AstroPix single chip irradiation test

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Motivation

- We want to study whether the AstroPix operation changes after the irradiation, and if so, how much it changes.
  - Measurement performance
    - IV scan
    - Noise scan
    - Injection scan
    - Source scan
  - Single Event Effects (SEE)
    - Single Event Upset (SEU)
    - Single Event Latch-up (SEL)

AstroPix chips tested

- We want to study whether the AstroPix operation changes after the irradiation, and if so, how much it changes.
  - Measurement performance
    - IV scan  × 24 (v3)  × 4 (v4)
    - Noise scan
    - Injection scan
    - Source scan

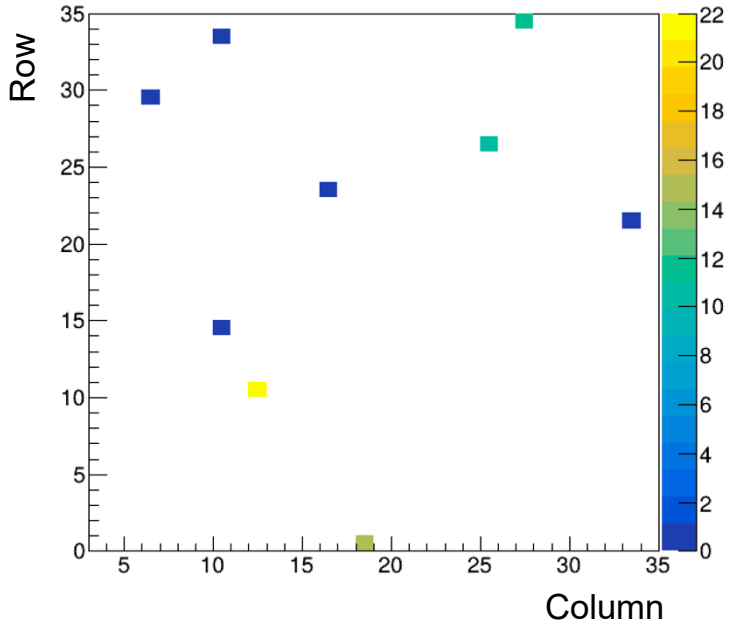
    

    × 3 (v3)
  - Single Event Effects (SEE)
    - Single Event Upset (SEU)
    - Single Event Latch-up (SEL)

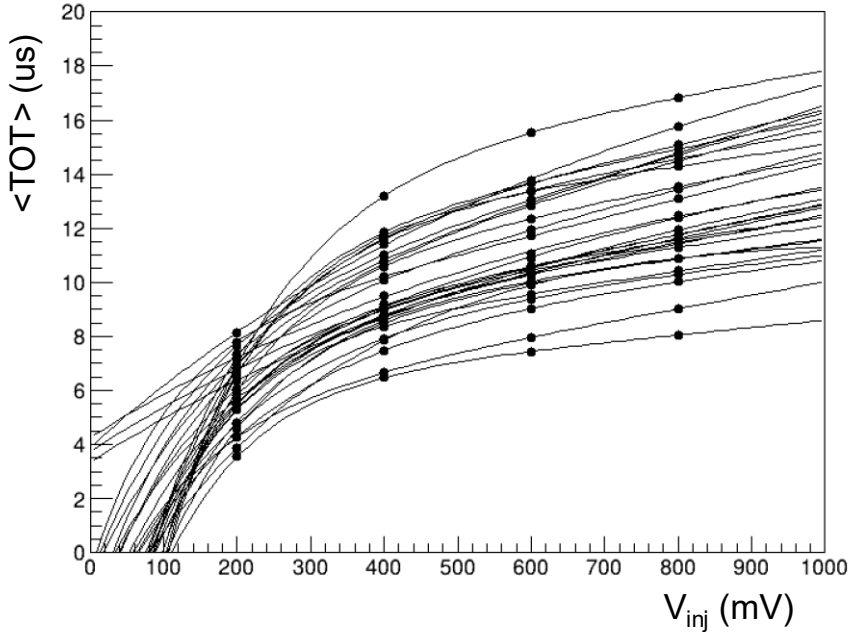
    

Noise scan & Injection scan

Noise scan (V_{th} = 200 mV)



