Irradiation of powered AtlasPix3.1 at Bonn Cyclotron

Maja Lecher

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Goal

- Dates: 18.-21.07.2022
- Irradiate HV-biased AtlasPix3.1 at Bonn HISKP Cyclotron facility
  - Available proton energies: 7 - 14 MeV
  - Applied irrad. currents: 20 - 60 nA
- Characterize chip before & after, take IV curves in between irrad. steps
- Study TID + bulk damage

Setup

Beam area

- Cooling box w Kapton foil entry housing DUT
  - Cooling via N_2 (T $\sim$ -15° C)
  - 2 temperature sensors
- DUT: AtlasPix3.1 powered via PCIe adapter and connected to PS's via long BNC cables (Supplied LV's: Vssa, Vdd, Vmin, gate)

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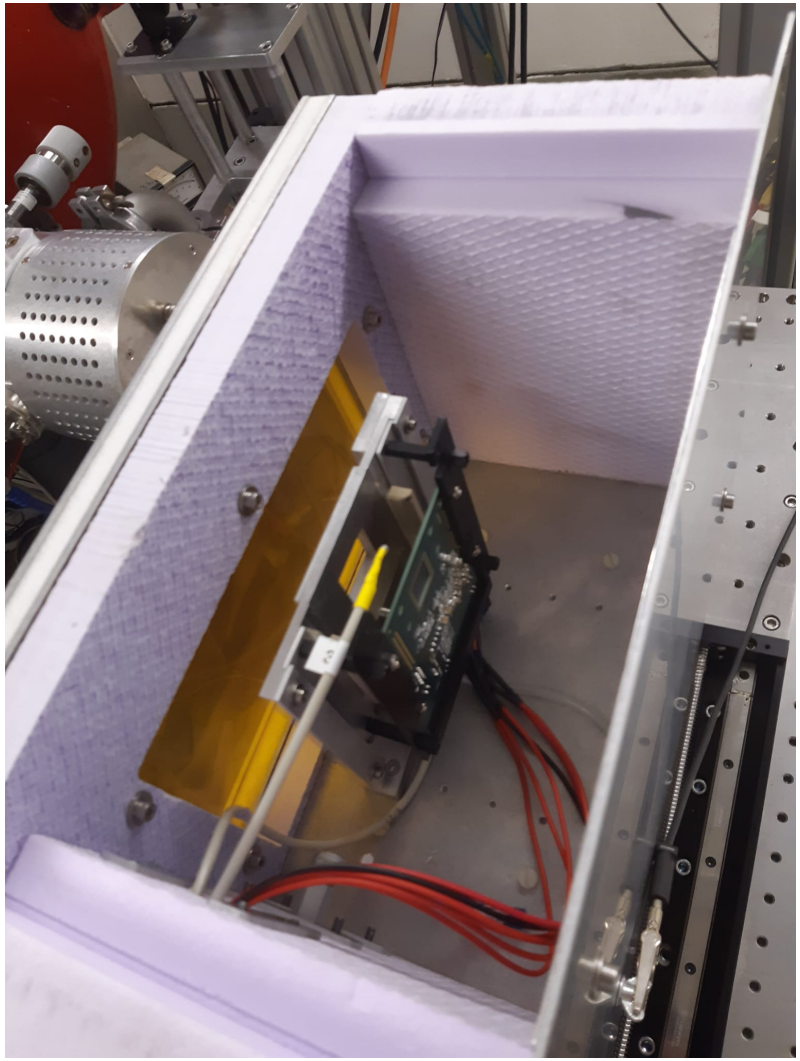

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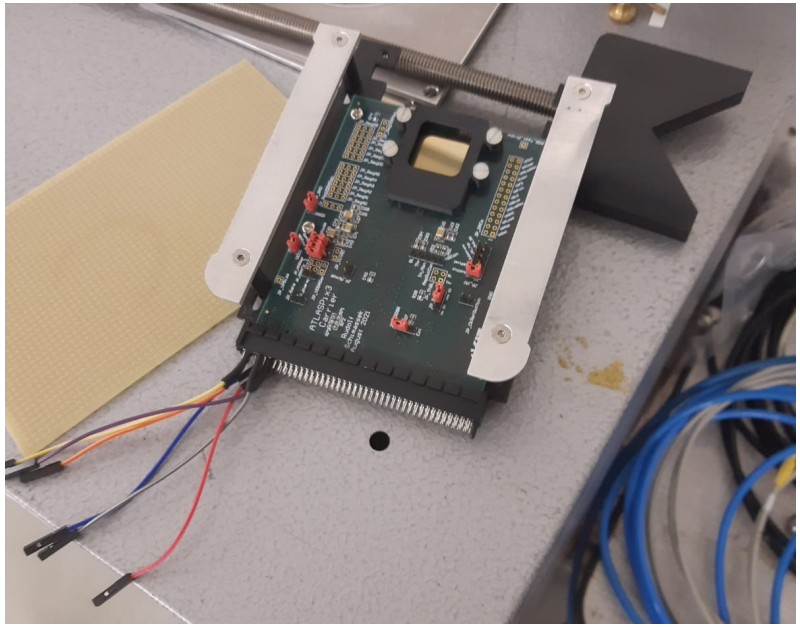


