Mixed Irradiations: Order Dependent?

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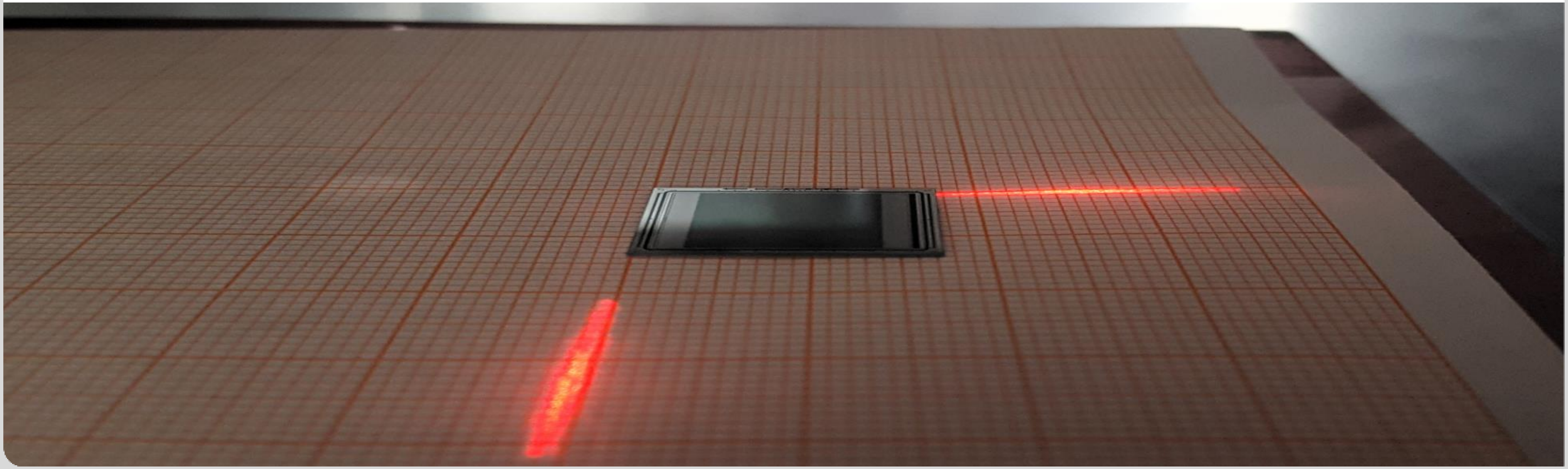
Institut für Experimentelle Teilchenphysik (ETP)



Introduction

- Strip sensors and diodes irradiated with a total fluence of **$\Phi \approx 6 \times 10^{14}$ n_{eq} cm^{-2}**
- Material (n-type):
  - diffusion oxygenated float zone (DOFZ), **magnetic Czochralski (MCZ)** and **float zone (FZ)** – From RD50's NitroStrip project (as in previous talk)
- Irradiation procedure for each material set:
  - 2 sensors and 1 diode irradiated with $\Phi \approx 3 \times 10^{14}$ n_{eq} cm^{-2} **protons** first and $\Phi \approx 3 \times 10^{14}$ n_{eq} cm^{-2} **neutrons** afterwards (**p+n**)
  - 2 sensors and 1 diode irradiated with $\Phi \approx 3 \times 10^{14}$ n_{eq} cm^{-2} **neutrons** first and $\Phi \approx 3 \times 10^{14}$ n_{eq} cm^{-2} **protons** afterwards (**n+p**)
- Measurements:
  - After first irradiation: CV characteristics (-20°C, 455Hz, guard ring floating)
  - After the second irradiation: CV and signal (ALiBaVa with ^{90}Sr source)
  - Annealing study: Seed signal

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Irradiation and Annealing

- Proton irradiation:
  - At ZAG (Karlsruhe) with 23 MeV (hardness factor of 2)
  - Samples are cooled down (to roughly -30°C) while irradiating
  - Measurement of the fluence with a Ni-foil ($\pm 15\%$)

    → First irradiation with protons $\Phi = 2.7 \times 10^{14}\ n_{eq}\ cm^{-2}$

    → Second irradiation with protons $\Phi = 2.9 \times 10^{14}\ n_{eq}\ cm^{-2}$
- Neutron irradiation:
  - At Ljubljana inside a spallation reactor
  - Samples are not cooled inside the reactor (roughly 20h annealing)
  - Real fluences

    → First irradiation with neutrons $\Phi = 3 \times 10^{14}\ n_{eq}\ cm^{-2}$

    → Second irradiation with neutrons $\Phi = 3.3 \times 10^{14}\ n_{eq}\ cm^{-2}$
- All equivalent fluence same ($\Phi = 3 \times 10^{14}\ n_{eq}\ cm^{-2}$) within 10%

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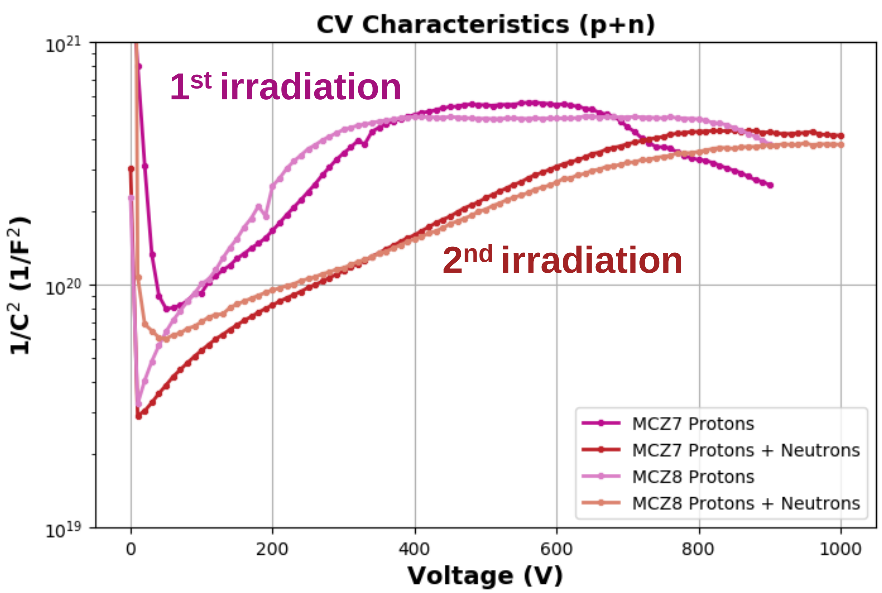
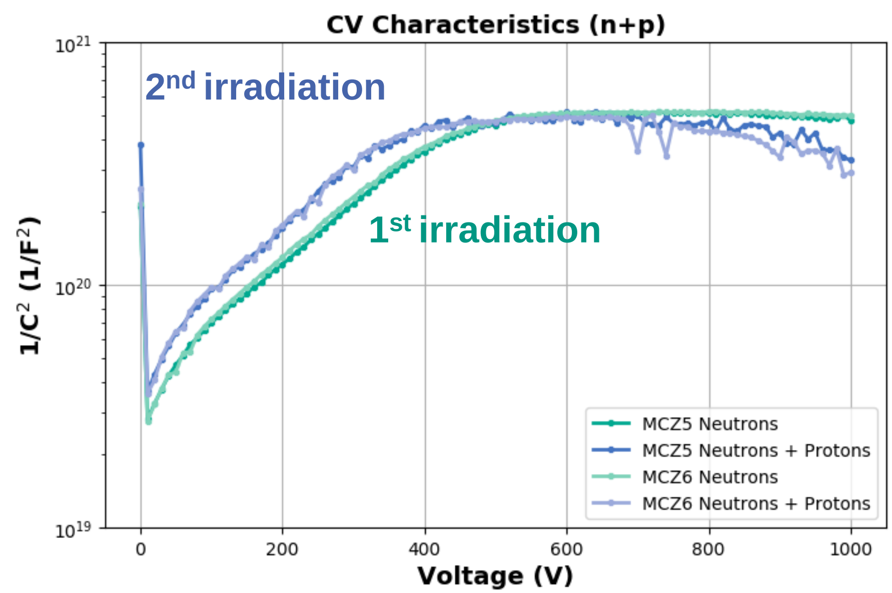
CV Characteristics of MCZ Strip Sensors

- **p → p+n**
  - First $\Phi = 2.7 \times 10^{14}\ n_{eq}\ cm^{-2}$ protons
  - Then $\Phi = 3.3 \times 10^{14}\ n_{eq}\ cm^{-2}$ neutrons (**p+n**)
  - → Depletion voltage increased (expected)
- **n → n+p**
  - First $\Phi = 3 \times 10^{14}\ n_{eq}\ cm^{-2}$ neutrons
  - Then $\Phi = 2.9 \times 10^{14}\ n_{eq}\ cm^{-2}$ protons (**n+p**)
  - → Depletion voltage unchanged/reduced!





