Carbon Nanotubes as Cold Electron Source

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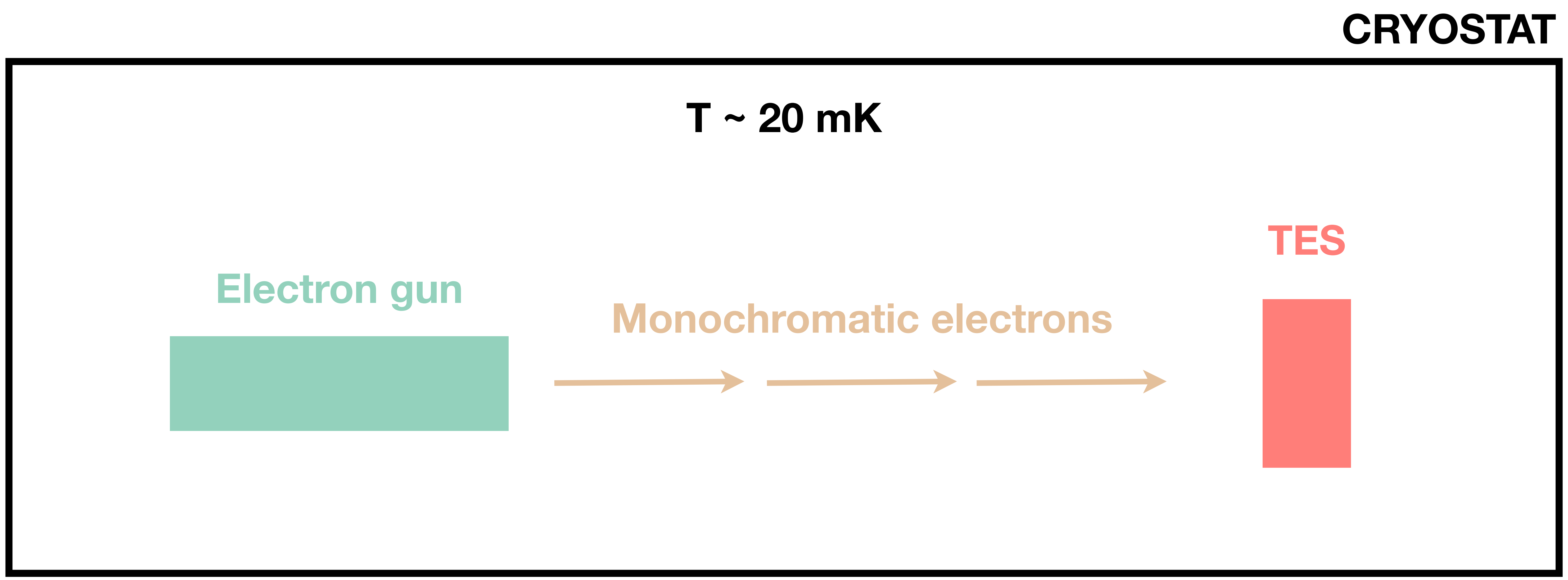
TES Could Use (Very) Cold Source for Calibration

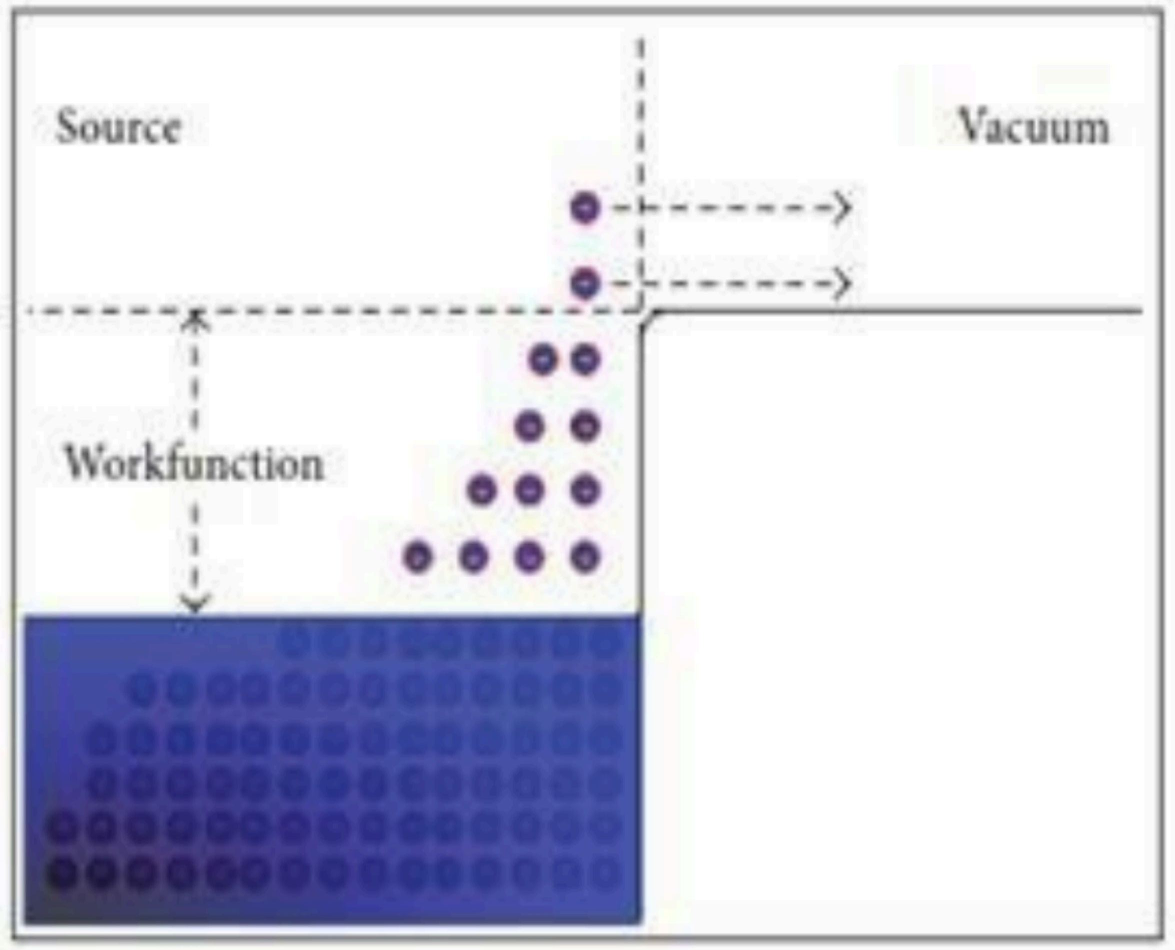


- Monochromatic electron source: **crucial step** for calibrating TES detectors
    - But needs to work in **cryogenic** environment (without spoiling it)
    - Most electron gun technologies based on **heating**

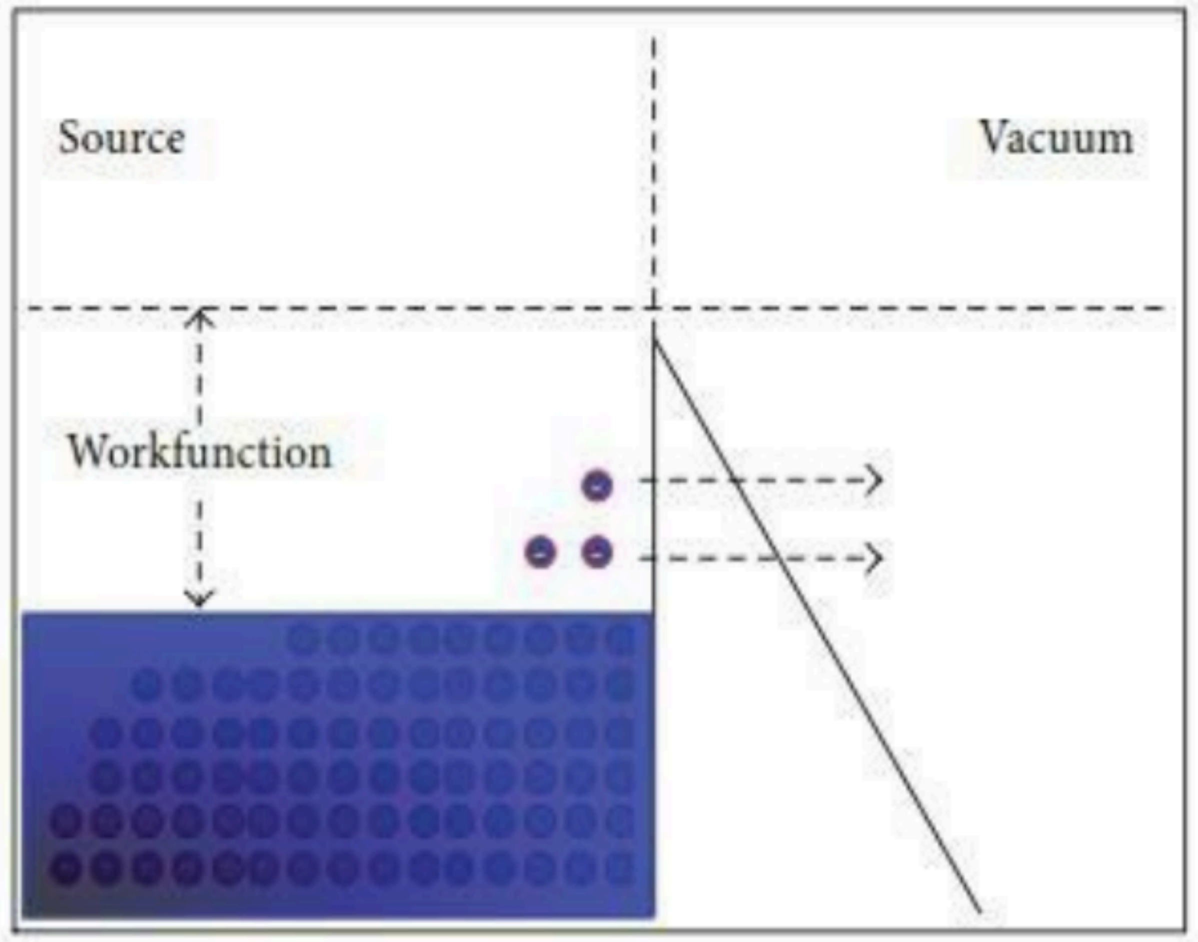
Field Emission Through Quantum Tunneling

- Field emission from flat surfaces only for **very intense** electric fields
  - $E > 10^7$ V/cm
  - Impractical
- In the case of nanotubes:
  - **Tip-effect** E field enhancement
  - Large **surface**: large current
- Quantum effect: **no heating**

