MPW2 testing in the RBI Microbeams

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Sam Powell[e], *Eva Villella*[e]
[e]*University of Liverpool, United Kingdom*

HELSINKI INSTITUTE OF PHYSICS

https://indico.cern.ch/event/1029124/

Presentation

- Ion Microbeam testing of the MPW2 monolithic detector chip
  - Ion Microbeam Facility (Ruder Boskovic Institute, Zagreb, Croatia)
  - Description of an Ion Microbeam test
  - Single Event Effects in Memory Cells
  - Charge Collection Efficiency in Monolithic Detectors
  - Prospective

Disclaimer: The first testbeam was along past week, June 14th to 18th 2021
It is still work in progress

Description of an Ion Microbeam Experiment

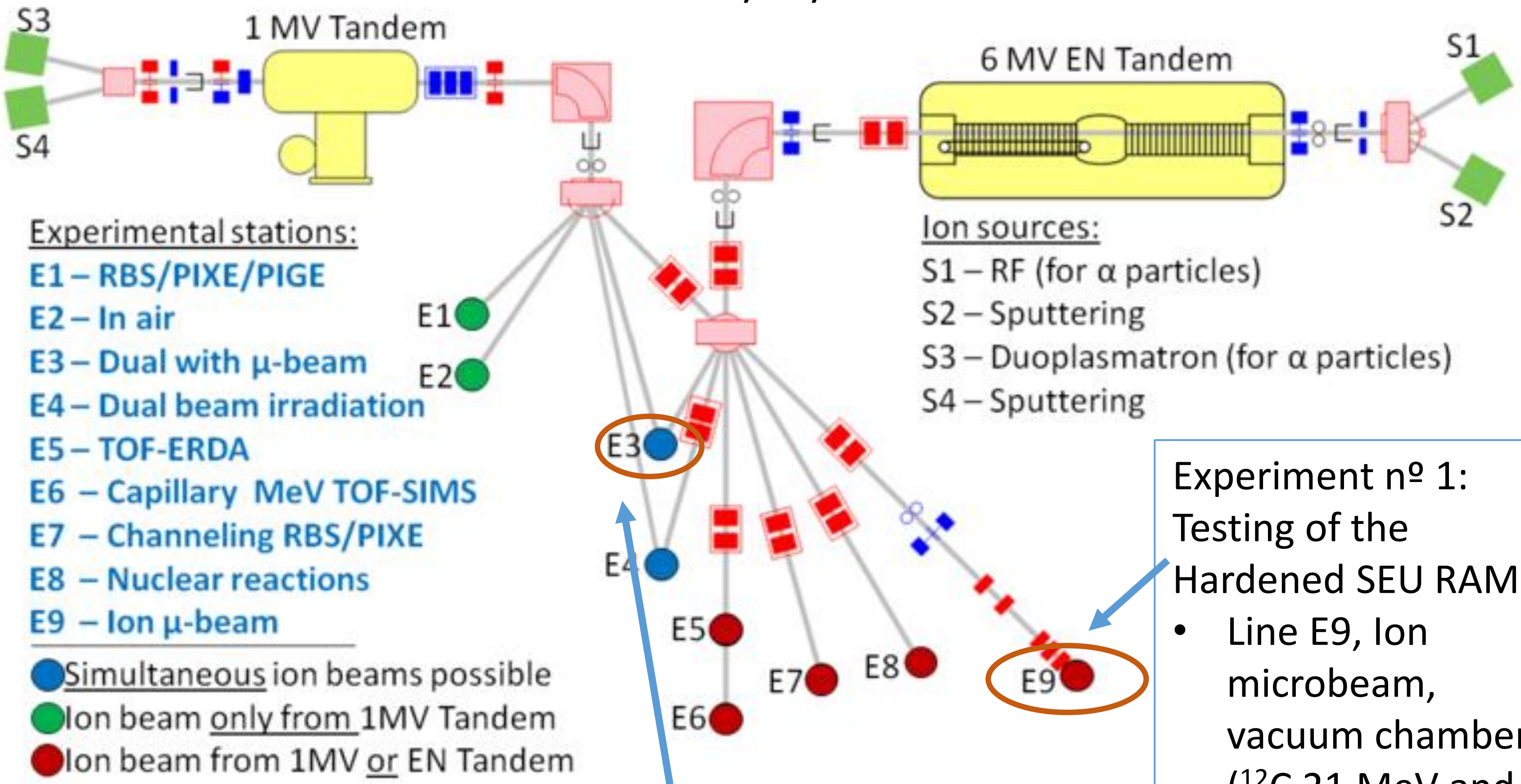
- An ion microbeam designates a low-medium energy hadron accelerator (1 -200 MeV), fixed target, with end station focusing capabilities (1-40 μm^2 tipically, even less)
- The beam can be defocused (up to a mm^2) or strongly focused by magnetic/electrostatic lenses.
- The flux is selectable from 100 ions/sec to more than 10E6 ions/sec
- The beam operates in fixed spot or in scanning modes (zig-zag, fan, etc).

Master equation:

E(MeV) =V(1+q)

where V is the accelerating voltage and q is the charge state of the ion. Ex. for protons, the RBI 6MV tandem accelerator gets a theoretical máximum of 7 MeV

RBI Facility Layout



Experiment nº 1: Testing of the Hardened SEU RAM.

- Line E9, Ion microbeam, vacuum chamber (^{12}C 21 MeV and others)

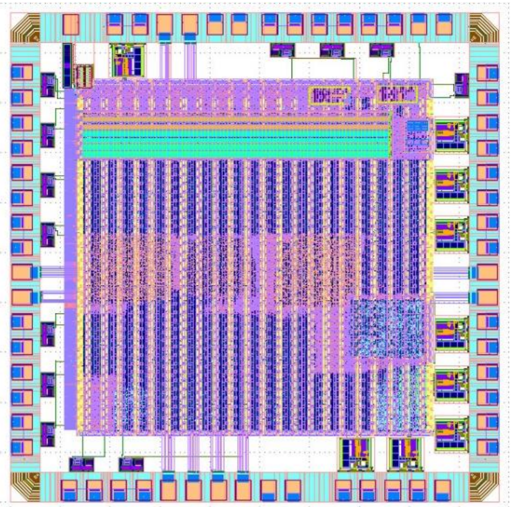
Experiment nº 2: Testing of the Pixel Matrix.

- Line E3, proton microbeam, in air (2 MeV)

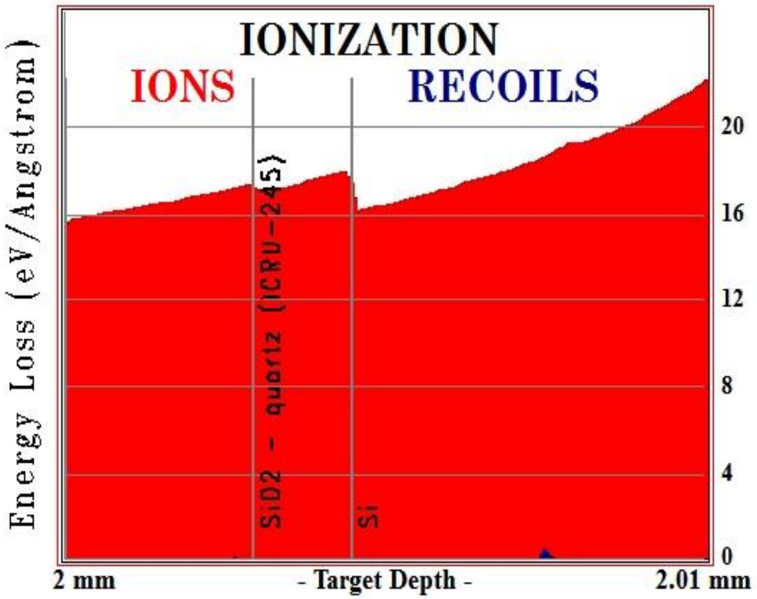
Ion Range in Target

For every target block we need to know:

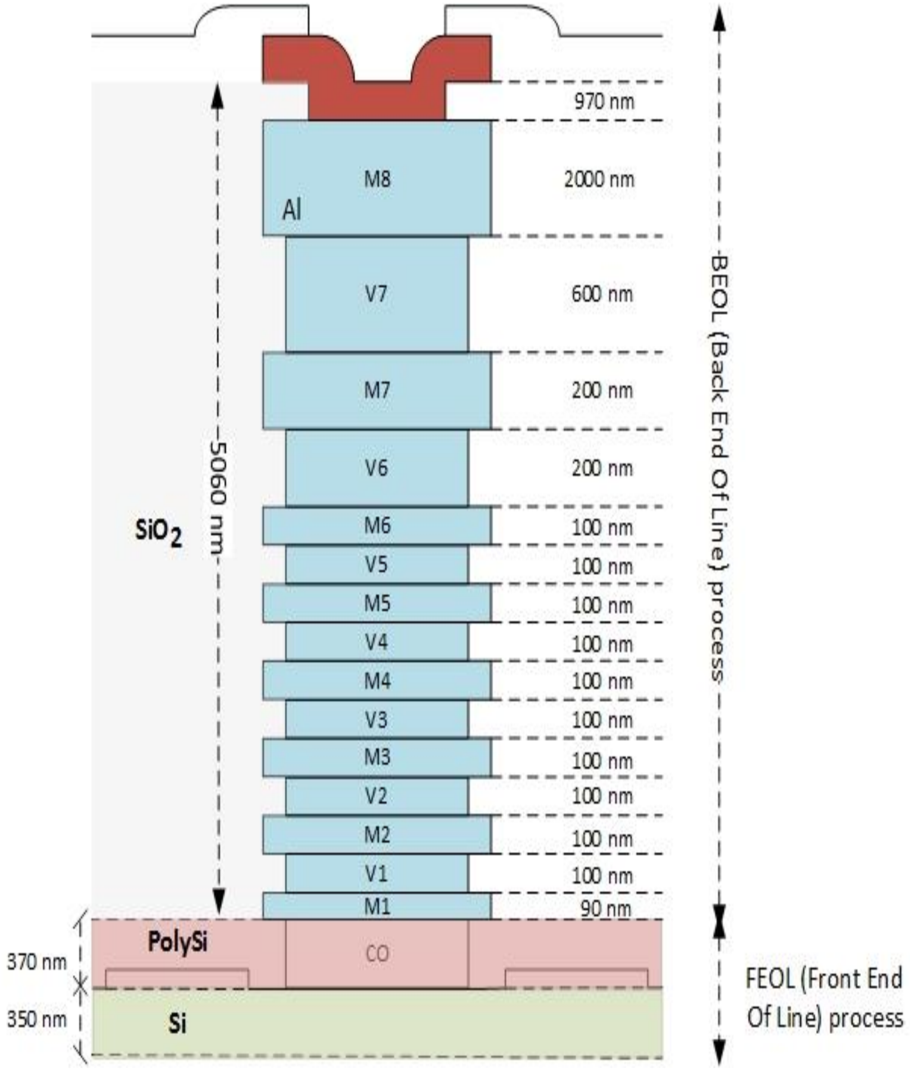
1. The set of (ions,energy) really available in the facility (accelerators are whimsical beasts)
2. Mapping the number of metallization and passivation layers really used in the target chip
3. The thickness and material of every layer (from Design Technology Kit documents, always under NDA)
4. A full set of Montecarlo simulations to predict range and LET in the active volumes (for SEE) or in the detector volumen (segmented detectors)



the chip is only an illustration



Classification of the different metallization layers for the ion range calculations

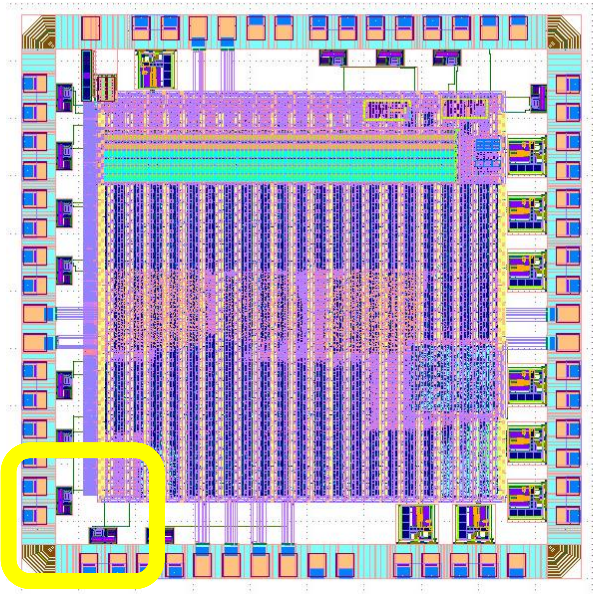


due to industry confidential reasons, the shown stack is only a representation, not the real Lfoundry 150nm one

Beam Targeting

Target Location means

1. Locating chip surface structures for XY coordinate frame determination, finding a coordinates origin and geographical waypoints for beam positioning.
2. Selecting the appropriate ion & energy set considering the cross-section of every target.
3. Coarse finding the XY positions by microscope optical inspection/local scintillation light (if possible)
4. Precise location of XY waypoints by Particle Induced X ray Emission (PIXE)



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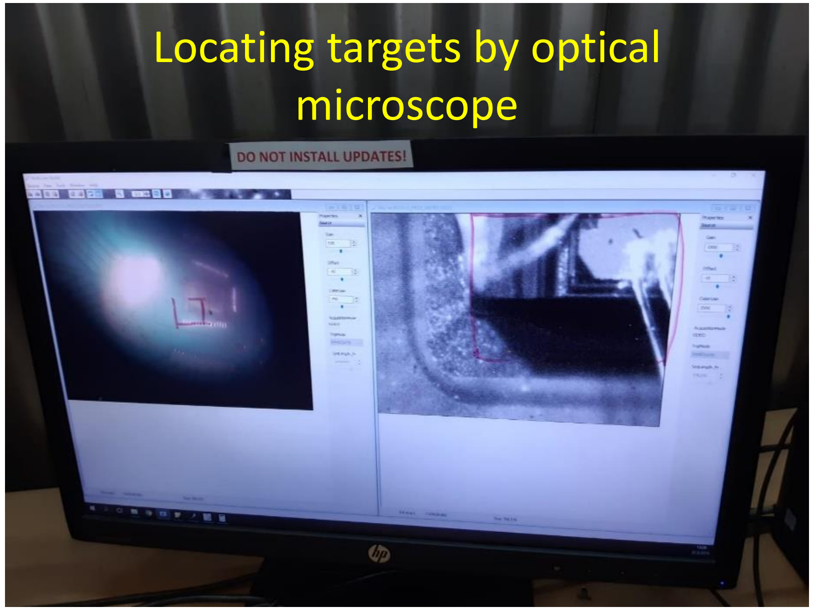
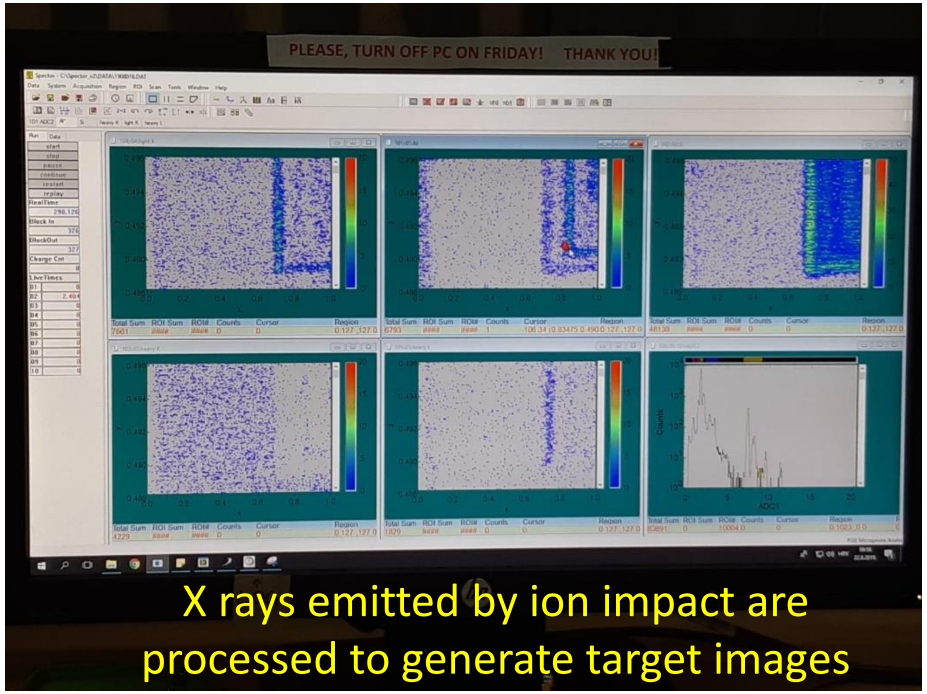




