CHIMERA (CHARM High-energy Ions for MicroElectronics Reliability Assurance) status and outlook

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CHIMERA project acknowledgements

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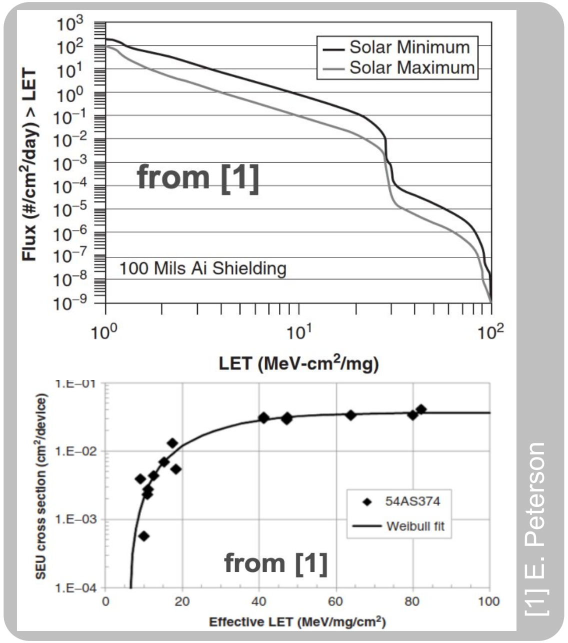
Outline of presentation

- Motivation for CHIMERA
- CHIMERA objectives
  - Requirements in terms of beam parameters
  - Infrastructure upgrades in PS East Area/CHARM
- Accumulated experience
  - LHC Run 2
  - Ion runs in November 2021
- Way forward
- Conclusion

Motivation for CHIMERA (1)

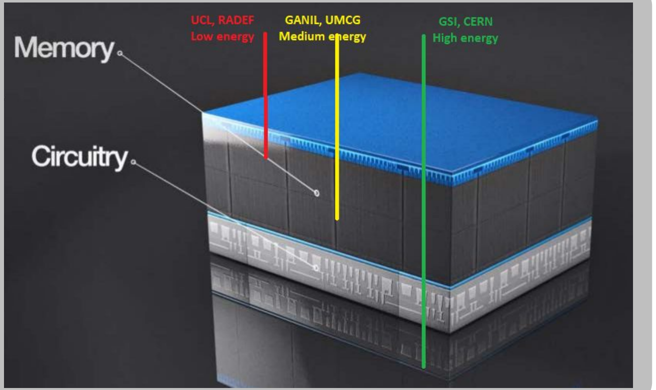
- Radiation effects on electronics are an important **engineering constraint** for critical (high reliability and availability) applications in which electronics operates in radiation environments. Stochastic interactions of energetic particles with electronics can cause **Single Event Effect (SEE)** errors (as opposed to cumulative damage) which impact component availability and reliability
    - In **space**: harsh radiation environment combined with high reliability requirements (top right)
    - In **accelerator** environments: instrumentation subject to mixed radiation field conditions
    - Other: avionics, automotive, critical IT, quantum computing applications

- **Key ingredient to radiation hardness assurance (RHA) is testing**
    - Electronics components of interest exist in a broad range and have evolved drastically, requiring extensive qualification before deployment (**COTS** components)
    - In testing, the SEE probability (or cross section) is extracted as function of the deposited energy or **LET** (linear energy transfer, bottom right)
    - This type of testing relies on the use of **heavy ions** (with a high LET)