Thermoionic Emission



Field Emission



$$J = AE^2 \exp \frac{-B\Phi^{3/2}}{\gamma E}$$

γ = enhancement factor can be ~10^3-10^4

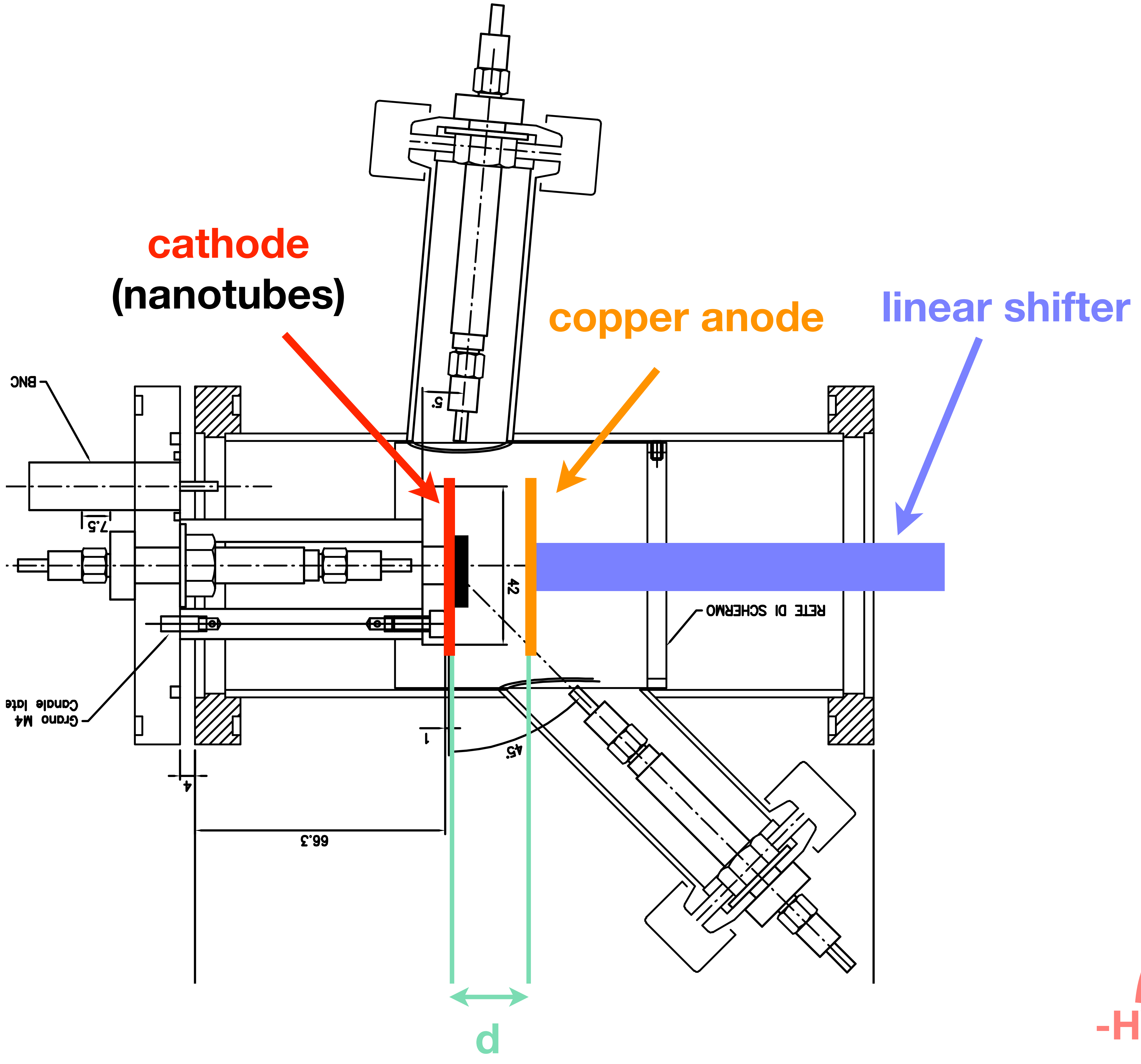
so emission can start with E < 10^3 V/mm

TES Requirements: A Back-of-the-Envelope Calculation

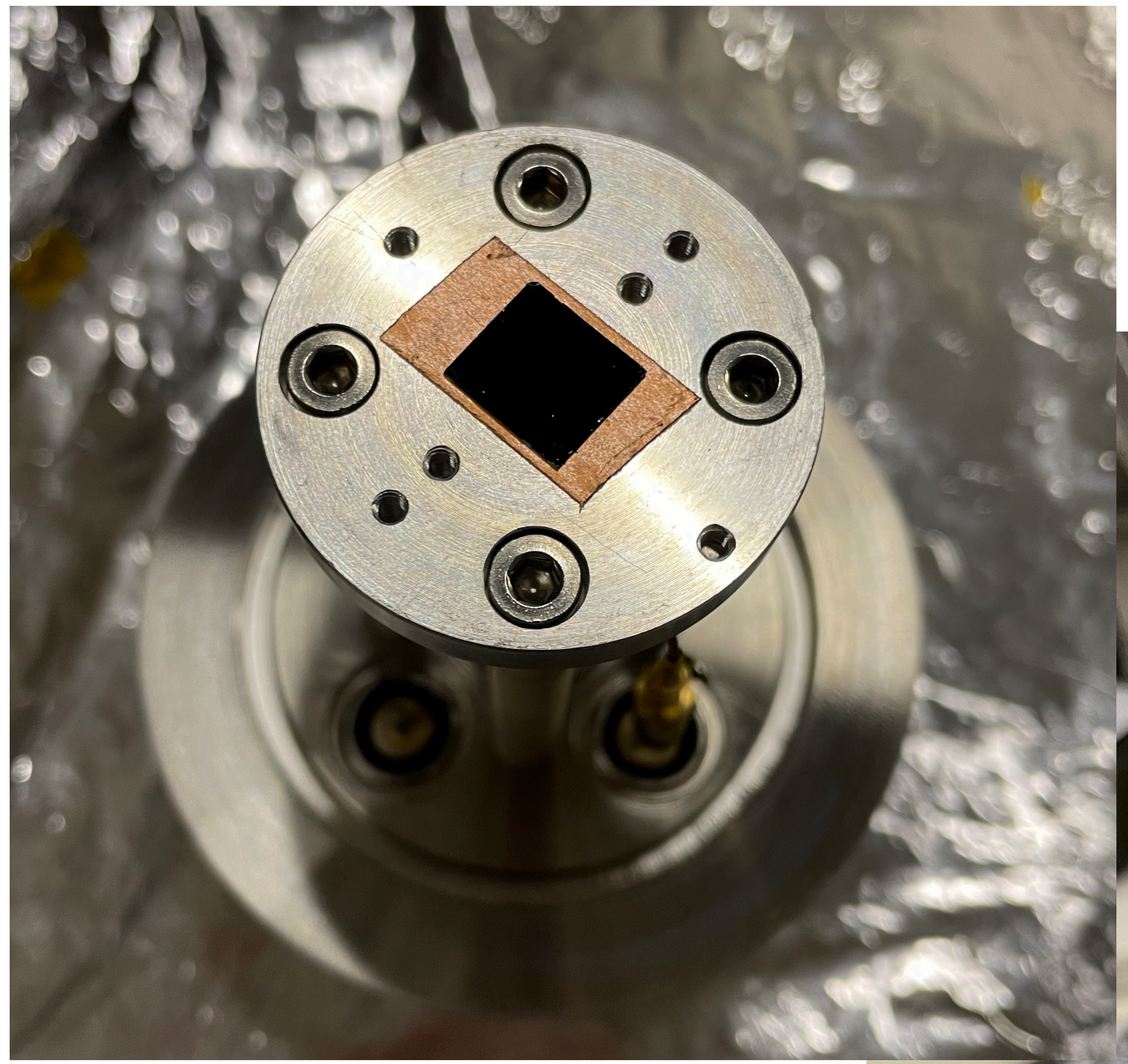
- For PTOLEMY need electrons with E = 100 eV
  - So need to work at ΔV = 100 V
- Maximum **rate** for TES ~ 10 kHz
  - Corresponds to a **current** I_{max} ~ 2 fA
- TES surface: 50×50 μm², CNT surface ~ 1 cm²
  - So this corresponds to **current density** J_{max} = 2 fA / 50×50 μm² = 80 pA / cm²
  - Considering that electrons are not bunched → **Aim for I ~ 1 pA with ΔV = 100 V**