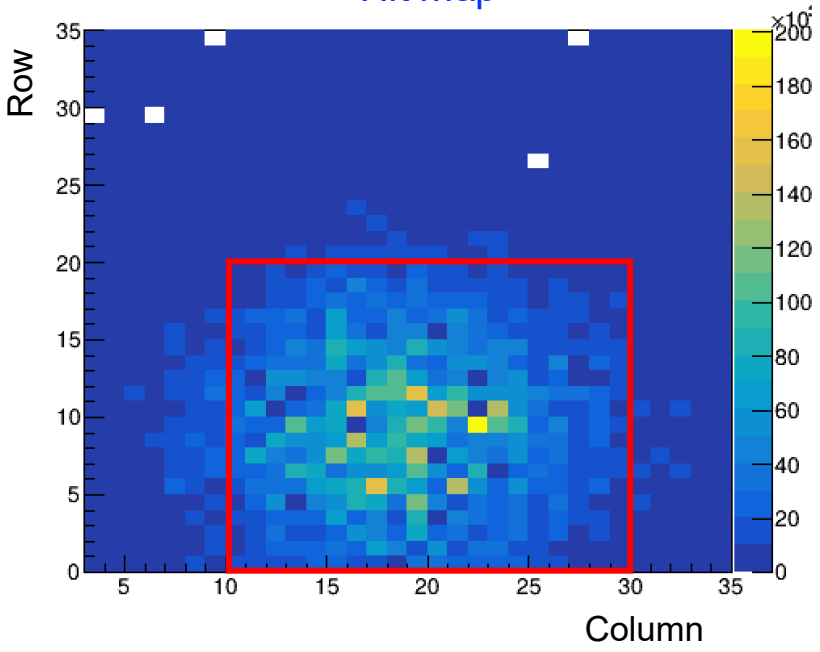
Injection scan



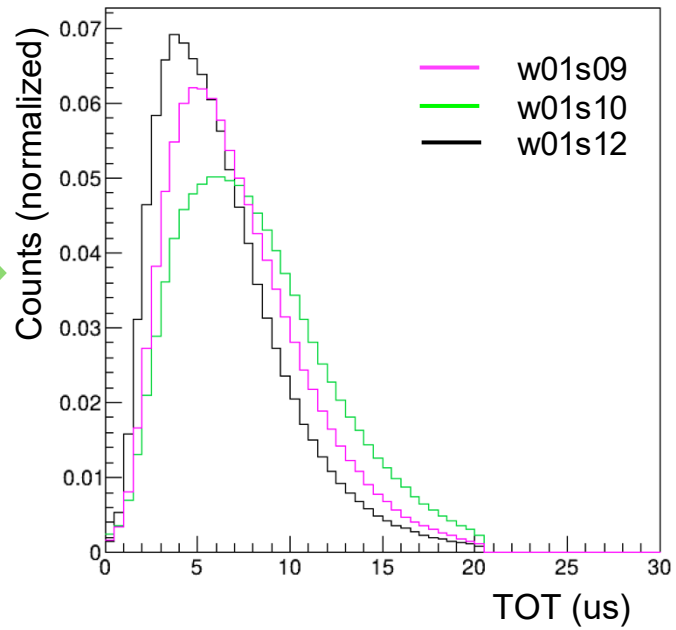
- How noisy each pixel is can be compared before and after the irradiation.
- The calibration curves can also be compared.

Source scan (Sr90)

