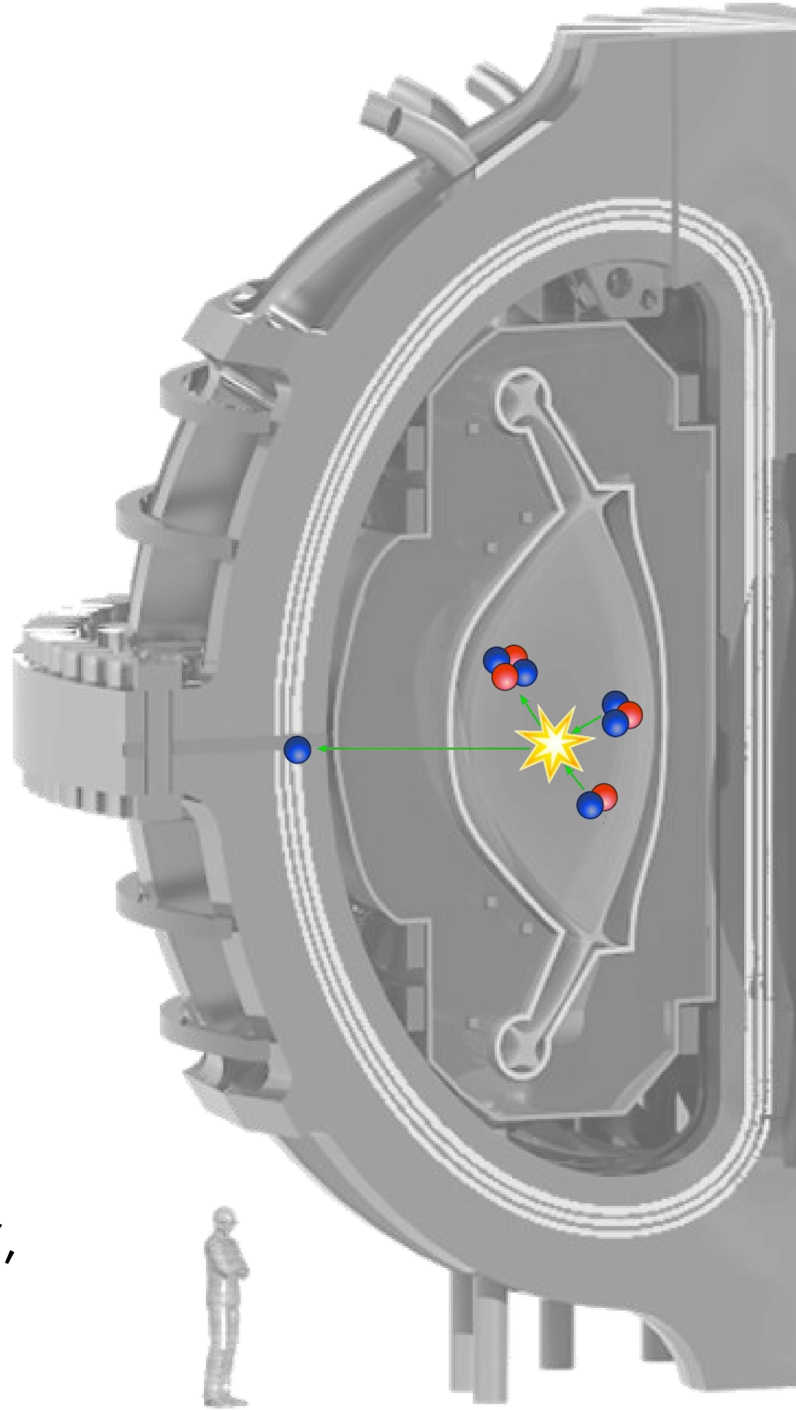
NSE
Nuclear Science
and Engineering

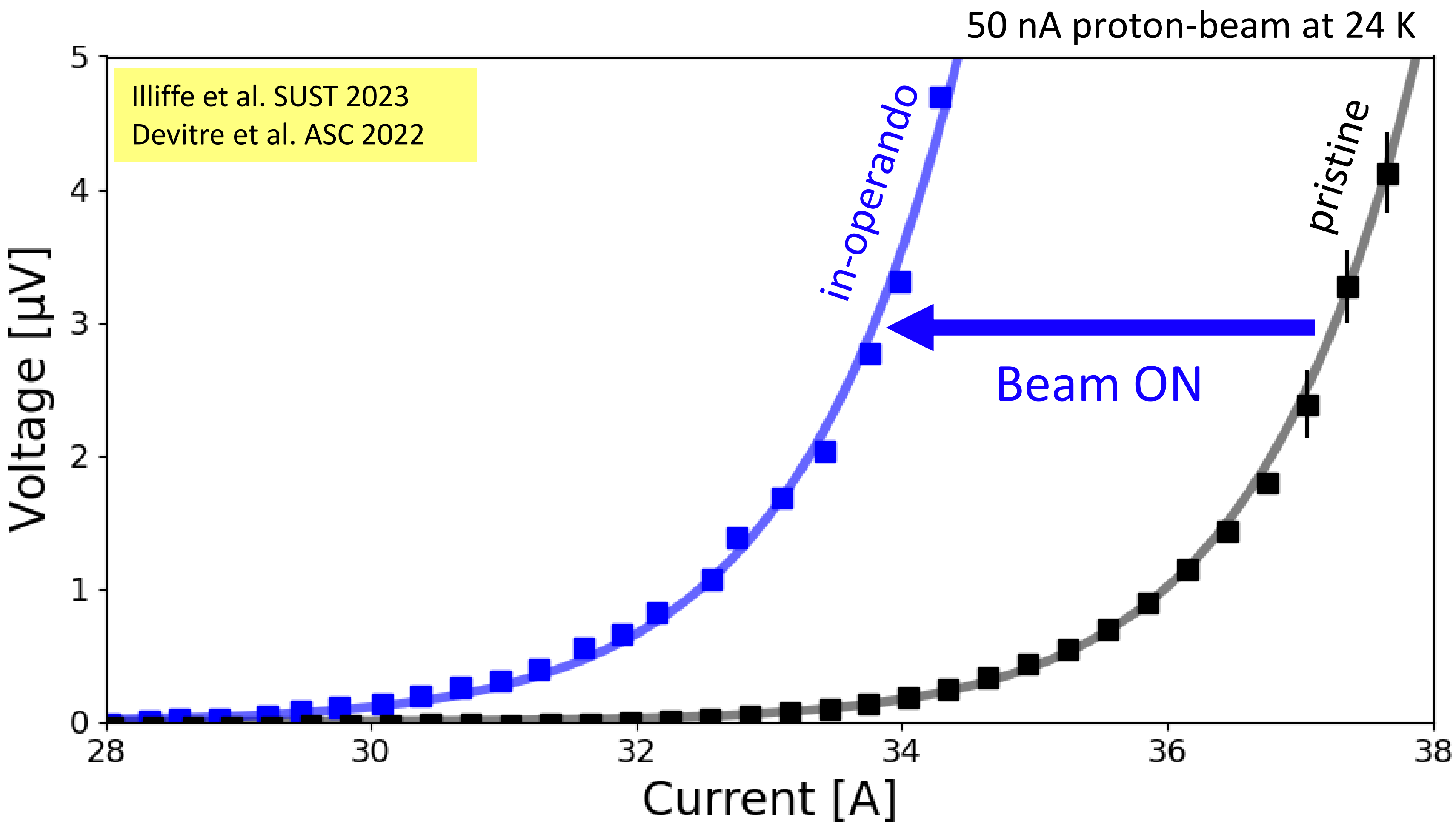
science : systems : society

Key insights from experiments on the beam on suppression of I_c during ion-irradiation.

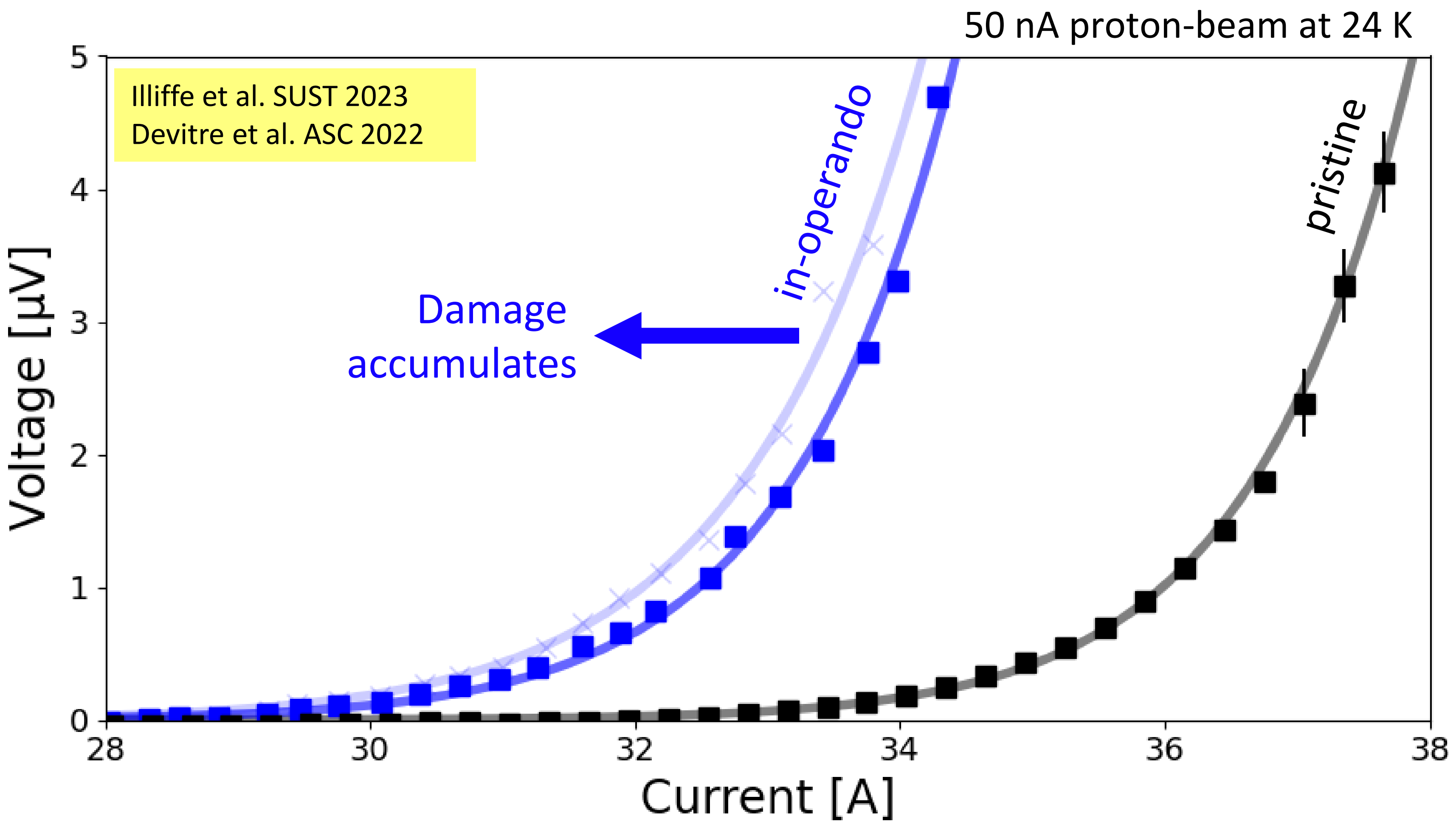


Alexis Devitre, D.X. Fischer, N. Riva, K.B. Woller, Z.L Fisher, M.P. Short, D.G. Whyte, Z.S. Hartwig.

Active ion-irradiation suppressed the critical current of REBCO coated conductors



As irradiation progresses, damage accumulates and the critical current further decreases



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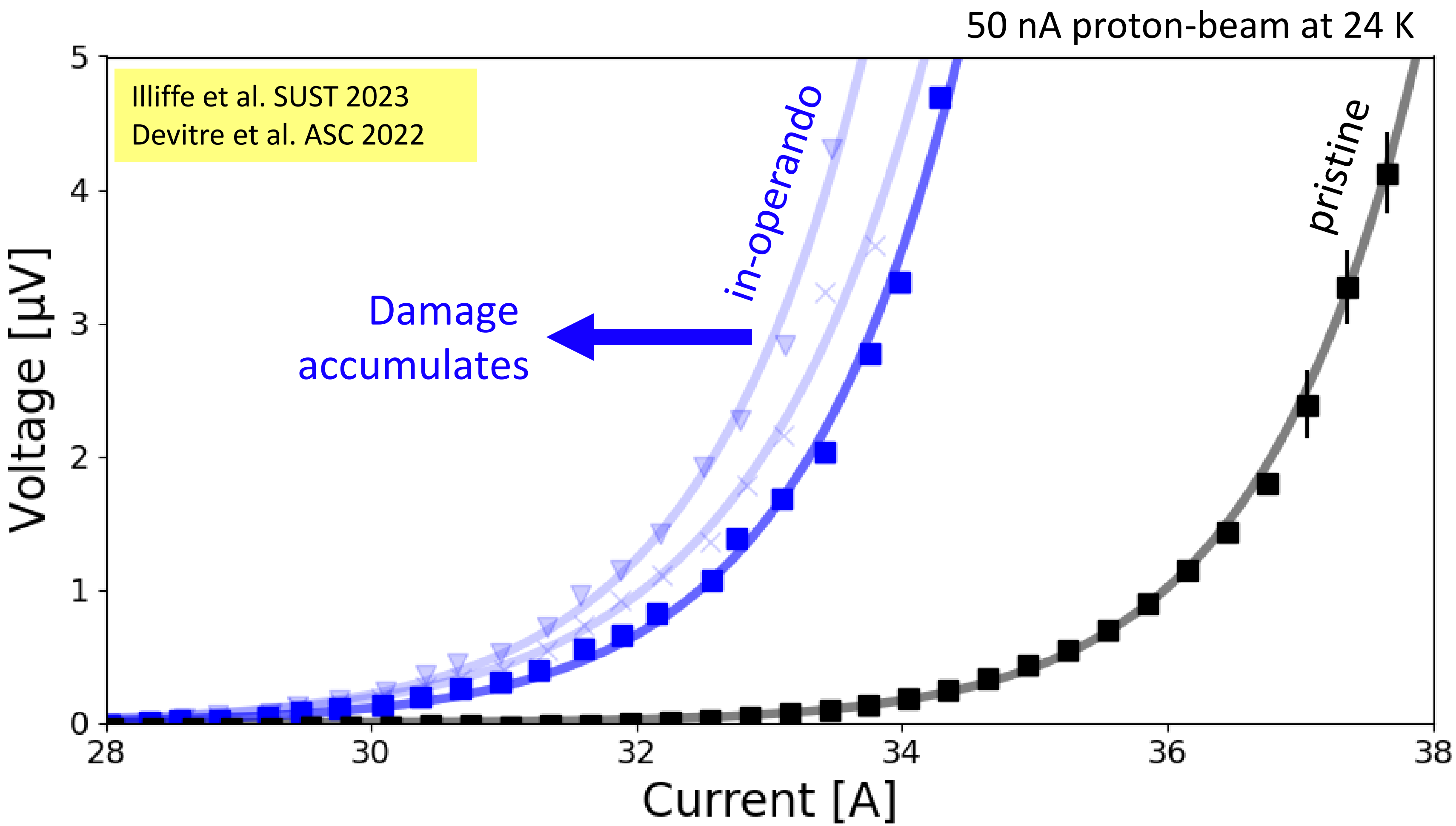

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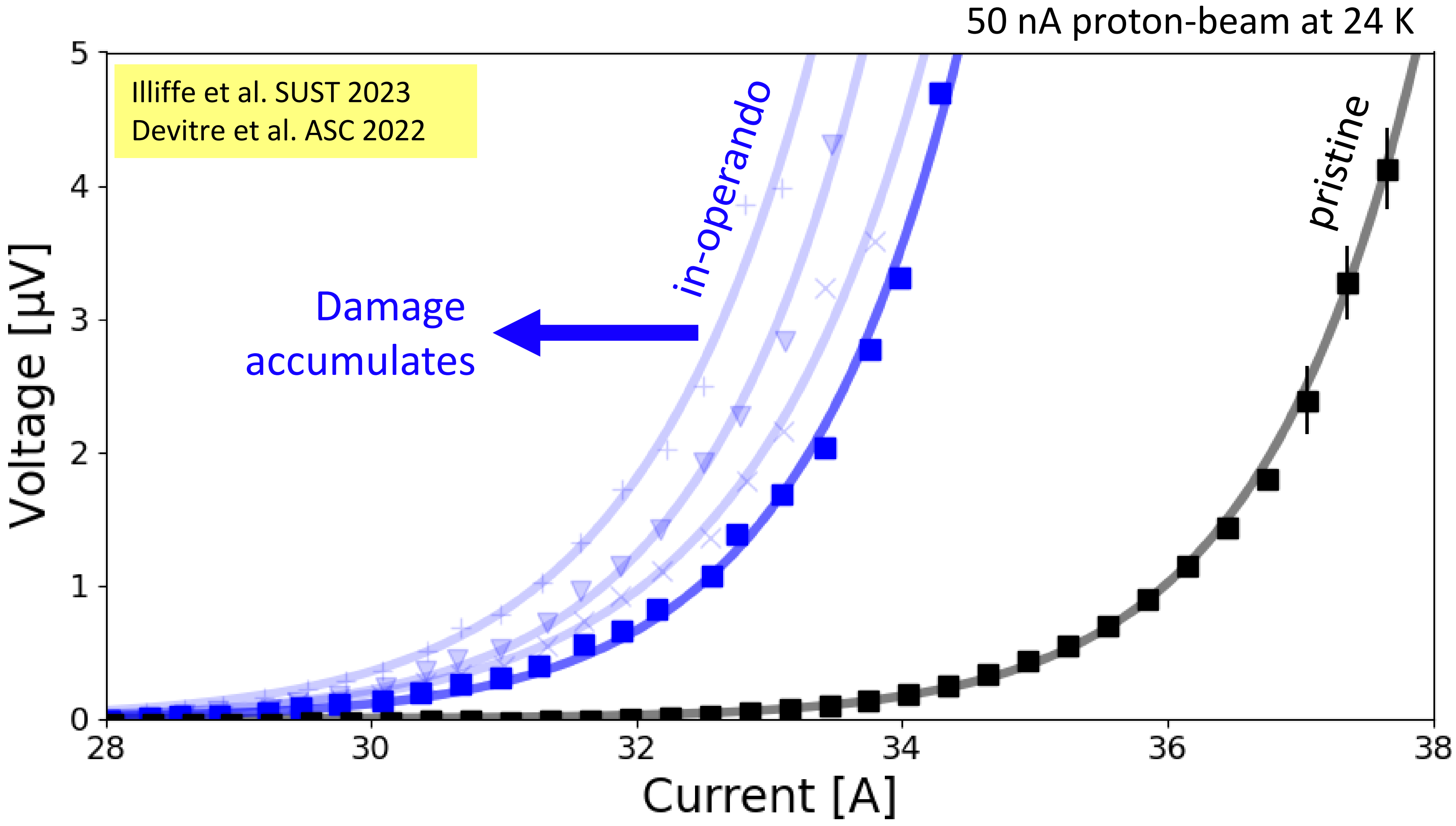

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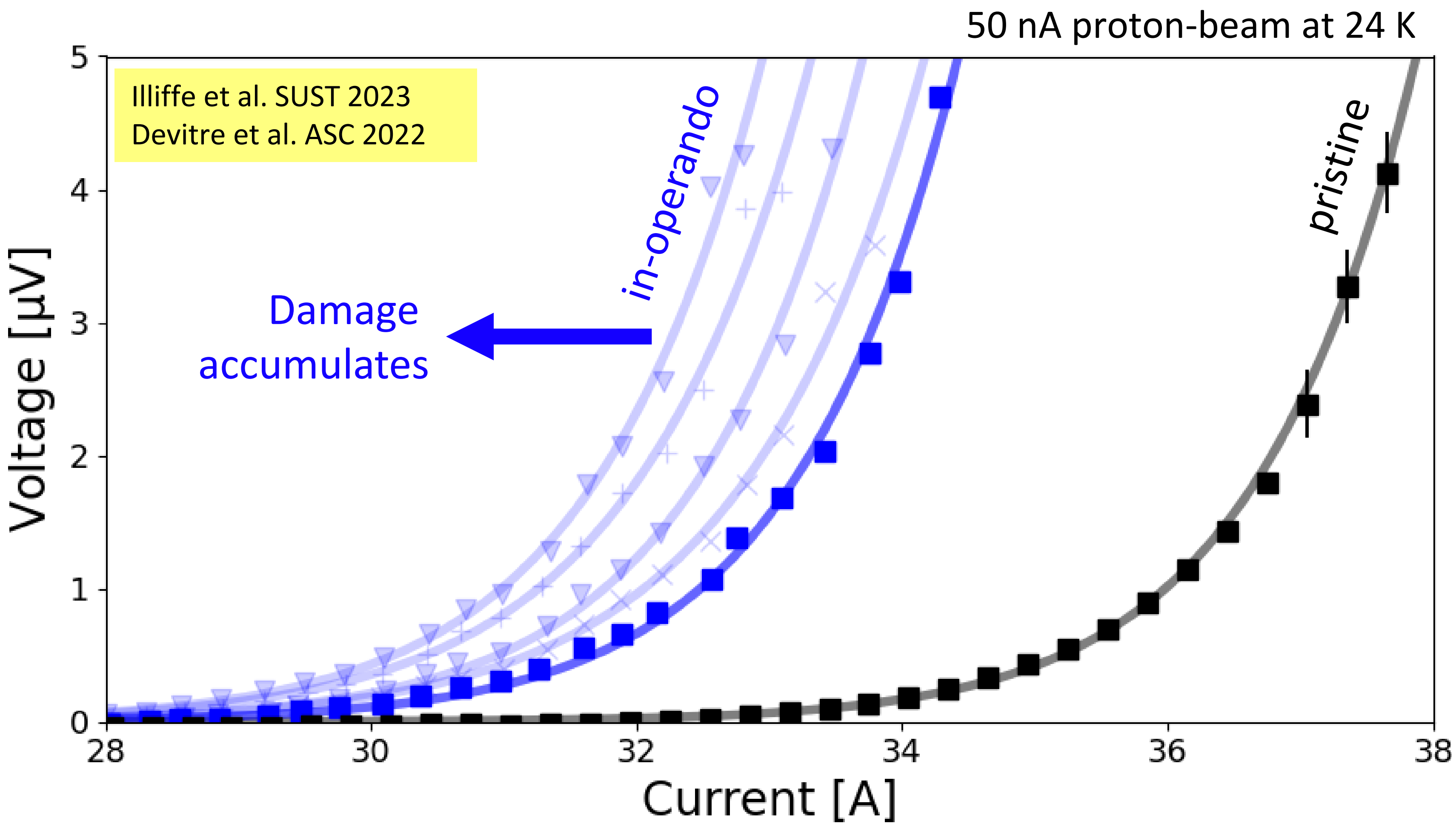

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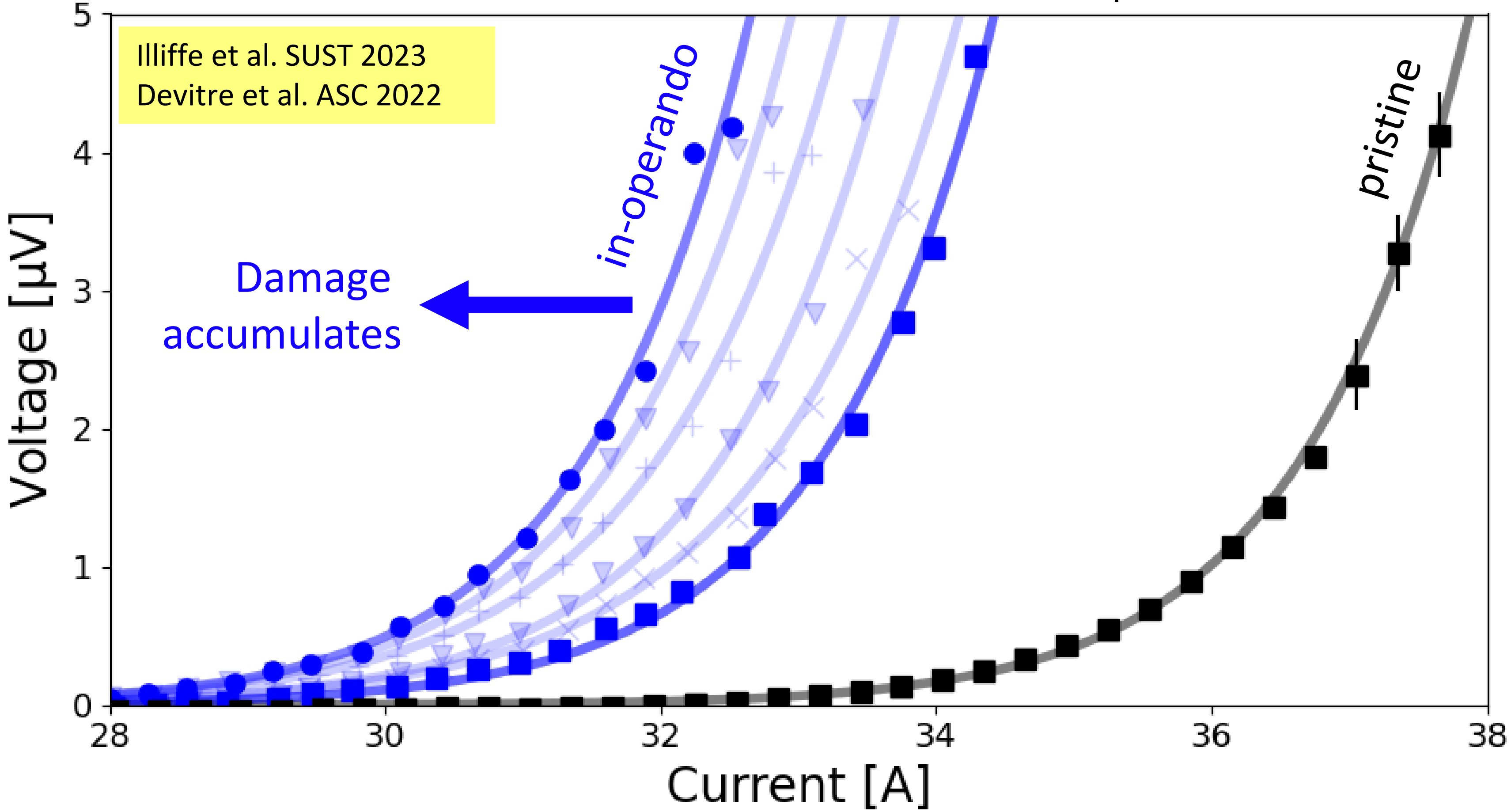
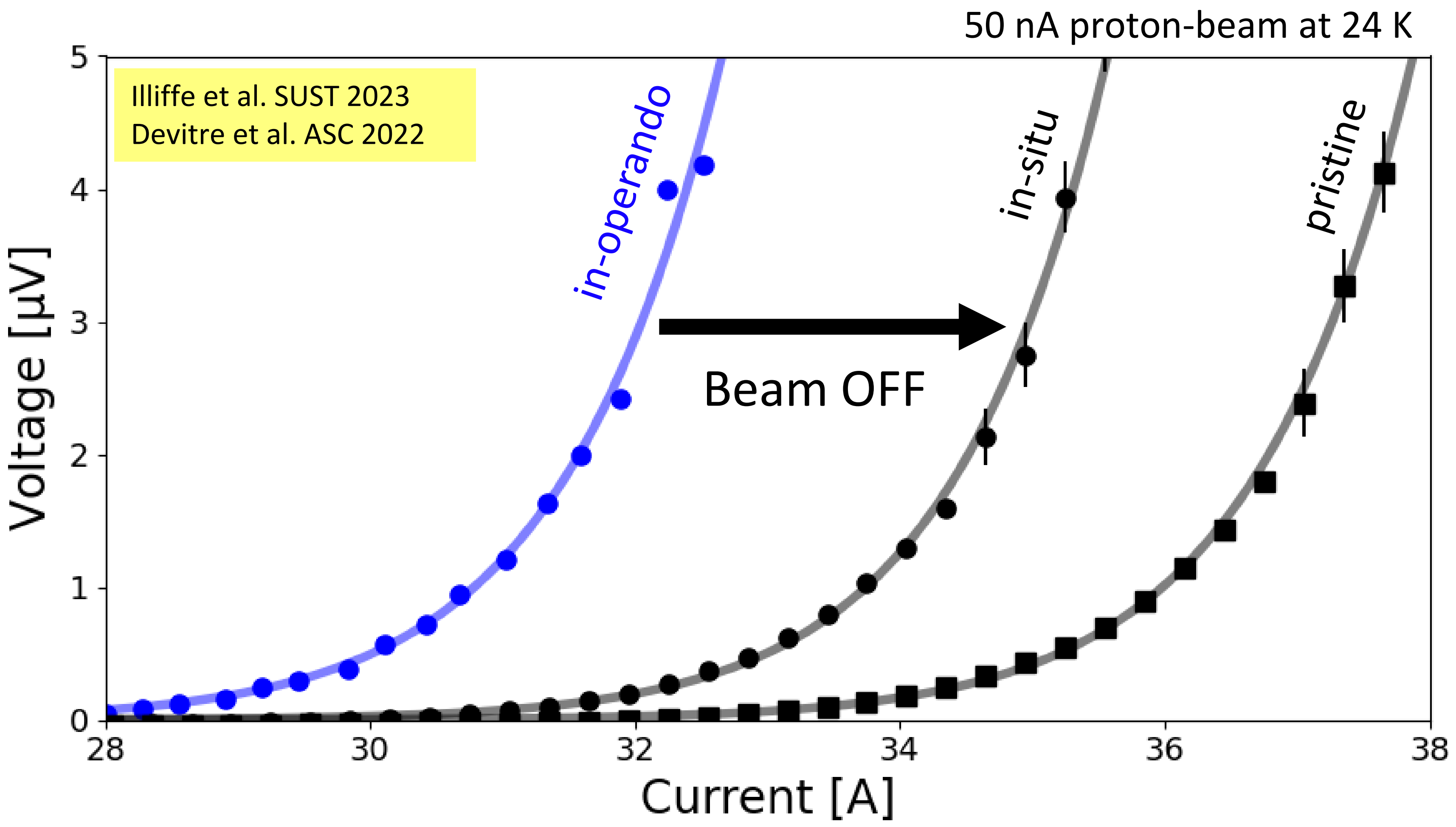
50 nA proton-beam at 24 K