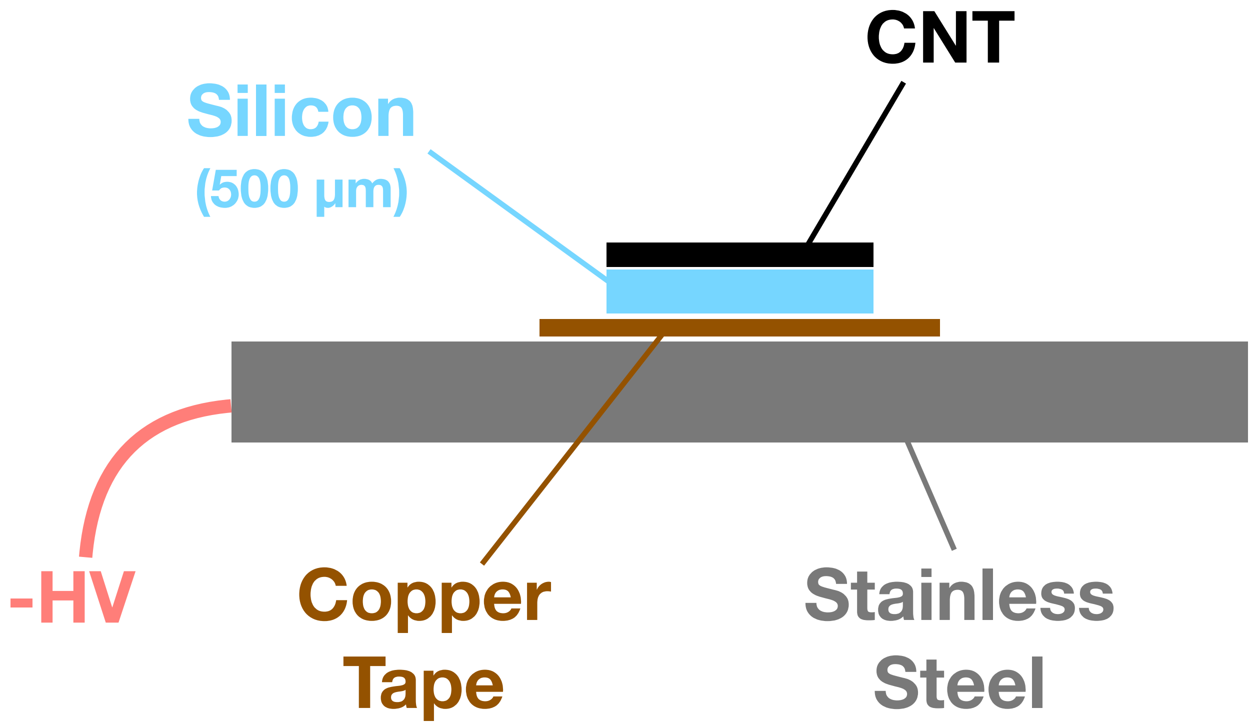
Original idea by Alice

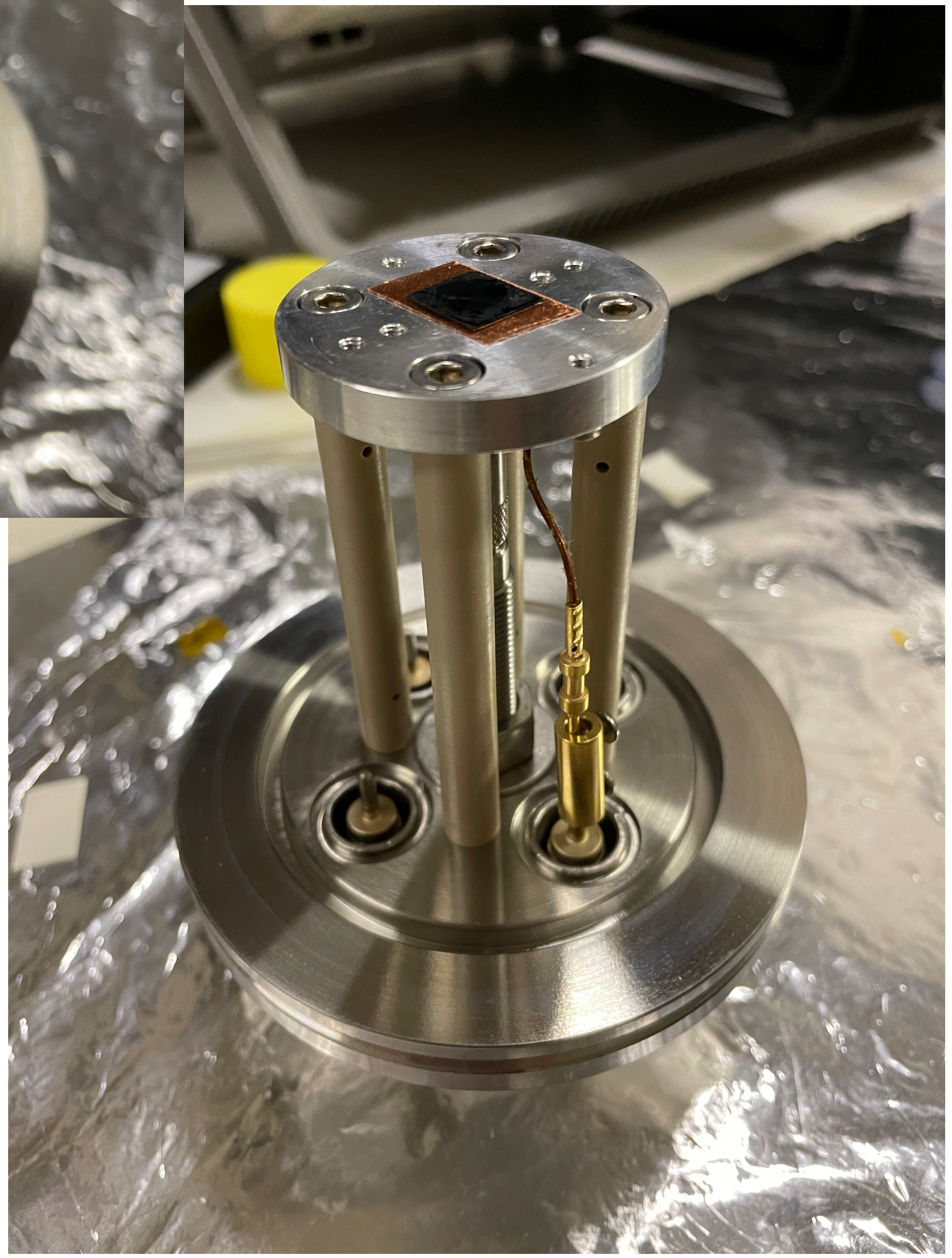
The Setup Inside the ‘Hyperion’ Prototype