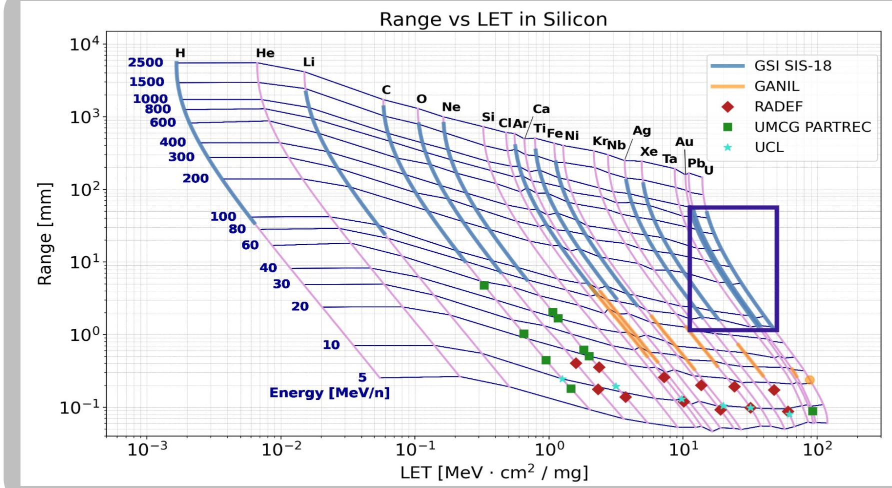
Motivation for CHIMERA (2)

State-of-the-art microelectronics has evolved to 3D structures. **High energy (>100 MeV/n), heavy ions** are needed for testing because of their large penetration depth.



Adapted from [2]

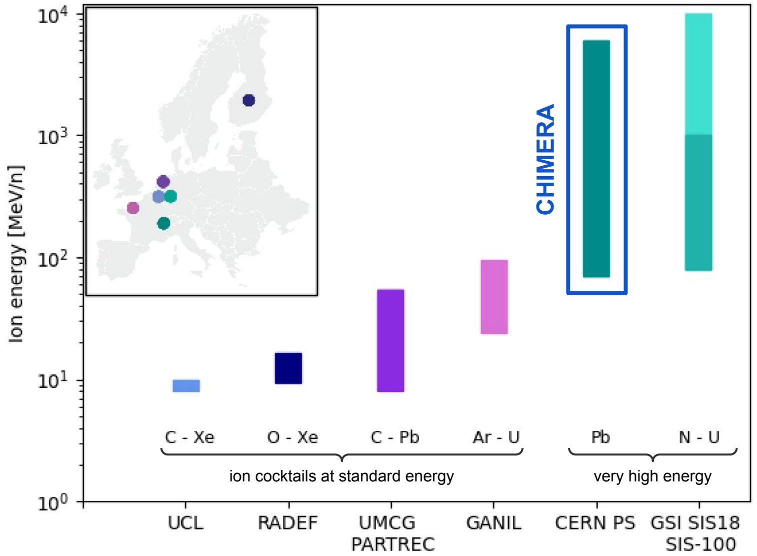
CHIMERA offers a "**sweet spot**" (blue rectangle) solution to physical trade-off: **high LET** (> 30 MeVcm^2/mg) and **high range** (>1 mm) in the CHARM facility in the PS East Area



G. Lerner using SRIM data [3]

The CHIMERA project aims at providing high energy (100 MeV - 1 GeV/n) heavy ions (Pb) to the CHARM facility for electronics irradiation testing. These beams will probe an interesting LET range combined with a high penetration depth in state-of-the-art electronics.

Motivation for CHIMERA (3)

