HEARTS P1 Review Meeting: WP7

25 September 2024

https://indico.cern.ch/event/1411185/

Rubén García Alía (CERN), on behalf of WP7

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.

Outline

- Deliverables, Milestones and Delays
- Risks
- Progress Achieved during P1
  - LET and Range
  - Flux, Fluence and Time Structure
  - Beam Size and Uniformity
  - Sample Holder and User Setup
- Recommendations from Annual Meeting
- 2024 pilot run (access provision) status
- Summary

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Deliverables and Milestones in P1

EDMS NO.	REV.	VALIDITY
3015929	1.0	Released

HEARTS

Grant Agreement No: 101082402

HEARTS

High-Energy Accelerators for Radiation Testing and Shielding

Horizon Europe project HEARTS

DELIVERABLE REPORT

DEFINITION OF EXTRACTION METHODOLOGY FOR PARALLEL USE OF THE HEAVY ION BEAMLINE FOR DIFFERENT ENERGIES

DELIVERABLE: D7.1

Document identifier:	HEARTS-D7.1
Due date of deliverable:	End of Month 12 (December 2023)
Report release date:	22/12/2023
Work package:	WP7: Upgrade of CHARM beam line at CERN for VHE ion testing
Lead beneficiary:	CERN
Document status:	Final

Deliverable Description:

This report will include the methodology that has been followed by the Proton Synchrotron (PS) operators and beam physicists to enable the parallel low-rigidity operation of the CHARM beamline to that at the standard, higher rigidity available. In this respect, the report will detail the beam optics and instrumentation used as well as the various settings needed to achieve the required energies and LETs.

HEARTS Consortium, 2023

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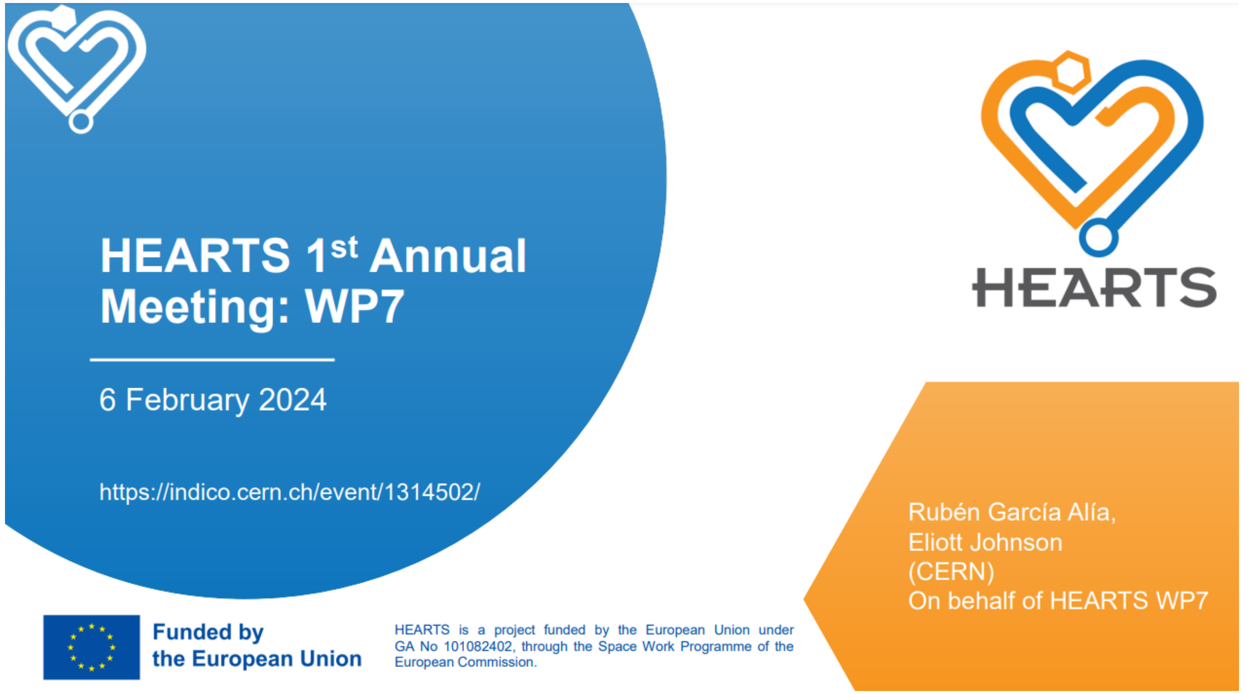

Deliverables due in P1

Deliv. No.	Deliverable name	Due date	Status	Summary
D7.1	Definition of extraction methodology for parallel use of the heavy ion beamline for different energies	2023-12-31	Achieved	This report includes the methodology that has been followed by the Proton Synchrotron (PS) operators and beam physicists to enable the parallel low-rigidity operation of the CHARM beamline to that at the standard, higher rigidity available

The achieved deliverables are available on HEARTS website page:
https://hearts-project.eu/project/deliverables/

Upcoming Deliverables & Milestones

Deliv. No.	Deliverable name	Due date	Status	Comments
D7.2	Demonstration of the achievements in terms of beam parameters (energy, LET, range, size)	2024-12-31	Pending	Will be mainly based on 2024 HEARTS@CERN campaign in November 2024 – see later in the presentation concerning the status
D7.3	Established framework for user access to the CHARM ion facility	2026-12-31	Pending	Good progress already in 2024, related to the pilot run with external users

Milest. No.	Milestone name	Due date	Status	Comments
M20	First external users at CHARM	2024-12-31	Pending	Foreseen as part of the HEARTS@CERN run
M21	Routine access for external users at CHARM	2026-12-31	Pending	2024 pilot run will serve as input/experience

Technically, the baseline is now IRRAD (but the user access is the same, including the physical access door, etc.)

Summary of delays in P1

- No delays have been experienced, nor are specifically foreseen (quite the opposite: currently we are advancing with a slight margin versus the original timeline, e.g. in terms of “fully external” access)

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Critical Risks & Mitigation Measures in P1

Risk #1:

WP5 to 9

Description: VHE beam requests require more beam time at HEARTS facilities than the initially allocated resources(i) medium, (ii) medium.

Mitigation measure: Maximize redundancy between CERN and GSI test facilities and capacity, so they can act as alternatives to each other

Did you apply the risk mitigation measure? (yes)

Did the risk materialise? (no)

Comments:

The risk did not materialize as such, likely simply because GSI and CERN are not yet actively promoting high-energy heavy ion irradiation opportunities, as this still requires an increased readiness level both from a technical and procedural perspective. Still, plans on how to maximize the redundancy between the two facilities are ongoing, and it is fully acknowledged by both organizations that this coordinated access effort will be beneficial for GSI, CERN and the radiation effects testing users.

This will likely remain a strong limitation as we move forward, as ~2 weeks per year are perceived by users are very limited (and possibly a bottleneck for an efficient exploitation of the facilities, even despite the GSI/CERN redundancy)

(some ideas in the pipeline to substantially increase the HEARTS@CERN beam time offer, but this is beyond the scope and timeline of the present project)

Critical Risks & Mitigation Measures in P1

Risk #2:

WP5 to 9

Description: Access to one facility becomes unavailable due to temporary hardware malfunction (i) low, (ii) high.

Mitigation measure: Maximize redundancy between CERN and GSI test facilities and capacity, so they can act as alternatives to each other

Did you apply the risk mitigation measure? (yes)

Did the risk materialise? (yes)

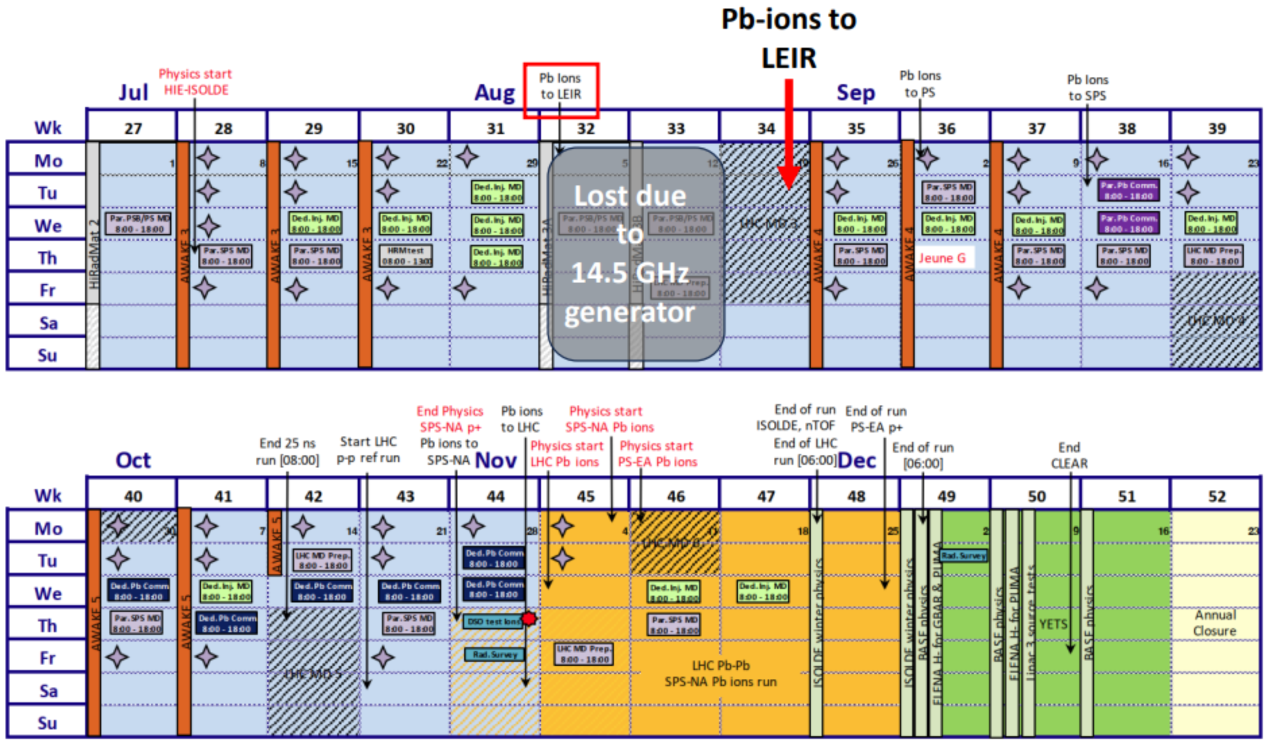
Comments: Indeed, due to hardware failures in the GSI accelerator infrastructure, three 8-hour shifts that had been assigned for the HEARTS electronics testing activity with uranium beams in June 2024 had to be fully cancelled, meaning the next high-LET irradiation opportunity at GSI will be Spring 2025. This is intended to be mitigated by performing part of these tests at the HEARTS@CERN facility in November 2024.

CERN PS and ion injector complex reliability and available (ion source, Linac3, LEIR) remains a risk

Critical Risks & Mitigation Measures in P1

Pb-ion beam commissioning planning

- ❑ Pb-ion beam in LEIR planned for W32
- ❑ Problem with the HV power supply in the 14.5 GHz generator → Beam in LEIR was delayed by 2 weeks



Critical Risks & Mitigation Measures in P1

Risk #5:

WP7

Description: Need to obtain more financial resources for beam line material (e.g., magnets, collimators, degraders) than what was allotted in order to meet requirements (i) low, (ii) medium

Mitigation measure: Coverage of additional funding through in-kind contribution later recovered through industrial access resources.

Did you apply the risk mitigation measure? (yes)

Did the risk materialise? (yes)

Comments:

Indeed, the need of some level of additional funding for the HEARTS@CERN activity has materialized and, for the time being, coverage through CERN's own resources has been possible and sufficient

Critical Risks & Mitigation Measures in P1

Risk #8:

WP7 and 8

Description: Too large levels of fragmentation and contamination for accurate SEE testing, as determined via simulations (WP3) and measurements (i) medium, (ii) medium

Mitigation measure: Minimizing material budget in beamlines.

Did you apply the risk mitigation measure? (yes)

Did the risk materialise? (yes)

Comments:

Indeed, according to simulations and measurements, the level of fragmentation (and primary beam energy – and hence LET – spread) at the end of the T8 was non-negligible, and considered to be close to the limit of what is acceptable for radiation effects testing of electronics. This has been mitigated, as initially foreseen, by reducing the material budget the ion beam encounters before reaching the Device-Under-Test which, in practice, has been achieved by moving the test station roughly 30m upstream, to the IRRAD Zone 1.

Critical Risks & Mitigation Measures in P1

Risk #9:

WP7

Description: Too large overhead in accelerator operation time and effort related to setting up and tuning cycles for variable ion energy extraction and transport. Lack of repeatability due to hysteresis effects (i) low, (ii) medium

Mitigation measure: Reducing the number of energy cycles available for SEE testing, and further tuning the energy with a degrader system.

Did you apply the risk mitigation measure? (no)

Did the risk materialise? (yes)

Comments:

Operator overhead in relation to the HEARTS@CERN has been kept at a reasonable level and has so far not represented an issue for the project. Intensity variability potentially due to hysteresis effects was indeed encountered during the 2023 run and attempts to reduce it are foreseen for the 2024 campaign (therefore, the mitigation measure has not yet been applied, but its application is foreseen in the near future).