Currently limited to d ≥ 2 mm

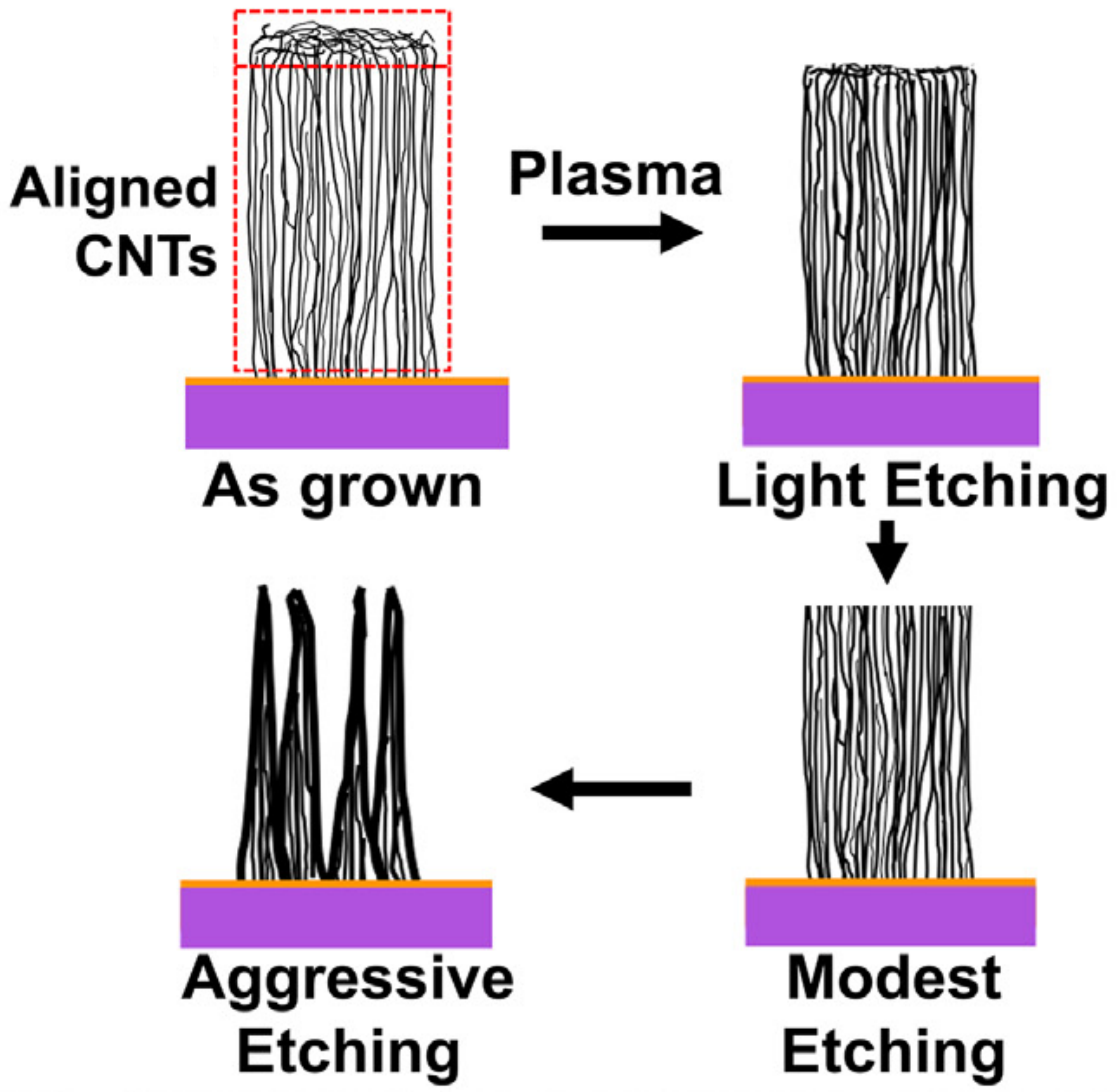




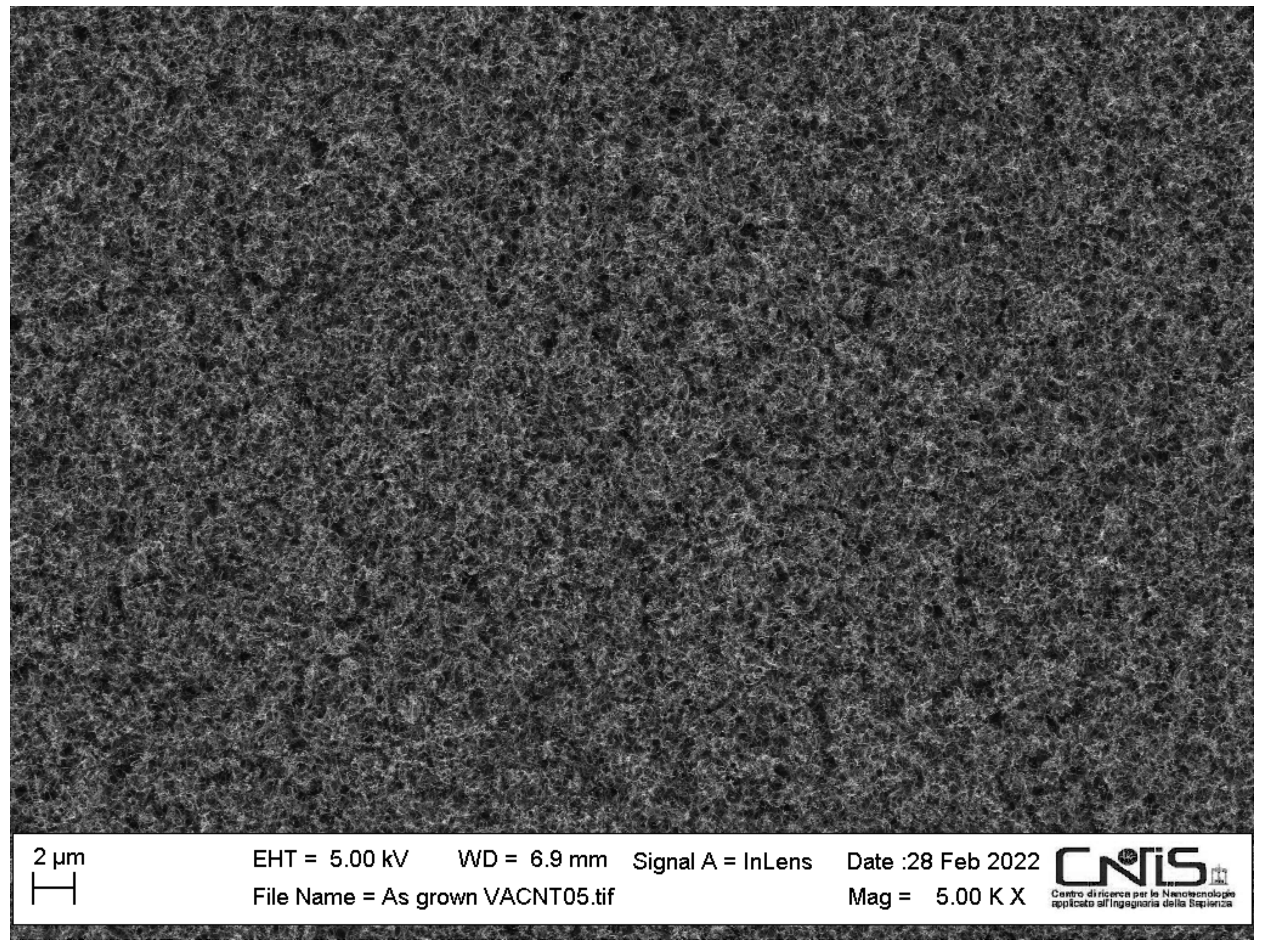


Two Samples: As-Grown and Plasma-Etched

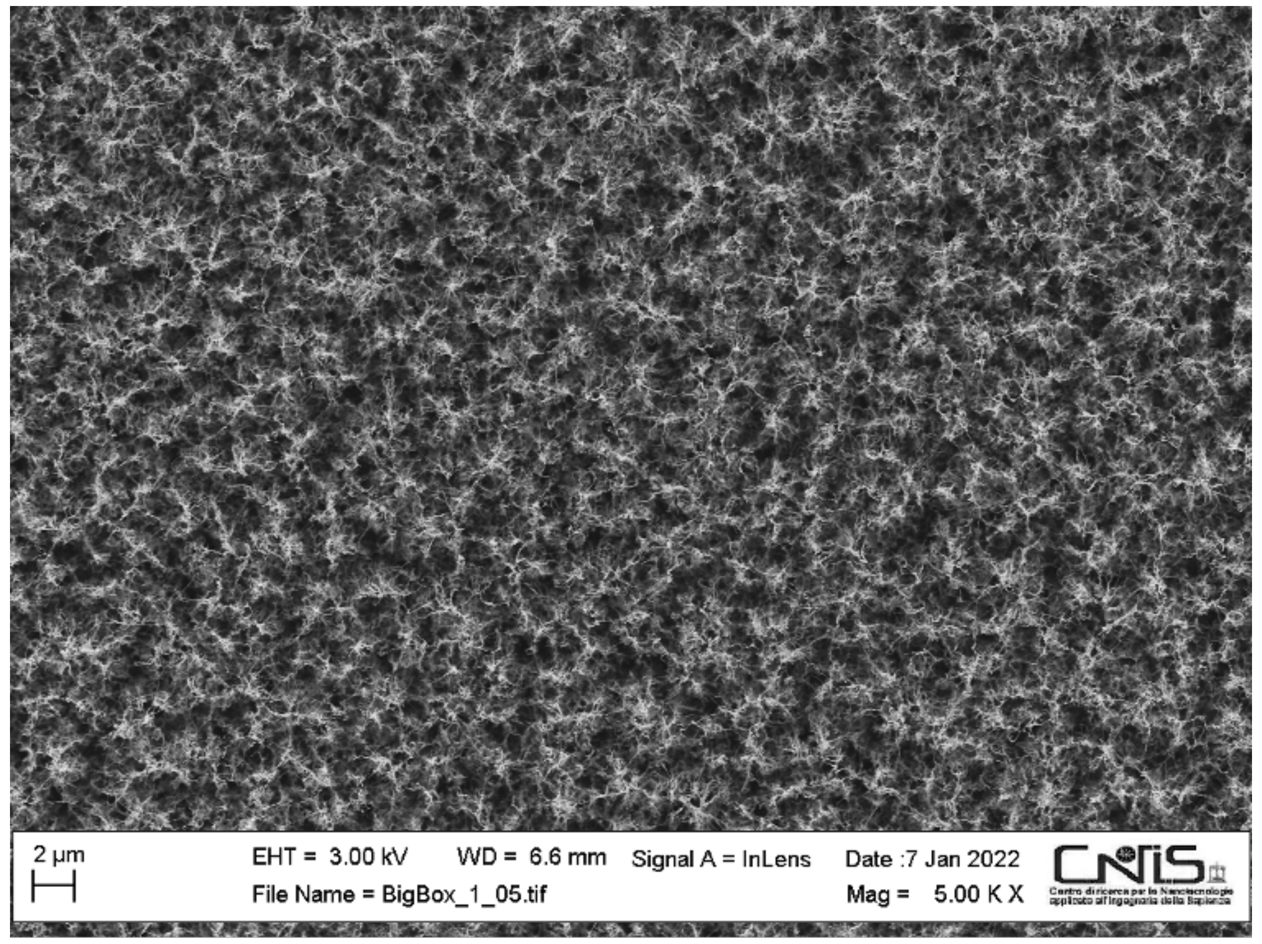
Plasma etching to remove non-aligned top (crust) layer



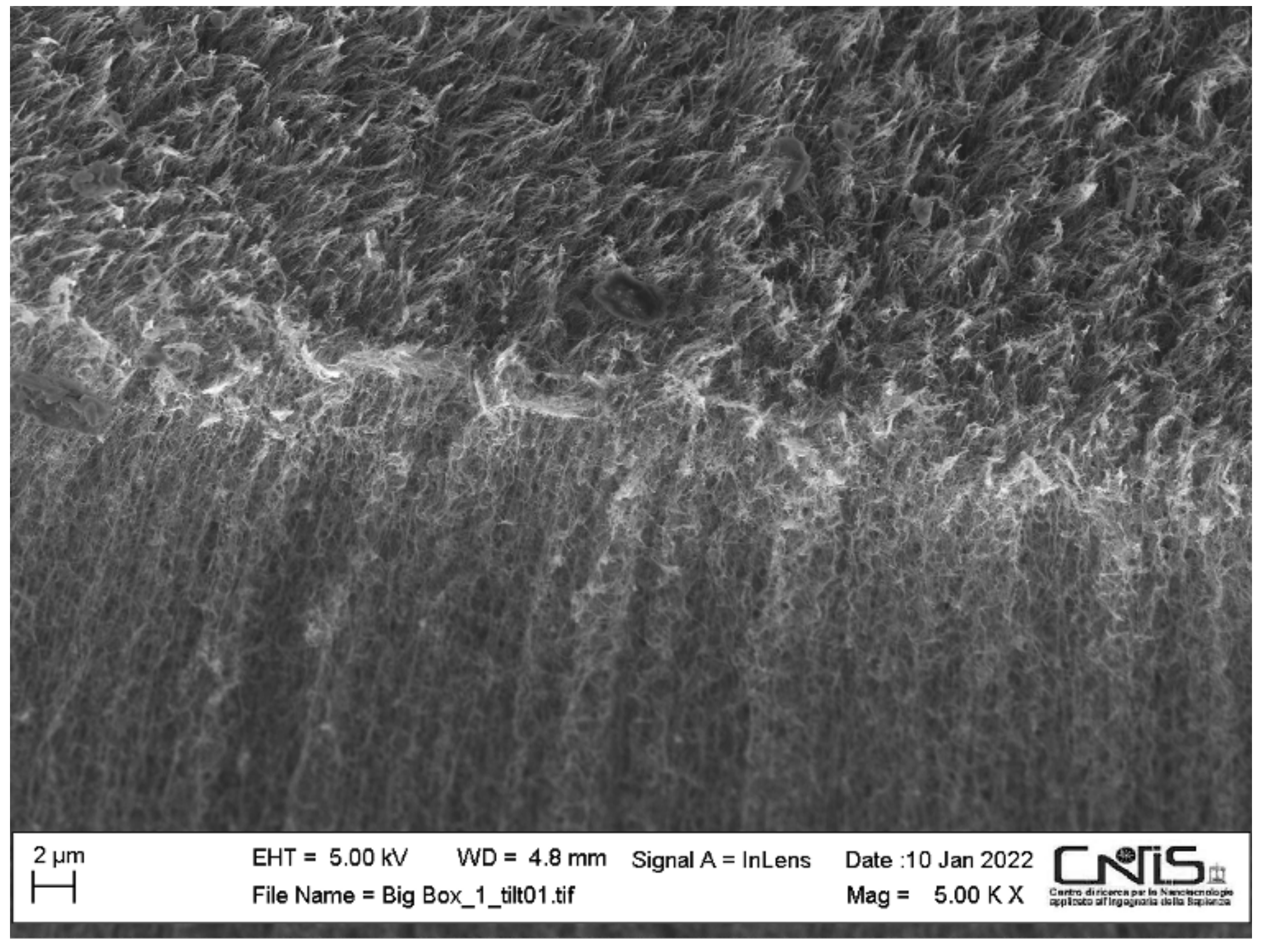
As Grown
(No Etching)



Sample N1
(Mild Etching)