Setup

Gallery

- Power supplies connected to DUT via BNC cables
  - 2 HAMEC LV supplies for Vdd, Vssa, Vmin, gate
  - 1 Keithley 2611b for HV
- Lab PC with slow control software
- Full GECCO + FPGA setup for data taking before/after irrad

Control room

- 2nd PC connected to lab PC via local network → manage slow control system from here

Procedure

- Pre-irrad characterization
  - IV curve → Breakdown voltage, leakage current
  - Fe55 spectrum → ToT
  - SCurves → Monitor threshold changes
- Irradiation
  - 5-10 fast scans at increasing bias voltages
    - Scanning speed: 60 mm/s
    - Irrad current: 40 nA
    - Bias voltages: 0 - 60 V, 10 V steps
    - Total dose: 1.9e13 protons/cm^2 $\approx$ 7.8e13 n_{eq}/cm^2
    - IV curve after each voltage step
  - Slow scans at 60 V bias voltage & decreasing irrad. currents
    - Scanning speed: 12 mm/s
    - Irrad. currents: 40 nA, 30 nA, 20 nA
    - IV curve after last irradiation

→ Total fluence after irrad.: 1.05e14 n_{eq}/cm^2; compare LHCb expectation: 5.9e14 n_{eq}/cm^2

Procedure

- Post-irrad. characterization (To Do)
  - Original intention: Fe scan before leaving, but: could not get chip back up and running properly after irrad.
    - Chip configurable (but needs re-tuning)
    - Leakage currents high ($\sim 500\mu$A)
    - Injections not working at all
    - Chip very noisy without cooling, some decoding errors pre-tuning
    - FPGA unhappy when cooled (commercial FPGA, specified for 0-85 °C op. temp.)
  - Plan: attempt to revive chip; if successful: Fe55 spectrum, SCurves

Irradiation protocol

Fast scan (60 mm/s):

V_{bias} during irrad. [V]	Total fluence [neq/cm^2]	I_{proton} [nA]
0	5.11e12	40 nA
0	1.14e13	40 nA
-10	2.32e13	40 nA
(failure; 0 V & LV off)	3.16e13	40 nA
-30	4.00e13	40 nA
-40	4.76e13	40 nA
-50	6.11e13	40 nA
-60	7.8e13	40 nA

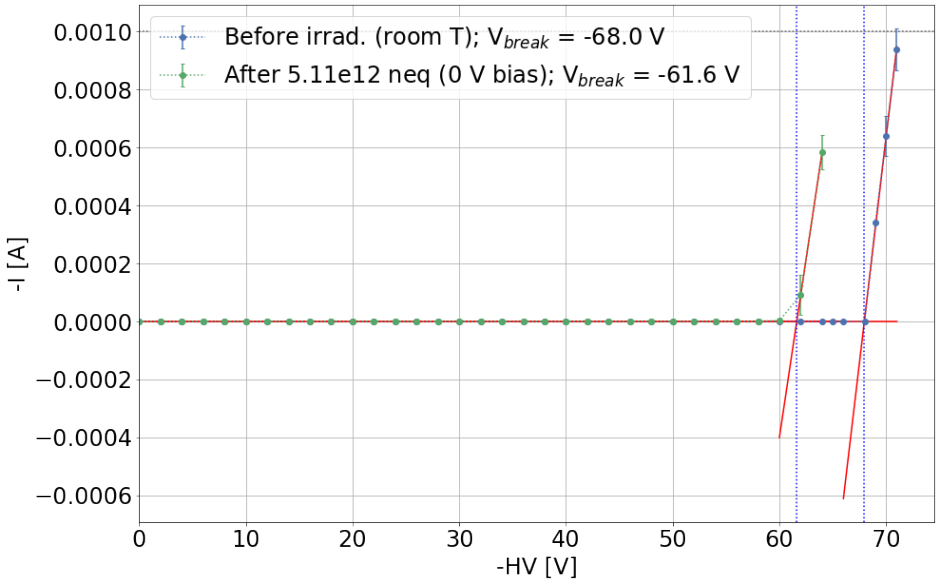
Slow scan (12 mm/s):

V_{bias} during irrad. [V]	Total fluence [neq/cm^2]	I_{proton} [nA]
-60	Unknown	40 nA
-60	Unknown	30 nA
-60	1.05e14	20 nA

IV curves

Breakdown voltage (Note: current limit set too low)

- V_{break} drops by $\sim$ 6.5 V after first irrad. scan (Note: T difference not yet accounted for)



