RBI microbeam experiment for HVCMOS RD50 MPW2 pixel matrix

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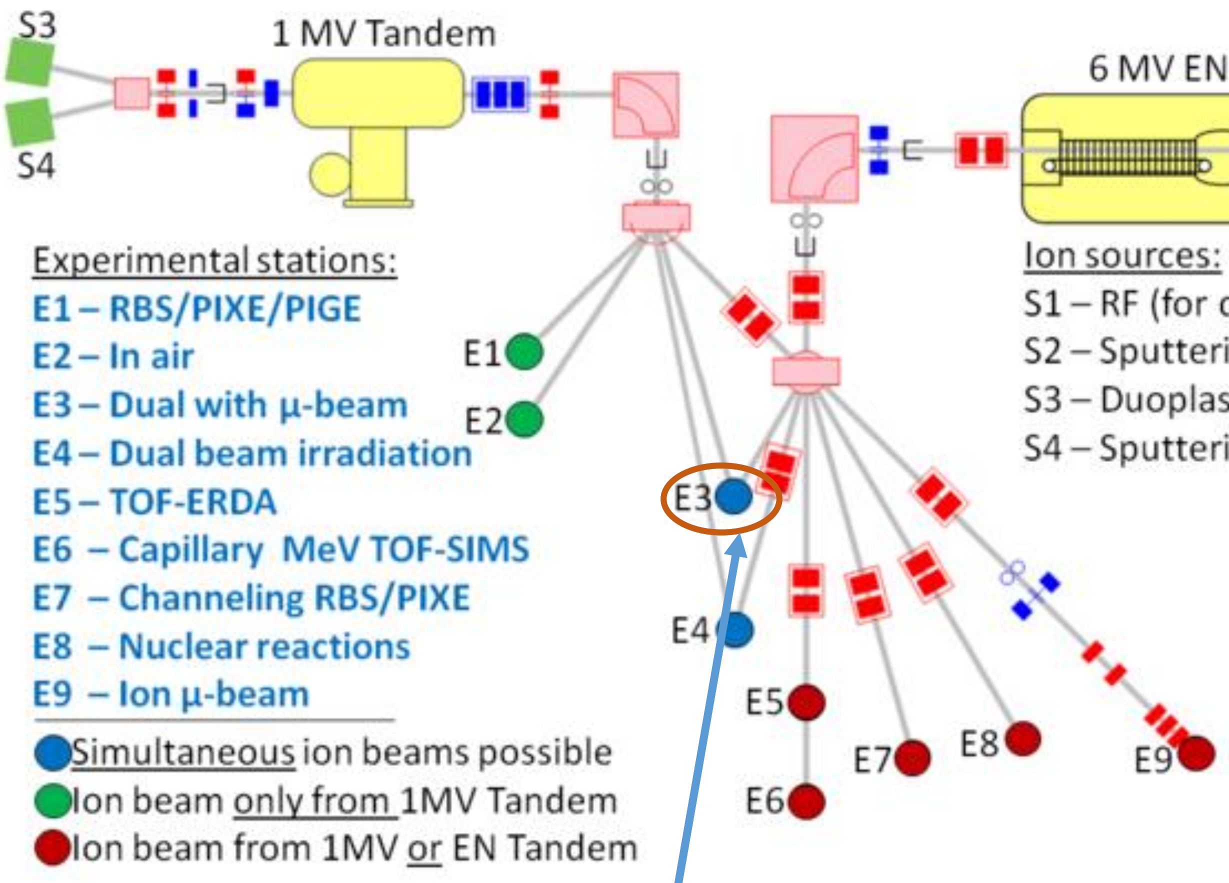
RD50

HELSINKI INSTITUTE OF PHYSICS

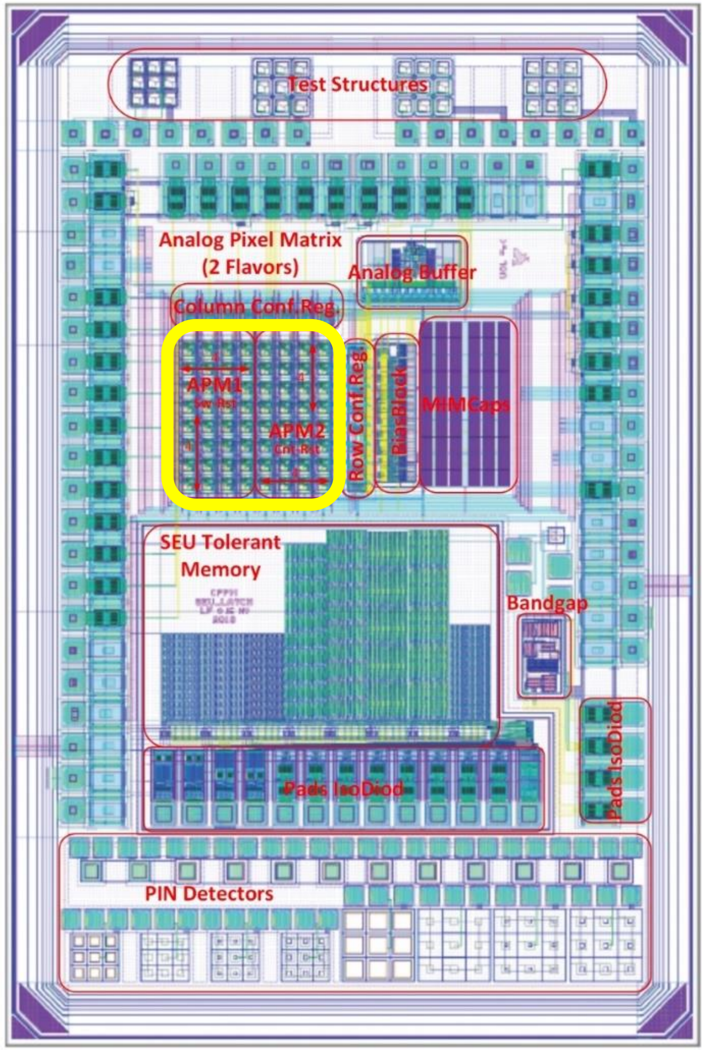
UNIVERSITY OF LIVERPOOL

Testing the MPW2 pixel matrix at RBI microprobe

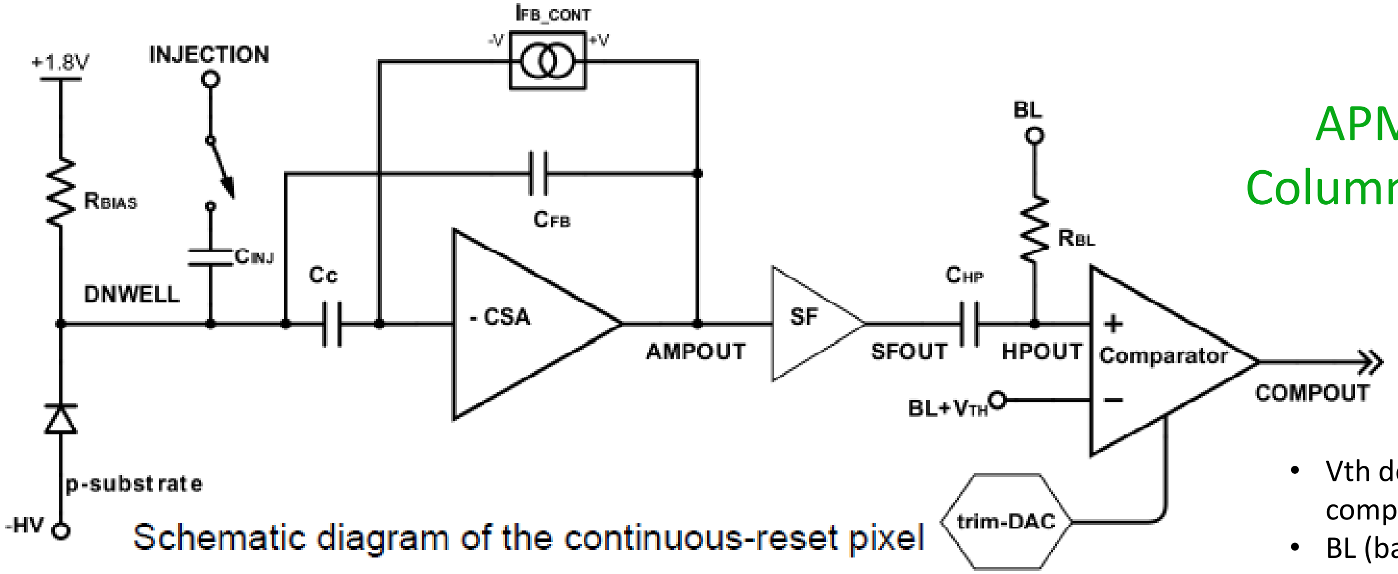


Testing of the Analog Pixel Matrix.

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



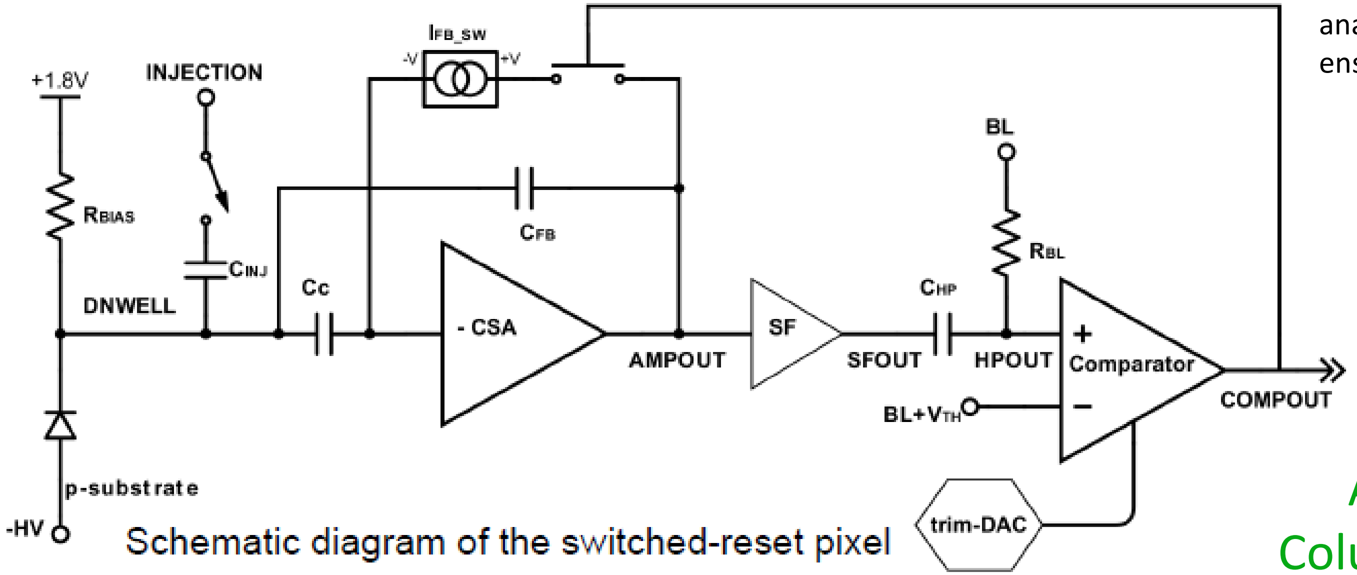
Testing the MPW2 pixel matrix at RBI microprobe



Schematic diagram of the continuous-reset pixel

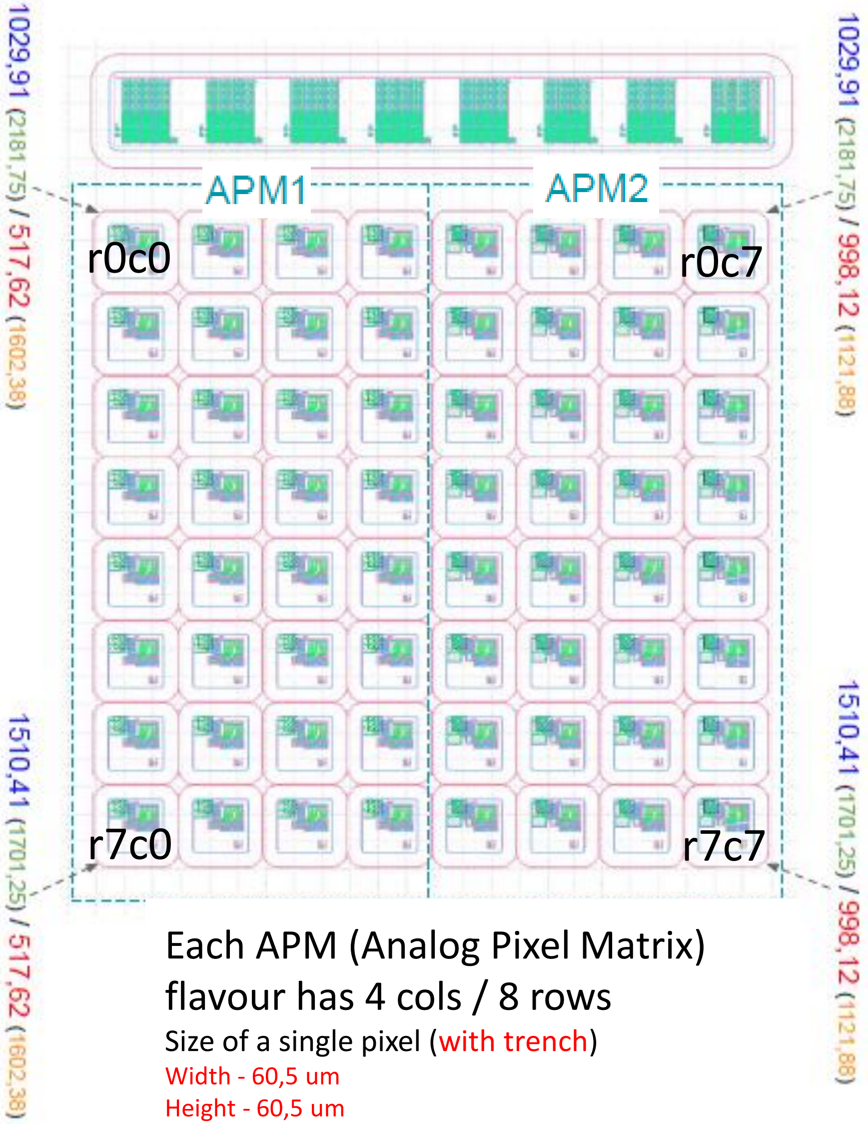
APM1
Columns 0-3

- Vth defines the comparator threshold
- BL (baseline) defines an offset to the analog output to ensure signal stability