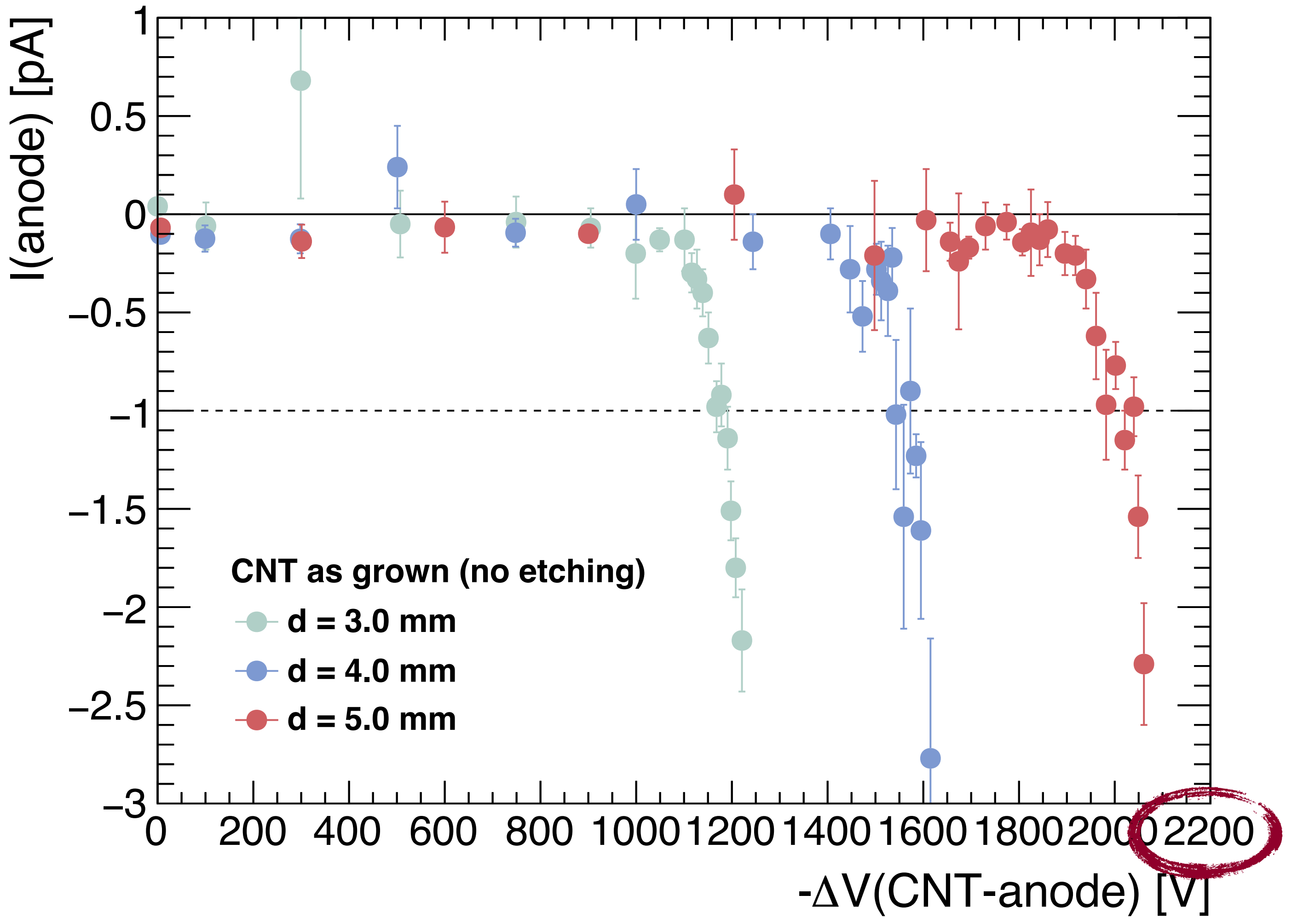
TOP VIEW

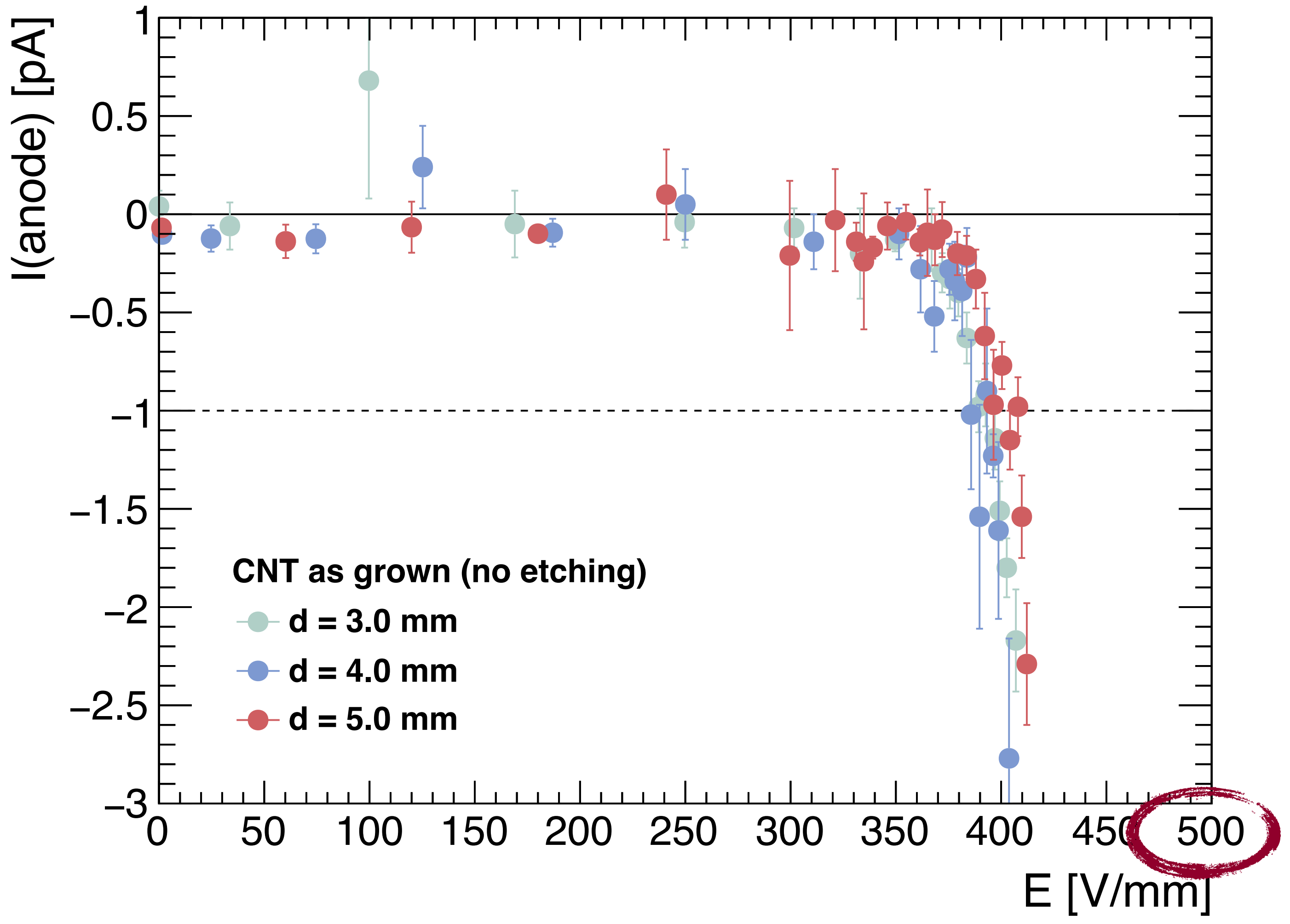


SIDE VIEW

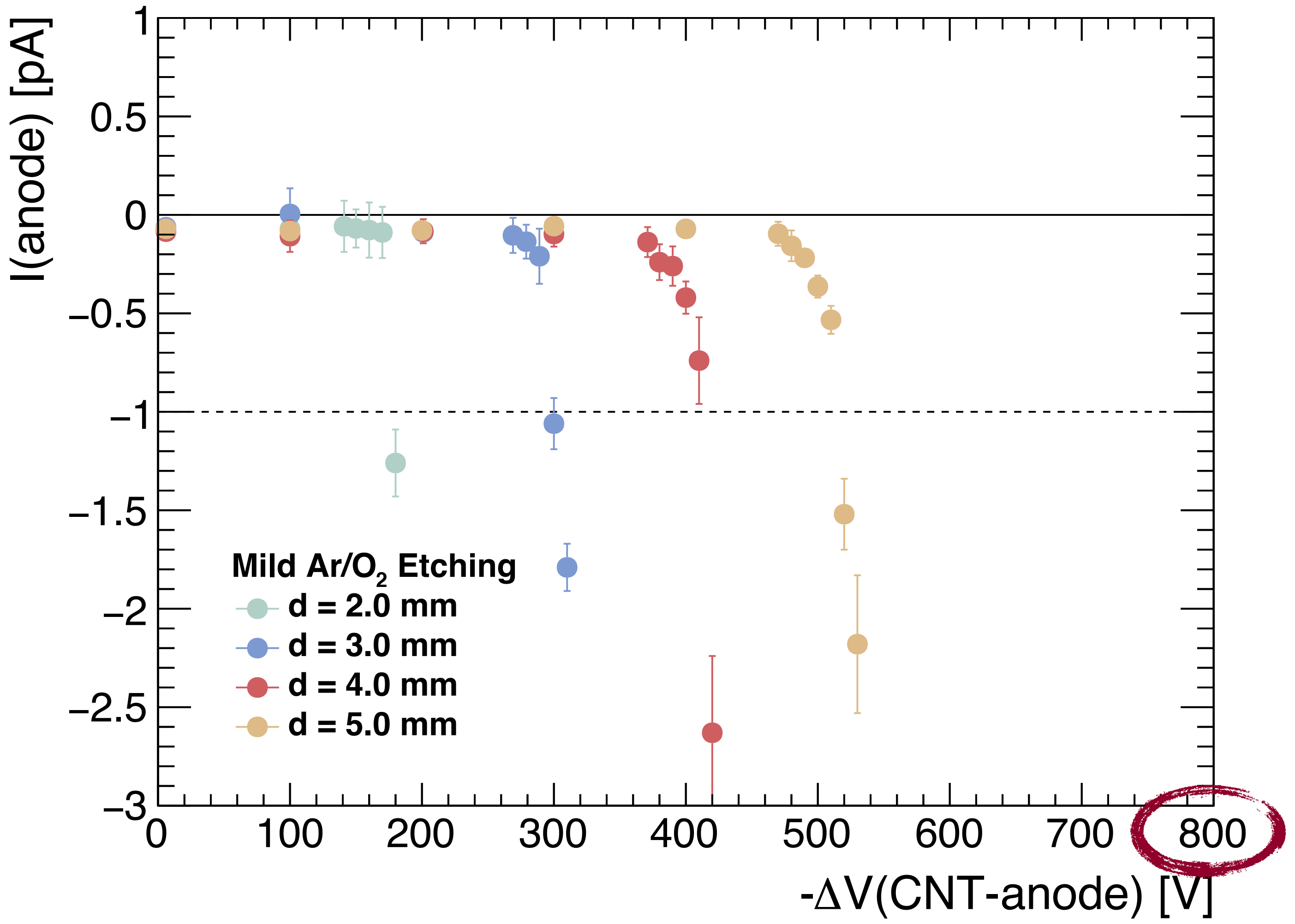
Etched Samples Can Achieve I = 1 pA and ΔV = 100 V