Identification of new risks

- No new risks have been identified (but the initially identified potential risks remain very pertinent, and are being closely monitored)

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Starting point: WP5 facility requirement document

https://hearts-project.eu/project/deliverables/d5.1/

Deliverable D5.1

Finalised list of beam parameter requirements concurring to establish a TRL 6-7 for the CHARM facility

Description

This report will provide the final list of VHE ion beam parameters that are appropriate to award a TRL6-7 to both CHARM and GSI facilities. This will include the most appropriate ion types, energies, LETs, ranges, beam time availability as well as commercial conditions of access for industry.

HEARTS

EDMS NO.	REV.	VALIDITY
2907439	1.0	RELEASED

Grant Agreement No: 101082402

HEARTS

High-Energy Accelerators for Radiation Testing and Shielding

Horizon Europe project HEARTS

DELIVERABLE REPORT

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

DELIVERABLE: D5.1

Document identifier:	HEARTS-D5.1
Due date of deliverable:	End of Month 6 (June 23)
Report release date:	26/06/23
Work package:	WP5: Radiation effects testing with VHE ions
Lead beneficiary:	UniPD
Document status:	Final

Abstract:
This document presents a set of requirements and recommendations for very-high energy heavy ion facilities, for the purpose of single event effects testing of electronic components. It covers beam features – LET, range, flux – and practical aspects related to the experimental measurement of the ionizing radiation sensitivity of electronic devices.

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LET and Range

Req. 2.1.a: the LETs of the available beams shall range from ~ 0.1 to >= 60 MeV · mg^{-1} · cm^2, in order to cover the full spectrum from SEE threshold to saturated cross section of modern electronic devices and be consistent with the characteristics of ionizing particles in space.

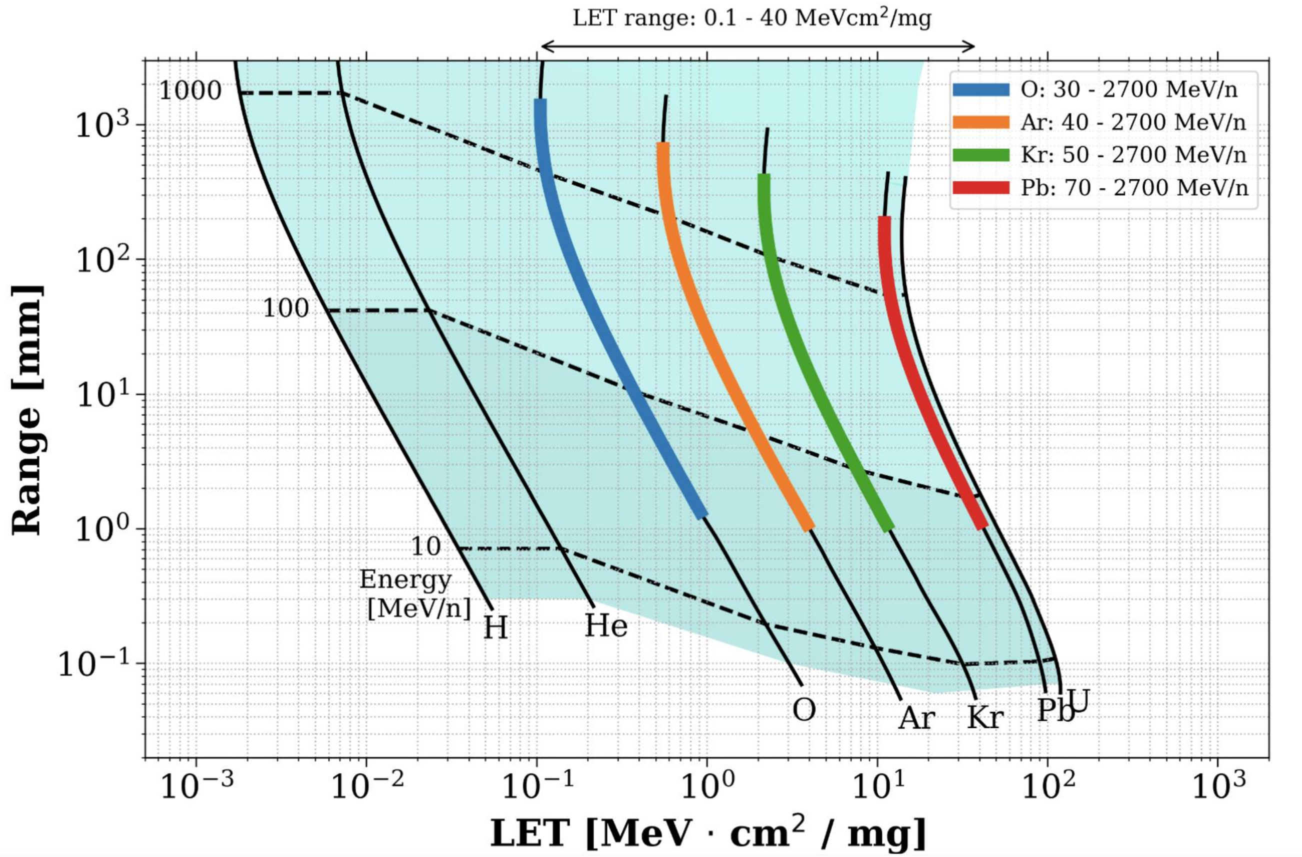
Low-LET beams are very important, because the long range of very-high energy heavy-ion facilities will be used to test advanced components with low LET threshold, and because of the abundance of low-LET particles in space.

Up to now, HEARTS@CERN has focused on the **~12-37 $MeVcm^2/mg$ LET range**

- Going to *larger LETs* is in principle possible, by reducing the beam energy (likely through a combination of accelerator energy and degraders)
    - **Accelerator energy reduction:** beam transport through transfer line becomes more challenging as the energy is reduced (limits and possible mitigation to be studied during 2024)
    - **Degrader energy reduction:** limited by energy/LET spread and fragmentation
    - How low do we want to go? Even if it were possible, overlapping with cyclotron facilities might not be desirable
- Going to *smaller LETs* requires a significant ion source and injector upgrade → currently being proposed at CERN level, and in synergy with physics applications (and would require partial external funding)

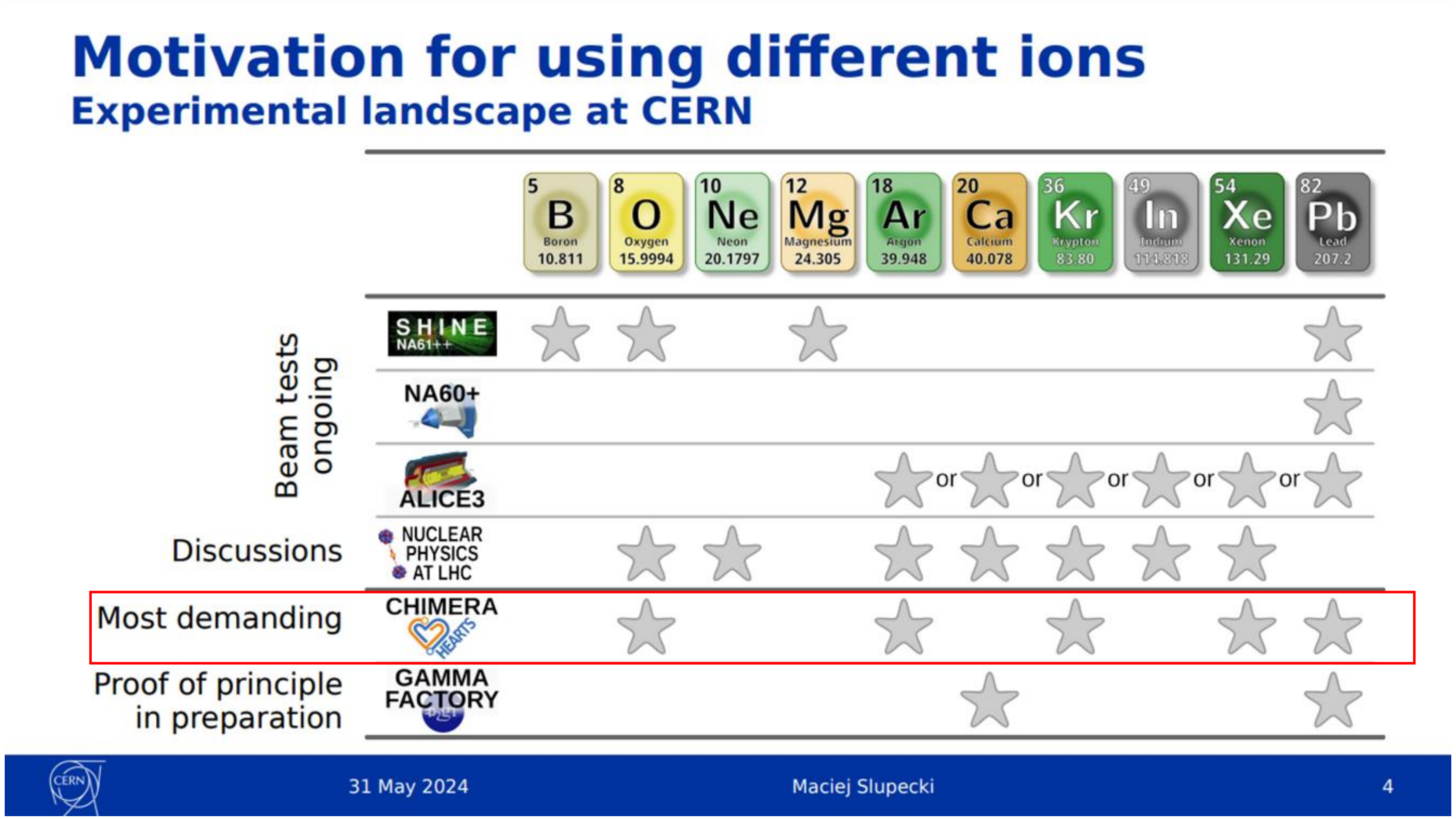
HEARTS

LET and Range: lower LETs



@Andreas Waets

LET and Range: lower LETs



@Maciej Slupecki

LET and Range: lower LETs

Projects' status and challenges

Experimental physics projects
Tests to assess feasibility in Run3

- NA61++ / SHINE
  - **Completed the first beam test with Mg up to flat-top energy in PS**
- NA60+
  - Ongoing beam tests with Pb → SPS extraction towards experimental area
- LHC experiments / ALICE3
  - Beam tests with Kr up to Linac3 done in 2023
  - One ion species to be selected to maximize luminosity
  - Need inputs from **source tests** with new ions and development of simulations
- Nuclear physics at LHC
  - Collecting feedback at workshops and conferences

Facilities

- HEARTS* – most demanding request
  - Provide: O, Ar, Kr, Pb
  - Every operational day, with switching times between species of max 15'
  - The experiment decides the order in which the species are delivered
  - Switch between ions at will
  - **Impossible with present injectors**:
    - switching between ions takes days/weeks (gas/solid)
- Gamma Factory
  - Proof of principle in the SPS is being prepared

* Heavy ion irradiation of electronics in the PS East Area, supported by EU and ESA, and formally known as CHIMERA

31 May 2024 Maciej Slupecki 5

@Maciej Slupecki

LET and Range

Req. 2.1.b: a full SEE characterization requires 3 to 5 LET values covering the LET range mentioned above, the maximum time spent in an ion change or in an LET change shall be less than 30 min.

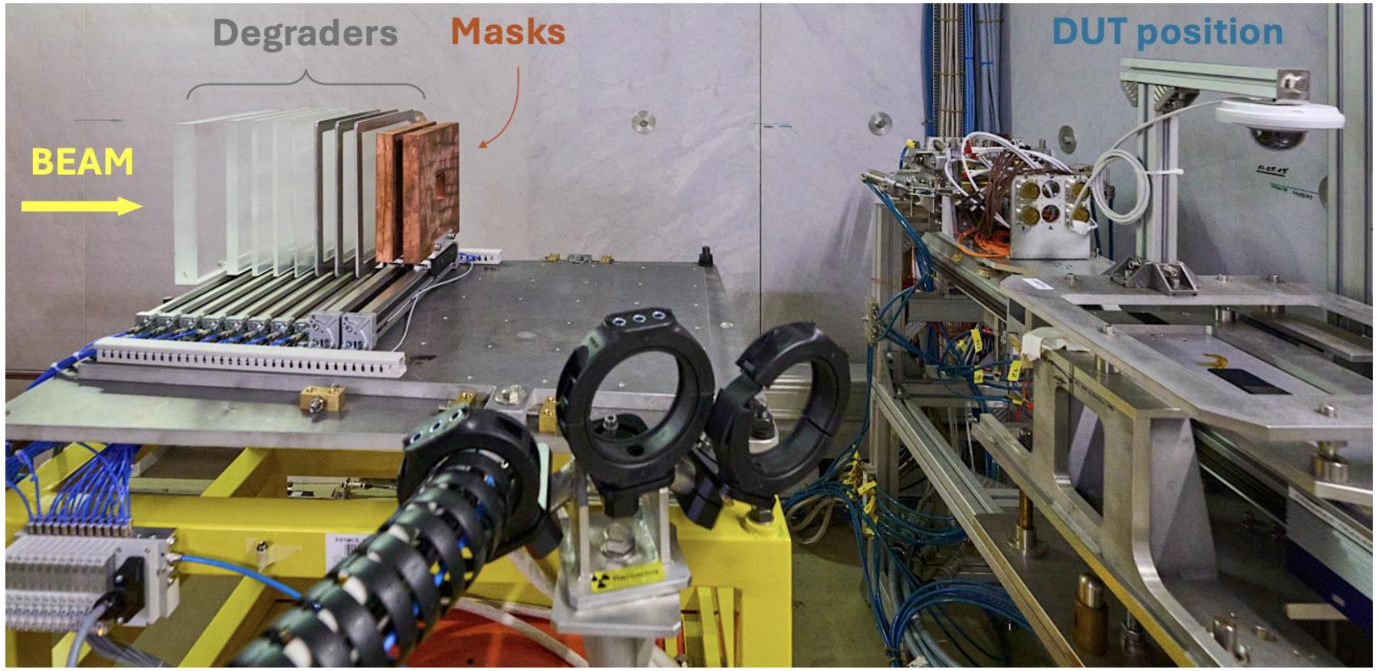
Req. 2.1.c: the heavy-ion beam LET shall have a +/-10% spread, in order to limit LET uncertainty. This should be intended as Full-Width Half Maximum (FWHM) of the LET distribution at the surface of the device under test in the sample position.

