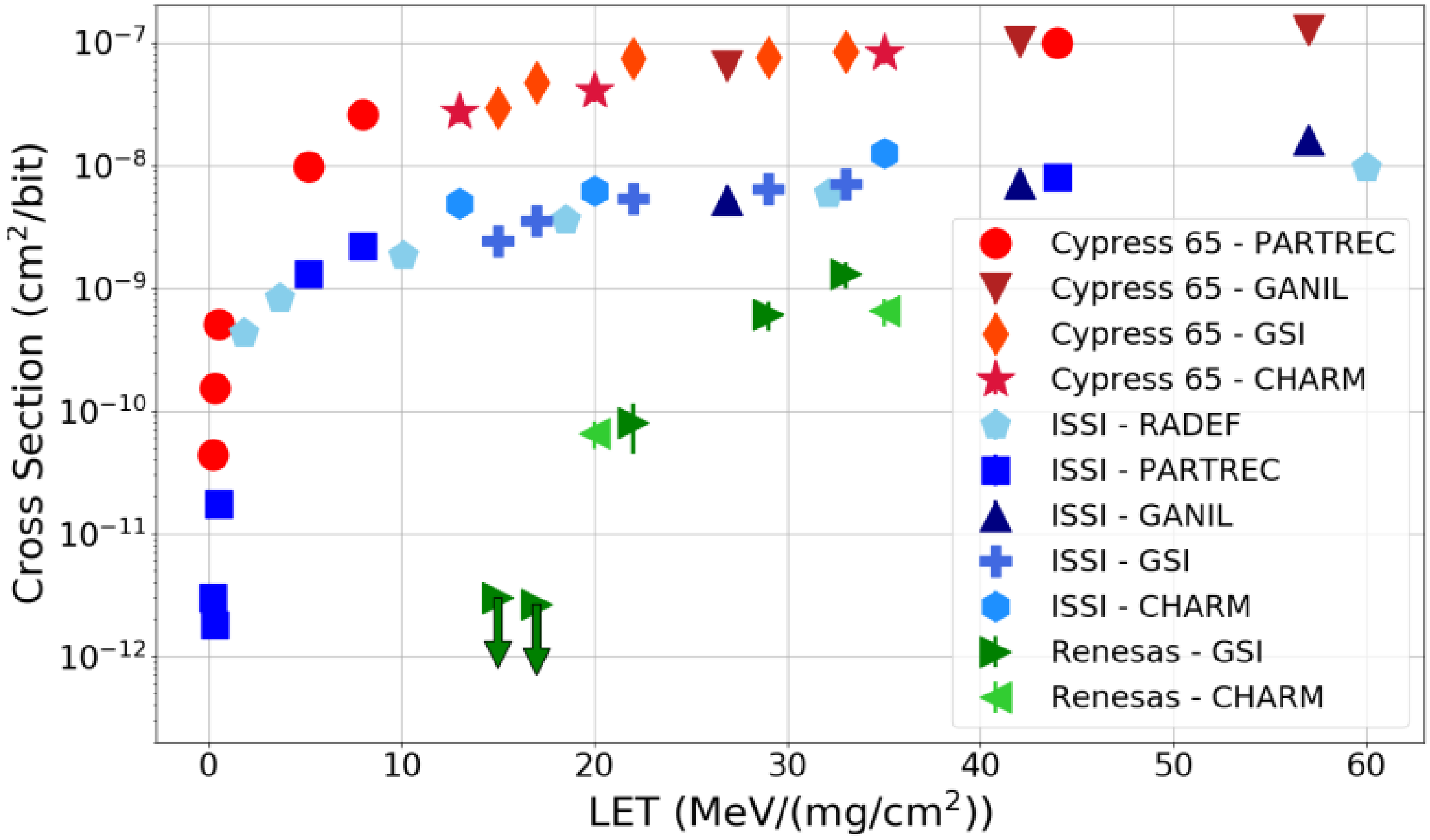
Three SRAMs mounted on the same frame as the diode

- ISSI 40 nm SRAM
  - Above diode
  - Decapsulated
- Cypress 65 nm SRAM
  - Opposite to diode
  - Decapsulated
- Renesas 110 nm SRAM
  - Beside diode
  - Encapsulated



Setup integration for electronics testing users

2022 achievements and starting point for HEARTS: radiation effects [preliminary] results (link to WP5)



Other technologies and effects (e.g. SEL, SEB, SEFI...)