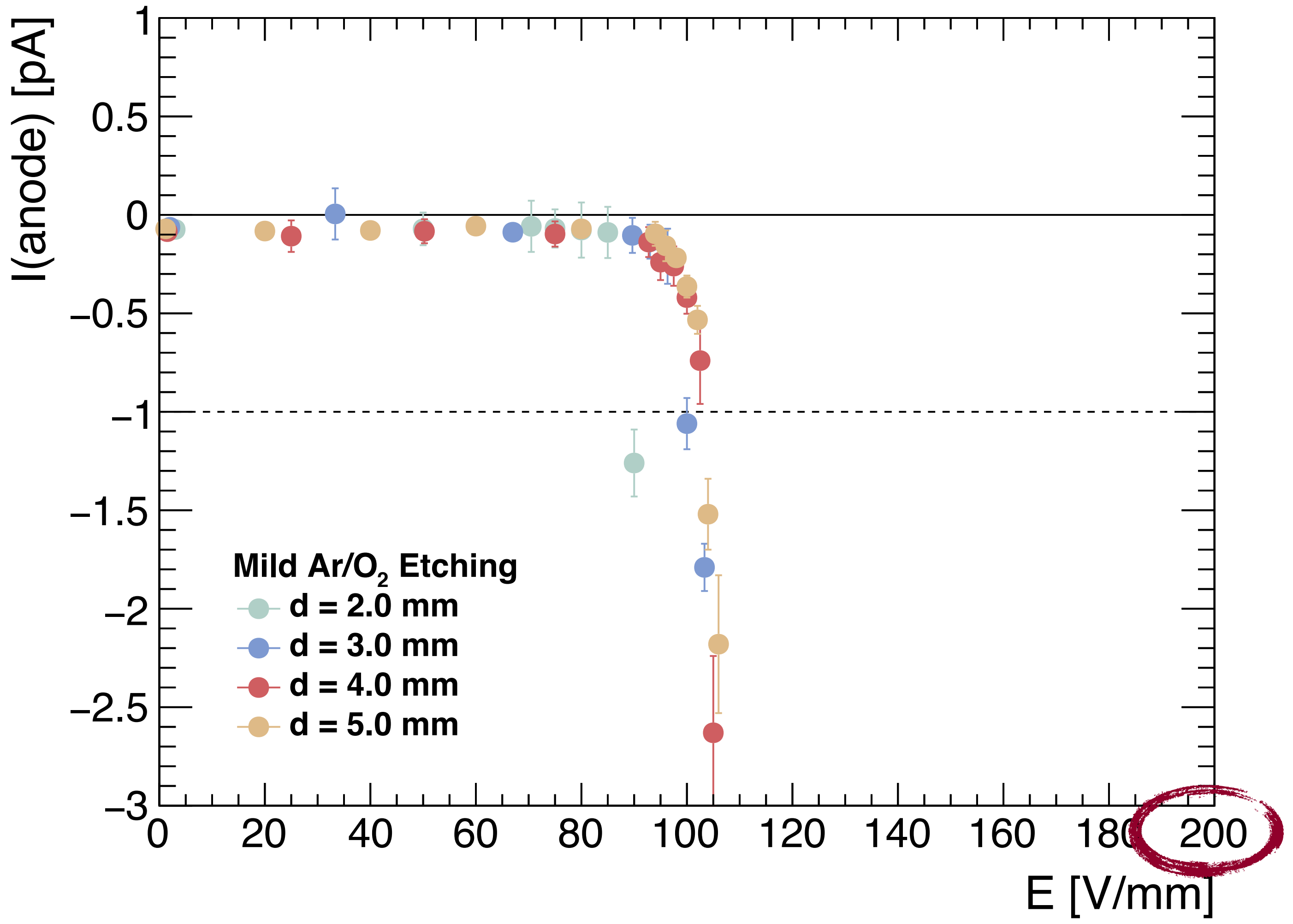
As Grown (no etching)