The critical current measured during irradiation is lower than immediately after



Outline

- MIT's cryogenic ion-irradiation facility

- Key insights from I_c measurements during irradiation
    - **Turning up the heat** (↑beam current at fixed energy)
    - **Increasing displacements/watt** (↑ beam energy at fixed power)

- Sensitivity analysis with finite-element modeling

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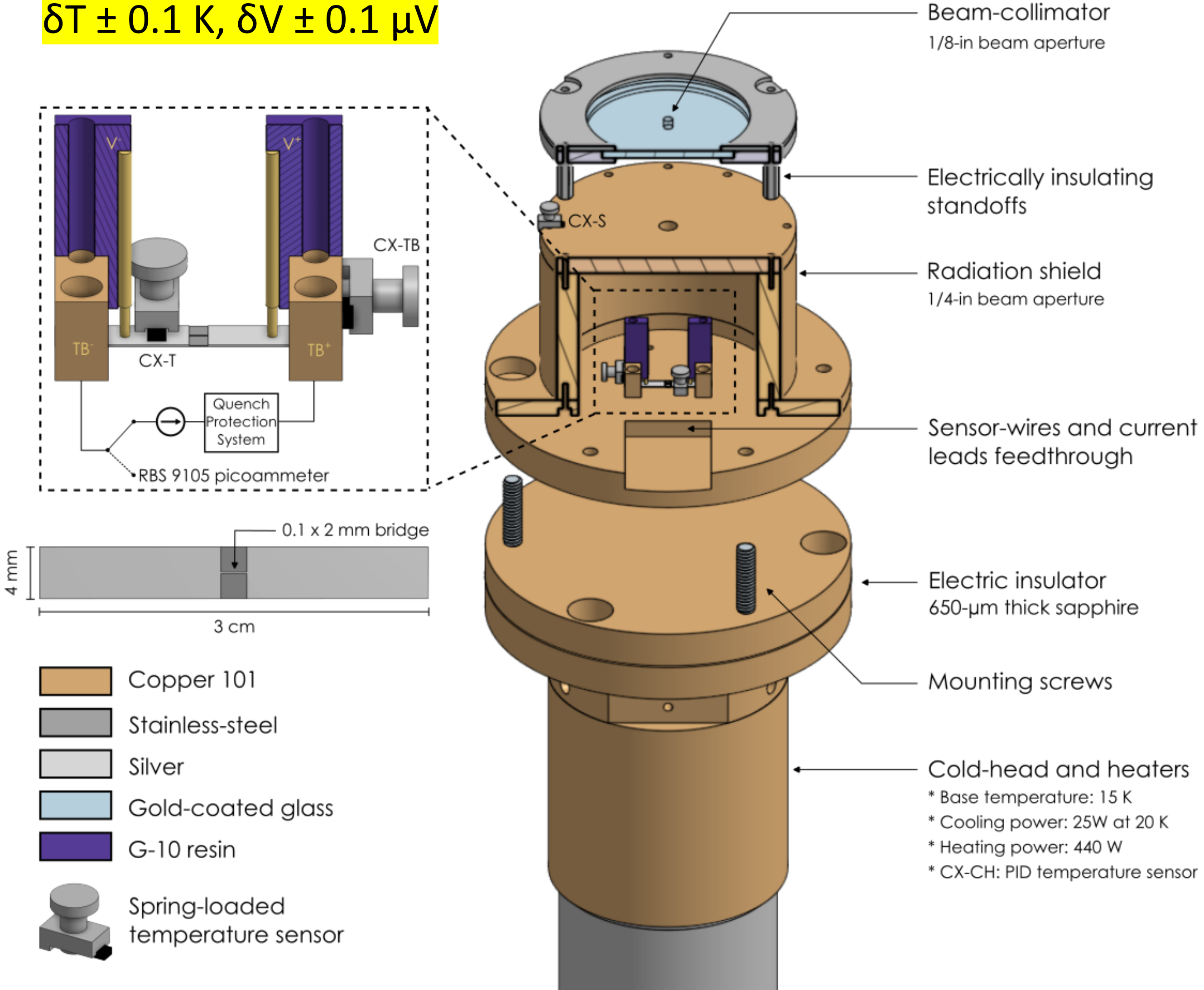
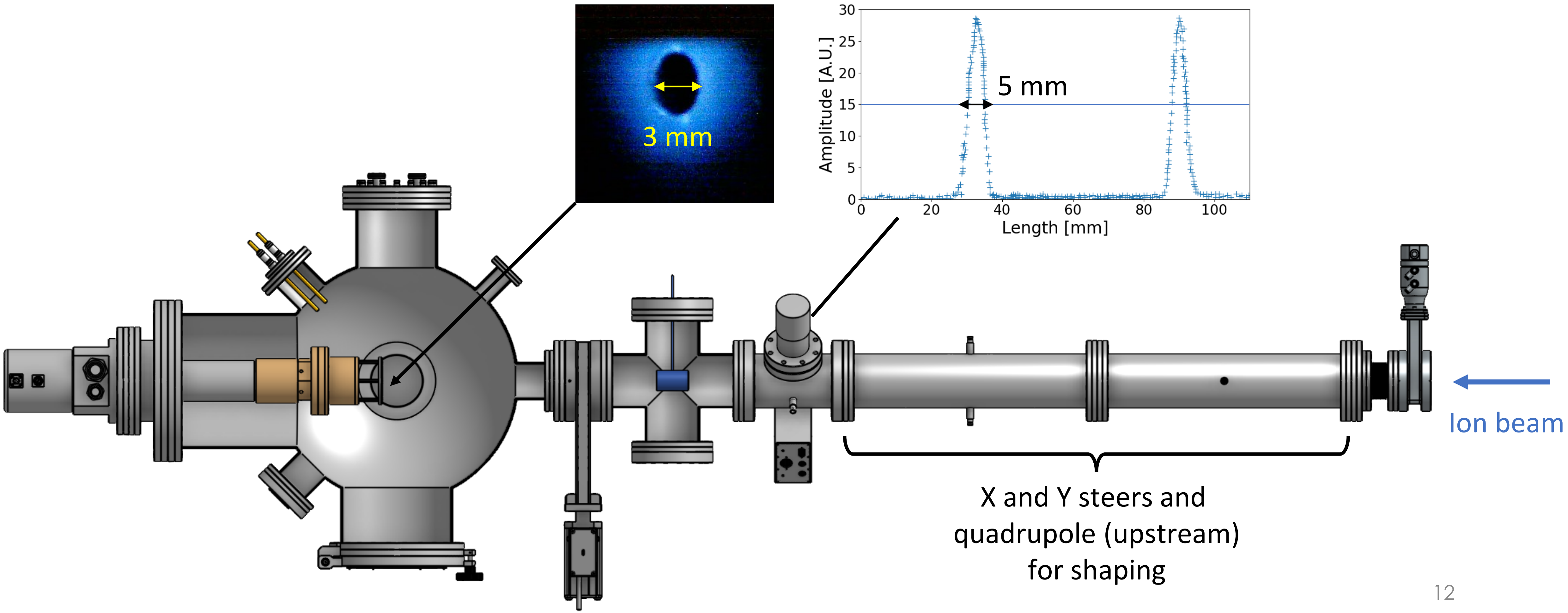
MIT cryogenic target performs transport measurements during ion-irradiation

δT ± 0.1 K, δV ± 0.1 μV



Uniform beam profiles maximize reproducibility



Linear accelerator knobs

Harder to change

- **Increase the beam current**
  - Increases the beam power
  - Increases damage-rate
- **Increase the beam energy**
  - Increases beam power
  - Lowers damage-rate
  - Increases implantation depth
- **Increase ion species Z**
  - Increases nuclear stopping power, compared to electronic stopping

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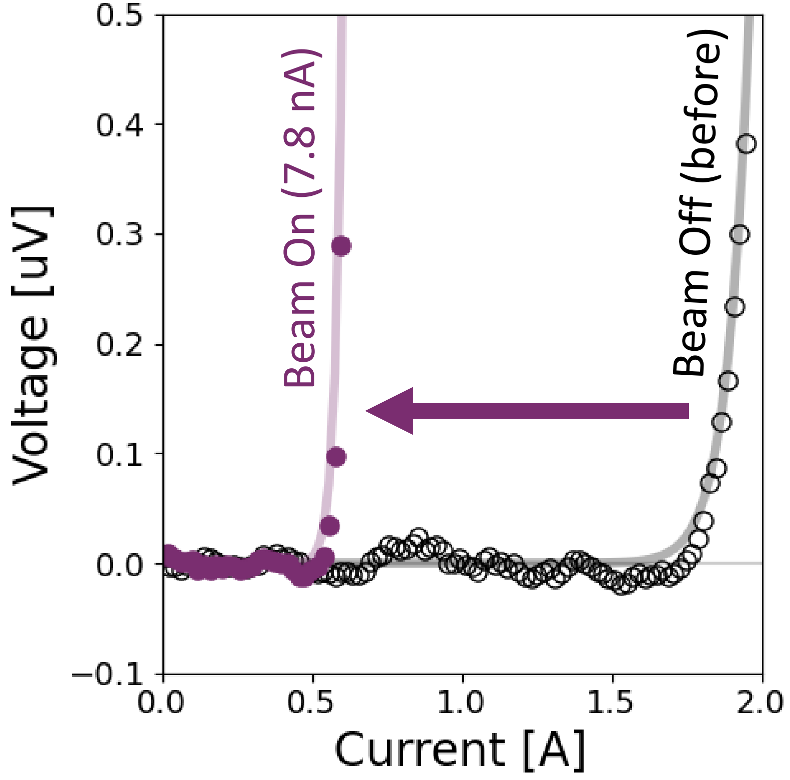
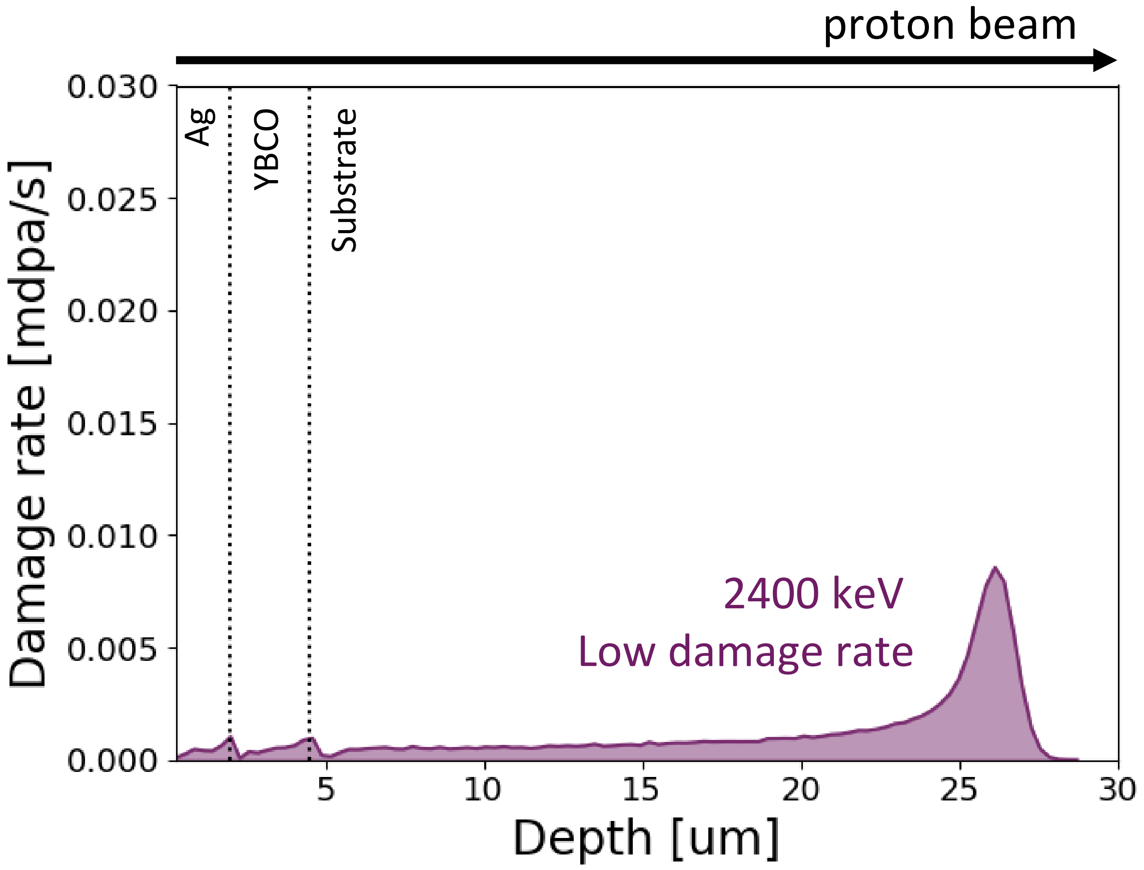
The ion-beam can **suppress I_c without causing permanent damage**





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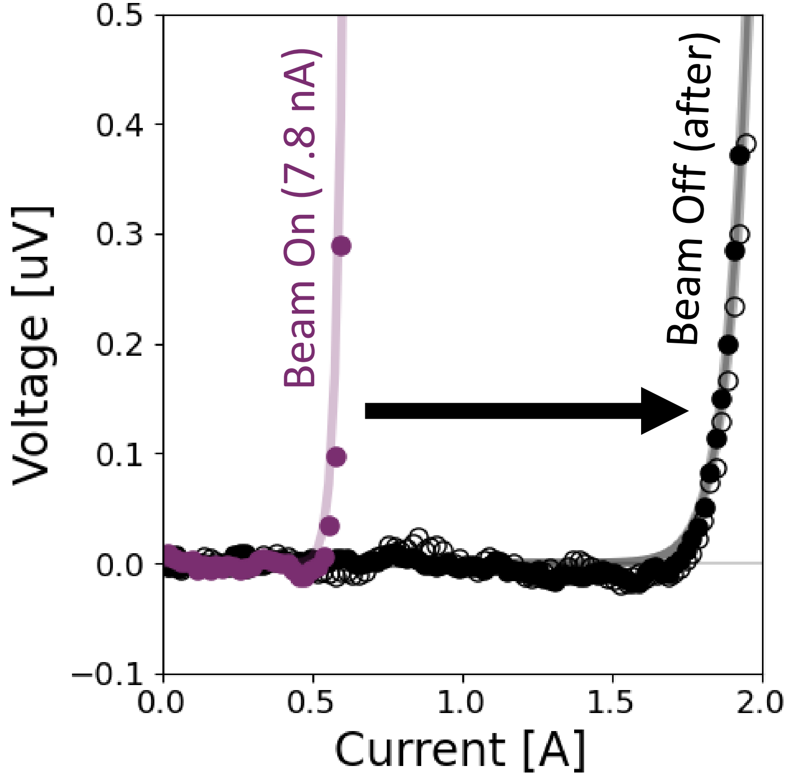
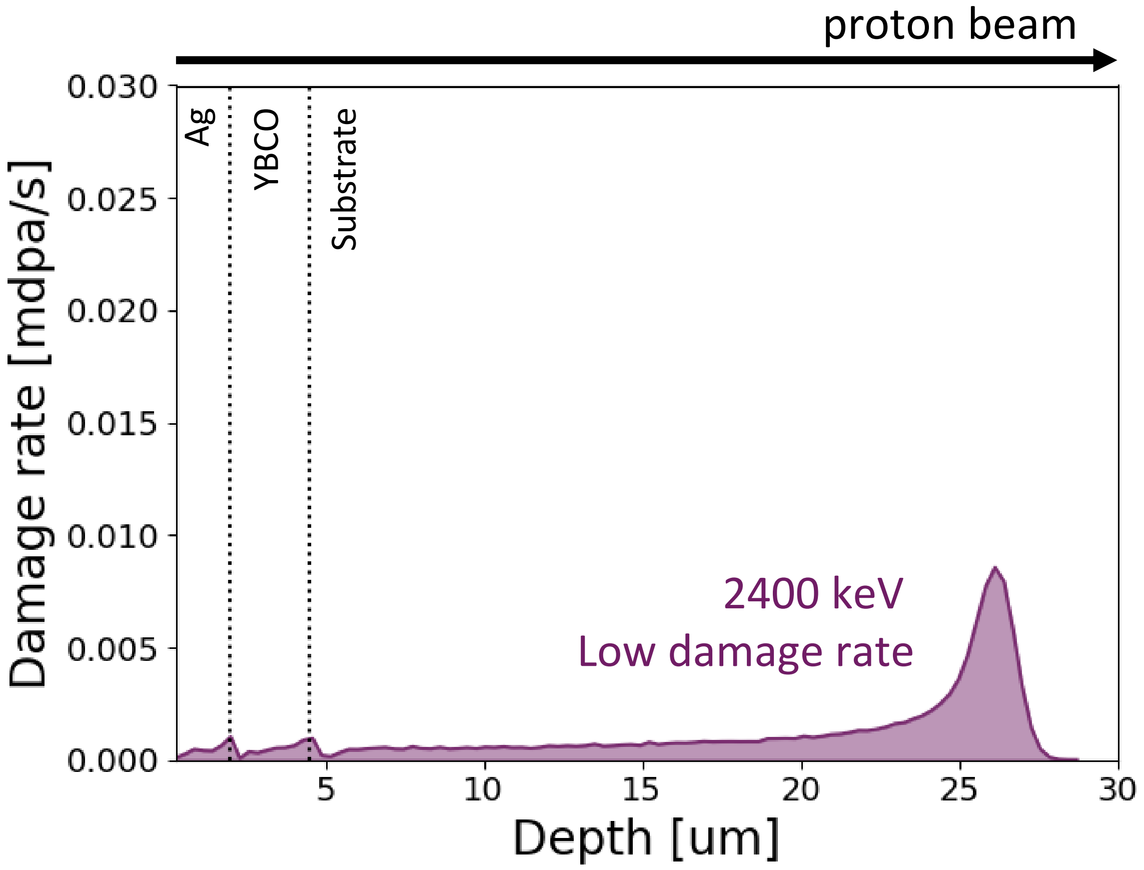
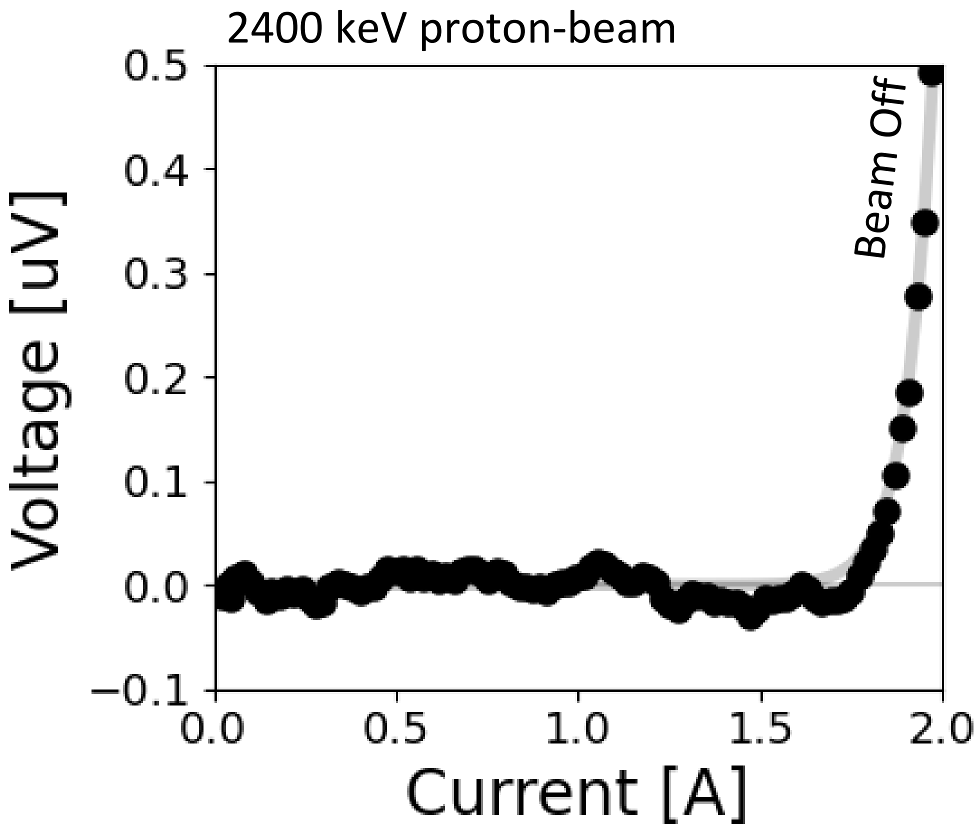
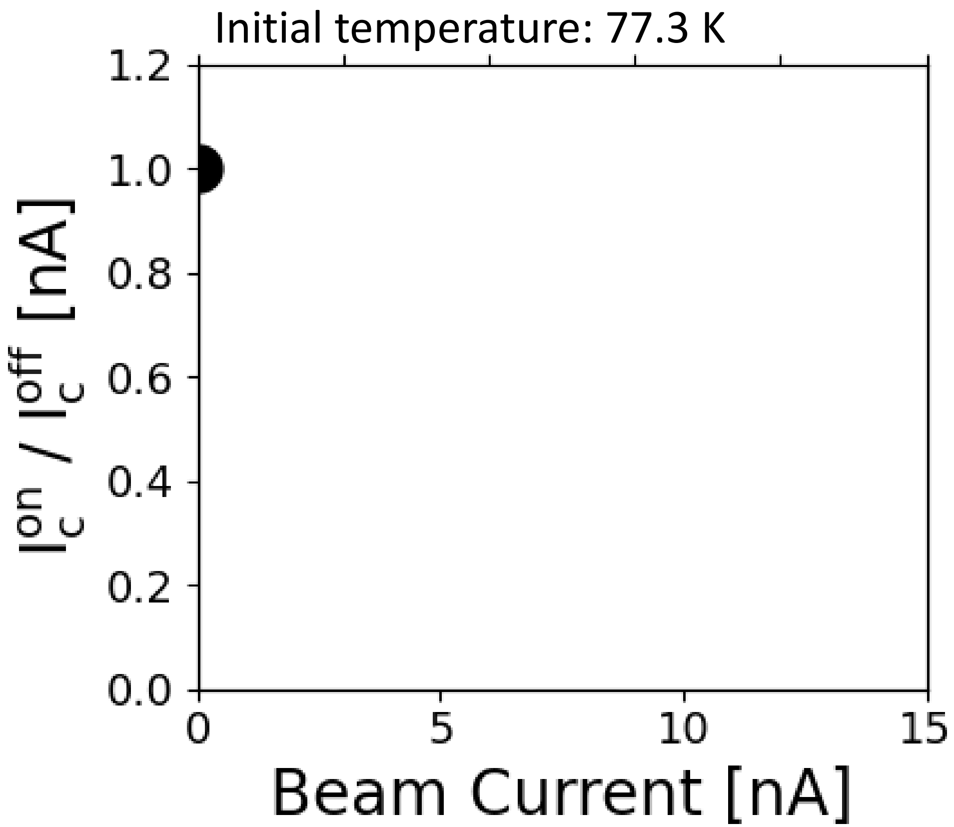




At fixed beam energy, I_C suppression is proportional to beam current





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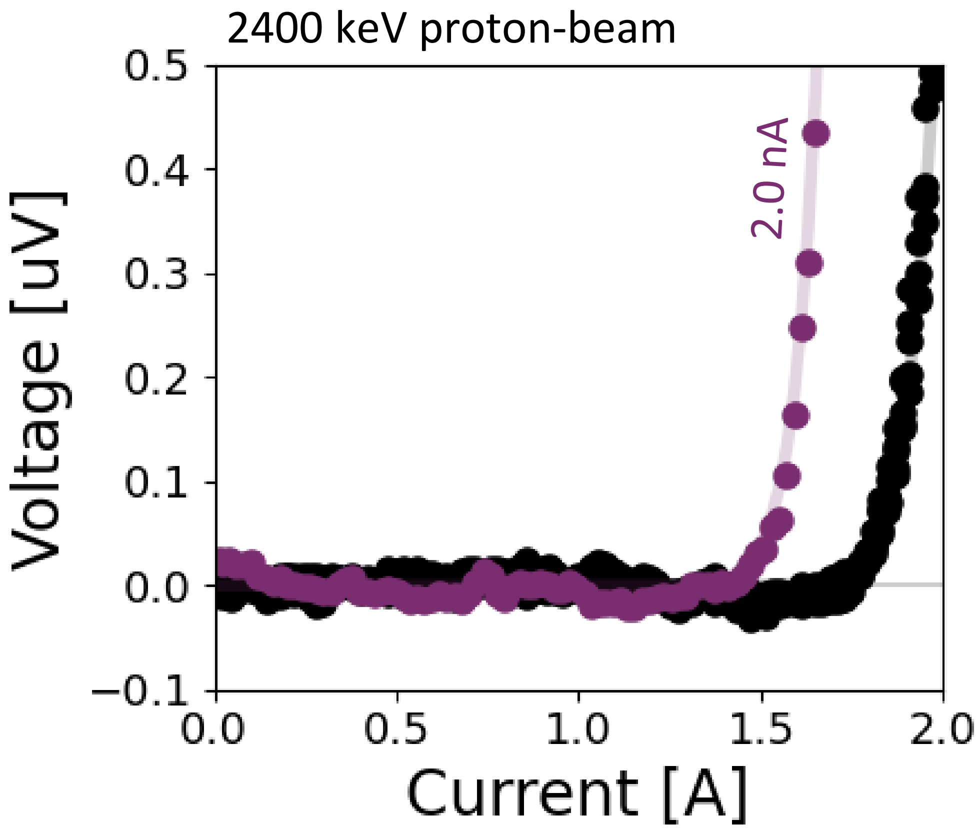

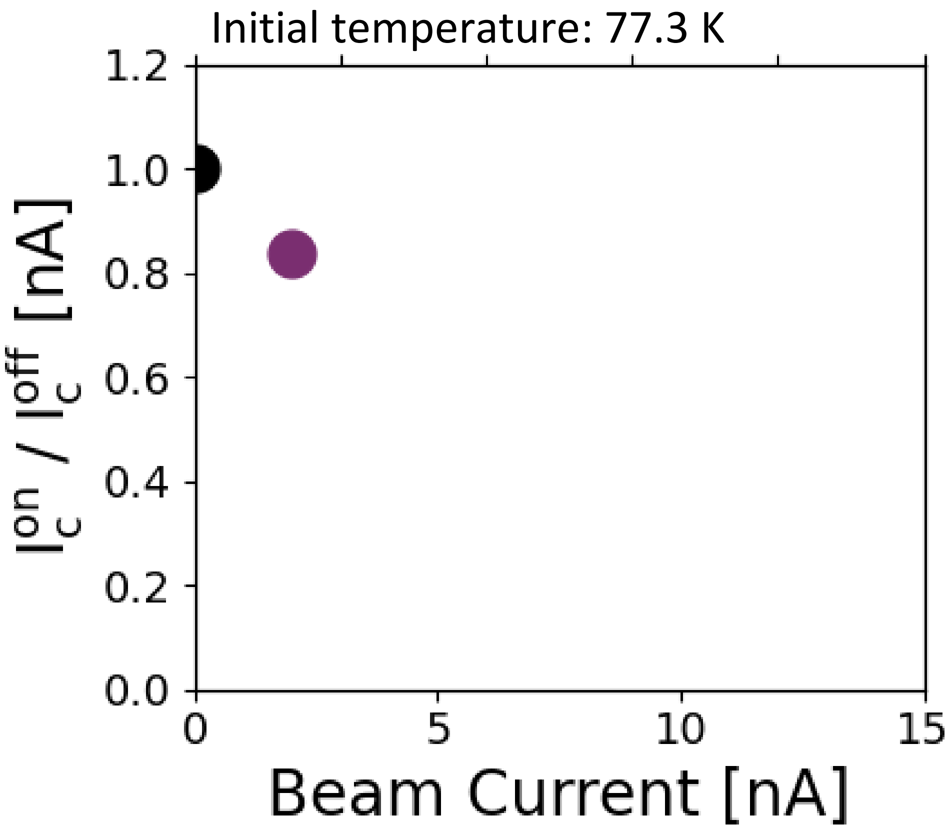

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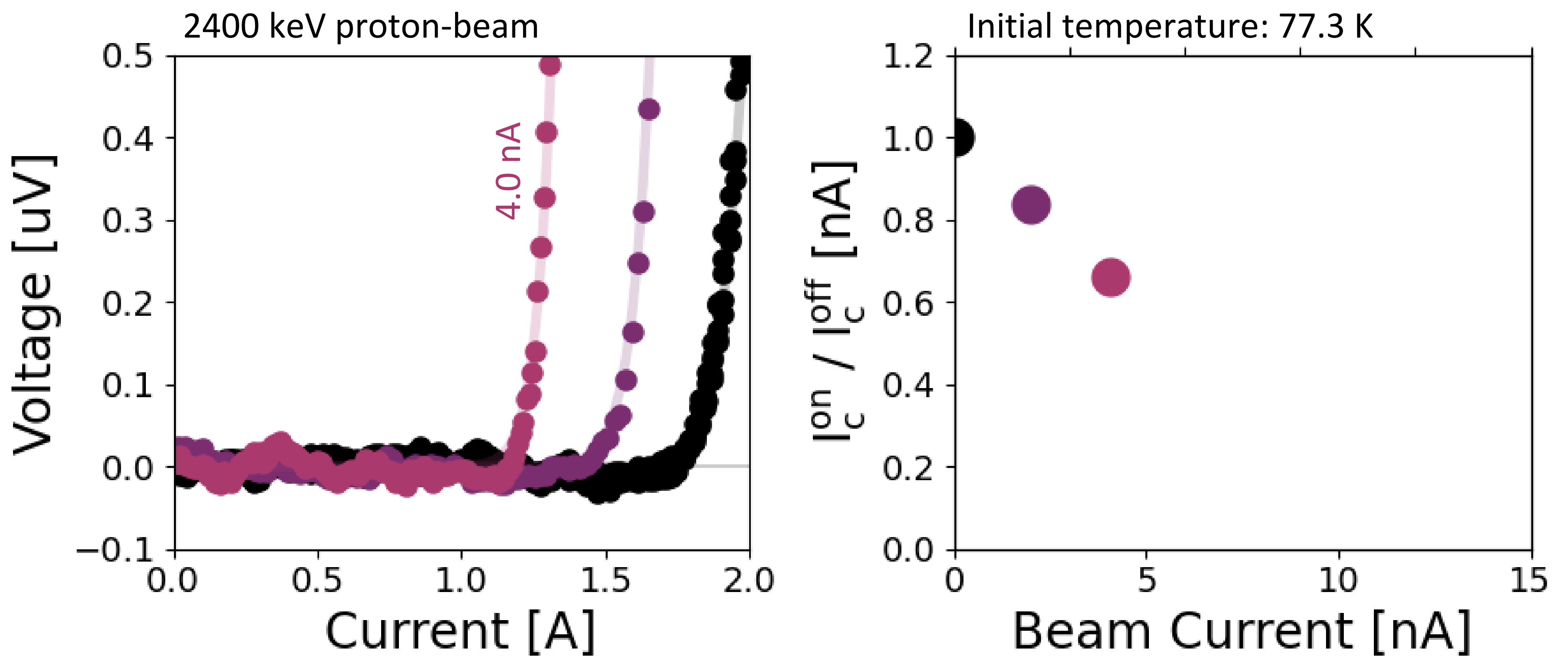