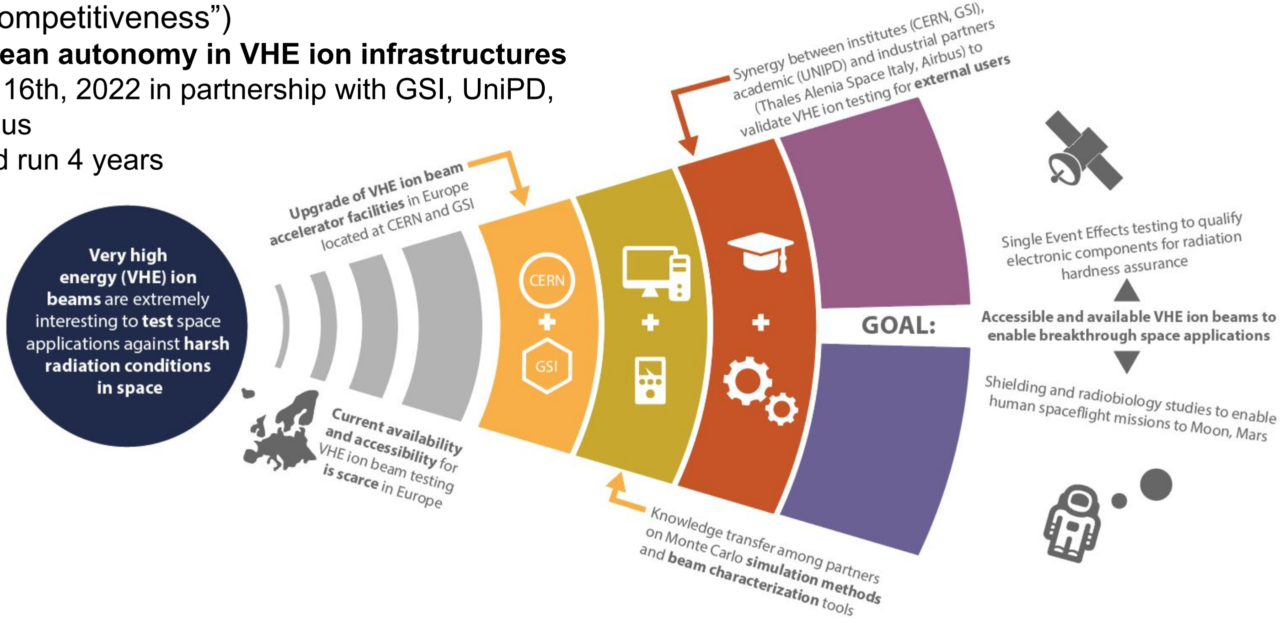


- The **current availability** of very high energy (VHE), heavy ion beams **is scarce**, even though there is a great interest
  - Dedicated facilities exist in other continents (NSRL in US as reference in space radiation research) but access is limited/expensive
  - European facilities operate mostly in standard energy range (cyclotrons), access to VHE ion facility at GSI is very limited
- Activity driven by collaboration agreement between CERN and ESA on key priorities, including high-penetration, heavy ion tests to assess EEE components and modules (COTS)
- **Contracts with ESA for CHIMERA funding** + funding through ESA's Open Science Innovation Platform
- Project benefits from collaboration with space community partners (e.g. CNES, Airbus, TAS, through RADSAGA/RADNEXT EU projects, etc.)

Motivation for CHIMERA (4)

HEARTS (High Energy Accelerators for Radiation effects Testing and Shielding) is a proposal for EU Commission funding of the CHIMERA activity answering specific Horizon Europe call ("Space technologies for European non-dependence and competitiveness")

- In particular: **increase European autonomy in VHE ion infrastructures**
- Proposal submitted February 16th, 2022 in partnership with GSI, UniPD, Thales Alenia Space and Airbus
- If successful the project would run 4 years