Testbeams #1 and #2

Testbeam #1

SEU Sensitivity Analysis

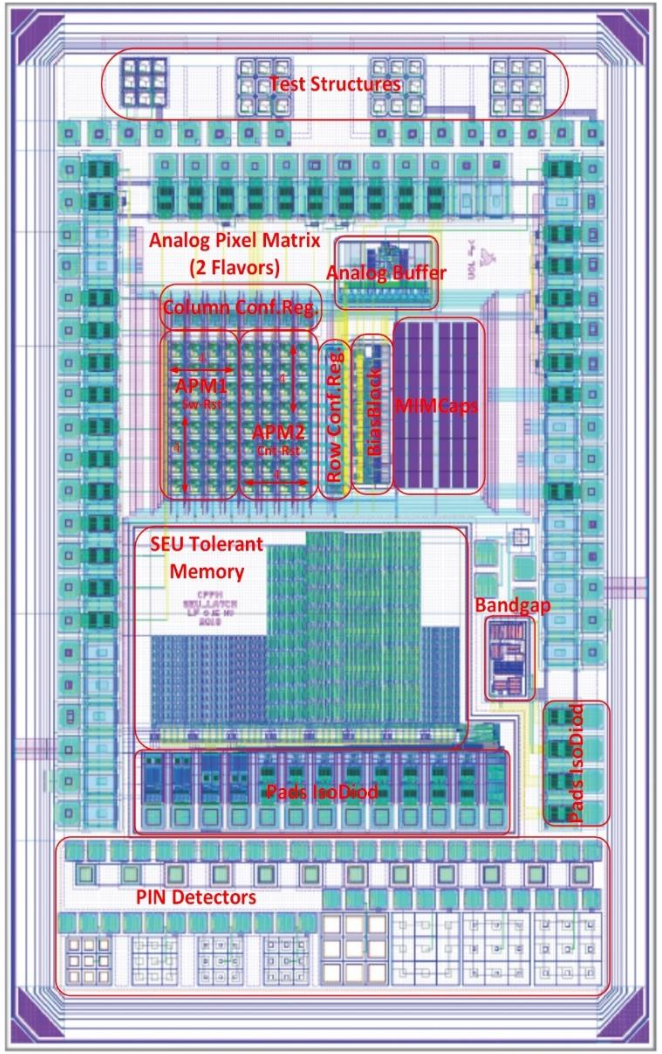
- We look for Single Event Upsets in the SEU tolerant memory cells. The objective is to have a SEU sensitivity map.

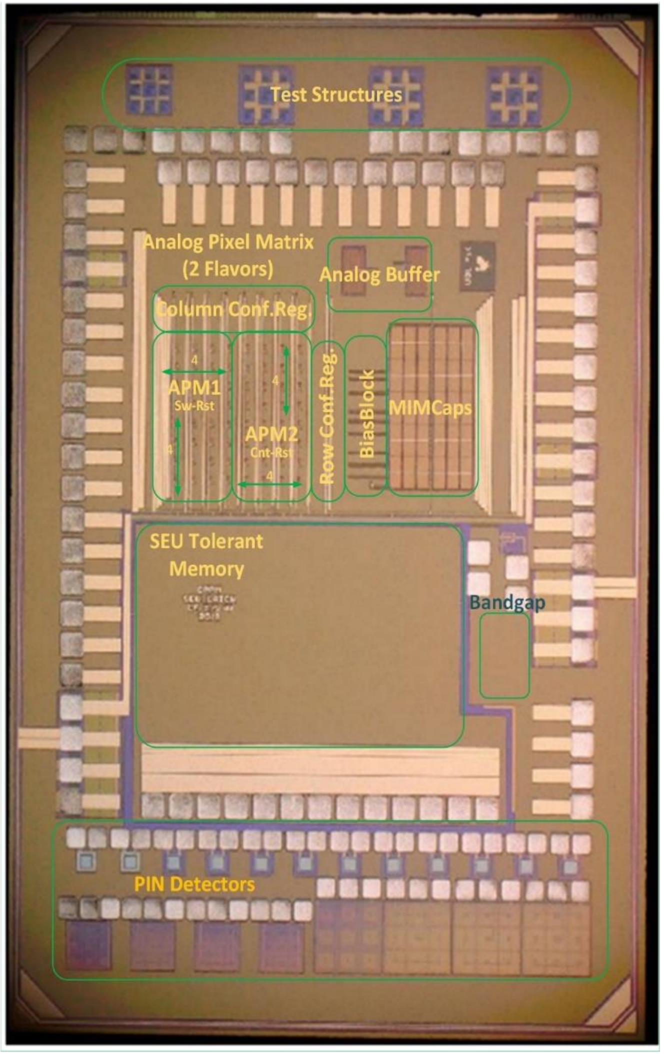
Testbeam #2

Pixel Charge Collection Efficiency

- The 8x8 pixel matrix has no addressable readout blocks so for a Charge Collection Efficiency analysis the beam make the addressing by physical aiming at every pixel.