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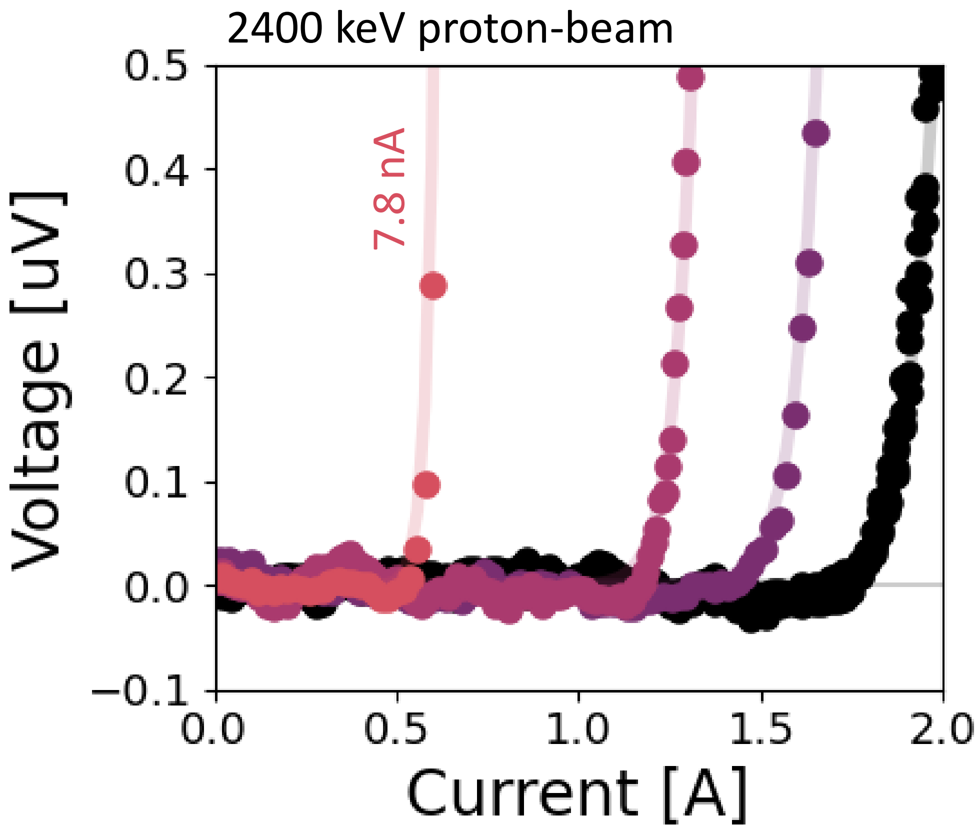

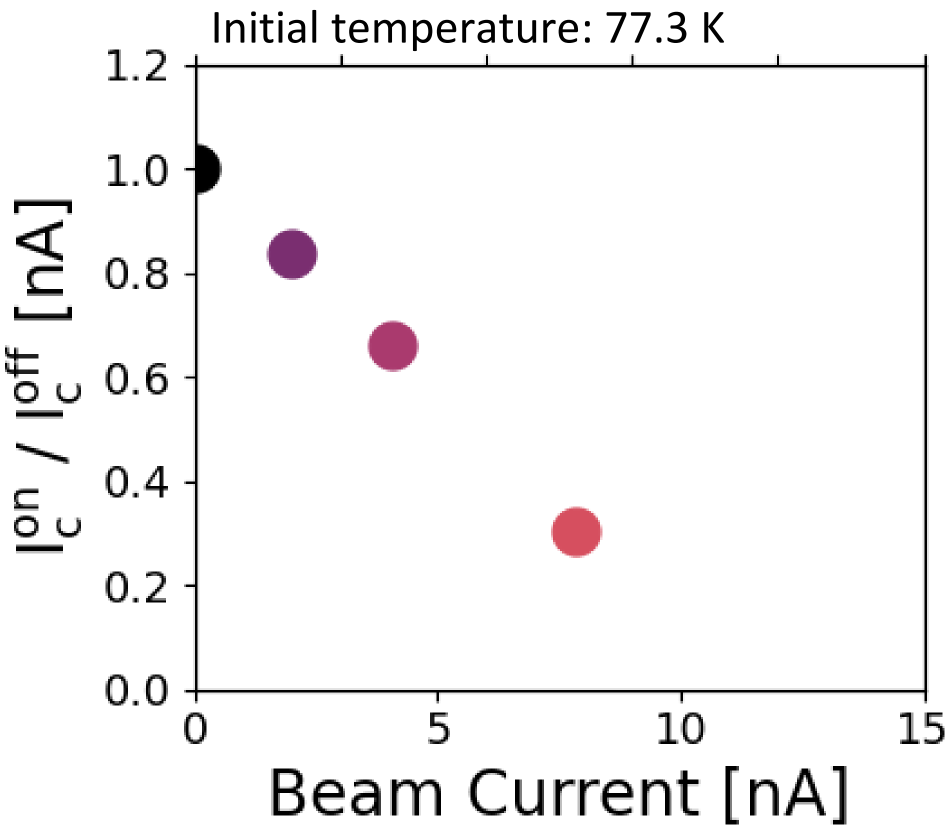

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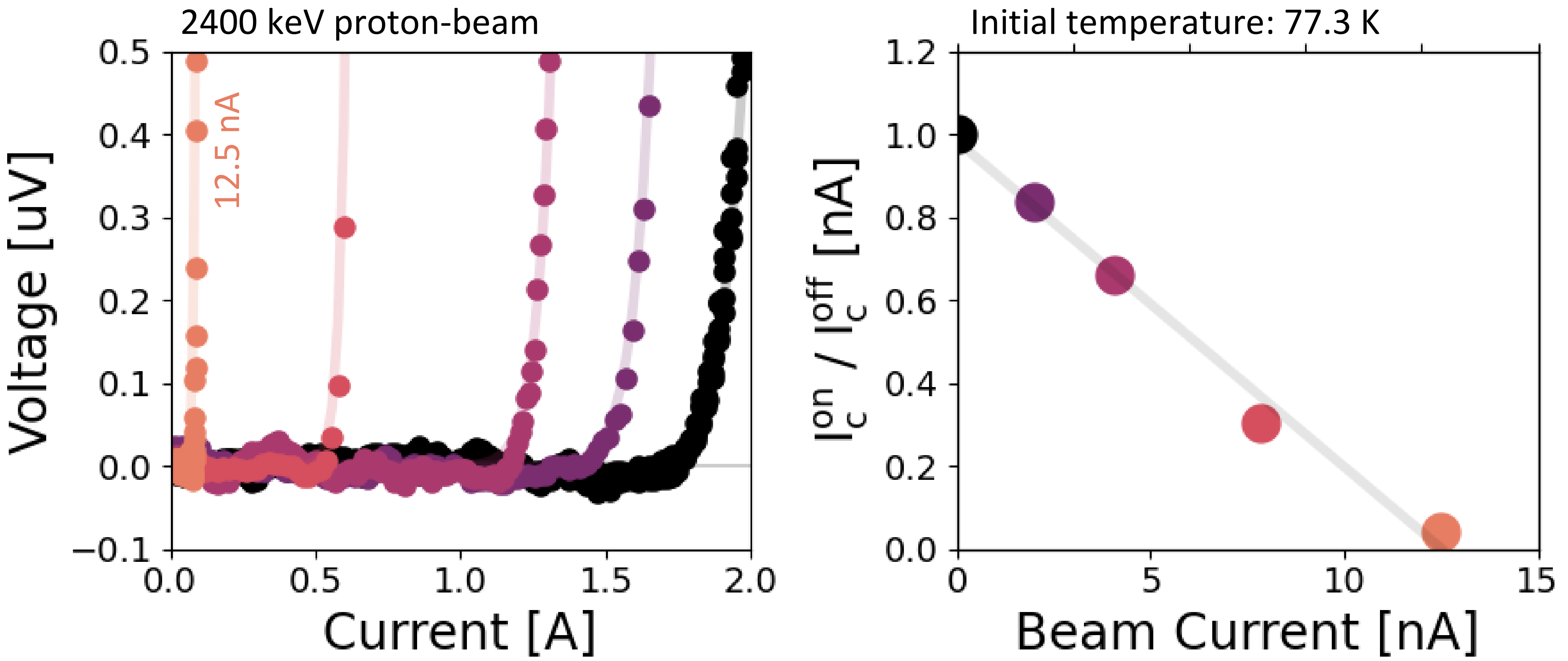
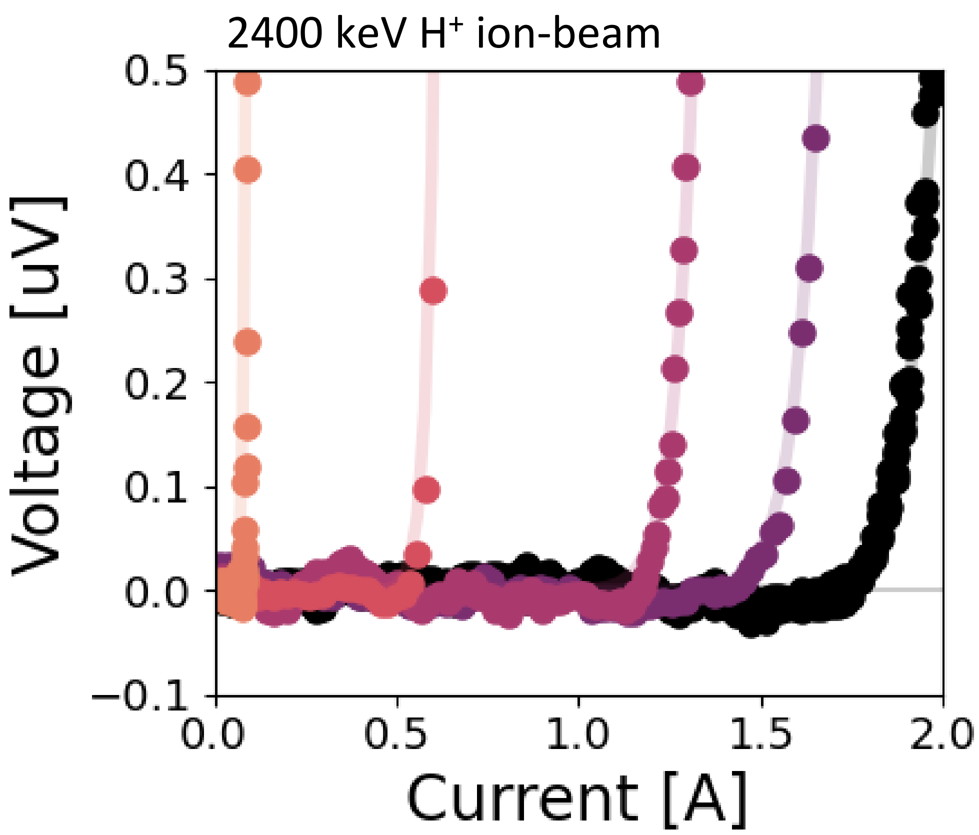
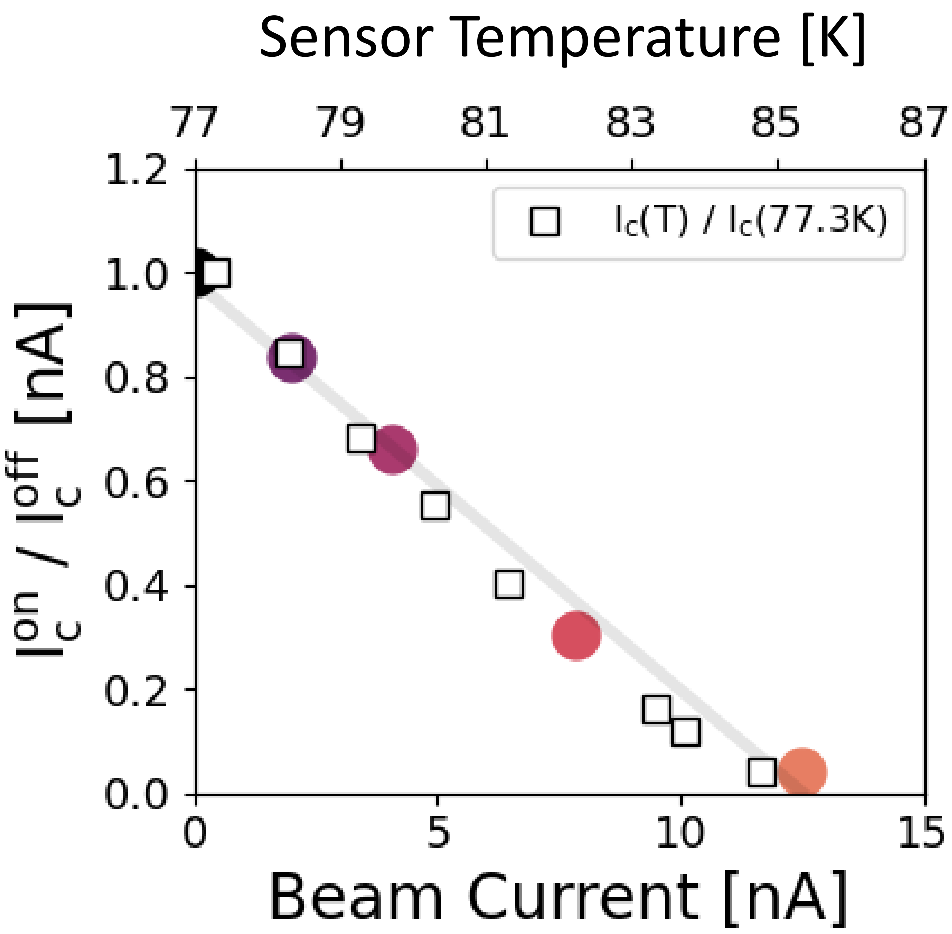
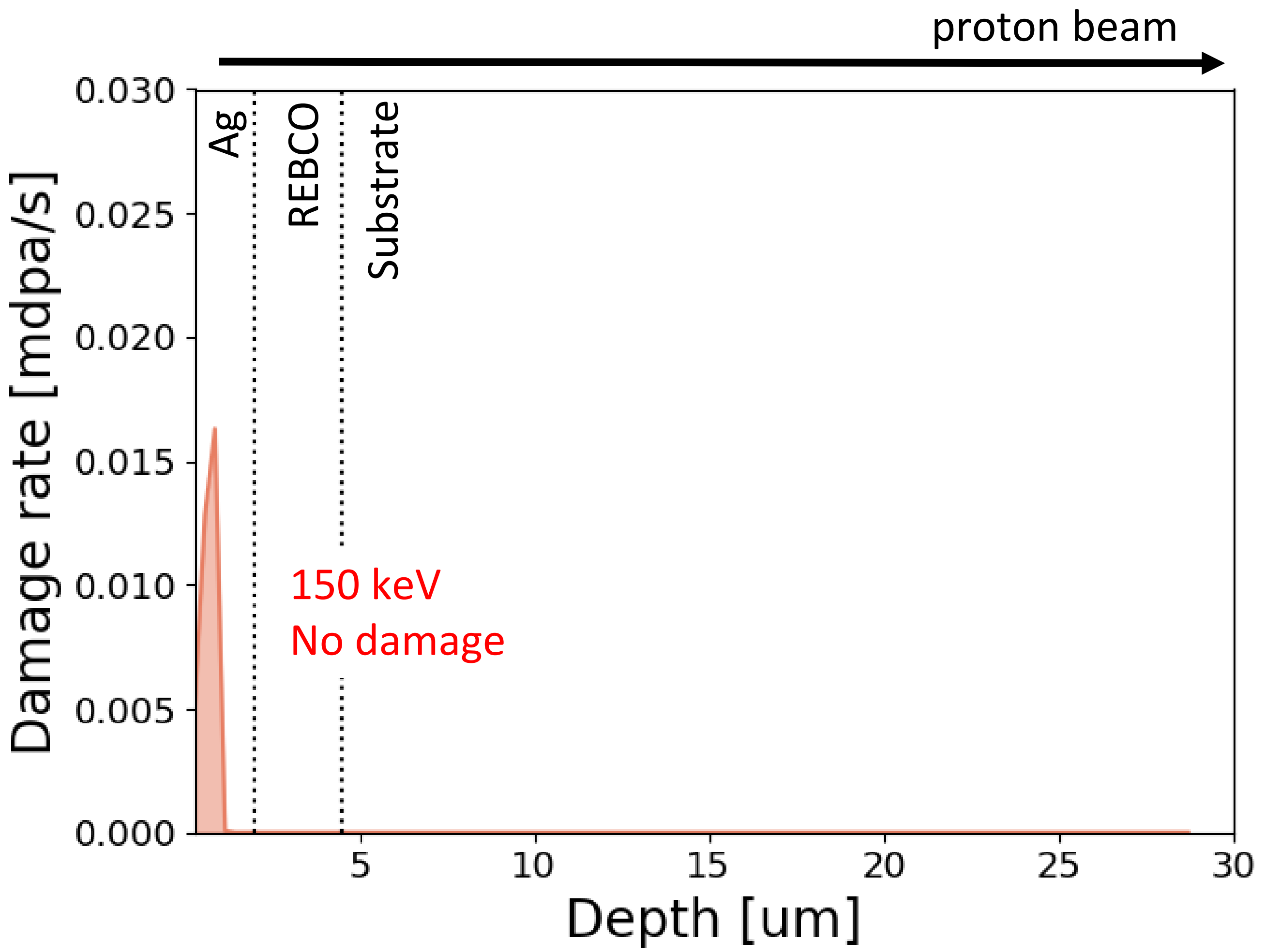


Beam heating is a plausible explanation for the beam-on suppression of I_c



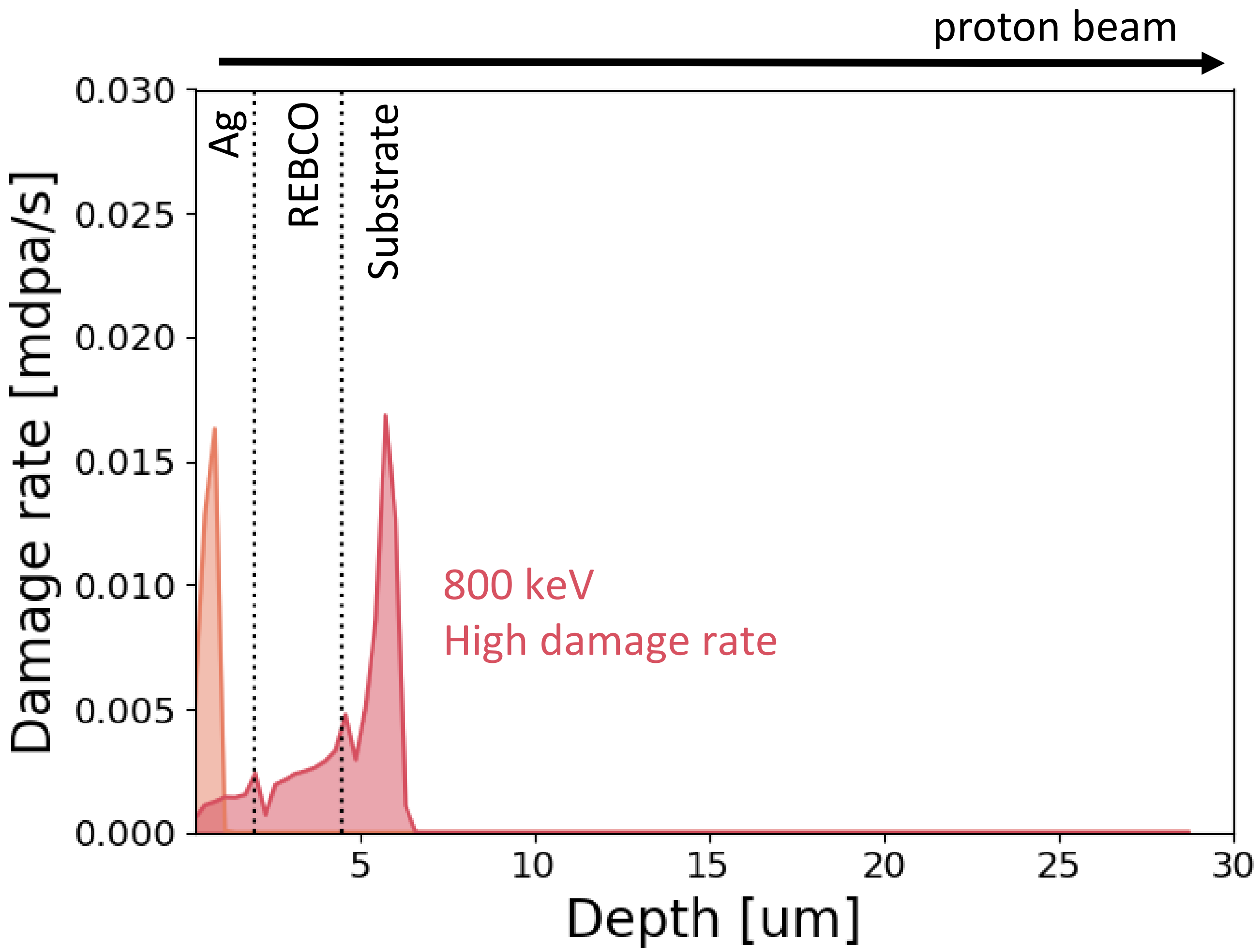


A very low energy beam can heat the sample without damaging the REBCO layer



- **No damage:** 150 keV protons stop in the silver layer

Increasing beam energy at fixed beam power, decreases the damage rate in the REBCO layer



- **No damage:** 150 keV protons stop in the silver layer
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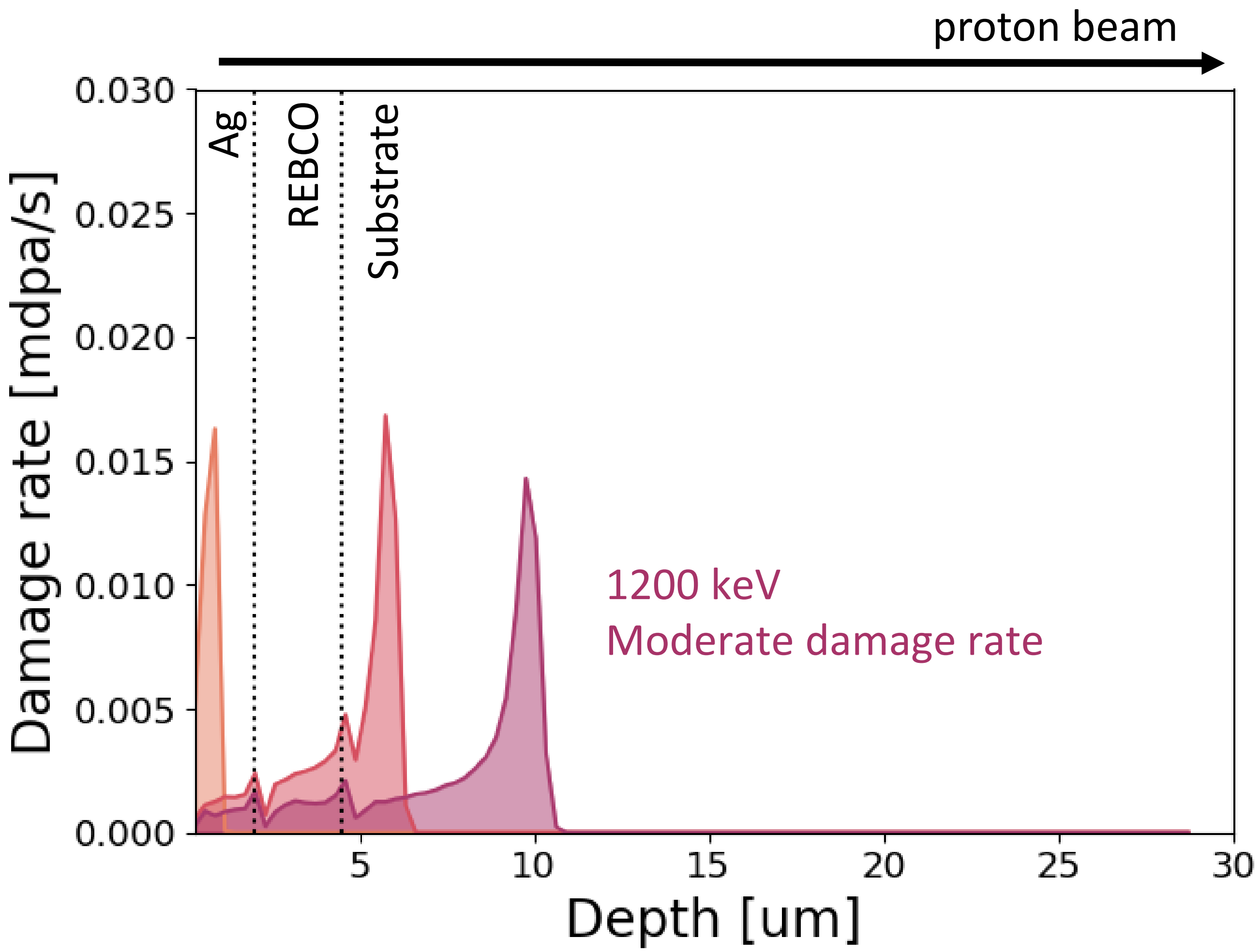

- **No damage:** 150 keV protons stop in the silver layer
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- **Moderate damage rate:** 1200 keV protons stop further into the substrate

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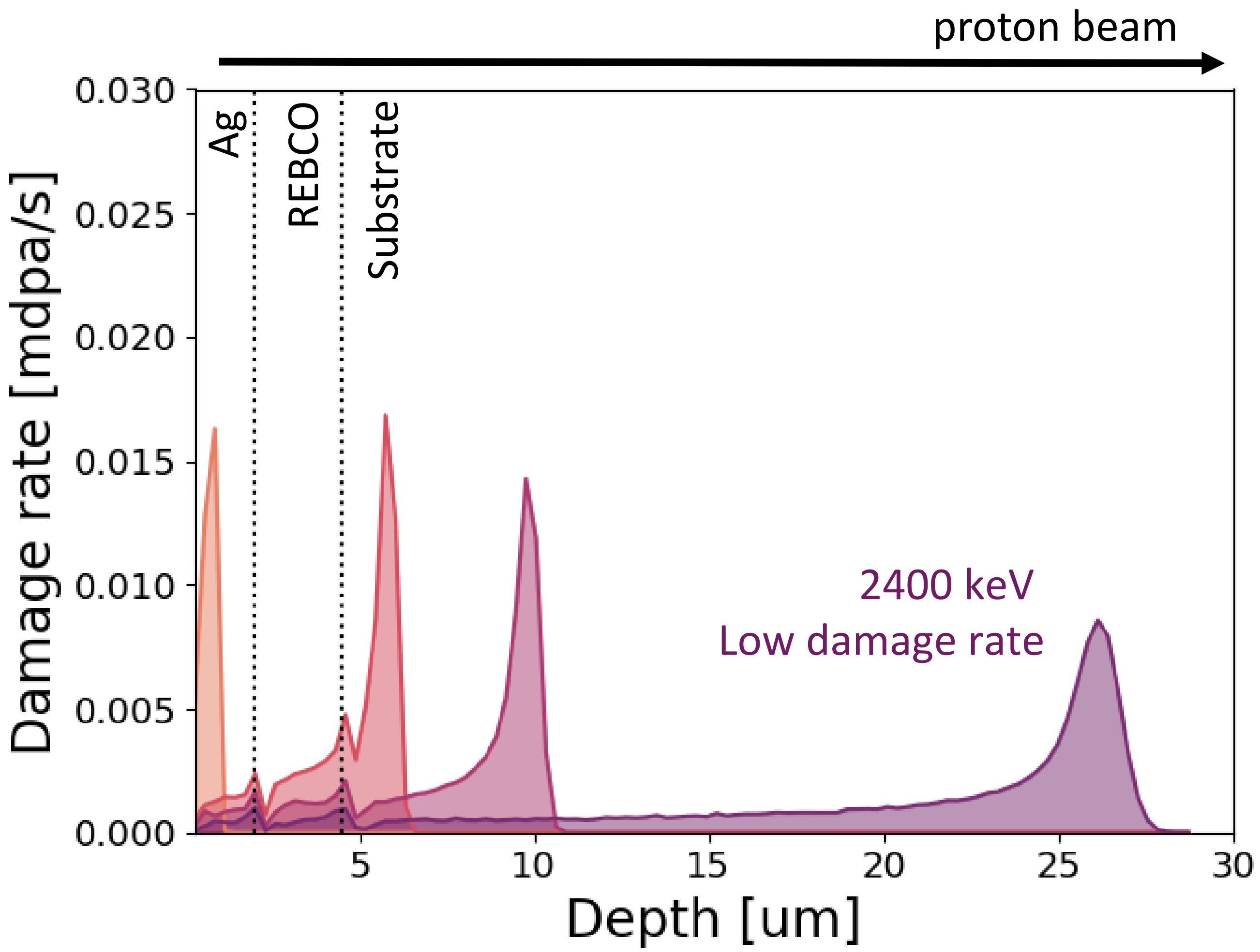

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- **Moderate damage rate:** 1200 keV protons stop further into the substrate
- **Low damage rate:** 2400 keV protons stop furthest into the substrate.