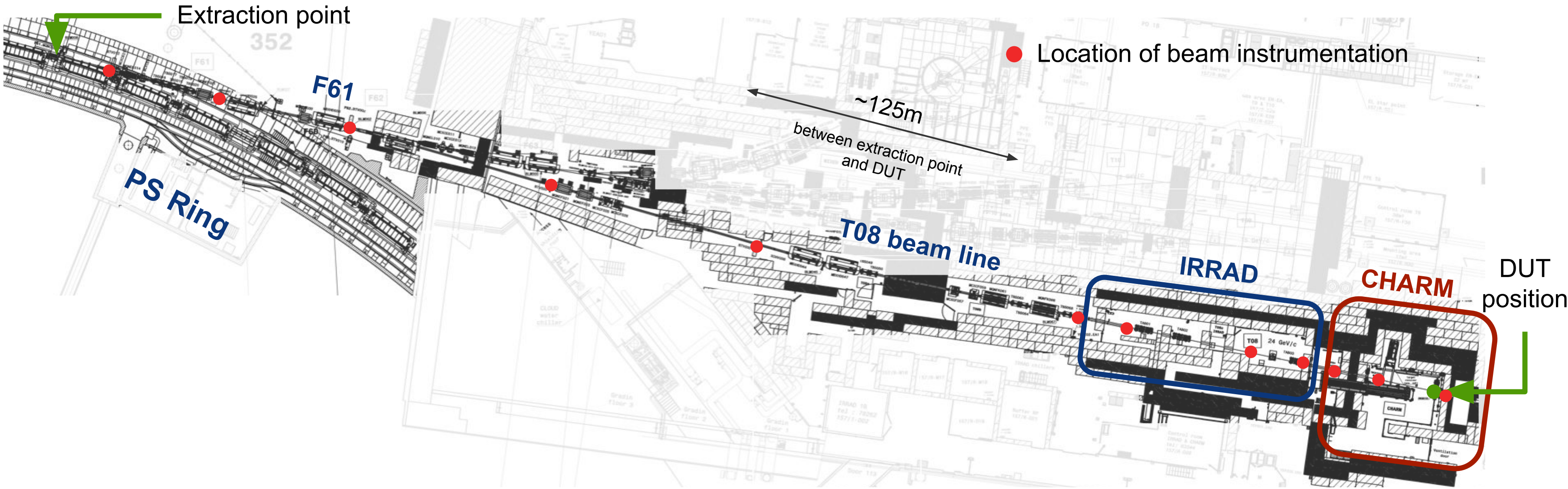
Requirements and goals

Upgrades are needed in the CHARM facility and beam line in the PS East Area to render infrastructure suitable for space electronics qualification using high-energy, high-penetration ions:

- Possibility of tuning **ion energy** in the “high LET variability” range
  - **70 MeV/n - 2 GeV/n**
  - Lower extraction energy from the PS, and/or a degrader system
- Possibility of tuning the **ion flux** in a large dynamic range with ± 10% uncertainty
  - **10^2 - 10^5 ions/cm^2/s**
  - Reduced ion extraction intensity and (mainly) collimation system
- Possibility of tuning the **beam size** for board level testing
  - up to **~ 20 x 20 cm^2**
  - Optimisation of beamline optics (and collimator)

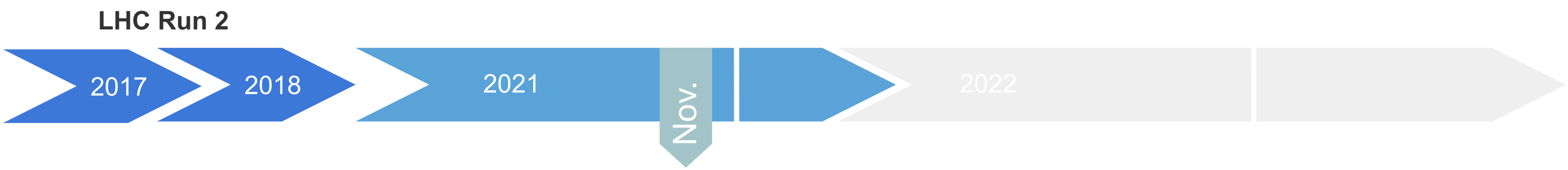
- Possibility to achieve an operation mode that is compatible with the rest of CERN’s physics programme, the other users of the PS, East Area and T08 beam line users (i.e. IRRAD).

PS East Area infrastructure



- (Re-)**installation of beam line instrumentation** (beam screens, secondary emission chambers, ionization chambers, beam current transformers, multi-wire proportional chamber) for proper characterization of ion beams during commissioning and operation [5].
- Investigation of using Si diode for **dosimetry** purposes is underway, providing real time beam info to users
- Cabling request made to install **scintillator** at DUT location to characterize beam (fragments, intensity)

Timeline (until today)



A variety of irradiation experiments were performed during the ion runs in 2017 (xenon) and 2018 (**lead**), both in the East Area and North Area:

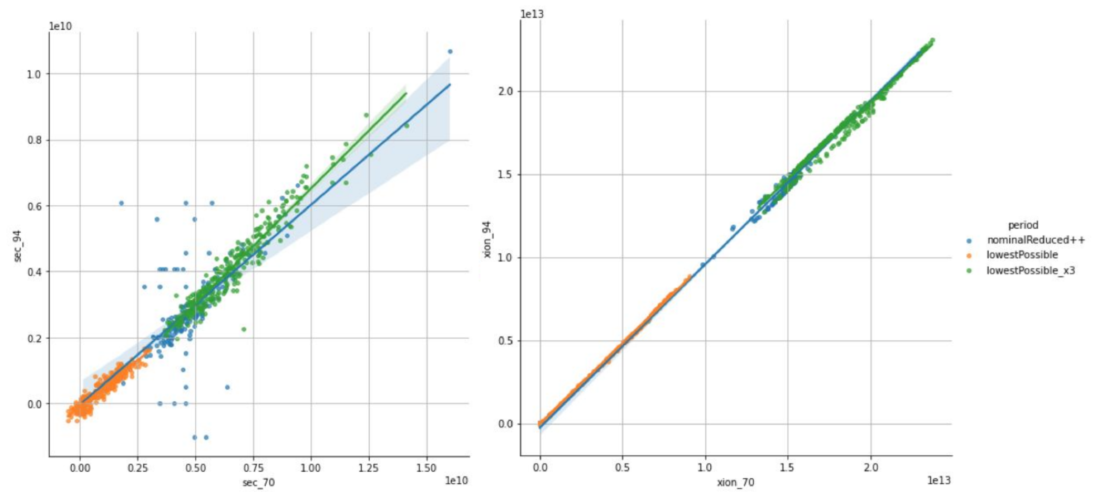
- Improved understanding of beam-electronics interactions at very and ultra high energies
- **Strong motivation of future exploitation** in a more systematic and user-oriented fashion.
- **Limitations**: relying on non-adequate beam instrumentation, constant ion energy, flux

Ion operation in PS and PS East Area in **November 2021** has allowed a **significant improvement** in understanding how to operate the infrastructure with ions **at top energy** (5.4 GeV/n) through cooperation of different systems and groups at CERN:

- Slow extraction MDs have allowed to study extraction methods by tuning the PS optics (use of octupoles, empty bucket channeling [6]) and beam steering down to CHARM
- Using beam instrumentation and assessment of their adequacy:
  - timing and logging of data, saturation, ranges of gain, consistency between different devices,
  - intensity stability check

Ion run November 2021 (1)