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CV Characteristics of FZ Strip Sensors

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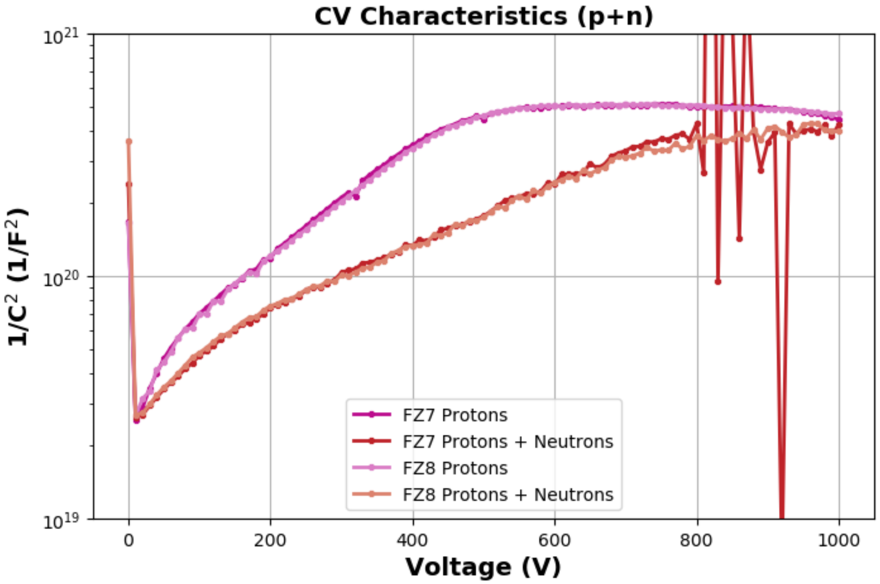
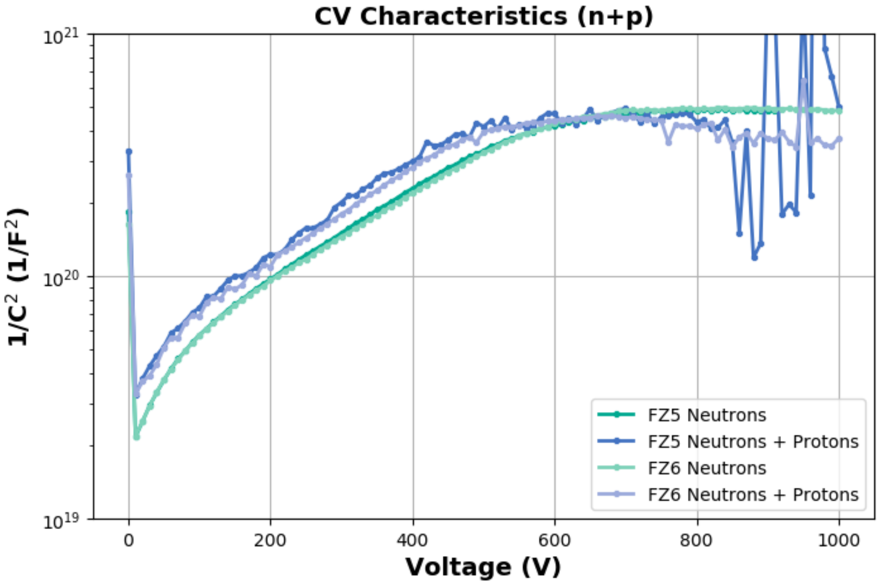
- **p → p+n**
  - First $\Phi = 2.7 \times 10^{14}\ n_{eq}\ cm^{-2}$ protons
  - Then $\Phi = 3.3 \times 10^{14}\ n_{eq}\ cm^{-2}$ neutrons (**p+n**)
  - → Depletion voltage increased (expected)
- **n → n+p**
  - First $\Phi = 3 \times 10^{14}\ n_{eq}\ cm^{-2}$ neutrons
  - Then $\Phi = 2.9 \times 10^{14}\ n_{eq}\ cm^{-2}$ protons (**n+p**)
  - → Depletion voltage unchanged/reduced!





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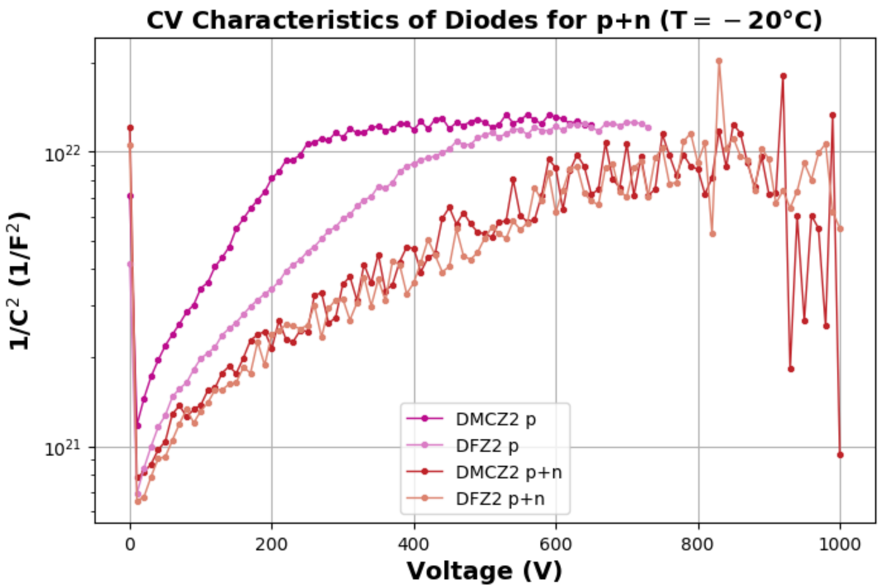
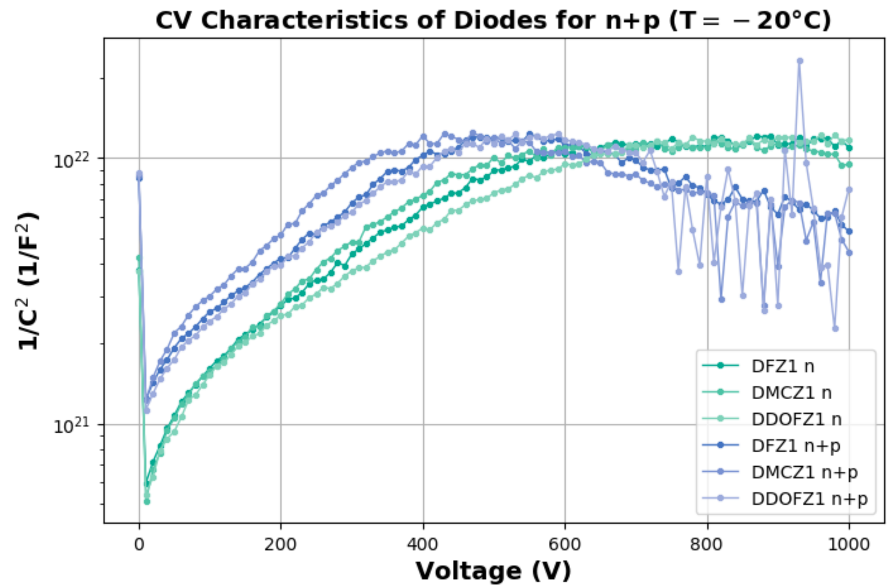
CV Characteristics of Diodes

- **p → p+n**
  - First $\Phi = 2.7 \times 10^{14}$ n_{eq} cm^{-2} protons
  - Then $\Phi = 3.3 \times 10^{14}$ n_{eq} cm^{-2} neutrons (**p+n**)
  - → Depletion voltage increased (expected)
- **n → n+p**
  - First $\Phi = 3 \times 10^{14}$ n_{eq} cm^{-2} neutrons
  - Then $\Phi = 2.9 \times 10^{14}$ n_{eq} cm^{-2} protons (**n+p**)
  - → Depletion voltage unchanged/reduced!





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Short Discussion – Frame Conditions

- **Result till now:**
  - The irradiation sequence **n+p** leads to a **lower depletion voltage** than **p+n** (all materials)
- **Annealing:**
  - Irradiation procedure protons + neutrons (p+n)
    - First proton irradiation → sensors are cooled down to -30°C
    - Then shipped to Ljubljana → uncontrolled annealing possible + annealing inside reactor
    - Shipped back → uncontrolled annealing could take place again
  - Irradiation procedure for neutrons + protons (n+p)
    - First neutron irradiation (temperature during shipment uncritical)
    - Annealing inside the reactor - similar to p+n
    - Shipment back to KIT → **same** annealing time as for p+n (all sensors in the **same** package)
    - Irradiation with protons → should be cooled down to -30°C
- **Preliminary conclusion:** Less depletion voltage (for n+p) due to annealing is only possible if sensors were not cooled down while irradiating with protons!