Req. 2.1 .b: foreseen situation for 2024 is to offer 6 LET values in the 12-37 MeVcm^2/mg range, separated by 5 MeVcm^2/mg, and being able to change between them in ~1 min (if using degraders) or ~3 min (if using the accelerator – requiring a call to the PS control room)

Req. 2.1. c: detailed FLUKA simulations of energy (and LET) spread induced by the transfer line and degrader system, aiming at preserving the related LET FWHM below 10%

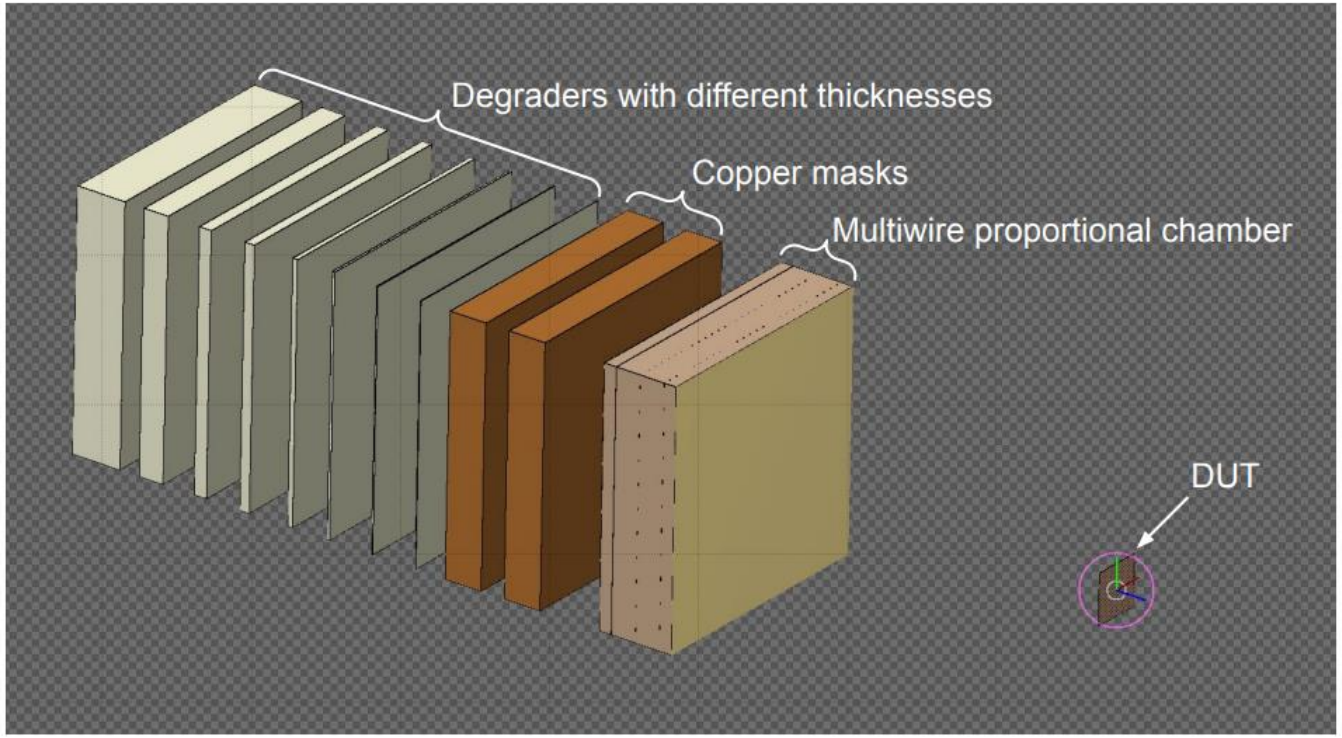
LET and Range

HEARTS LET booster



LET and Range

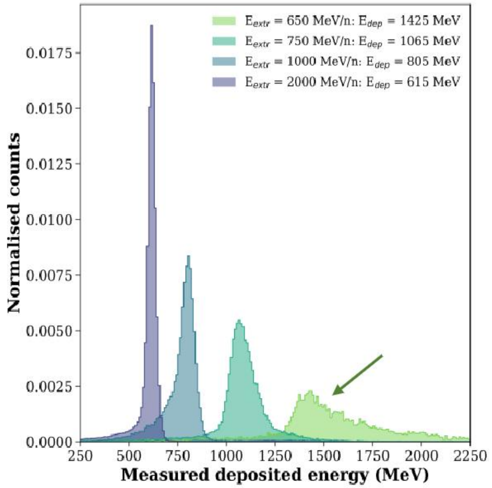
Simulations setup



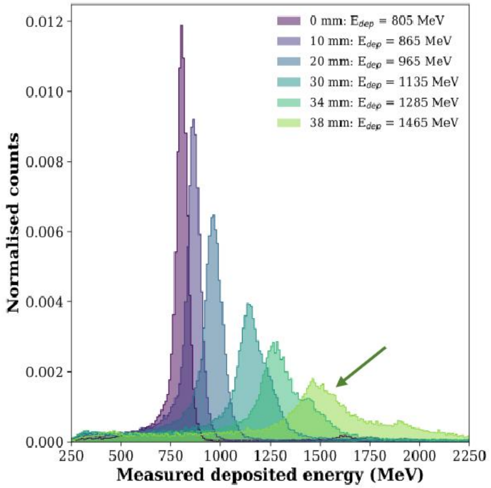
LET and Range

Increasing LET

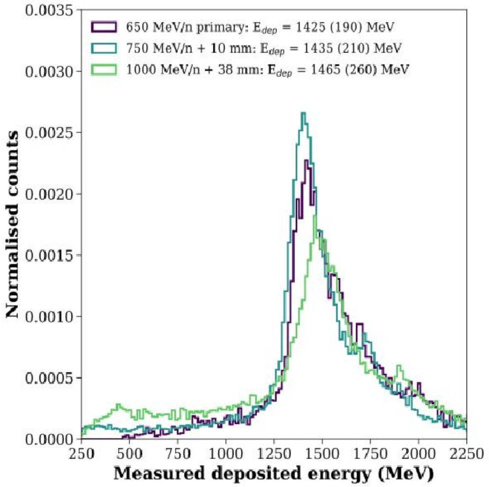
Method 1
Lowering beam energy



Method 2
Energy degraders



Similar LET result



@Natalia Emriskova

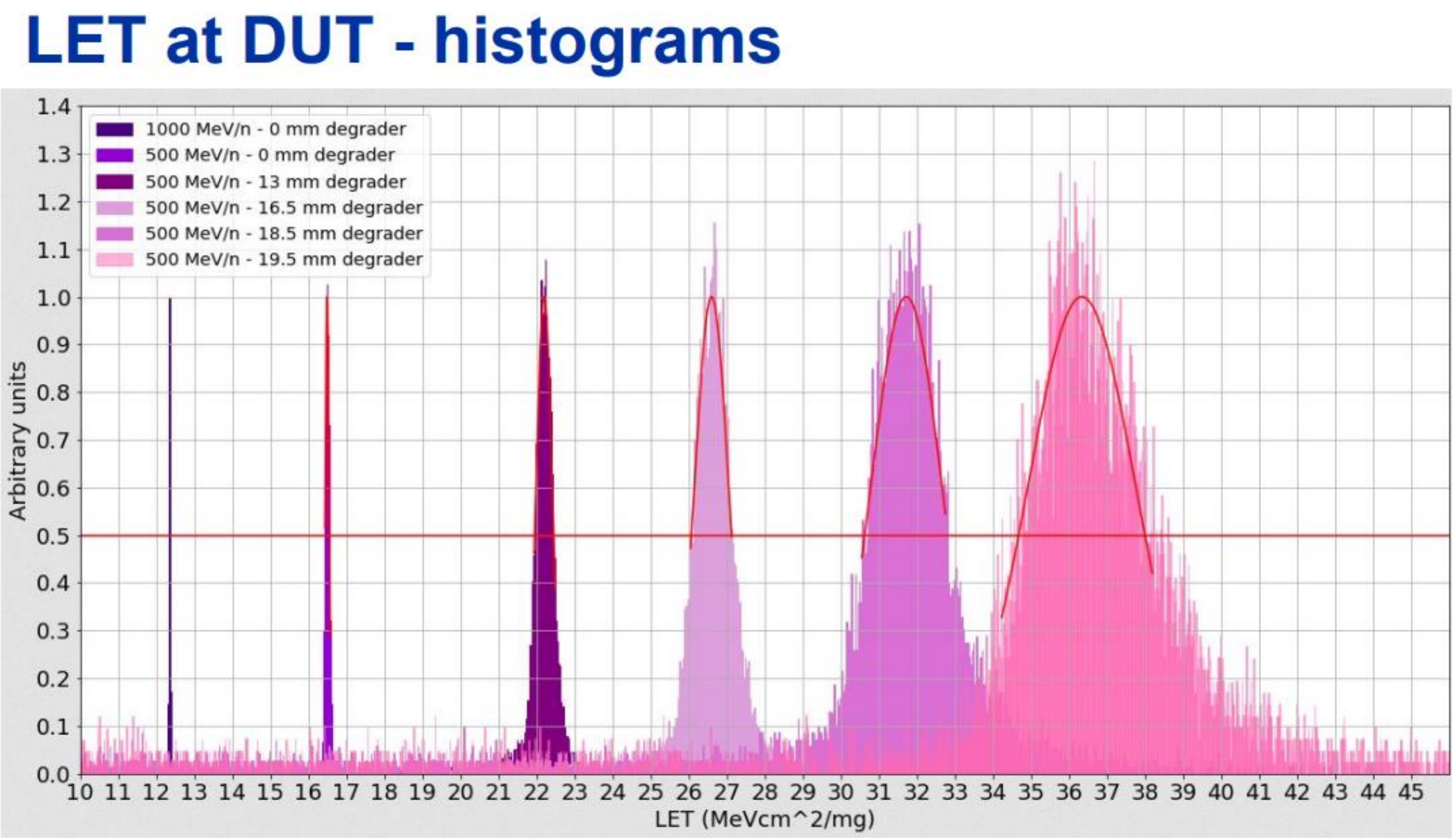
LET and Range

Beam parameters

Extracted energy [MeV/n]	Degrader thickness [mm]	Energy at DUT position [MeV/n]	Surface LET [MeVcm^2/mg]	Range in Silicon [mm]
2000	0	1665 (21)	11.4 (0.1)	108.4
1000	0	660 (13)	13.4 (0.1)	31.4
750	0	361 (14)	17.0 (0.2)	12.9
650	0	223 (14)	21.7 (0.7)	6.1
1000	38	220 (26)	21.8 (1.2)	6.0
750	10	226 (18)	21.6 (0.8)	6.3
750	16	120 (26)	30.8 (3.5)	2.4

@Natalia Emriskova

LET and Range



@Karolina Klimek

LET and Range

LET values at DUT

Extraction energy [MeV/n]	Degrader thickness in beam [mm]	Mean LET (simulated) [MeV cm^2/mg]	FWHM LET (simulated) [MeV cm^2/mg]
1000	0	12.34	0.04
500	0	16.49	0.12
500	13	22.20	0.50
500	16.5	26.60	1.06
500	18.5	31.72	2.19
500	19.5	36.33	3.32