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WP5 input for WP7: requirement definition

AGS HEET Layout and Capabilities

Key Performance Parameter (KPP)	Variable Description	Threshold Values	Objective Values
Simulation of the natural space environment (e.g., GCR, solar events)	Kinetic energy ($^{56}Fe^{26+}$ to target)	40 – 2000 MeV/u ($^{56}Fe^{21+}$ in AGS)	40 - 2600 MeV/u ($^{56}Fe^{26+}$) Up to 6.32 GeV H^+
Simulation of the natural space environment (e.g., GCR, solar events)	Ion species	H to U [Z = 1 to 92]	H to U [Z = 1 to 92]
Provide a range of flux inclusive of target value	N/A	$[10,10^6]$ ions/(cm^2-s)	$[10,10^6]$ ions/(cm^2-s)
Variable beam diameter (spot size) [a]	N/A	1 - 400 cm^2	1 - 400 cm^2
Transverse uniformity (dosimetry over spot size) [b]	N/A	± 10%	± 5%
pulse to pulse flux stability	Average flux variance	± 10%	± 5%
Beam microstructure[e]	Peak-peak flux variance (spikes)	± 30%[c]	± 10%[d]
	rms DF	90%	95%
Facility availability	Over 1-year period	4 Season availability; flexibility to access a second and third shift	4 Season availability; flexibility to access a second and third shift

[a] Smaller spot sizes are possible using collimation. The largest spot size without over-focusing is 200 cm². Larger spot sizes are easily produced by over-focusing at the target, although this increases the angular divergence at the target. The size of the beam stop limits the final beam sizes in these cases.

[b] Uniformity at first may be distorted by non-Gaussian tails in Horizontal phase space and lack of a perfect achromatic tune in early commissioning period.

[c] microstructure initially will be poor, as power supplies get tuned to reduce ripple, active filters get commissioned, and finally as the high frequency quadrupole ripple compensation gets commissioned.

[d] Final achievable microstructure will be intensity dependent (signal to noise in the intensity measurement) and the amount of power the ripple compensation can apply to reduce harmonics. The best achievable in the world is in the range of 10%-20%, using the methods we propose. RF structure, from the main accelerating RF in the AGS, may be present initially but can be eliminated by moving the RF off frequency from the beam revolution frequency.

[e] Duty factor is defined as $DF = 1/(1 + \frac{1}{2}\left(\frac{dV}{V_0}\right)^2)$, where dV is the rms amplitude of the oscillations and V_0 is the average flux. Spikes effect duty factor differently and can be calculated as $DF_s \approx 1/(1 + \frac{T_1}{T_2}\left(\frac{N_2}{N_1}\right)^2)$, where T_1 is the main spill length, T_2 is the time of the spike, N_1 is the #particles in T_1, and N_2 is the #particles in T_2.

Brookhaven National Laboratory

These parameters are challenging but achievable.

Requirement definition: importance of not being lost in translation between beam physics and radiation effects + means of verification (WP3, WP4, WP5) + associated intermediate TRL steps