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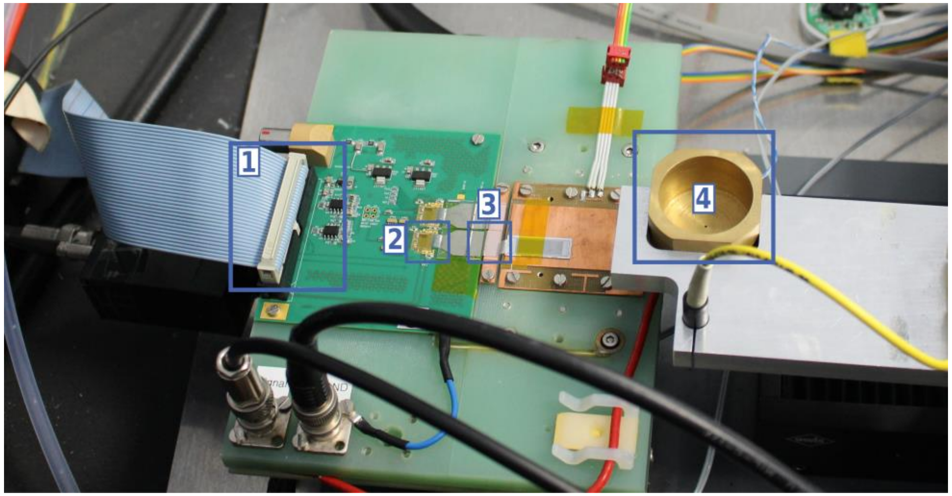
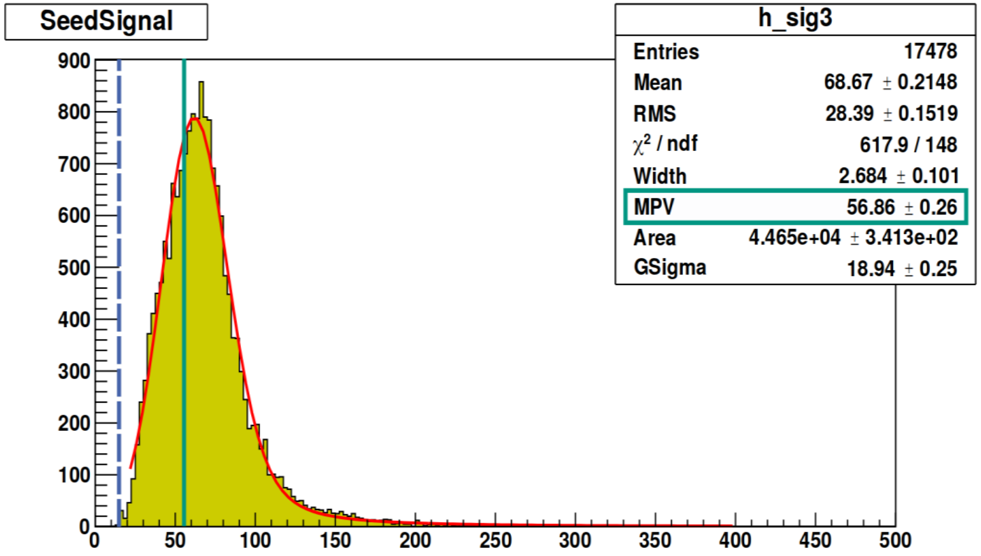
Signal measurements with an ALiBaVa setup

- **Daughterboard inside a shielded box**
  - 1 – Connection to motherboard
  - 2 – Beetle chip for readout
  - 3 – Pitch adapter
  - 4 – Radioactive source holder
- Copper block temperature controlled via peltier elements (-20°C to 80°C)
- Scintillator below the copper block to trigger the readout
- **Measurement procedure**
  - Pedestal run to measure the noise
  - Calibration run to calibrate the gain
  - Radioactive source run to measure the generated signal





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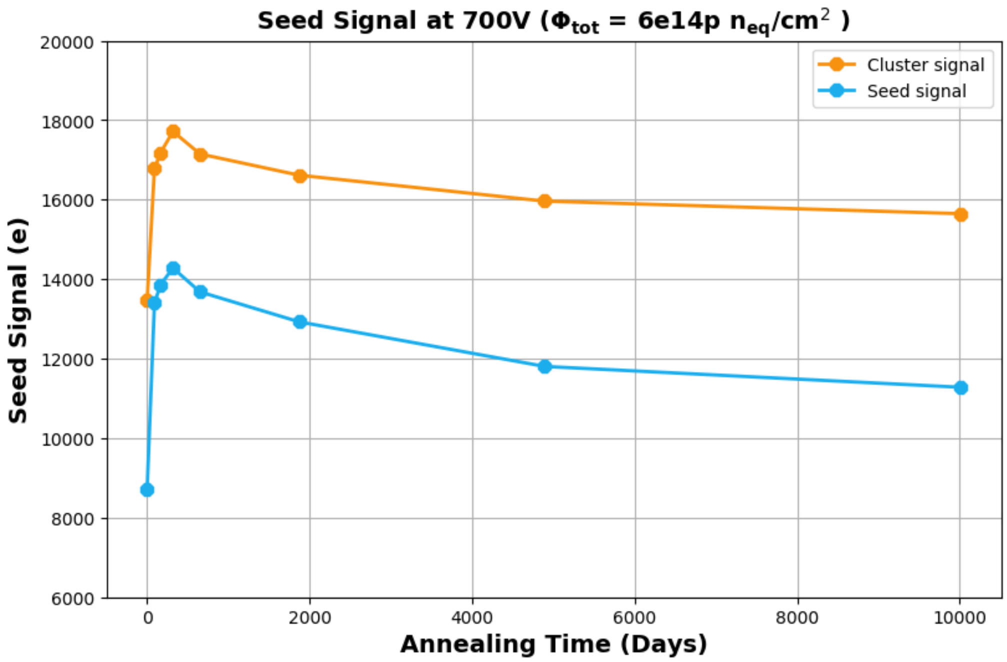
Seed Signal vs Cluster Signal

- Charged particle traversing a sensor generates signal in a set of strips (cluster)
  - Seed signal: signal of the strip with the most signal ($SNR \geq 4$)
  - Cluster signal: seed signal + signal of neighbouring strips ($SNR \geq 2$)
- **Main difference between cluster and seed signal is an offset**

→ Comparison of both signal definitions for a proton irradiated MCZ strip sensor



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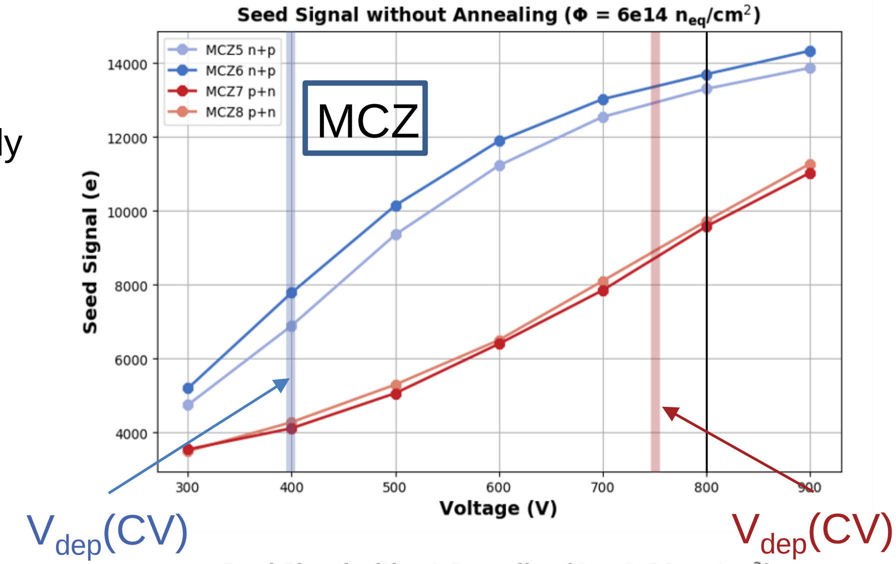
Seed Signal before Annealing

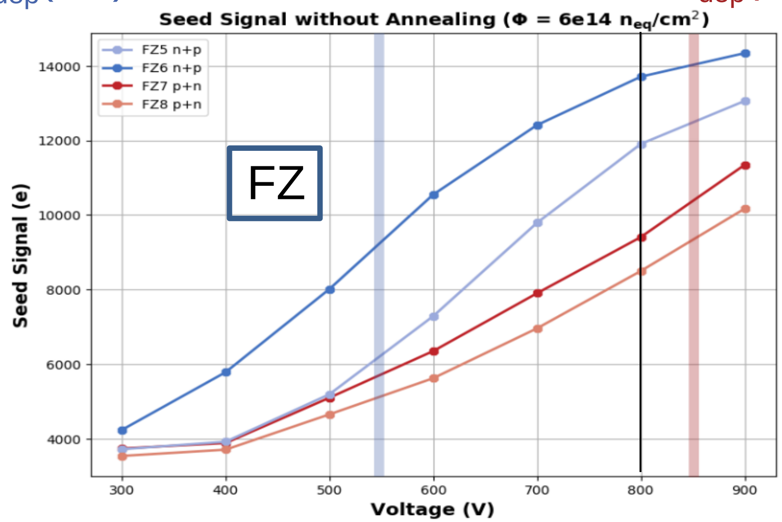
- **Voltage dependence of the signal (MCZ)**
  - Sensors irradiated with **n+p** show a significantly higher signal for all bias voltages above 300V
  - Consistent with the CV characteristics

    → Lower depletion voltage for **n+p**



- **Voltage dependence of the signal (FZ)**
  - One sensor with **n+p** clearly above the others
  - FZ5 similar signal to **p+n** for low voltages but higher signal at higher voltages(?)
  - Others consistent with CV characteristics

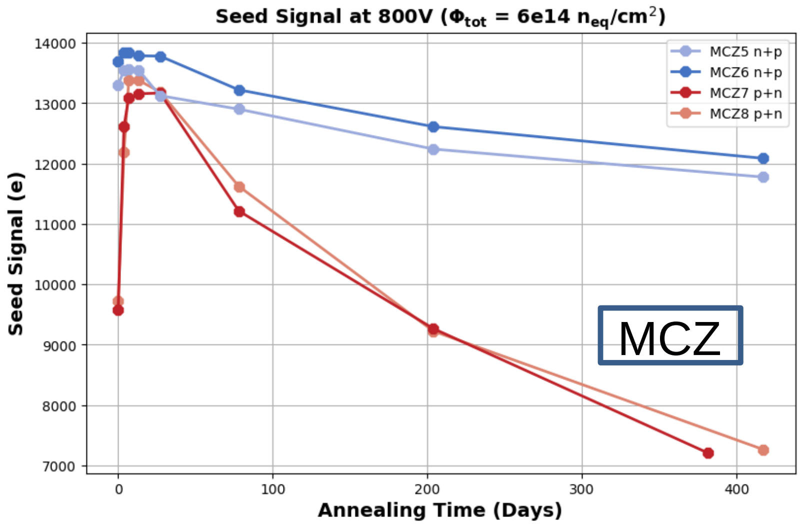
    → Lower depletion voltage for **n+p**