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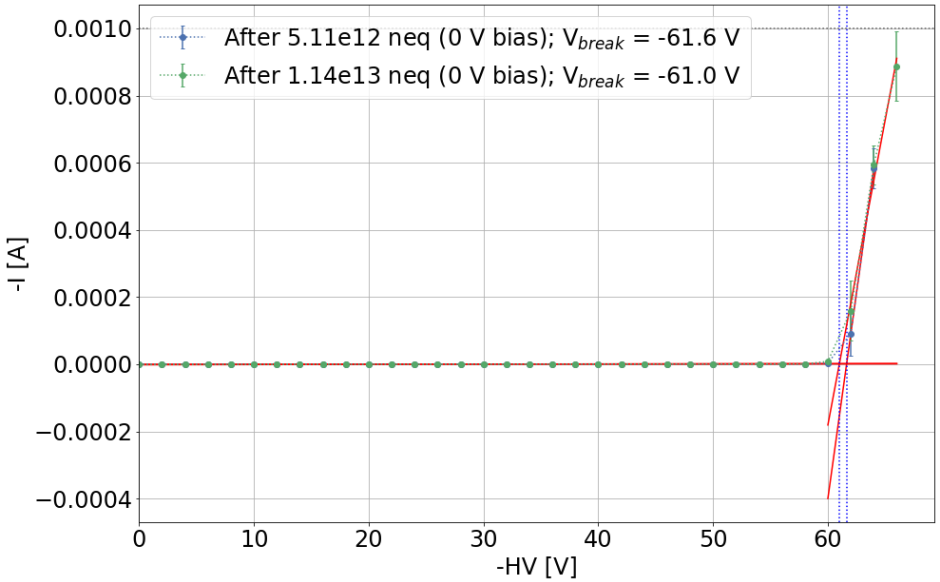

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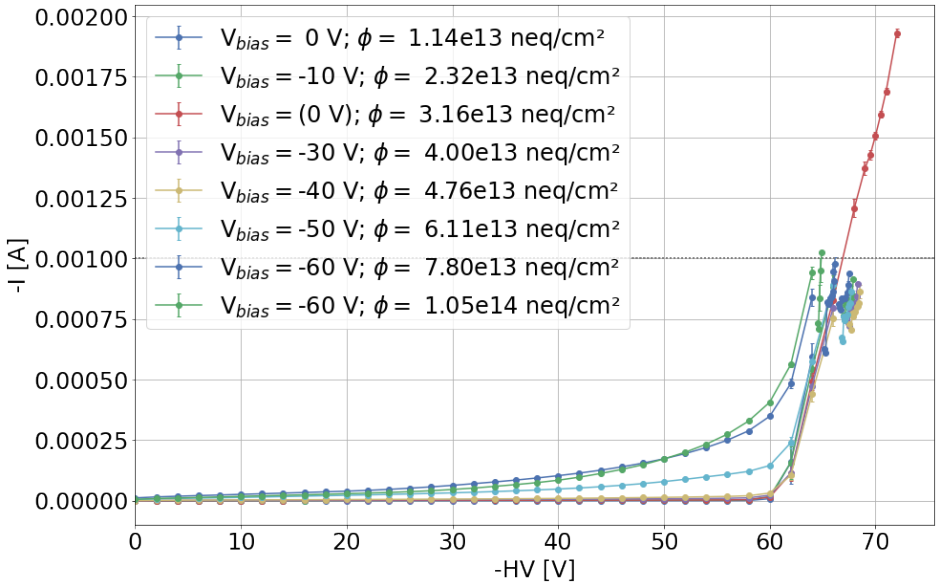