Mild Ar/O_2 Etching





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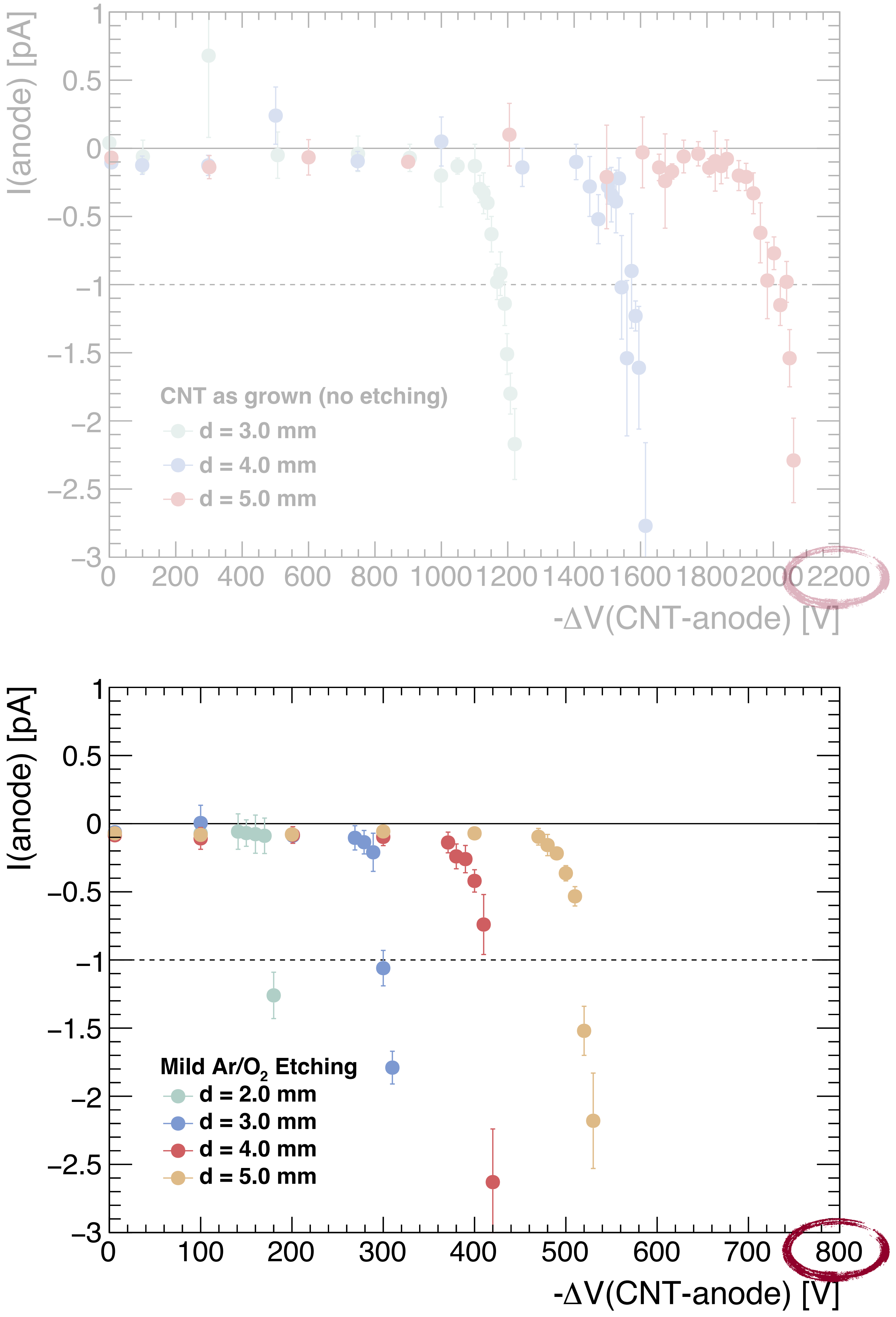
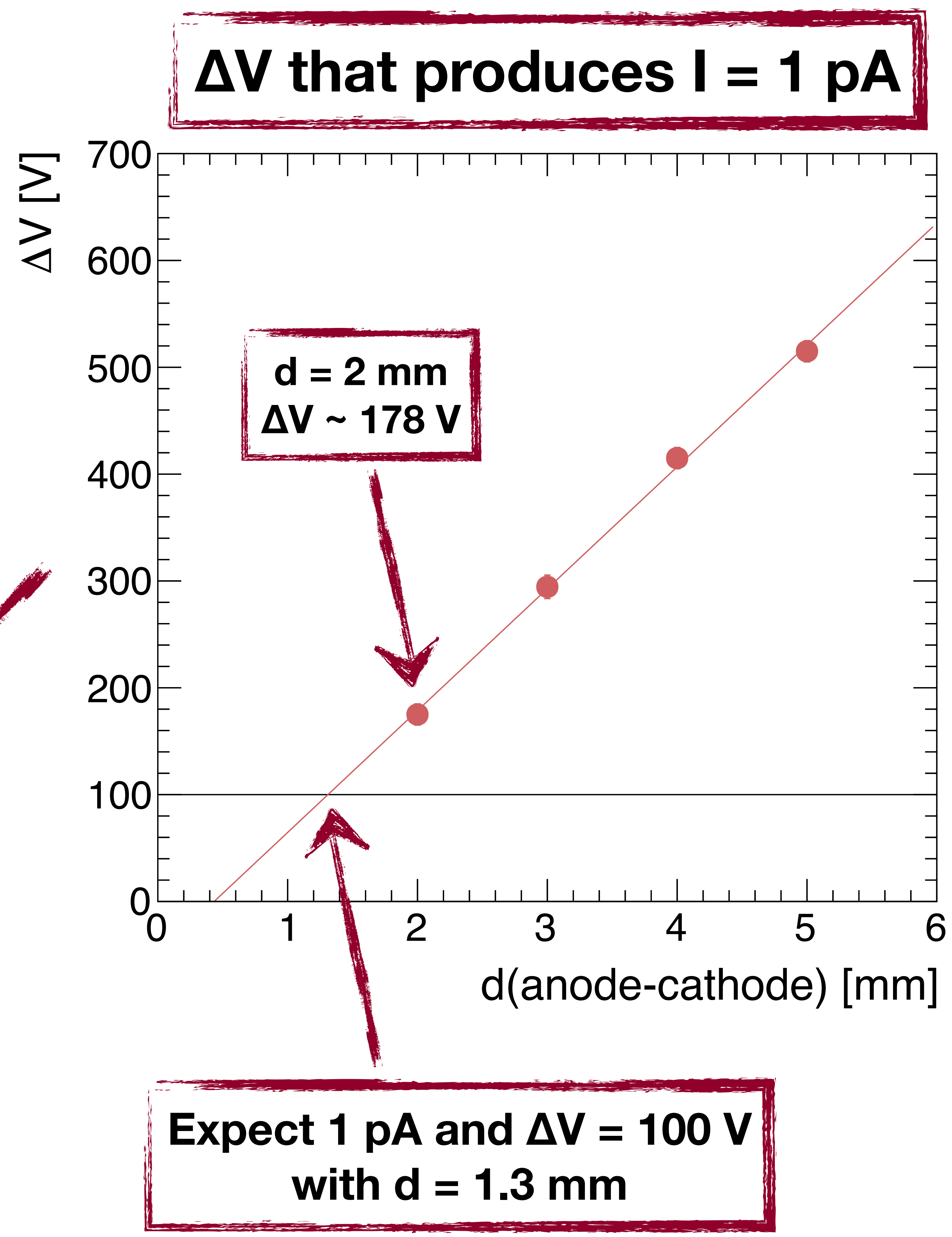
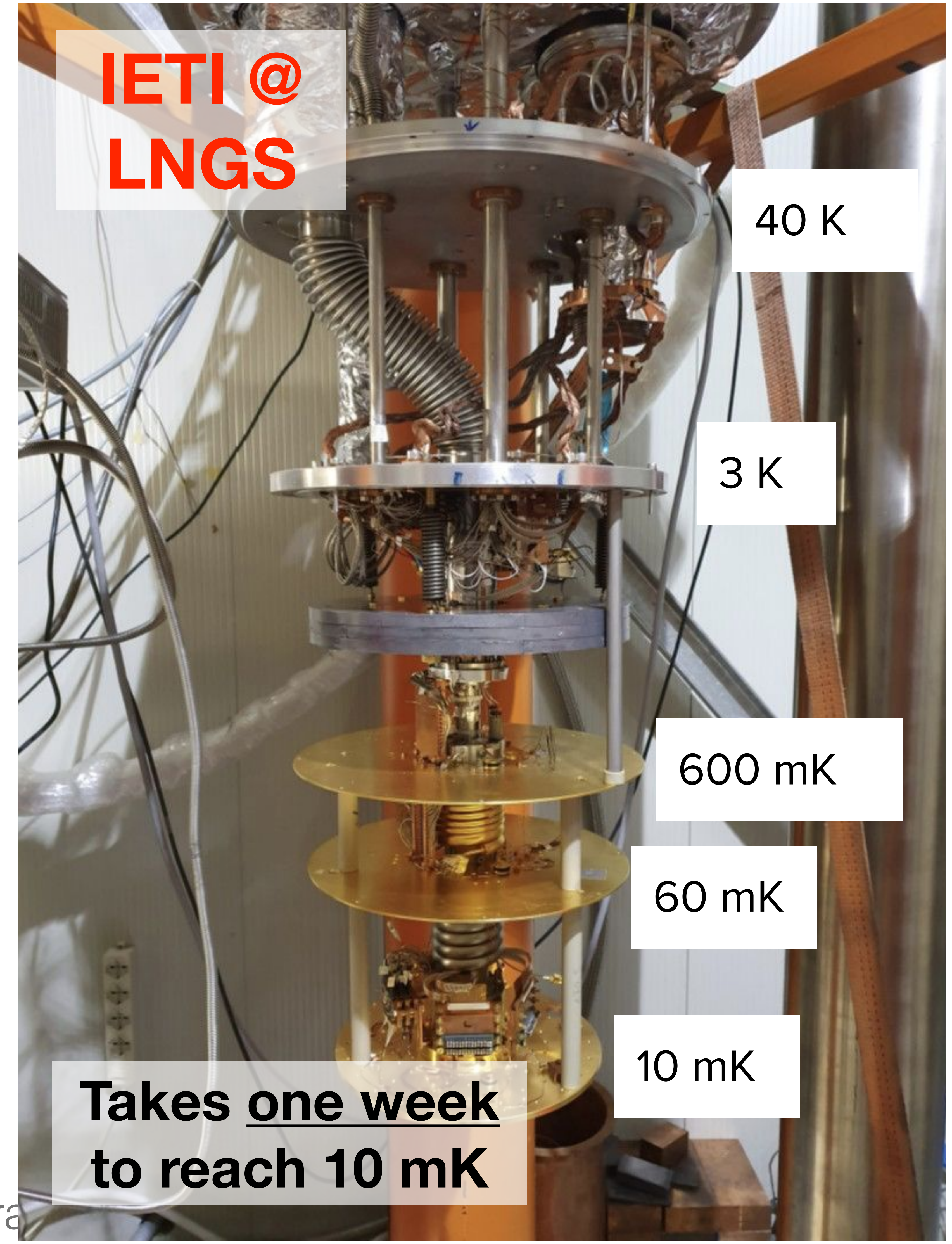
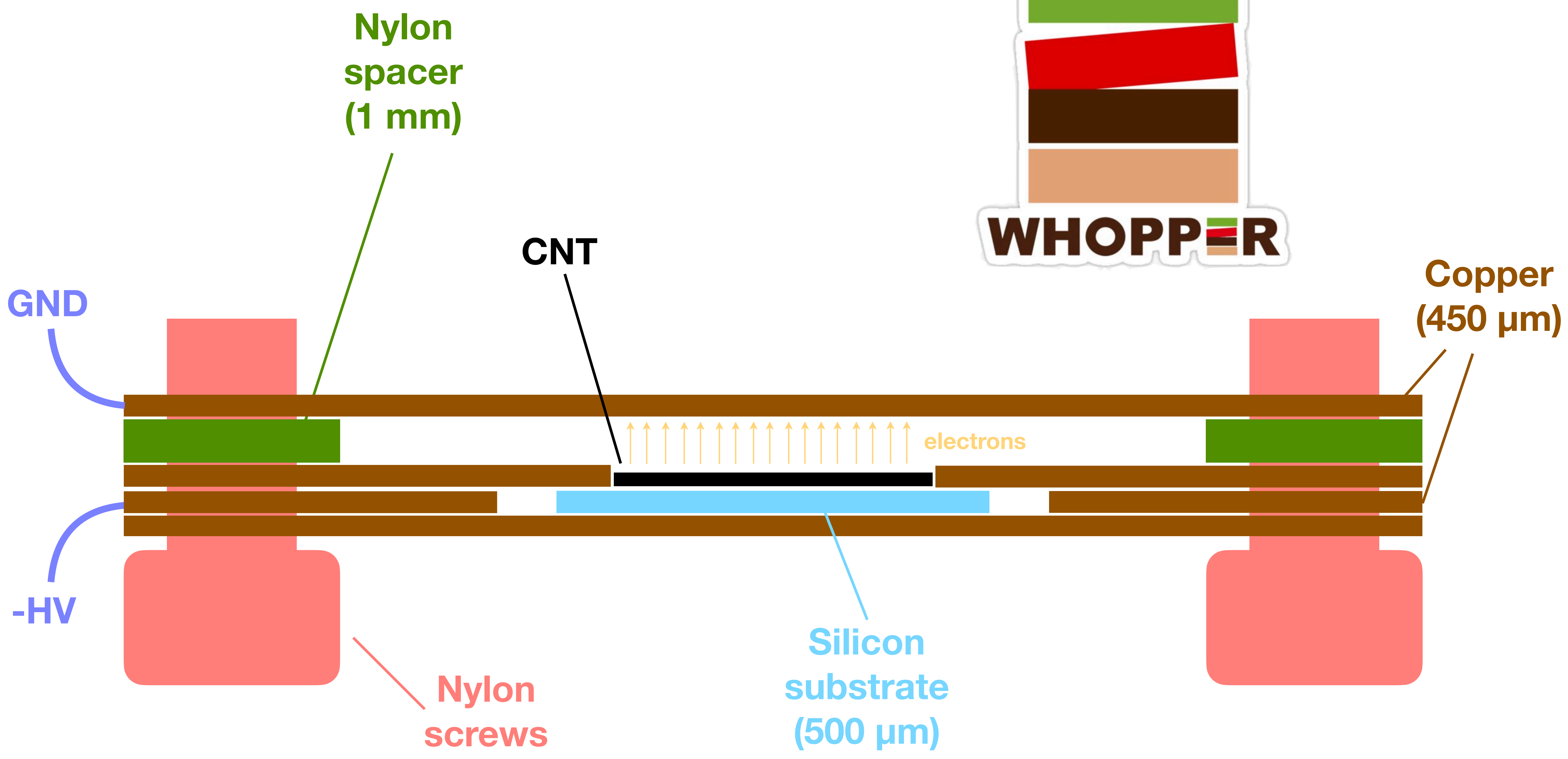




Before Summer: Using Whopper Gun @ IETI Cryostat (LNGS)