Schematic diagram of the switched-reset pixel

APM2
Columns 4-7



Each APM (Analog Pixel Matrix) flavour has 4 cols / 8 rows

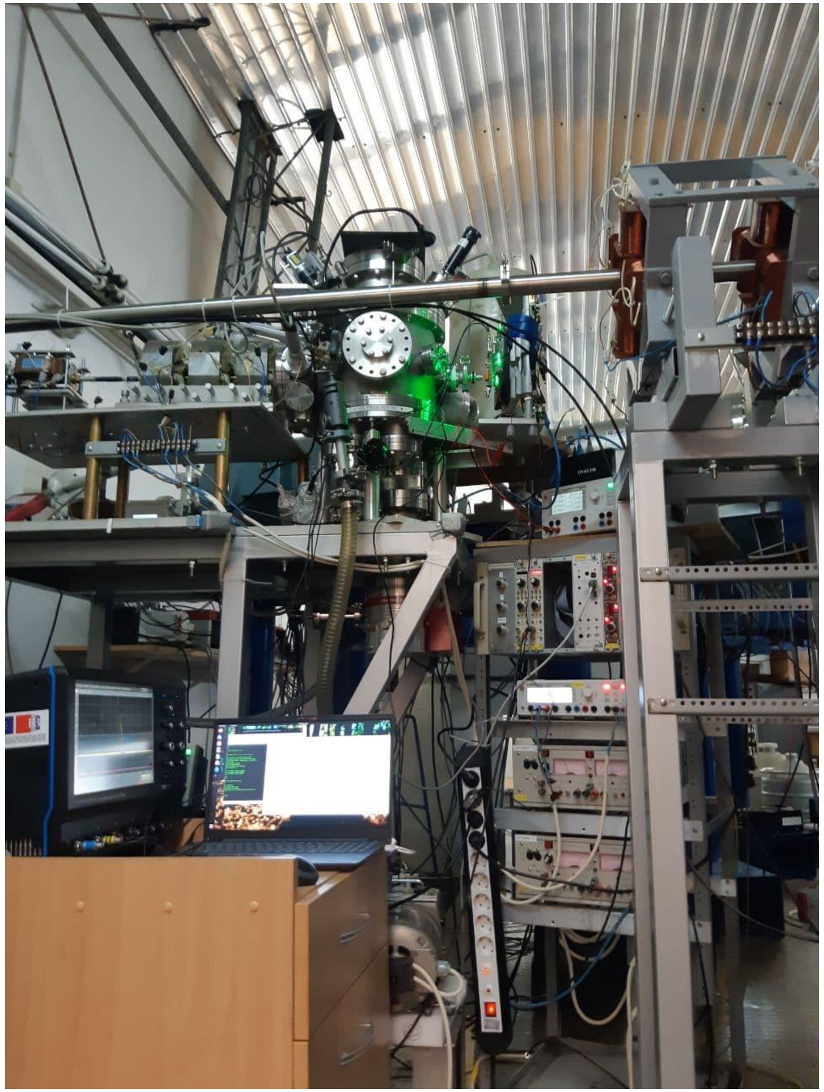
Size of a single pixel (with trench)

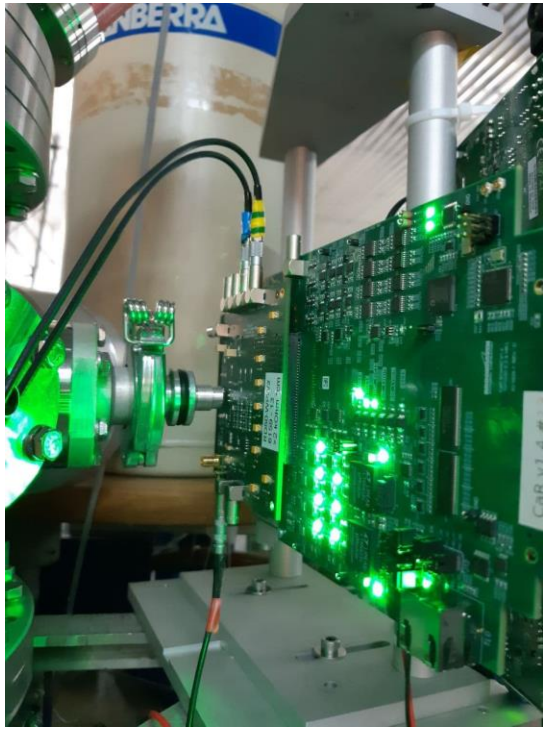
Width - 60,5 um
Height - 60,5 um

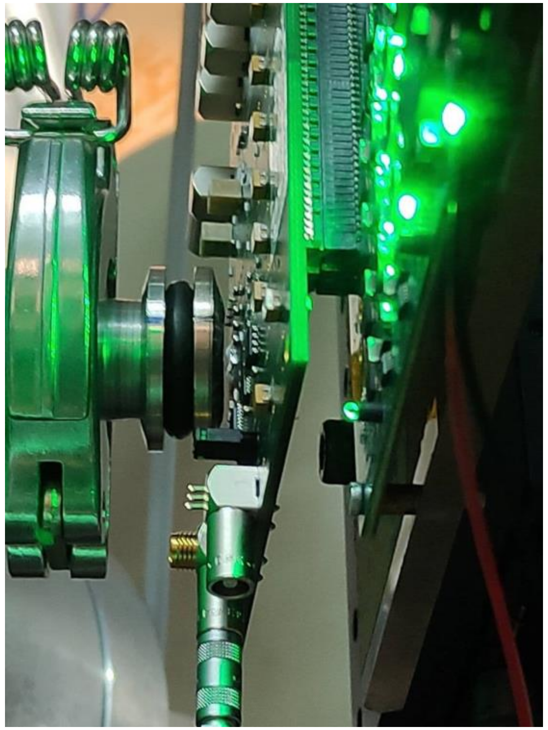
Size of a single pixel (without trench)

Width - 39,68 um   Trench$_W$ - 20,3 um
Height - 39,68 um   Trench$_H$ - 20,3 um

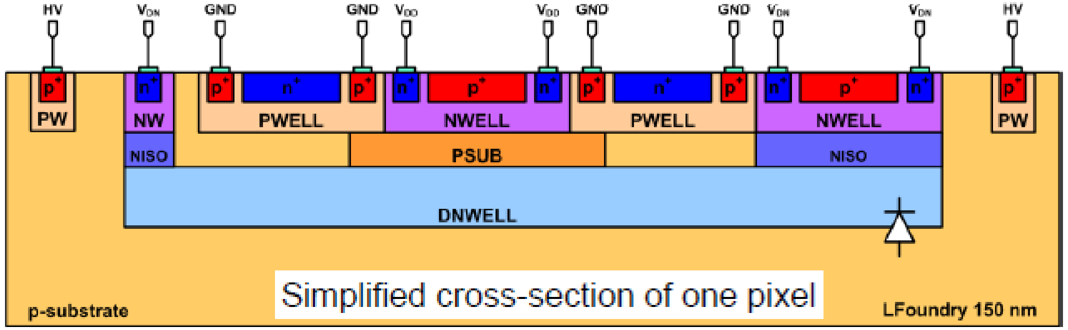
Testing the MPW2 pixel matrix at RBI microprobe





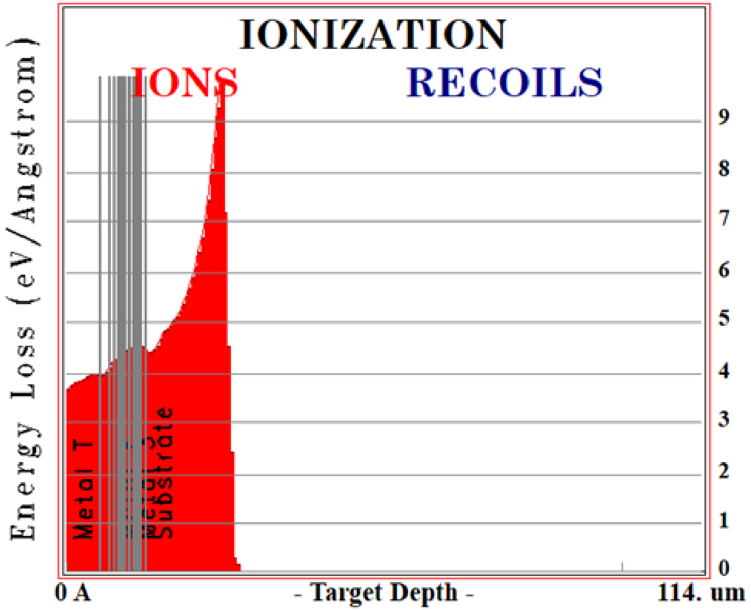


- The MPW2 chip and DAQ setup (Caribou and ZC706 cards) are placed on a holder in front of the external microbeam outport window (Al). Proton Beam Energy at beam pipe out, 2 MeV. Proton beam energy after the Al window (in air) 1.8 MeV

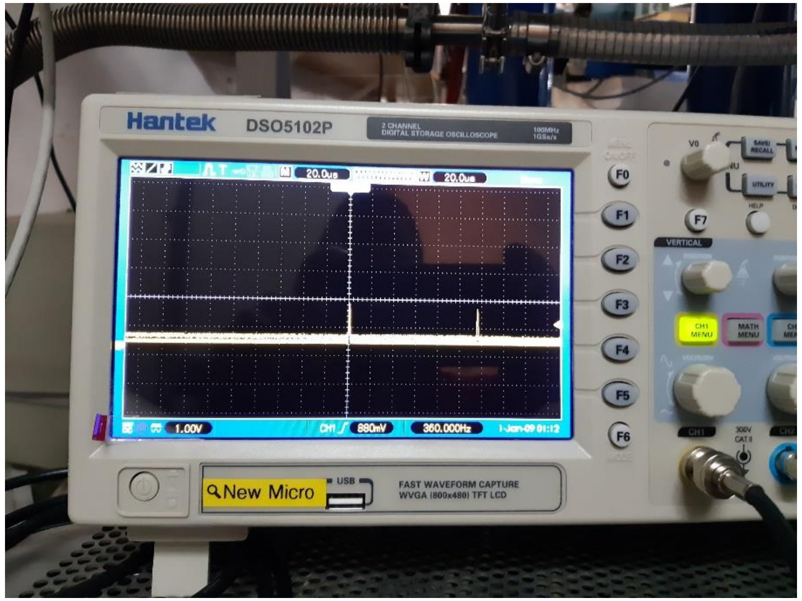


Simplified cross-section of one pixel

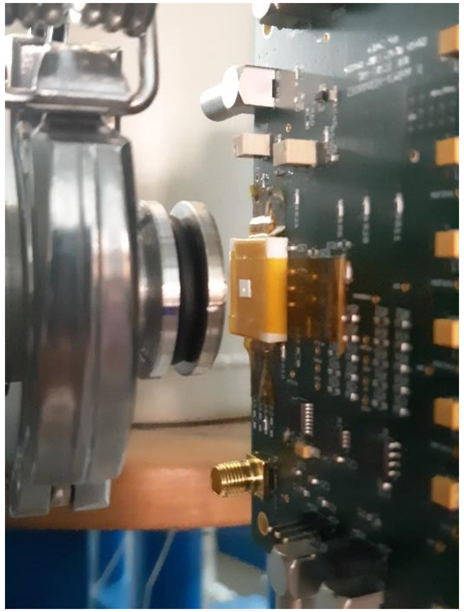
Testing the MPW2 pixel matrix at RBI microprobe



By SRIM we can use up to 1.5 MeV protons

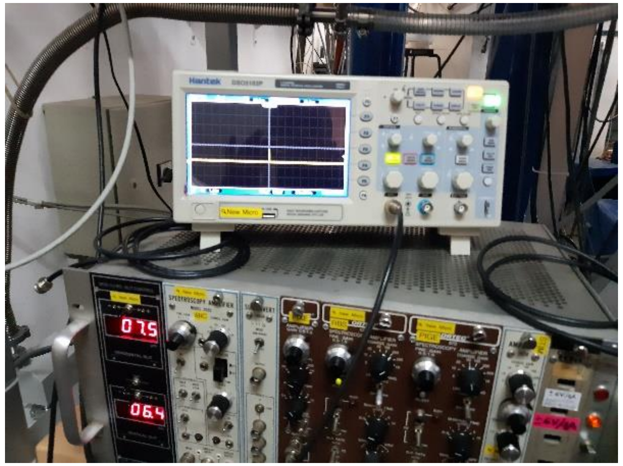


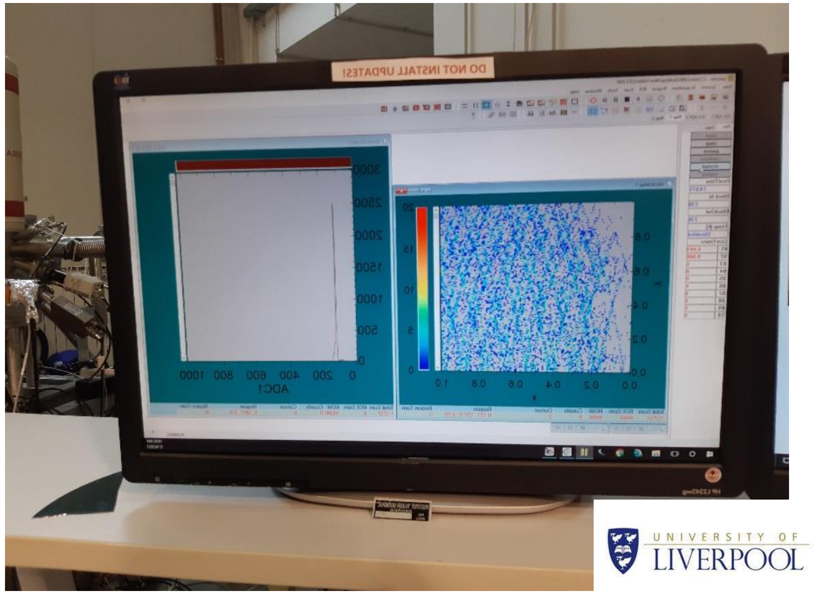
2 MeV Proton Flux control very precise by a local scope looking at the pick up signal



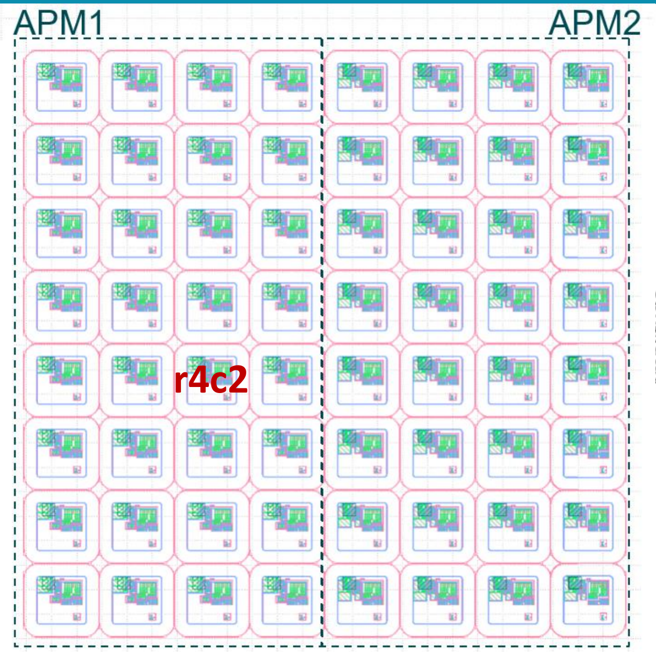
Coarse aiming with a gadolinium scintillator patch

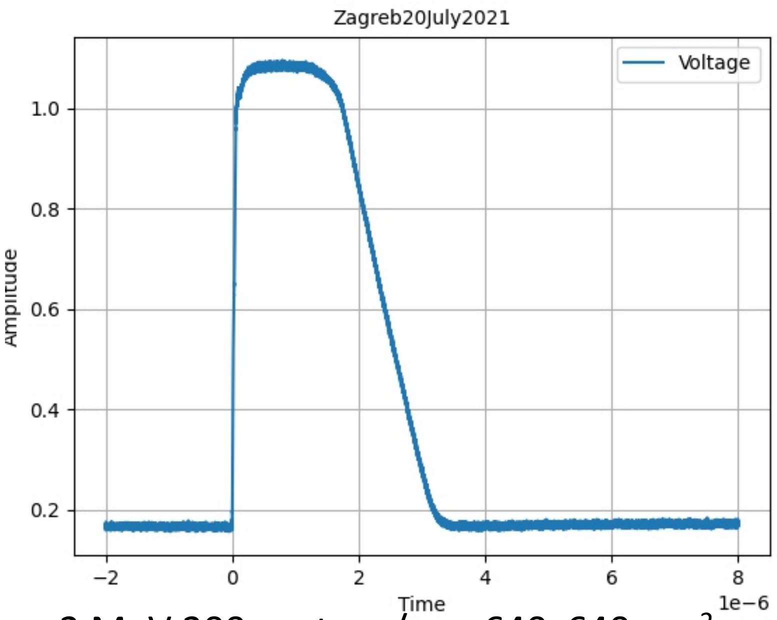
Signals coming from the chosen pixel are routed to the microprobe DAQ to generate MCA histograms and XY maps with the custom Spector software. The beam centroid has a positioning precision of 1.8 µm .