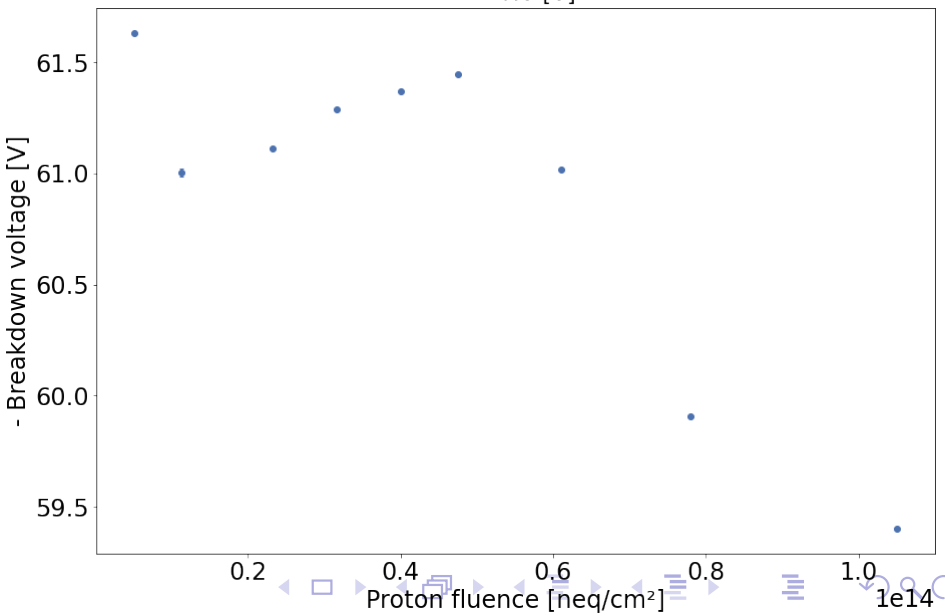

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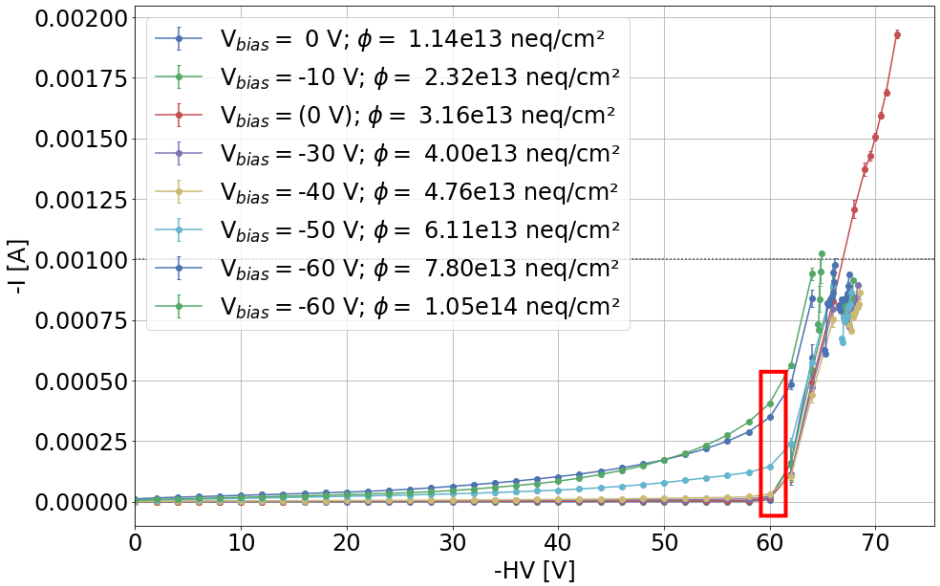