@Karolina Klimek

LET and Range

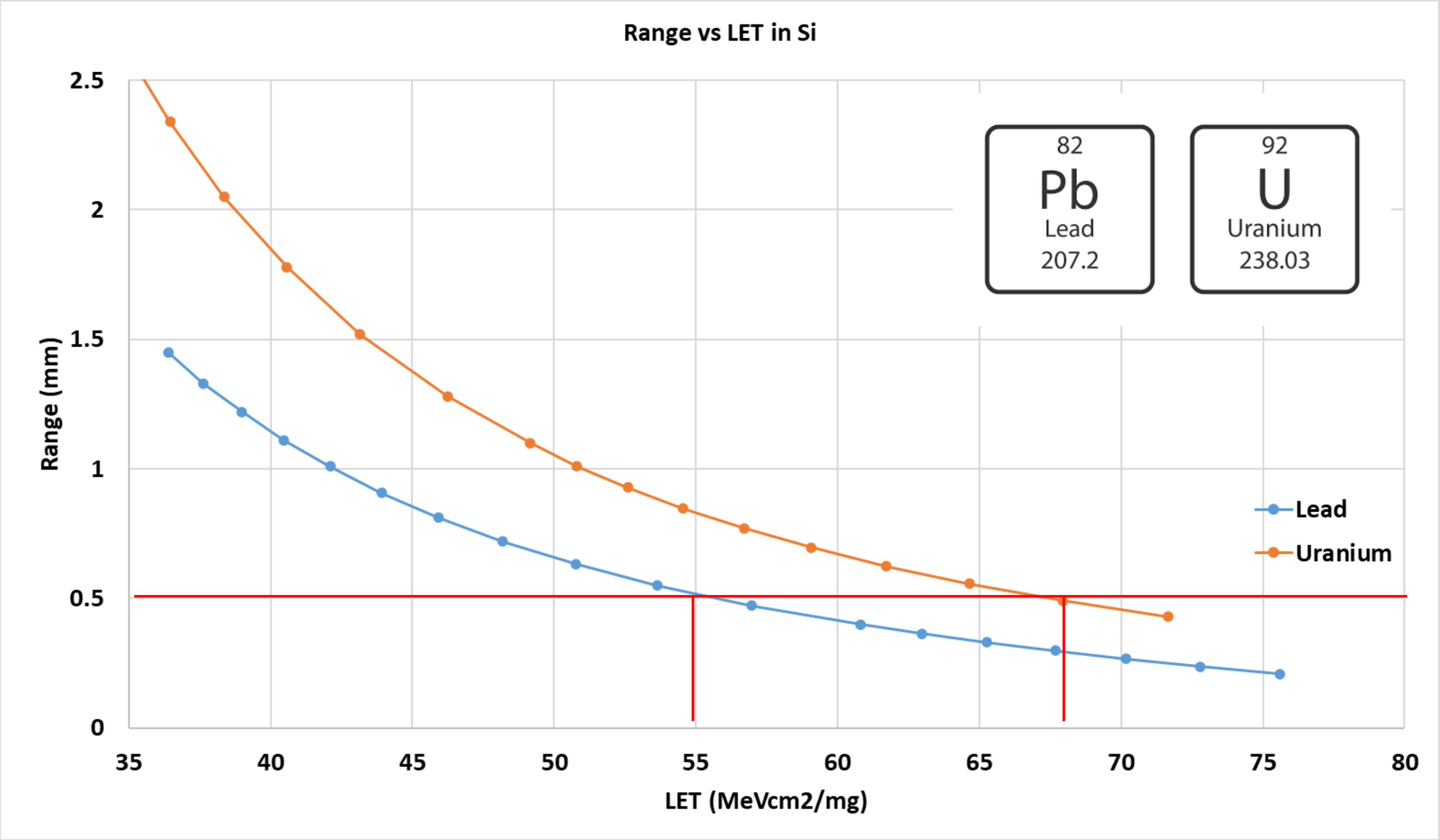
- In summary, we have so far investigated the following conditions:
  - **750 MeV/n** from the PS, in the CHARM test location and with 16mm degrader → LET limit of 10% FWHM is **~30 MeVcm²/mg** → tested in 2023
  - **500 MeV/n** from the PS, in the IRRAD test location and with 19.5mm degrader → LET limit of 10% FWHM is **~36 MeVcm²/mg** → currently in commissioning, for usage during 2024 test campaign
    - (if things work for 500 MeV/n – also in terms of obtaining a large enough flux – we will certainly be tempted to extract and transport lower energies, obtaining larger LET values with an acceptable spread)

LET and Range

Req. 2.1.d: the particle range shall exceed 500 µm in Silicon for the full LET range. In addition, several use cases require significantly longer ranges. The beams provided by the facilities shall cover as many as possible of the following scenarios:

	Equivalent range in Si
Wire-bonded chip with plastic package	> 0.5 mm
Flip-chip device without lid and with glue removed	> 0.8 mm
Single-die 3D devices	> 1 mm
Chip with ceramic package lid	> 1 mm
Flip-chip device with plastic package	> 2 mm
Multi-chip package	> 2 mm
Chip with heat spreader	> 3 mm

LET and Range



LET and Range

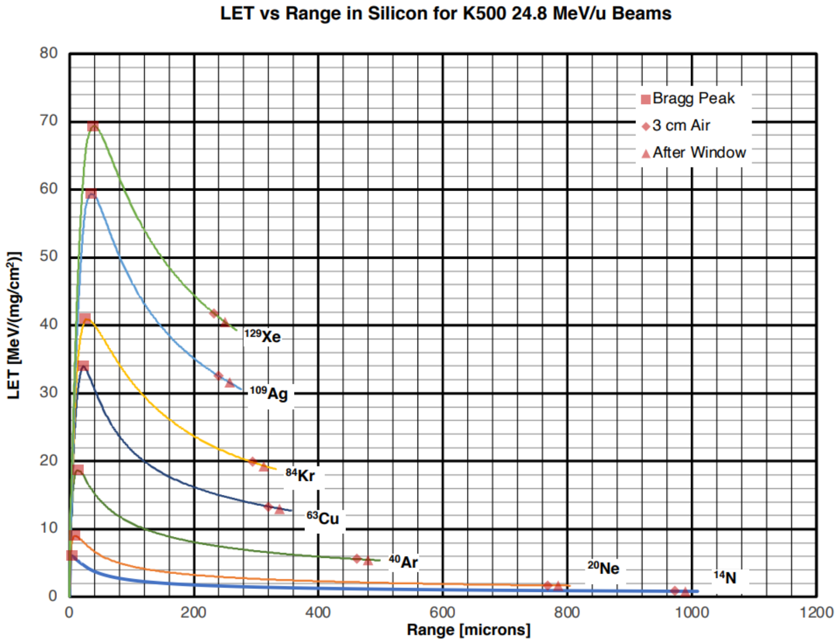
TEXAS A&M UNIVERSITY
Cyclotron Institute

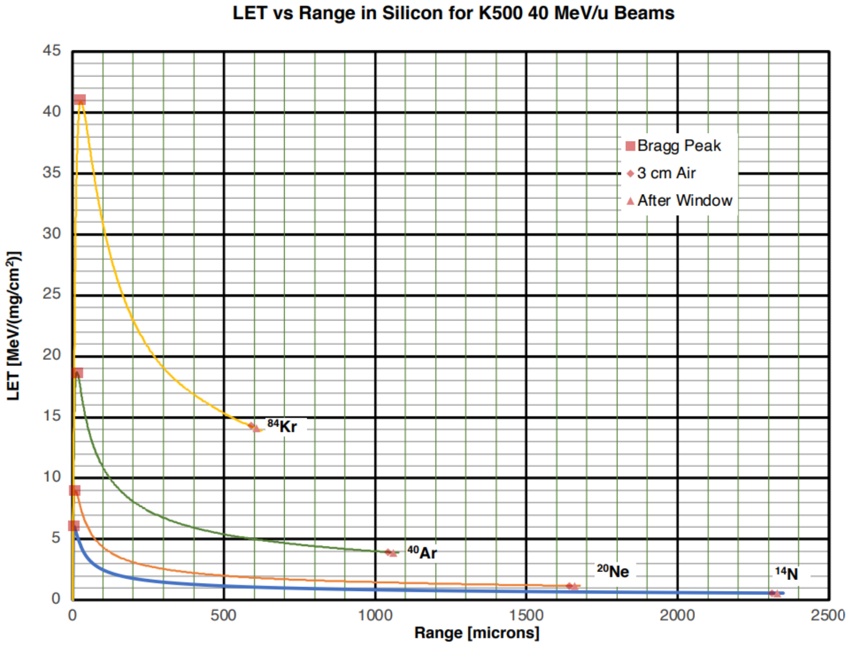
cyclotron.tamu.edu/ref
phone: 979-845-1411
fax: 979-845-1899

Available K500 Heavy Ion Beams

(LET and range values are for Si)

Ion	Mass [amu]	A MeV	Total Energy [MeV]	Energy at Bragg Peak [MeV]	Range to Bragg Peak [microns]	Range in vacuum [microns]	LET in vacuum [MeV/(mg/cm2)]	Range after window [microns]	LET after window [MeV/(mg/cm^2)]	Range after 3 cm air [microns]	LET after 3 cm air [MeV/(mg/cm2)]	Range at Bragg [microns]	LET at Bragg Peak [MeV/(mg/cm2)]
^{129}Xe	128.905	24.8	3197	451	230.3	268.7	39.3	250	40.5	232	41.8	38.4	69.3
^{78}Kr	77.920	40	3117	170	602.4	626.9	13.9	608	14.1	590	14.3	24.5	41.0





LET and Range

Req. 2.1.e: the code and version used to calculate the LET and range values shall be provided when reporting results.

Req. 2.1.f: the facility shall provide a user-friendly tool to help the users in determining the LET at the sensitive volume depth. It is important to note that the input data in terms of composition and thicknesses of the overlayers on top of the sensitive volume are key for the accuracy of the LET estimation.

Req. 2.1 .e: indeed, important point which deserves further attention, as we have seen some non-negligible differences between e.g. SRIM and FLUKA

Req. 2.1. f: we are, at least for the time being, relying on the BNL/NSRL tool, in which lead was (kindly!) included as a projectile particle (as well as PMMA – used in the HEARTS degrader system - as target material)

LET and Range

Characterization of fully fragmented high-energy heavy ion beams for SEE testing through measurements and simulations

A. Waets, R. Garcia Alia, K.Bilko, N. Emriskova, L. Esposito, , Christoph Schuy, Tim Wagner, Petteri Nieminen, Uwe Schneider

***Abstract*—Fully fragmented, very-high-energy heavy ion beams offer interesting possibilities for radiation hardness assurance testing of electronic components exposed to the Galactic Cosmic Ray space environment. In this paper, we perform the dosimetry of these fully fragmented ion beams through a combination of solid state detector measurements and detailed Monte Carlo FLUKA simulations in FLUKA focusing on the interaction between beam and device-under-test. The experimental configurations tested highlight the challenges for implementing this method in VHE ion facilities. The Monte Carlo simulations offer further insight in the optimization of this approach.**

I. INTRODUCTION

In recent years, the radiation effects testing community has taken great interest in using very high-energy, heavy ion beams (VHE, between 100 and 5000 MeV/n kinetic energy) for qualifying electronic components. The motivation for using

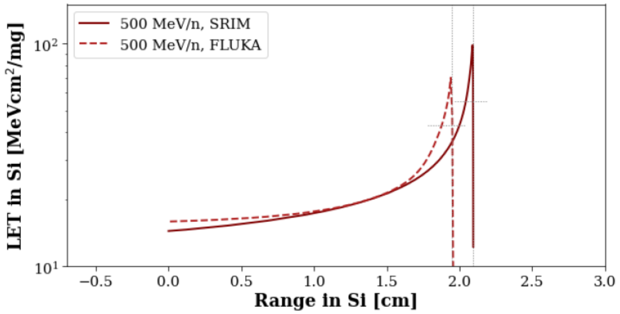


Fig. 1: LET as function of range in silicon calculated for Pb (lead) ions using SRIM and FLUKA for 500 MeV/n kinetic energy. The LET values from FLUKA are approximated by scoring the energy deposition in 100 µm slices of Si.

@Andreas Waets

LET and Range

https://www.bnl.gov/nsrl/stackup/

Brookhaven National Laboratory — NASA Space Radiation Laboratory

Home | User Guide | StackUp Tool | About | Apply for Beam Time | Run Information | Related Facilities | PETRA

Beam Energy [MeV/u]: 350 — Multiple Layers Calculator

	Material	Thickness [mm]	Exit Energy [MeV/u]	Residual Range [mm]	Entrance LET	Exit LET
Layer 1:	Polyethylene	0	350.00	23.23	21.90	21.90
Layer 2:	Copper	3.3	94.05	0.53	14.08	28.66
Layer 3:	Silver	0.05	87.49	0.46	25.58	26.63
Layer 4:	Silicon	0.25	77.09	1.22	36.18	38.95

NSRL StackUp Calculator

The high energy beams available at NSRL allow for heavy ions with significant range across types of materials. In order to determine what beam conditions are appropriate for experiments and testing at NSRL, we offer an Excel-based calculator database so that users can explore how the beam energy, range of ions, and instantaneous energy transfer will behave based on a multi-layer transport approximation. A database of energy, range, dE/dx, and straggling information has been assembled for all ions available at NSRL and more across a selection of materials traditionally used by the heavy ion radiation field. This database is an extraction from the Stopping and Range of Ions in Matter (SRIM/TRIM) free software by J. F. Ziegler. This software uses a Monte Carlo binary collision approximation method to determine the values for range and stopping power for a given incident energy ion in a specific target material. For these calculations, a classical coulombic potential is combined with a semi-empirical screening function known colloquially as the ZBL potential which was developed in-part by Ziegler found in the citation below. More information about the SRIM software can be found at www.SRIM.org.