Annealing Characteristics

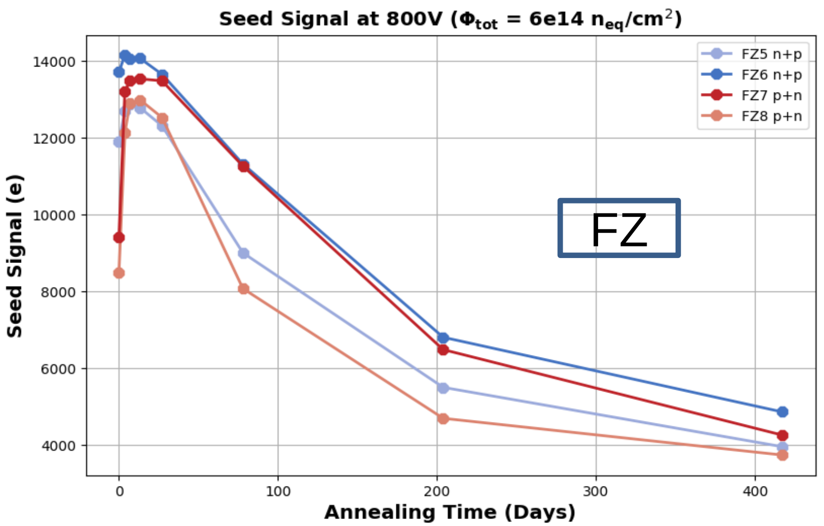
- **Annealing behaviour at 800V (MCZ)**
  - Dependent on the irradiation sequence!

    → Excludes annealing as an explanation for the differences after n+p and p+n irradiation



- **Annealing behaviour at 800V (FZ)**
  - Independent of the irradiation sequence
  - Before annealing: higher signal of **n+p**

    → Fast vanishing of the difference
- **Oxygen concentration**
  - MCZ: $4.6 \cdot 10^{17}\ \mathrm{cm}^{-3}$
  - FZ: $< 9 \cdot 10^{15}\ \mathrm{cm}^{-3}$



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Conclusions

- Investigation of CV characteristics and signal dependent on the irradiation sequence
- The irradiation sequence **n+p** results in a lower depletion voltage than for **p+n** irradiated samples for all investigated materials (MCZ, FZ, DOFZ)
- In agreement with this lower depletion voltage, the signal is higher (before annealing)
- The signal difference vanishes rapidly (after some days annealing time) due to strong beneficial annealing of the **p+n** irradiated sensors

  → The signal annealing behaviour is similar for both irradiation sequences and FZ material
- It is ambiguous if this is also the case for DOFZ material
- Contrary, the irradiation sequence was crucial for the annealing behaviour of MCZ material

  → **n+p** irradiated samples showed significantly less reverse annealing

  → Finally excludes annealing as a possible explanation

- Similar effects were also observed for p-type material

  → But no full comparable data set (CVs of **n+p** irradiated sensors)

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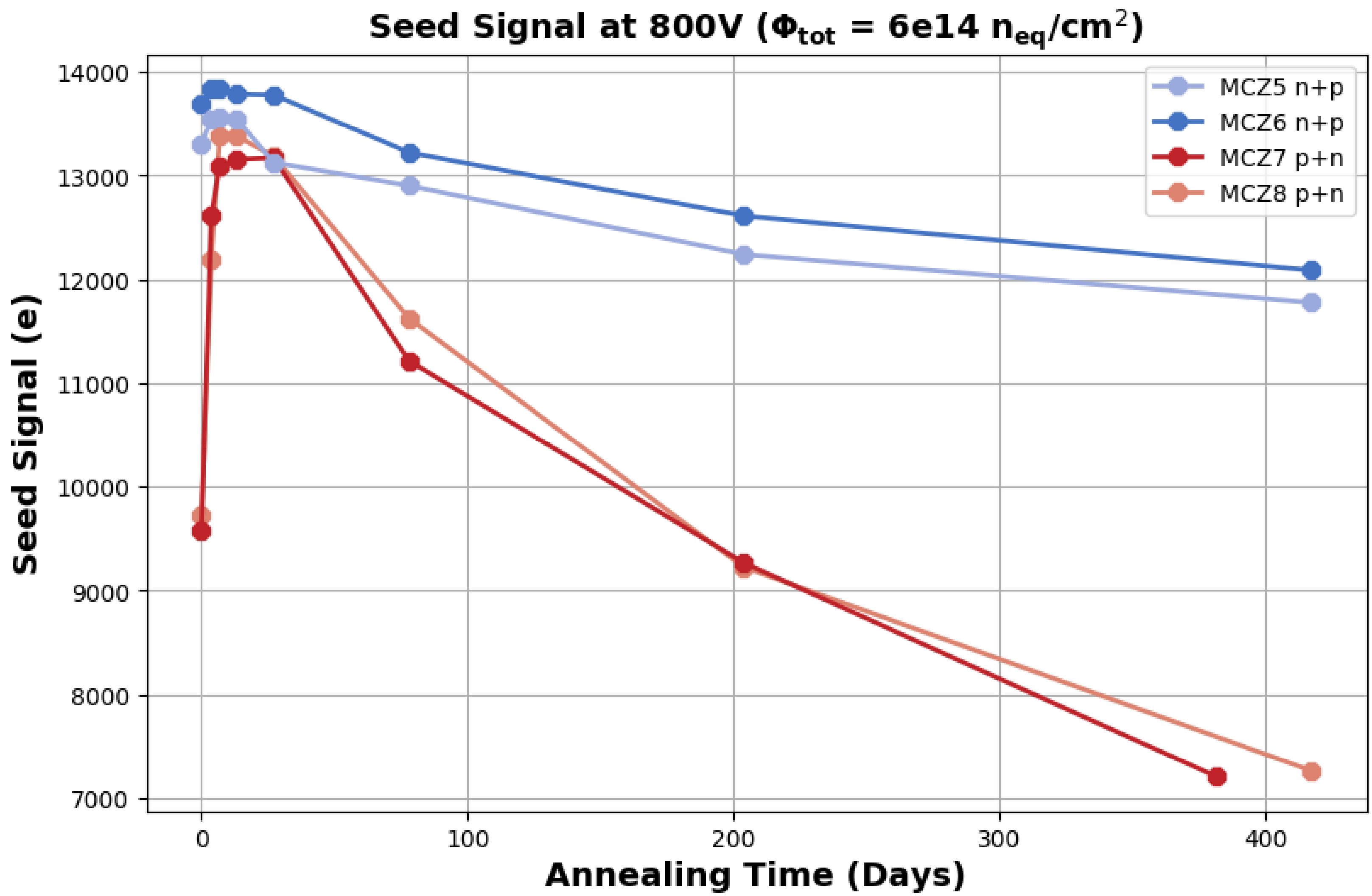
Backup