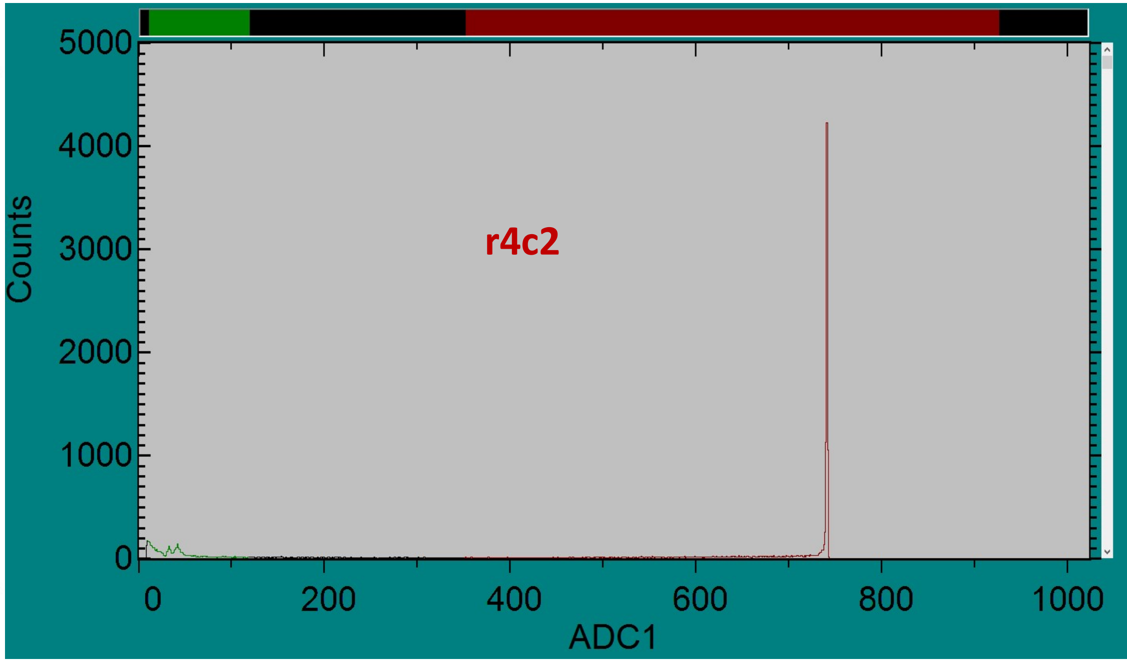
Testing the MPW2 pixel matrix at RBI microprobe

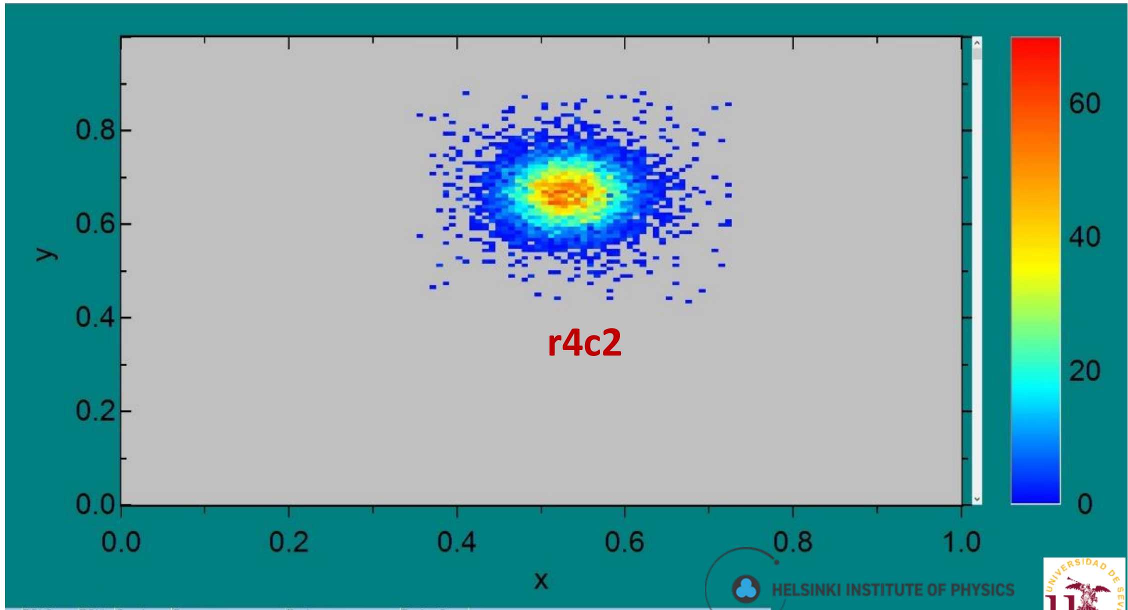




1.44 mV per channel Maximum Max statistical frequency at channel 741
Signal Amplitude 1.07 V

2 MeV 200 protons/sec, 640x640 μm^2 zig-zag scan, 60V bias, 30 μm^2 spot área
1 minute of scanning for each hitmap, (Vth=1050 (1.0256V) for comparator, BL=900 (0.8791 V) for the baseline).

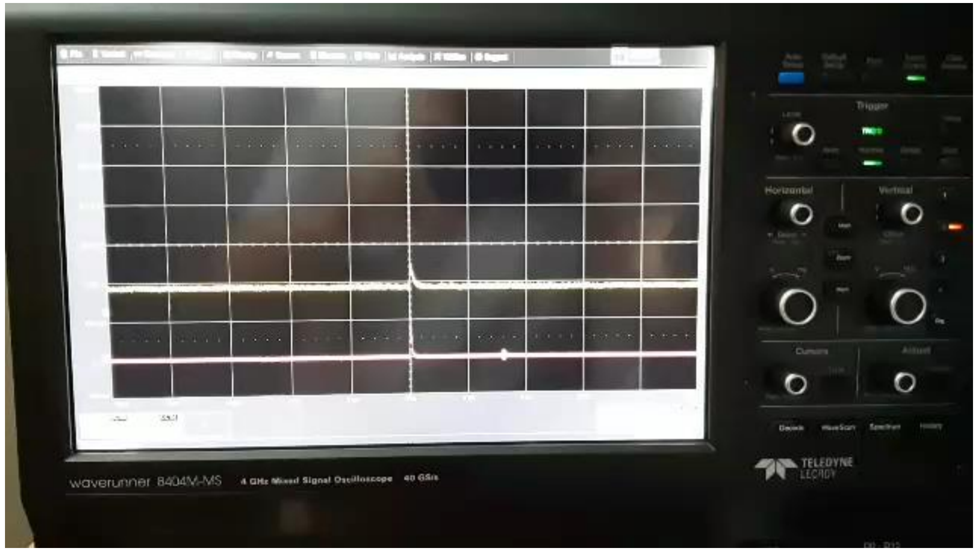


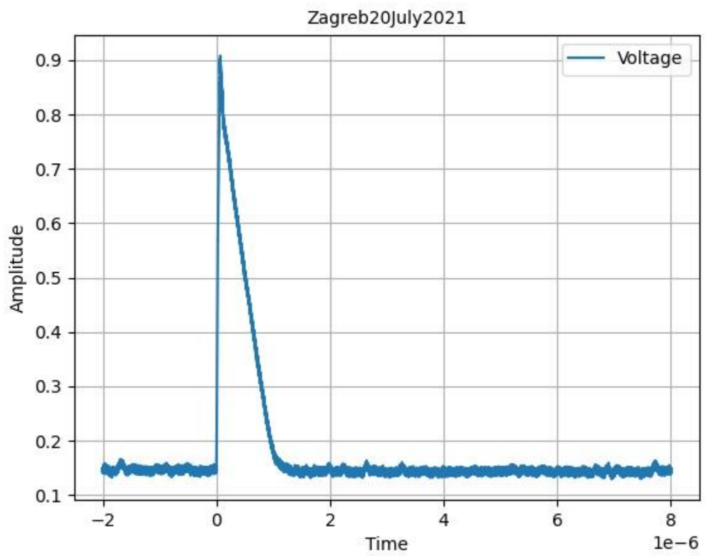


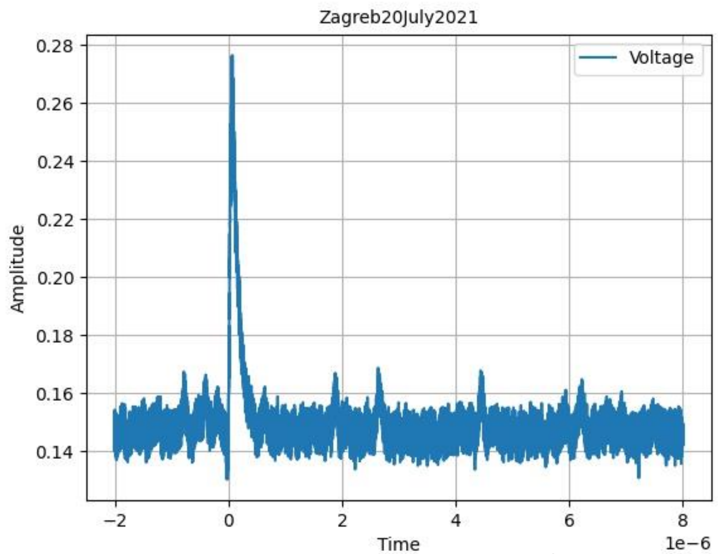
The scope raw signal gives us the calibration for the MCA histogram. The MCA histogram is relevant because inform us about the statistical frequency of signals when we shoot a proton zig-zag pattern. The XY histogram is relevant for aiming and also to know about posible halo effects.

Testing the MPW2 pixel matrix at RBI microprobe

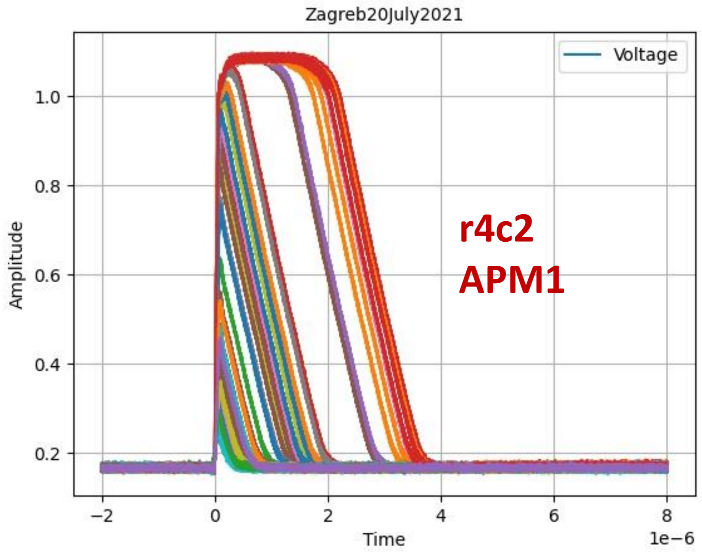
Scope Capture triggered by the detector signal raising edge (yellow signal in the movie)

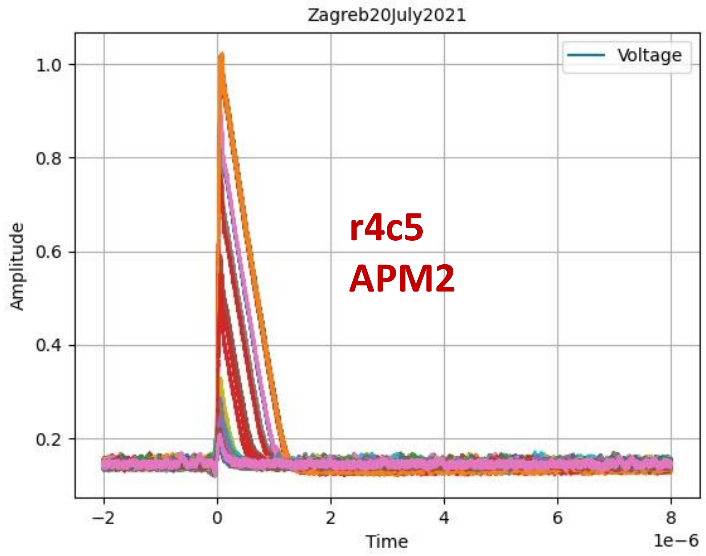




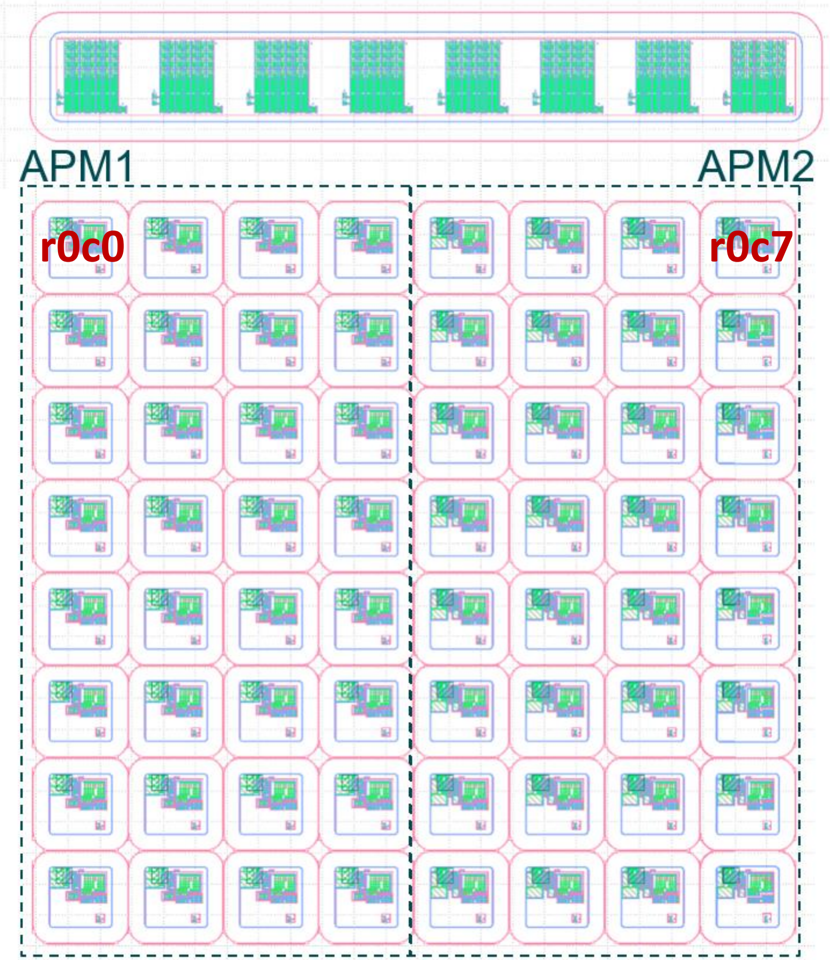


2 MeV 200 protons/sec, 640x640 μm2 zig-zag scan, 60V bias, 30 μm^2 spot area
1 minute of scanning for each hitmap, Vth=1050 (1.0256V), BL=900 (0.8791 V) for the comparator signal (pink in the scope movie).