Publications From SRIM

Ziegler, J. F., & Biersack, J. P. (1985). The Stopping and Range of Ions in Matter. In Treatise on Heavy-Ion Science (pp. 93–129). Springer US. https://doi.org/10.1007/978-1-4615-8103-1_3

James F. Ziegler, M.D. Ziegler, J.P. Biersack (2010). SRIM – The stopping and range of ions in matter. Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms Vol. 268. Elsevier. https://doi.org/10.1016/j.nimb.2010.02.091

NSRL StackUp Download
Version 9, August 2024

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Flux, Fluence and Time Structure

Req. 2.2.a: the heavy ion accelerator shall be capable of delivering ions with variable flux ranging from a few (10) ions/cm^2/s to at least 10^6 ions/cm^2/s on the device under test. This should be intended as an instantaneous flux, and not an average flux, in case beam is delivered in spills. The maximum instantaneous flux (10^6 ions/cm^2/s) is intended for those tests in which users are interested to reach a target of 10^7 ions/ cm^2 in the fastest possible way.

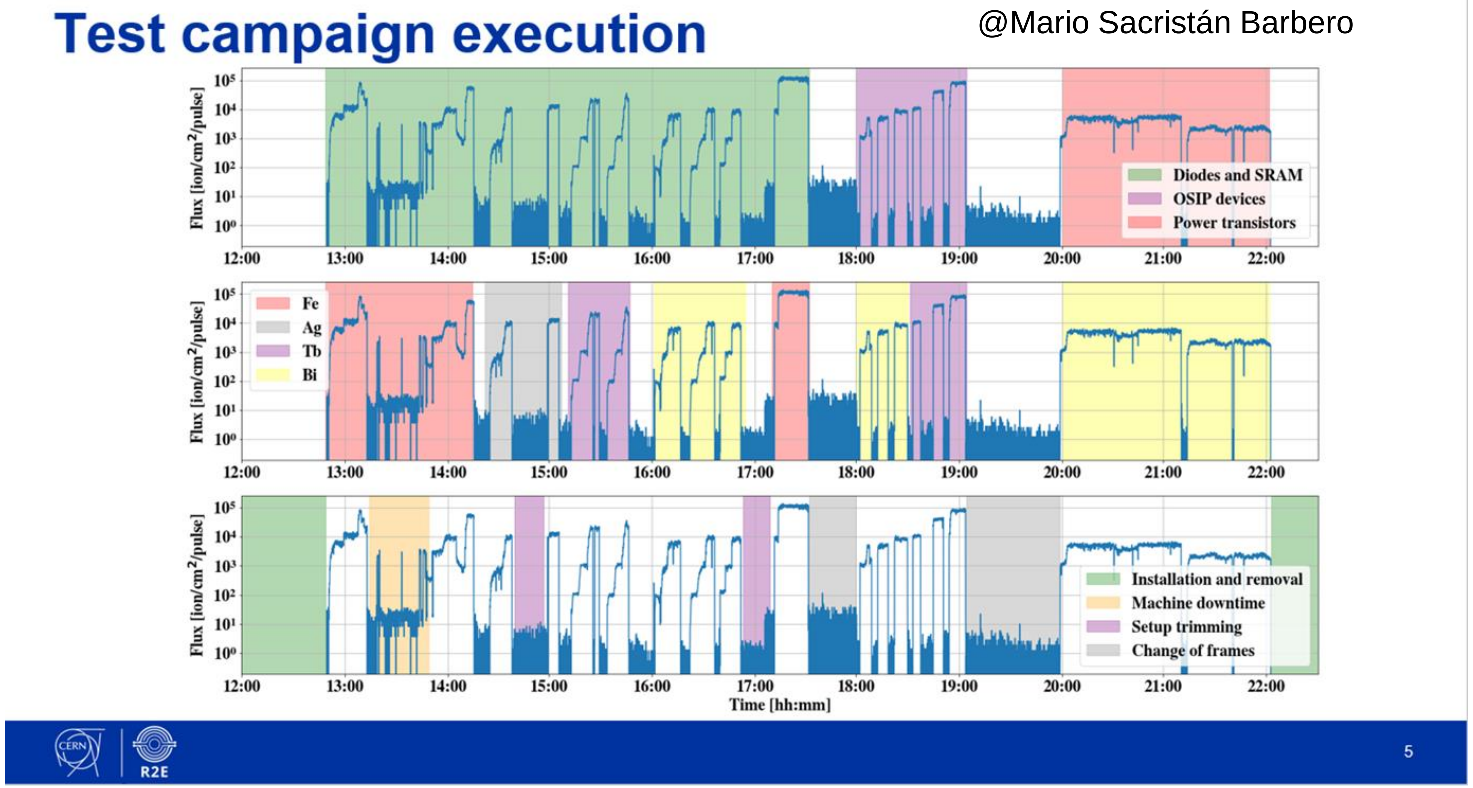
So far, we have achieved ~10^2 – 10^5 ions/cm^2/spill(*) which, considering one spill every ~10s, is an order of magnitude lower in terms of ions/cm^2/s

(as reference, the NSRL high-LET beam – i.e. bismuth – provide a maximum flux of a few 10^4 ions/cm^2/spill)

(*) for the largest energy – for lower energies (higher LETs) the flux is a few 10^4 ions/cm^2/spill, though our feeling is that we have room for improvement (to be checked in 2024)

Flux, Fluence and Time Structure

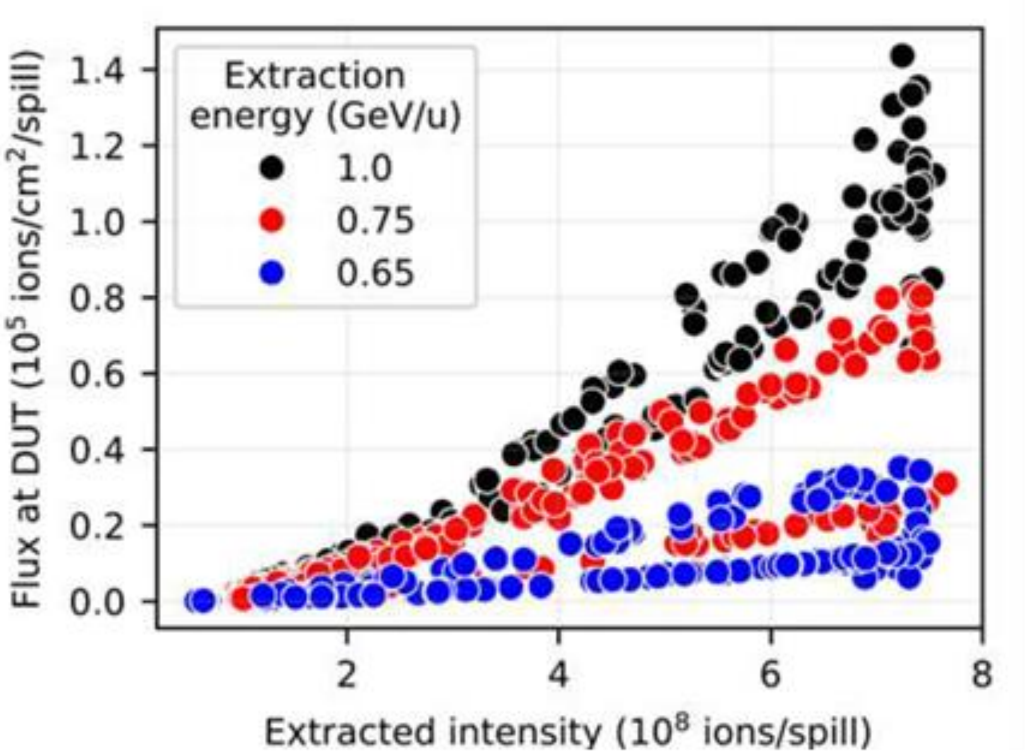
@Mario Sacristán Barbero



CERN R2E/HEARTS tests at NSRL in July

Flux, Fluence and Time Structure

@Kacper Bilko



HEARTS@CERN 2023 flux per spill versus extracted ions, for different energies

Flux, Fluence and Time Structure

Req. 2.2.b: the radiation field shall be uniform within ±10% over the area of the device(s) under test in terms of fluence.

Req. 2.2.c: dosimetry shall allow the continuous monitoring of the flux at the device throughout the test with an accuracy of ±10%.

Req. 2.2.d: reached fluence until device failure or until the end of the run should be provided to calculate the cross section with an accuracy of ±10%.

Req. 2.2 .b: achieved through large Gaussian beam spot cut on the sides; measured with 2D (or 2x 1D) beam profile monitors

Req. 2.2 .c and .d: Flux/fluence accuracy is difficult to calculate/validate (e.g. comparison between different methods, etc.) but good SEE agreement with other facilities is encouraging

Flux, Fluence and Time Structure

Req. 2.2.e: the facility shall maintain a procedure for calibrating the provided beam. A calibration procedure shall be used each time the primary beam energy or the particle species is changed, unless the last performed calibration has been carried out recently (at most a few days prior to the shift) and proof can be given or arguments can be made that it is still valid. Upon the User's request, the facility shall be able to provide the calibration data. This includes:

- beam purity and energy spectrum
- beam flux and fluence, and spatial uniformity.

Our dosimetry procedure relies on the absolute measurement of the particle flux/fluence over a small surface, and the correlation of it with the relative intensity measurements carried out permanently during user irradiation

So far, the linearity between the two values has been demonstrated over a large range of fluxes and energies (with the linearity factor depending on the energy)

Detailed beam purity information is available through a combination of measurements and simulations

Flux, Fluence and Time Structure

Req. 2.2.f: the facility shall provide a way to immediately stop the heavy ion beam at user request (e.g., if a device failure occurs) by instructing the machine operator.

Req. 2.2.g: the facility shall provide a dedicated signal to remotely stop the beam (or close a shutter) within 3 seconds for a limited amount of time (some seconds to a few minutes, e.g., for resetting the device under test). The dosimetry system should not count the fluence while the shutter is closed.

The previous requirement is useful in many testing scenarios. This is possible at RADEF and HIF, where the shutter can be directly controlled from the user test bench (it can be linked for example with different operational phases of a memory/FPGA/complex IC under test).

Current situation: beam ON/OFF button available in experiment control room, and usable by the HEARTS shift team (which will be working with the users in the experiment control room)

Reaction time of related solution (i.e. time between beam OFF command and actual removal of the beam) likely within few second range, but will need to be more accurately determined

Flux, Fluence and Time Structure

Req. 2.2.h: a clear and simple user interface to view the selected ion/beam, flux and current fluence (percentage of completion) during the irradiation runs shall be provided to avoid misunderstandings and communication errors between the users and the machine operators.

Two parallel (and complementary) developments:

- PS OP “WRAP” tool, for operator purposes
- User interface tool, by Cosylab → dedicated meeting tomorrow

Flux, Fluence and Time Structure

Req. 2.2.i: the facility shall provide a precise description of the beam temporal structure (scanning speed, spill structure) to the user. Synchronization signals shall be provided, such as spill start, spill end, next point during scanning as applicable.

Req. 2.2.j: if applicable, the facility shall give the possibility to change scanning speed and pattern, and the number of ions per position to optimize the SEE tests.

For some types of measurements, the temporal structure of the beam is irrelevant. This is the case when the events are measured after a certain fluence has been reached and flux does not impact on the results. For instance, the number of SEU in a memory can be measured in this way.

For other types of measurements, the beam temporal structure may represent an issue. This is the case when different operations are performed on the device under test in sequence, each with a non-negligible duration compared to the beam structure.

It is important to avoid correlations between the testing algorithms and the beam delivery (e.g., in a program/read loop, the beam should not be delivered only during the read phase).

Flux, Fluence and Time Structure

For HEARTS@CERN, the beam time structure is relatively simple: ~1s “uniform” spill every ~10s

This is achieved with a broad beam, and does not involve magnetic scanning

Synchronization signals available (but not routinely used – need to be tested, etc.)