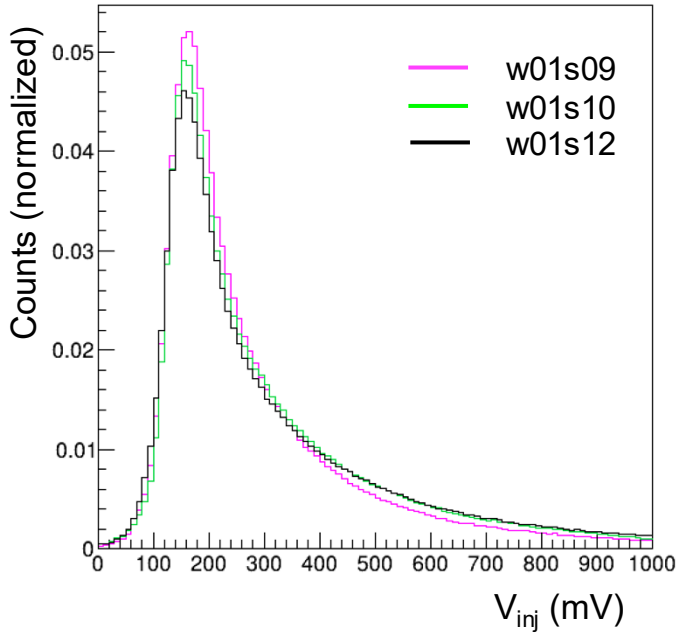
Hit map



Raw TOT



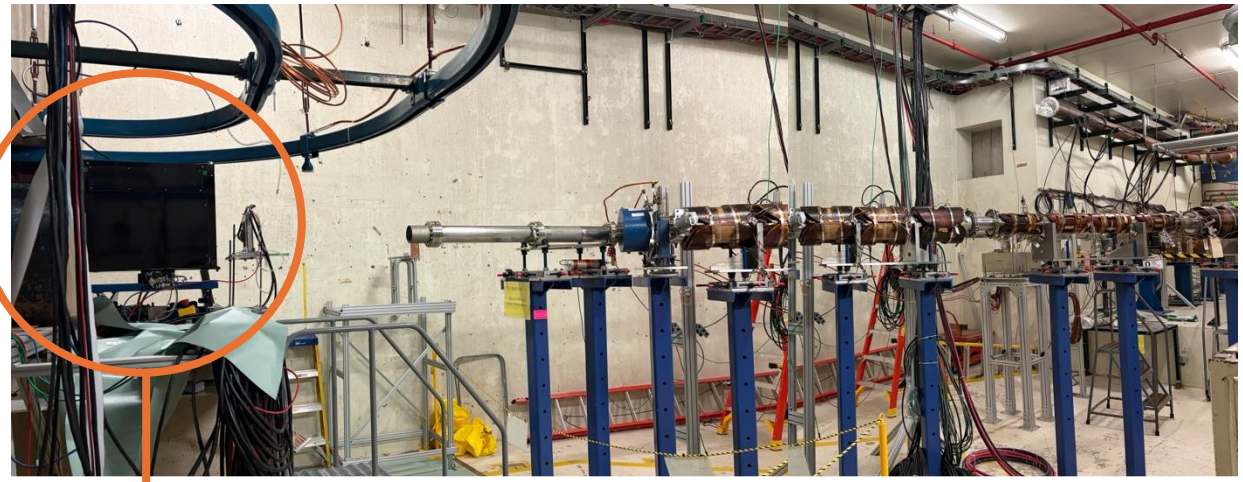
Converted V_{inj}

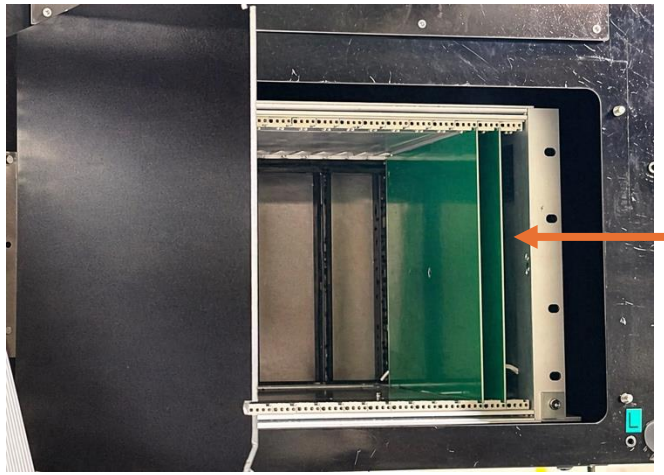


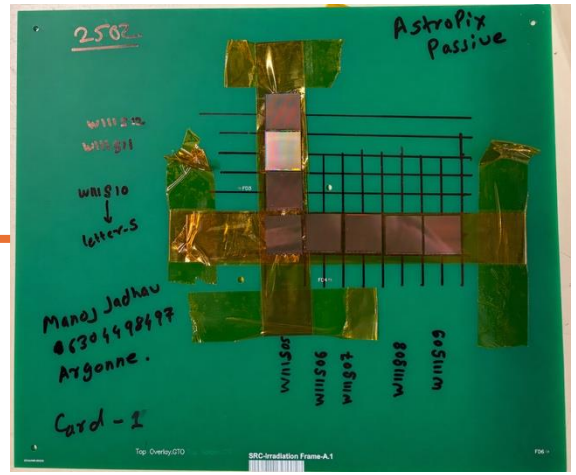
- The converted V_{inj} distributions show similar peak locations and shapes. → All the mounted chips work properly to the injection and source scan.
- The raw TOT and converted V_{inj} distributions will also be compared before and after the irradiation.