Signal Annealing of MCZ Material



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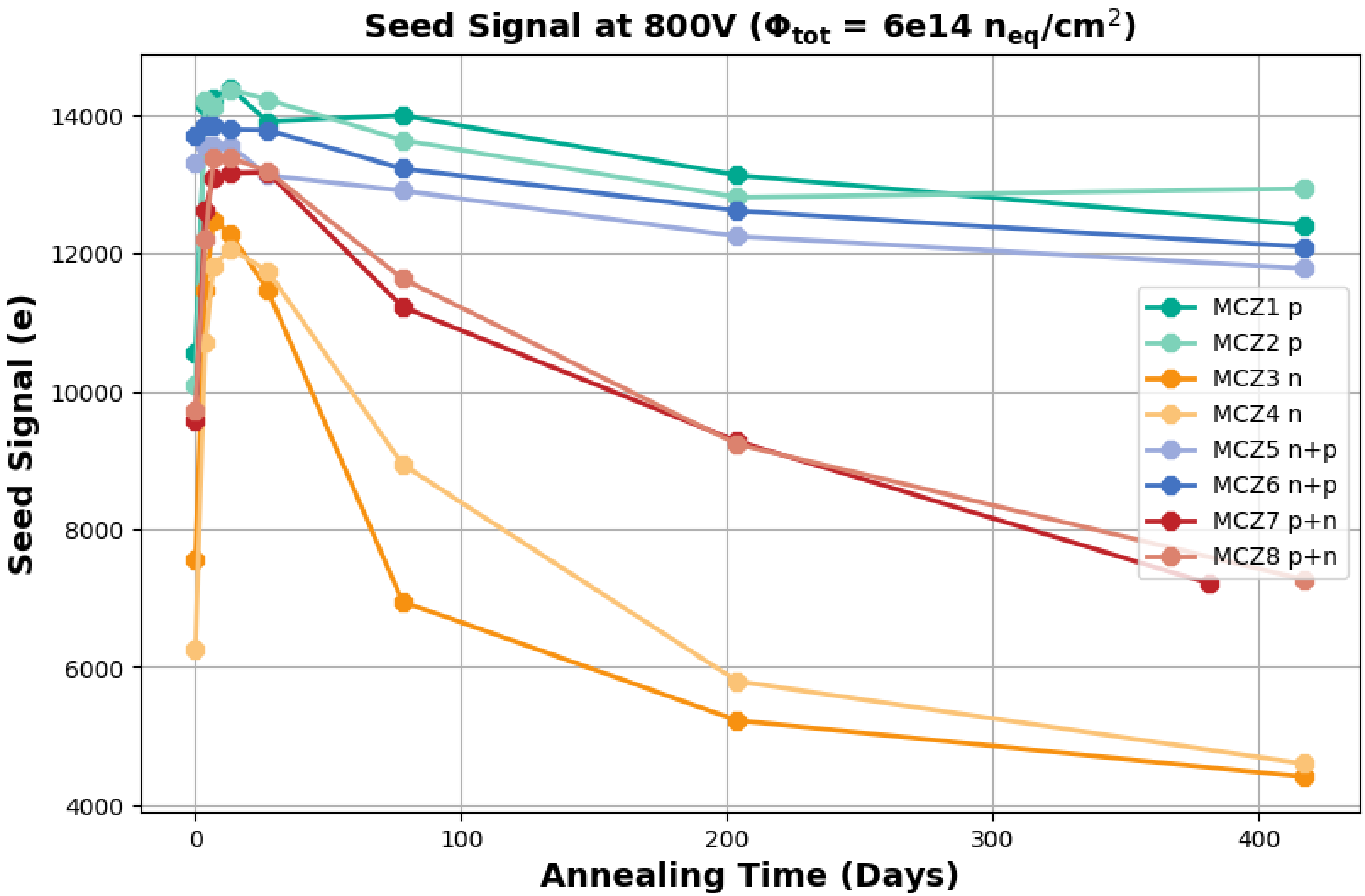
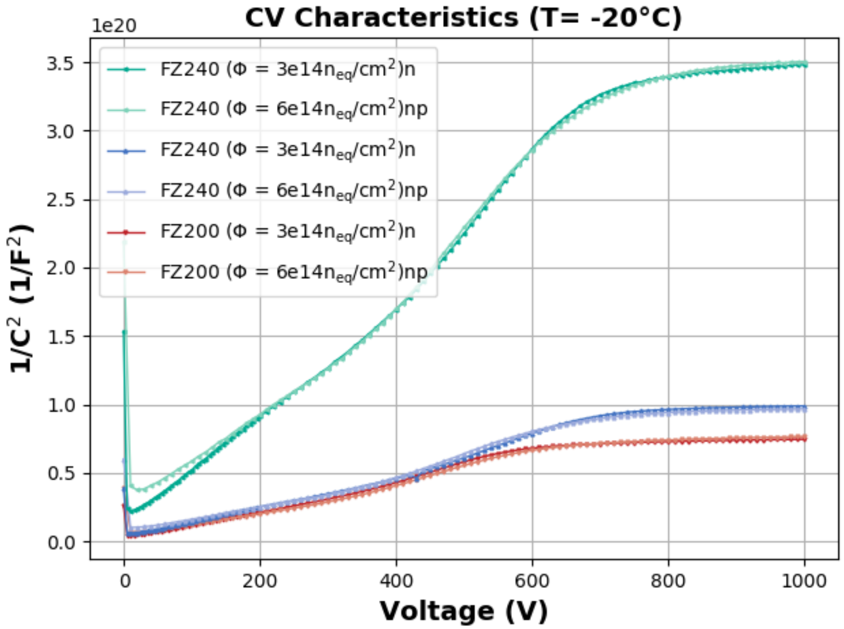
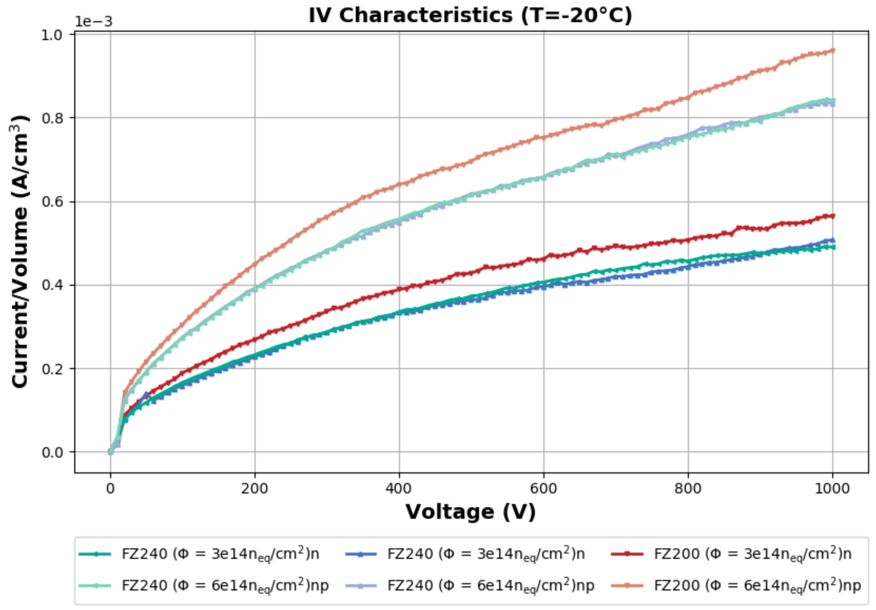
Signal Annealing of MCZ Material



HPK Material – CV and IV Characteristics





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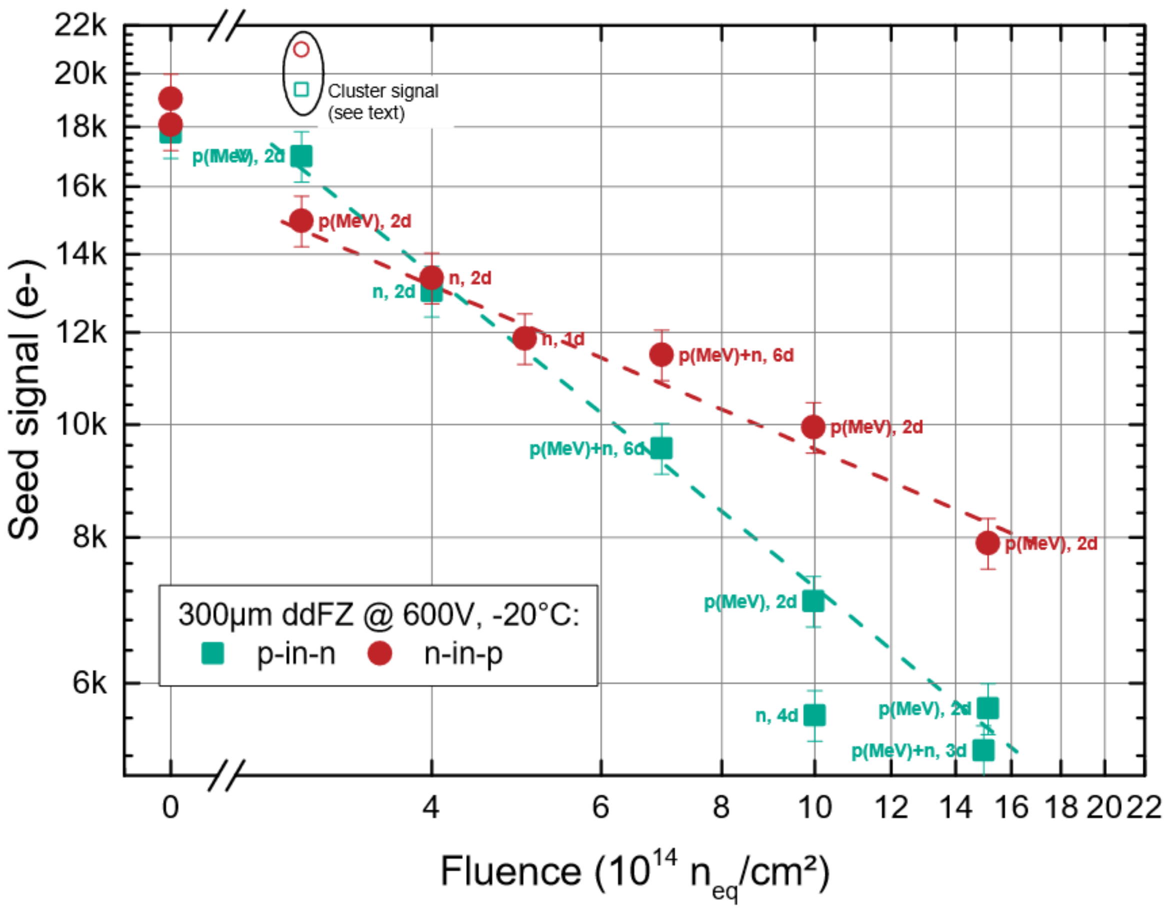
Signal over Fluence of n-type Sensors