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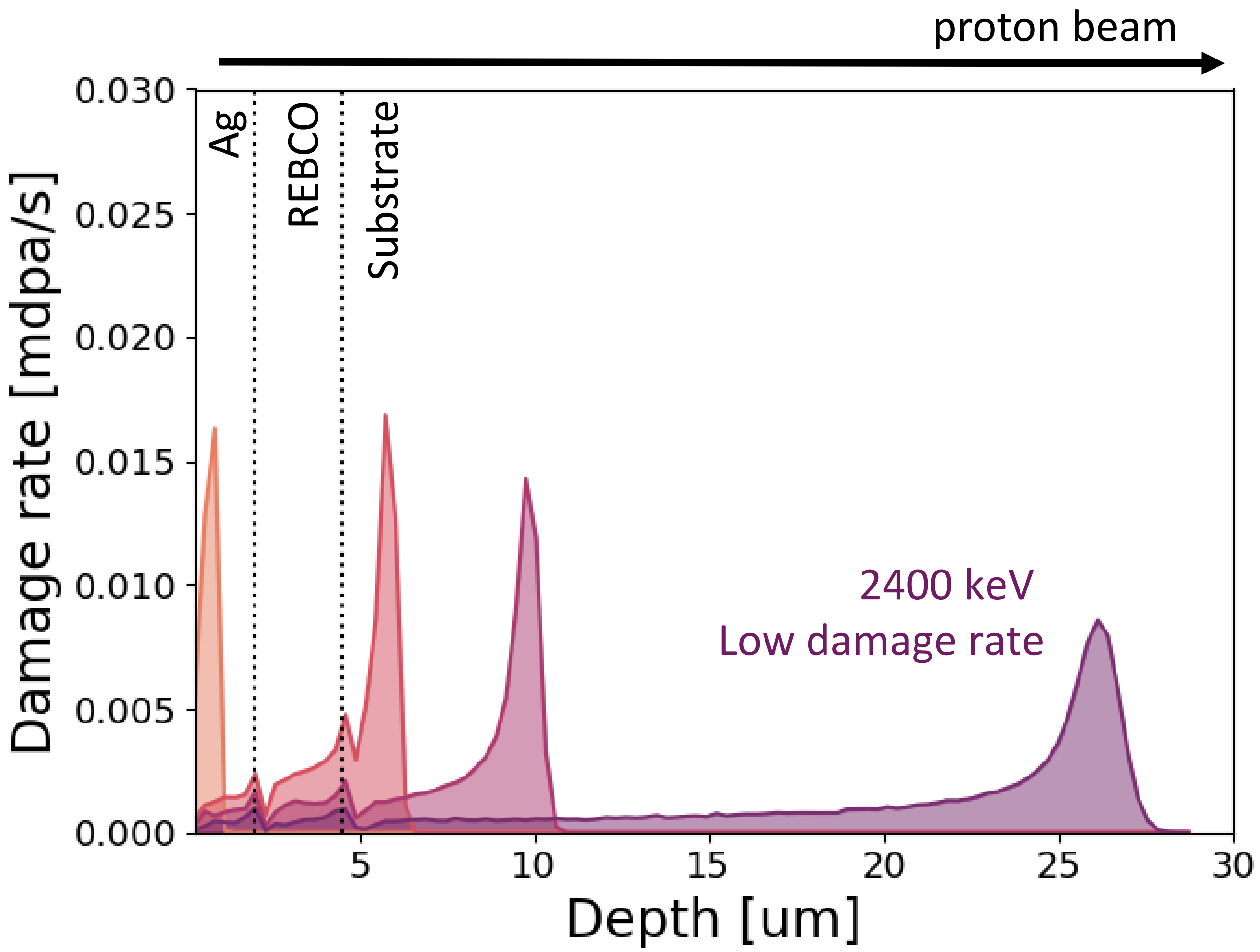

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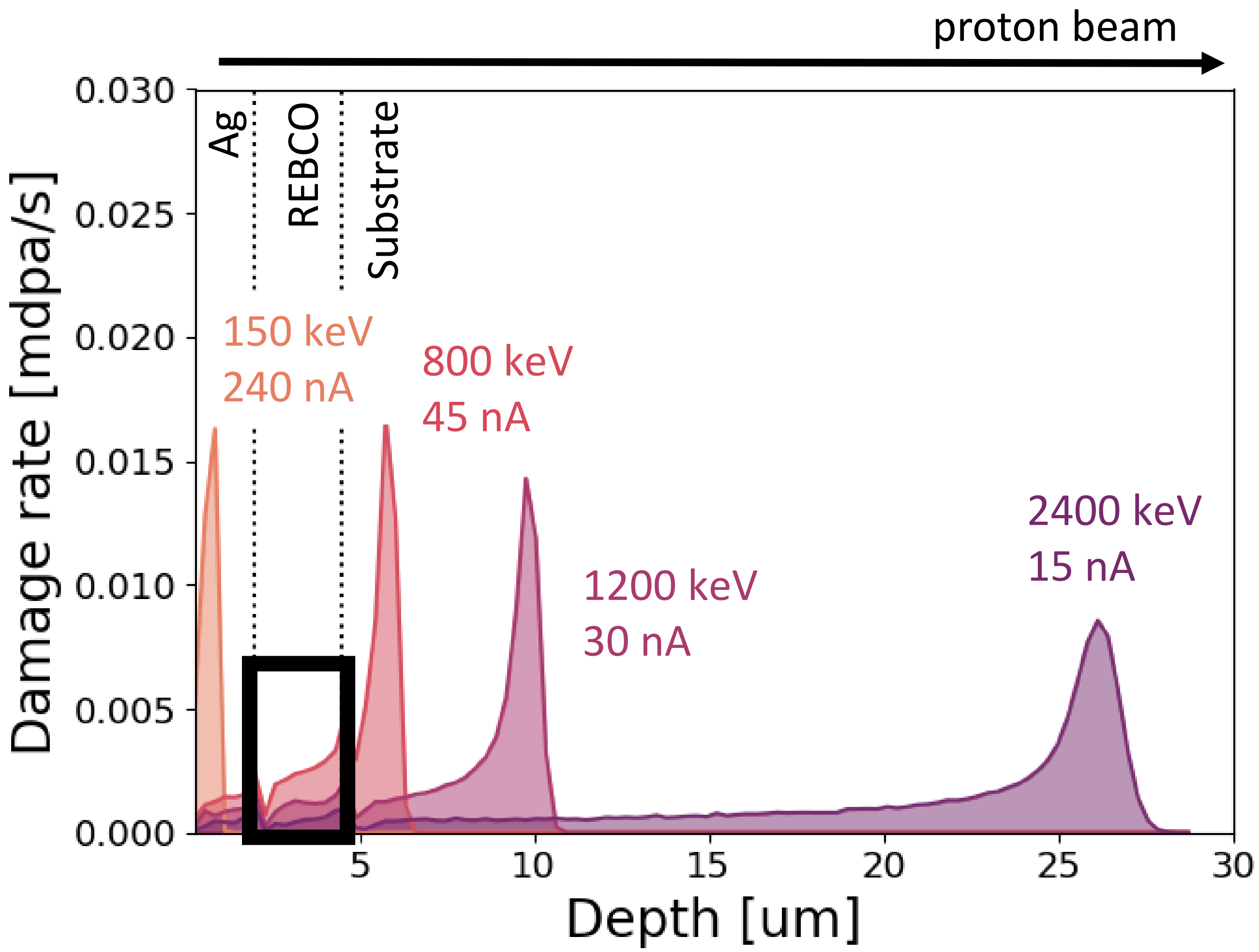
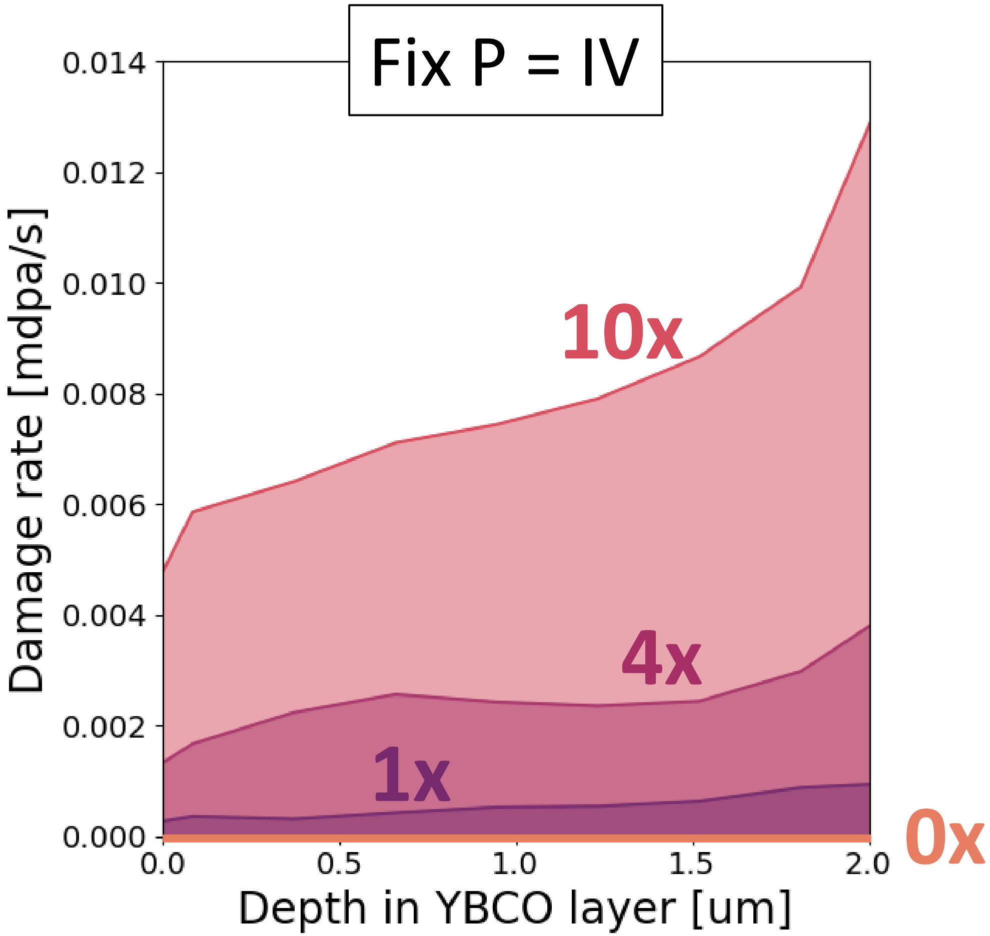
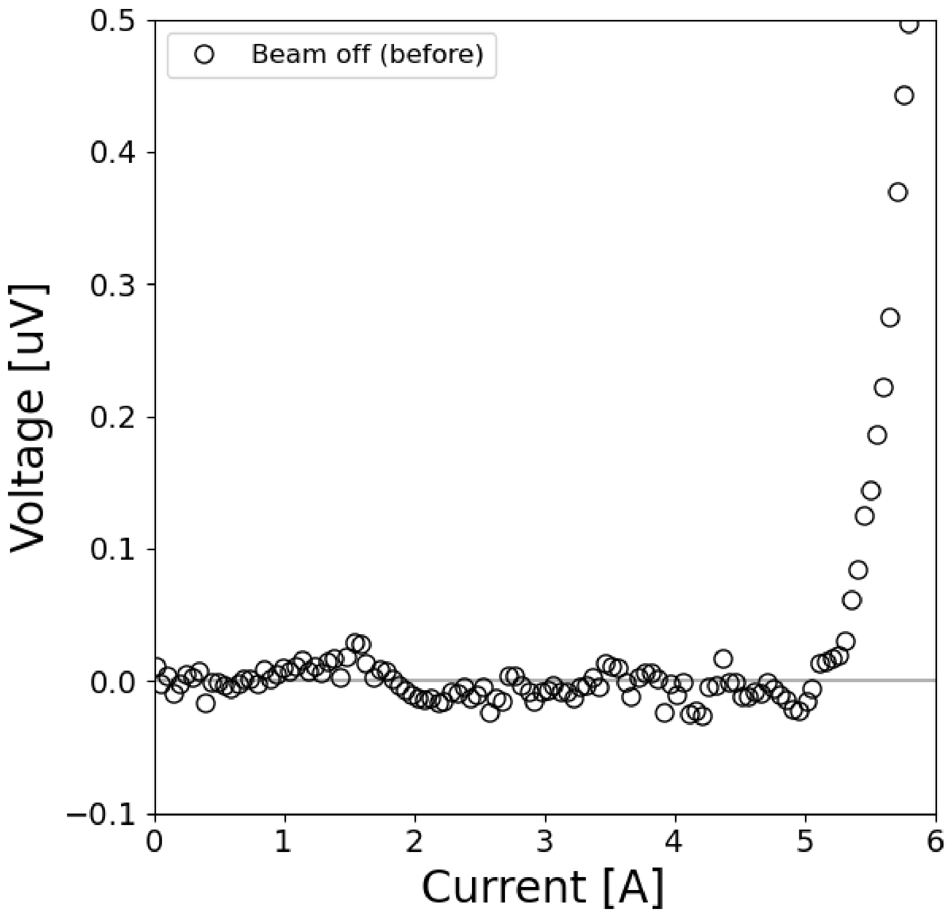
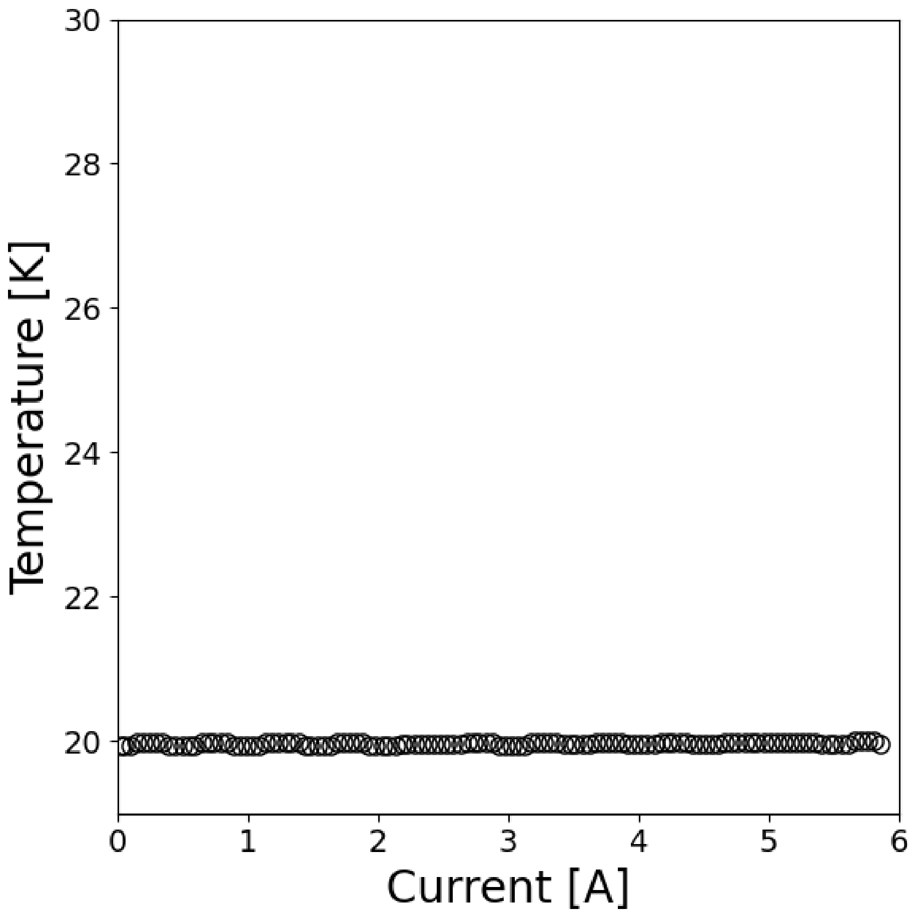
We can produce **more displacements/watt in YBCO** by varying the beam energy

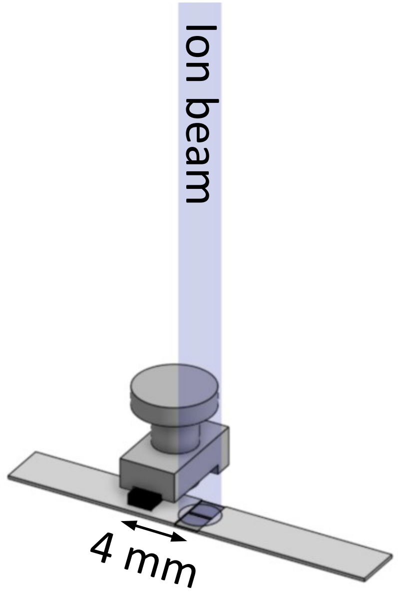




At fixed power, Jc suppression is similar for different beam energies (mdpa)







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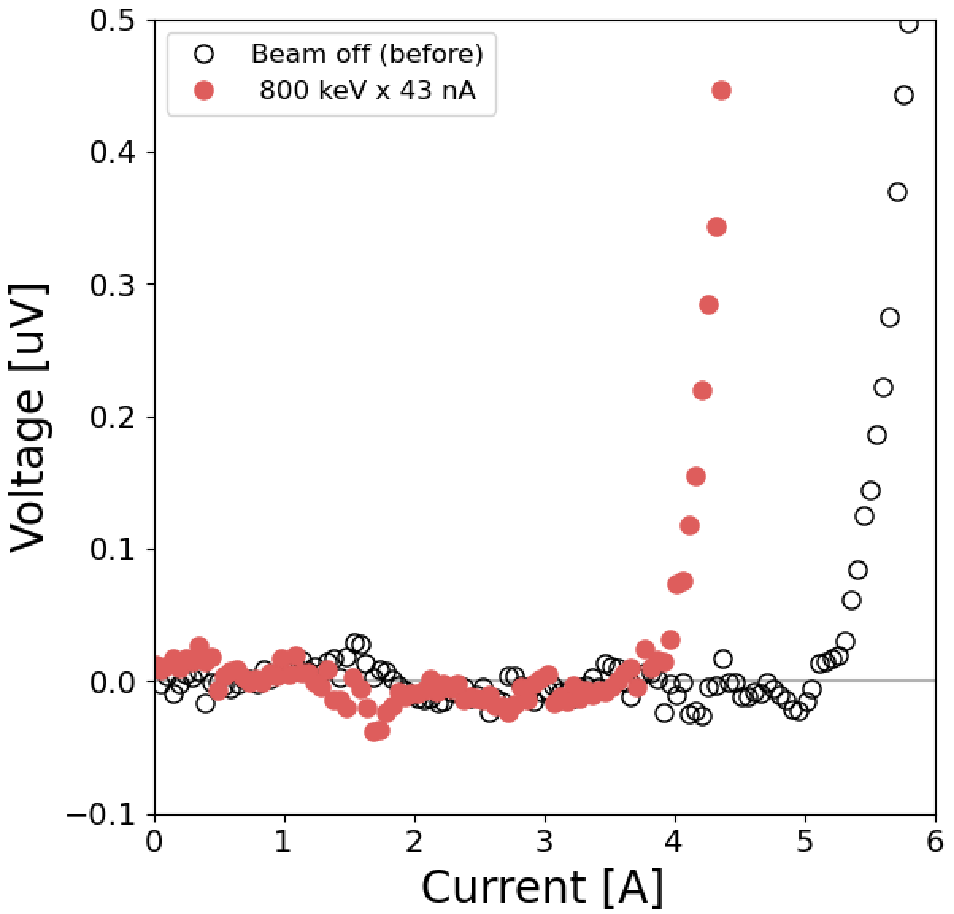

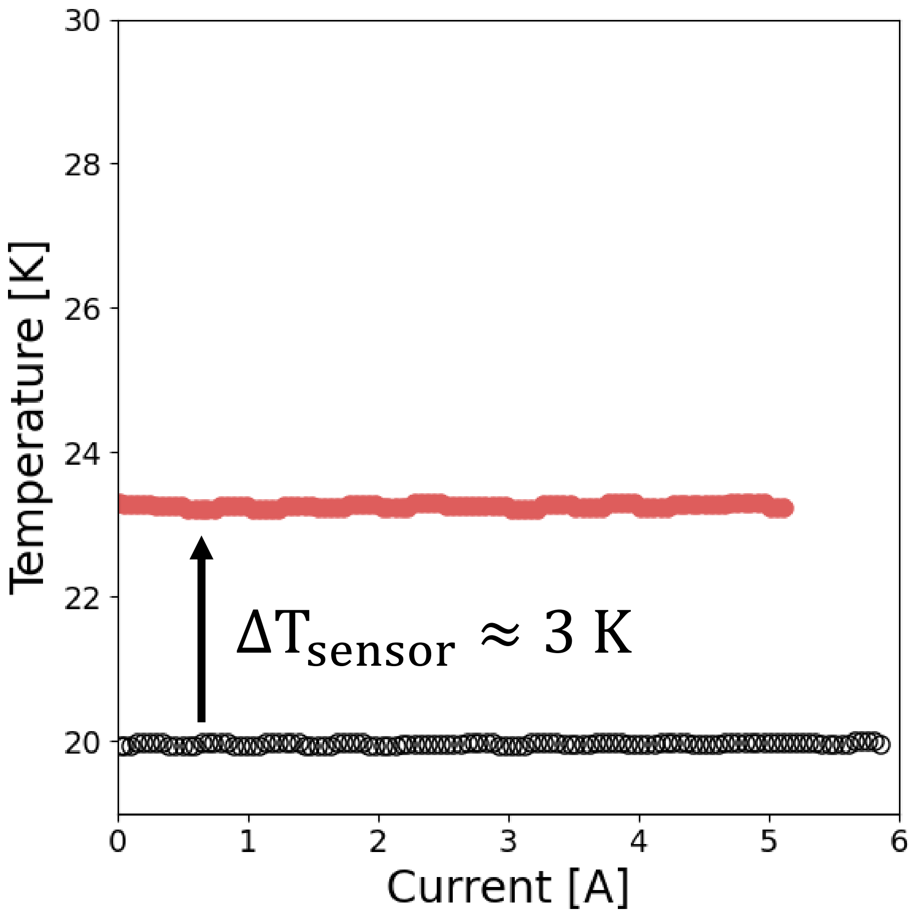

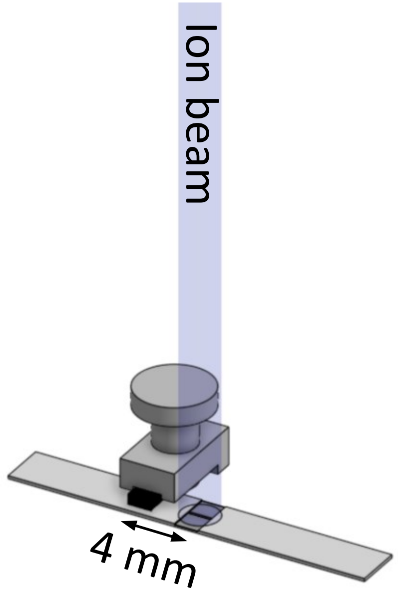

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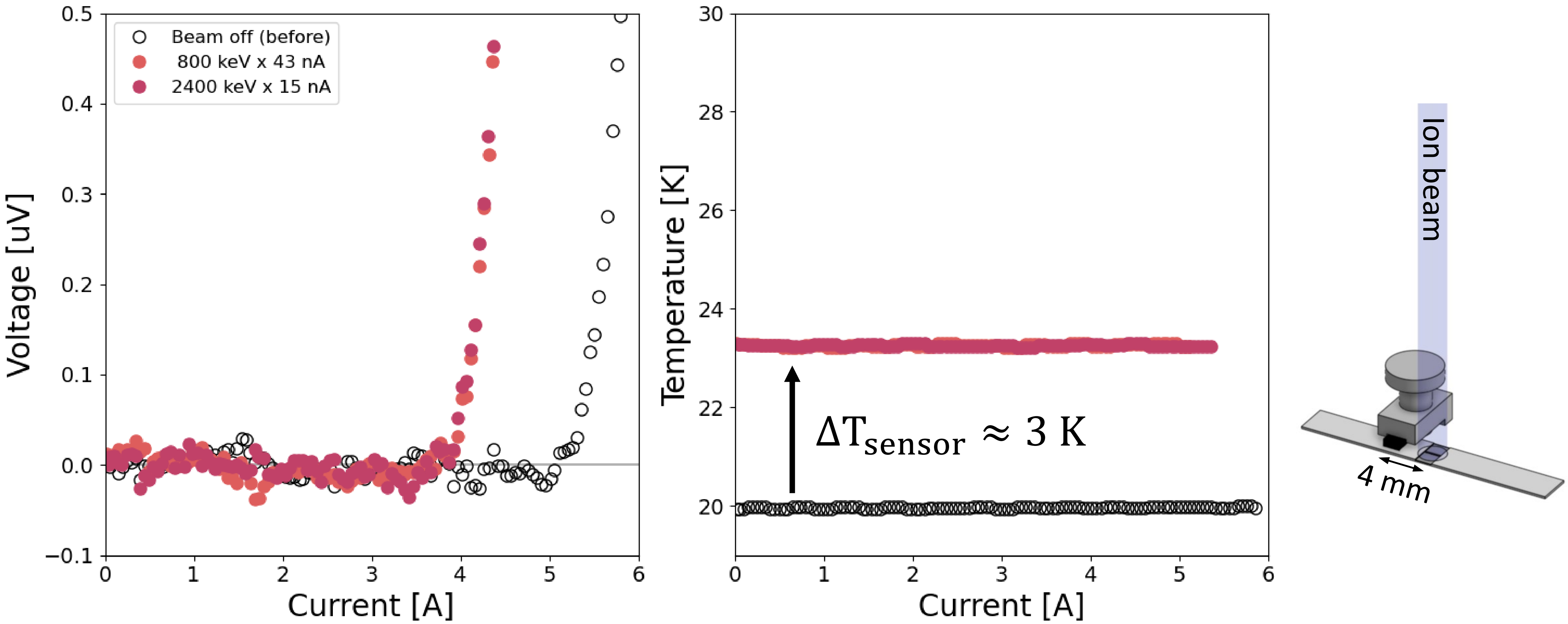

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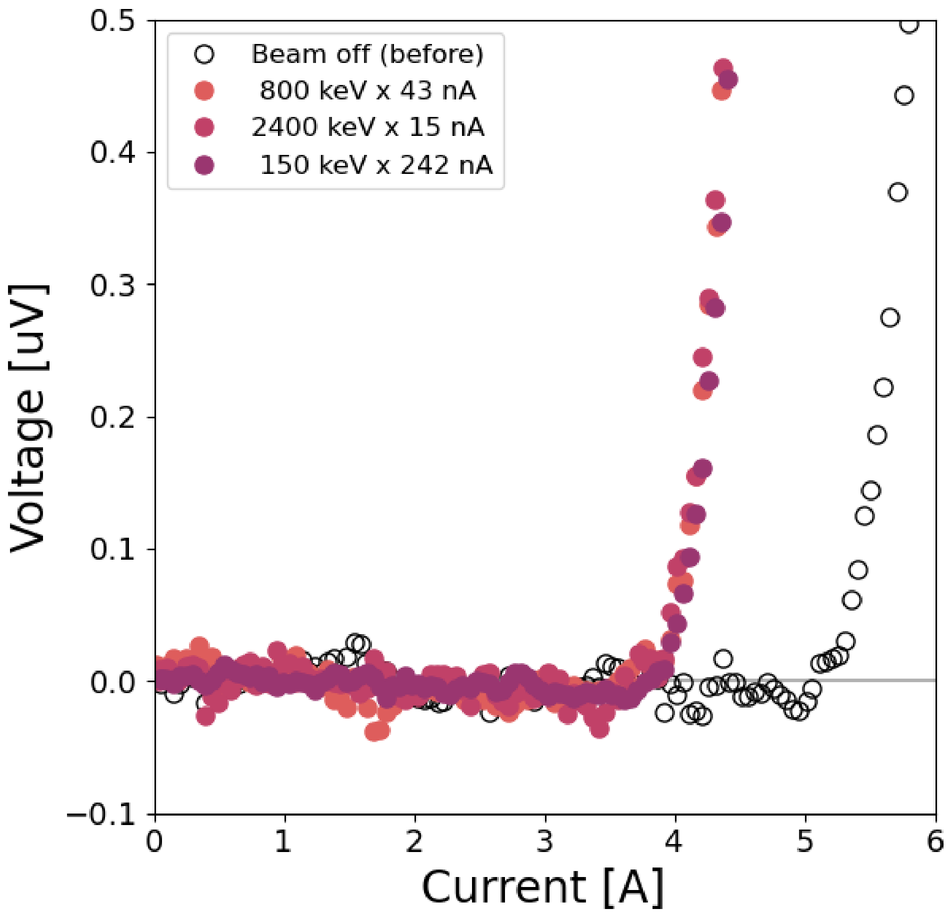