Outline

- Deliverables, Milestones and Delays
- Risks
- **Progress Achieved during P1**
  - LET and Range
  - Flux, Fluence and Time Structure
  - **Beam Size and Uniformity**
  - Sample Holder and User Setup
- Recommendations from Annual Meeting
- 2024 pilot run (access provision) status
- Summary

Beam Size and Uniformity

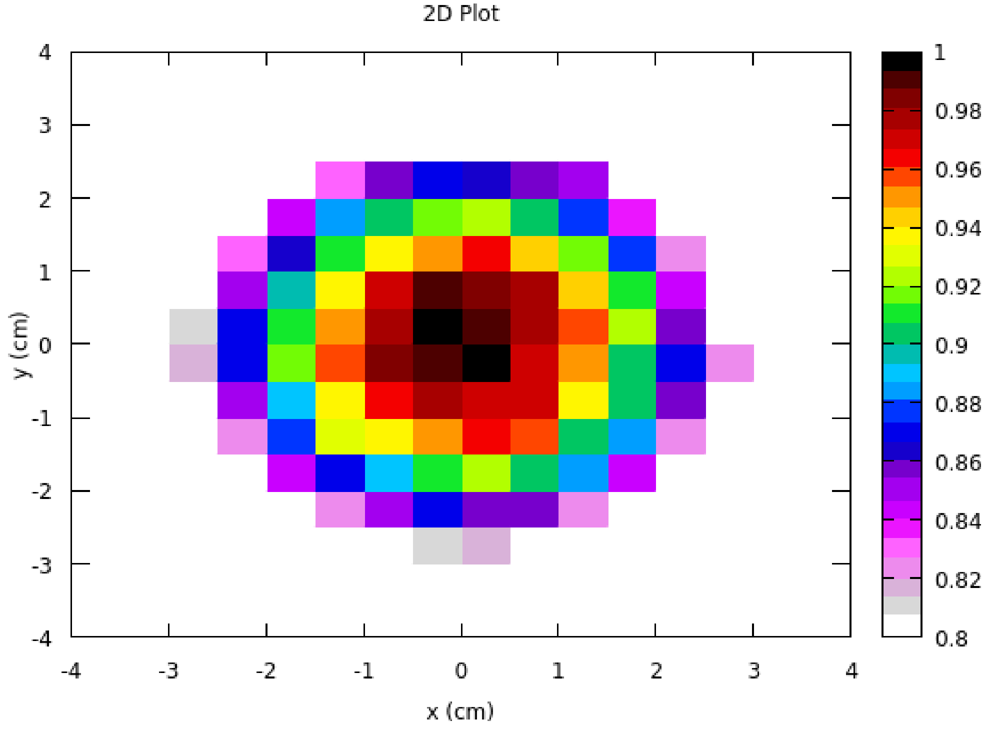
Req. 2.3.a: an irradiation area with a size tunable from 2 by 2 cm to 20 by 20 cm shall be made available, with a step of 2 cm and a +/-10% uniformity. Flux outside the irradiation area should be at least an order of magnitude lower.

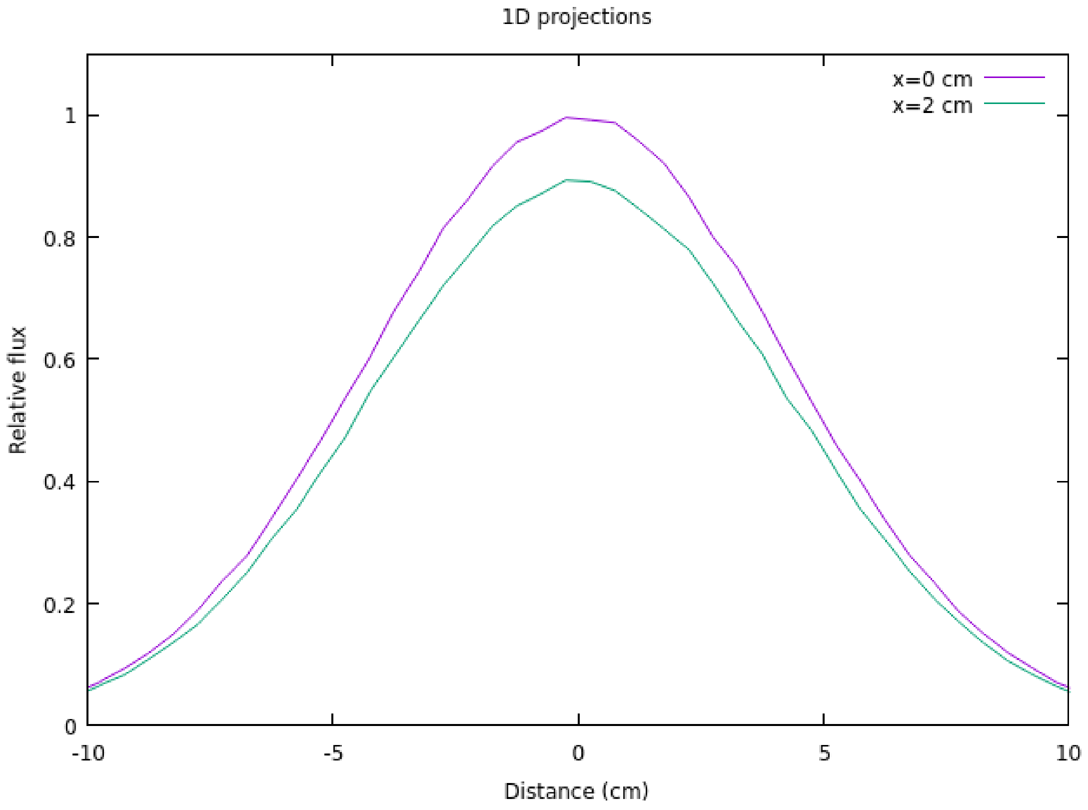
We generate our uniform, square surface from a Gaussian beam, therefore going beyond sizes of ~5 x 5 cm^2 with the current beam line configuration will be challenging

The flux outside of the irradiation area will actually be at least 3-4 orders of magnitude lower (to be seen if this is sufficient to have a low enough SEE rate on the peripheral electronics, i.e. active devices that are part of the test board, e.g. development kit, but that can be very radiation sensitive and compromise the execution of the beam)

Beam Size and Uniformity

BEAM Beam: Energy ▾ E: 1.0 Part: PROTON ▾
Δp: Flat ▾ Δp: Δϕ: Flat ▾ Δϕ:
Shape(X): Gauss ▾ x(FWHM): 10.0 Shape(Y): Gauss ▾ y(FWHM): 10.0





Beam Size and Uniformity

10 cm FWHM

BEAM Beam: Energy ▾ E: 1.0 Part: PROTON ▾
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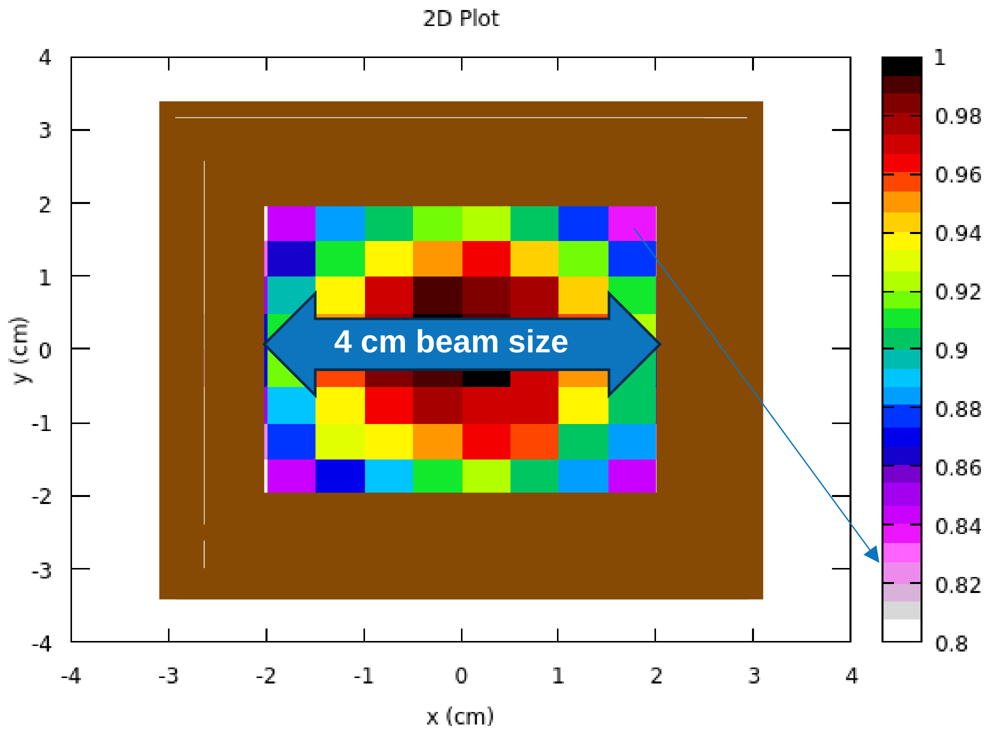

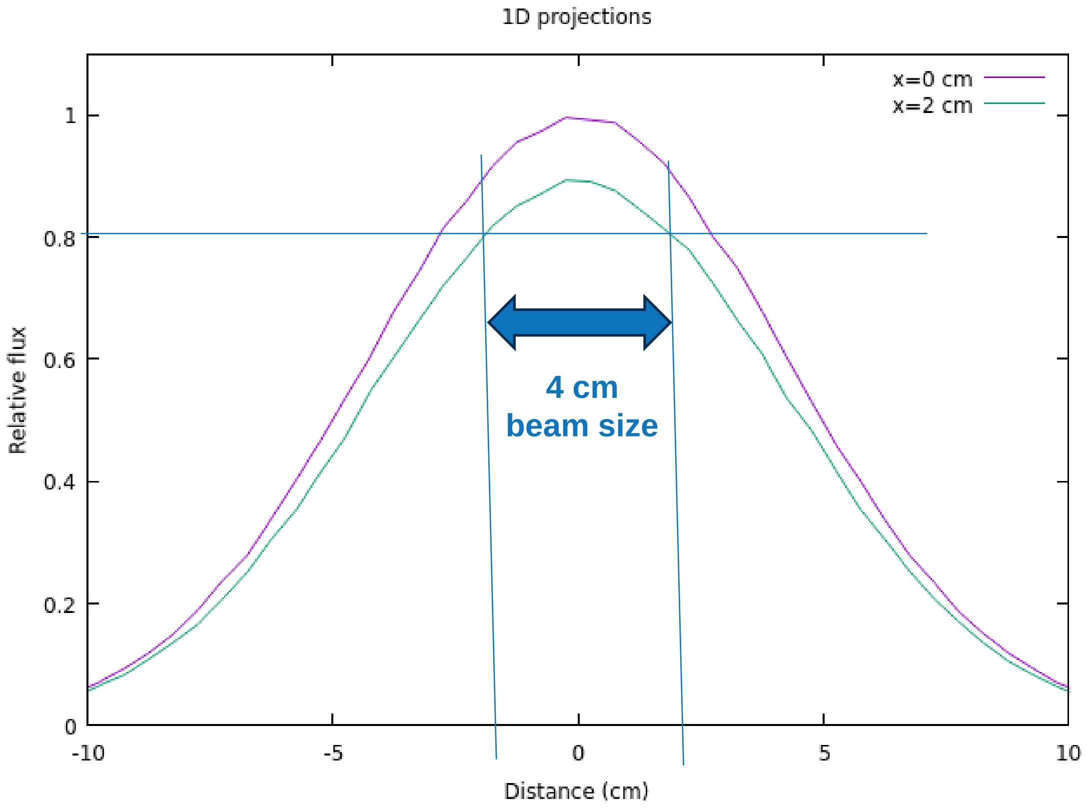

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Sample Holder and User Setup

Req. 2.4.a: a sample holder with a removable frame as compatible as possible with other irradiation facilities (see the following drawing) shall be used, in order to ensure maximum reuse of available hardware.

Req. 2.4.b: the sample holder shall make it possible to position each DUT on the test board accurately in the path of the beam, by providing movements along the X and Y axes.

Req. 2.4.c: rotation of the axis of the component with respect to the beam (along X and Y axis – commonly entitled as tilt and roll) shall be provided with an accuracy of 1 degree, since it allows users to characterize the device as a function of angle of beam incidence.

Req. 2.4.d: an automatic measurement of tilt/roll angle should be provided together with remote tilting/rolling monitoring capability from the control room.