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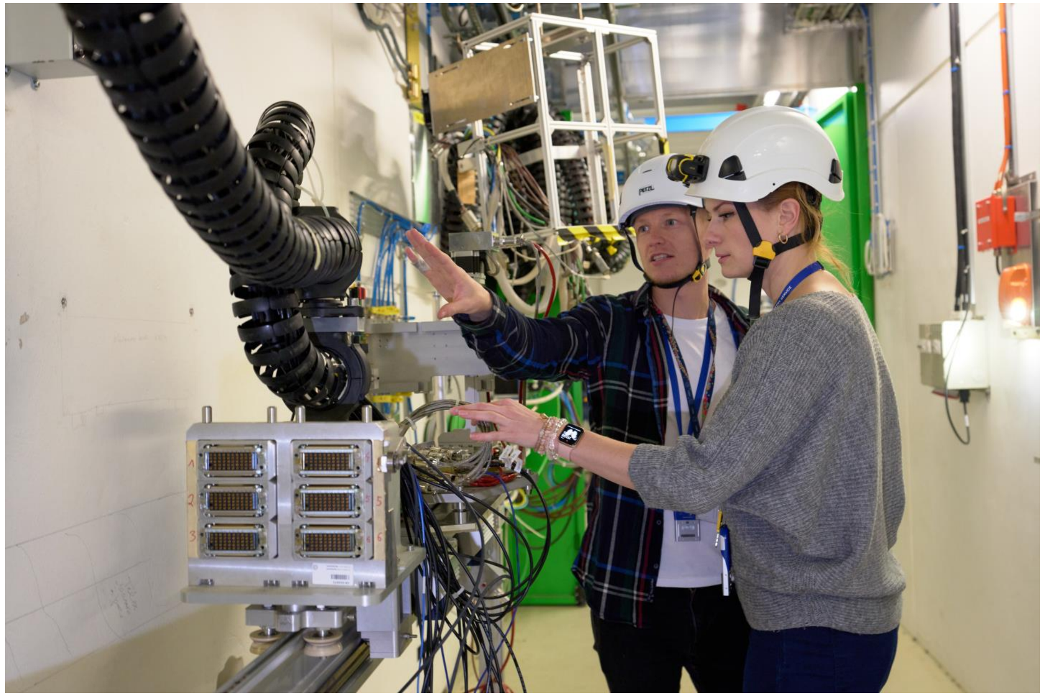
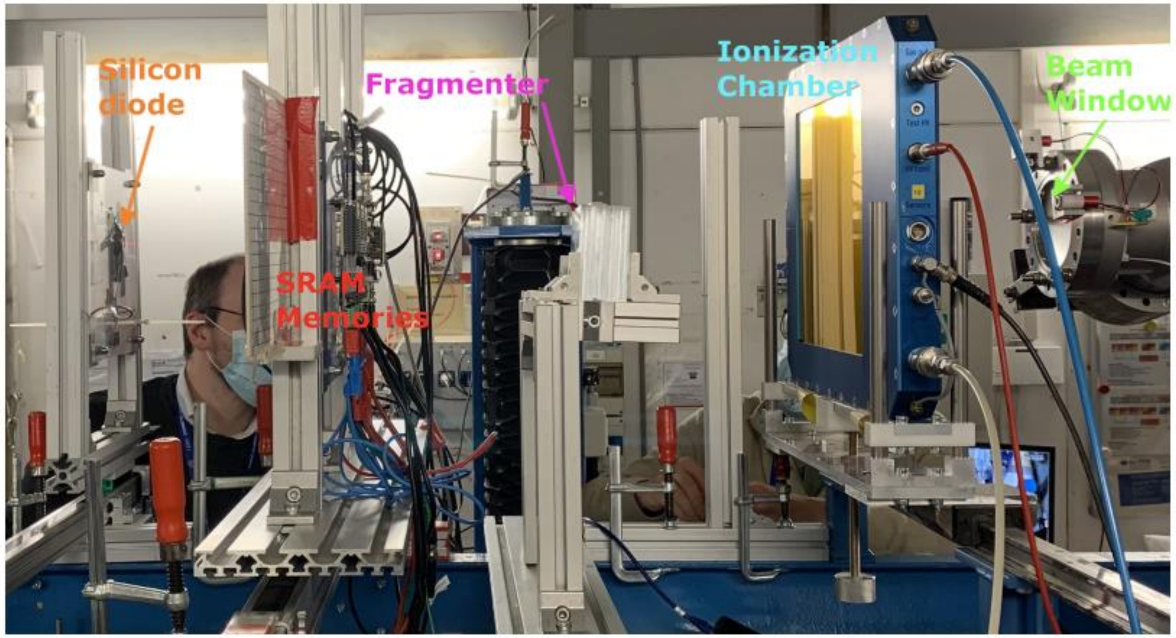
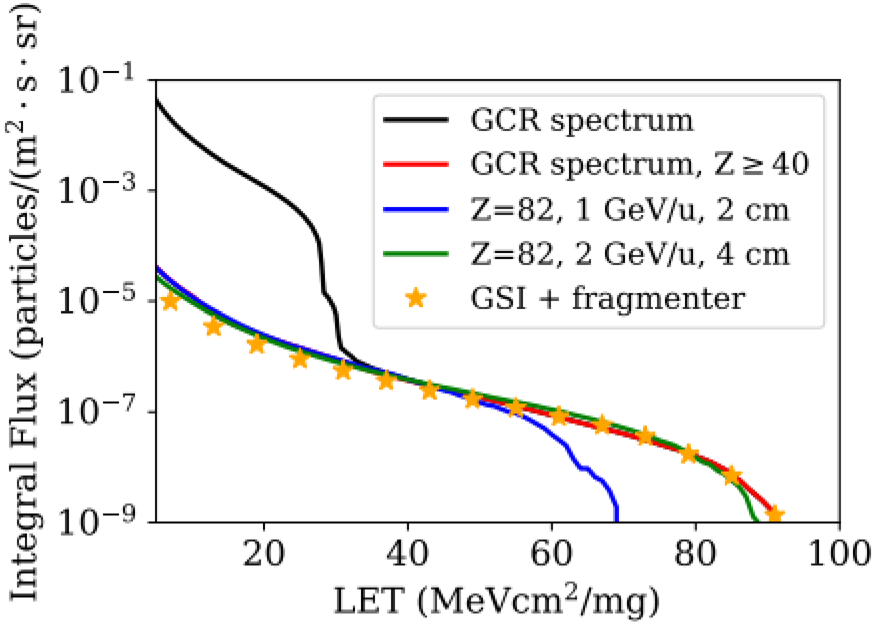
HEARTS WP7 resources: PhD and postdocs in beam physics, radiation-matter interaction and radiation effects on electronics



+ (in-kind) supervision contribution from CERN senior physicists

Radiation effects testing with LET spectra?