Testing the MPW2 pixel matrix at RBI microprobe



Each APM flavour has 4 cols / 8 rows

Size of a single pixel (with trench)
Width - 60,5 um
Height - 60,5 um

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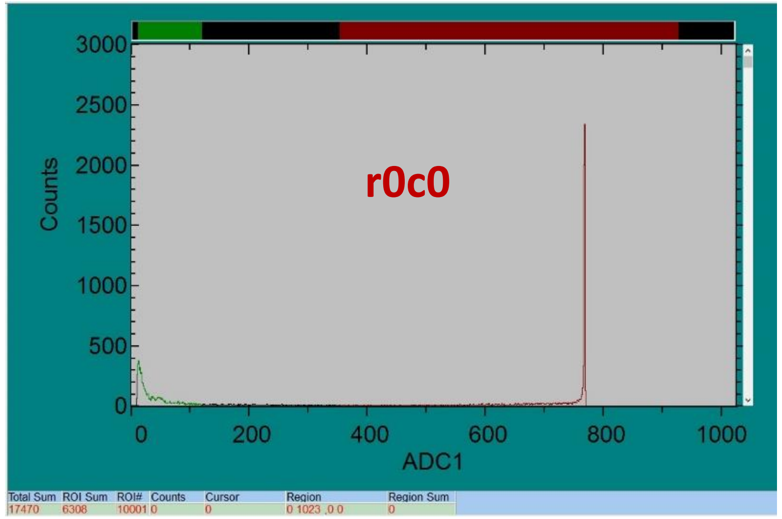
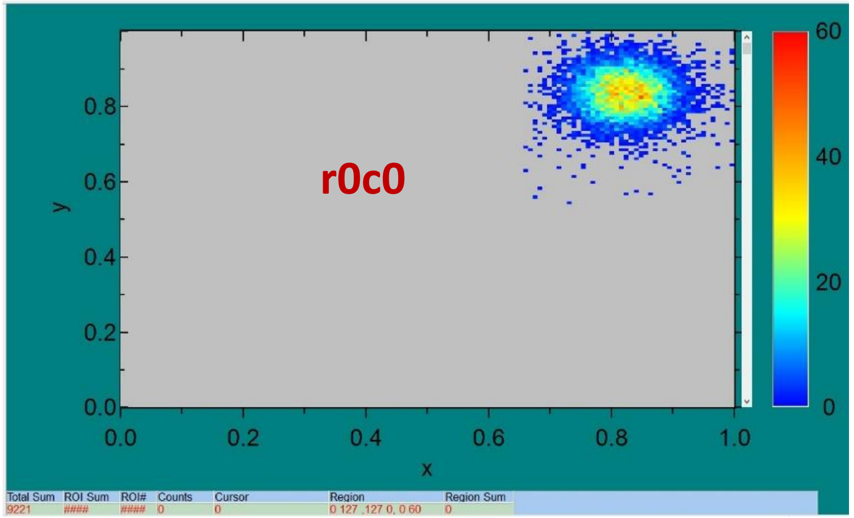
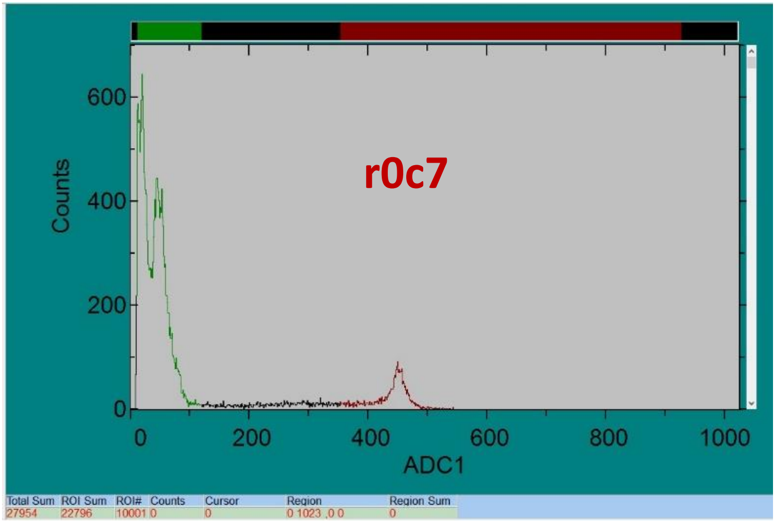
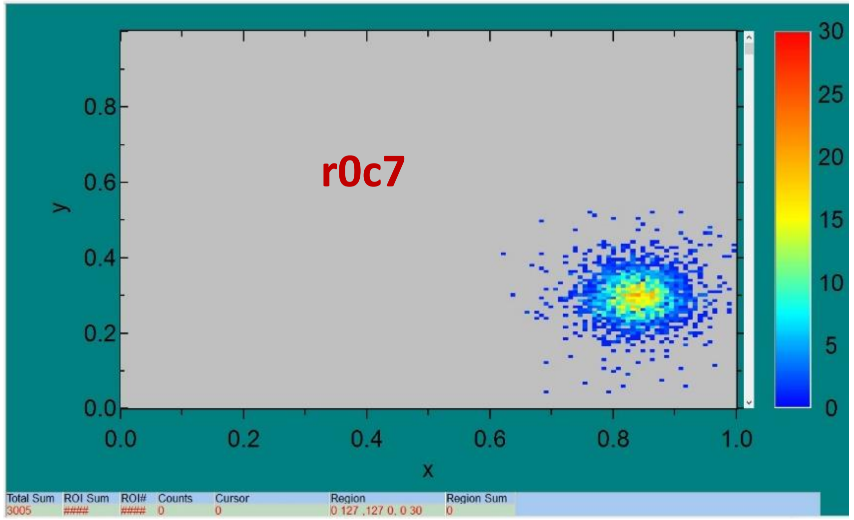




2 MeV 200 protons/sec, 640x640 μm2 zig-zag scan, 60V bias, 30 μm^2 spot area
1 minute of scanning for each hitmap, Vth=1050 (1.0256V), BL=900 (0.8791 V)





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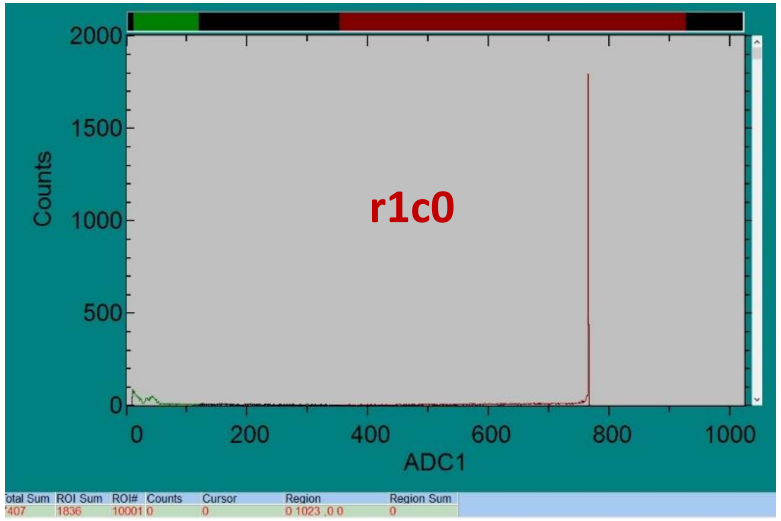

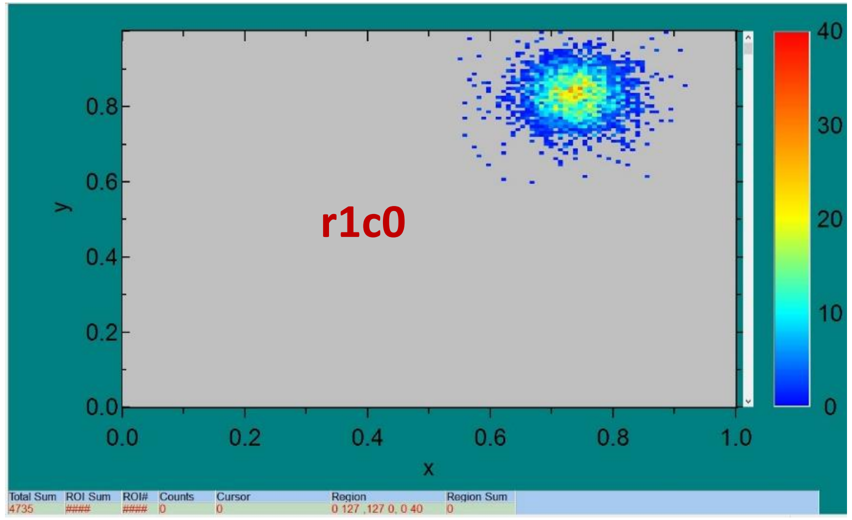

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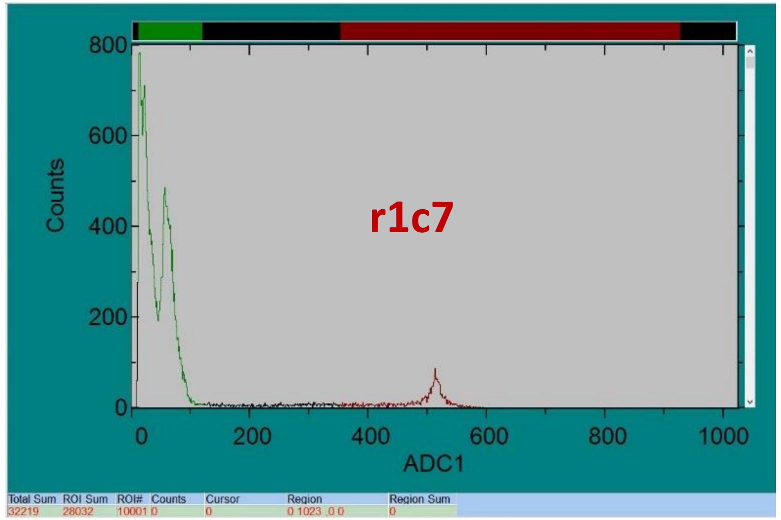

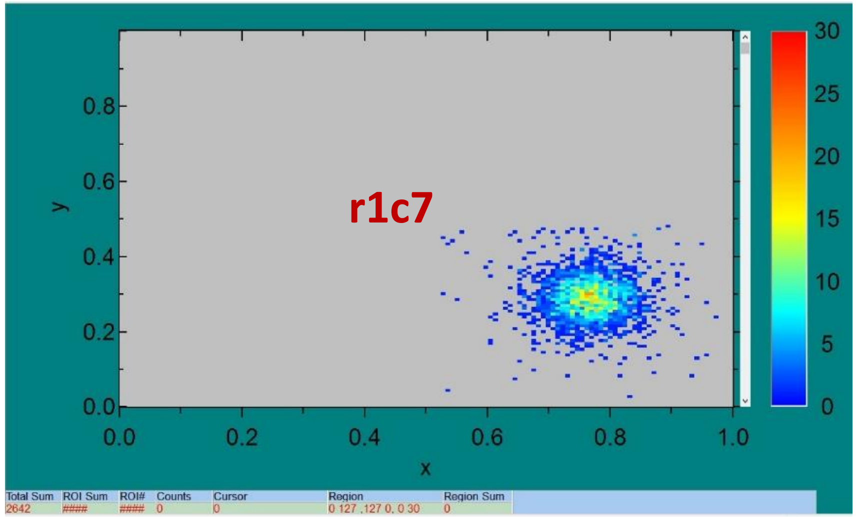

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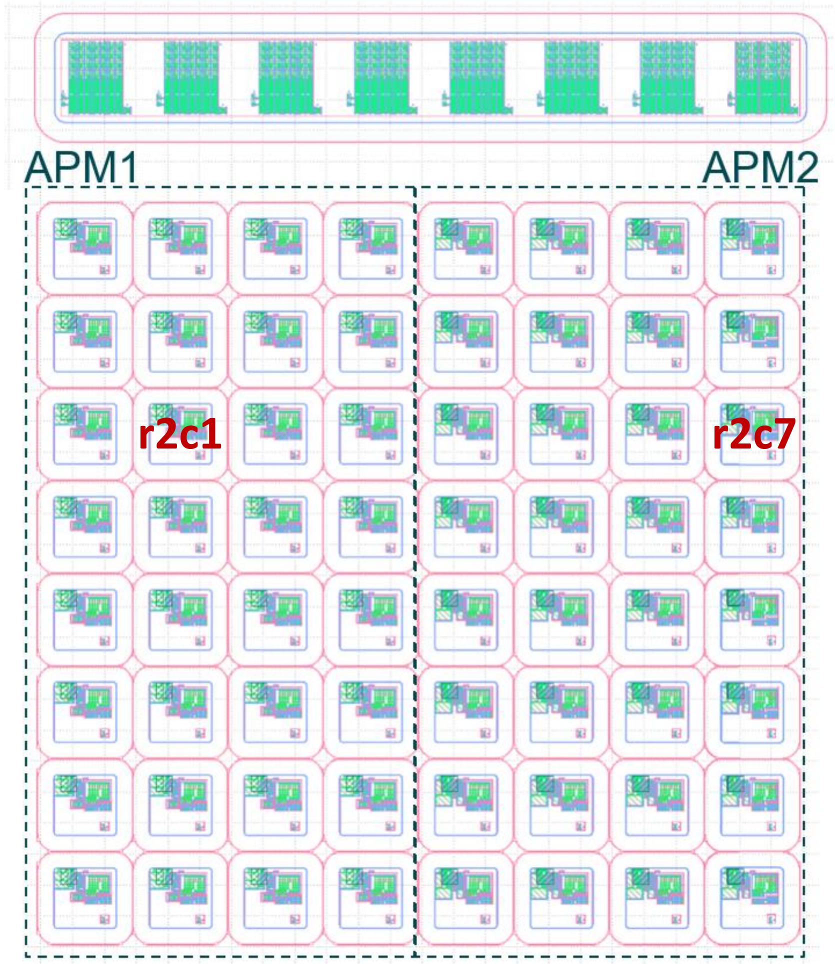

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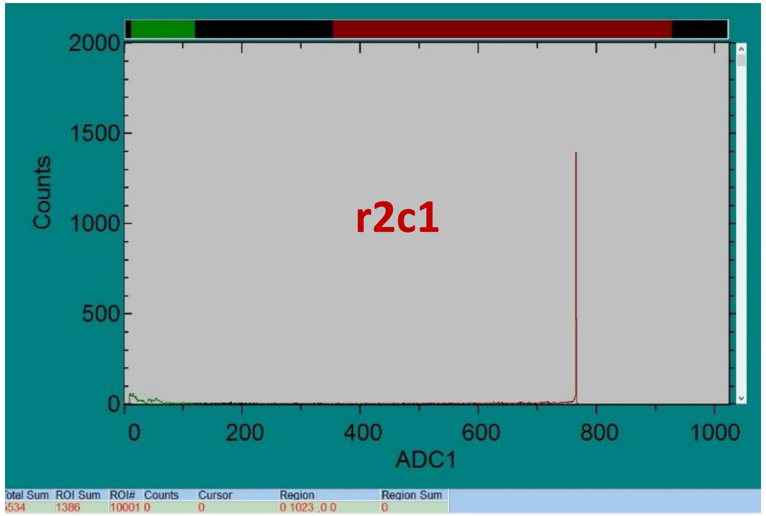

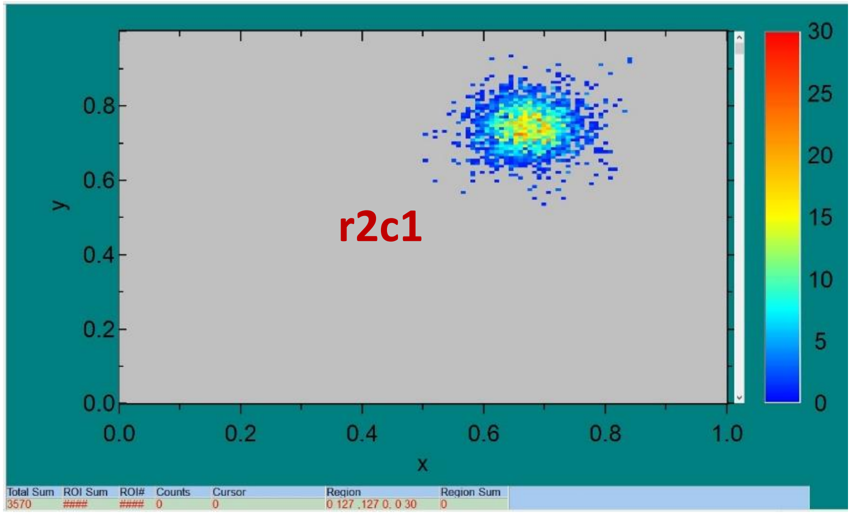

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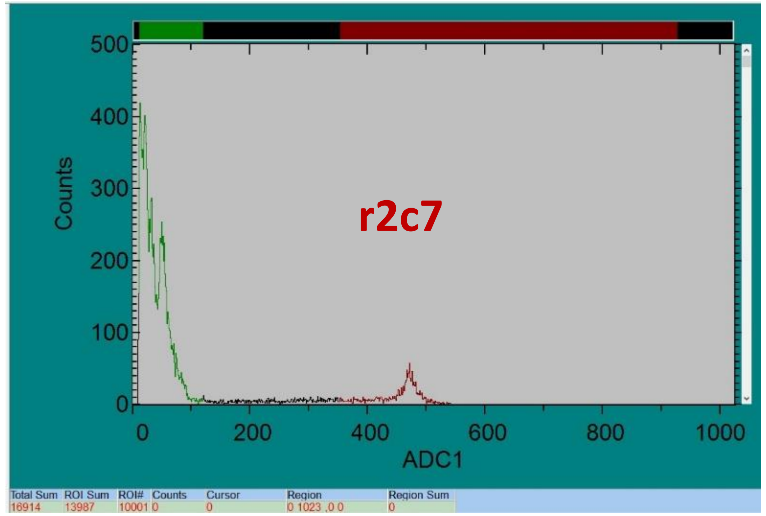