Irradiation test

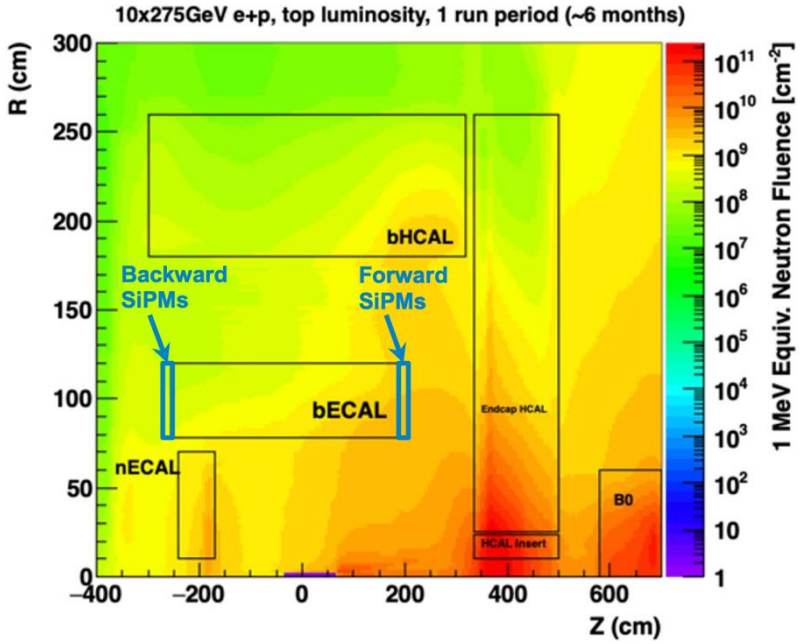
- We are performing the irradiation test at FermiLab ITA (Irradiation Test Area). They provide 400 MeV maximum ~3.60 × 10^{13} protons / minute.

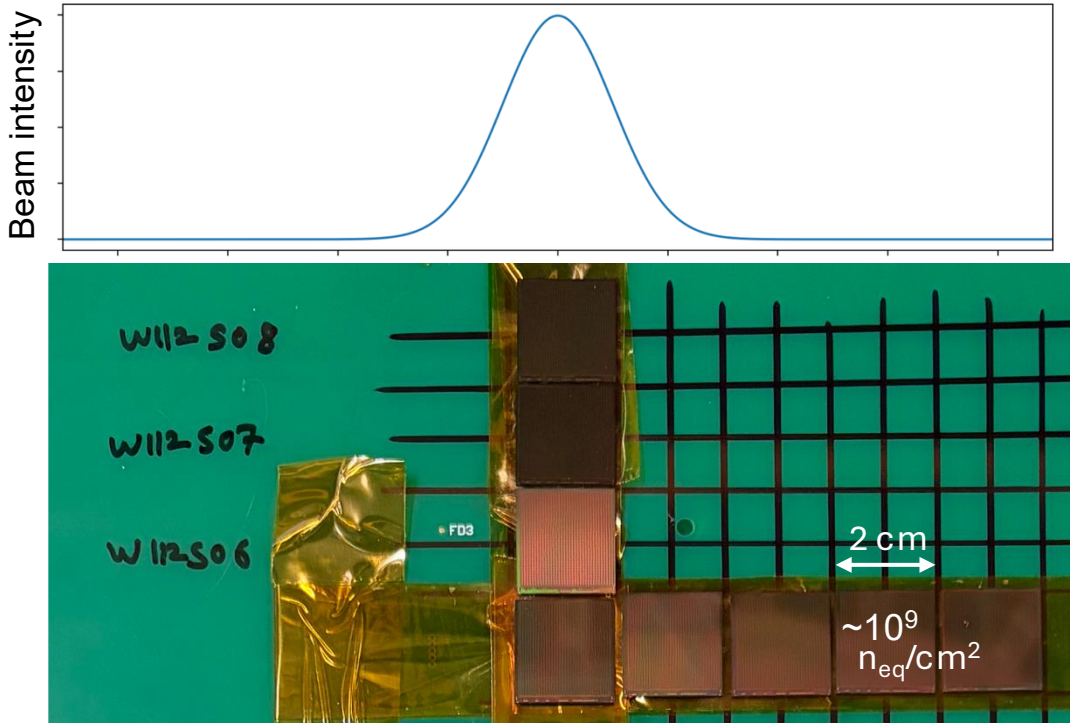






Passive test





Aluminum foil

- We expect the maximum EIC dose about 10^9~10^{10} n_{eq}/cm^2 or less.
- Taking into account the σ of the beam profile is ~1 cm and the conversion from 400 MeV proton fluence to1 MeV neutron fluence, we have accumulated radiation dose so that the fourth chip approximately has a comparable level with the maximum EIC dose (~10^9 n_{eq}/cm^2).
- The precise estimation will be done using the aluminum foil.