Fragmented high-energy heavy ion beams for electronics testing

Rubén García Alía; Kacper Bilko; Francesco Cerutti; Andrea Coronetti; Natalia Emriskova; Luigi Esposito; Francesc Salvat Pujol; Andreas Waets; Sylvain Girard; Frédéric Saigné; Marco Durante; Christoph Schuy; Tim Wagner

IEEE Transactions on Nuclear Science

Year: 2022 | Early Access Article | Publisher: IEEE

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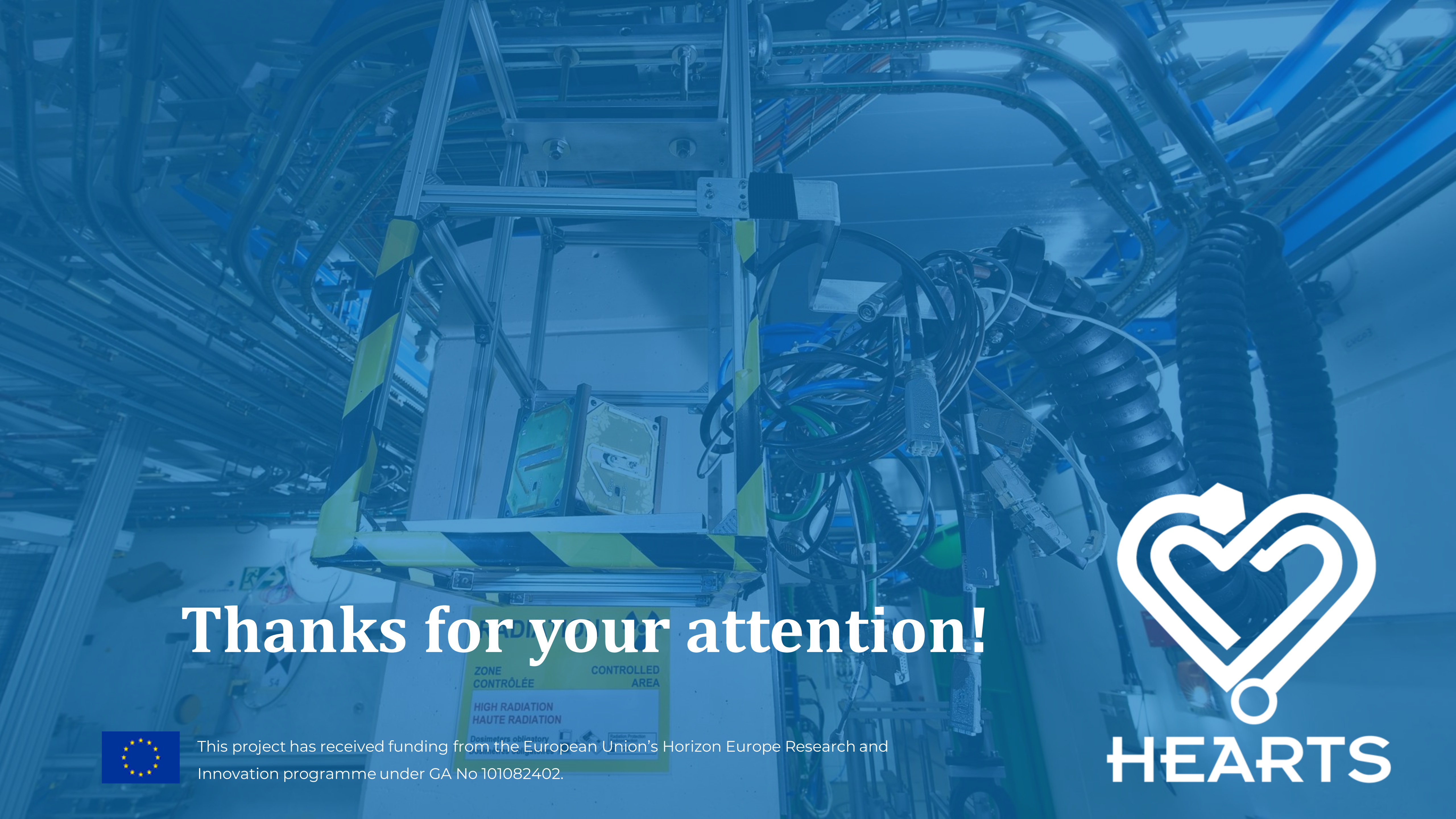

Thanks for your attention!

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