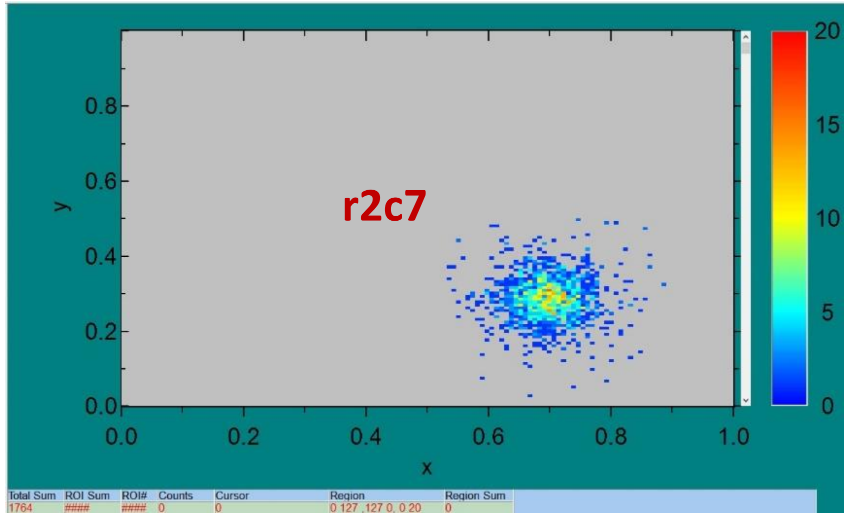

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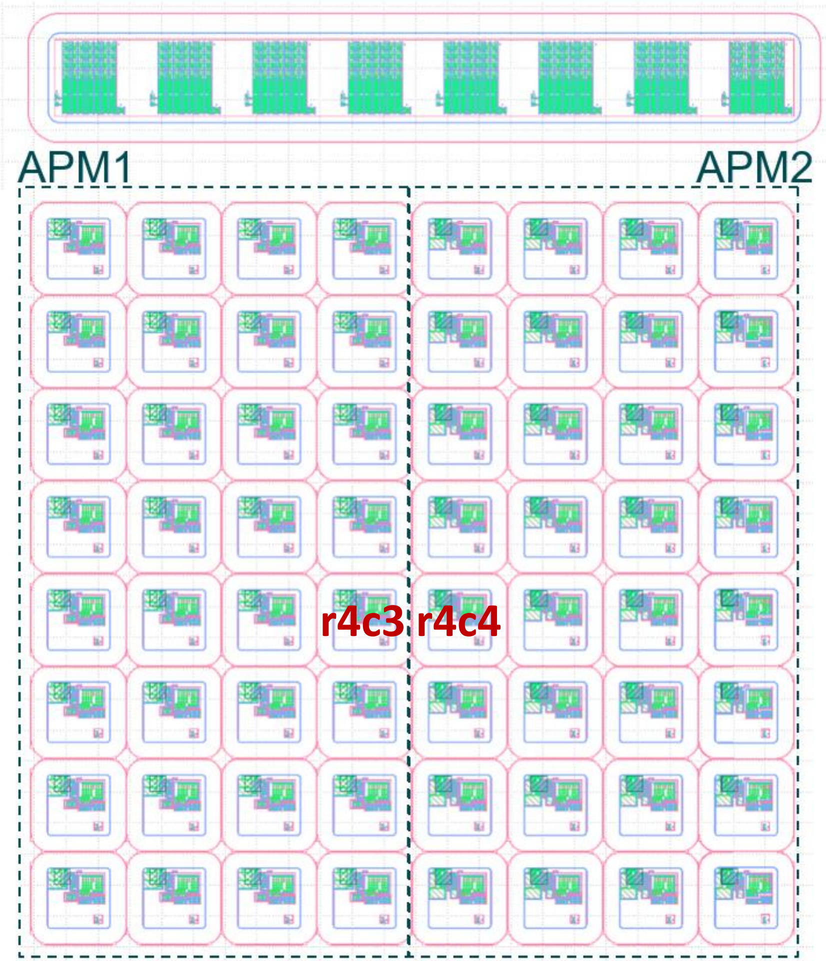

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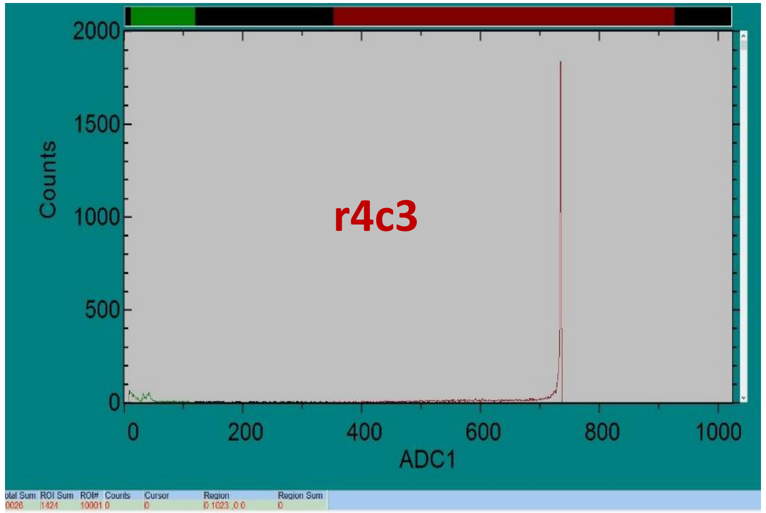

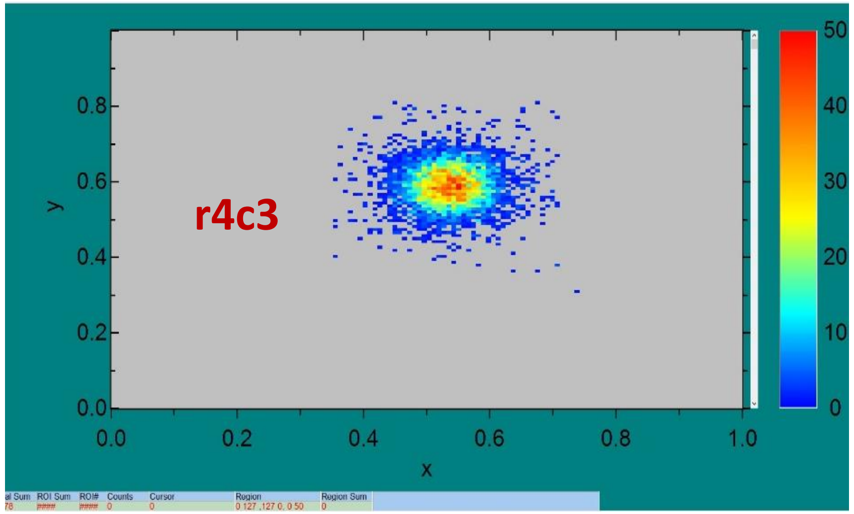

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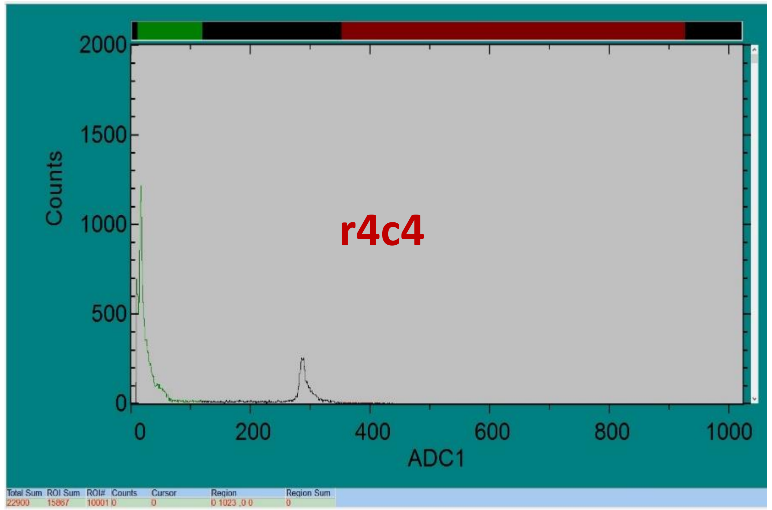

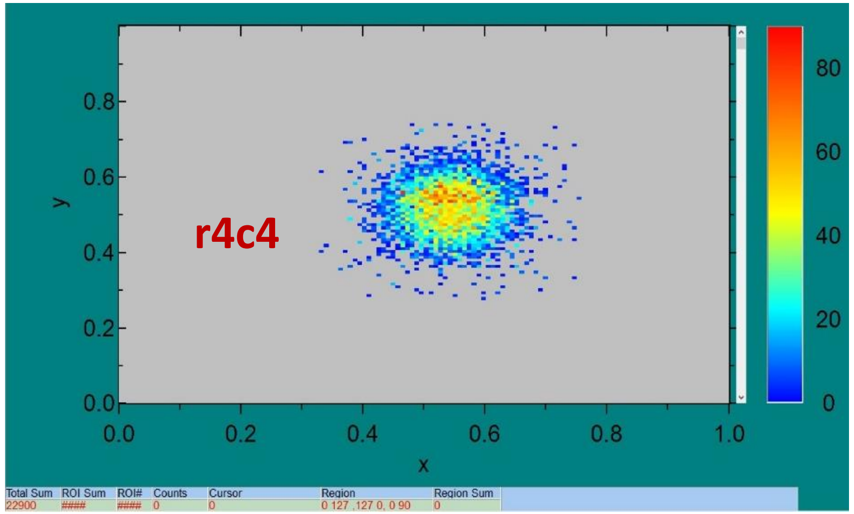

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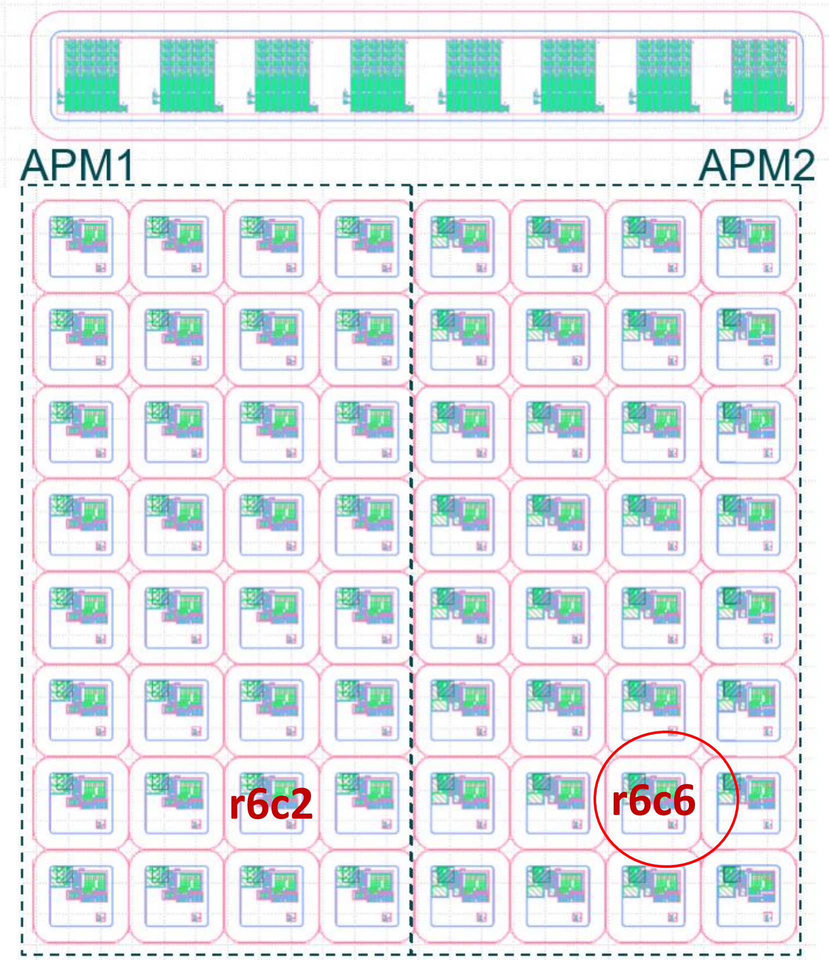

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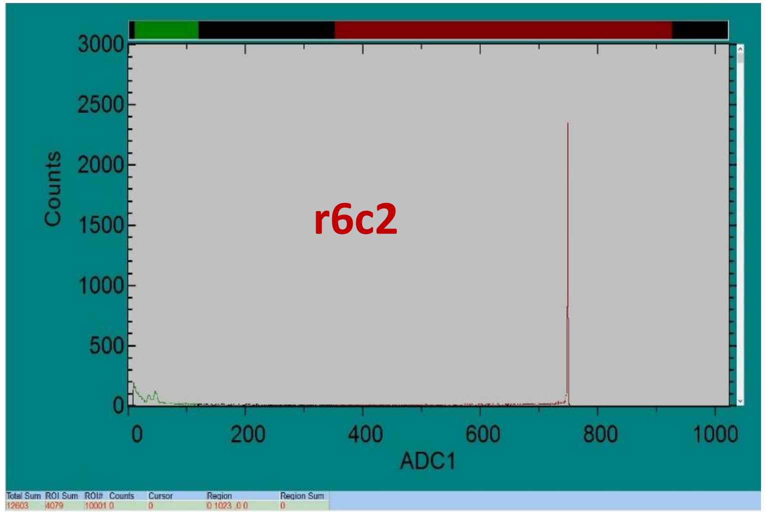