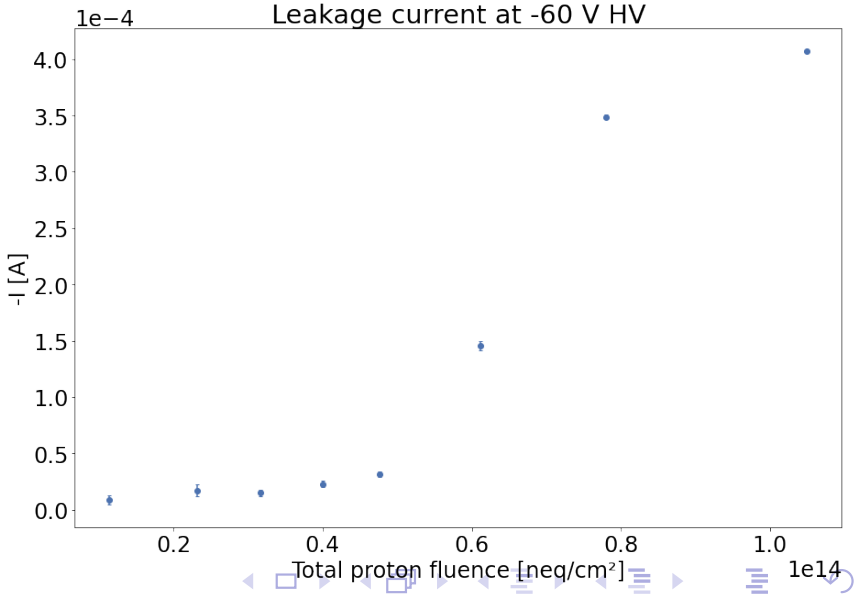

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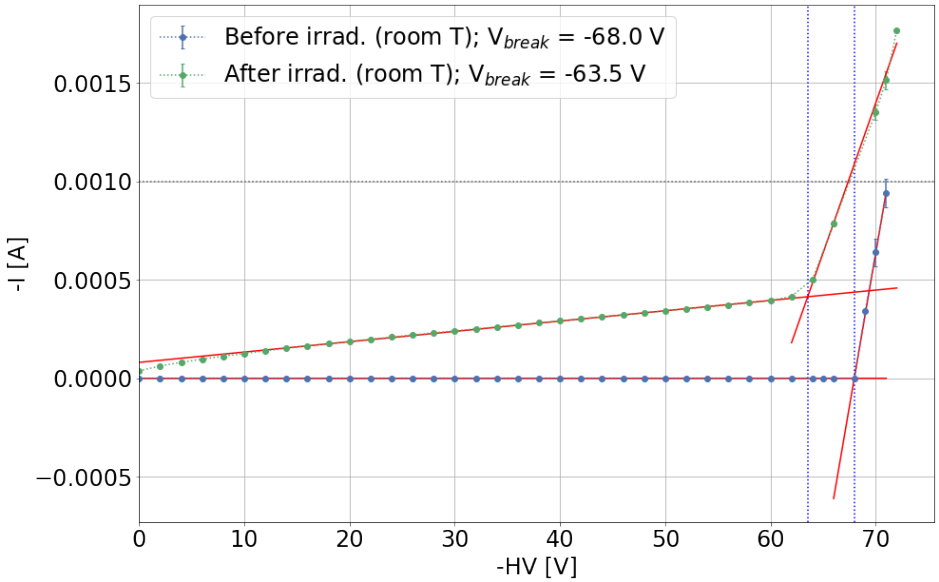
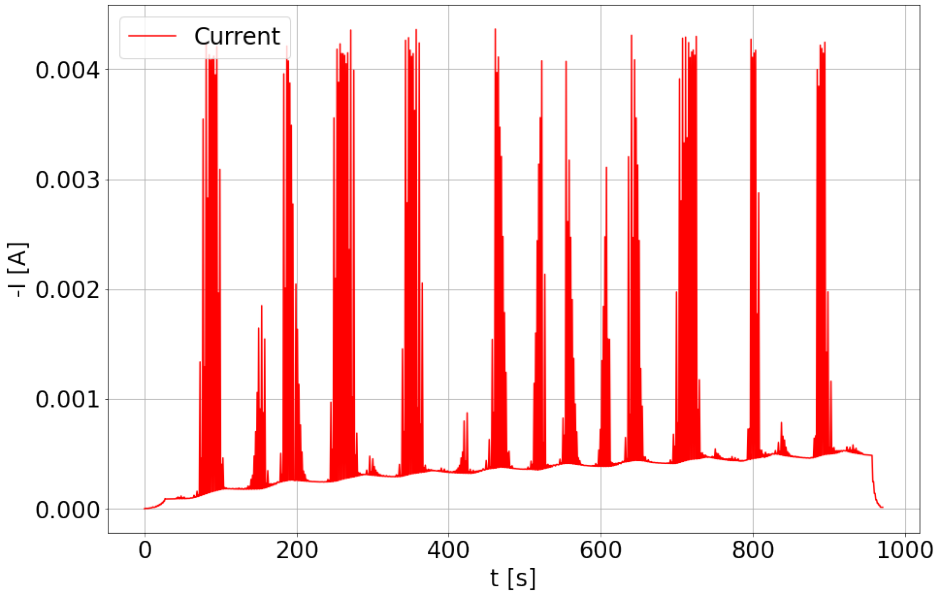
- Day after irrad. at room T: $V_{break} \sim$ -63.5 V $\rightarrow$ Shift in breakdown voltage partially reversed



Leakage current during irradiation

- Proton spill structure clearly visible in leakage current
- Expected beam-induced current for 40 nA proton current, 100 μm depletion zone: 7 mA $\Rightarrow \sim$ 4 mA leakage current during spills (seen for all bias steps) plausible
- Leakage current between spills: from lower envelope $\Rightarrow$ steady increase



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Answer: The rate R of protons is equal to

$$R = \frac{I}{q_e}$$

The energy deposited per proton is

$$E = \frac{\Delta E}{\Delta X} \cdot \rho_{Si} \cdot d = 29 MeV cm^{-2} g^{-1} \cdot 2.31 \frac{g}{cm^3} \cdot 100 \mu m = 6.7 \cdot 10^5 eV$$

The number of electrons produced by one proton is

$$N_e = \frac{E}{3.65} = \frac{6.7 \cdot 10^5 eV}{3.65 eV} = 1.8 \cdot 10^5$$

Combining all that gives

$$I_{leak} = q_e N_e \cdot R = N_e \cdot I = 1.8 \cdot 10^5 \cdot 40 nA = 7.2 mA$$

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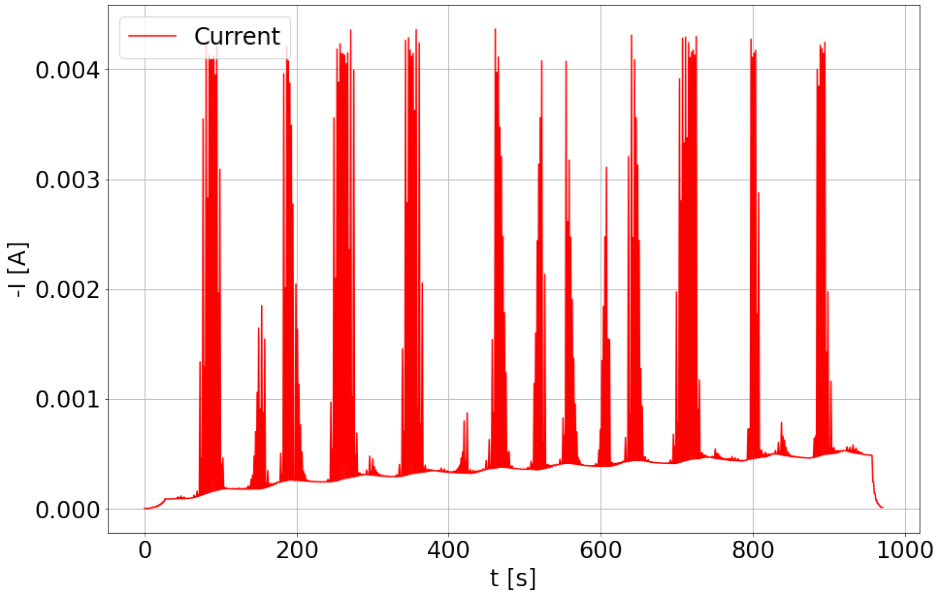