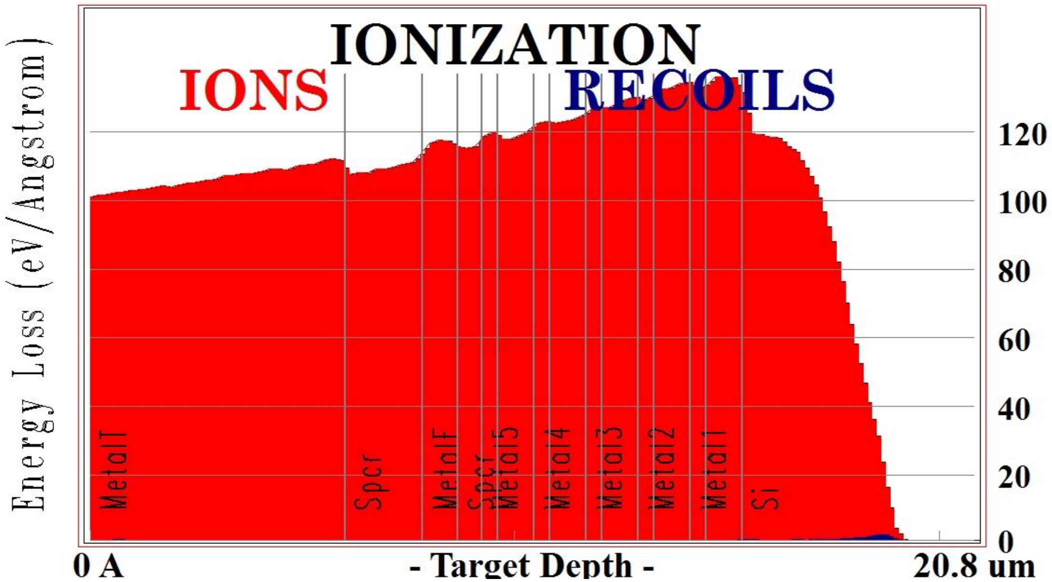
MPW2 RD50 Test chip

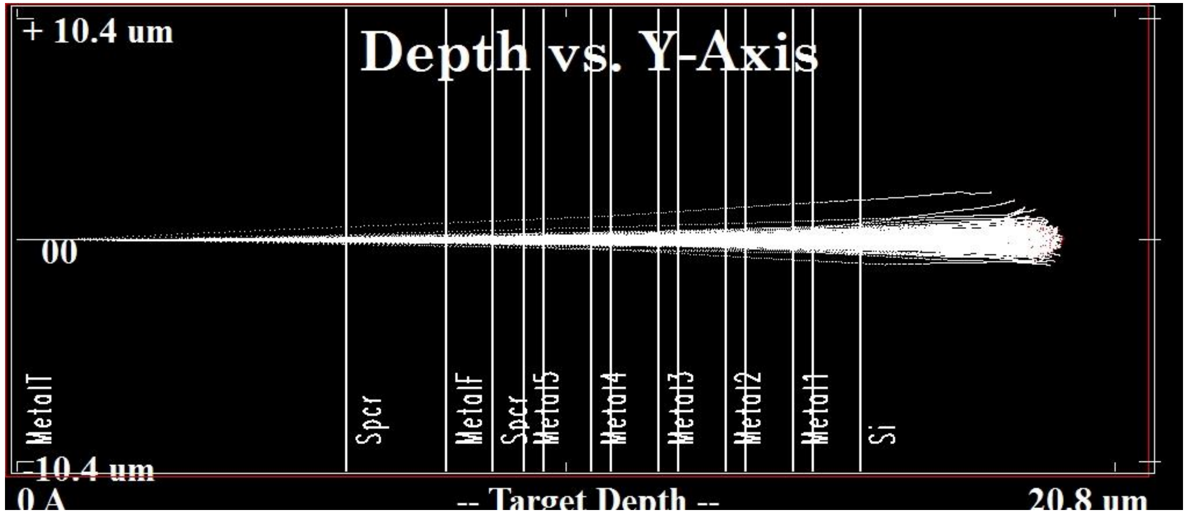




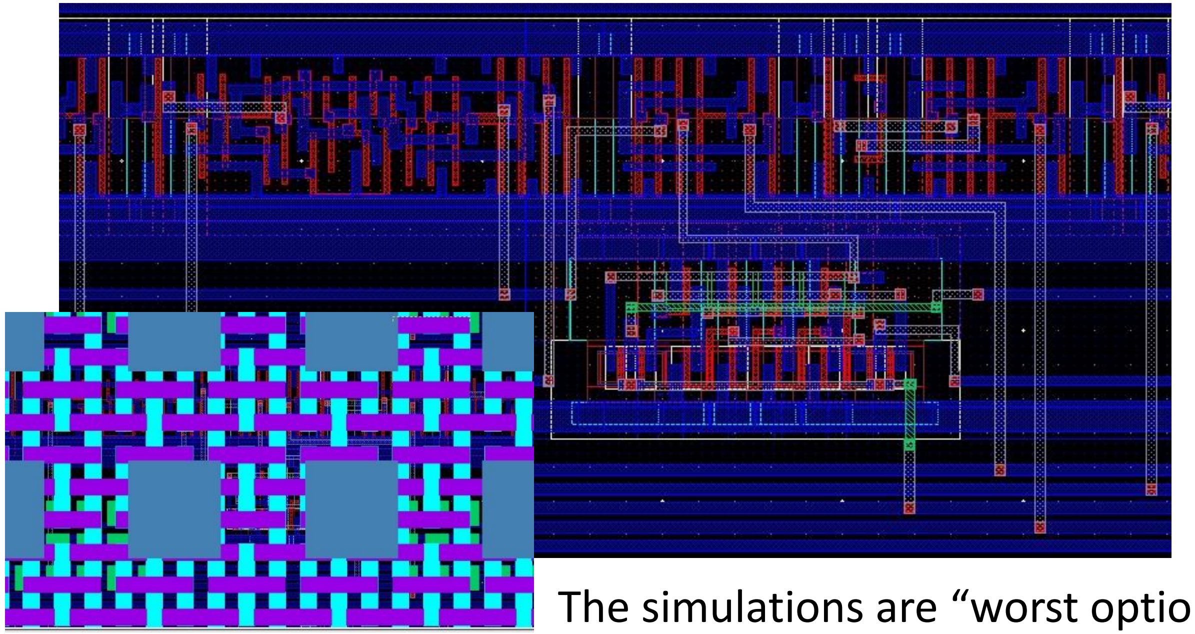
Exp#1: SRIM Simulations

120 eV/Angstrom translates into LET ~5 MeV-cm^2/mg



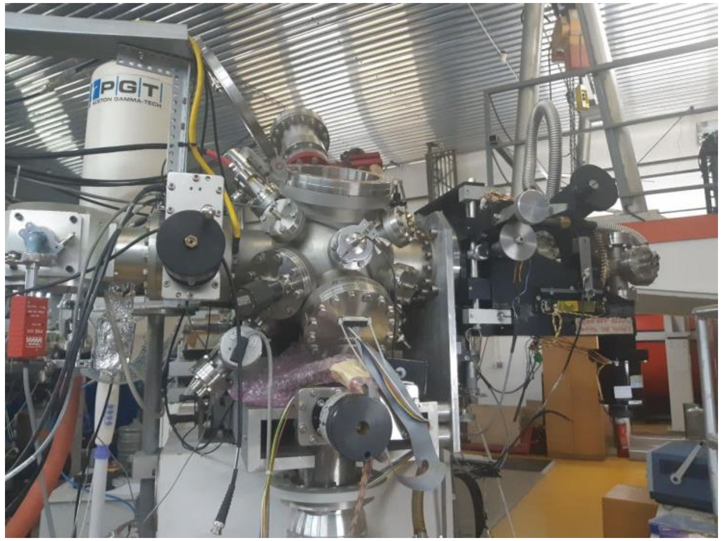


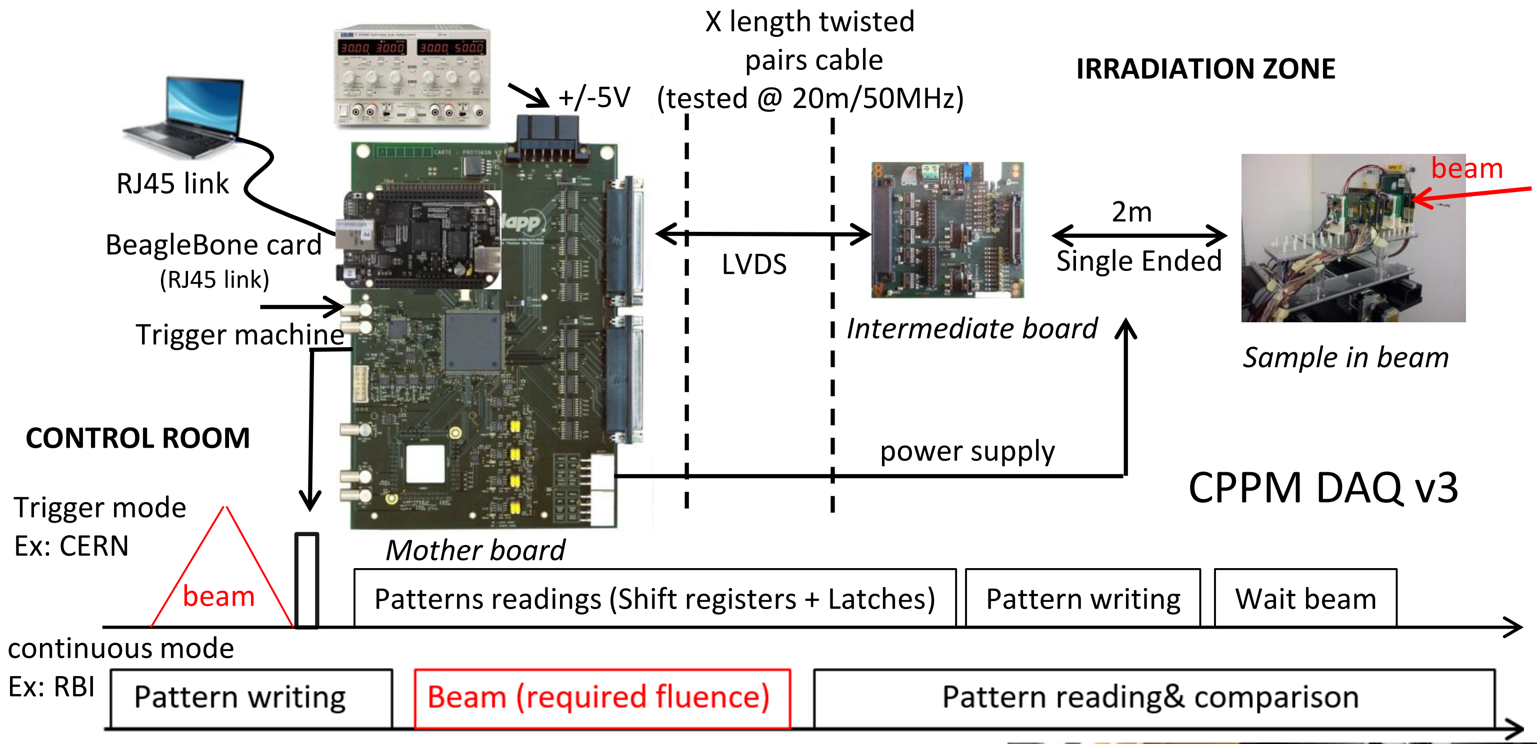
- Li 3+ 14 MeV gives 30 eV/Ang (1.28 MeV-cm2/mg), Boron 17.5 MeV gives 90 eV/Ang (4.4 MeV-cm2/mg), low under Carbon ions, C5+. Oxygen O6+ 24.5 MeV reaches the active volume but gives only 30 eV/Ang there, same as Li3+. C5+ 17.3 MeV gives 40 eV/Ang so it is the starting point for aiming.
- We chose ^{12}C 5+ ions at 20 MeV because they can deposit enough energy in the transistors active volume and can range deep into the memory cell, LET ~ 5 MeV-cm^2/mg



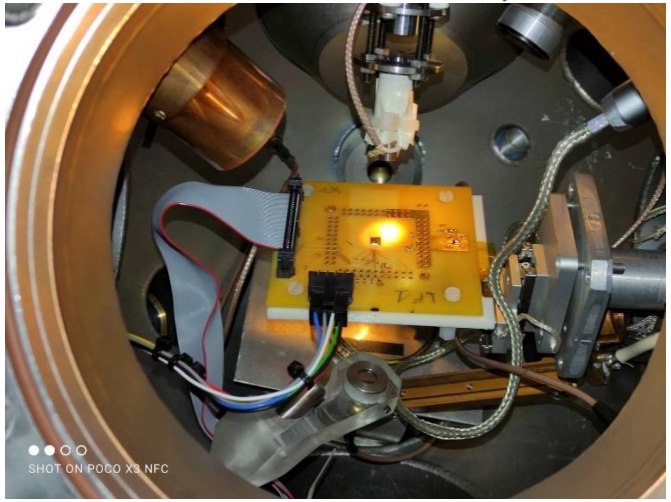
The simulations are “worst option” to consider filling density layers

Exp#1: DAQ system and general layout





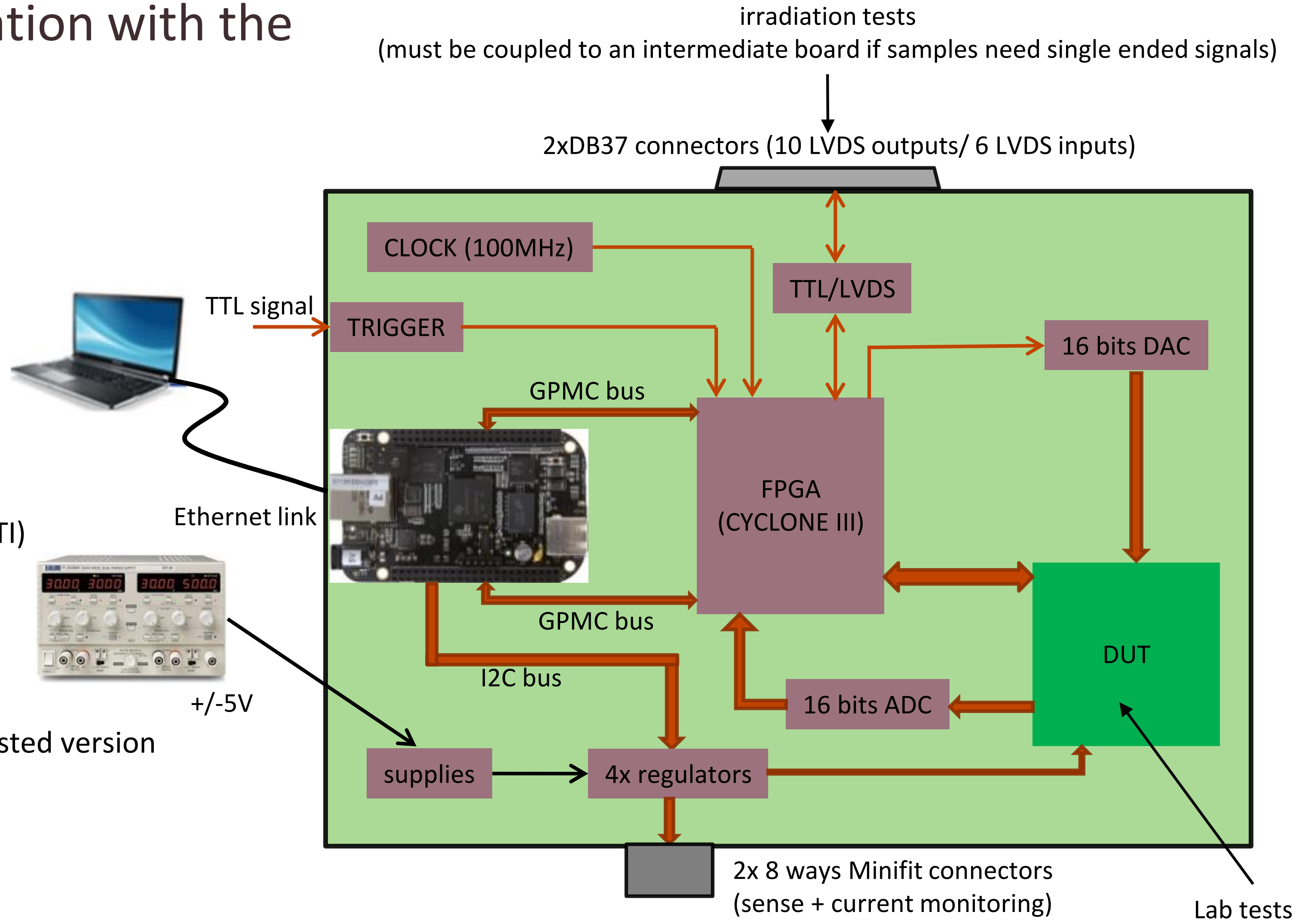
General Layout: The target MPW2 chip is inside the microbeam vacuum chamber, connected with flat ribbon cables to the external DAQ. The CPPM DAQ v3 operates in continuous mode. The X ray detector in the chamber monitors the PIXE emission continuously.



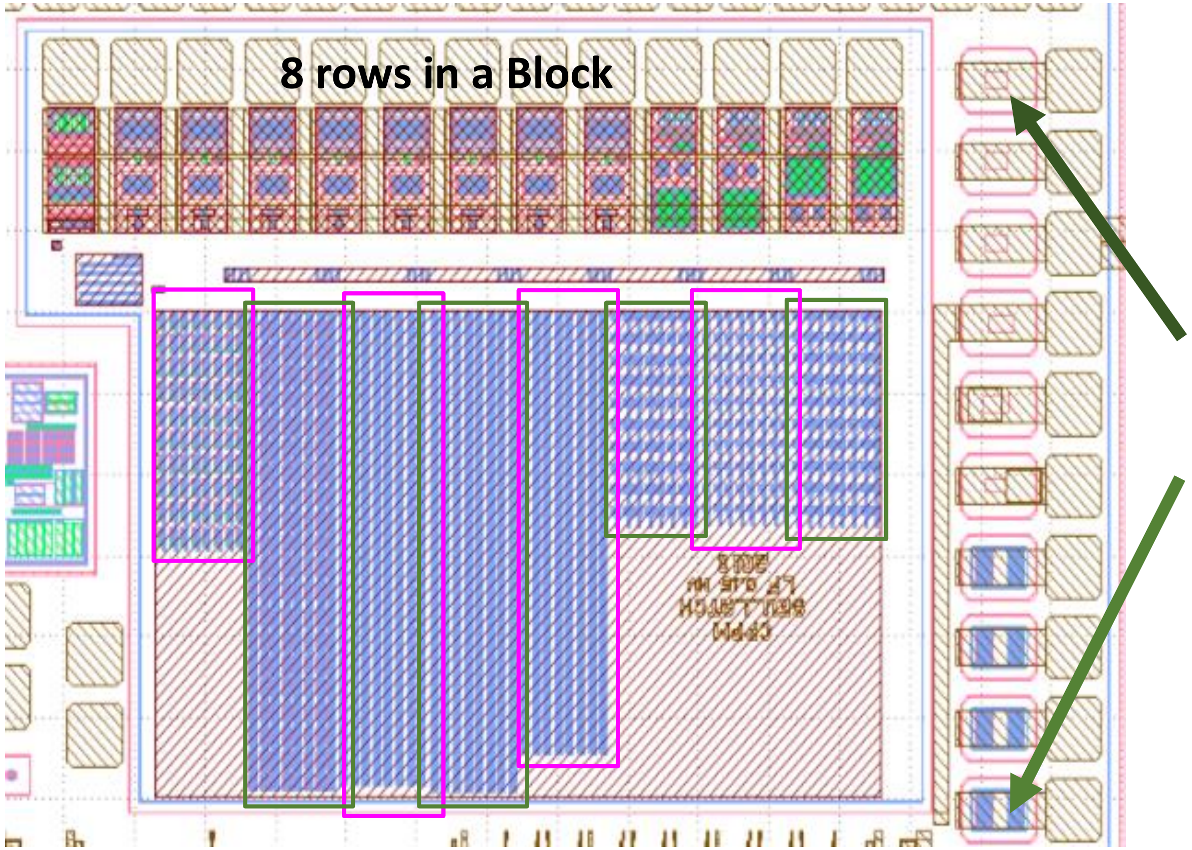
Exp#1: DAQ system and general layout

- Mother board designed in collaboration with the IN2P3 Annecy laboratory
- Features:
  - require +5 V (3A) / -5V (100mA)
  - nanoPC BeagleBone card + FPGA
    - Connected via GPMC bus
    - Flexible programing
    - 40 TTL signals
    - 30 LVDS signals
    - Analog channels available
      - 4 channels SAR ADC's 16 bits (ADS8568 – TI)
      - 10 DAC's 16 bits (DAC8830 – TI)
    - 4 programmable regulators
      - 2 x LT 3021
      - 2 x LT 3026 (up to 1,5 A)
        - Must be tested
    - Monitoring:
      - °C: MAX31865 (RTD-digital converter)
      - current supply: MAX611
  - Lab tests (local mode)
  - irradiation tests (remote mode via LVDS signals)

For the lasted version



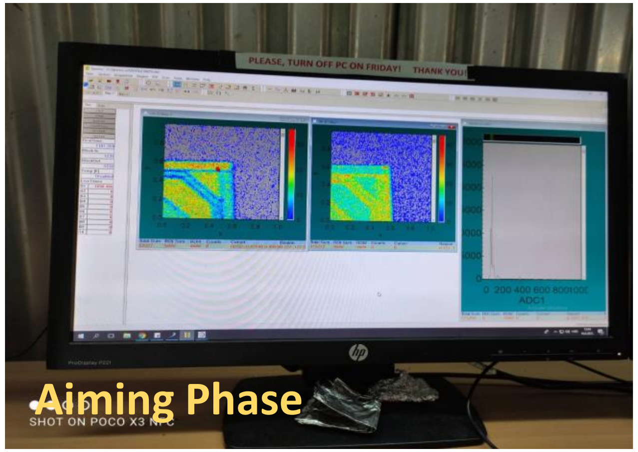
Exp#1: MPW2 memory flavours

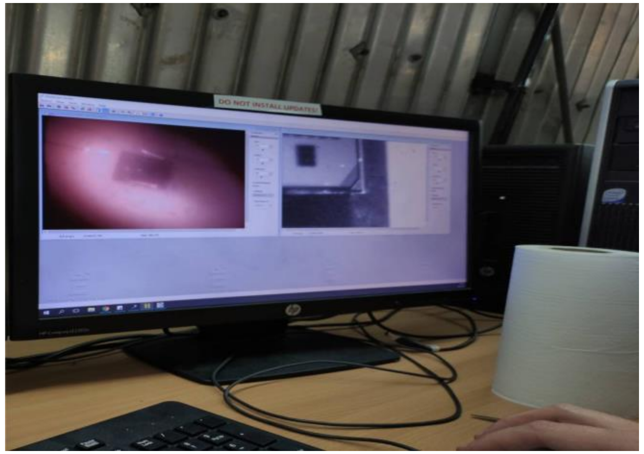


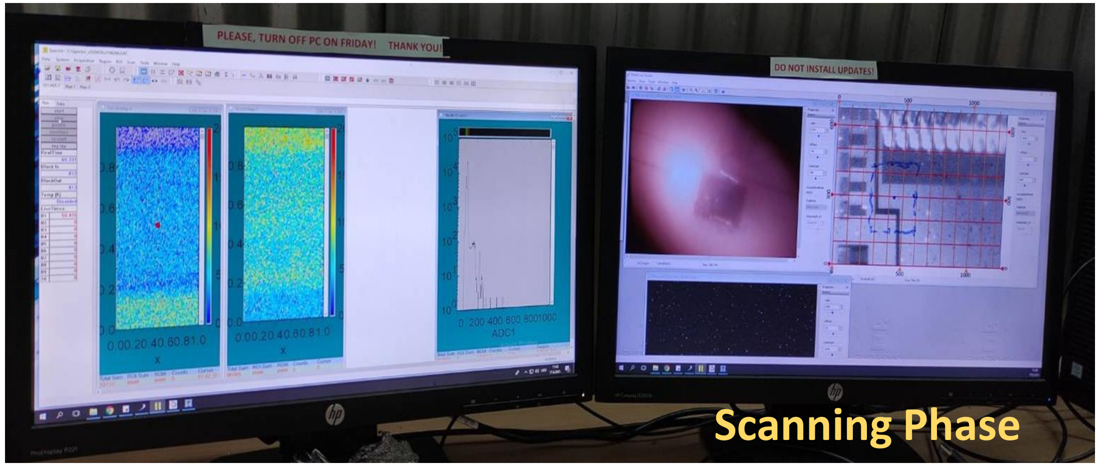
	Width [μm]	Length [μm]
SEU TM PI 1	122,47	267,1
SEU TM PI 2	122,34	267,7
SEU TM PI 3	122,34	267,1
SEU TM PI 4	122,26	548,23
SEU TM PI 5	122,26	592
SEU TM PI 6	122,26	585,91
SEU TM PI 7	122,26	592
SEU TM PI 8	122,44	295,72