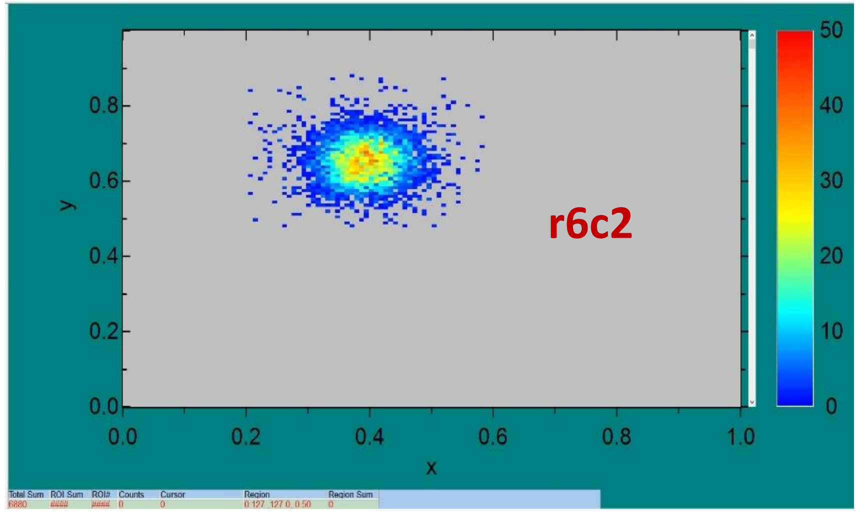

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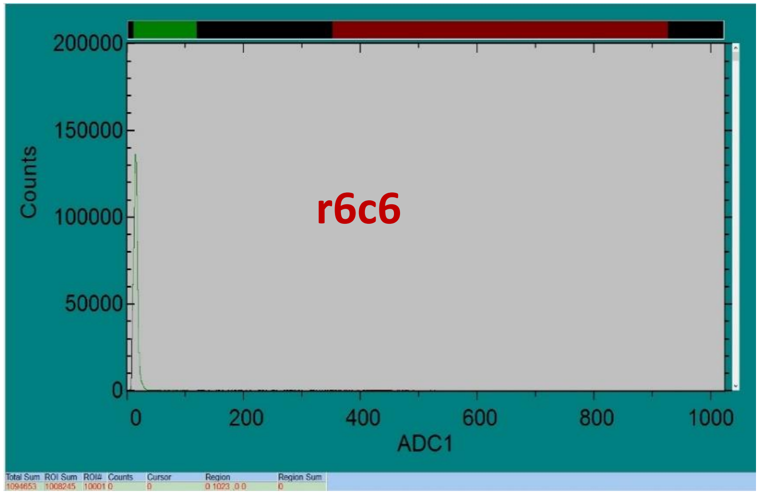

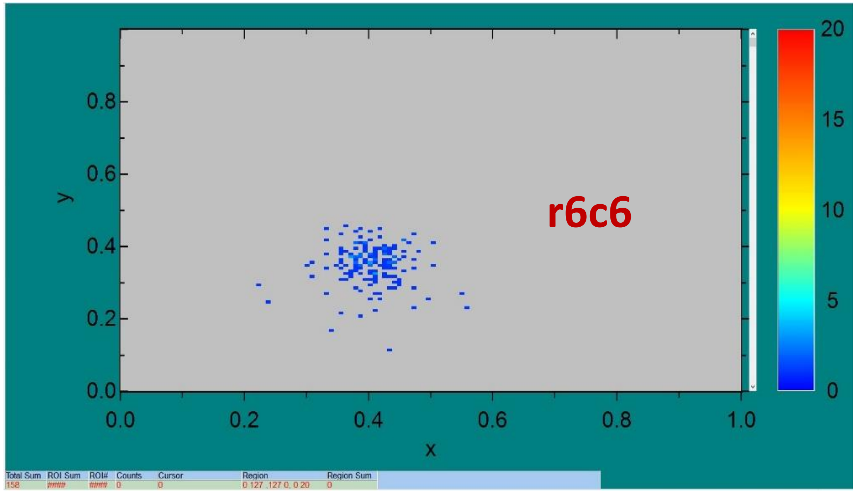

Testing the MPW2 pixel matrix at RBI microprobe

- First Testing of a monolithic pixel sensor in a microbeam (protons 2MeV)
- Flux control (200 protons/sec) is more important than XY precisión for pixel characterization
- MCA histograms show clearly the relevance of each pixel signal
- XY histograms informs about “halo detections”
- We see too many small amplitude signals, possible SETs?, to be further analyzed by circuit simulation (AFTU tool) from the design schematics.

Thanks for your attention!

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aneliya.karadzhinova@cern.ch

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and Project COMRAD-2, Spanish National
Science Programme, RTI2018-099189-B-C21

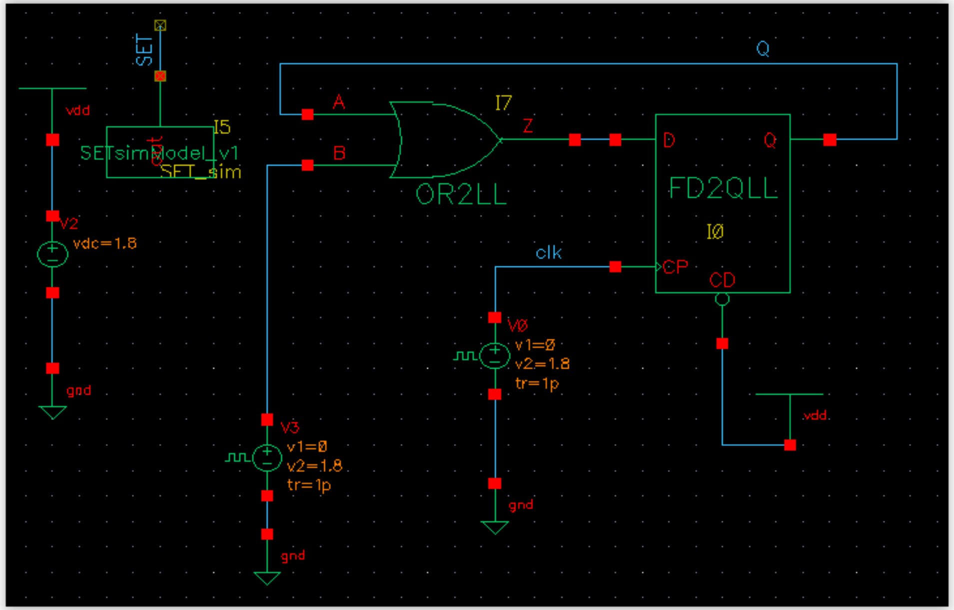
Spare Slides

What is AFTU?

The Analog FTU Hardware Debugging System
is a software tool to evaluate the SEE sensitivity
of analog/mixed signal circuits
at transistor level

How does it work?

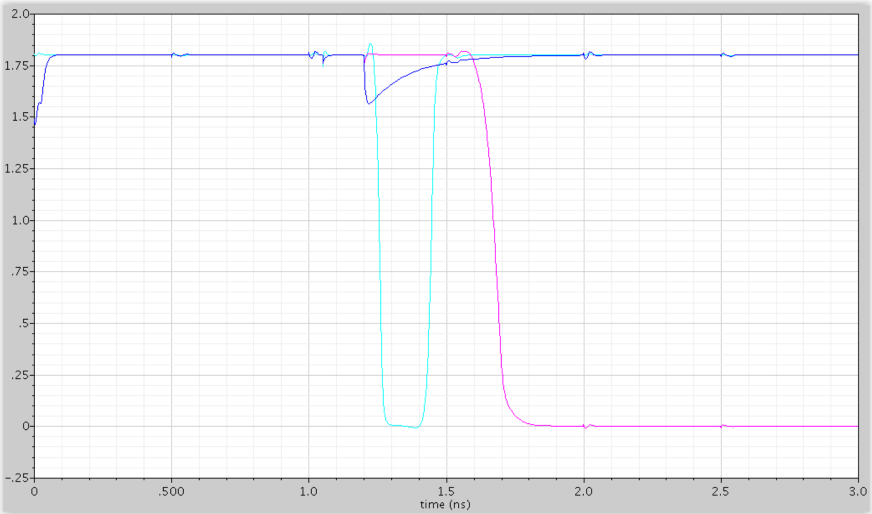
AFTU parses a Spectre design netlist...

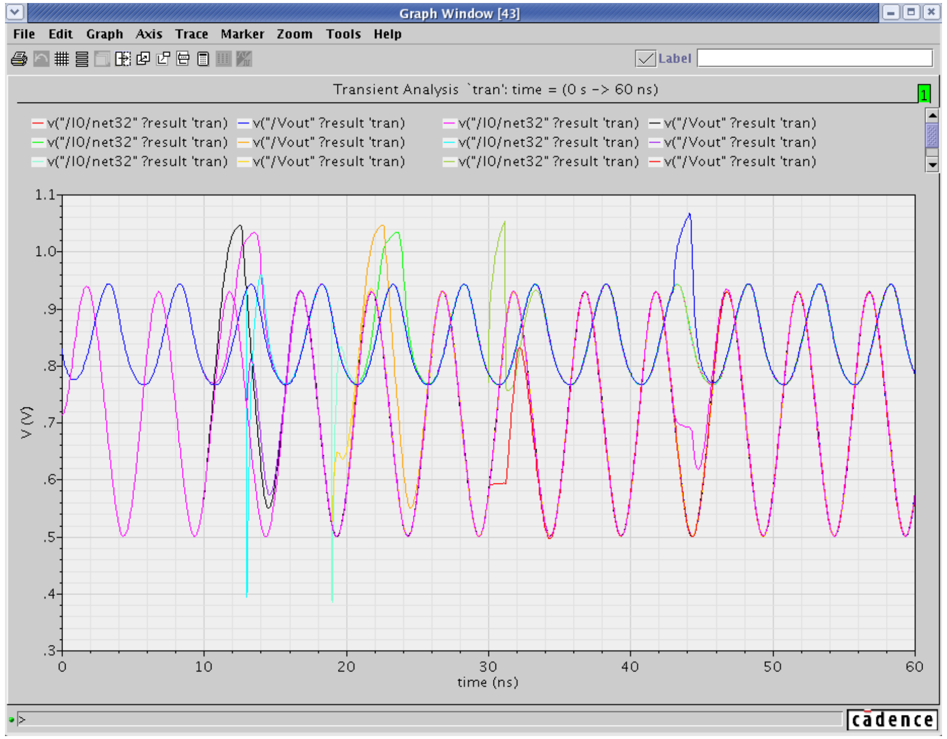


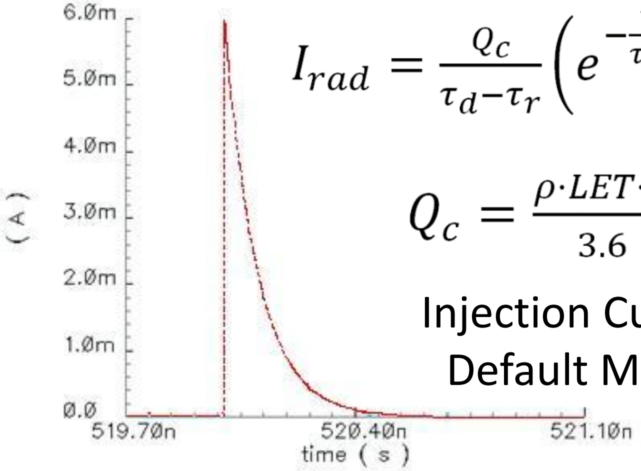
...to generate a parametric simulation Ocean script

-Analysis of Transient Effects in Analogue Topologies, F.Marquez, F.Muñoz, F.R.Palomo, M.A.Aguirre and M.Ullán, AMICSA 2012, Noordvijk, Netherlands 26th -28th August 2012, http://microelectronics.esa.int/amicsa/2012/amicsa2012.htm
-Automatic inspection of SET sensitivity in analog cells, F.Márquez, F.Muñoz, M.A.Aguirre, F.R.Palomo and M.Ullán, SMACD'12, Sevilla, Spain, 19th-21st Sept. 2012 http://www2.imse-cnm.csic.es/~smacd2012/SMACD_2012/HOME.html
-AFTU, an analog single event effects automatic analysis tool, F.Marquez, L.Sanz, F.R.Palomo, F. Muñoz and M.A.Aguirre, AMICSA 2014, CERN, Switzerland, 30th June-1st July 2014, https://indico.cern.ch/event/277669/
-Automatic Single Event Effects Sensitivity Analysis of a 13-Bit Successive Approximation ADC, F.Márquez, F.Muñoz, F.R.Palomo, L.Sanz, E.López-Morillo, M.Aguirre and A.Jiménez, **IEEE Transactions on Nuclear Science,62(4) 2015, pp.1609-1616**

…emulates Single Event Effects…







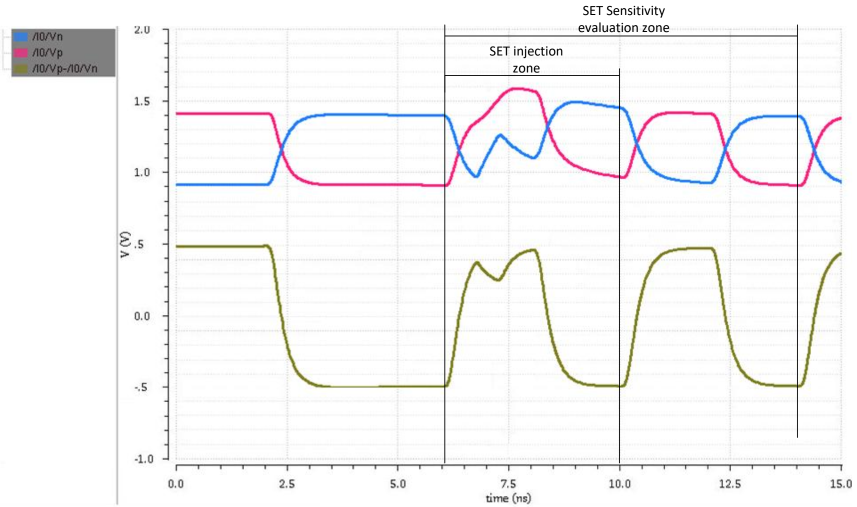
$$I_{rad} = \frac{Q_c}{\tau_d - \tau_r}\left(e^{-\frac{\tau}{\tau_d}} - e^{-\frac{\tau}{\tau_r}}\right)$$

$$Q_c = \frac{\rho \cdot LET \cdot d}{3.6}$$

Injection Current
Default Model

An injection current source at every node or at user selected nodes is the way to emulate the SEE. The injection source model can be changed.

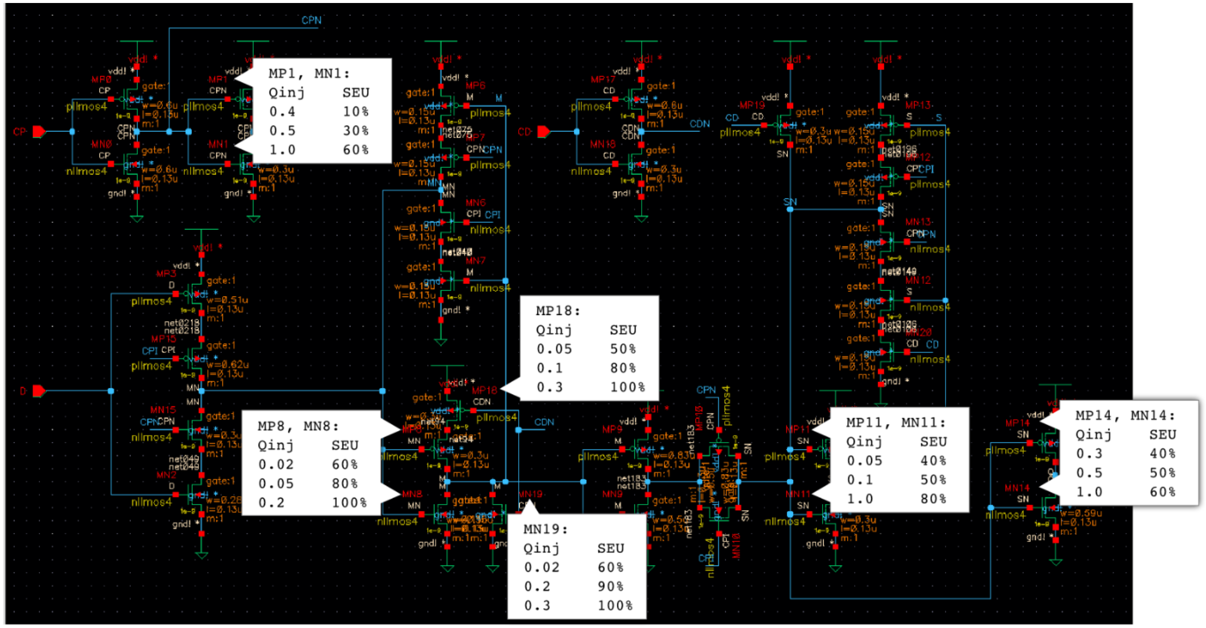
... and evaluates vulnerabilities



- The user defines injection and evaluation zones
- and select the appropriate hard coded heuristic to analyze the parametric simulation results

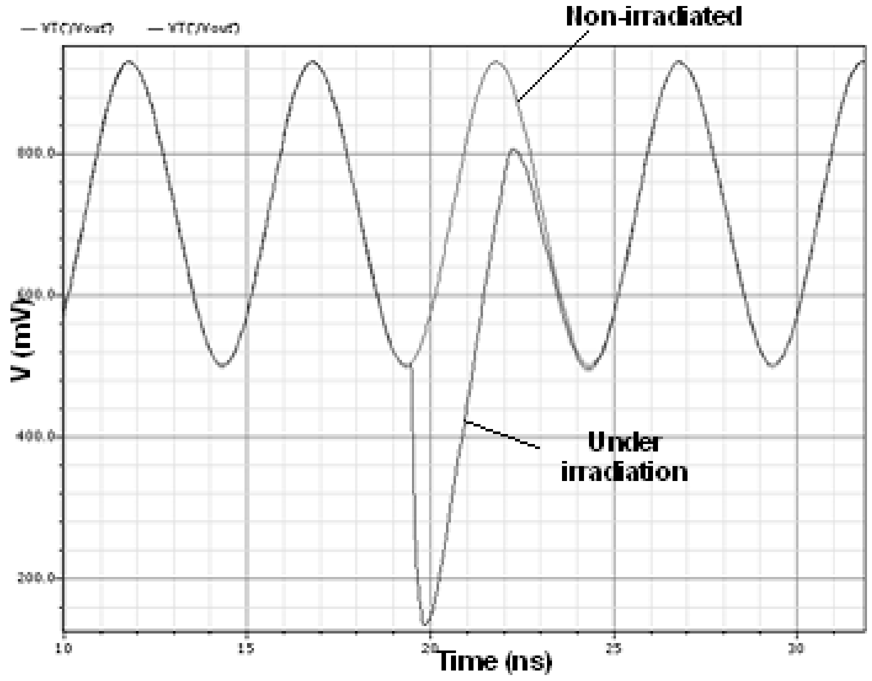
D-latch circuit , STMicroelectronics 130 nm

- The final result is a list of vulnerabilities (in terms of the heuristic) for each user selected node in the design.