Sample Holder and User Setup

https://edms.cern.ch/document/3153280

Preliminary draft 08:04 20 August 2024

20 August 2024
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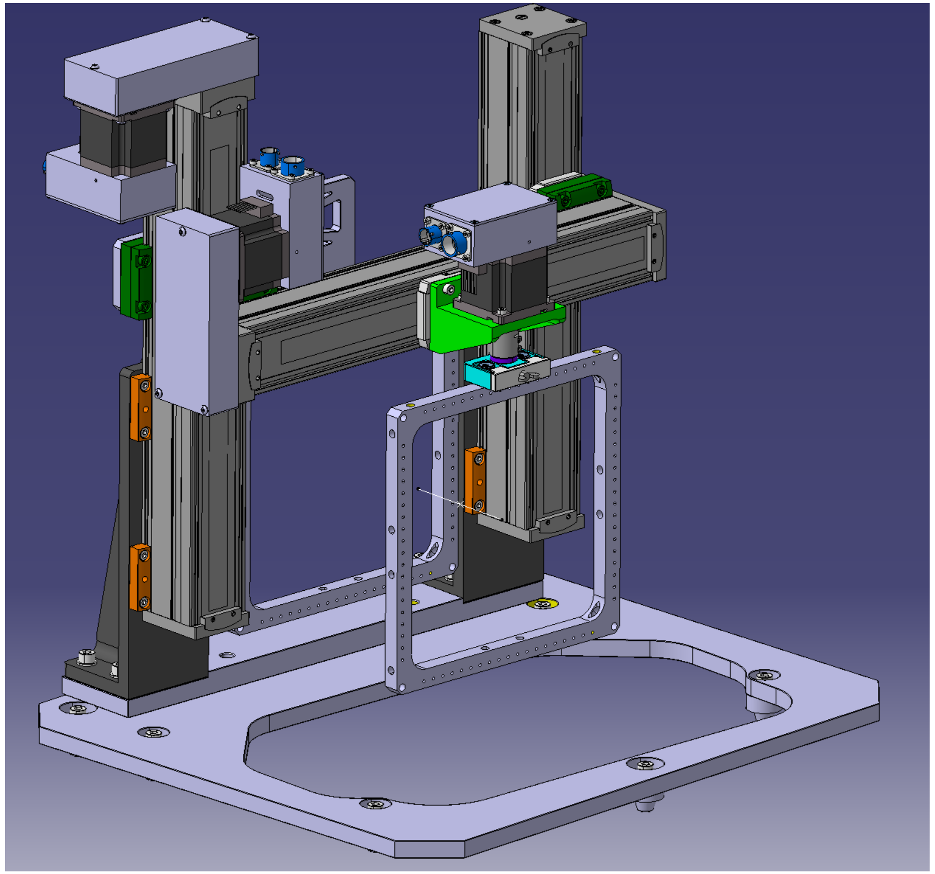
HEARTS 2024 - Guidelines for external users to prepare and execute a heavy ion test at IRRAD facility

N. Emriskova on behalf of HEARTS WP7
CERN, CH-1211 Geneva, Switzerland
CERN EDMS document number: 3153280 (v0.5)

Keywords: CERN, East Area, IRRAD, Very-high energy heavy ions, electronics testing, radiation test, integration

Summary

This document introduces the external users to the HEARTS heavy ion activity at CERN and to the IRRAD irradiation facility, where the associated radiation tests of electronics with very high energy heavy ions take place. It describes all the important features of the facility, as well as the formalities to do before and upon arrival to CERN for a test. It gives guidelines on how to use the facility in agreement with the existing safety and operational procedures and how to prepare and execute a radiation test at the facility.



Sample Holder and User Setup

Contents

Sample Holder and User Setup

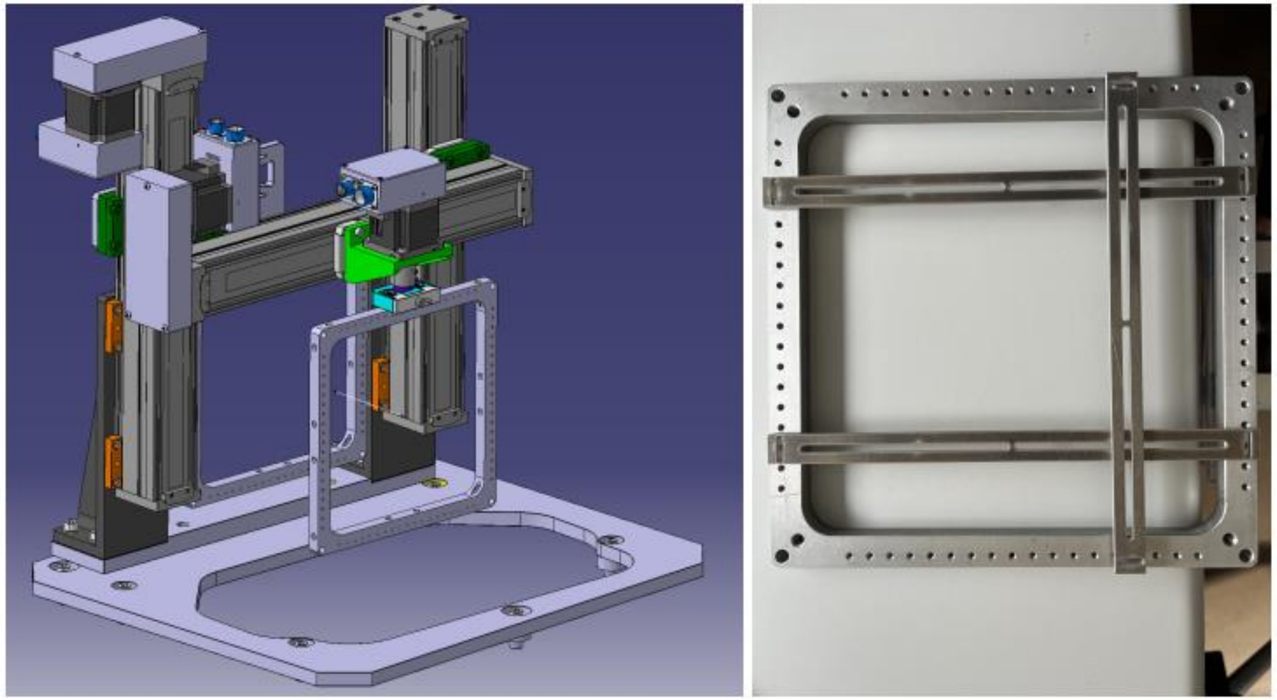


Figure 14: 3D design of the new IRRAD target station for heavy ion irradiations (left) and photo of the support frame with additional support rails (right).

Sample Holder and User Setup

Req. 2.4.e: Users expect to perform their tests in air. Users shall be able to use either of the following two testing systems:

1. a self-contained system residing fully in the ion beam cave or
2. a split system with a portion of the test equipment residing in the user control room and cables running to a test board in the cave.

The self-contained unit increases interface speed and simplicity and reduces parasitic capacitances and resistances from long cabling. Test setups with a portion in the control room are advantageous in some respects, as they can be modified without need for time-consuming entries to the beam cave.

Req. 2.4.f: the facility should provide a suitable space to install the instruments needed for the SEE measurement, both in the irradiation and in the control room.

Req. 2.4.g: Patch panels with connections from the control room to the DUT position, including at least BNC, SMA, Ethernet and USB shall be made available.

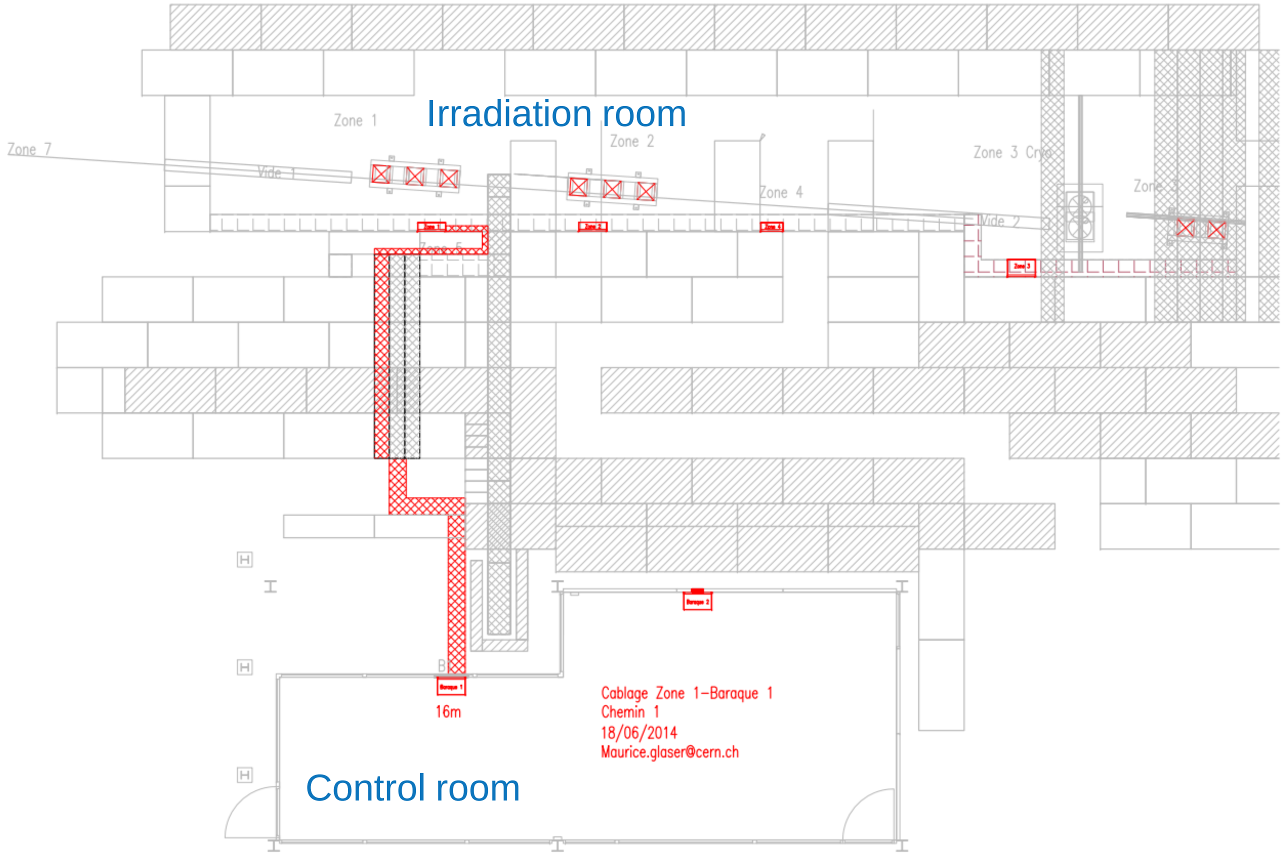
Req. 2.4.h: a camera with a laser pointing system to visualize the position of the beam shall be available.

Req. 2.4.i: an audio connection between the user area in the control room and the beam line shall be provided to quickly setup the system.

Req. 2.4.j: compressed air and cooling water shall be provided for board testing or when devices with large power consumption are tested.

Req. 2.4.k: access to the experimental cave shall be possible within 10 minutes after stopping the beam.

Sample Holder and User Setup



Sample Holder and User Setup

Req. 2.4.e: available space and support element for test setup within irradiation cave

Sample Holder and User Setup

Req. 2.4.f: control room setup installation

Sample Holder and User Setup

https://ps-irrad.web.cern.ch/ps-irrad/cabling.php

Req. 2.4.g: cable patch panels

Cabling infrastructure

Zone 1

Control room patch panel view

Sockets

Summary of Sockets/Cables
link to specs
link to specs

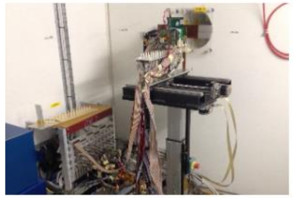
Cables

Link to specs
Link to specs
Link to specs

Distance

Distance from Counting Room to Zone 1

Zone 2



Control room patch panel view

Sockets

as Zone 1 + SHV
link to specs
link to specs

Cables

Link to specs
Link to specs
Link to specs

Distance

Distance from Counting Room to Zone 2

Zone 3

Control room patch panel view

Sockets

as Zone 1 + SHV + HF
link to specs
link to specs

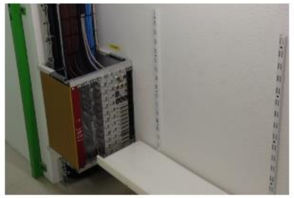
Cables

Link to specs
Link to specs
Link to specs

Distance

Distance from Counting Room to Zone 3

Zone 4



Control room patch panel view

Sockets

as Zone 1
link to specs
link to specs

Cables

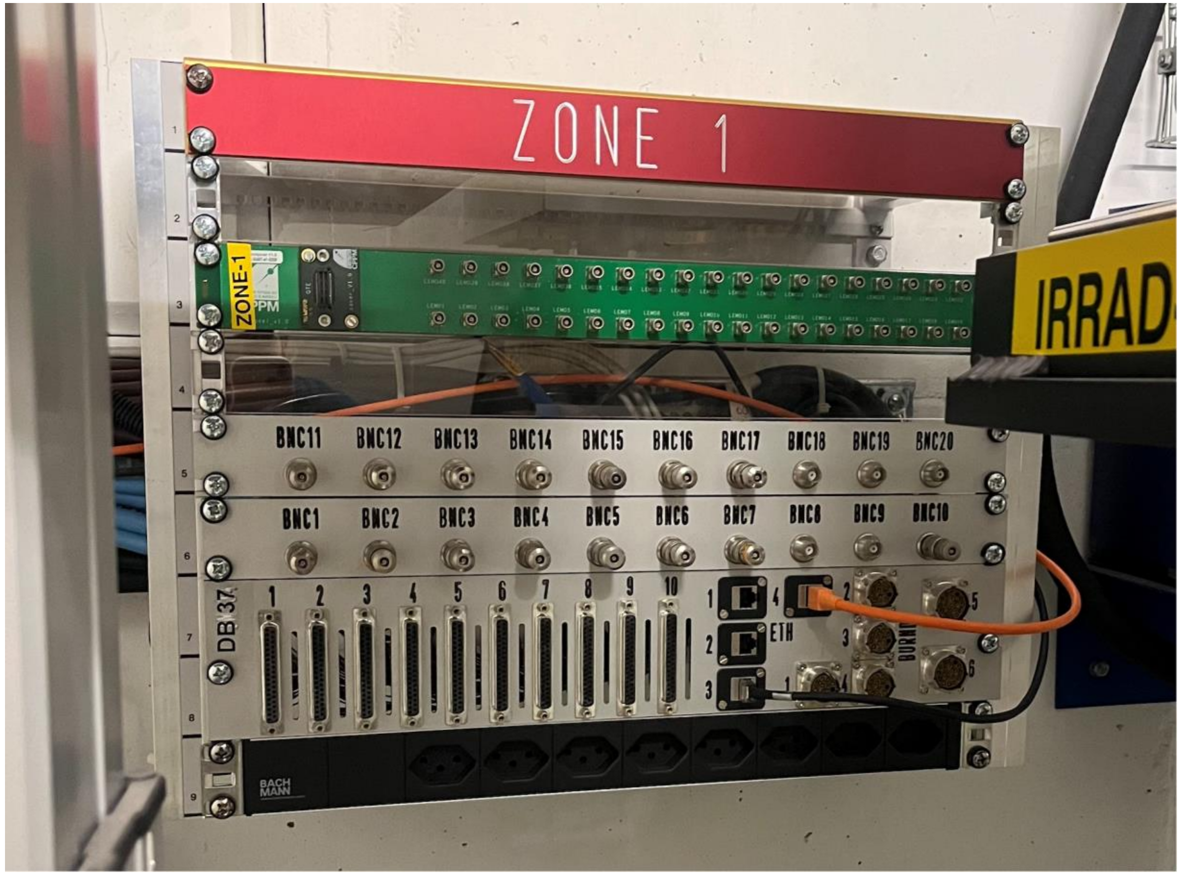
Link to specs
Link to specs
Link to specs