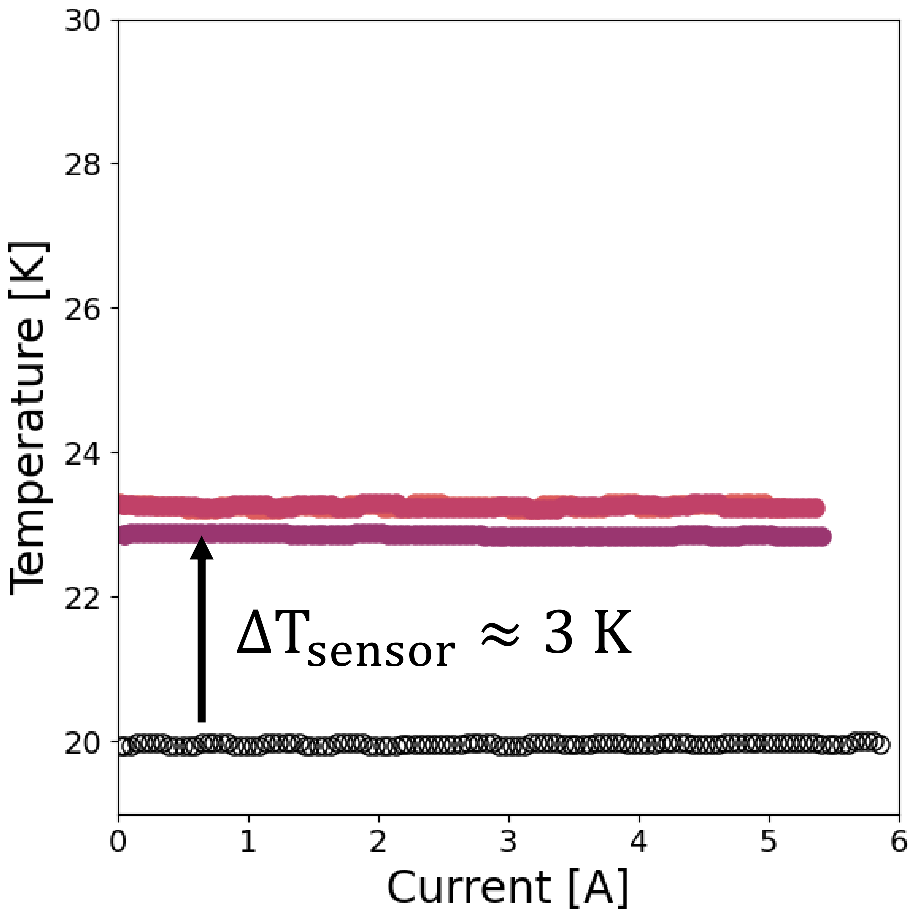

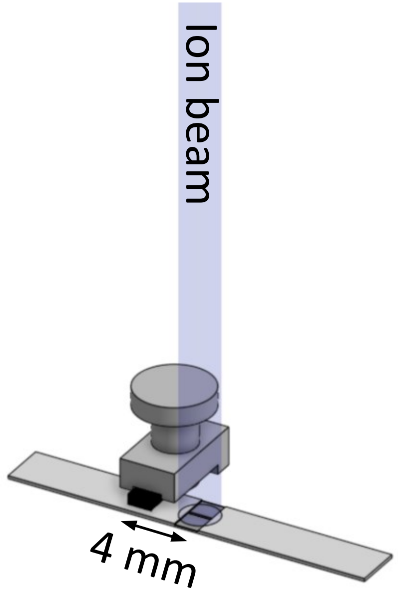

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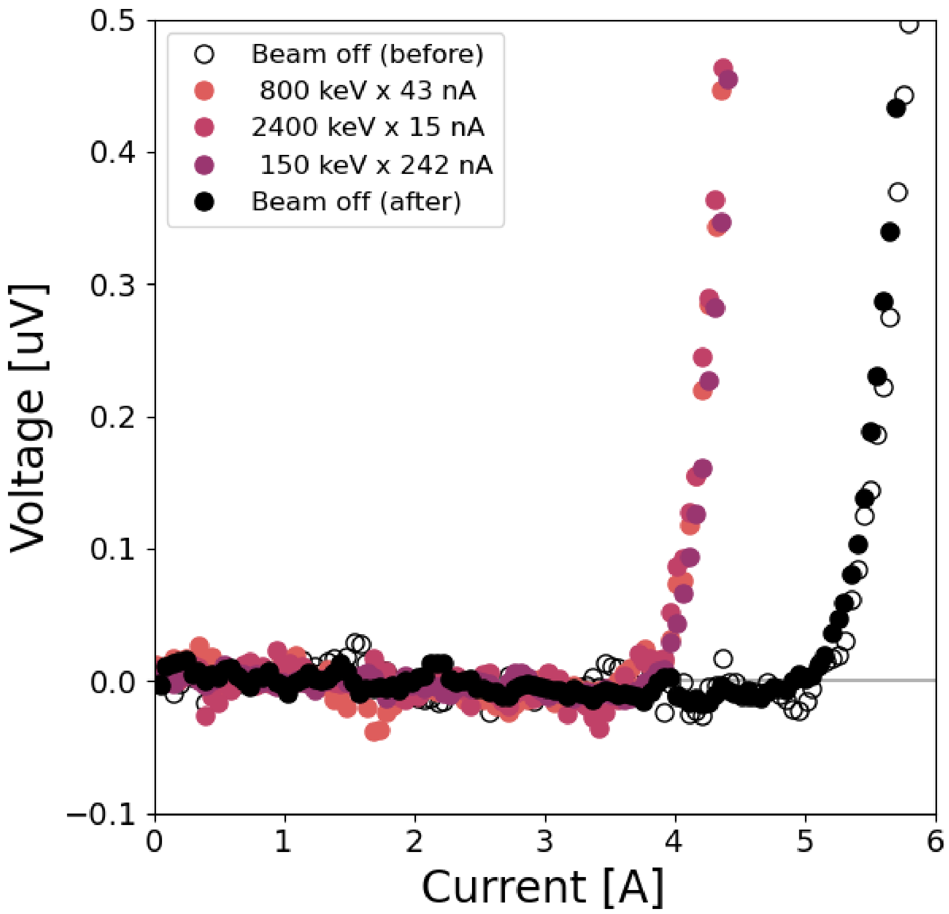
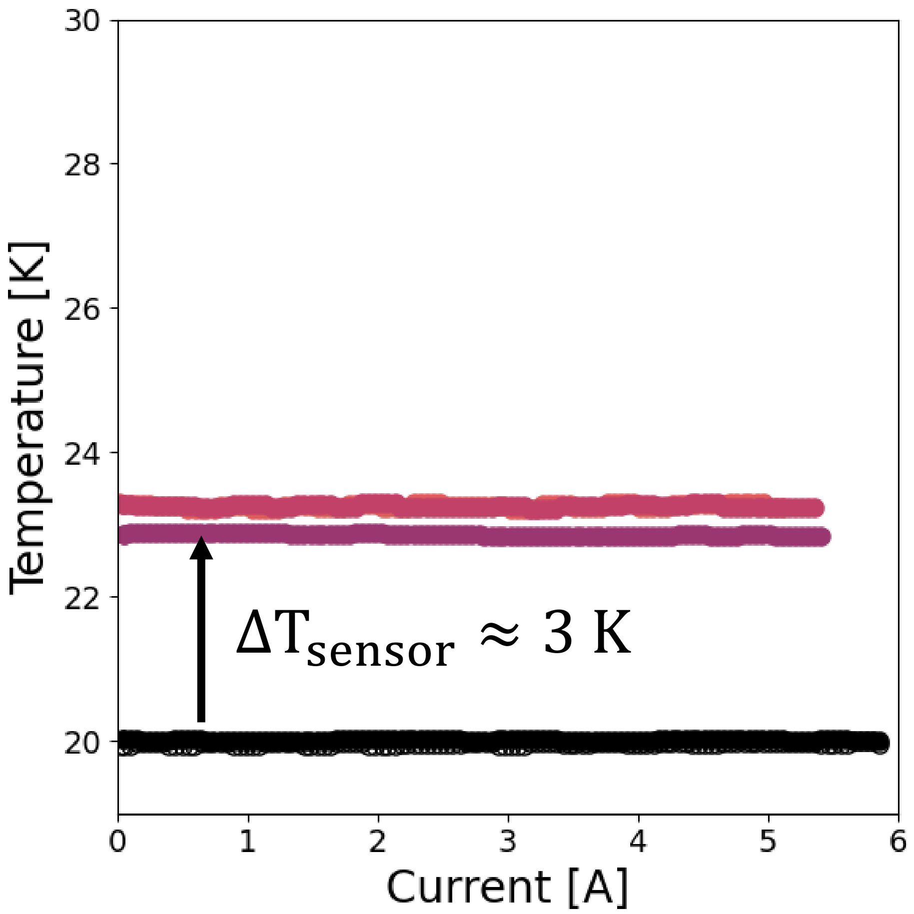
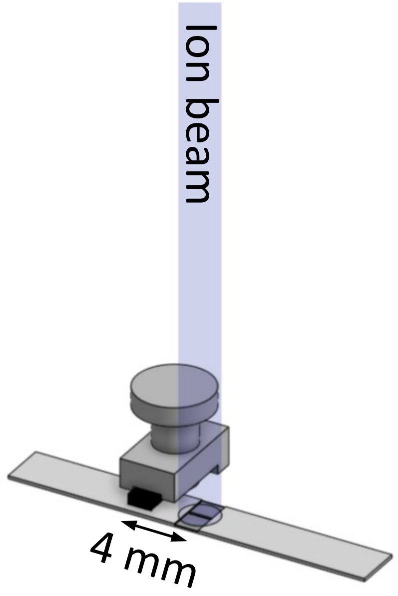
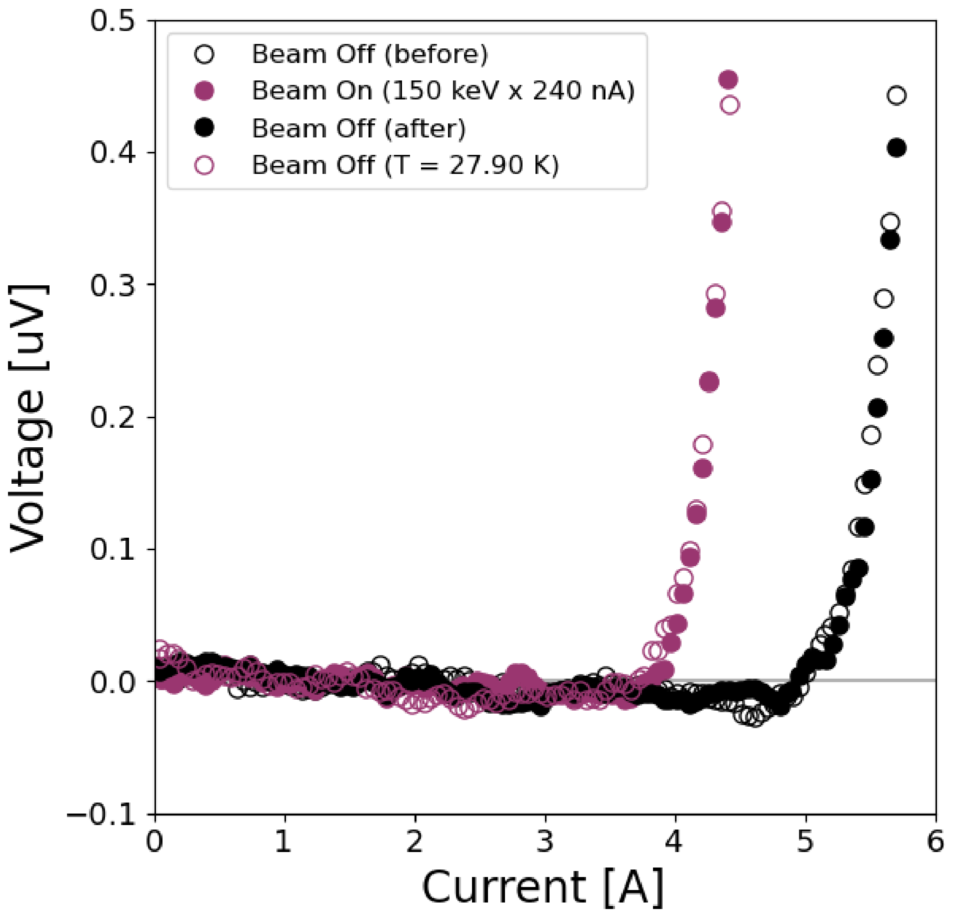
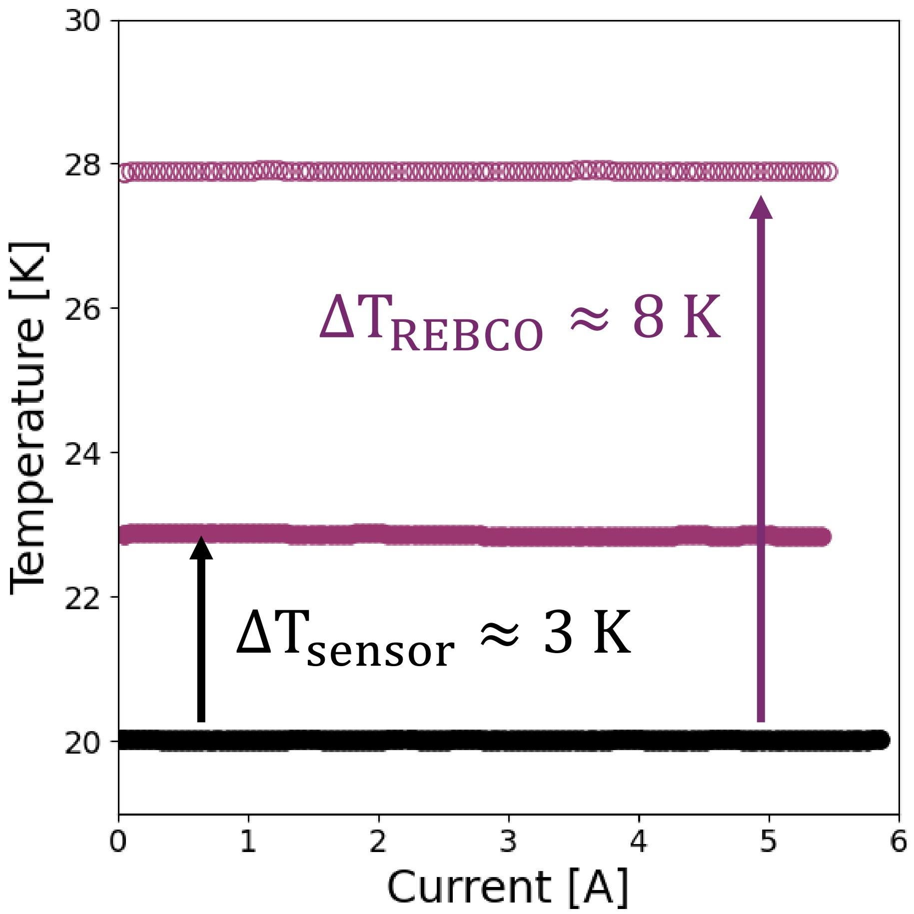


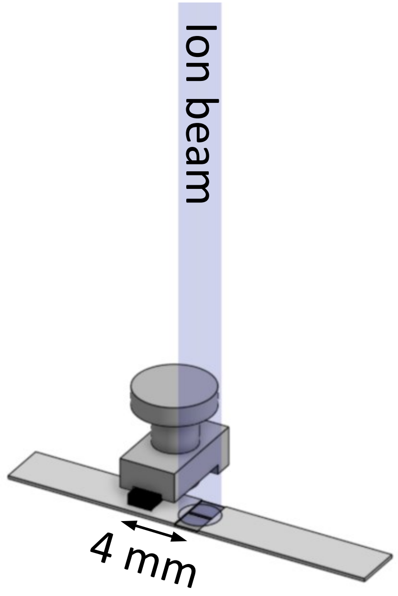




Using I_c as a thermometer to measure the true irradiation temperature







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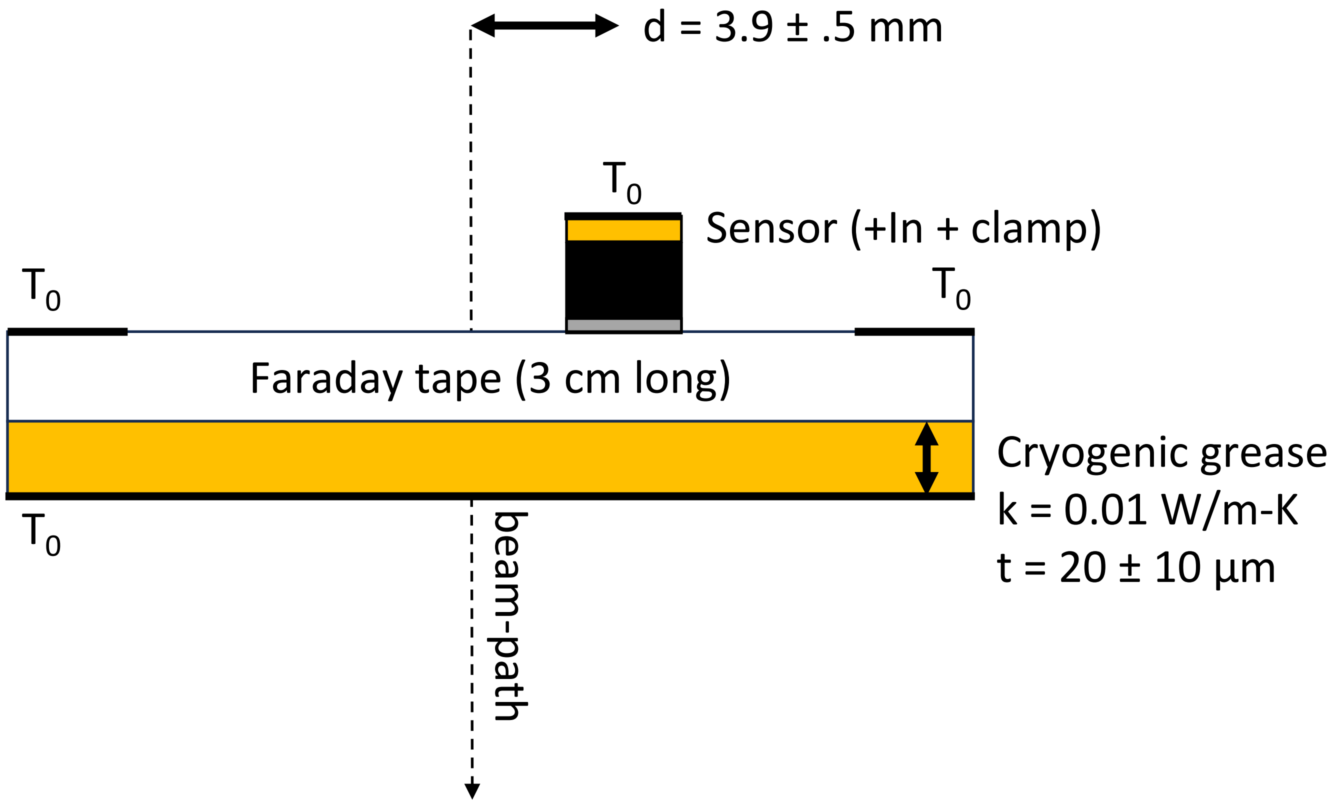
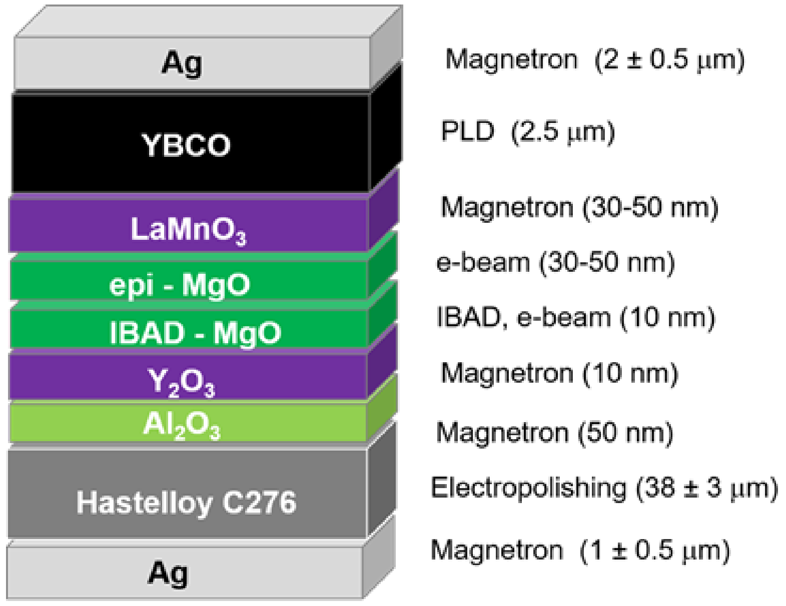
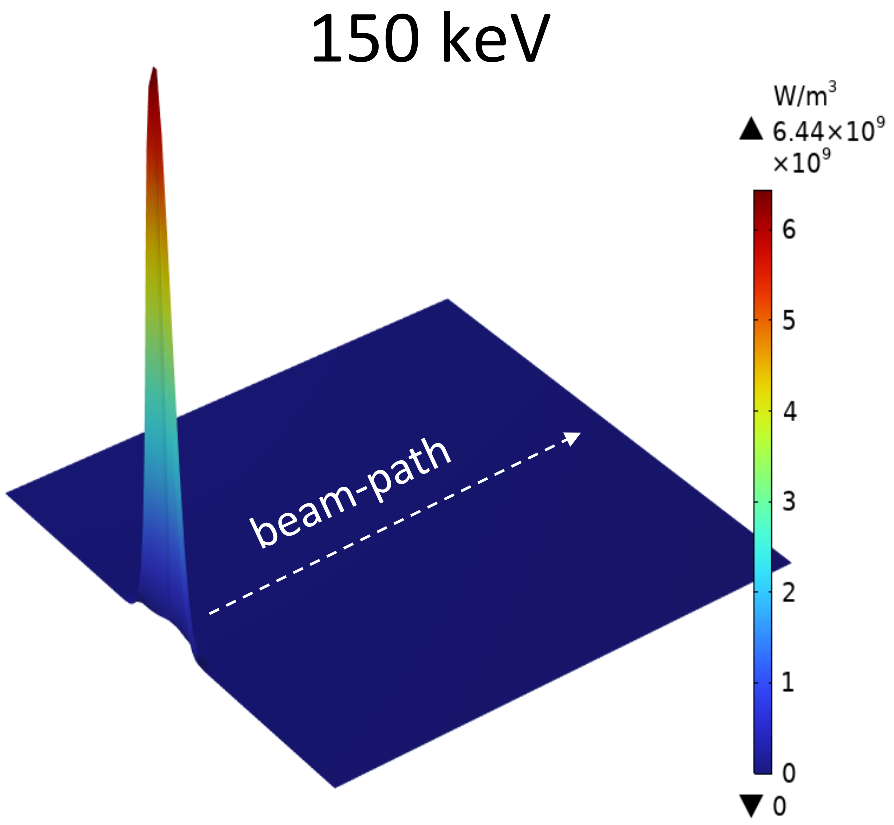
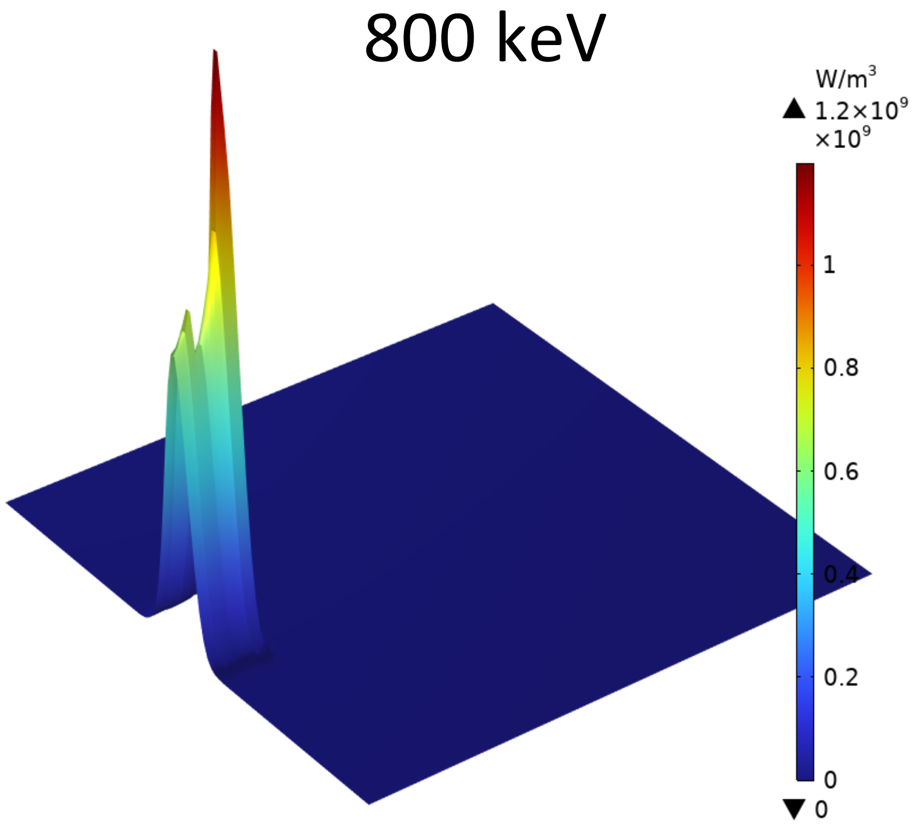
Finite-element model setup





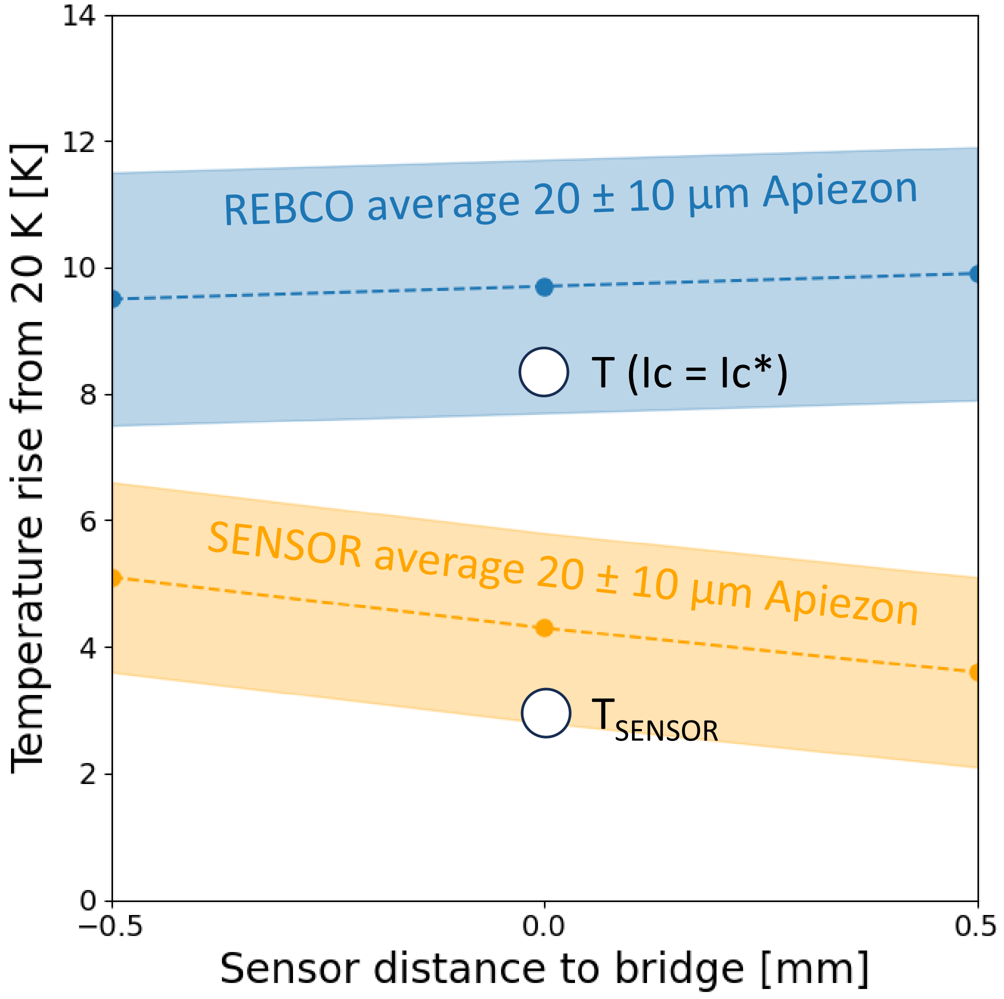
Heat source for different beam energies





3-mmm FWHM Beam heating profile
from SRIM (IONIZ.TXT + PHONONS.TXT**)**

The absolute temperature rise is sensitive to thermal coupling and the position of the temperature sensor

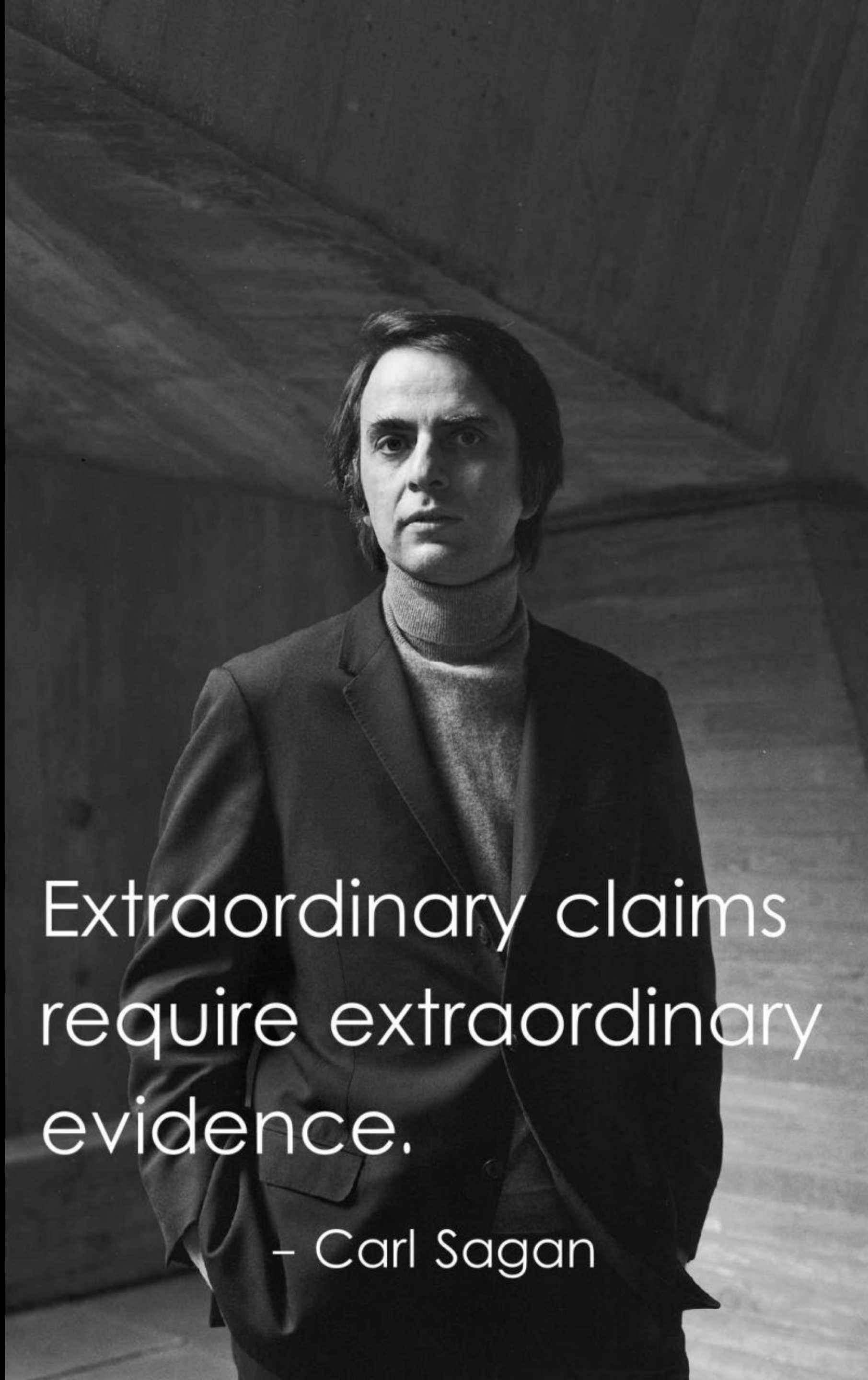


We get reasonable between model and experiments when

- The sensor is close enough to the irradiated area to detect a temperature rise.
- We determine coupling of sensor to target-holder (here it's a *free-parameter*) .
- Modeling the bridge is not necessary (2D vs 3D).
- Thermal coupling of tape (N-Apiezon grease) to target-holder is key to reproduce temperatures.