- Col1 : Standard Cells
- Col2 : DICE Latch "Dual Interlocked Storage Cell"
- Col3 : Enhanced DICE Latch
- Col4 : Triple redundancy standard cells
- Col5 : Triple redundancy DICE latch
- Col6 :Split Triple redundancy with standard cells
- Col7 :Split Triple redundancy with DICE cells
- Col8 : SRAM

Exp#1 Results and Prospective

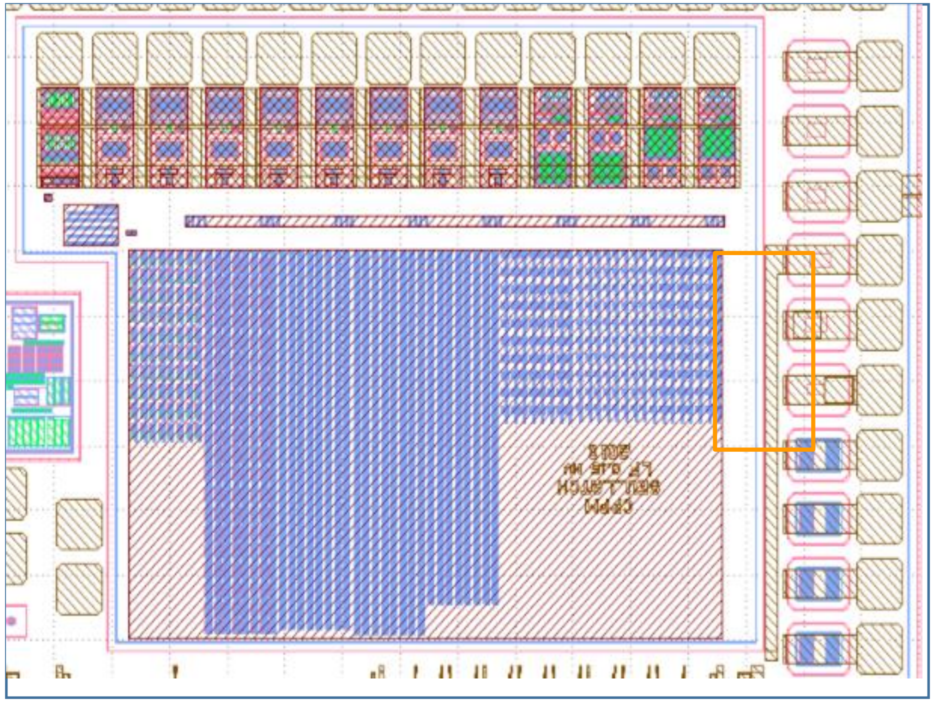






The aiming phase and the scanning phase made with ^{12}C ions 20 MeV (~4.8 MeV-cm2/mg in this structure), Beam Spot 10 μm^2

Scanning area (135 x 270) µm x 1.3 => 175.5 x 351 µm
Map size: **128 x 128 pixels**



Flux: 4E6 ions/cm^2-sec
Scanning time: tipically between 60 to 600 sec
Total Ionization Dose on target less than 100 Mrad (150 nm Lfoundry tech is very TID resistant, no stuck bits observed during the full experiment)

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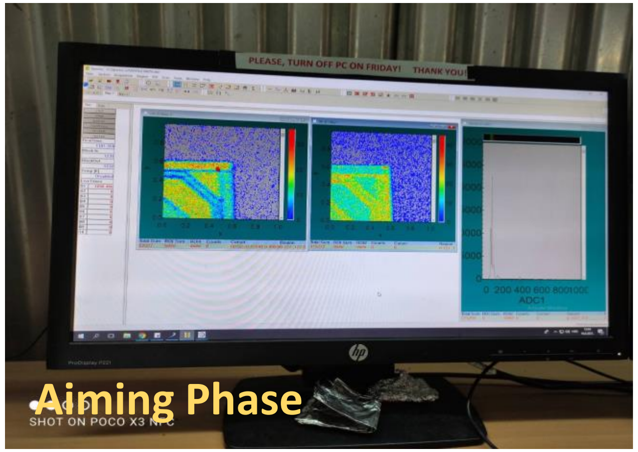

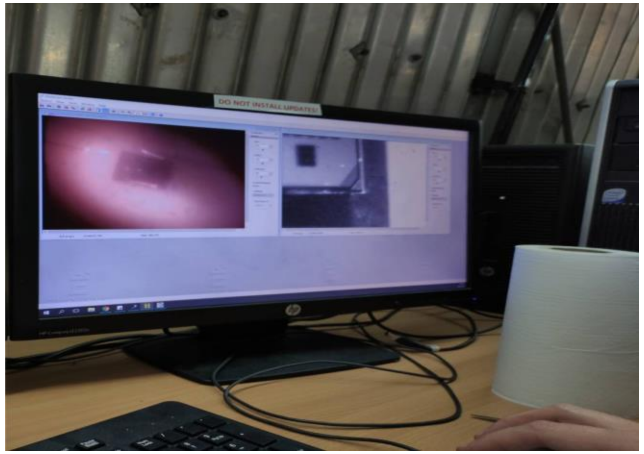

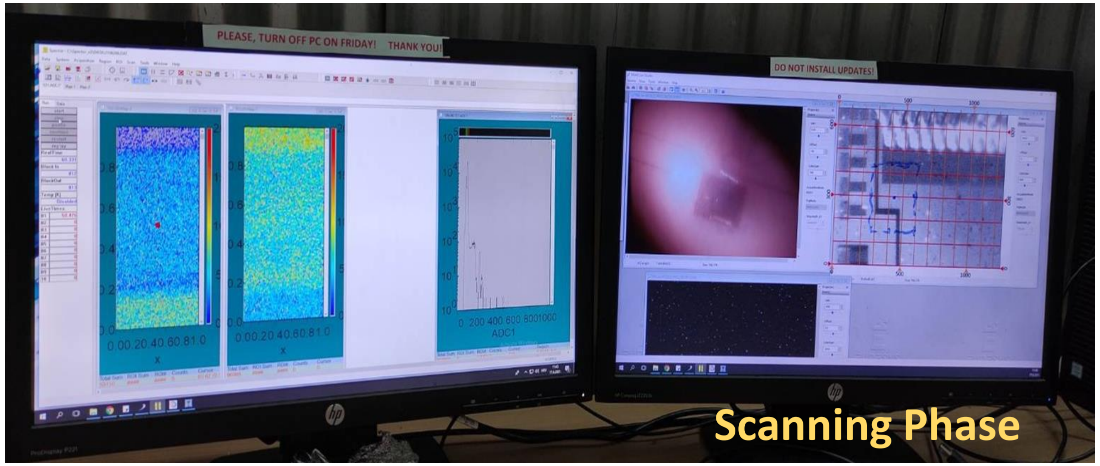

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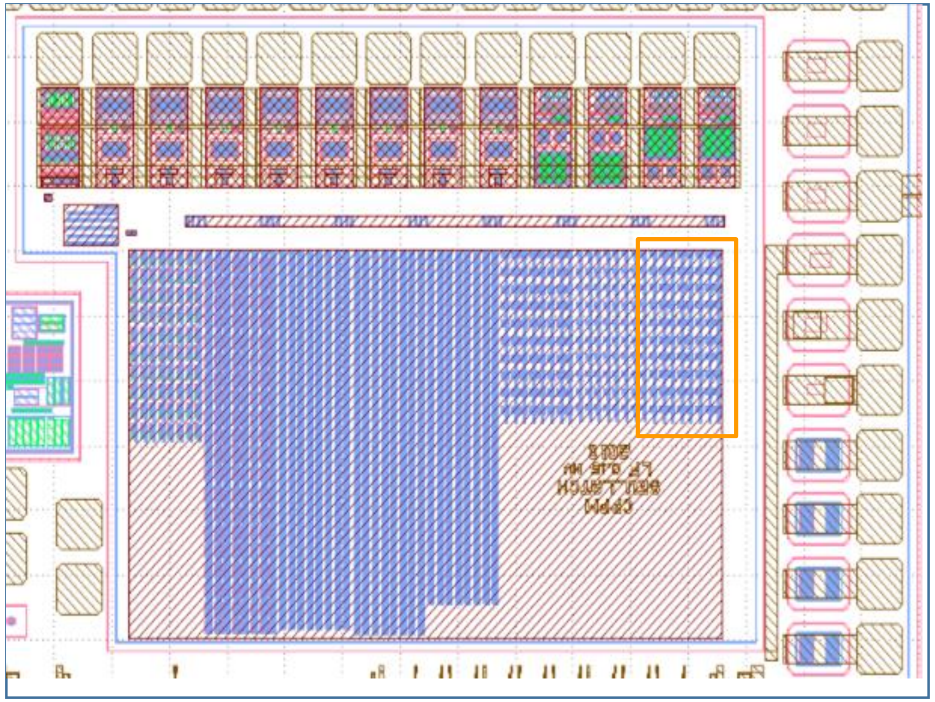

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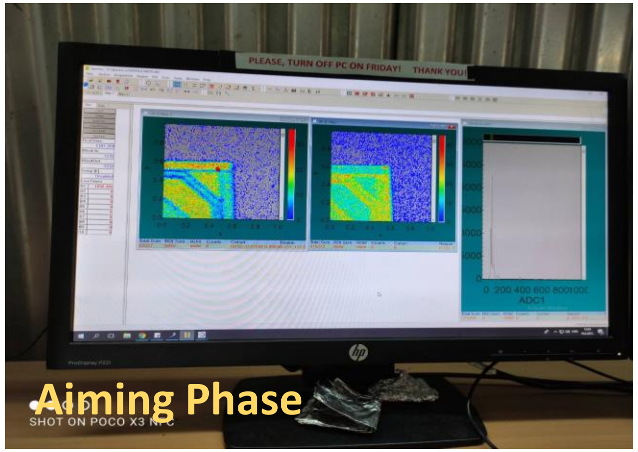

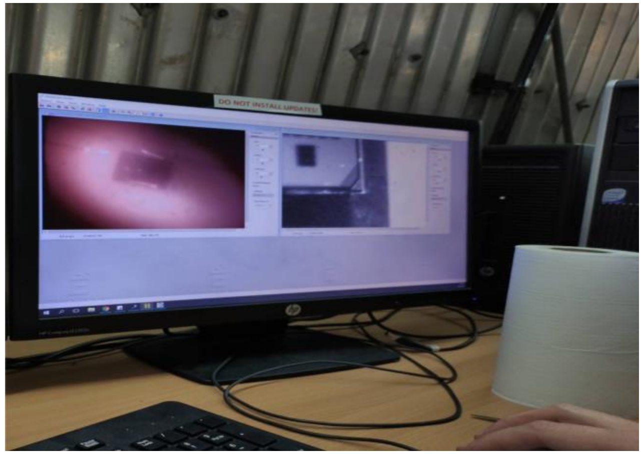

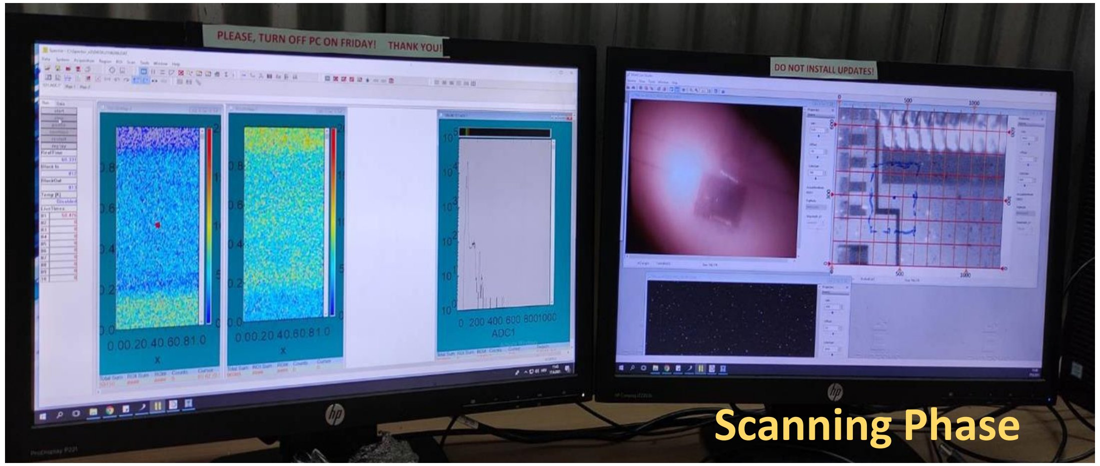

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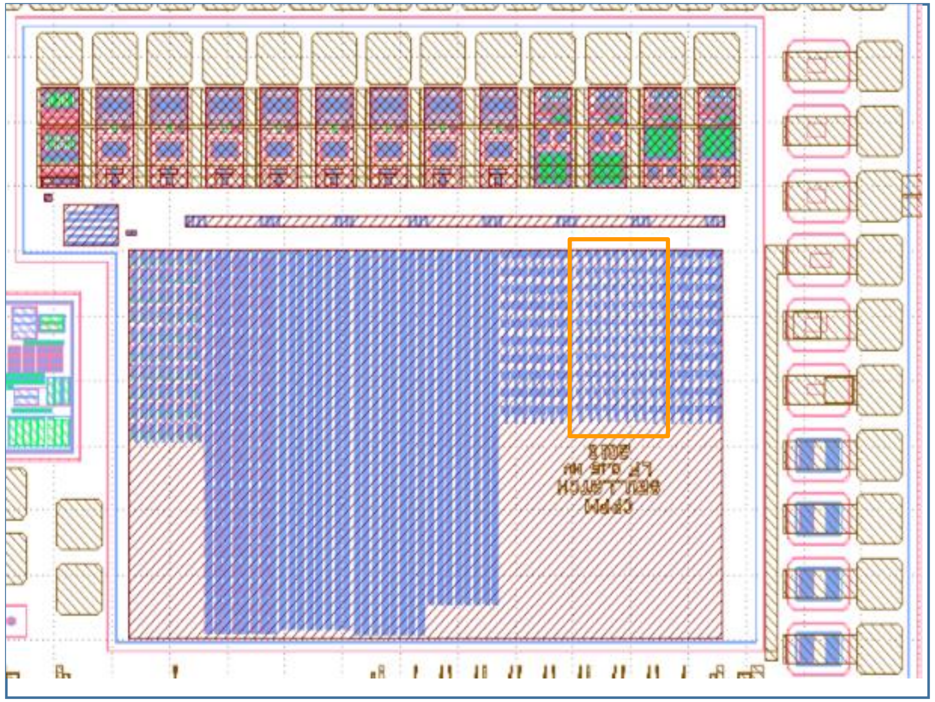