Active test; SEU

```
2026-03-11 11:27:52,864:864.__main__.INFO:[1] 2026-03-11 11:27:52 MISMATCH (n_mismatch=2)
2026-03-11 11:27:52,865:865.__main__.INFO:[1] expected_bits=10000000000000000000000000000000010010100000000000001010000000100101000000000000000000000000000000
00000001001010000101111100000010111100000000111100011110000111000101010101011000111001000000000101010101011101010100001111111111111111111111111111111111000111
11111111111111111111111111111000111111111111111111111111111111111111111000111111111111111111111111111111110001111111111111111111111111111111110001111111111
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11111111111110
2026-03-11 11:27:52,865:865.__main__.INFO:[1] read_bits    =01000000000000000000000000000000010010100000000000001010000000100101000000000000000000000000000000
00000001001010000101111100000010111100000000111100011110000111000101010101011000111001000000000101010101011101010100001111111111111111111111111111111111000111
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11111111111110
2026-03-11 11:28:12,577:577.rfg.io.ftdi.INFO:Closing FTDI Device
2026-03-11 11:28:12,578:578.rfg.io.ftdi.INFO:Closed FTDI Device b'Digilent USB Device A'
```
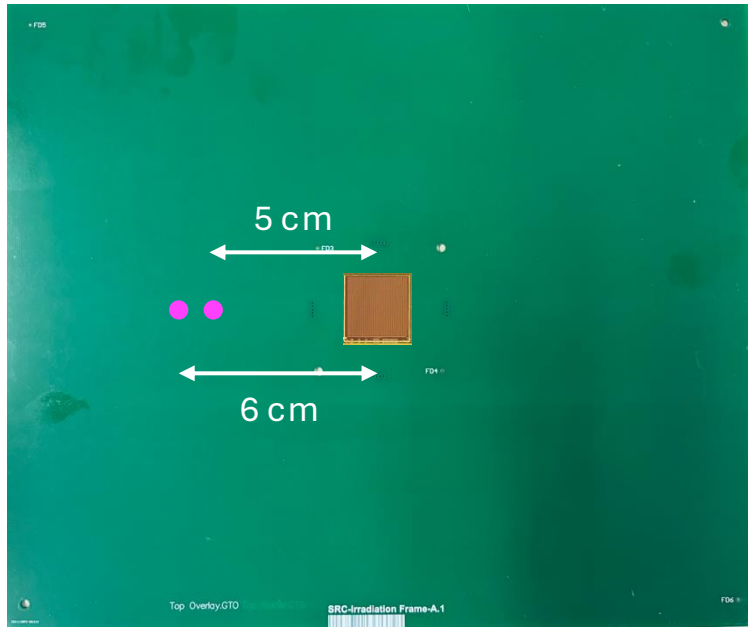
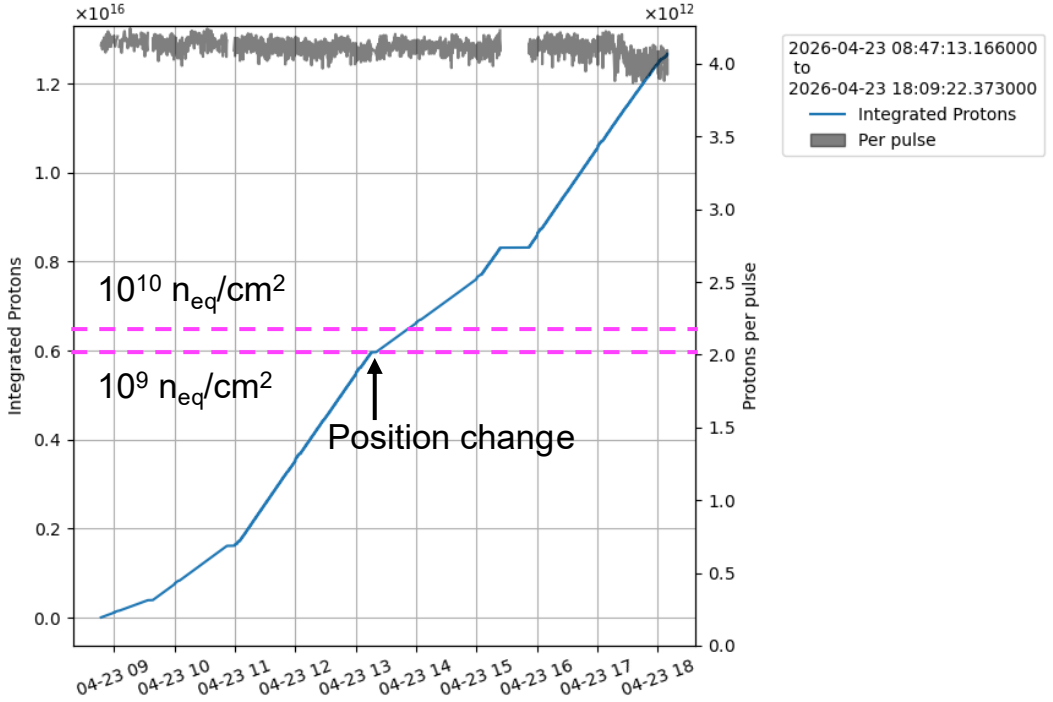