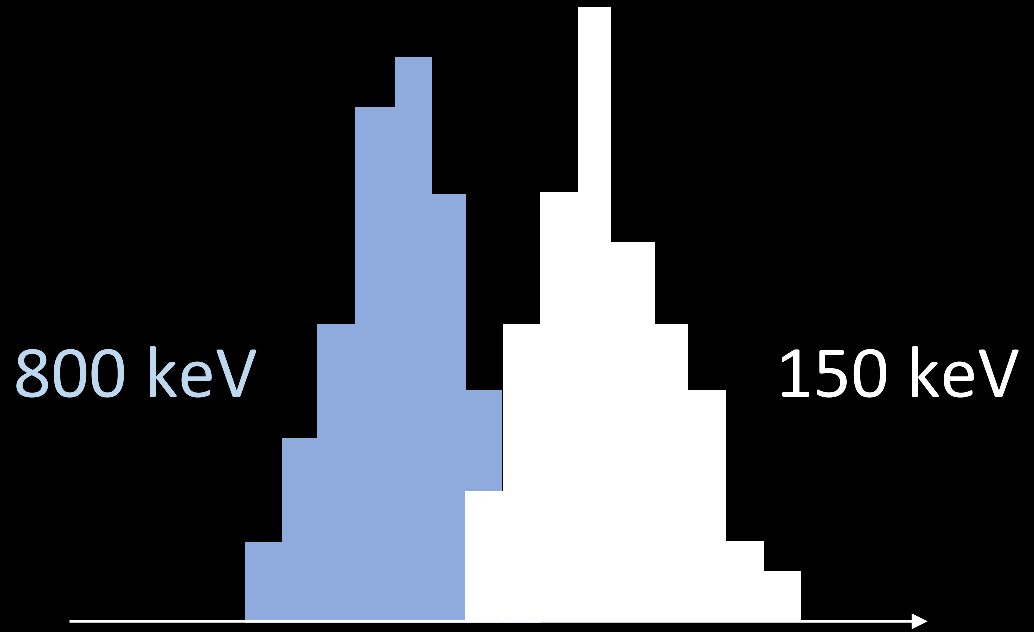
Key findings concerning the beam-on effect

- I_c is suppressed during irradiation but there is no permanent damage
- Ions do not need to interact directly with the REBCO layer to suppress I_c
- The beam-on effect is accompanied by a temperature rise
- $\mathrm{I_c}$ vs T and $\mathrm{I_c}$ vs $\mathrm{I_{Beam}}$ have the same functional dependence
- Thermal coupling strongly influences the absolute temperature rise

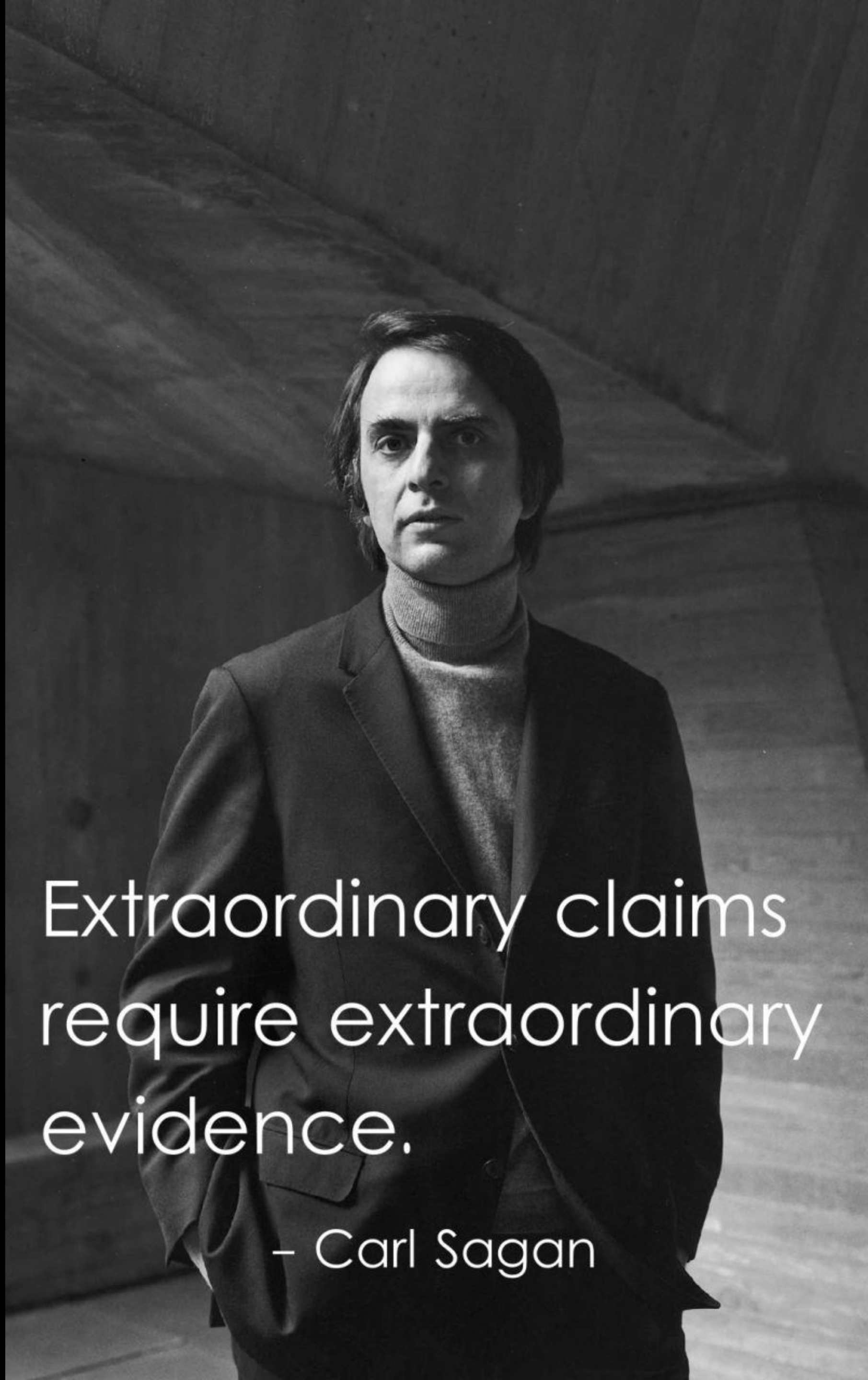


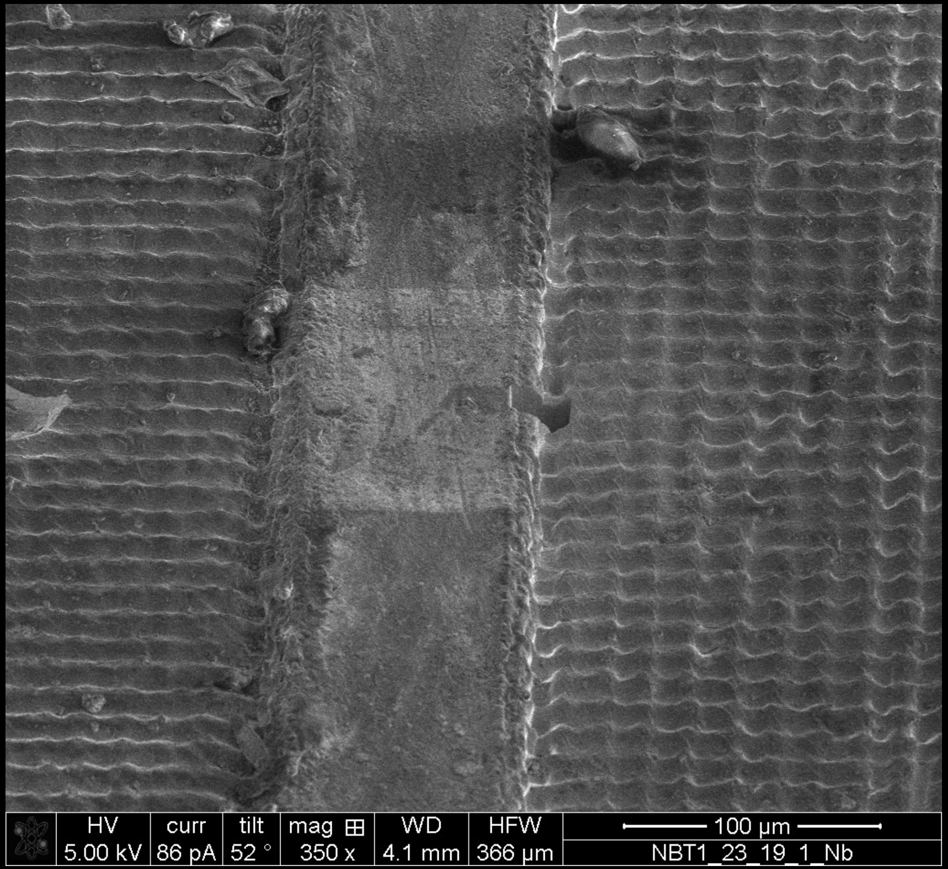
Backup slides

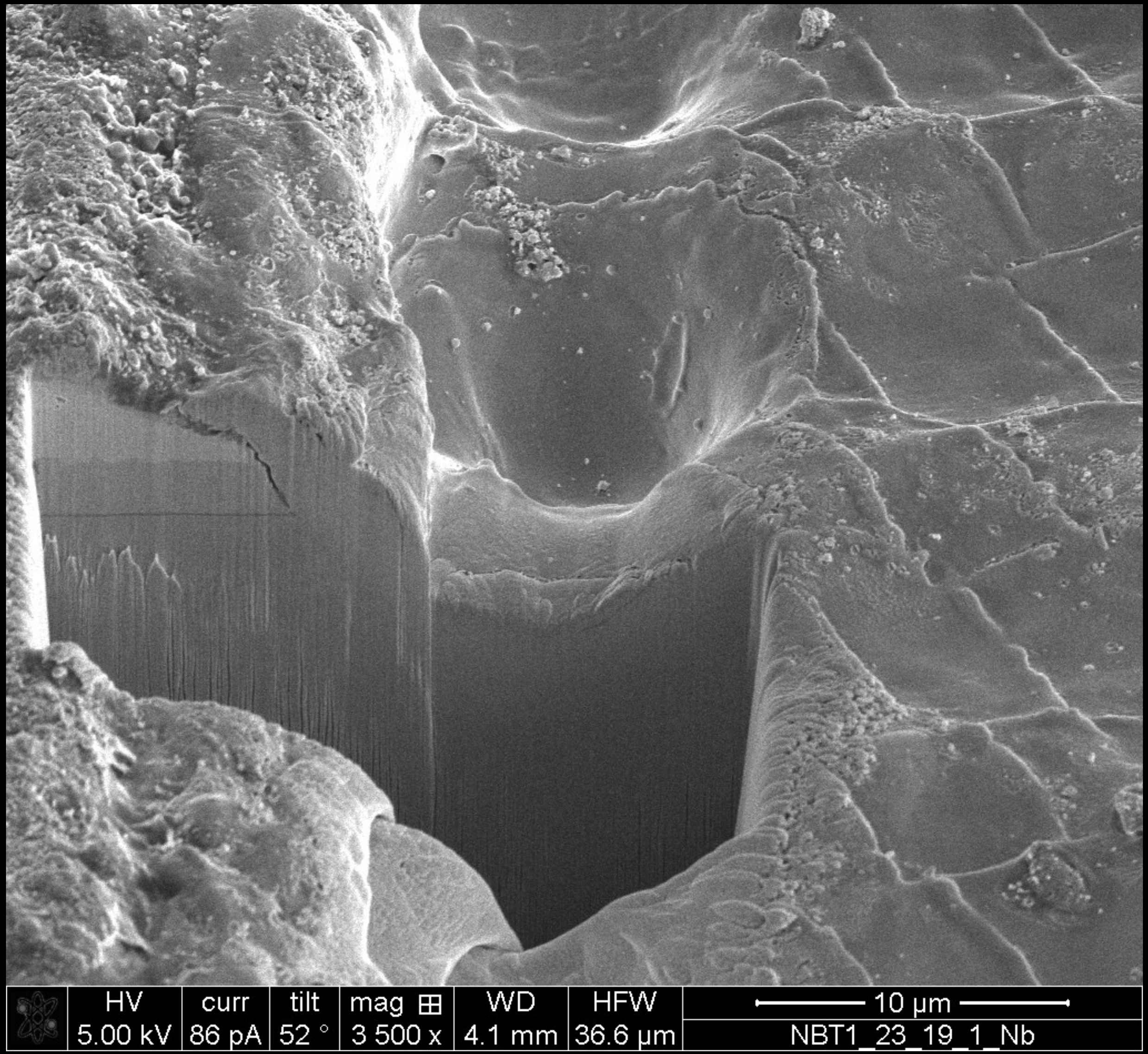
…in fact, any claim should be supported by good statistics



Can temperature alone explain the suppression of I_C during irradiation?




HV
curr
tilt
mag ⊞
WD
HFW
100 µm
5.00 kV
86 pA
52 °
350 x
4.1 mm
366 µm
NBT1_23_19_1_Nb


HV
curr
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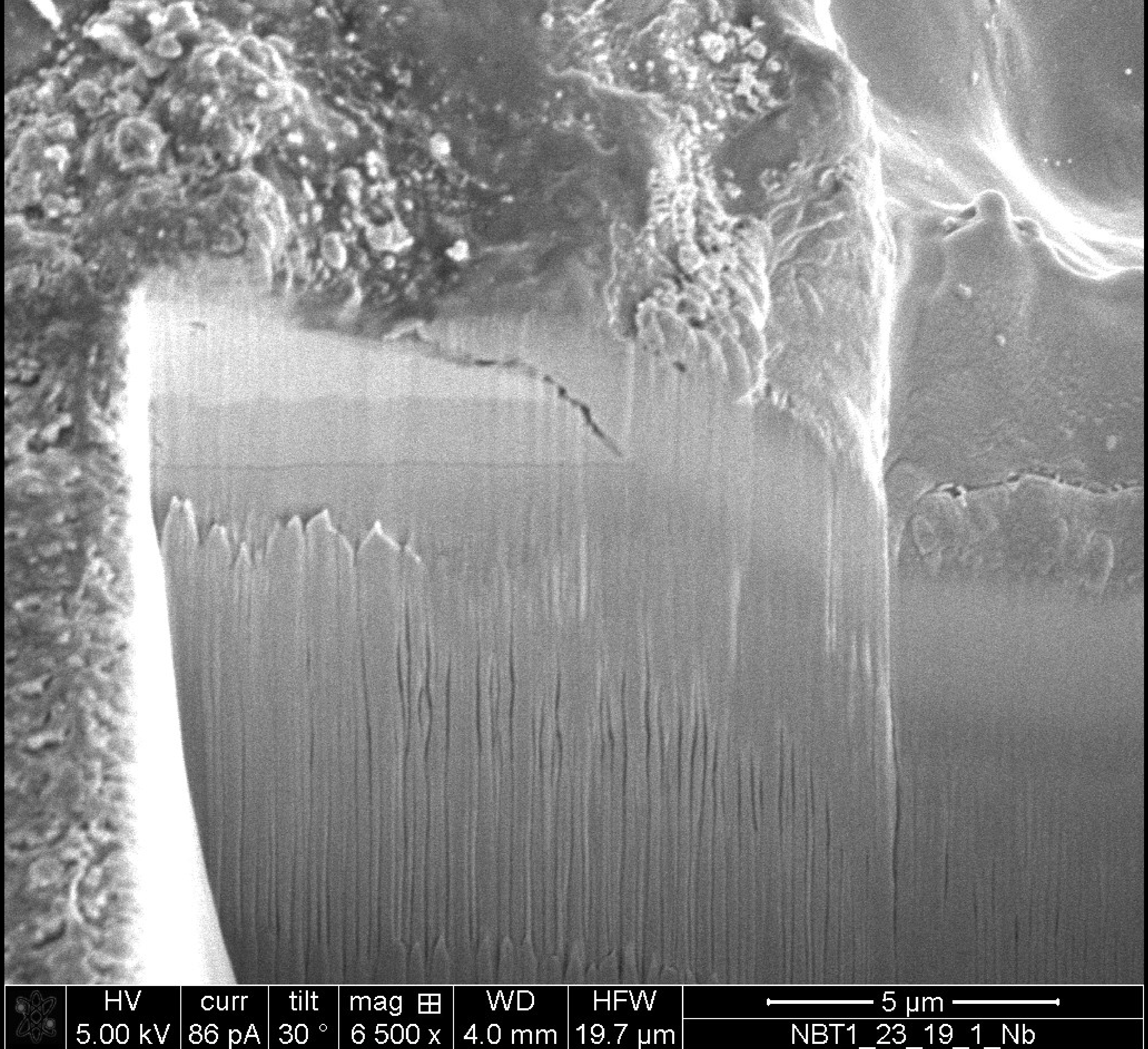
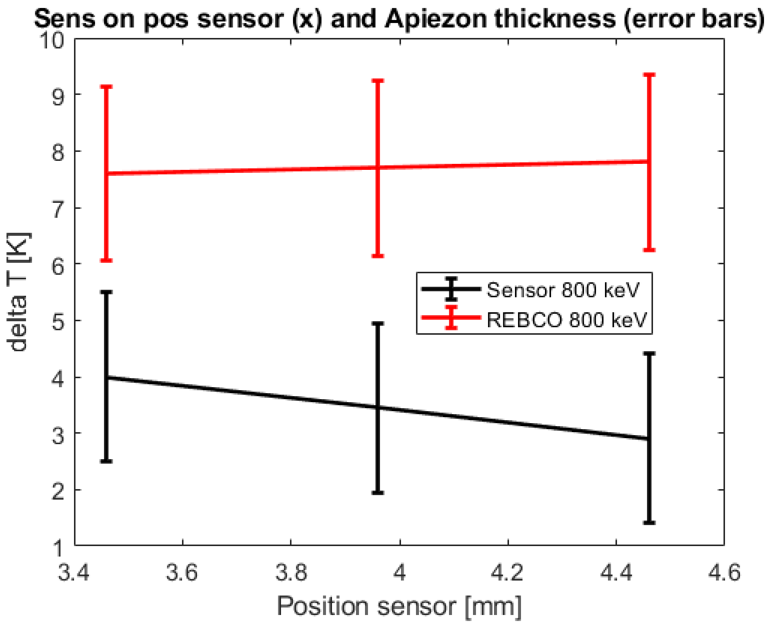
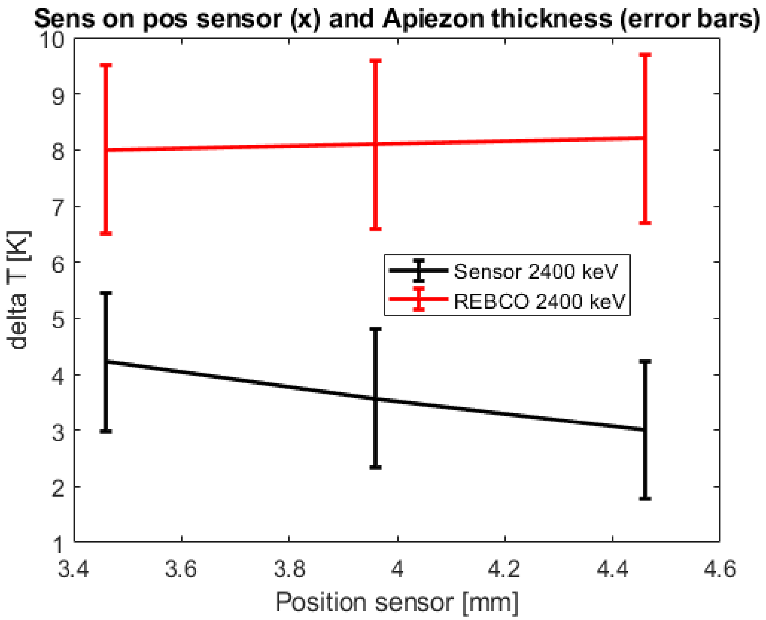
10 µm
5.00 kV
86 pA
52 °
3 500 x
4.1 mm
36.6 µm
NBT1_23_19_1_Nb

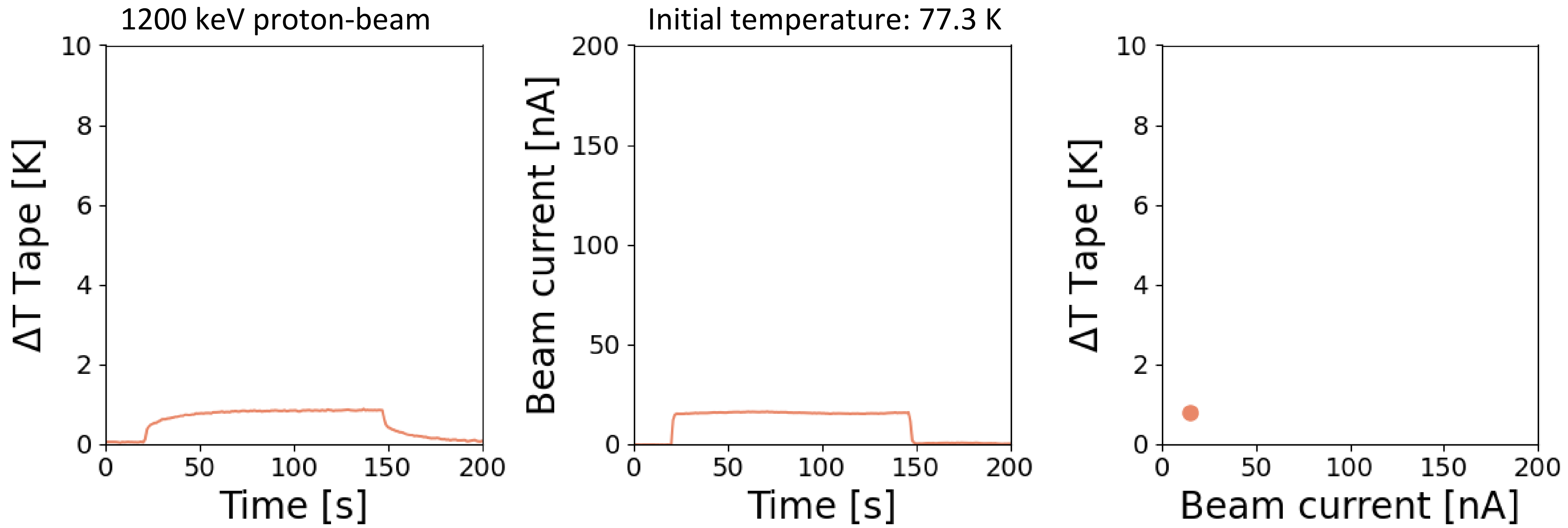

HV
5.00 kV
curr
86 pA
tilt
30 °
mag
6 500 x
WD
4.0 mm
HFW
19.7 µm
5 µm
NBT1_23_19_1_Nb

FE 800 and 2400 keV

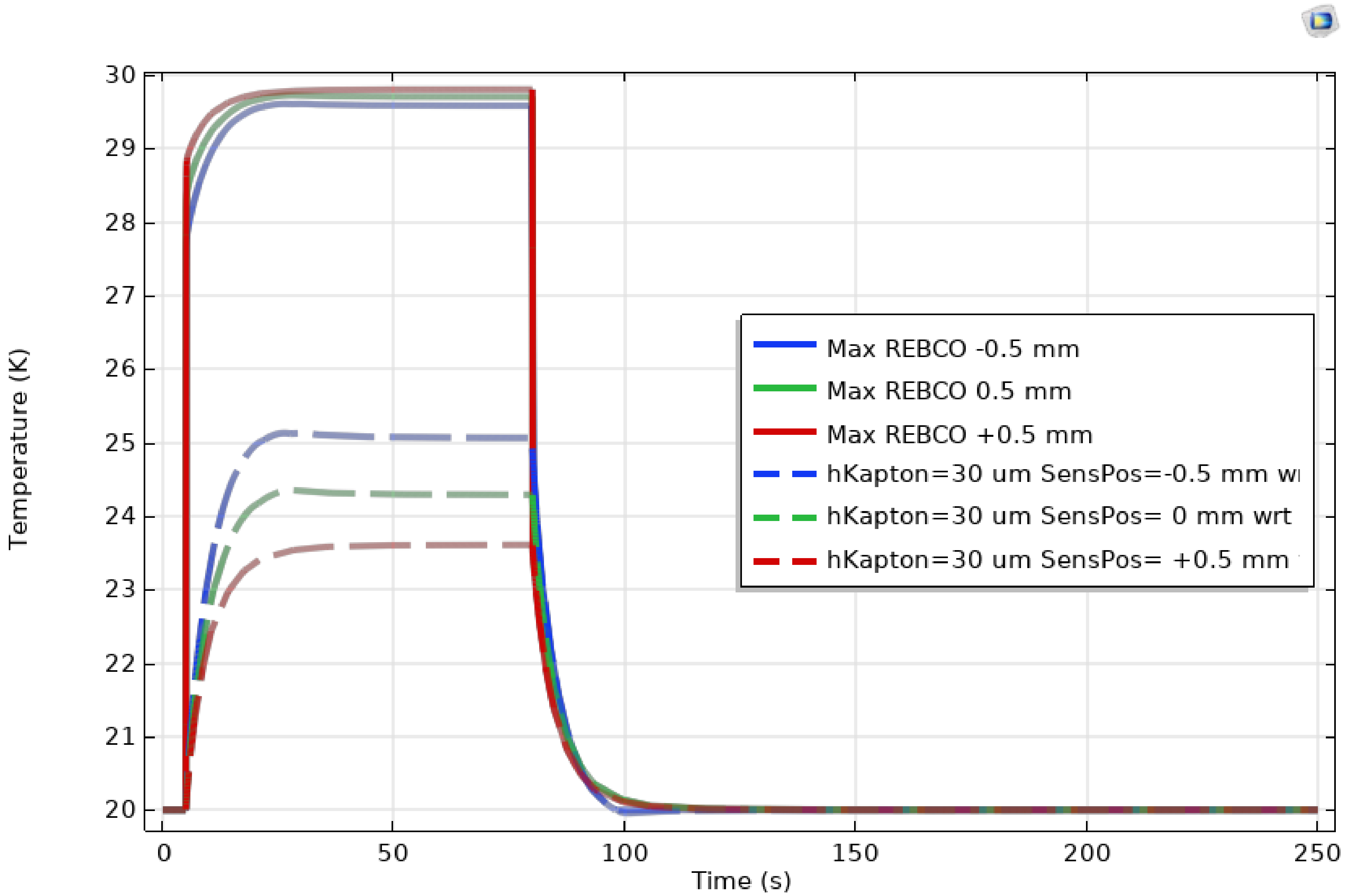




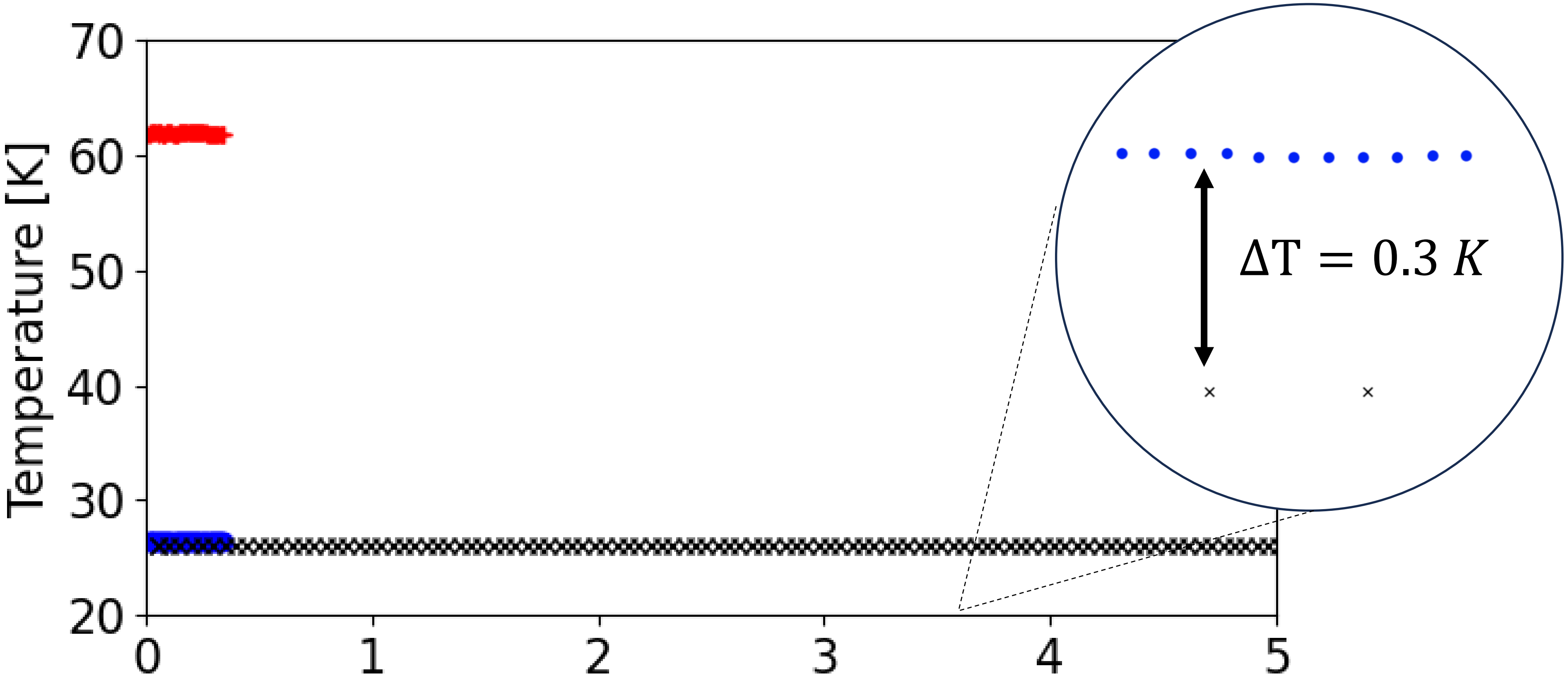
At fixed energy, the temperature rise is proportional to beam current