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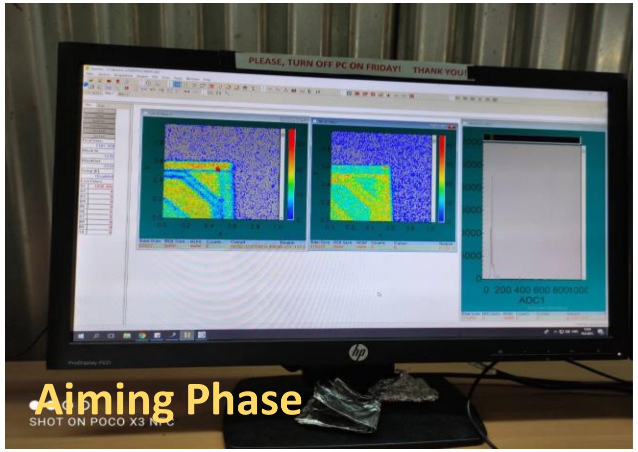

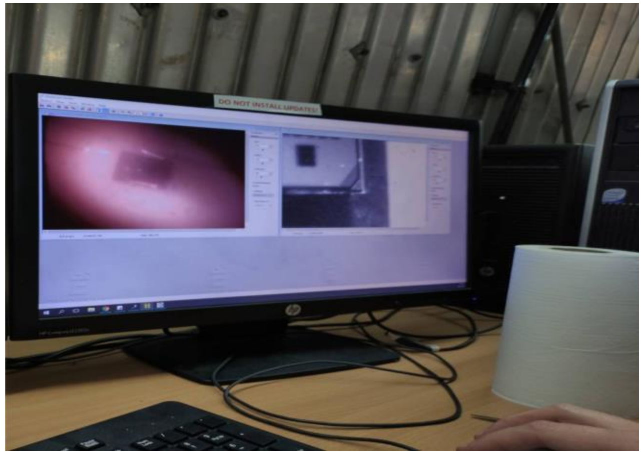

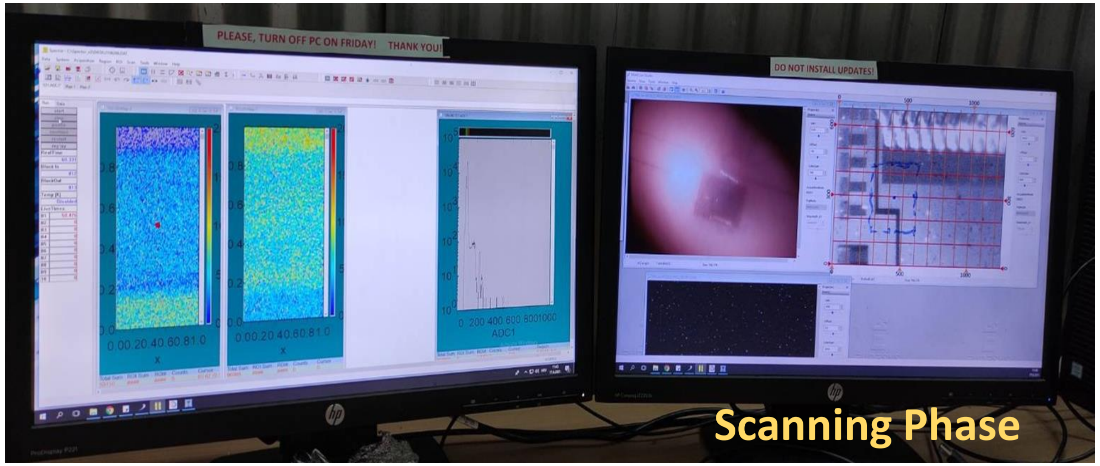

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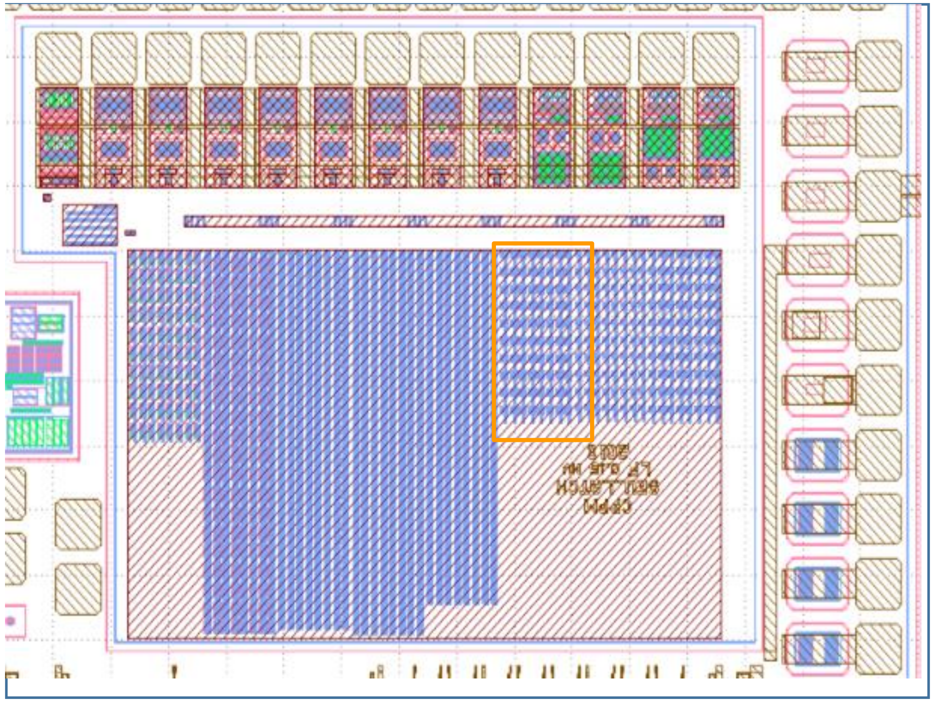

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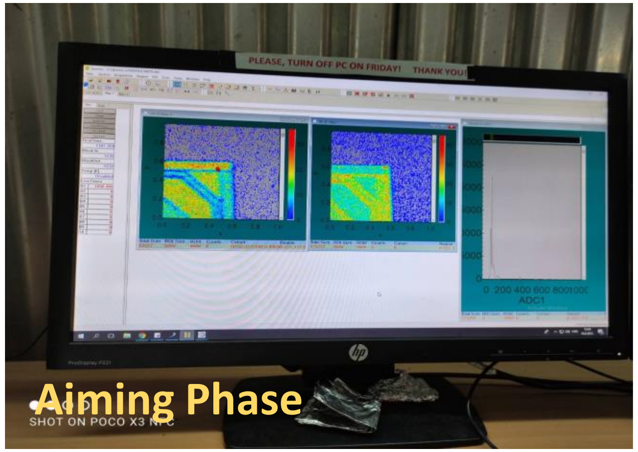

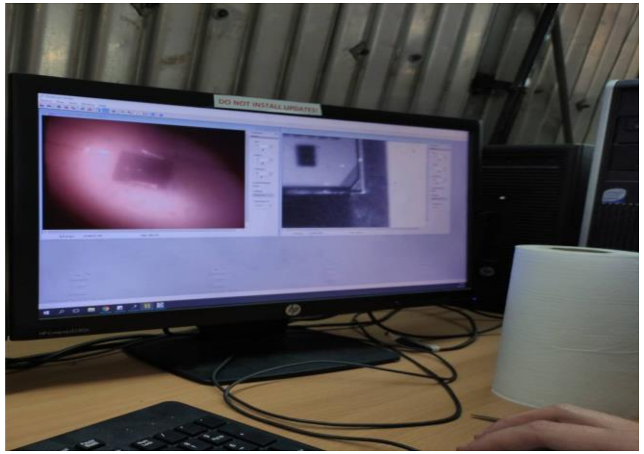

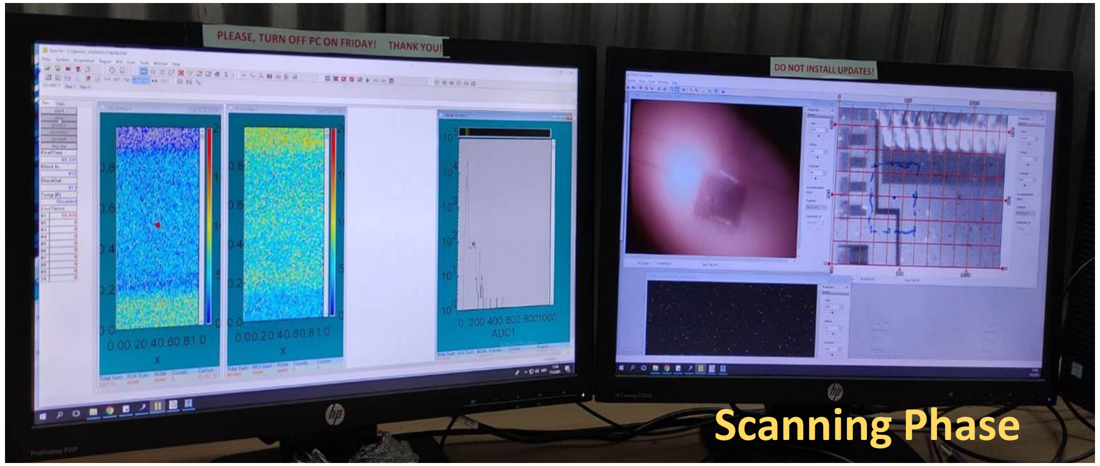

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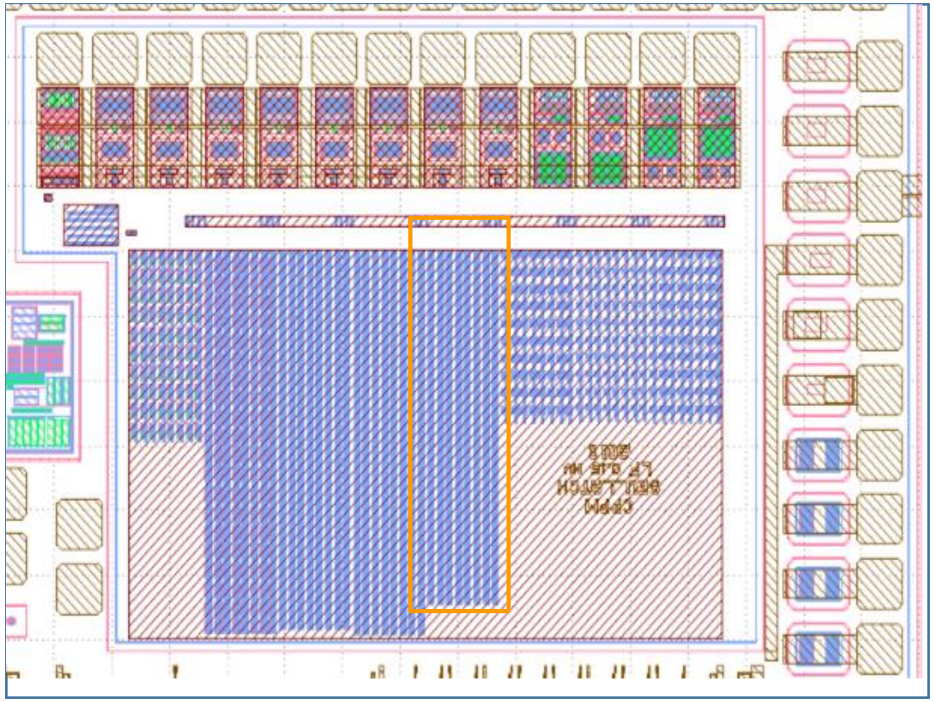

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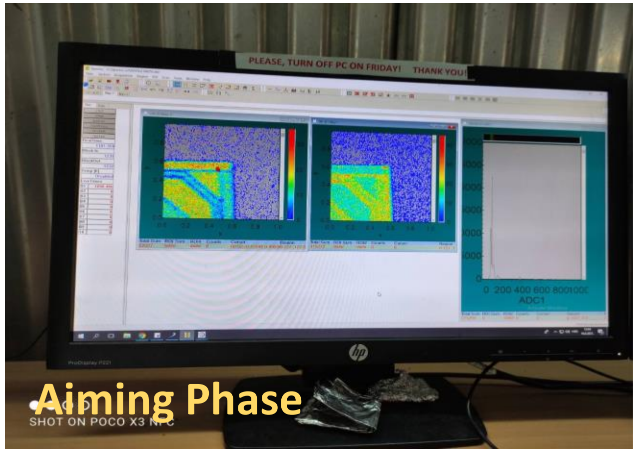