- To study the SEU, we keep sending the above bit pattern into the chip and reading it back for comparison during the irradiation.
- The first two bits are mismatched because of a readback-related bit shift. We are monitoring the SEU taking into account this characteristic.

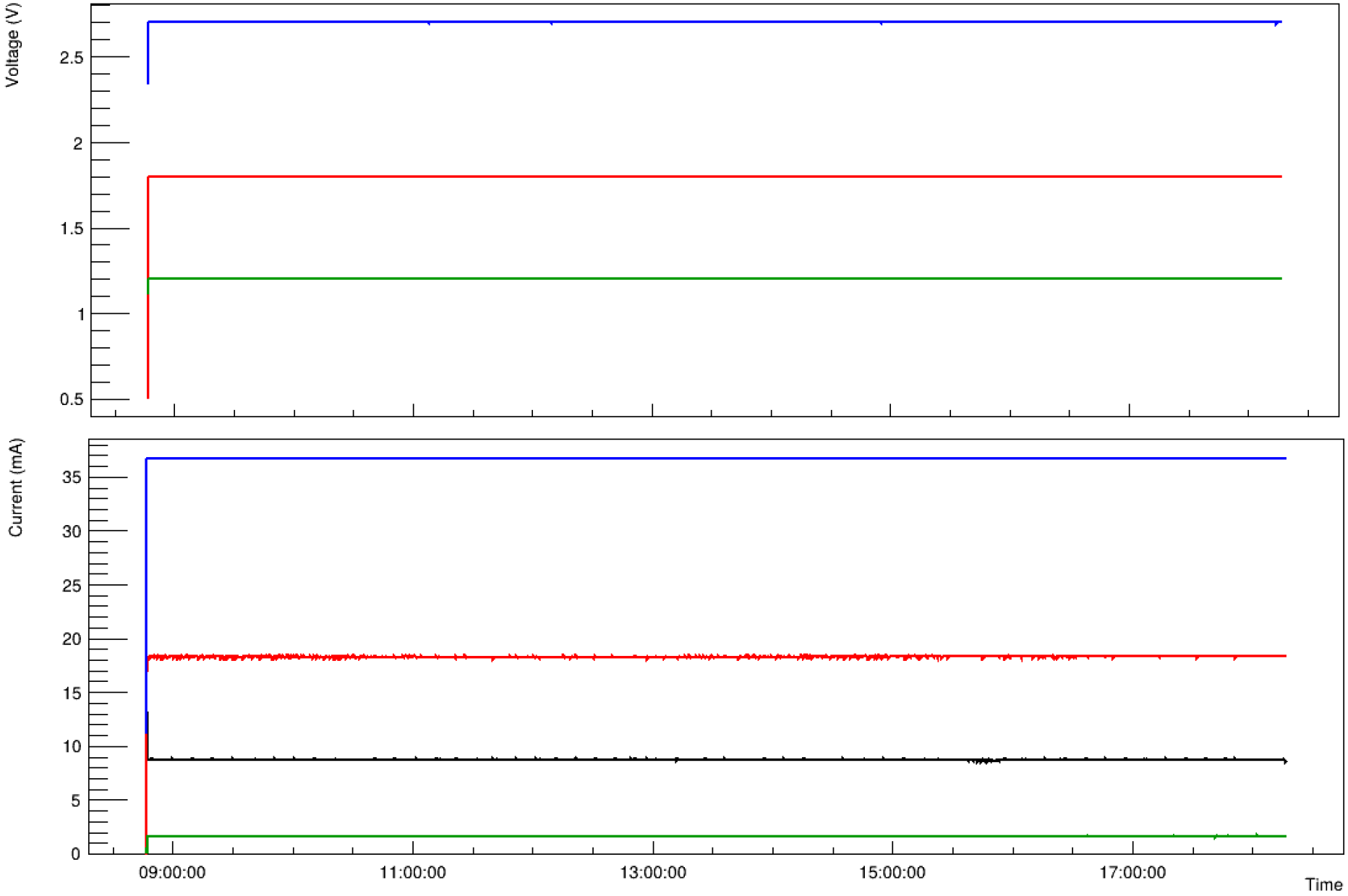