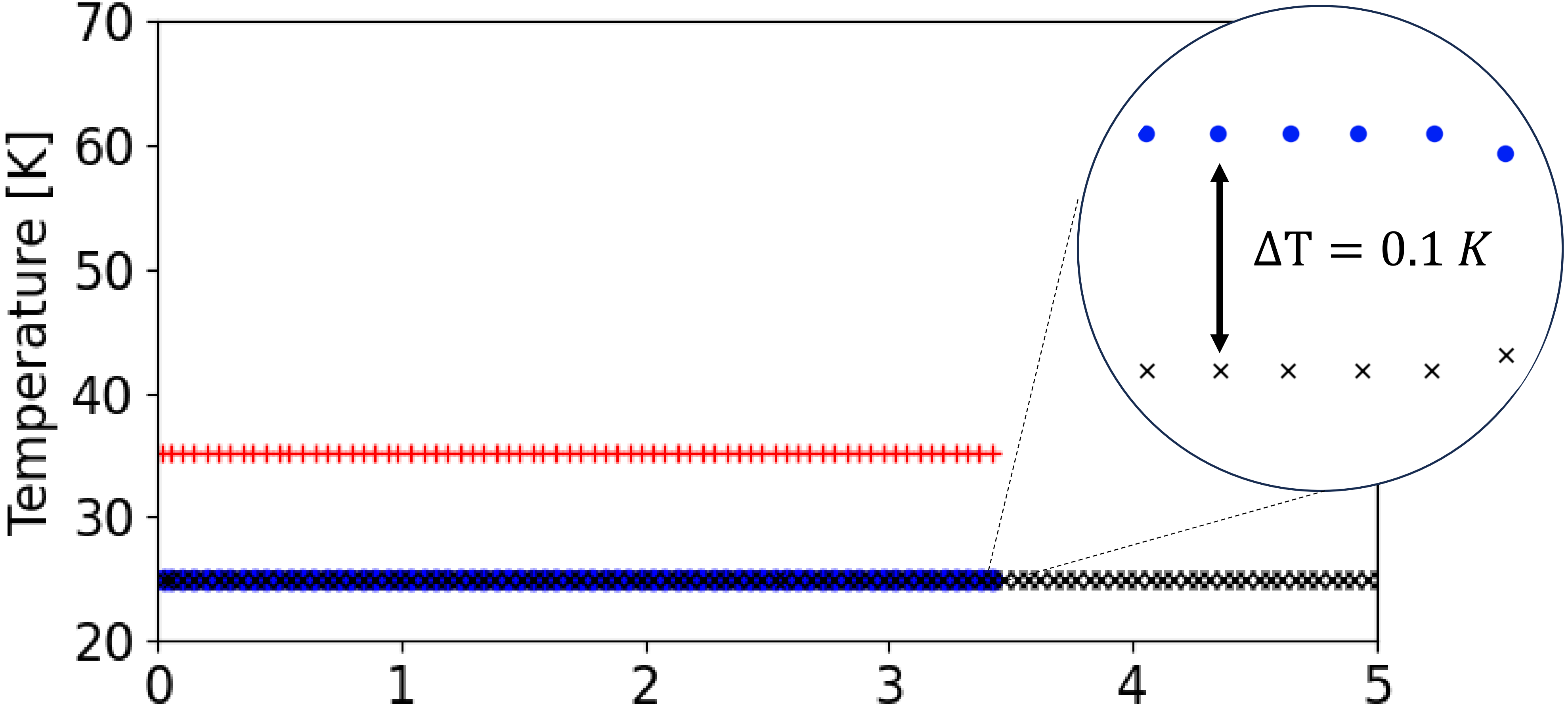
Beam current is 200 nA?



Temperature stability during Ic measurements with a 1200 keV beam

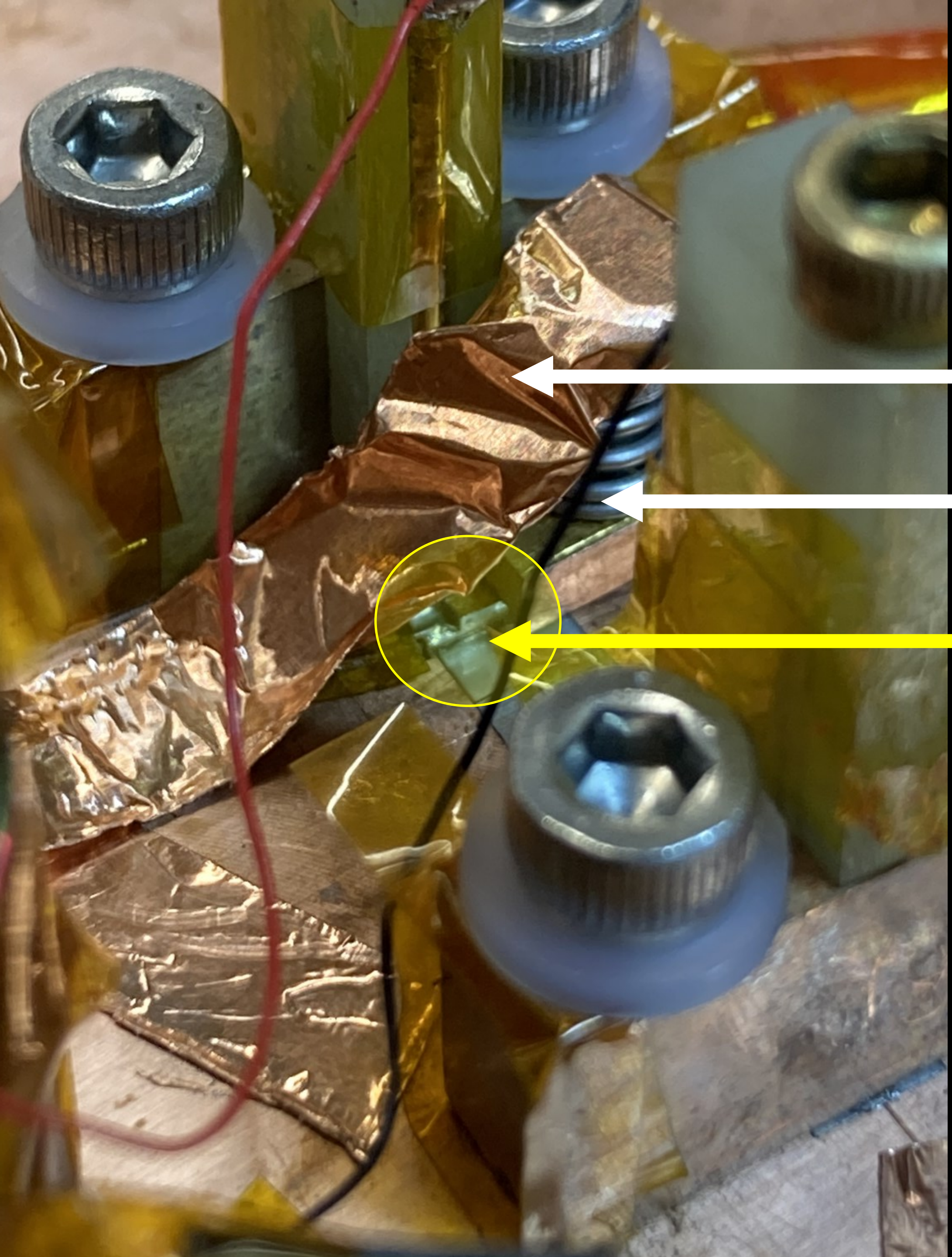


Temperature stability during Ic measurements with a 300 keV beam

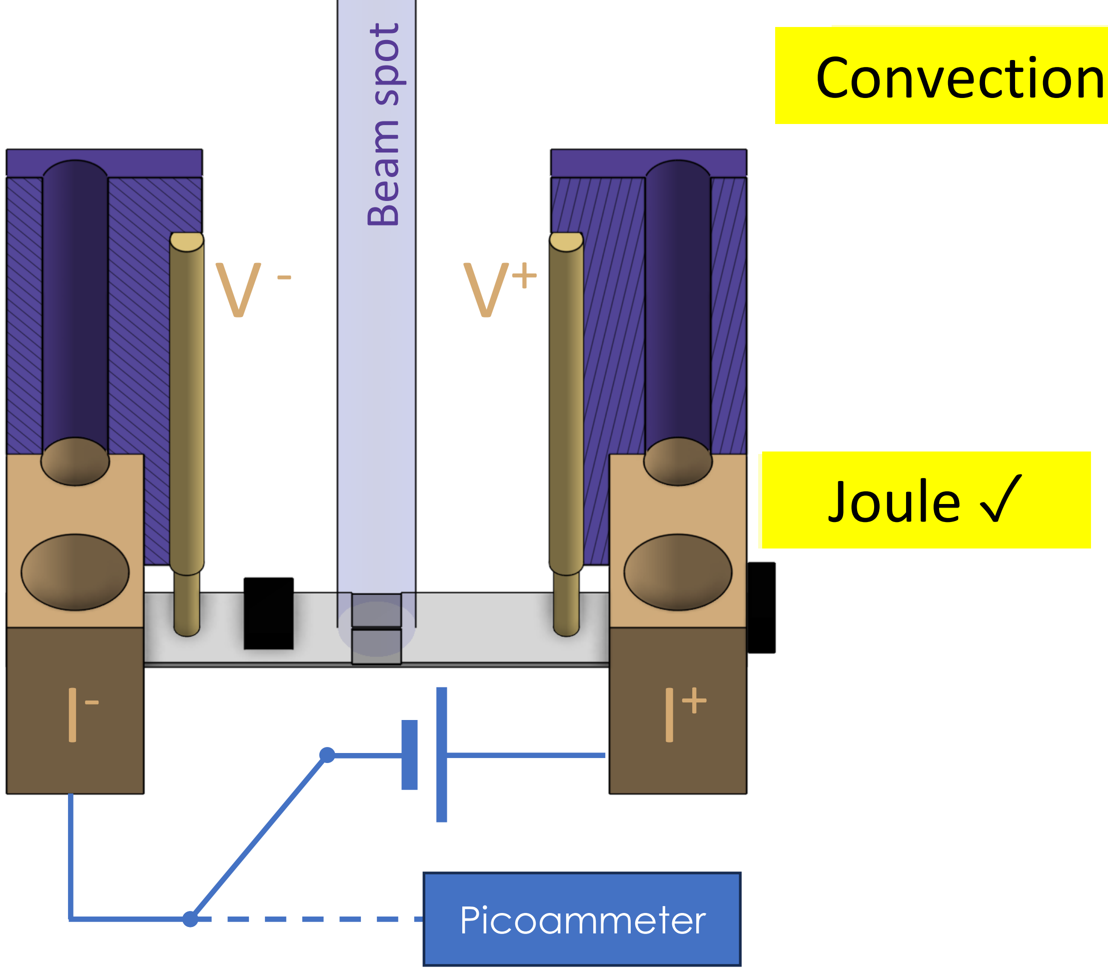


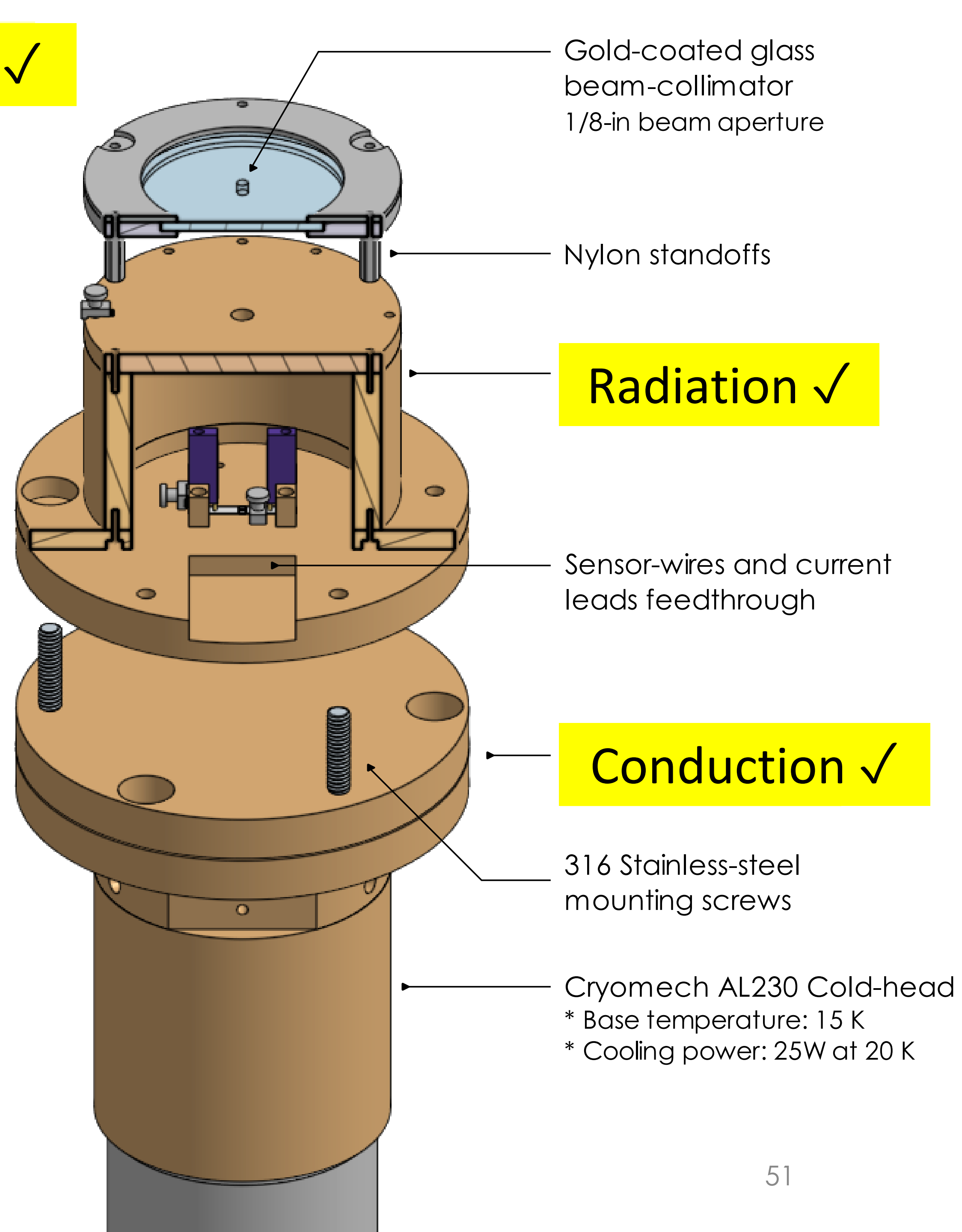
The bridged-tape is mounted directly on copper with a thin layer of cryogenic grease (N-Apiezon).

Temperature sensor T3 is pressed down against the surface of the tape, **in the irradiated area.**



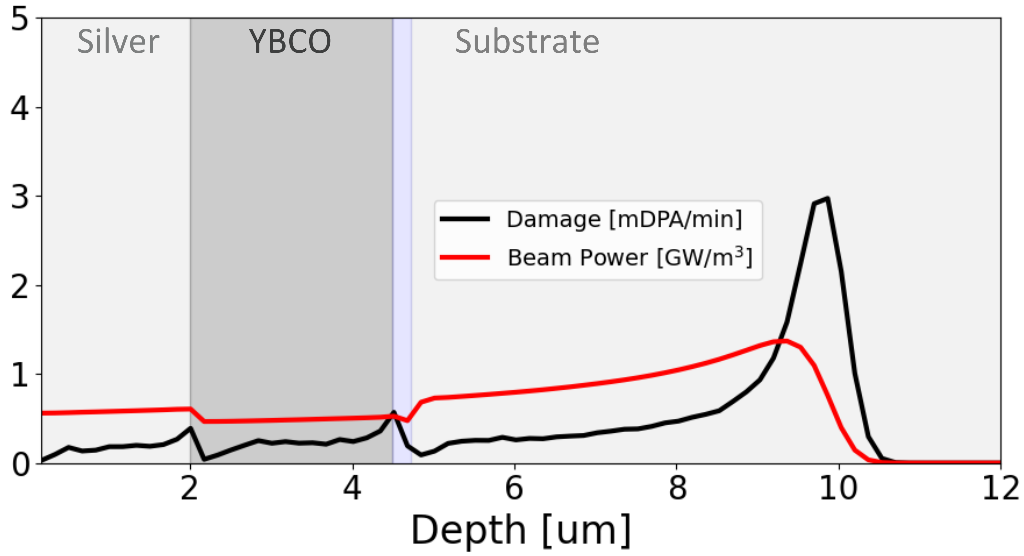
For this test, the sensor was occluded from the beam by copper tape. The tape touches the samples holder, but it doesn't contact the sensor directly.



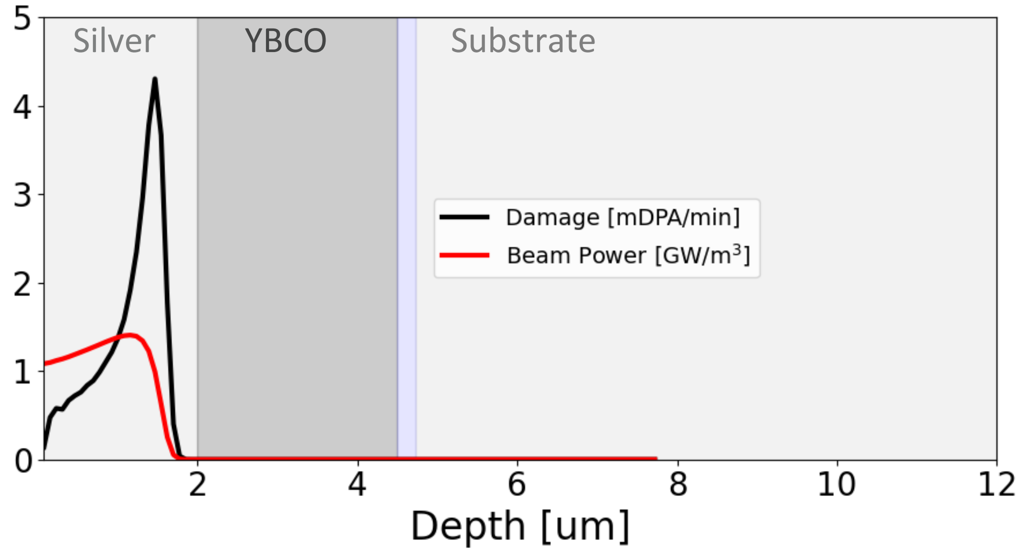


Re-engineered cryogenic target maximizes heat removal

Can we separate beam-heating from atomic-displacements?



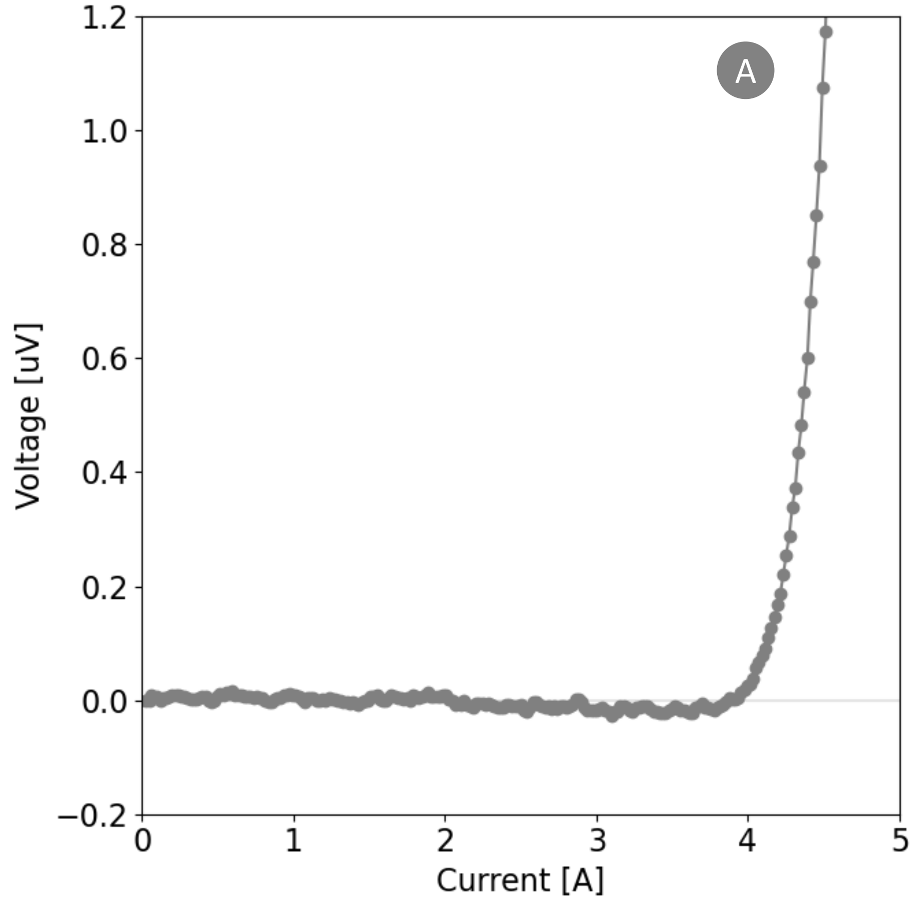
1200 keV protons **heat and damage** the REBCO

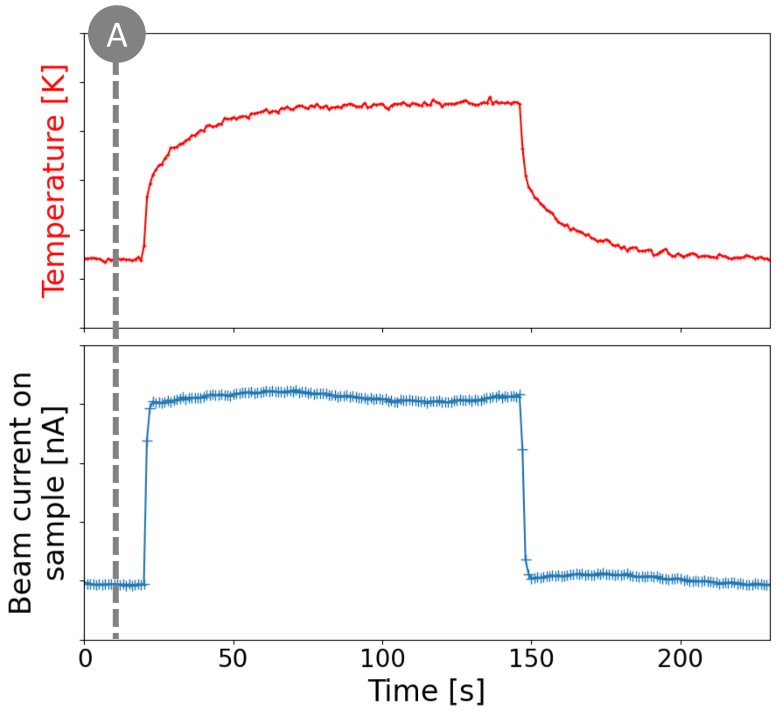


300 keV protons **only heat** the REBCO layer

Case 1: 1200 keV protons **heat** and **damage** the REBCO

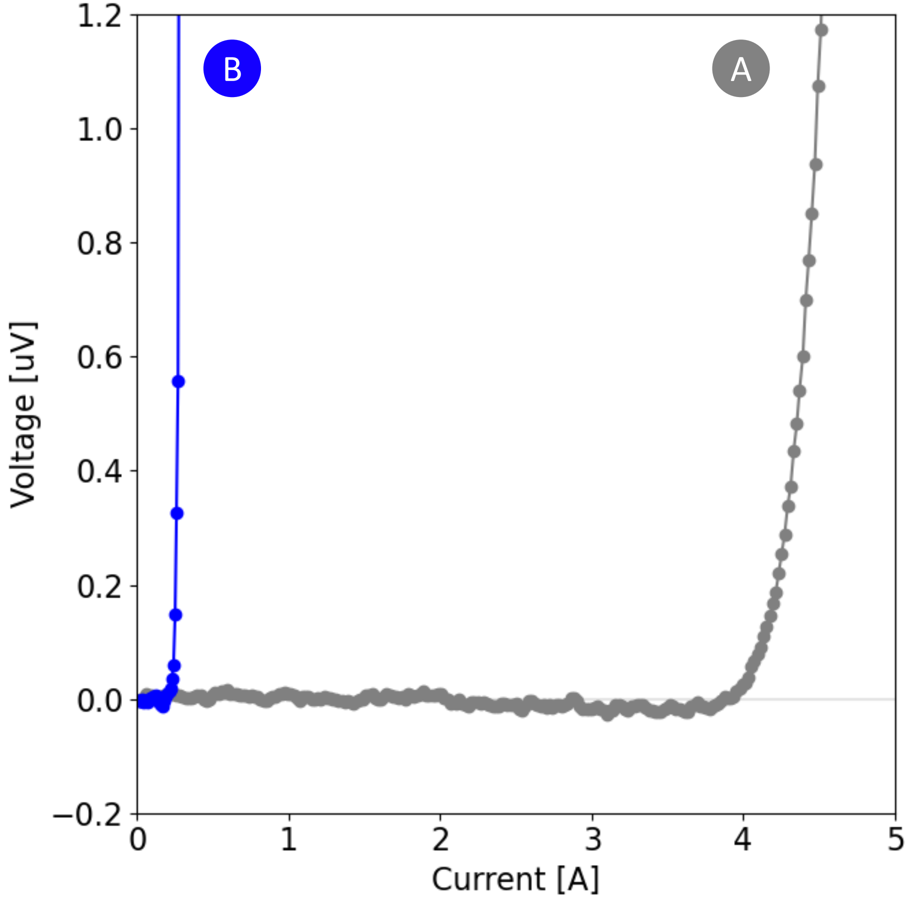
Curve A is the reference before irradiation

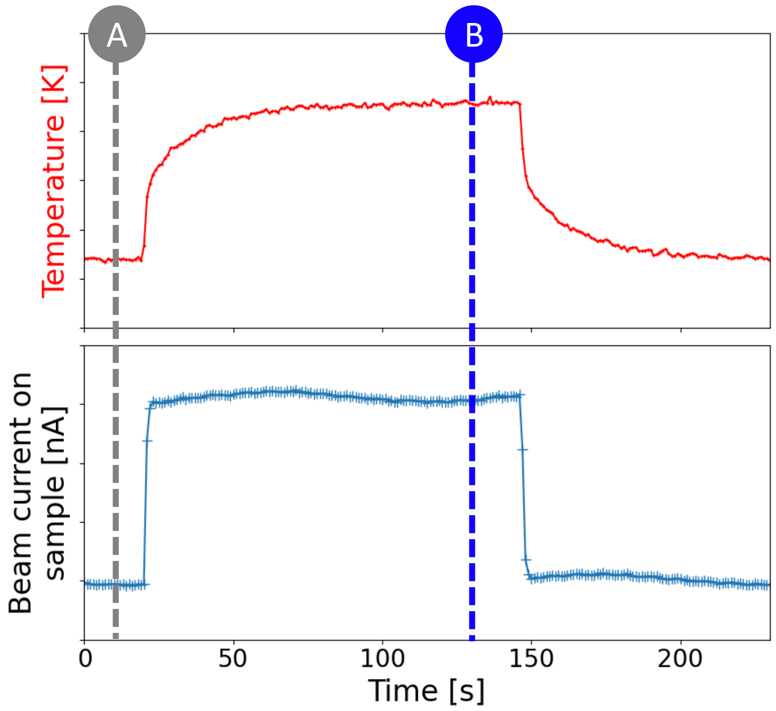




Case 1: 1200 keV protons **heat** and **damage** the REBCO

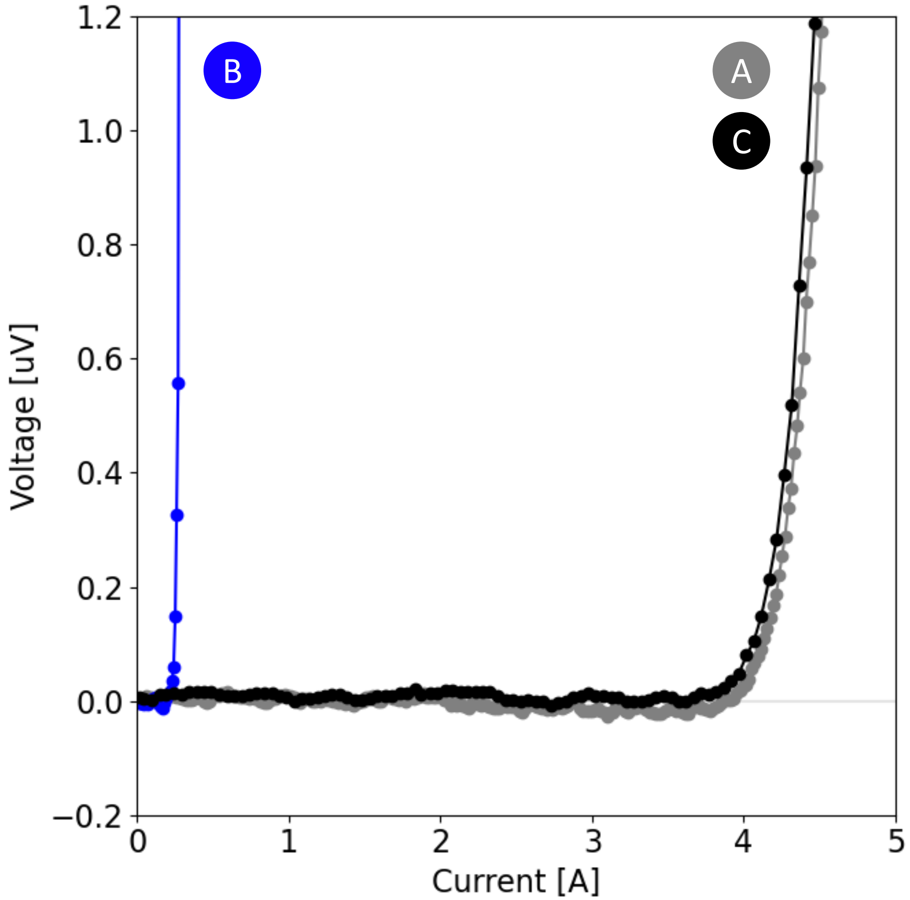
Curve B is measured during irradiation (stable temperature)