- From 2017 JINST 12 P06018

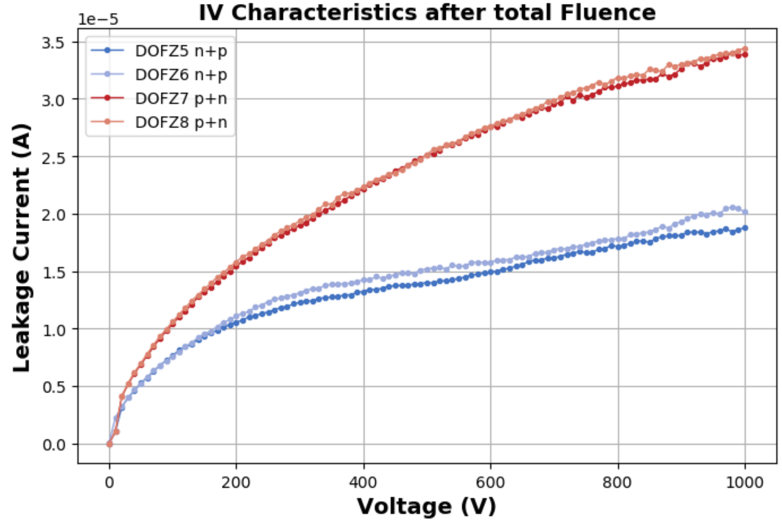


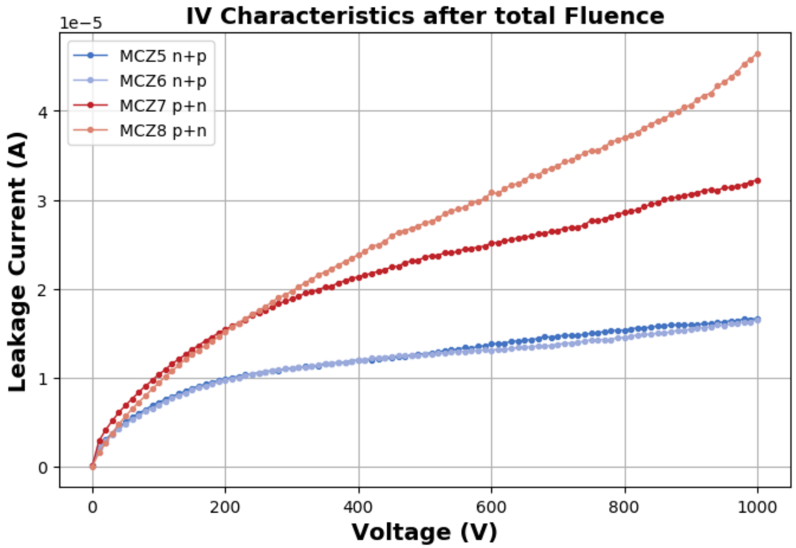
IV Characteristics n+p vs p+n

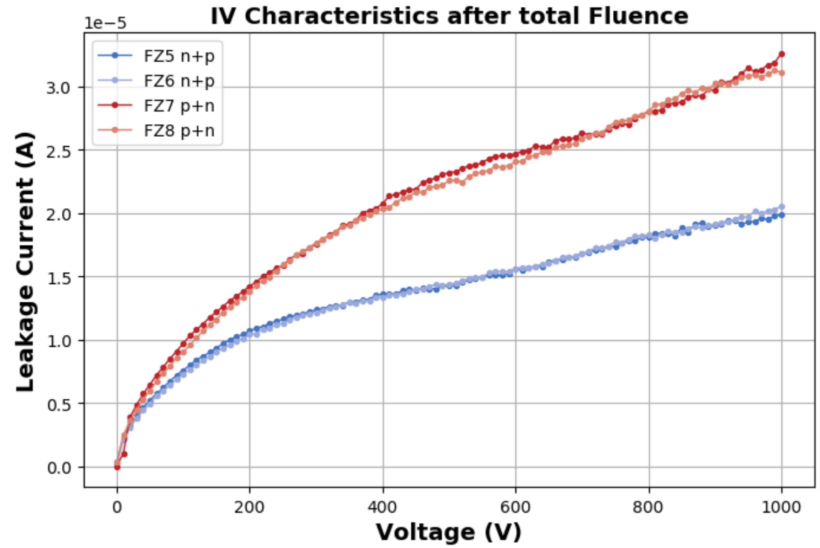
- **After the total fluence of $\Phi \approx 6e14\ n_{eq}\ cm^{-2}$**
  - Neutron after proton irradiation (**p+n**)

    → More leakage current
  - Proton after neutron irradiation (**n+p**)

    → Less leakage current







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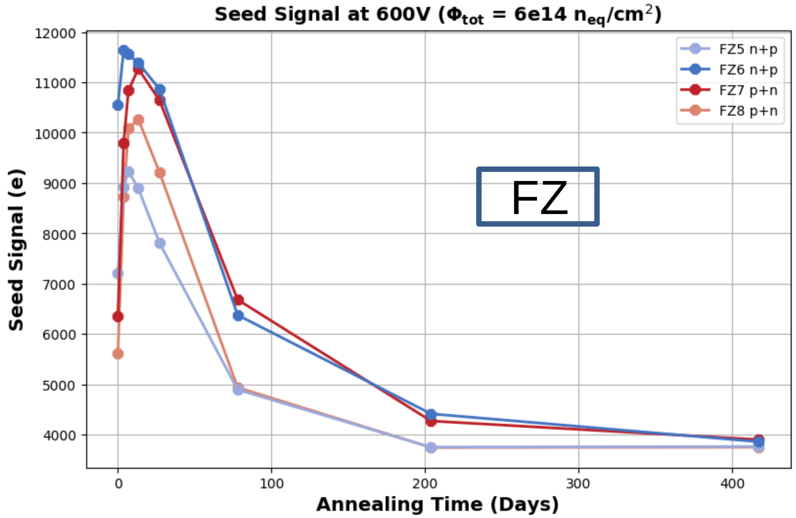
Signal after Irradiation – FZ and DOFZ 600V

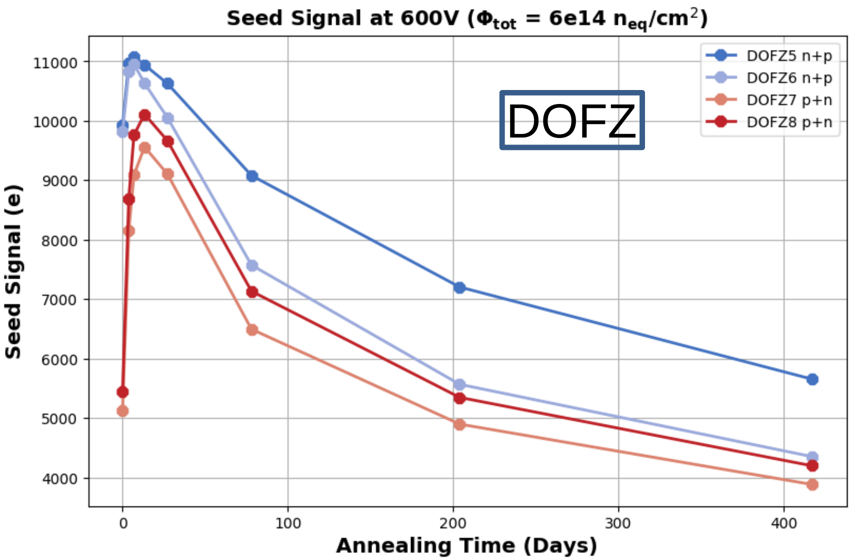
- **Annealing behaviour of the seed signal (FZ)**
  - Independent of the irradiation sequence
  - Before annealing: higher signal of **n+p**

    → Consistent with CV measurements



- **Annealing behaviour of the seed signal (DOFZ)**
  - Dependent on the irradiation sequence?
  - Before annealing: higher signal of **n+p**

    → Consistent with CV measurements



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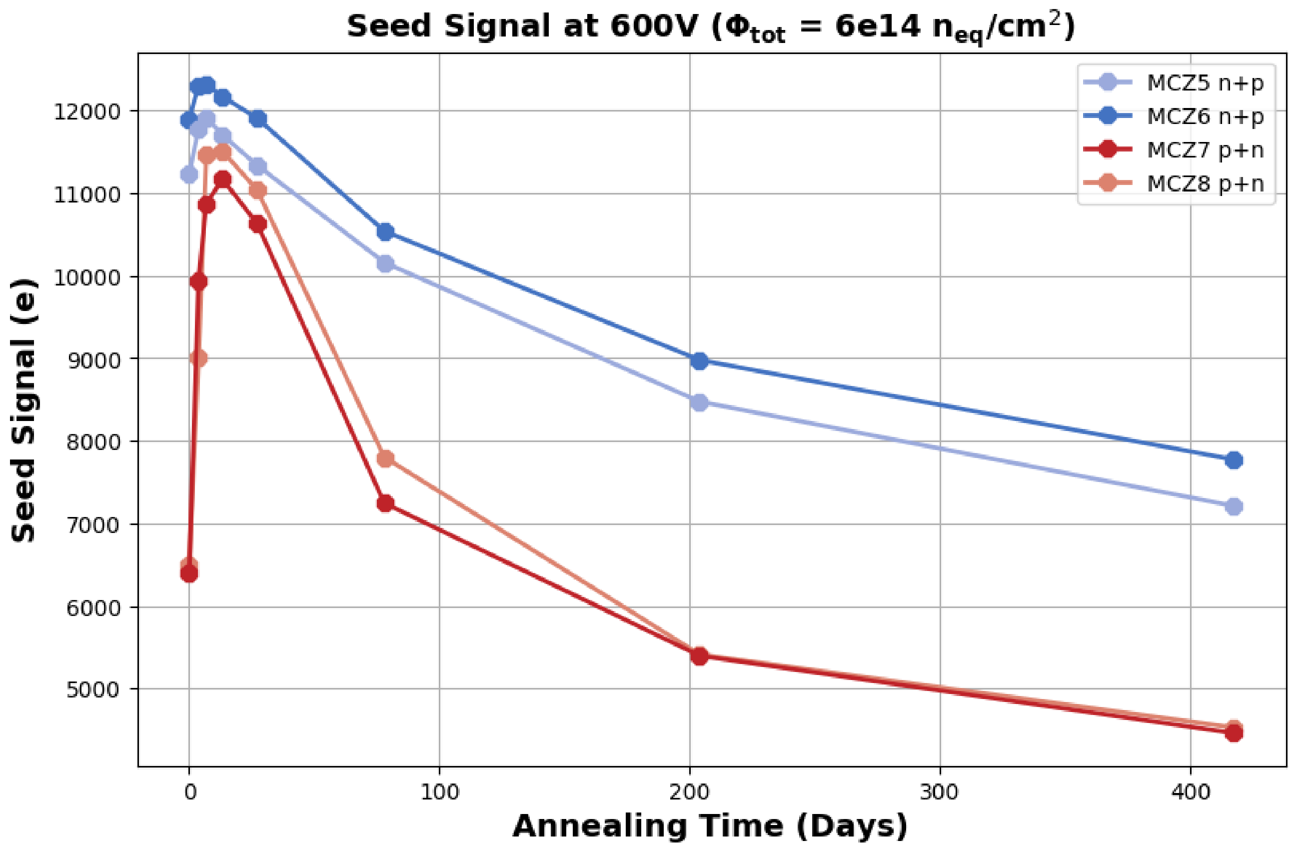
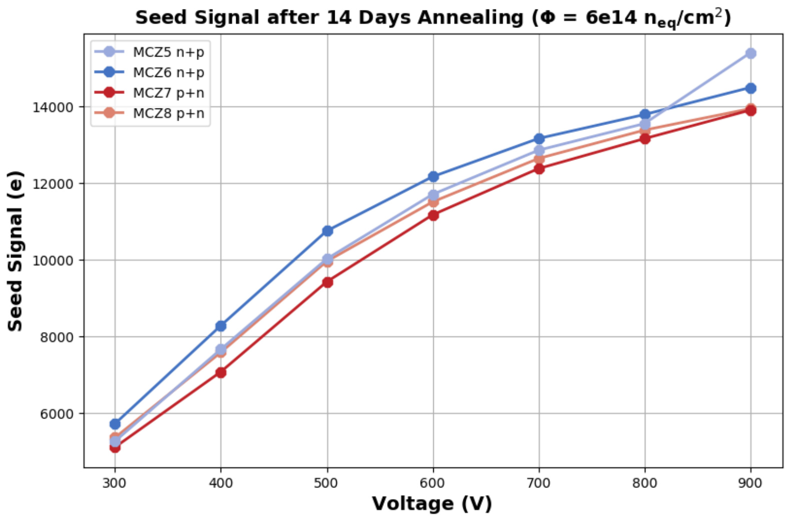
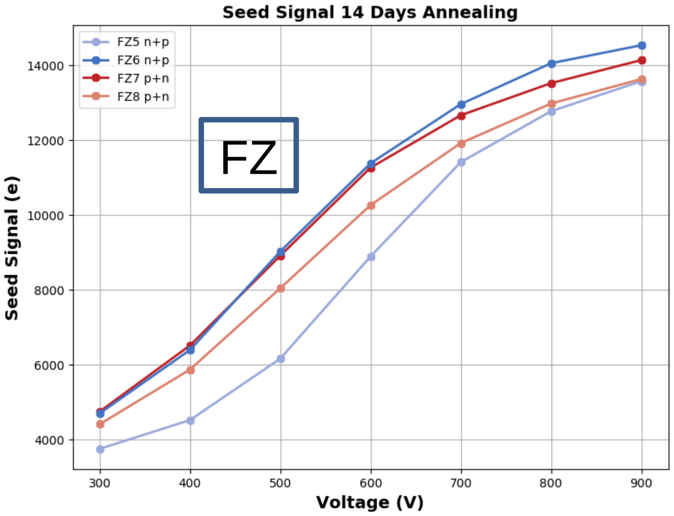
Signal after Irradiation – MCZ 600V