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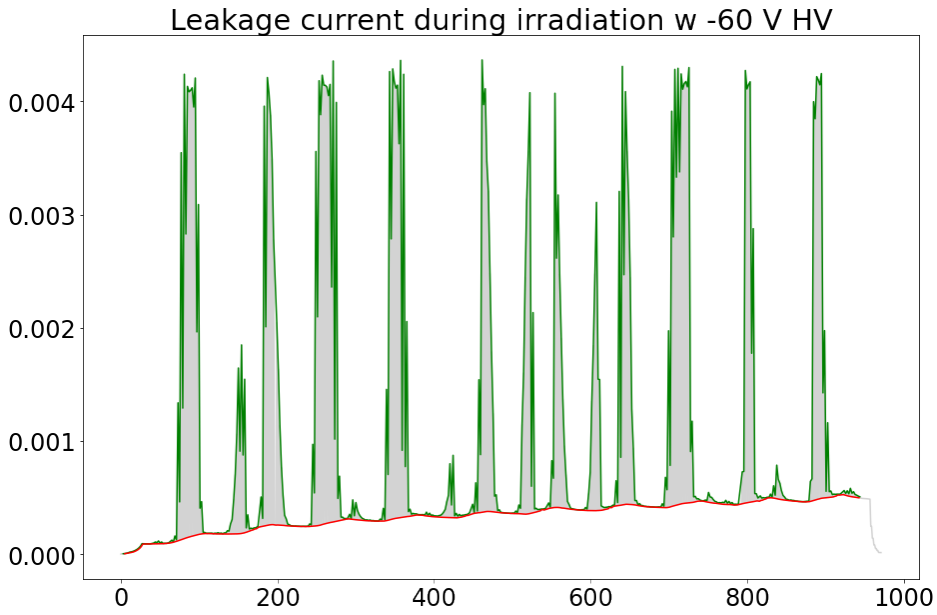

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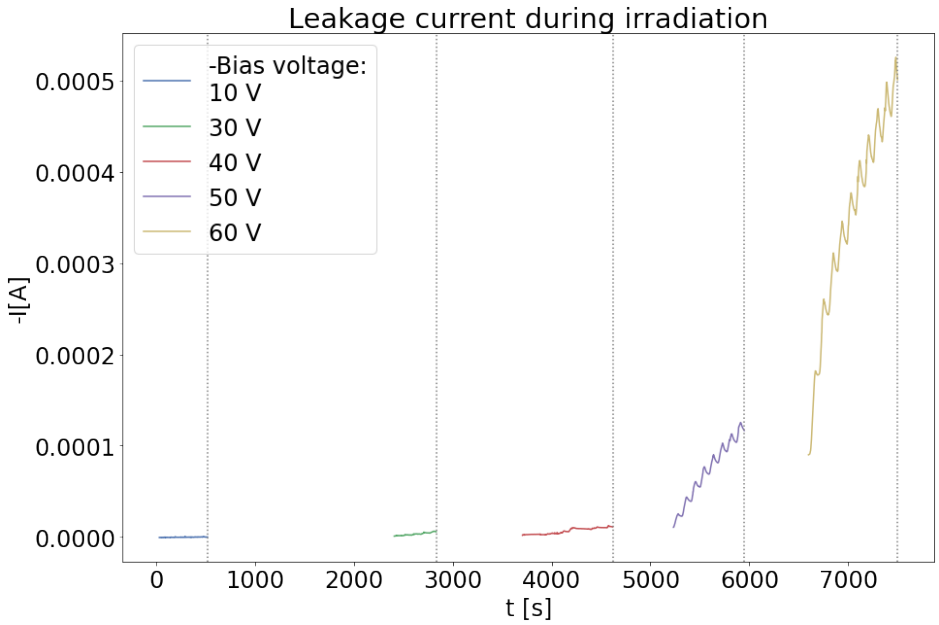
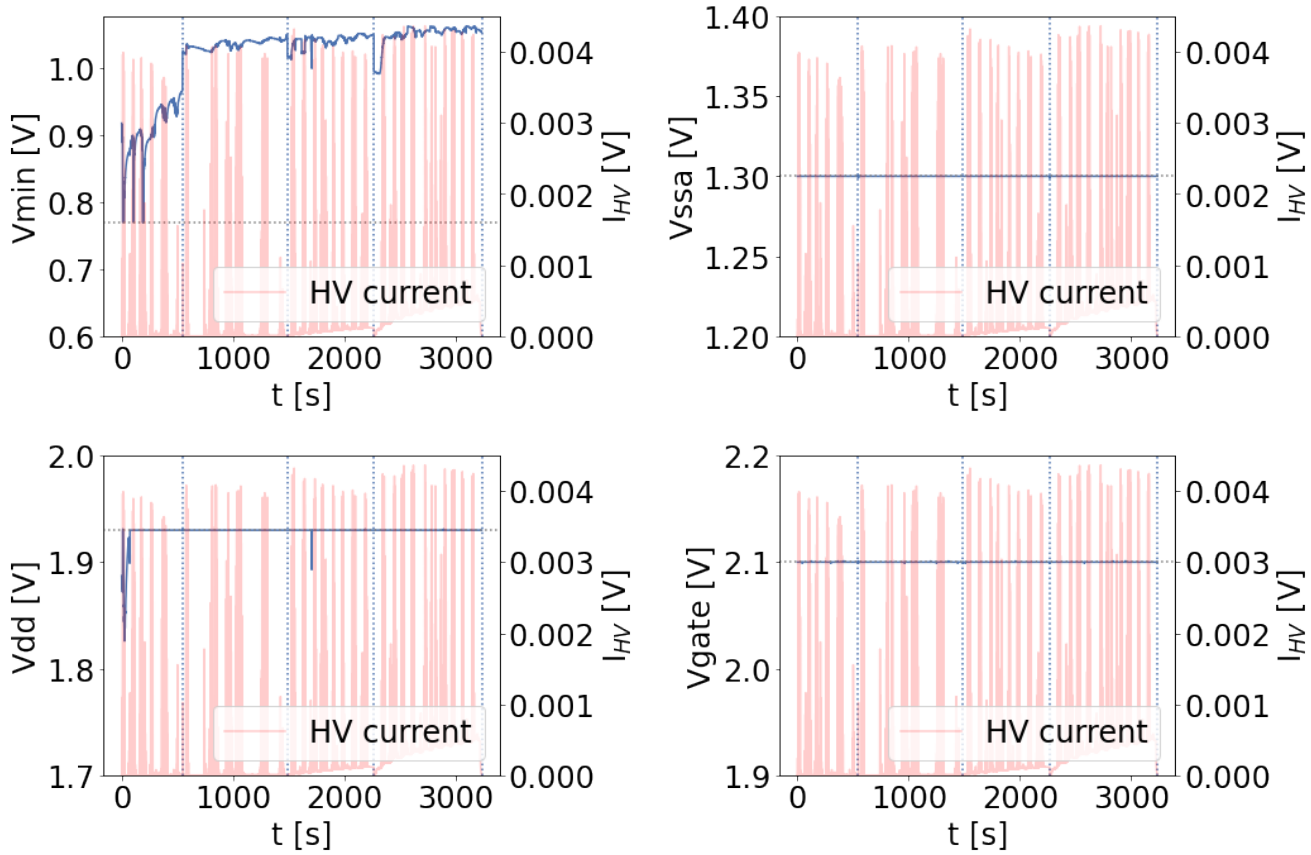