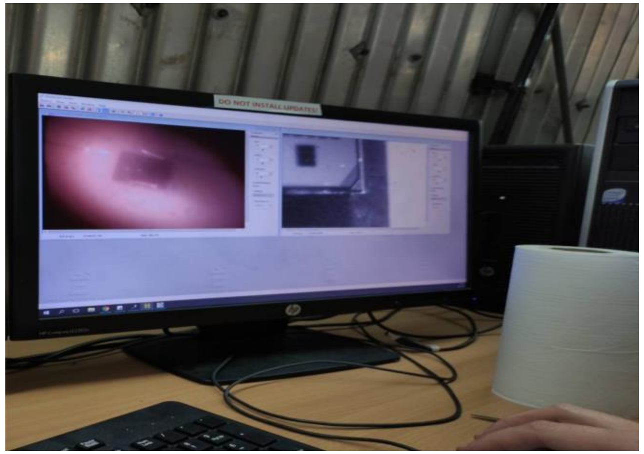

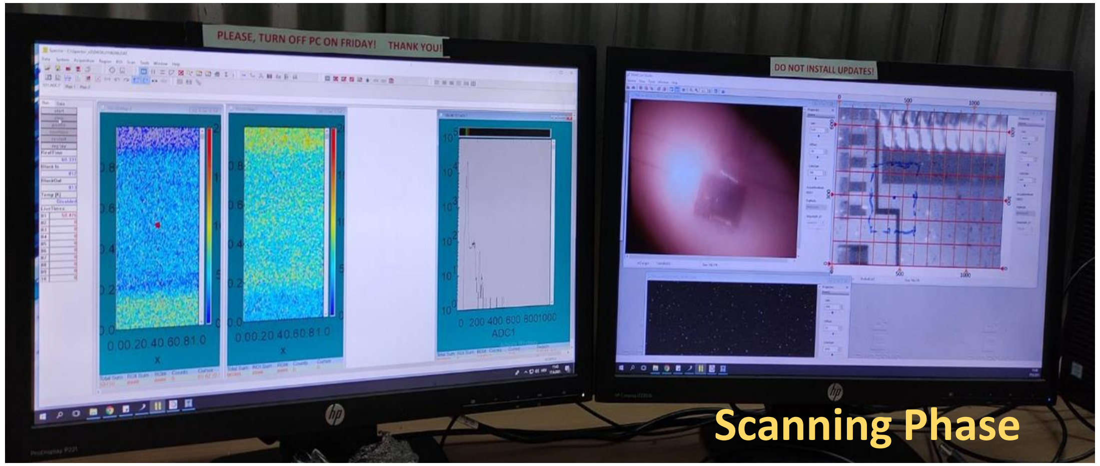

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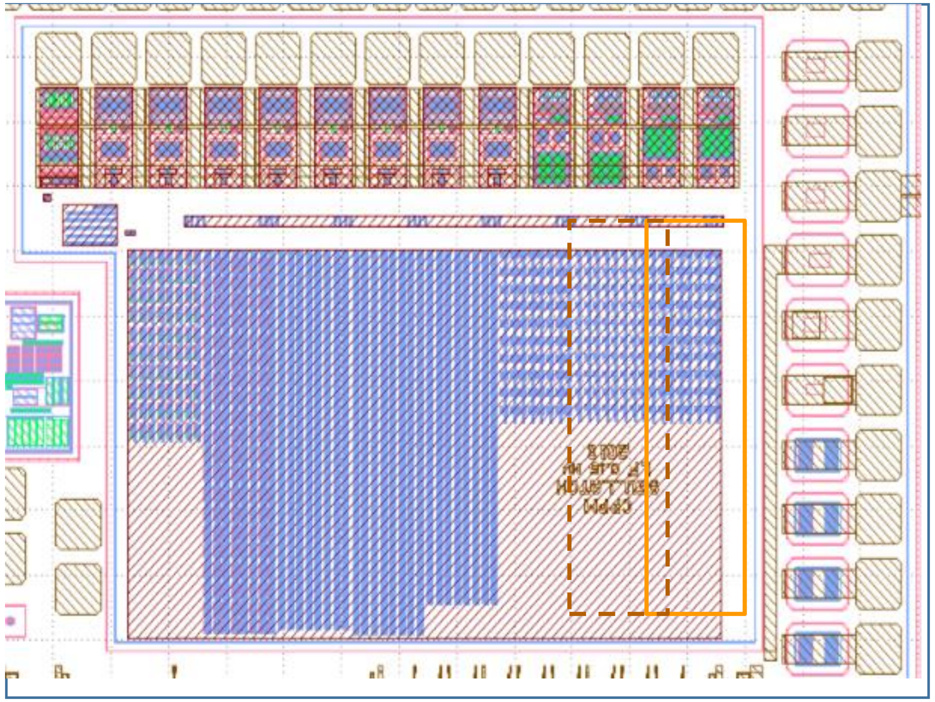

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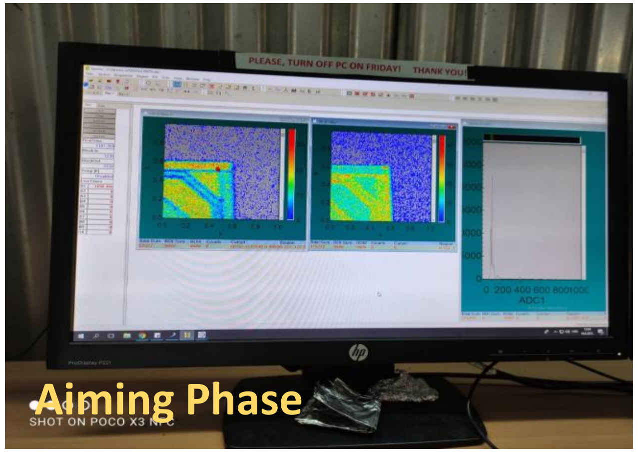

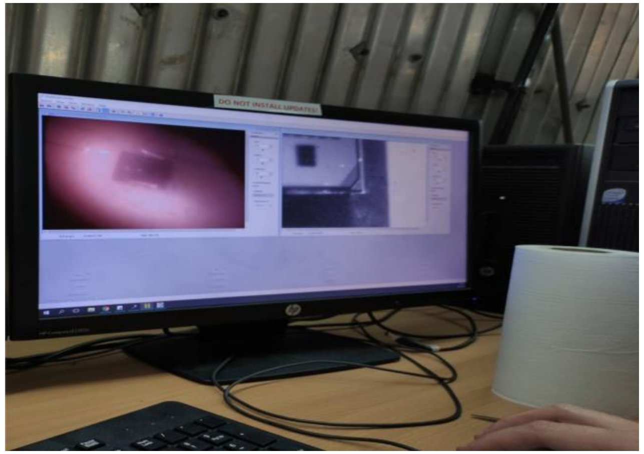

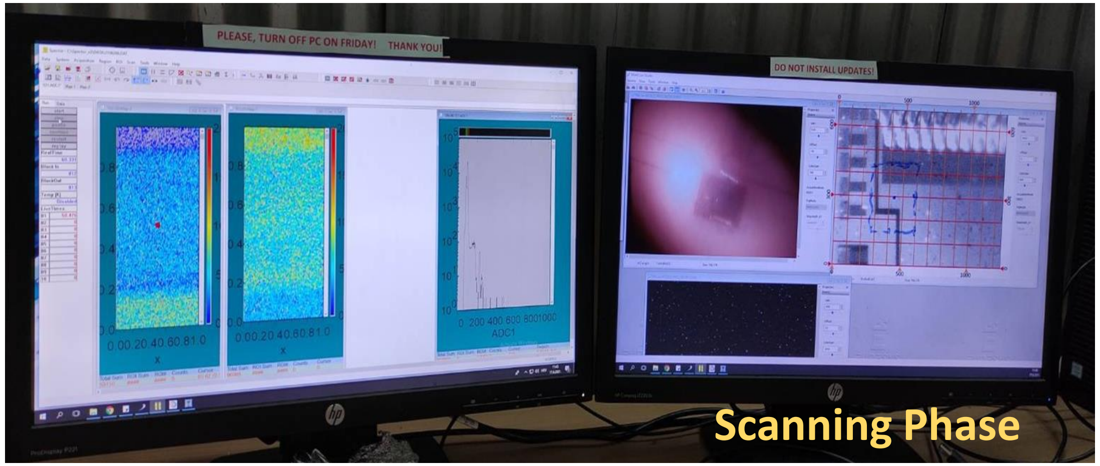

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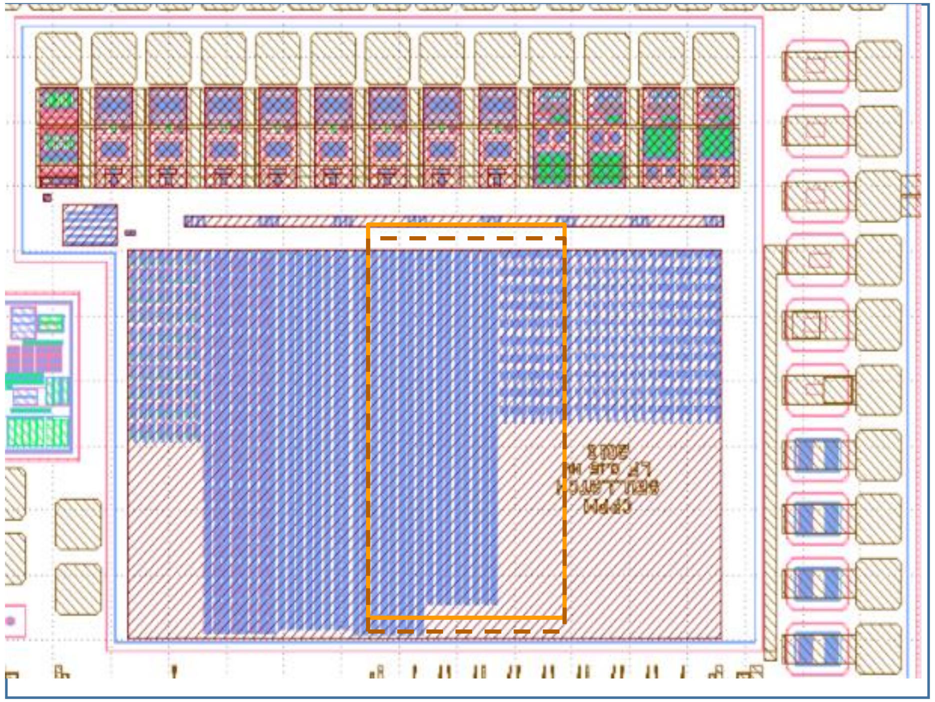
Scanning area (135 x 270) µm x 2.6 and X $_{calibration}$ ***= 0.64 x 10*** => 351 x 702 µm
Change in the map size: **256 x 256 pixels**



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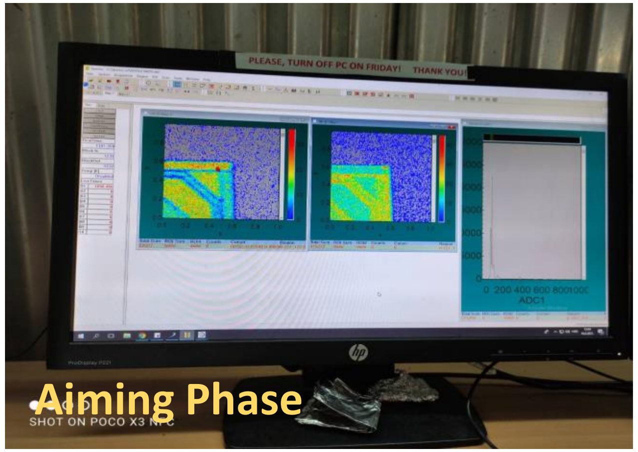

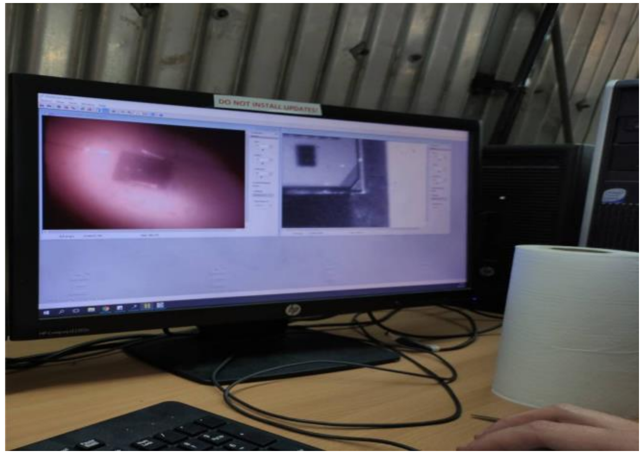

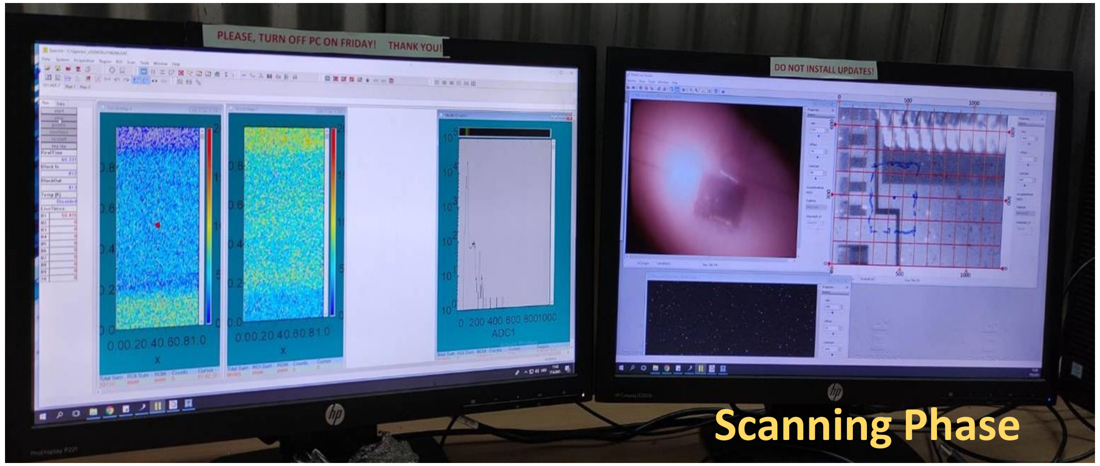

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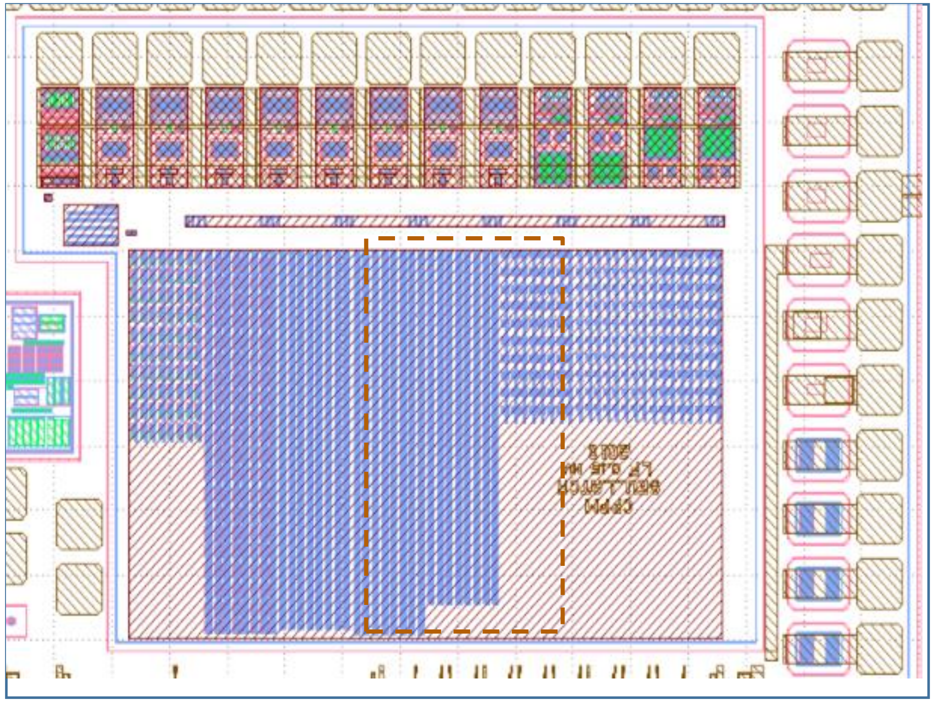