Active test; SEU



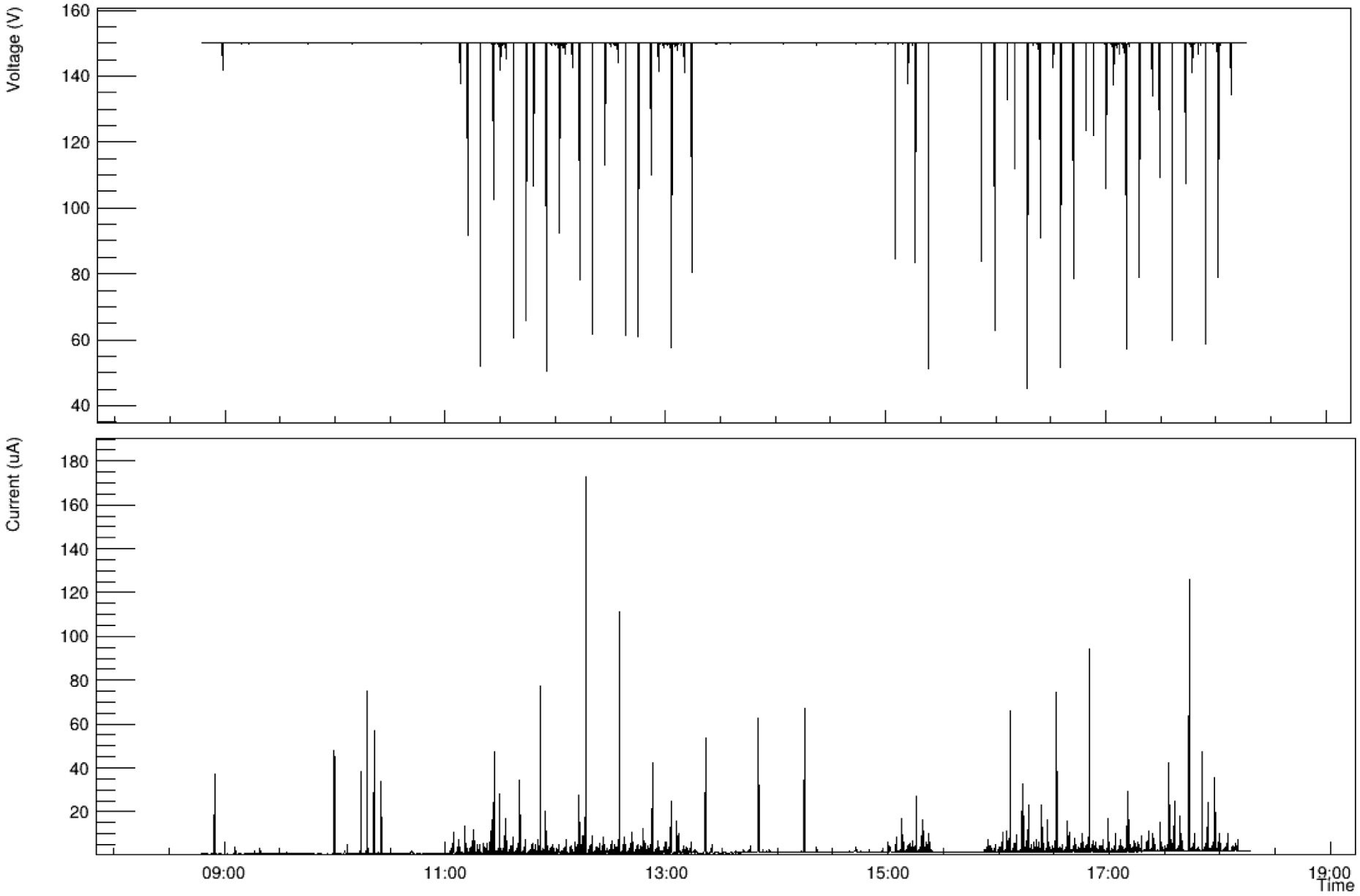


- We started the active test by placing the chip 6 cm away from the beam center and we are accumulating the radiation dose by gradually moving the chip closer to the beam.
- The total radiation dose already exceeded the maximum EIC dose yesterday, but no SEU was observed.