LV behaviour (Voltages)



LV voltages at -10, -40, -50, and -60 V bias voltage during irradiation

$\rightarrow$ Vssa, Vdd, Vgate relatively stable; Vmin increased by up to $\sim$ 200 mV above set level after 2.32e13 neq/cm^2 fluence

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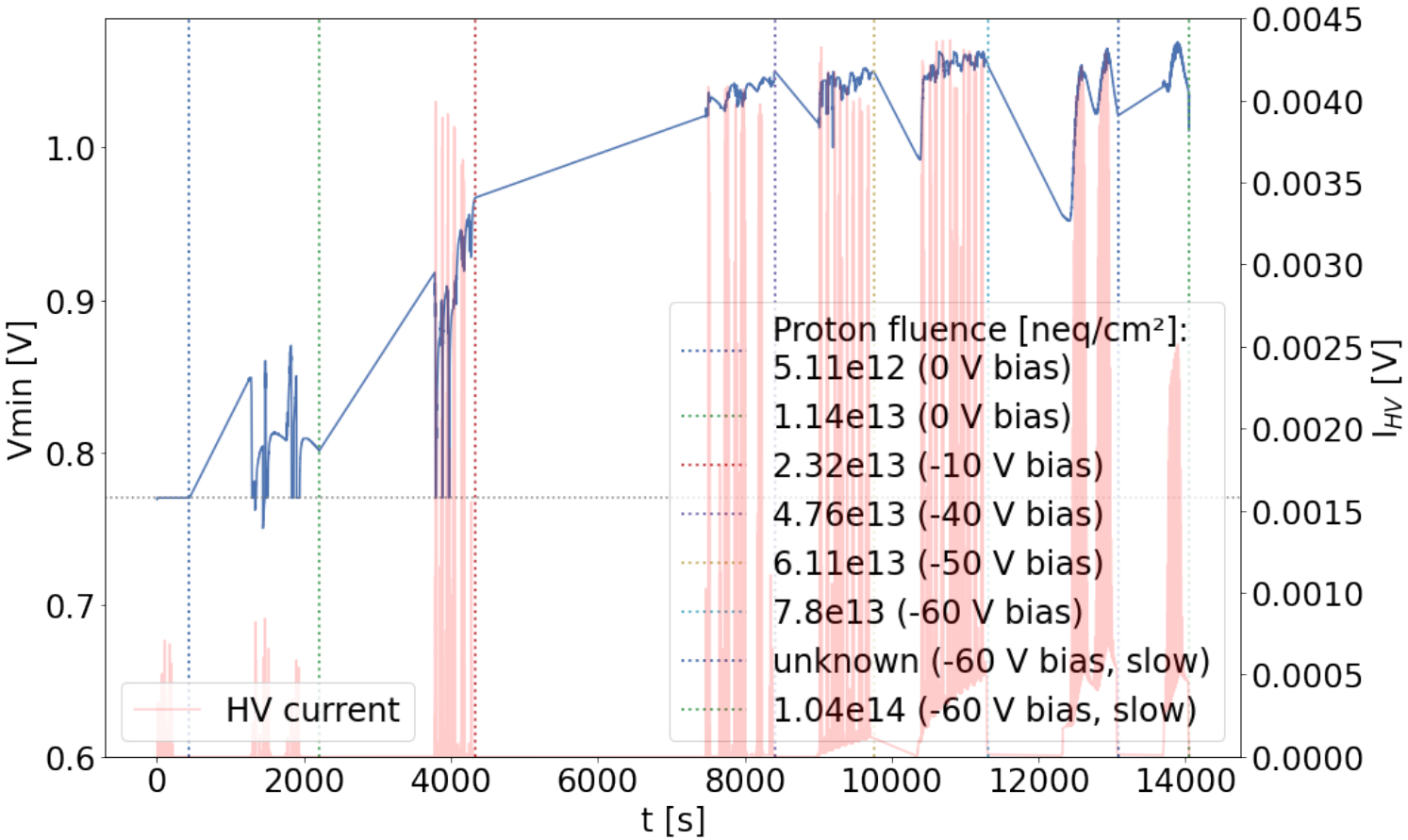