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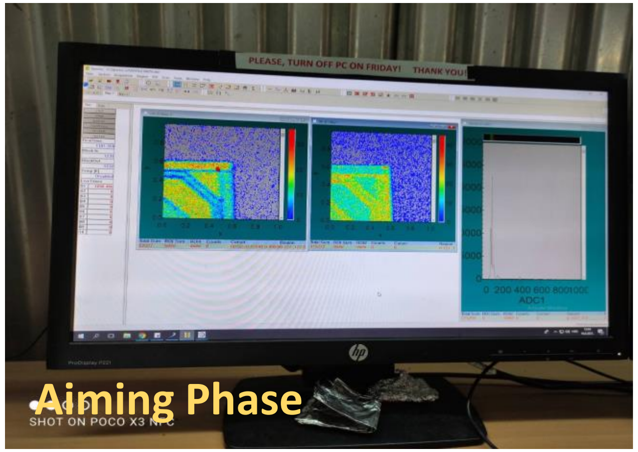
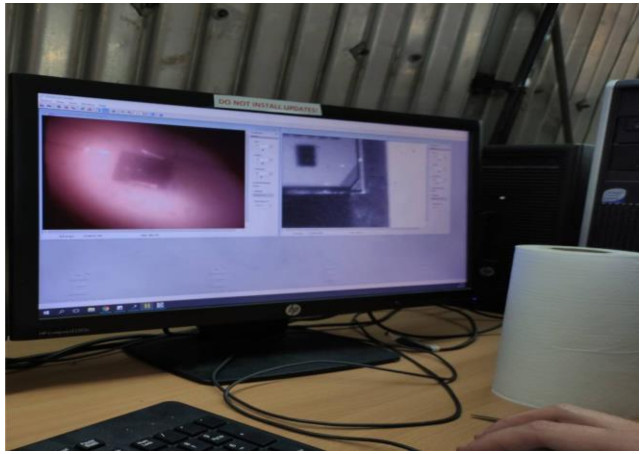
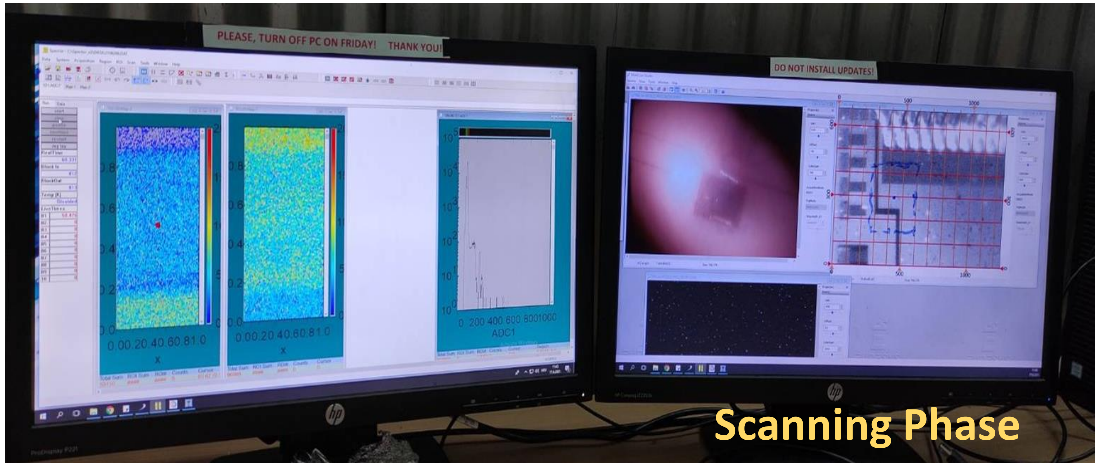


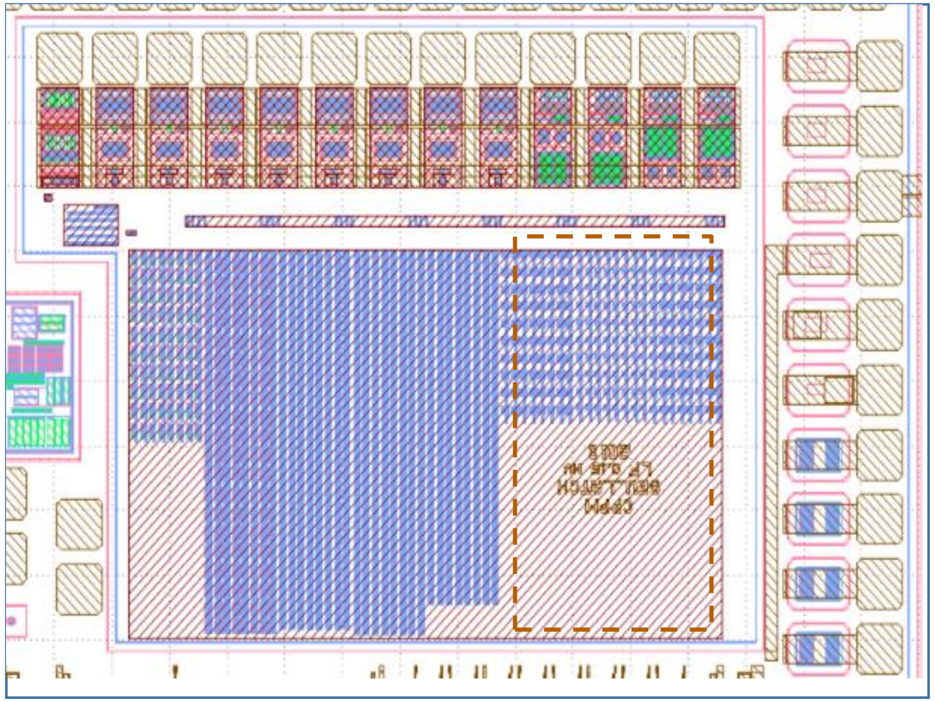




The aiming phase and the scanning phase made with ^{12}C ions 20 MeV (~4.8 MeV-cm2/mg in this structure), Beam Spot 10 μm^2

Scanning area (135 x 270) µm x 2.6 and $X_{calibration}$ *= 0.64 x 10* => 351 x 702 µm

Change in the map size: **256 x 256 pixels**



Flux: 4E6 ions/cm^2-sec

Scanning time: tipically between 60 to 600 sec

Total Ionization Dose on target less than 100 Mrad (150 nm Lfoundry tech is very TID resistant, no stuck bits observed during the full experiment)

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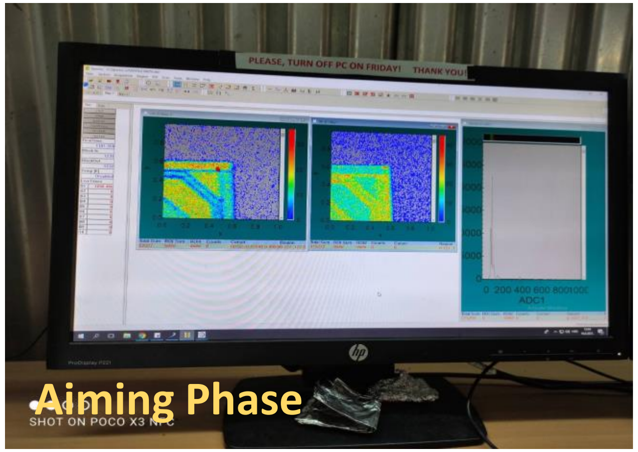

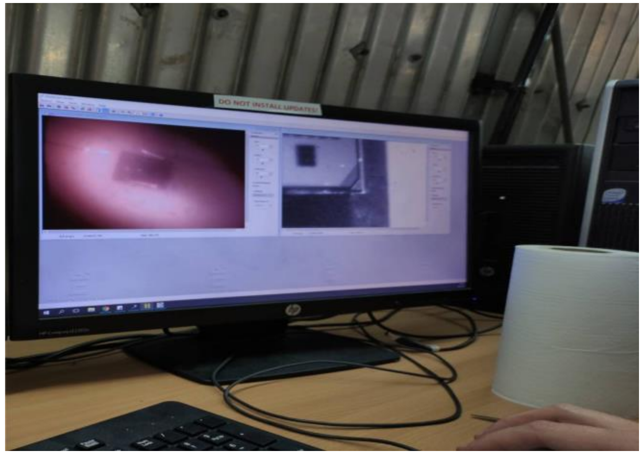

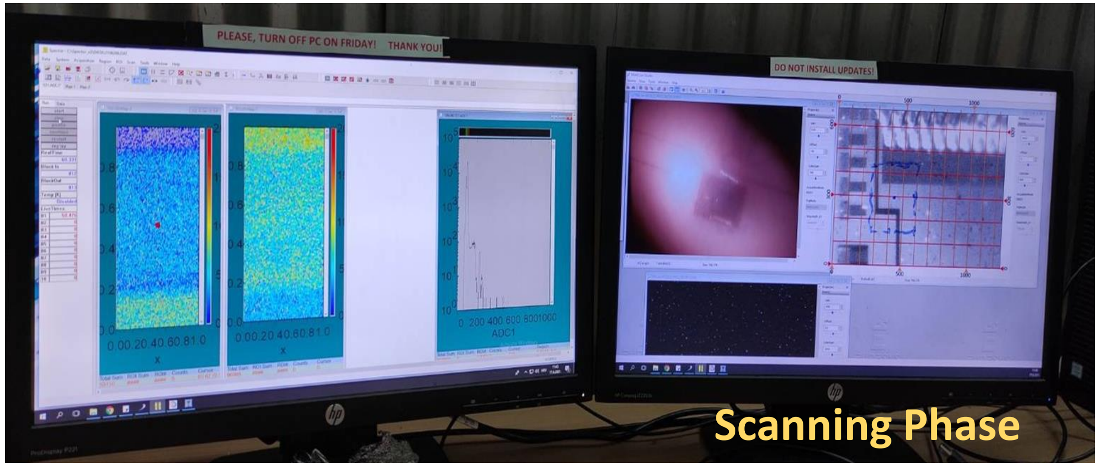

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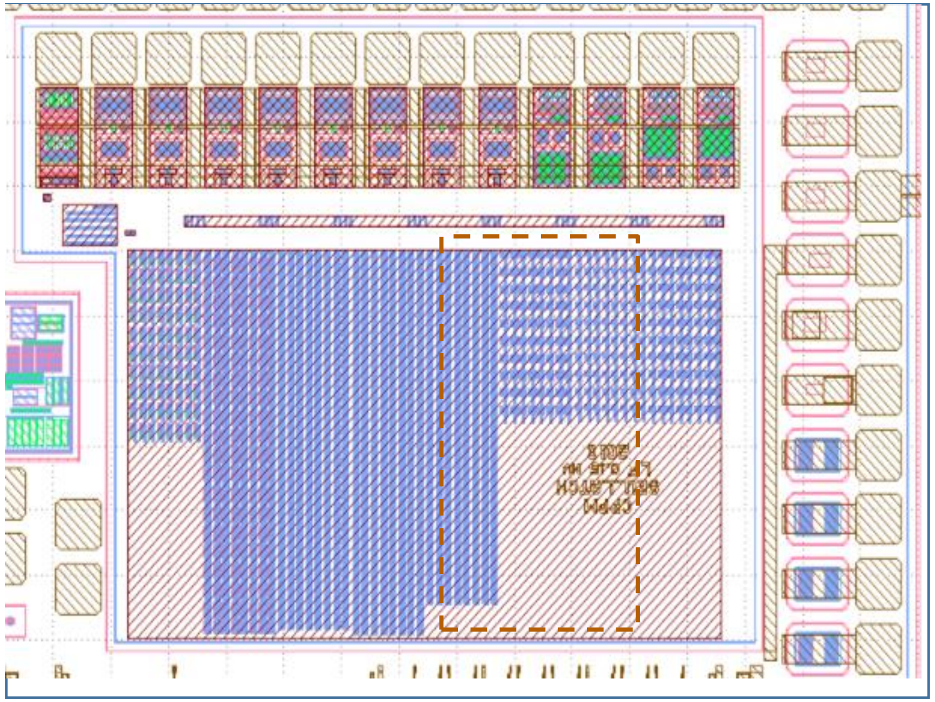

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Total Ionization Dose on target less than 100 Mrad (150 nm Lfoundry tech is very TID resistant, no stuck bits observed during the full experiment)

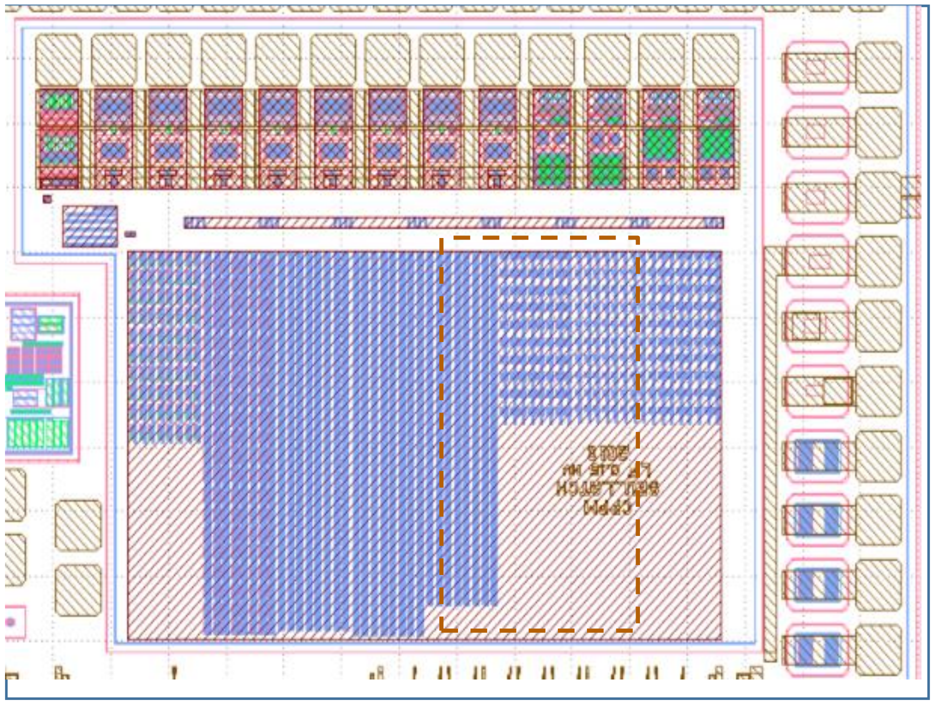
Exp#1 Results and Prospective

Observed SEUs in:

- Col1 : Standard Cells (after 60-600 sec of scanning)
- Col2 : DICE Latch "Dual Interlocked Storage Cell"
- Col3 : Enhanced DICE Latch

No observation of SEUs (after 44 min of scanning):

- Col4 : Triple redundancy standard cells
- Col5-8 : Not scanned in this experimental run



Further data analysis under way at the moment

Exp#2 General Layout

-For the Pixel CCE we use the external microbeam line fed by the Tandem accelerator (2 MeV protons, around 1.5 MeV when in air)

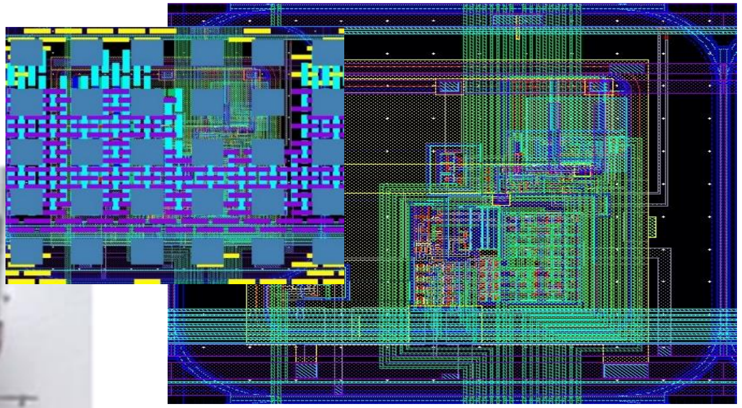
-Protons 1.5 MeV means LET ~0,25 MeV-cm²/mg , enoughfor a particle detector (1 GeV proton has a LET ~0,0018 MeV-cm²/mg)