XION: Argon ionization chamber
XSEC: secondary emission chamber

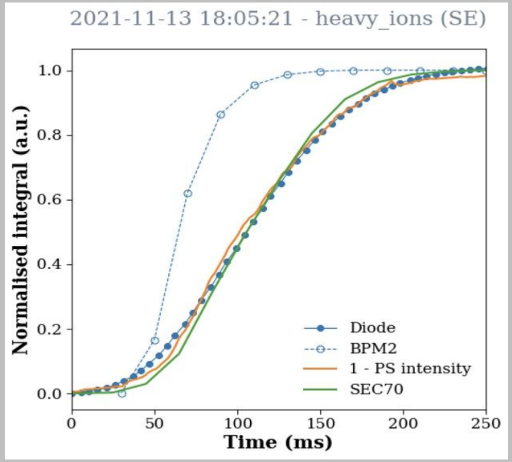


K. Bilko [8]

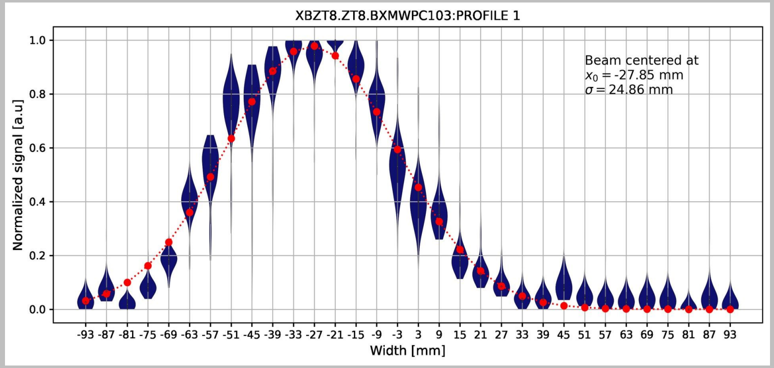
F. Roncarolo, M. Durrafourg

- **Very wide ion intensity range covered** (~10^6 – 10^9 ions/spill assuming 100% transmission)
- For the lowest achieved intensity (10^6 ions/spill)
  - there is a linear dependence between XIONs and XSECs (70&94)
- For higher intensities
  - there is a linear dependence between XIONs and XSECs themselves but not between XION and XSEC
  - to be further investigated through FLUKA/experimental assessments
- An absolute beam intensity calibration is possible with operational BCTs.

Ion run November 2021 (2)



See talk by N. Emriskova [8]



D. Prelipcean [9]

- **Si diode** deployed in IRRAD in close to the beam
  - In the long run: provide real-time dosimetry for users
  - Comparison of spill profiles to simulations to aid in analysis of bunched beams during MDs [P. Sota]
  - **Cross-check with SEC and PS intensity during extraction show excellent agreement**

- Multi-wire proportional chamber **(MWPC)** is located directly downstream of DUT position and can be used to check the beam position and size
  - Instrument operating mode and response need to be better understood for use in the future
  - In coordination with BI team to calibrate instrument for ions instead of protons

Requirements and goals (revisited)

Upgrades are needed in the CHARM facility and beam line in the PS East Area to render infrastructure suitable for space electronics qualification using high-energy, high-penetration ions:

- Possibility of tuning **ion energy** in the “high LET variability” range
  - **70 MeV/n - 2 GeV/n**
  - Can be achieved through a lower extraction energy from the PS, and/or a degrader system and/or a spectrometer
- Possibility of tuning the **ion flux** in a large dynamic range with ± 10% uncertainty
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  - Can be achieved through beamline optics (and collimator)

- Possibility to achieve an operation mode that is compatible with the rest of CERN’s physics programme, the other users of the PS, East Area and T08 beam line users (i.e. IRRAD).

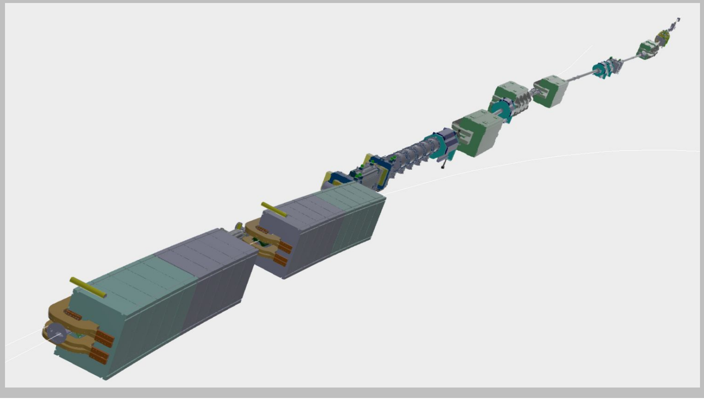
Extraction of Pb ion beams at PS top energy. ECR drafted to extend to lower energies while maintaining safe parallel operation with T9/10/11

Slow extraction at top energy and associated intensity reduction demonstrated, bringing T08 beam intensity within this range

Short periods of ion operation has already yielded a lot of information and experience

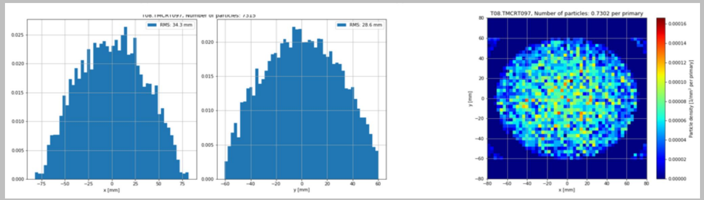
Way forward

- After accumulating invaluable experience, preparations for 2022 activities are underway
- In terms of **beam optics** in the PS and T08 beam line [M. Fraser, N. Charitonidis, E. Johnson, R. Taylor]
  - Improve understanding of optics parameters of extracted beam
  - PS main unit stray fields
  - **Repeat operation and measurements** to achieve experimental validation in 2022