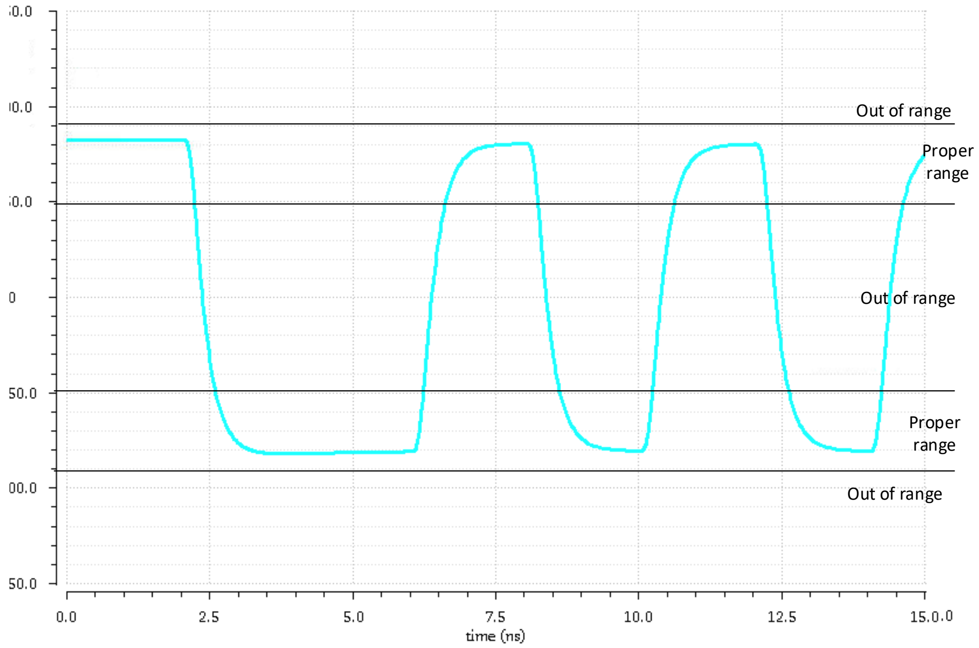
Hard Coded Heuristics

Deviation Recovery
(ex. analog circuits SET’s)



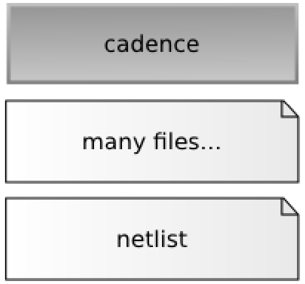
- Recovery Time
- Signal Voltage Deviation

Time Ranges
(ex. digital SEU’s & differential circuits SET’s)



- Total time between up to 4 signal thresholds

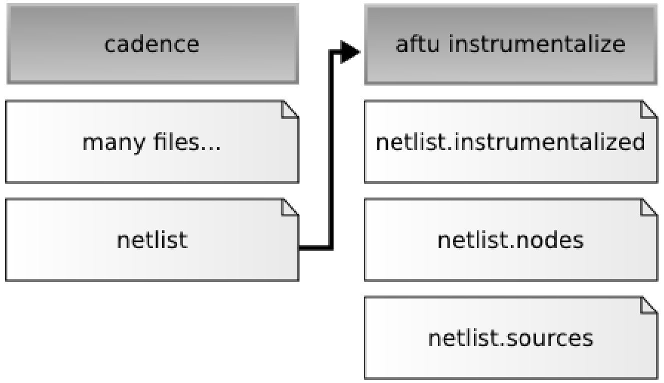
AFTU ToolChain



Before using AFTU:

- The user designs a circuit with Cadence as usual.
- The design is simulated through a testbench.
- Of all files generated by Cadence, we pick the **netlist**.

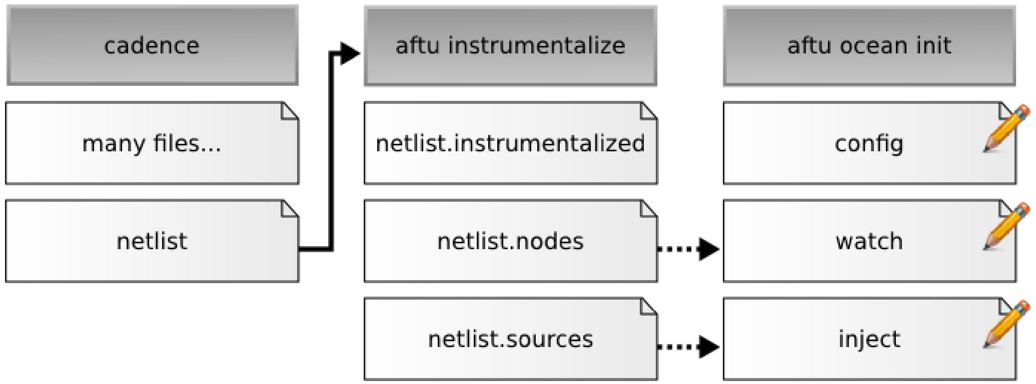
AFTU instrumentalize



The instrumentalizer implements a parser for the SPECTRE language

- Replaces the **netlist** with a *functionally identical* one allowing radiation emulation.
- **netlist.nodes** lists all observable circuit nodes.
- **netlist.sources** lists all transistors where an impact can be emulated.

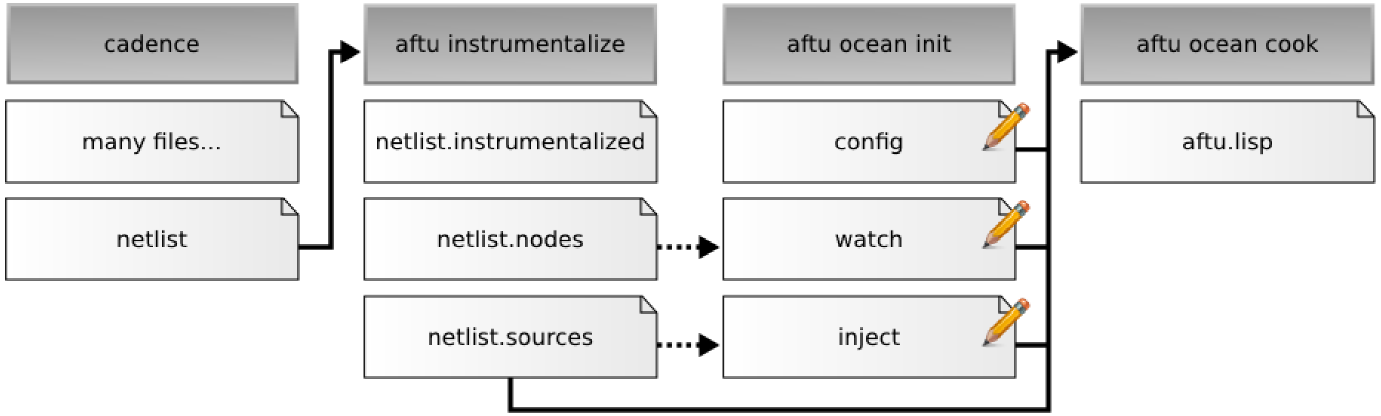
AFTU ocean init



AFTU projects are flexible and give the user many options for analysis.

- **config** contains paths, times, heuristics, initial values…
- **watch** defines all elements in the circuit to be observed during the simulation
- **inject** defines where, when and how much charge we inject (SEE emulation).

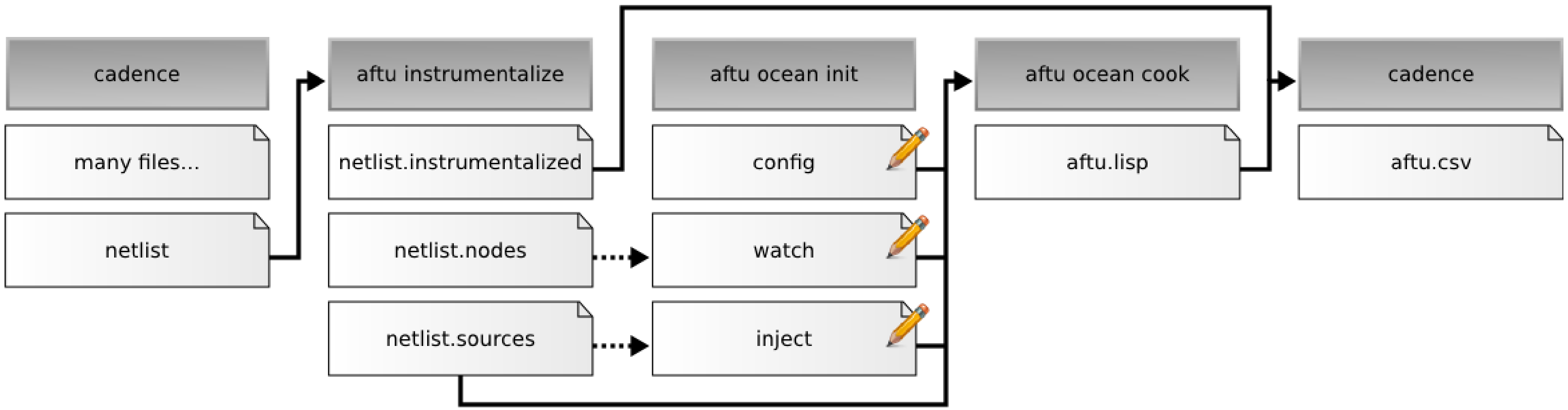
AFTU Ocean cook



From all this data an Ocean simulation script is produced

- Includes all paths and required data.
- Describes the way to perform the user defined test campaign.
- Defines how to analyze the results of the campaign.

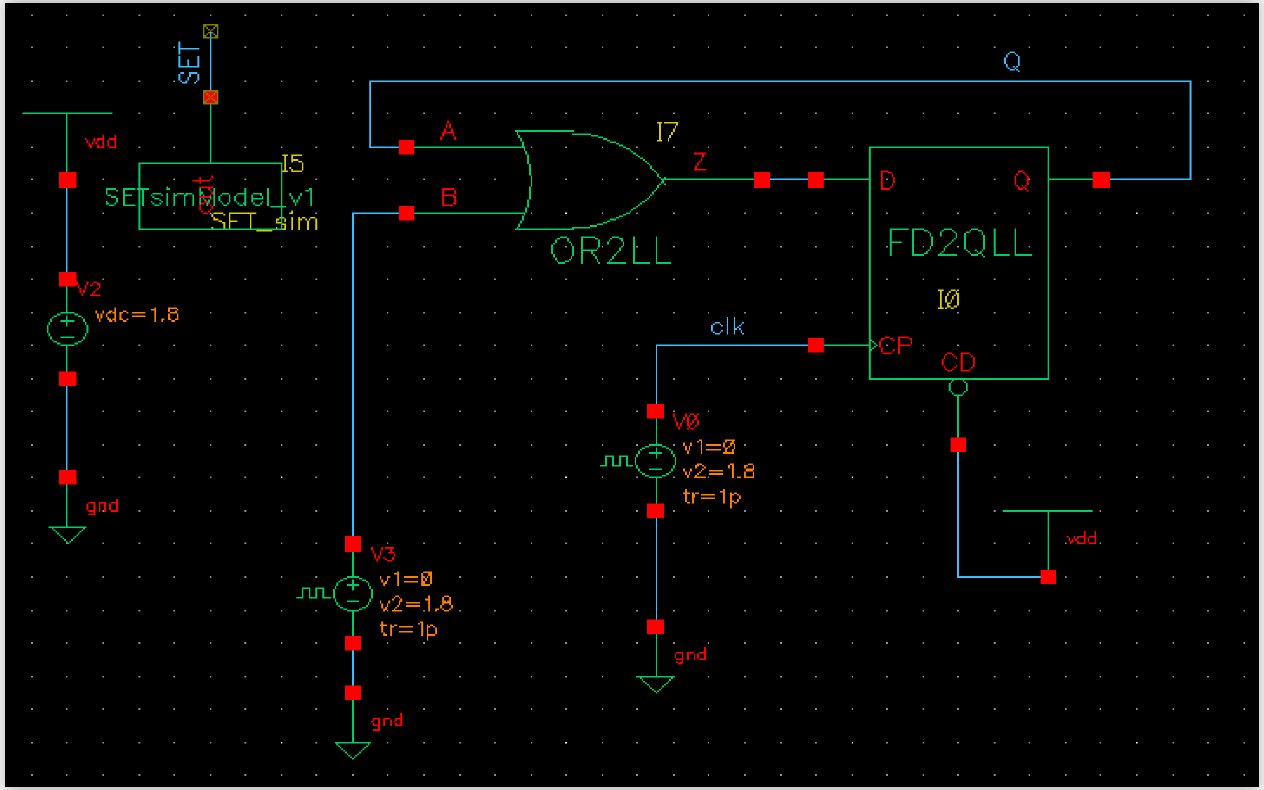
AFTU campaign



Cadence runs the provided script.
It produces a CSV file with the desired statistics.
This uncovers radiation vulnerabilities in the circuit.