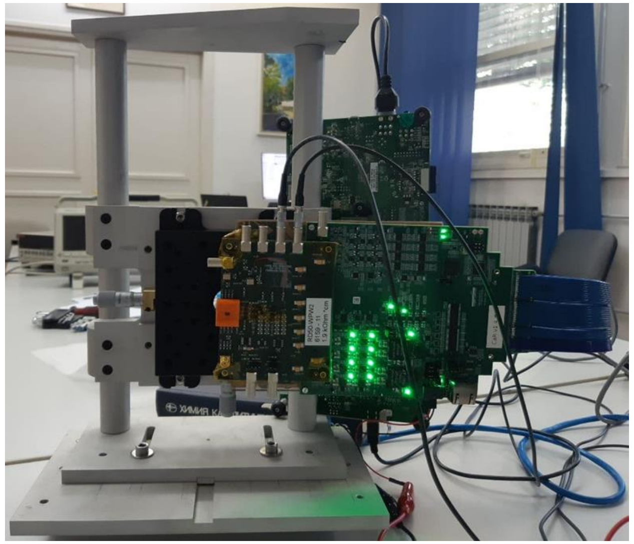
-The microbeam can be spot focused up to 30 μm²

Pixel area is ~60x60 μm²

-Step by Step beam scanning mode

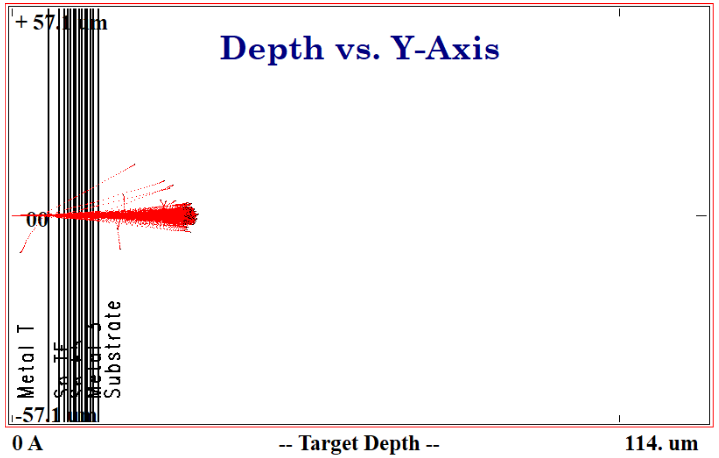
-No need of vacuum so a great simplification in the experiment layout

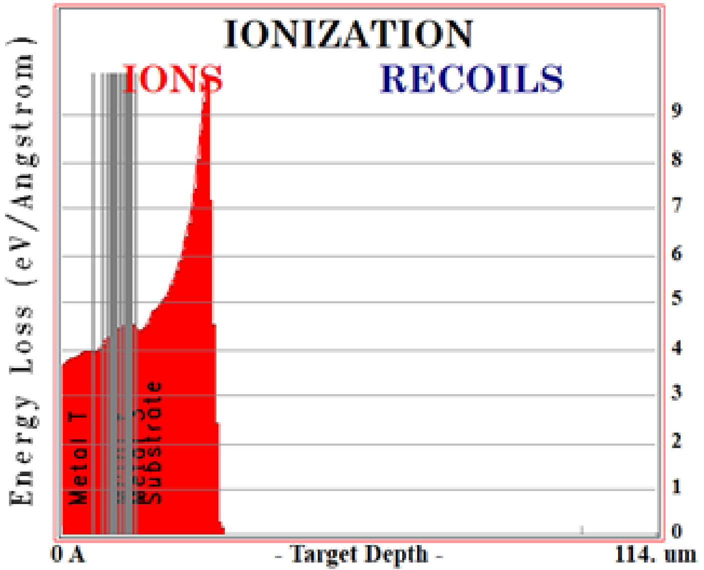




MPW2 card + Caribou ADC card + ZC706-Zynq Controller Card + Graphical User Interface in a nearby laptop

Protons 1.5 MeV can go through metal/passivation layers and reach the pixel detector active volume





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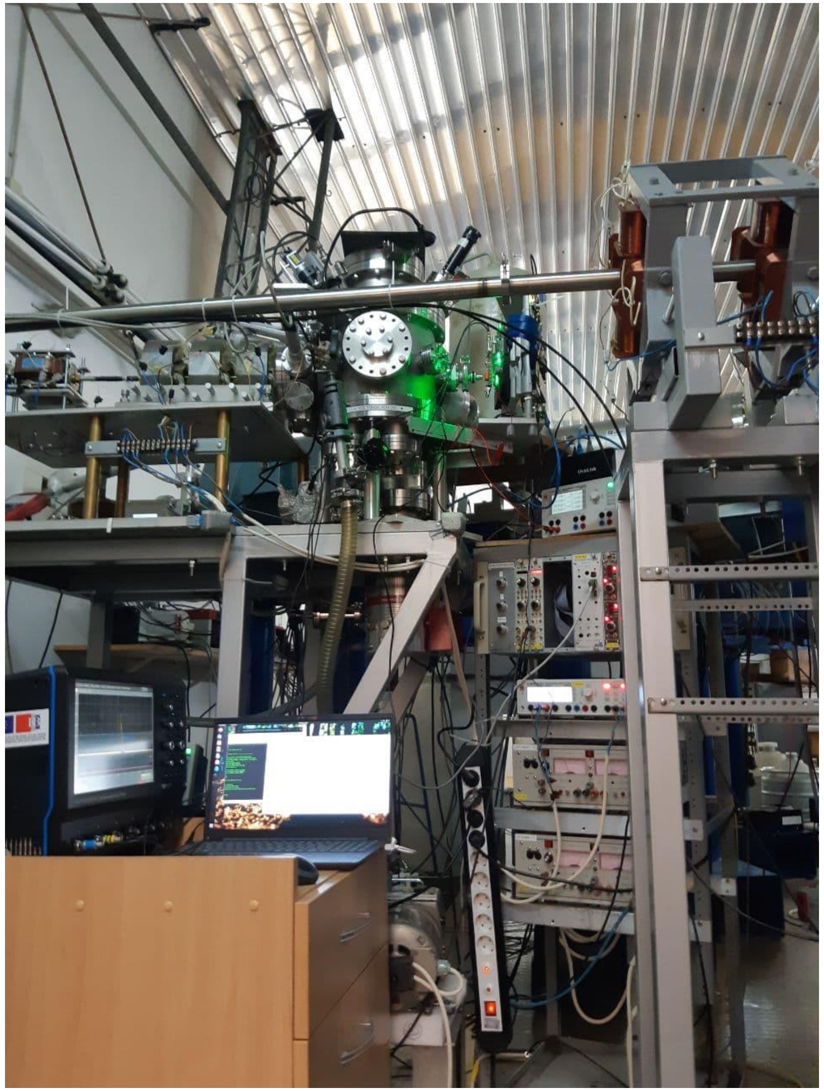

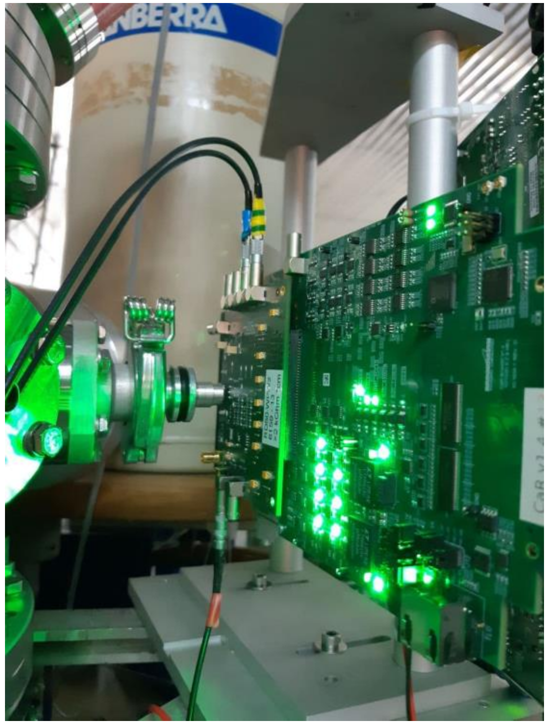

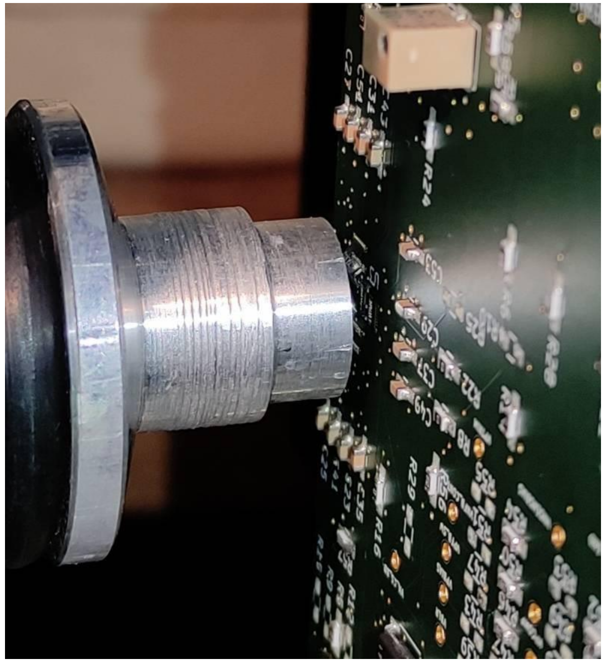

- The MPW2 chip and DAQ setup (Caribou and ZC706 cards) are placed on a holder in front of the external microbeam outport window.
- The DAQ system Works properly, we need more chips
- Beam window availability very soon next month

Conclusions

- The SEE experiment showed SEU events in several columns
- The CCE pixel experiment is in standby waiting for beam opportunity
- The microbeam approach is useful for SEE Sensitivity Maps and for Physical Addressing detector pixel matrices (a form of IBIC/TRIBIC experiment)
- Future improvements at the RBI facility will make this testbeams even better

The End

Thanks for your attention!

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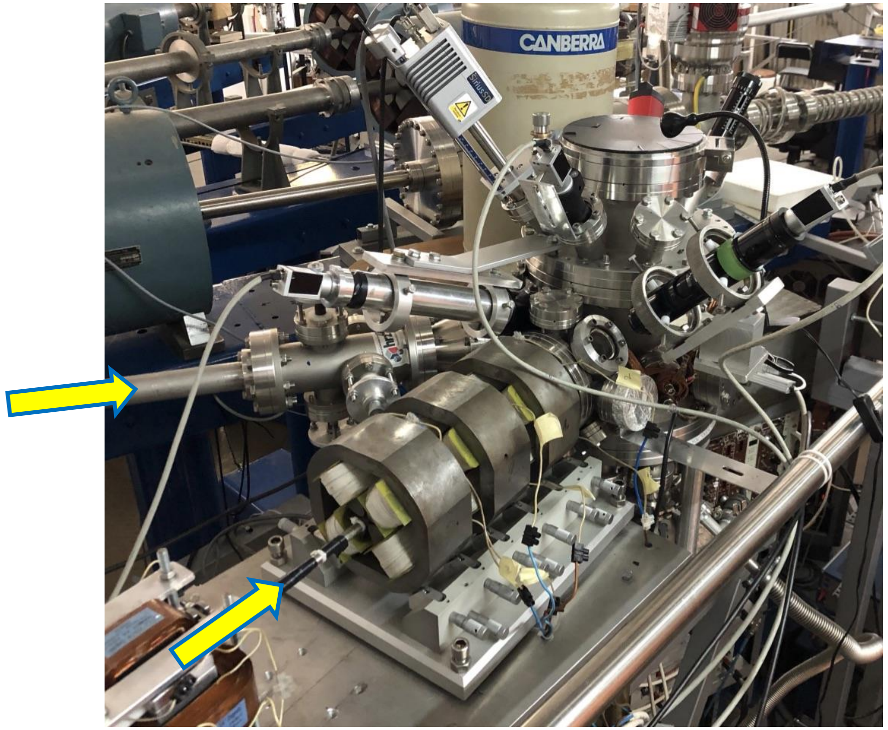
CENTRE DE PHYSIQUE DES PARTICULES DE MARSEILLE CPPM

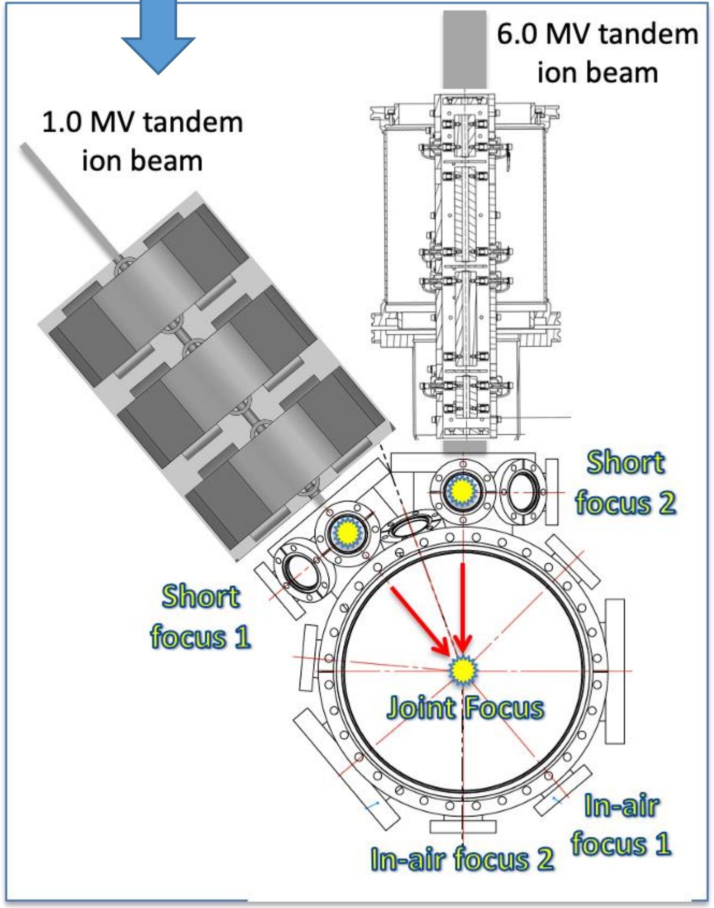
HELSINKI INSTITUTE OF PHYSICS

Backup 1: RBI Short Term Upgrades

Relevant upgrades of the RBI facility: 2022 – new dual microprobe:

- Two ion microbeams in the same time:
    - High LET ions from 6.0 MV for damaging or Single Event Effects
    - low LET (protons) from 1.0 MV for targeting coordinates and detector testing
- Electrostatic quadrupoles will enable focussing of higher LET ions:
    - C ions – now 20 MeV, soon 25 MeV
    - Si ions – now 25 MeV, soon 35 MeV
    - Au ions – now 10 MeV, soon 50 MeV





Backup 2: RBI Mid Term Upgrades

Relevant upgrades of the RBI facility: 2023/24 - transfer to the new hall:

- Old tandem van de Graaff to be replaced with modern 6.0 MV tandem
- Higher rigidity magnets (ME/q^2 up to 200 MeV) will enable higher LET heavy ions