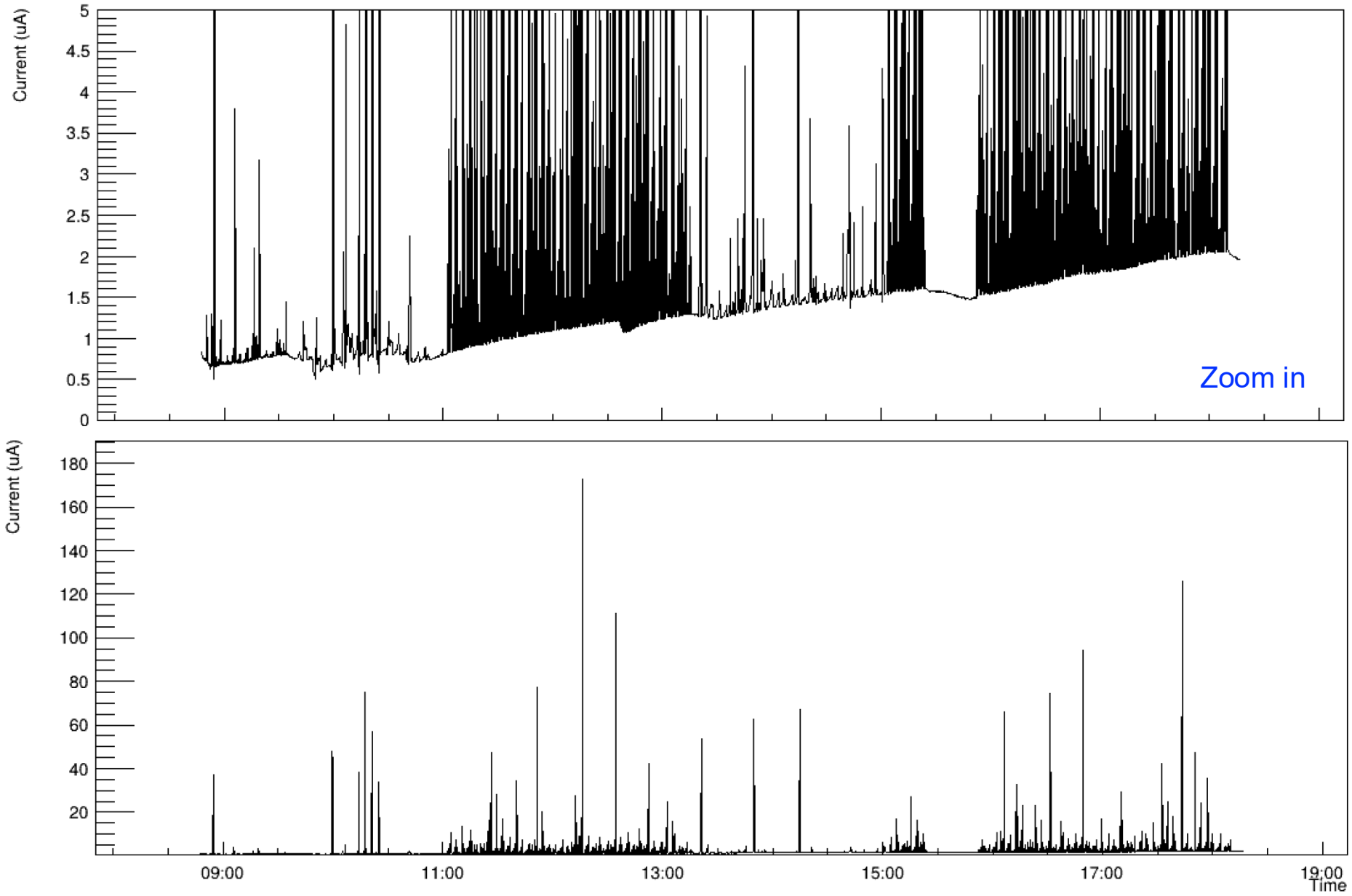
Active test; SEL (LV module)



Active test; SEL (HV module)



Active test; SEL (HV module)



Summary & Plan

- We are performing the irradiation test to study the effect of the radiation to the AstroPix chip.
  - No SEU was observed even at doses far above the EIC maximum.
  - We observed that the current gradually increased as the dose increased.
- After the irradiation test, we will measure AstroPix's measurement performance again and compare it with the one measured before irradiation