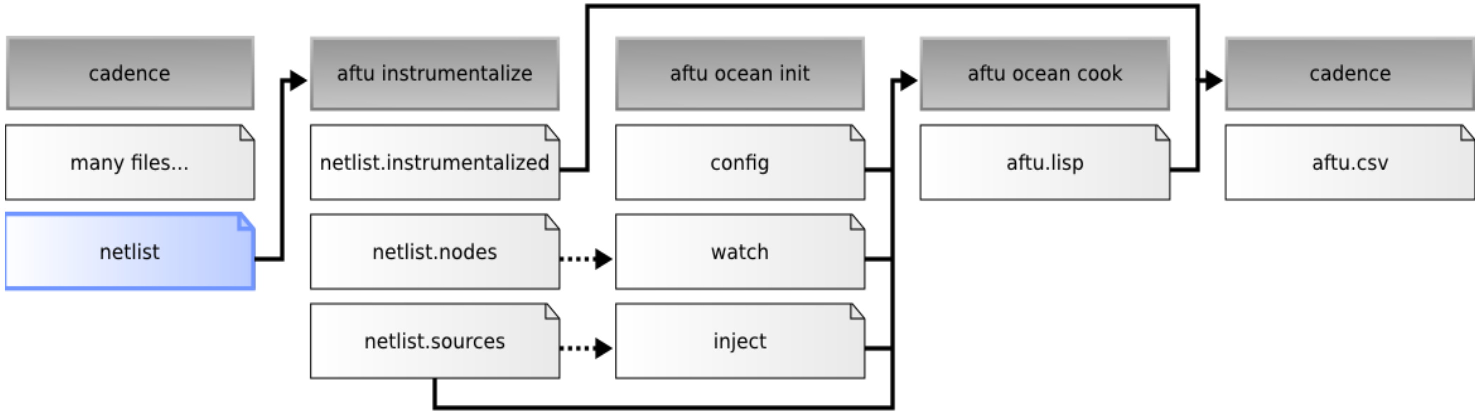
A Practical Example

Let's say we have this circuit:

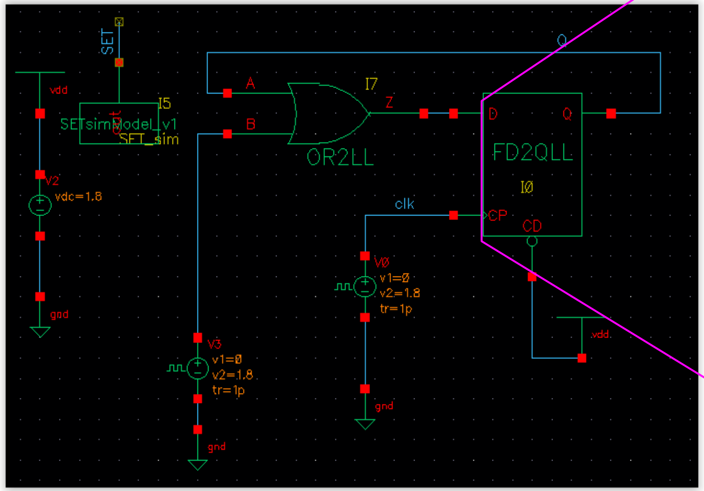


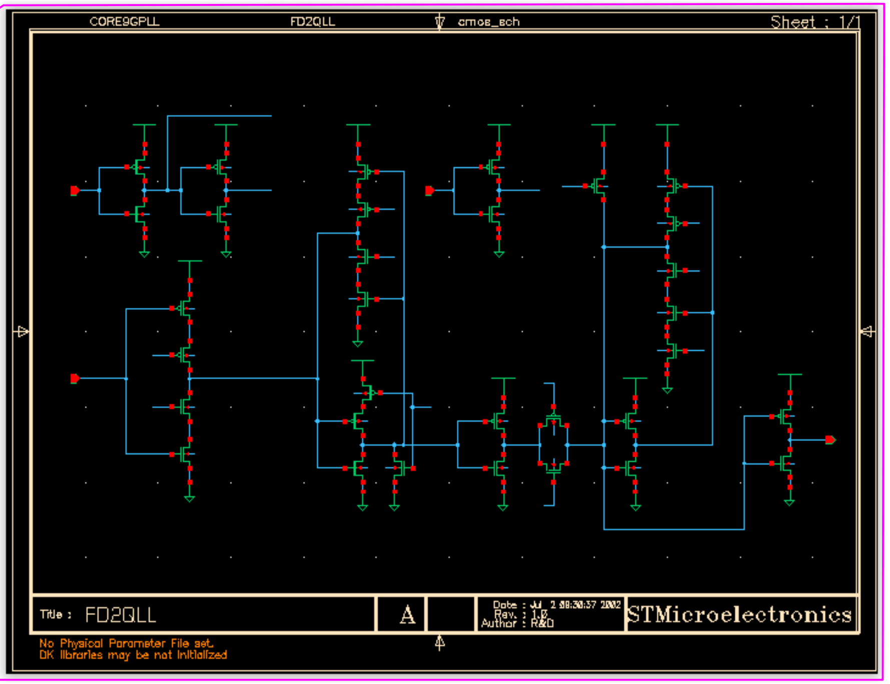
What is the critical charge to produce a SEU?

Netlist

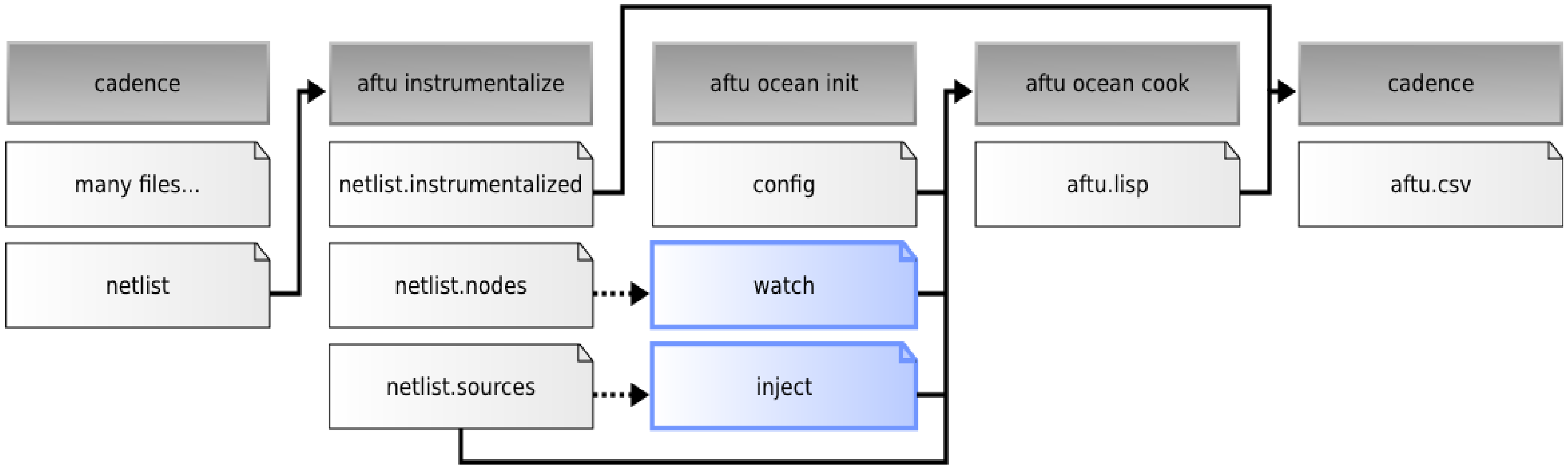


D-latch transient testbench and schematic view of the digital cell STMicroelectronics 130 nm





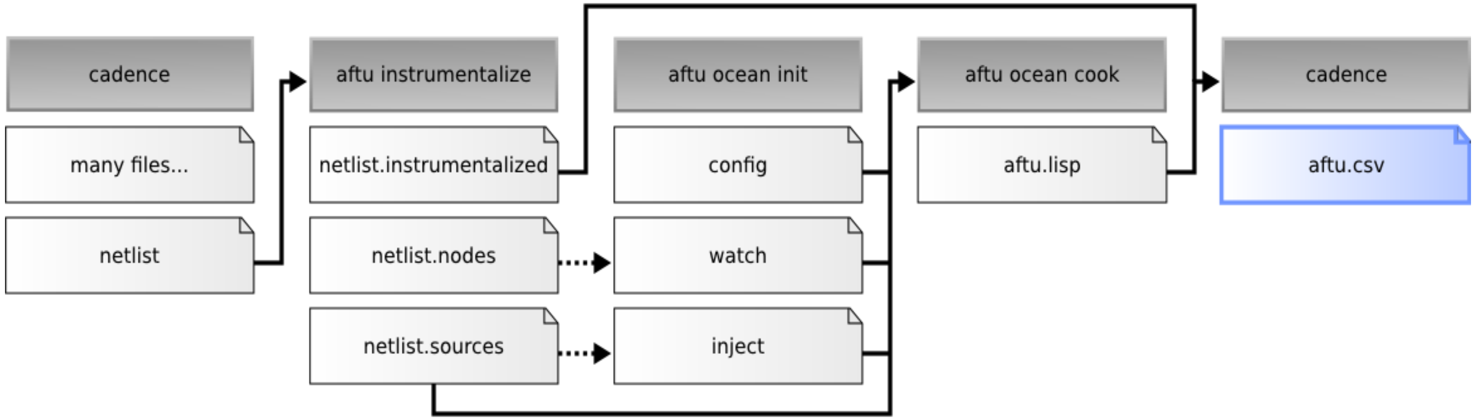
Watch & Inject




```
watch Q = /Q :
        threshold = 0.975 ;
```

```
inject I0_MP19:
        Q = .025p, .05p, 0.1p, .2p, .5p, .75p, 1p, 1.5p;
        t = 1.0n, 1.1n, 1.2n, 1.3n, 1.4n, 1.5n, 1.6n, 1.7n, 1.8n, 1.9n;

    inject I0_MN19:
        Q = .025p, .05p, 0.1p, .2p, .5p, .75p, 1p, 1.5p;
        t = 1.0n, 1.1n, 1.2n, 1.3n, 1.4n, 1.5n, 1.6n, 1.7n, 1.8n, 1.9n;

    inject I0_MP18:
        Q = .025p, .05p, 0.1p, .2p, .5p, .75p, 1p, 1.5p;
        t = 1.0n, 1.1n, 1.2n, 1.3n, 1.4n, 1.5n, 1.6n, 1.7n, 1.8n, 1.9n;
```

Results

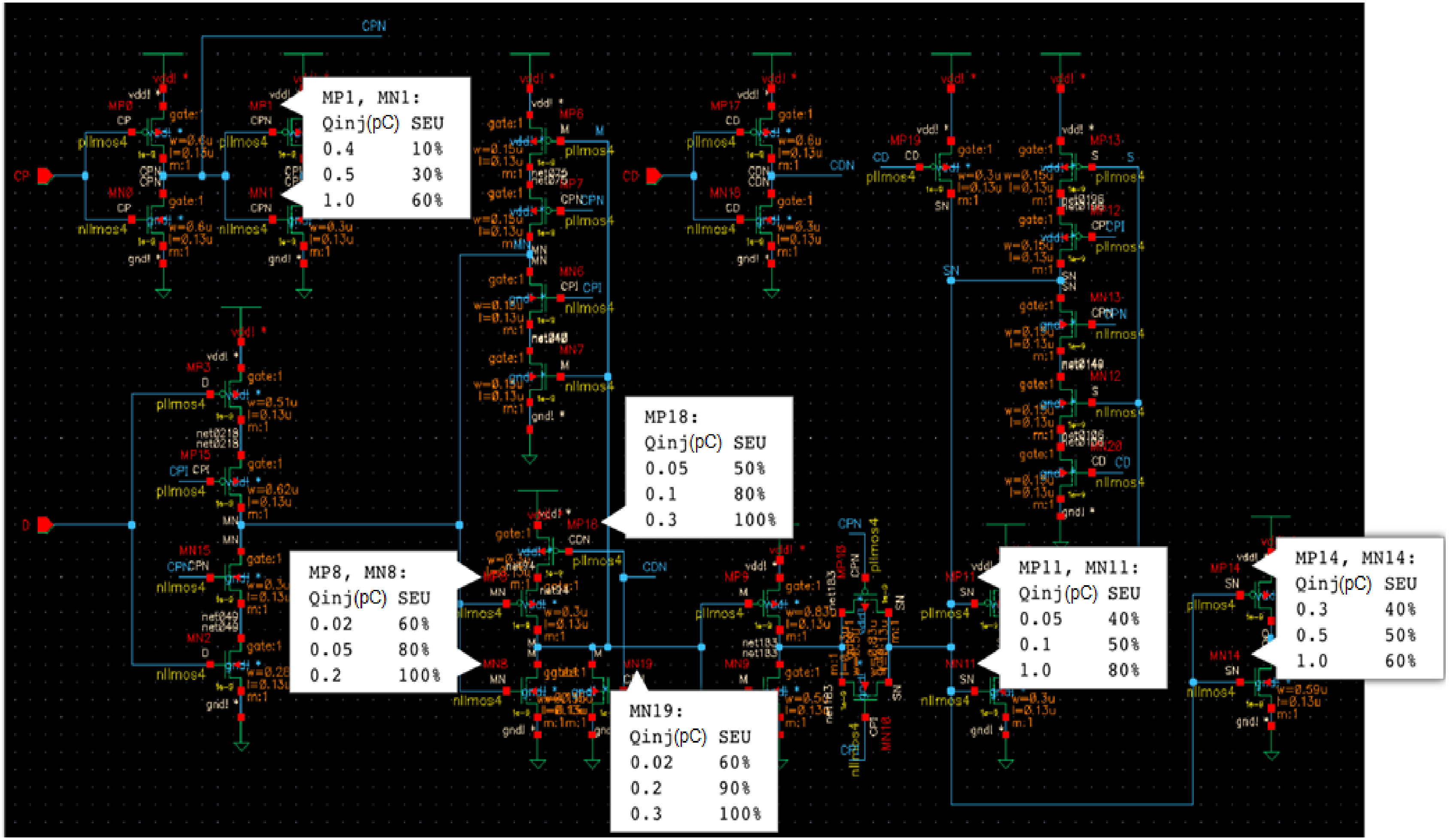



```
Output ImpactNode Qinj  Timp    Trec     Vmax

V_Q    I0_MP18  2.5e-14 1e-09   0.000000 0.001941
     V_Q    I0_MP18  2.5e-14 1.1e-09 0.000000 0.00219

V_Q    I0_MP18  2.5e-14 1.9e-09 0.000000 0.003664
     V_Q    I0_MP18  5e-14   1e-09   2.000000 1.807421
     V_Q    I0_MP18  5e-14   1.1e-09 1.910000 1.807422
     V_Q    I0_MP18  5e-14   1.2e-09 1.800000 1.807426
     V_Q    I0_MP18  5e-14   1.3e-09 1.700000 1.807384

     V_Q    I0_MP18  5e-14   1.8e-09 0.000000 0.519730
     V_Q    I0_MP18  5e-14   1.9e-09 1.100000 1.803023
```

```
Output ImpactNode Qinj  Timp    Trec     Vmax

V_Q    I0_MN11  2.5e-14 1e-09   0.000000 0.006827

V_Q    I0_MN11  2.5e-14 1.9e-09 0.000000 0.016568
     V_Q    I0_MN11  5e-14   1e-09   0.000000 0.017084

     V_Q    I0_MN11  5e-14   1.3e-09 0.000000 0.005371
     V_Q    I0_MN11  5e-14   1.4e-09 1.610000 1.806680
     V_Q    I0_MN11  5e-14   1.5e-09 1.500000 1.806814
     V_Q    I0_MN11  5e-14   1.6e-09 1.400000 1.805740
     V_Q    I0_MN11  5e-14   1.7e-09 1.300000 1.802925
     V_Q    I0_MN11  5e-14   1.8e-09 0.240000 1.404223
```

“Deviation Recovery” heuristic analysis

Results


MP1, MN1:
Qinj(pC) SEU
0.4 10%
0.5 30%
1.0 60%
MP18:
Qinj(pC) SEU
0.05 50%
0.1 80%
0.3 100%
MP8, MN8:
Qinj(pC) SEU
0.02 60%
0.05 80%
0.2 100%
MN19:
Qinj(pC) SEU
0.02 60%
0.2 90%
0.3 100%
MP11, MN11:
Qinj(pC) SEU
0.05 40%
0.1 50%
1.0 80%
MP14, MN14:
Qinj(pC) SEU
0.3 40%
0.5 50%
1.0 60%
CPN
CP
CD
D
CDN

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Sevilla