D. Brethoux

- **FLUKA simulation study** campaign is ongoing
  - Beam parameters from tracking simulations are used as input
  - Detailed geometric model of all beam line elements
  - Beam characterization (beam energy and size at DUT, fragmentation,)
  - Instrument response (chambers & scintillator)
  - Collimator implementation



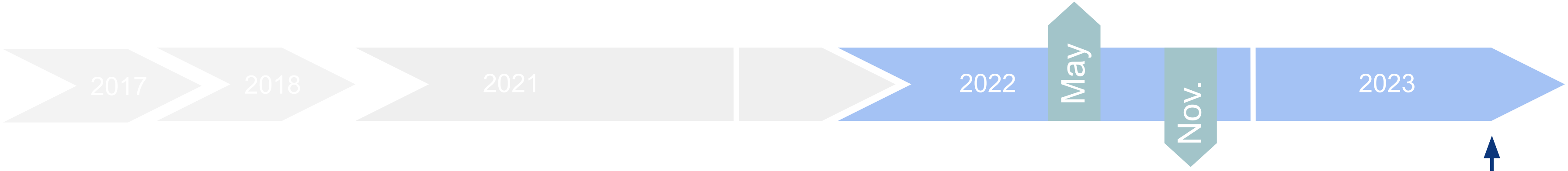
L. Esposito

- Further consolidate and expand internal/external support

Timeline (from today)

MD activities can happen as early as end of **May 2022**

- As soon as ions are set up in PS
- Reaching only F61 dump (occasional propagation down to T8/CHARM)



- **Two weeks of CHIMERA operation in November/December 2022**
    - First week dedicated to set up, commissioning and benchmarking activities
    - Second week open to external users, campaign coordinated with ESA

After the 4 years of project, if successful, the plan would be to **transition to a user facility operation, sustained mainly by external user contributions** (2-3 weeks of operation per year)

Conclusion

- **CHIMERA** is the CERN activity related to **very high-energy** (VHE, 100 MeV/n - 5 GeV/n) **ion irradiation of electronics** in the PS East Area, T8 beam line and CHARM facility.
- Initially motivated by the CERN-ESA collaboration, CHIMERA aims to accommodate testing of stat-of-the-art microelectronics with a **unique combination of high range and high LET** using VHE Pb ions (100 MeV/n - 5 GeV/n, 10^2 - 10^5 ions/cm$^{2/}$s, up to 20x20 cm^2 beam size).
- Building on heavy ion operation experience during Run 2:
  - Ion runs end of 2021 allowed familiarization with operating in the PS/T08/CHARM infrastructure and instrumentation - nominally suited for proton operation, expand capabilities to ions
  - Beam physics studies in PS and T08 + FLUKA simulation campaign to aid preparation of experimental activities later in 2022.
- **CHIMERA aims to provide VHE ion testing capability to external users on a regular basis and in a sustainable way in the future**.

Thank you for your attention!

References

[1] E. Petersen, *Single Event Effects in Aerospace*, Wiley IEEE Press (2011)
[2] As published on: https://www.eetimes.com/micron-leapfrogs-to-176-layer-3d-nand-flash-memory/ Image courtesy of Micron Technologies, Inc.
[3] J. F. Ziegler, *SRIM-2003,* Nucl. Instrum. Methods Phys. Res. B. 219-220
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[5] F. Ravotti et al., ECR PSZ-B-EC-0002 *New beam instrumentation for the EA-IRRAD facility on the T08 beam line*,
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[7] K. Bilko, *Beam intensity analysis*, CHIMERA (T8 ion beam) 2021 data, analysis and outlook for 2022: https://indico.cern.ch/event/1107452/
[8] N. Emriskova, *Diode measurements in IRRAD*, CHIMERA (T8 ion beam) 2021 data, analysis and outlook for 2022: https://indico.cern.ch/event/1107452/
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