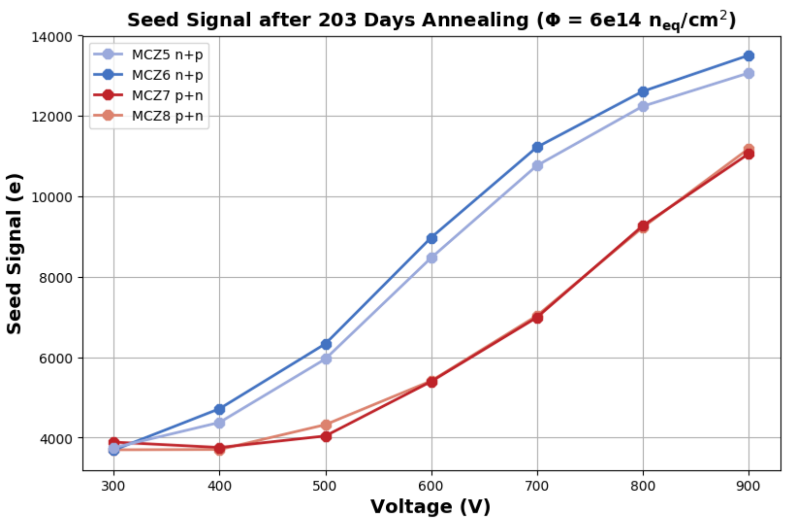
- **Annealing behaviour of the seed signal (MCZ) at 600V**
  - Still stronger reverse annealing of the **p+n** irradiated material



Voltage Dependence after Annealing







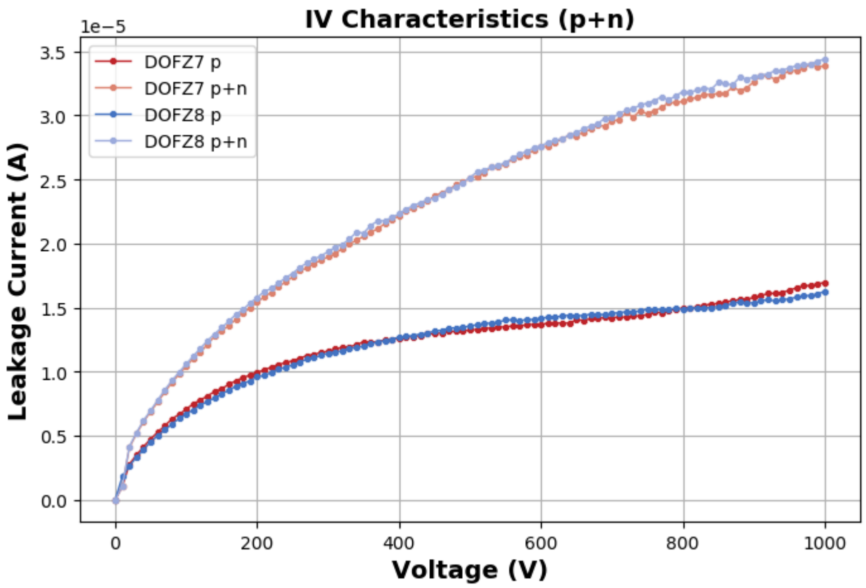
IV Characteristics of DOFZ Material

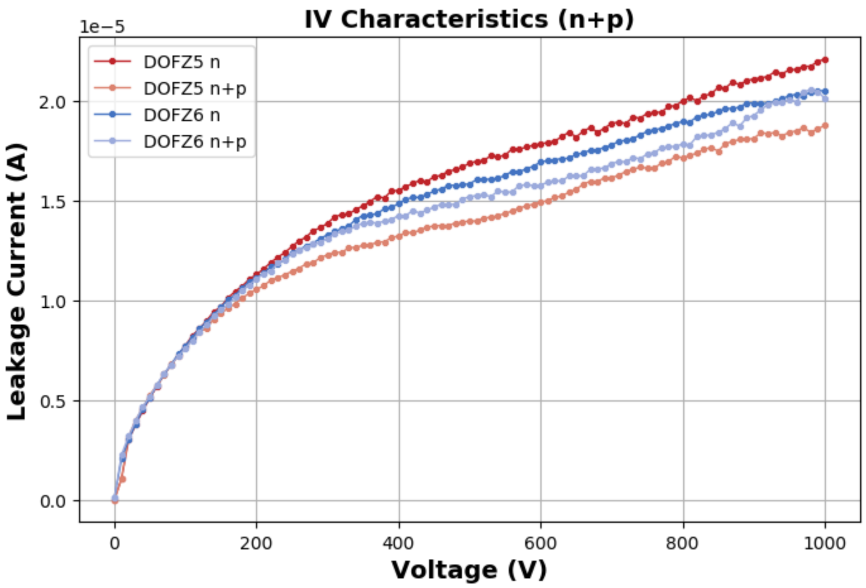
- **Left side:**
  - First proton then neutron irradiation (p+n)

    → Leakage current increased (expected)

- **Right side:**
  - First neutron then proton irradiation (n+p)

    → Leakage current unchanged!





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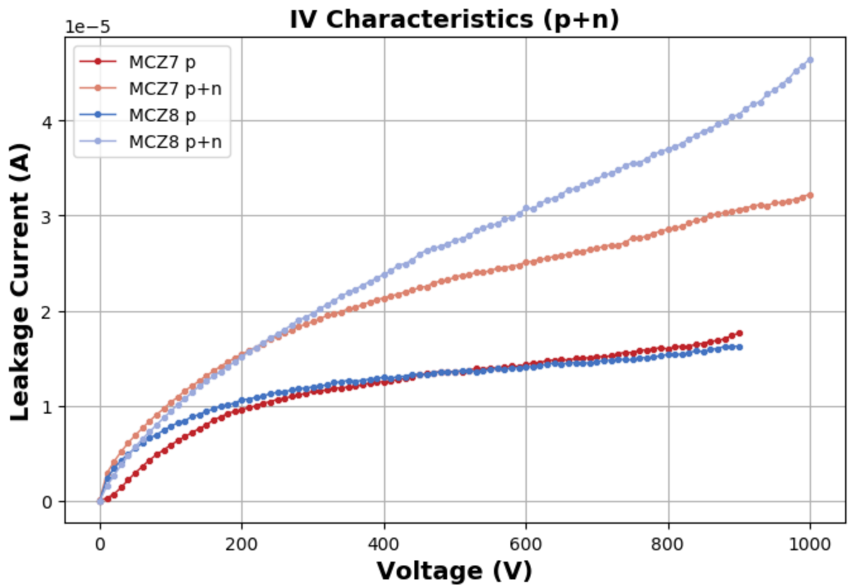
IV Characteristics of MCZ Material