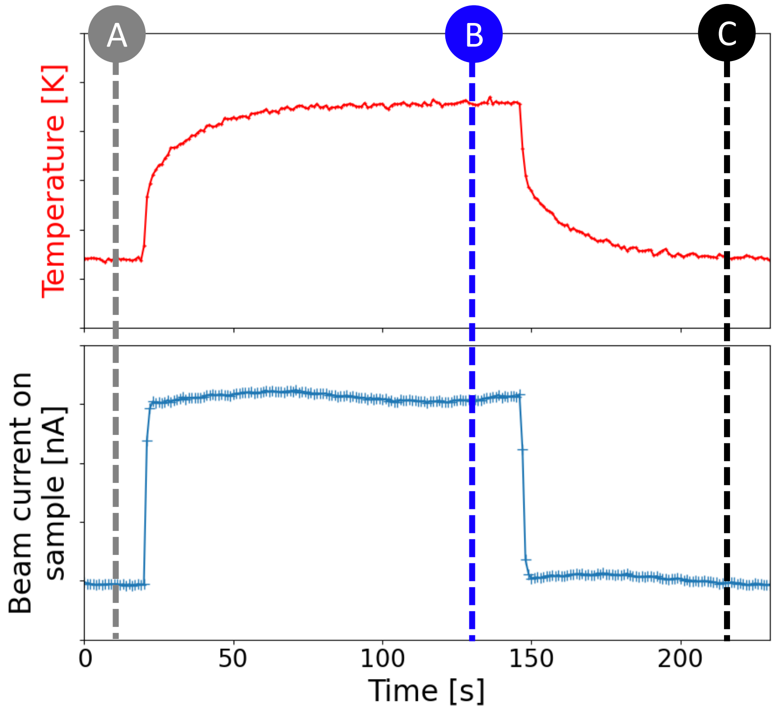




Case 1: 1200 keV protons **heat** and **damage** the REBCO

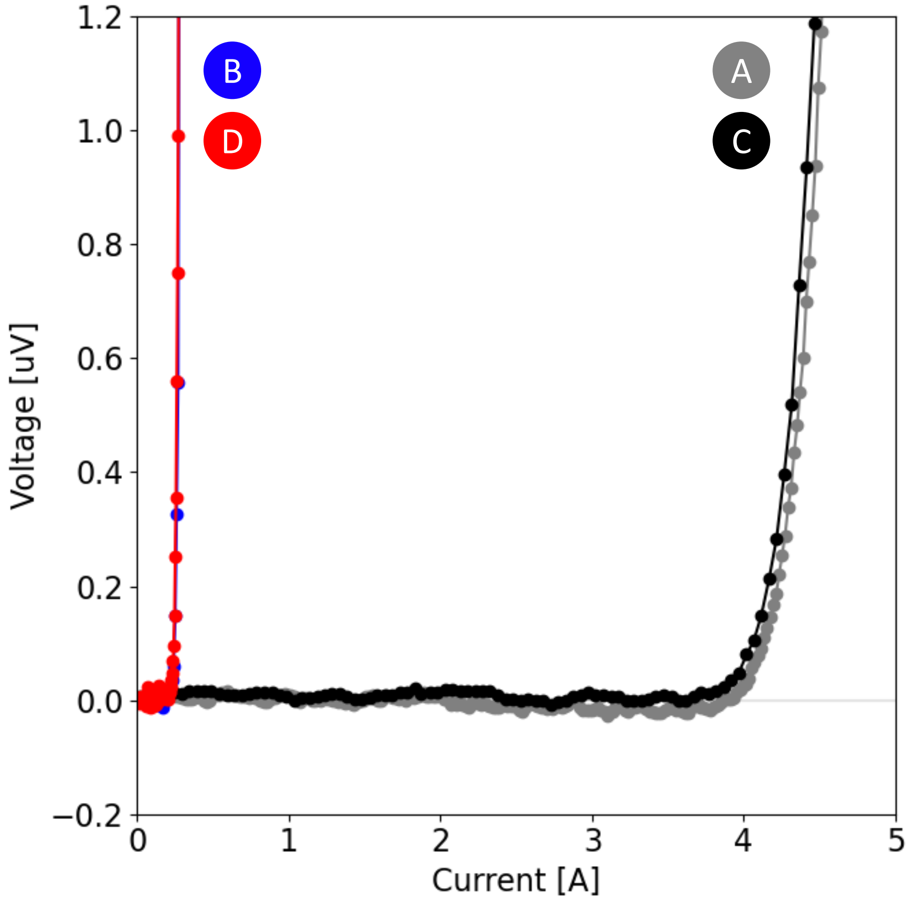
Curve C is measured after irradiation

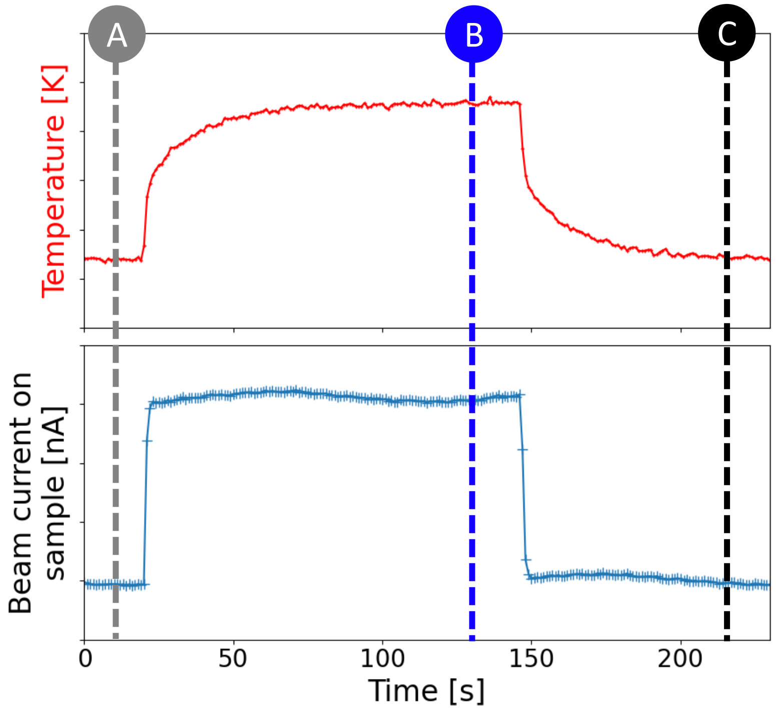




Case 1: 1200 keV protons **heat** and **damage** the REBCO

Curve D is measured at the matching temperature



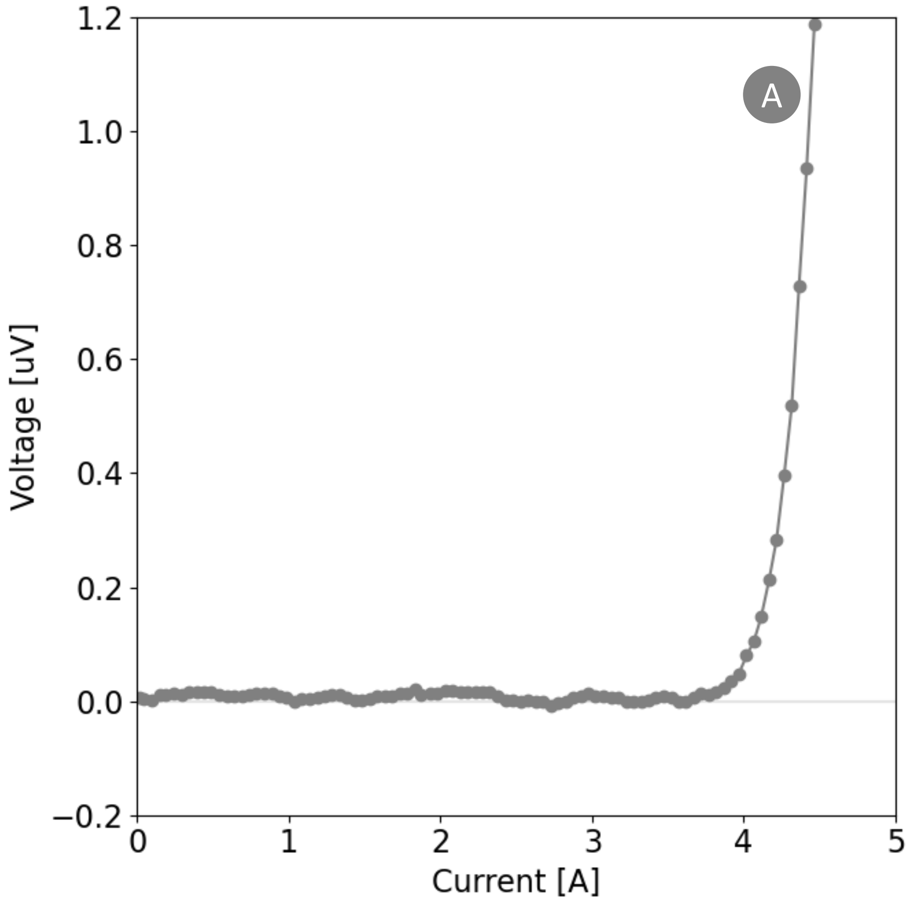


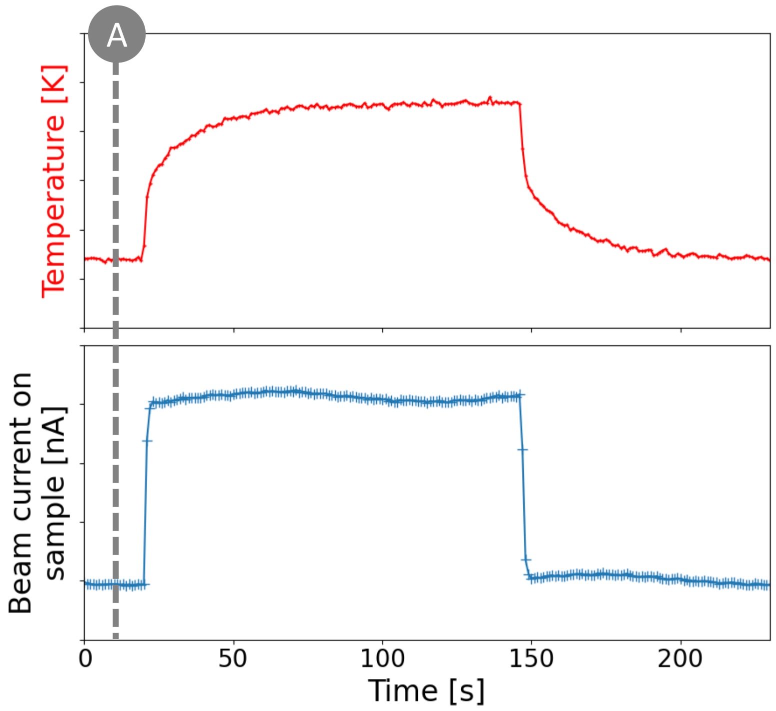
D Measured at the temperature which matches the beam-OFF and beam-ON curves

T_{irr} = 25 K → T_{eq} = 62 K → ΔT = 37 K

Case 3: 300 keV protons **only heat** the REBCO

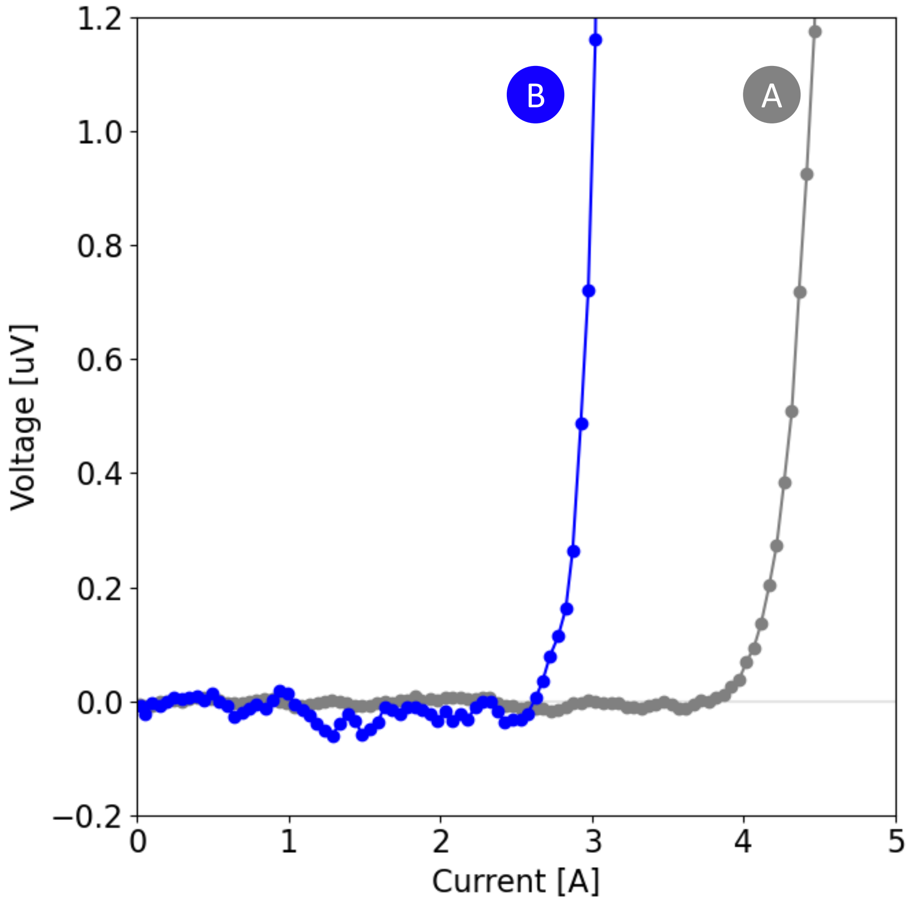
Curve A is the reference before irradiation

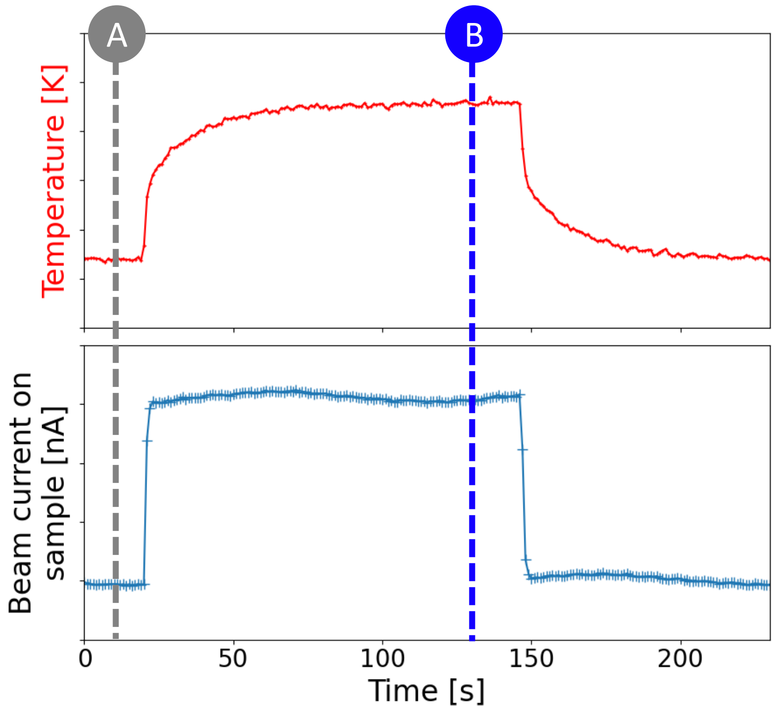




Case 2: 300 keV protons **only heat** the REBCO

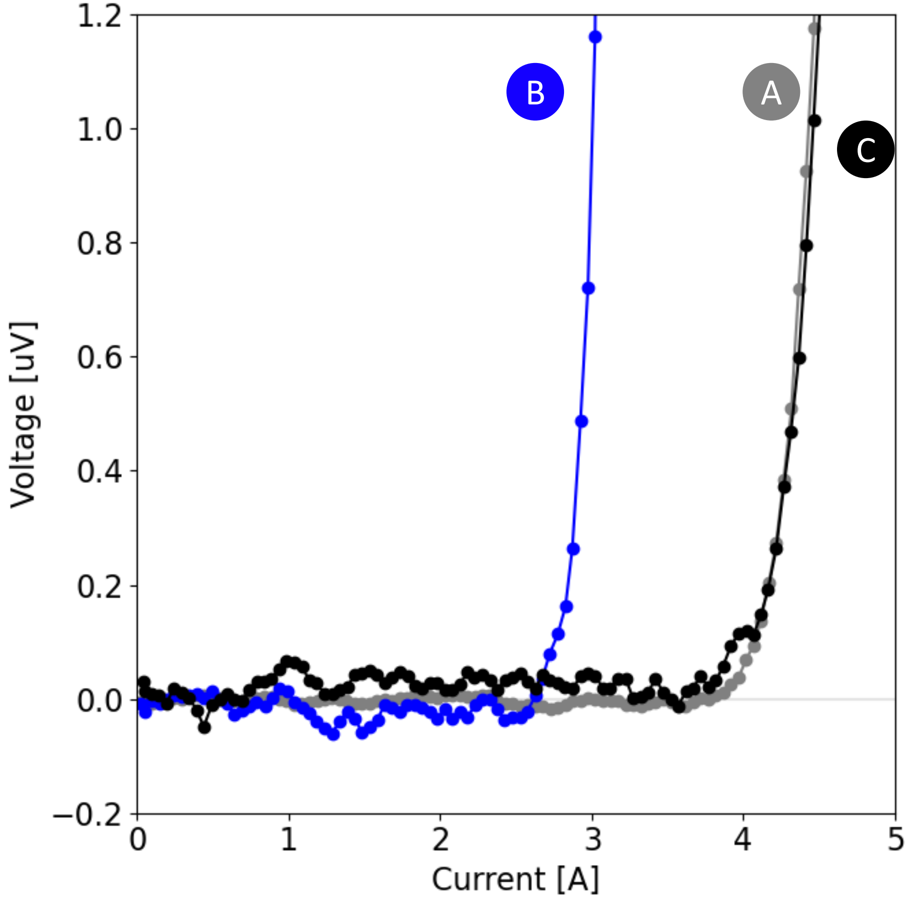
Curve B is measured during irradiation (stable temperature)

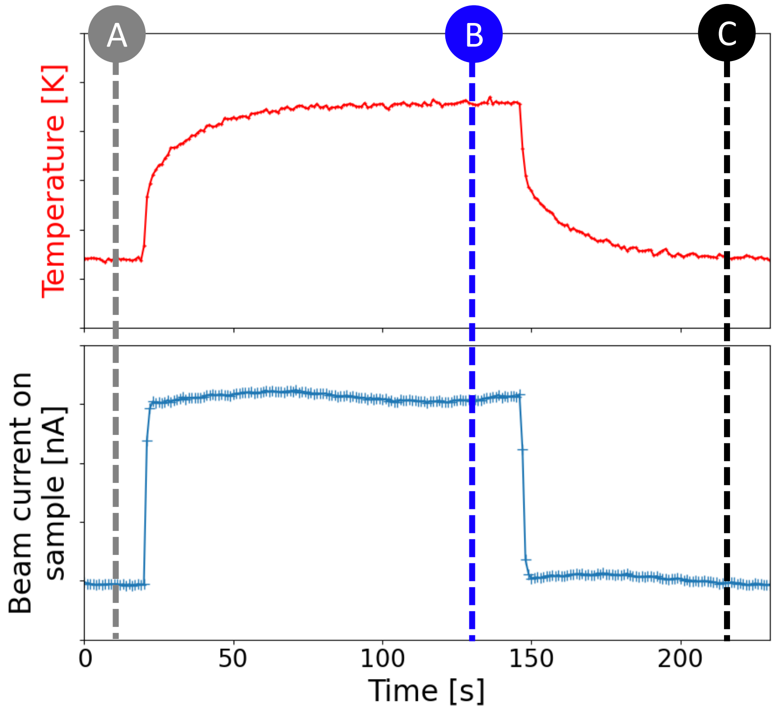




Case 2: 300 keV protons **only heat** the REBCO

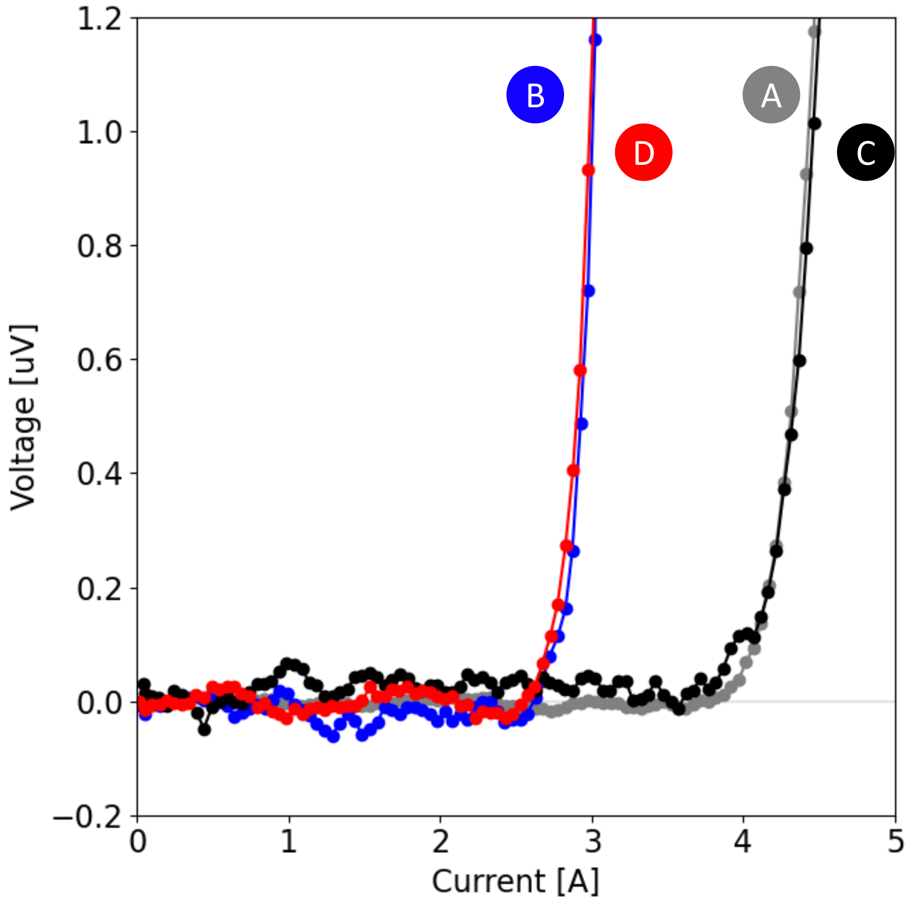
Curve C is measured after irradiation

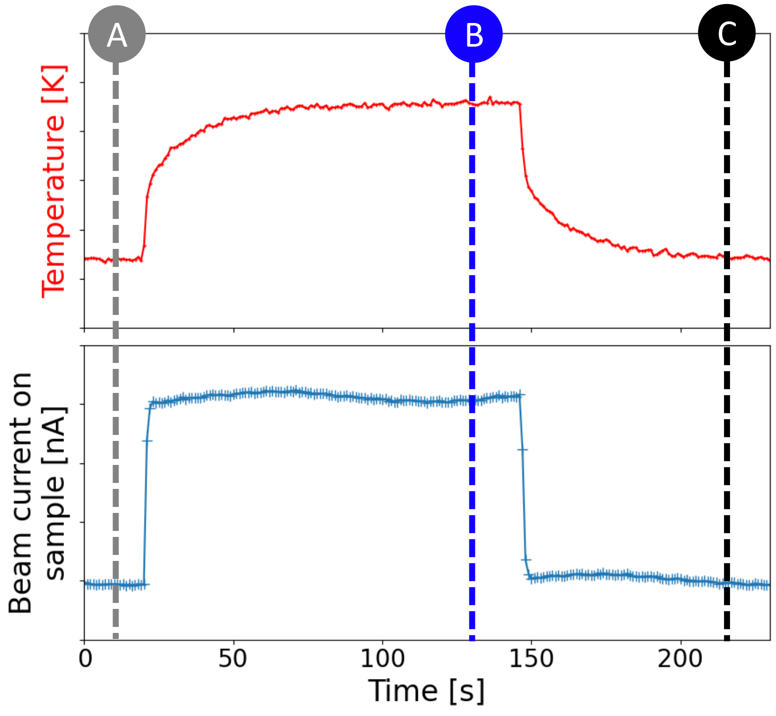




Case 2: 300 keV protons **only heat** the REBCO

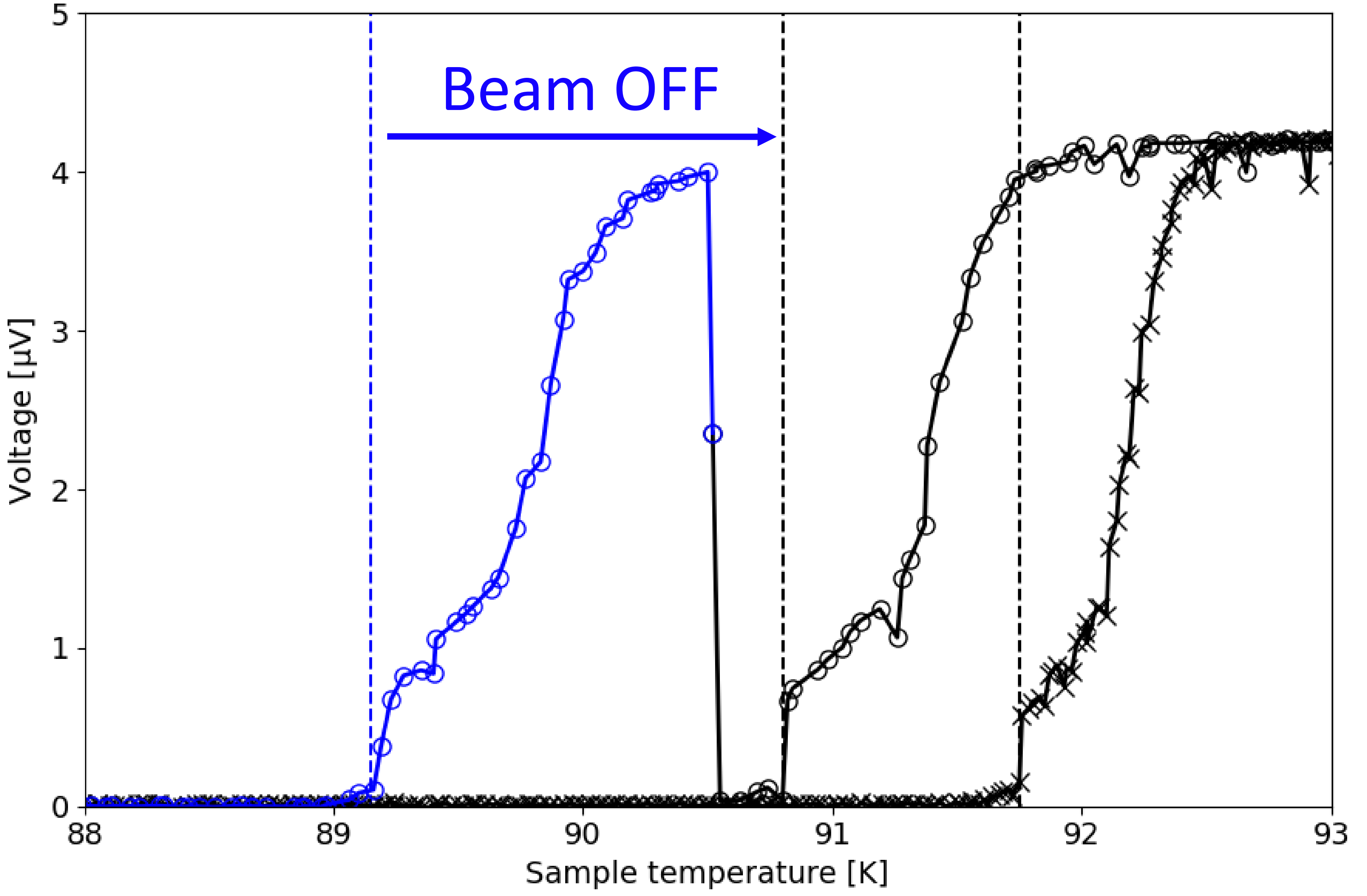
Curve D is measured at the matching temperature (35 K!)





D Measured at the temperature which matches the beam-OFF and beam-ON curves

T_{irr} = 25 K → T_{eq} = 35 K → ΔT = 10 K


Beam OFF
Voltage [µV]
Sample temperature [K]
0
1
2
3
4
5
88
89
90
91
92
93