Distance

Distance from Counting Room to Zone 4

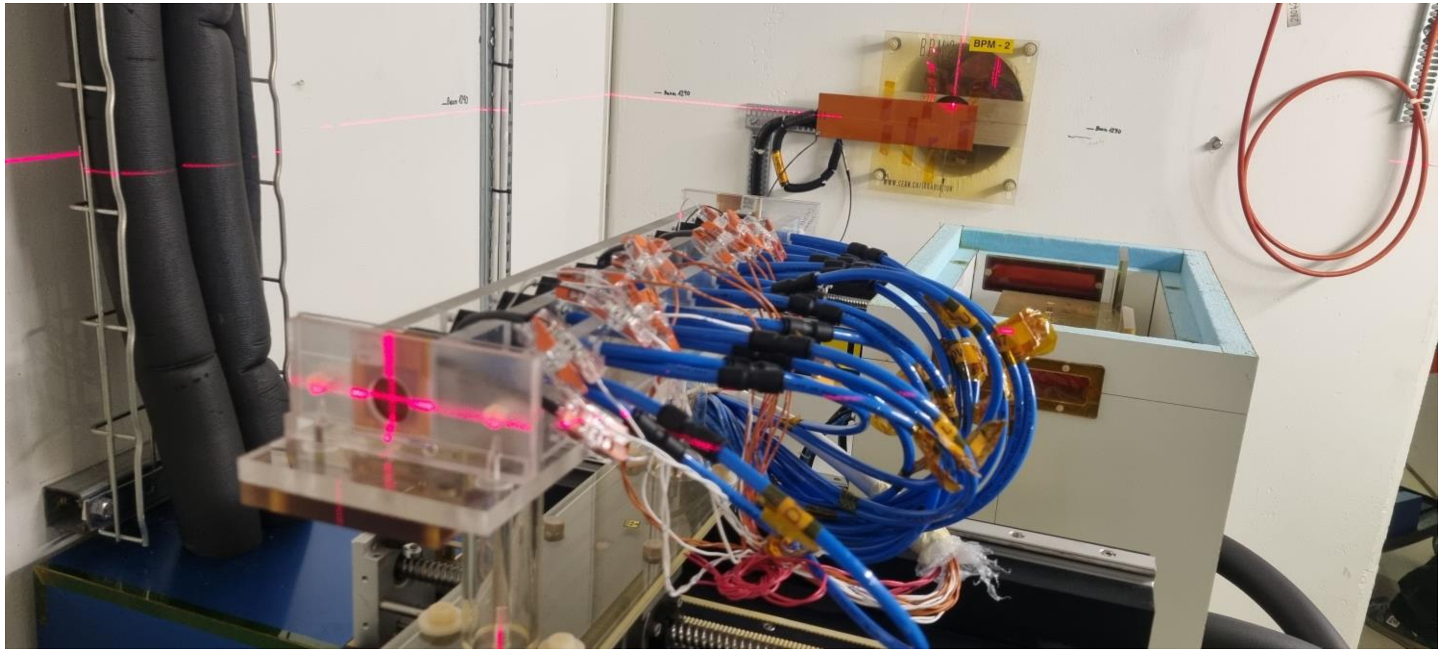
Sample Holder and User Setup

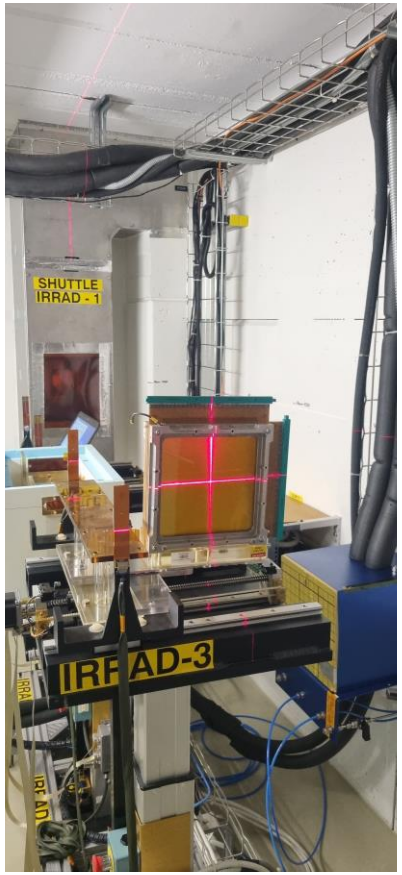
Req. 2.4.g: patch panels



Sample Holder and User Setup

Req. 2.4.h: laser alignment





Sample Holder and User Setup

- **Req. 2.4.i:** CERN GSM phone to be used - there is GSM signal inside the bunker, and we have a “user” GSM phone that can be given to every user team during their test
- **Req. 2.4.j:** compressed air and natural gas are there available already. We have thermostatic boxes also in place with cooling fluid.
- **Req. 2.4.k:** Possible mainly thanks to change of air flushing time (30min for protons, 5min for ions), in compliance with Radiation Protection and Beams Department safety

Sample Holder and User Setup

https://cyclotron.tamu.edu/ref/heavy_ions.html

Hot Air Blower and IR Camera

A hot air blower is available for our guest to use to heat devices under test. The blower can be controlled locally at the unit or remotely from the data room.

A FLIR IR camera is also available for use. A software driven control system has been developed for use with both the hot air blower and the IR camera.

You can download the user guides here:

Hot Air Blower User Manual
FLIR IR Camera Software Manual

A video demonstration can be viewed here:

Hot Air Blower Demo Video

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Recommendations from Annual Meeting technical review

- Implementation of a specialized holder capable of precisely **tilting the component** under test by 50-60 degrees relative to the beam axis, hence increasing the related LET → designed, manufactured and ready for installation and utilization during the 2024 HEARTS@CERN run (but, of course, not everyone "believes" in effective LET 😉)
- Development of a **user-friendly tool for calculating the incident LET** based on the component's material composition and beam path, so to empower users to estimate the appropriate LET for their specific needs → incorporation of lead in NSRL tool (see previous slides)
- Acknowledgement of LET limitations for VHE ions, especially due to **fragmentation**, which is not accounted for in conventionally used tools like SRIM, and careful assessment of its validity as radiation effects testing figure-of-merit → substantial progress in the experimental and simulated analysis of fragmentation and its impact on Single Event Effects testing has been achieved, as presented during the NSREC 2024 conference
- Production of detailed **documentation of the beam characteristics** and energy deposition metrics for each beam configuration in order to guarantee full traceability of the obtained results → the beams used for SEE testing during the 2023 run have been carefully analyzed (both experimentally and through simulation) and characterized, notably though their energy and LET distributions, confirming that configurations used for SEE data taking in 2023 can be considered as mono-LET beams (i.e. with the guarantee that the relevant SEEs are clearly dominated by the primary beam [within a ±10% LET acceptance] and not its secondary particles, or primary particles with larger LET variations).

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User Management

- Ongoing:
  - User registration and computing account generation
  - Agreement signature
  - Online training (plus on-site, likely to be done right before campaign)
  - Technical preparation meetings
  - Shipment logistics

Experiment Preparation Form

HEARTS@CERN Experiment preparation form

Dear User(s),

Please, complete this form as part of the preparation for you HEARTS @ CERN high-energy heavy ion beam campaign for radiation effects testing and help us to better schedule and organize your radiation test.

Disclaimer: Please note that the 2024 HEARTS @ CERN ion beam time proposed to users is a pilot run. As such, despite our best efforts to provide high-quality beam time, it may experience deviations from the requirements and suboptimal operational conditions due to the lack of experience. We appreciate your understanding in relation to this point. Of course, any beam time not compliant with the requirements will not be charged for.

HEARTS @ CERN Experiment preparation form 2024

2. Beam characteristics

Please refer to the HEARTS in IRRAD user guide to fill up the following info

Ion species	$^{82+}$**Pb**
Estimated beam time *(min. 8h)*	hours
Estimated number of runs	
Estimated fluence per run *(multiple values if applicable)*	ions/cm^2
Estimated flux per run *(multiple values if applicable)*	ions/cm^2/spill

Surface LETs (and corresponding range in Si)

☐ 12 MeVcm^2/mg (50 mm) ☐ 27 MeVcm^2/mg (3.5 mm)
☐ 17 MeVcm^2/mg (14.5 mm) ☐ 32 MeVcm^2/mg (2.3 mm)
☐ 22 MeVcm^2/mg (6.0 mm) ☐ 37 MeVcm^2/mg (1.5 mm)
☐ *Other

** If you need an LET not available in the default menu, but in between these values, please select 'other' and provide the desired value, the HEARTS team will investigate if it can be provided or not.*

Beam size

☐ 2.5 × 2.5 cm^2 ☐ 5 × 5 cm^2 ☐ 7.5 × 7.5 cm^2 ☐ *Other

** Please chose from the proposed irradiation areas, the option 'other' may be used to submit a proposal for a different irradiation area to the HEARTS team, which will be evaluated but not necessarily granted.*

Shielding

Is it critical for your test to thoroughly shield from the beam the area immediately surrounding the irradiation area (e.g. components on the same board, but outside the irradiation window) ?
☐ yes / ☐ no

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Facility Access Agreement

ORGANISATION EUROPEENNE POUR LA RECHERCHE NUCLEAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

AGREEMENT
For use of the HEARTS@CERN Facility
KRxxxx

Company: [Name to be specified]

ARTICLE 1	SCOPE OF THE AGREEMENT
ARTICLE 2	ACCESS MODALITIES
ARTICLE 3	PARTNER PERSONNEL
ARTICLE 4	SAFETY OBLIGATIONS
ARTICLE 5	FINANCIAL CONDITIONS
ARTICLE 6	CONFIDENTIALITY
ARTICLE 7	INTELLECTUAL PROPERTY
ARTICLE 8	LIABILITY AND WARRANTIES
ARTICLE 9	DURATION
ARTICLE 10	TERMINATION
ARTICLE 11	GOVERNING LAW
ARTICLE 12	AMENDMENTS
ARTICLE 13	CORRESPONDENCE AND REPRESENTATION
ARTICLE 14	COMMUNICATION AND PUBLICATIONS

User Overview

- Three HEARTS users: Padova University, Airbus, Tesat
- One RADNEXT user: SpacePNT (Switzerland)
- 6x industrial users, fully external
  - 2x Germany
  - Italy
  - UK
  - US
  - Japan

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Summary

- The main current objective is clearly a successful **HEARTS@CERN 2024 pilot user run**
- From an **access formality** point of view, things are progressing, and we do not have any identified showstoppers (still needs to be fully completed, however)
- From a **practical test execution** perspective, we will need to see how efficient the typical workflow is (setup installation, further accesses, beam control and monitoring, changes of beam LET, size and flux, etc.)
- From a beam preparation and performance point of view:
  - Beam commissioning is ongoing, in a staged approach (and requiring combination of operator availability and T8 “opportunity window” for ion propagation)
  - Beam characterization and calibration will follow
  - Some identified challenges:
    - **Lower energy limit** for high-flux beam propagation (remember, the lower the PS energy, the higher the LET value, as degraders alone have limitations) → objective for 2024 is 37 $MeVcm^2/mg$, with the main challenge of flux limitation (if successful, higher LET values could be of interest)
    - Limit on homogeneous **beam size** that can be achieved → objective for 2024 is 7.5 x 7.5 cm^2 and, from initial commissioning efforts, we are not far, but not quite there (yet)

Thank you for your attention. Questions?

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.

HEARTS