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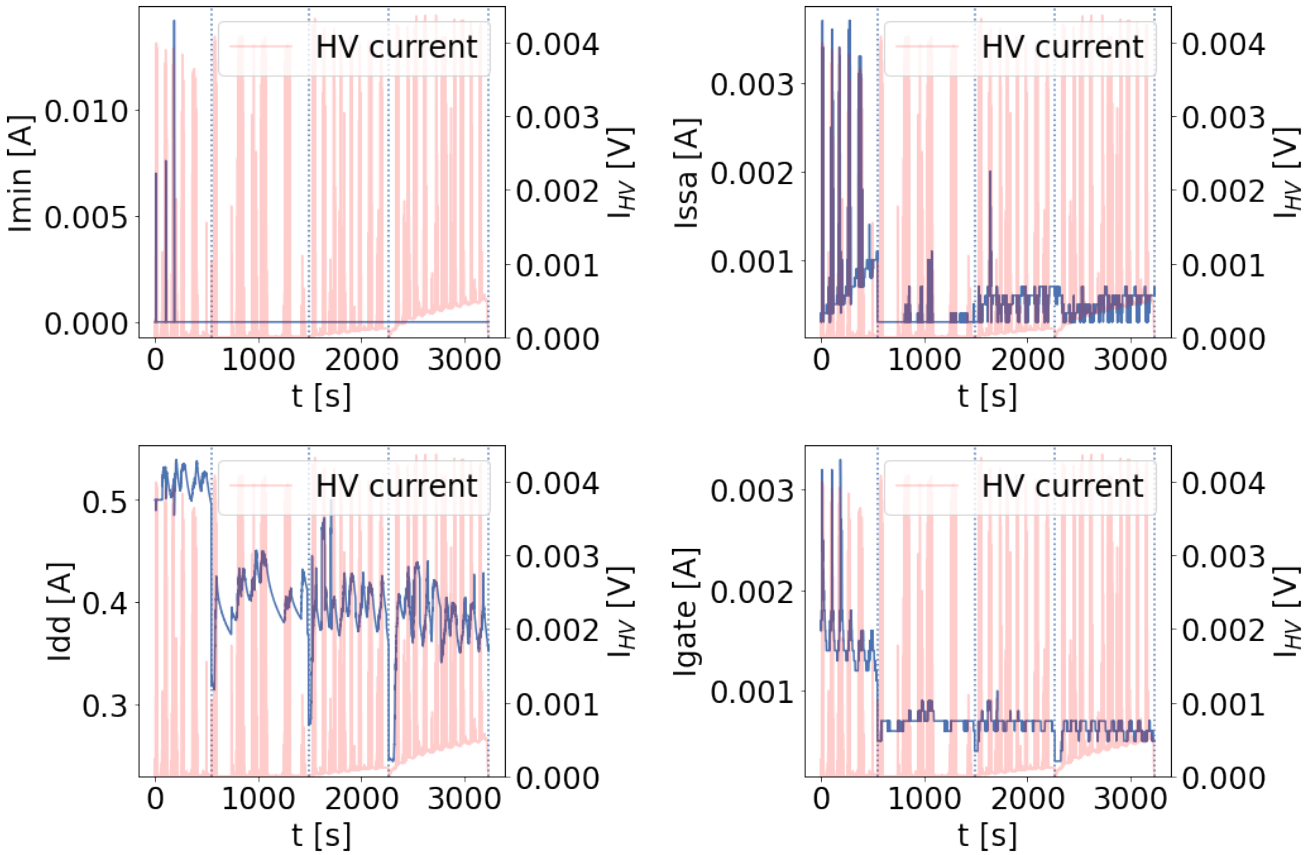
LV behaviour (Currents)



LV currents at -10, -40, -50, and -60 V bias voltage during irradiation; Note: -20, -30 V missing

→ Proton spill structure visible in Idd, Issa, and gate; not in Imin

To Do

- New IV's with returned chip (incl. scans in climate chamber)
- Incorporate temperature & fluence data from irrad_control
- Analyze slow scans
- New irrad. campaign in Bonn?