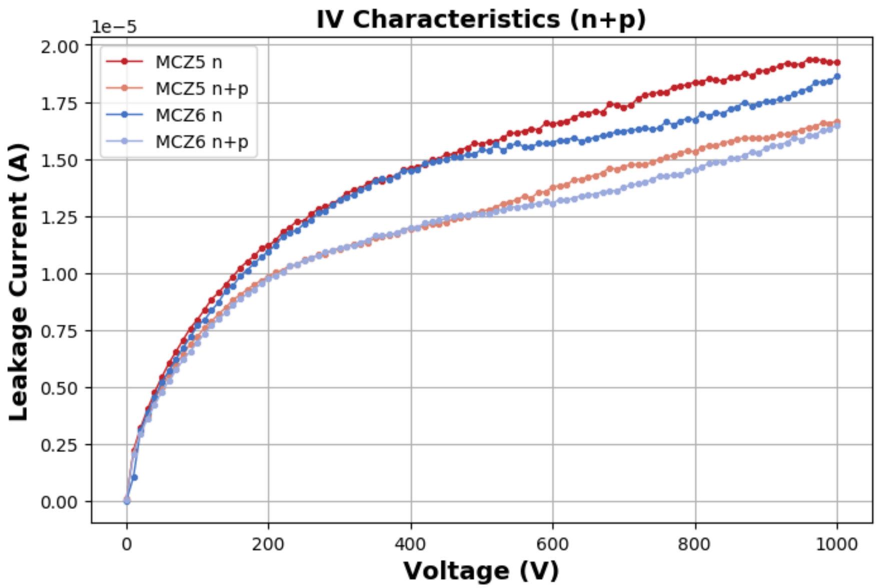
- **Left side:**
  - First proton then neutron irradiation (p+n)

    → Leakage current increased (expected)

- **Right side:**
  - First neutron then proton irradiation (n+p)

    → Leakage current unchanged/reduced!





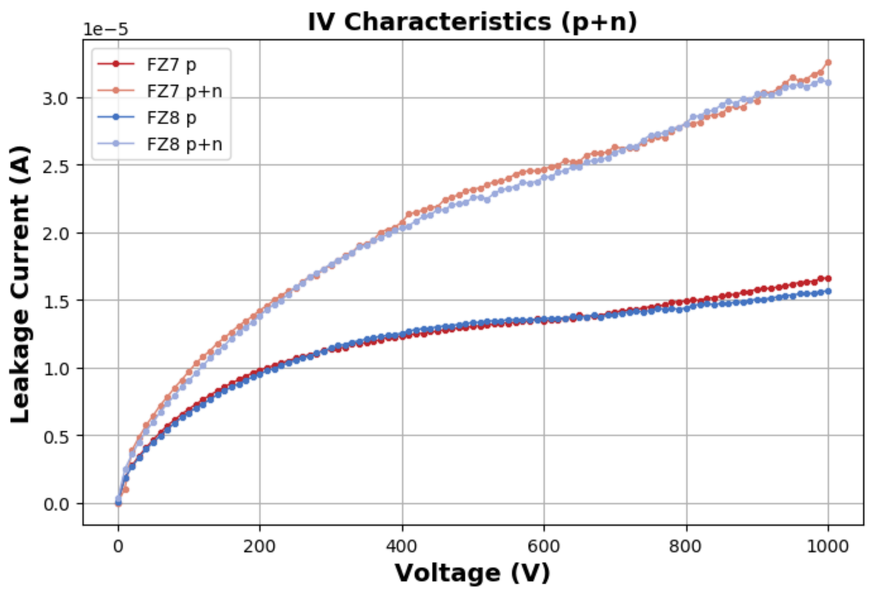
IV Characteristics of FZ Material

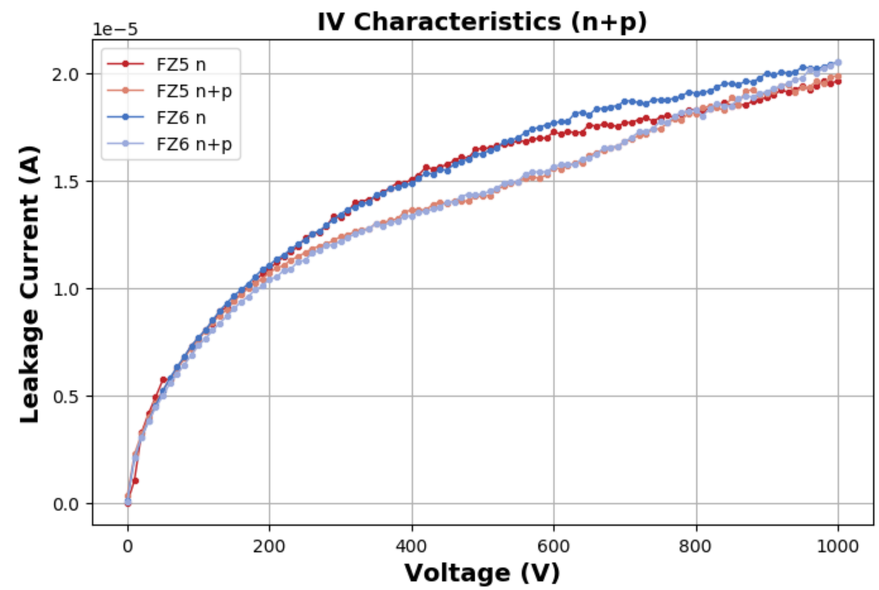
- **Left side:**
  - First proton then neutron irradiation (p+n)

    → Leakage current increased (expected)

- **Right side:**
  - First neutron then proton irradiation (n+p)

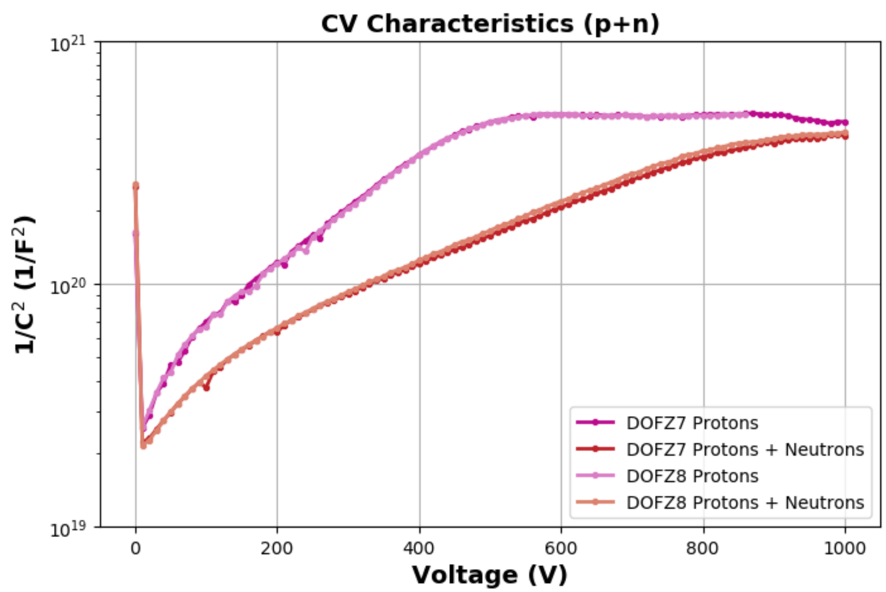
    → Leakage current unchanged/reduced!

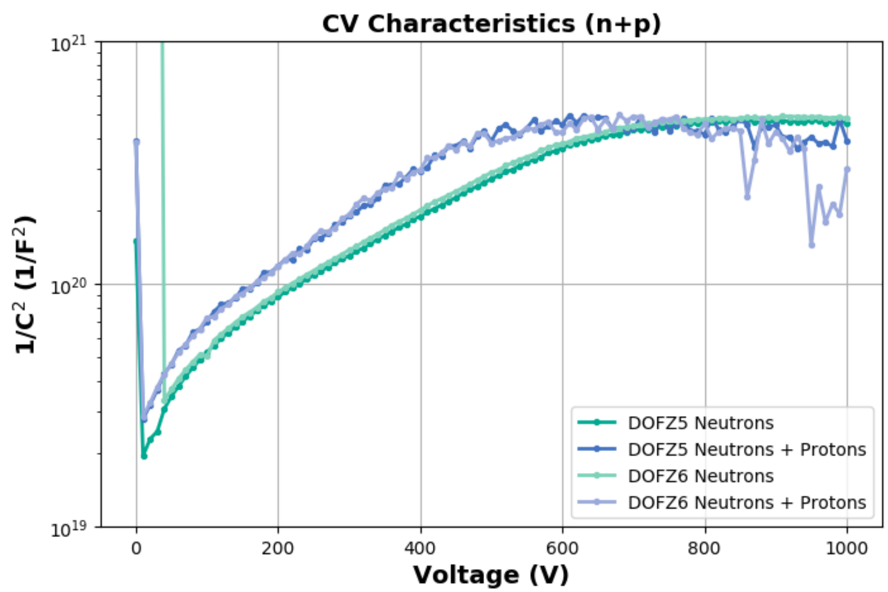




CV Characteristics of DOFZ Material

- **p → p+n**
  - First Φ = 2.7 x 10^{14} n_{eq} cm^{-2} protons
  - Then Φ = 3.3 x 10^{14} n_{eq} cm^{-2} neutrons (p+n)
  - → Depletion voltage increased (expected)
- **n → n+p**
  - First Φ = 3 x 10^{14} n_{eq} cm^{-2} neutrons
  - Then Φ = 2.9 x 10^{14} n_{eq} cm^{-2} protons (n+p)
  - → Depletion voltage unchanged/reduced!





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