WHOPPER

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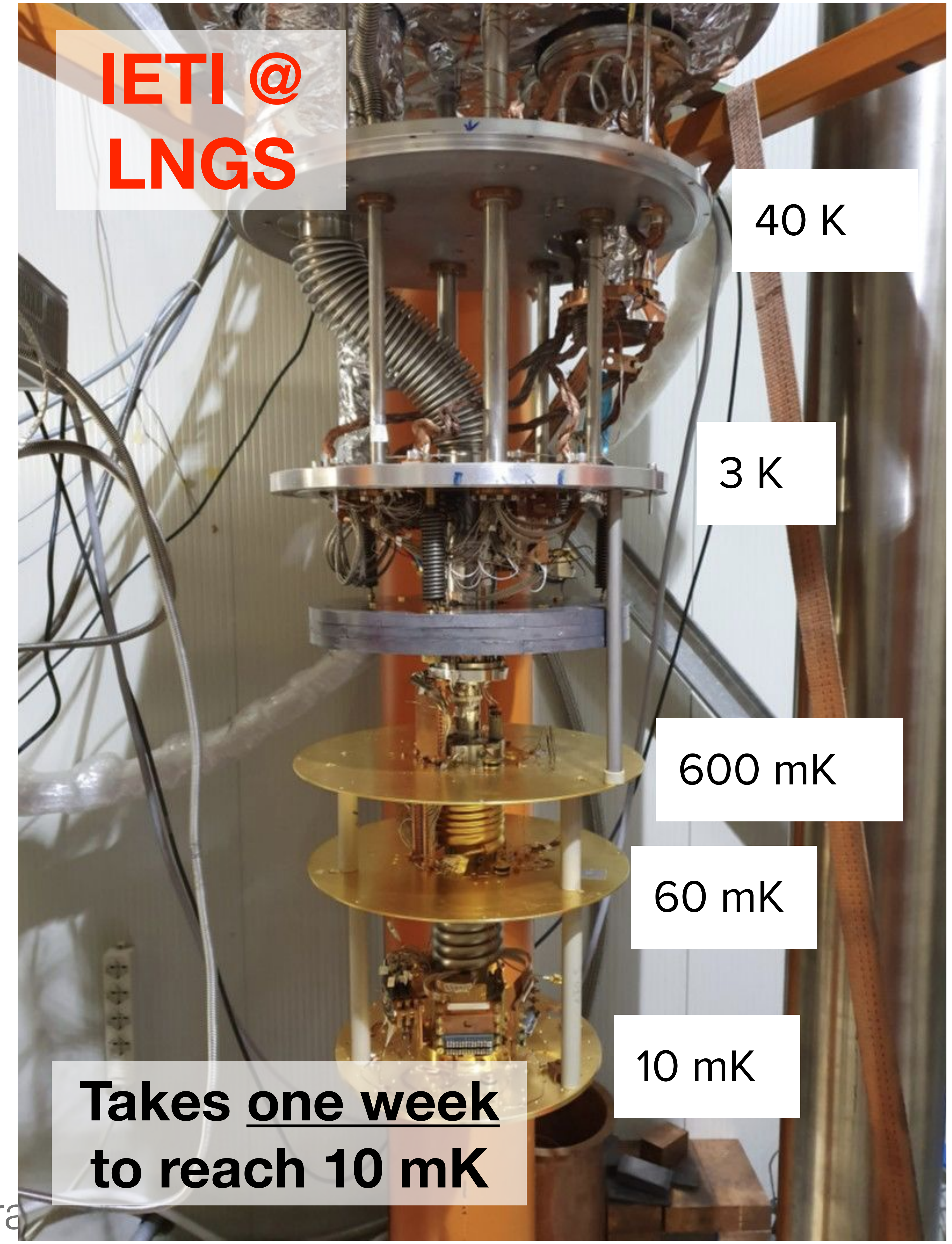
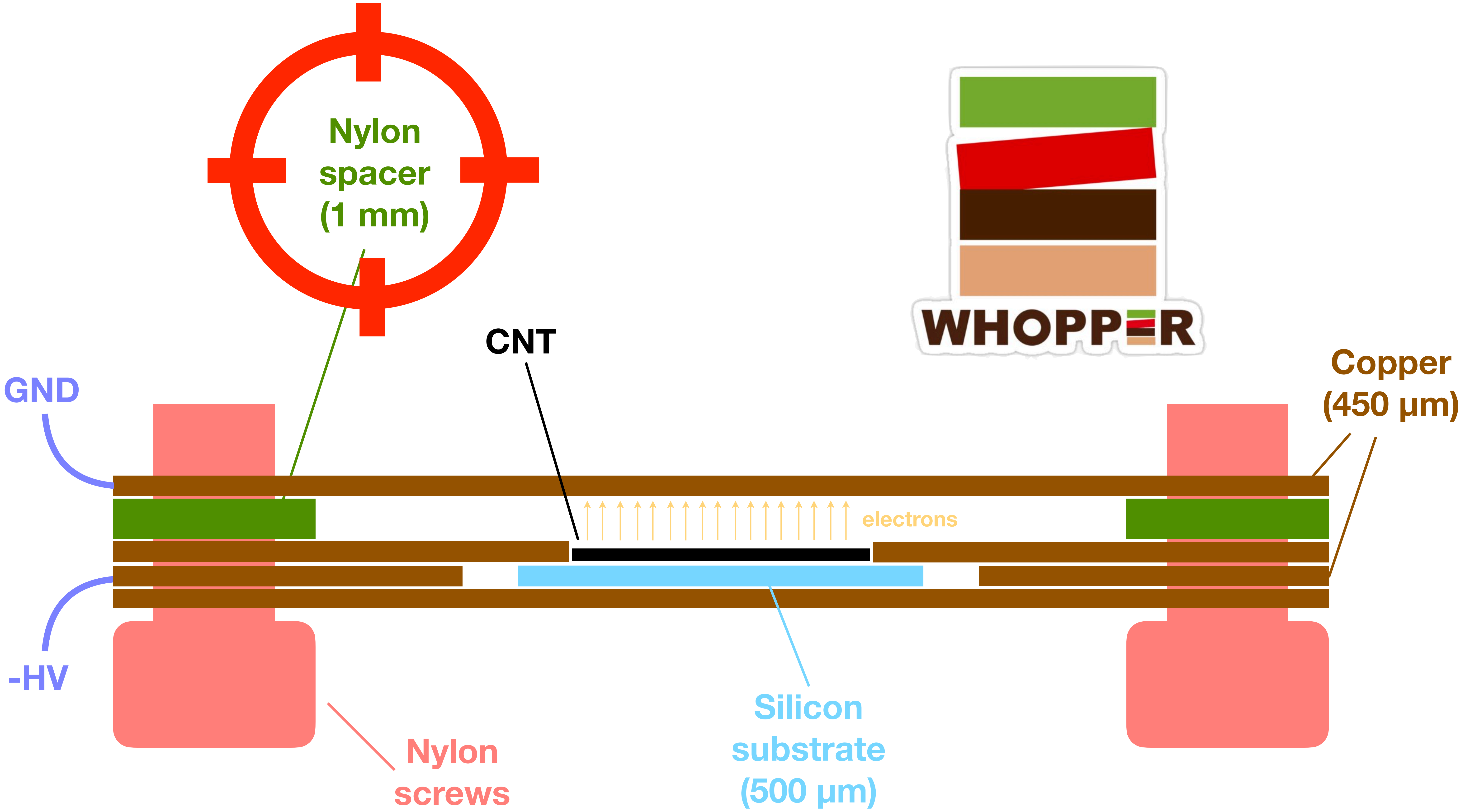
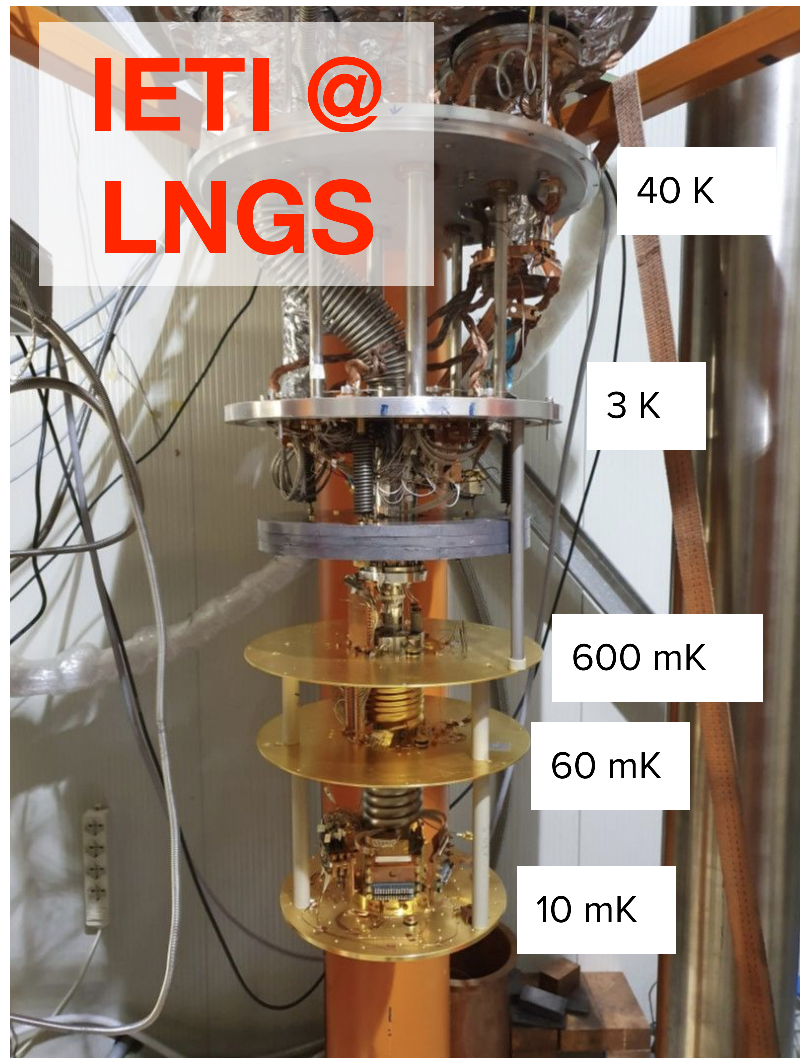




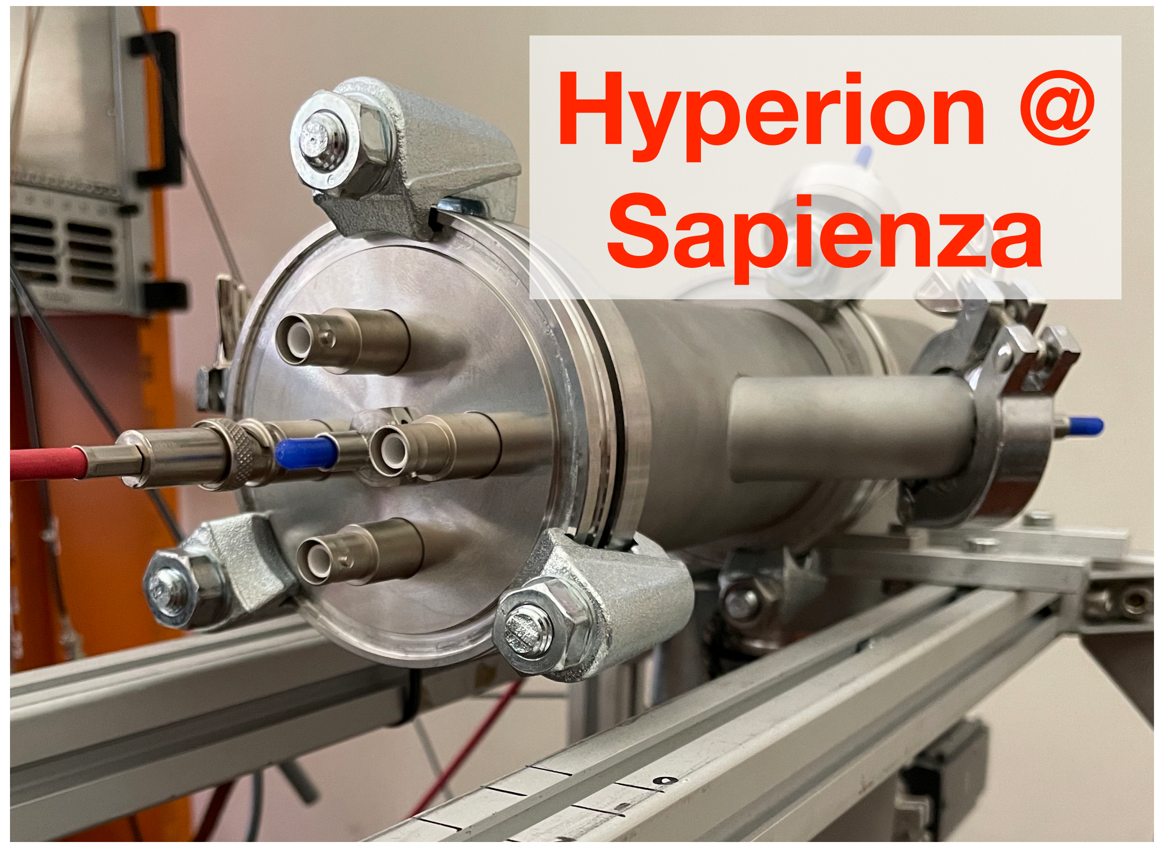
Nylon Spacers Caused Ohmic Leak

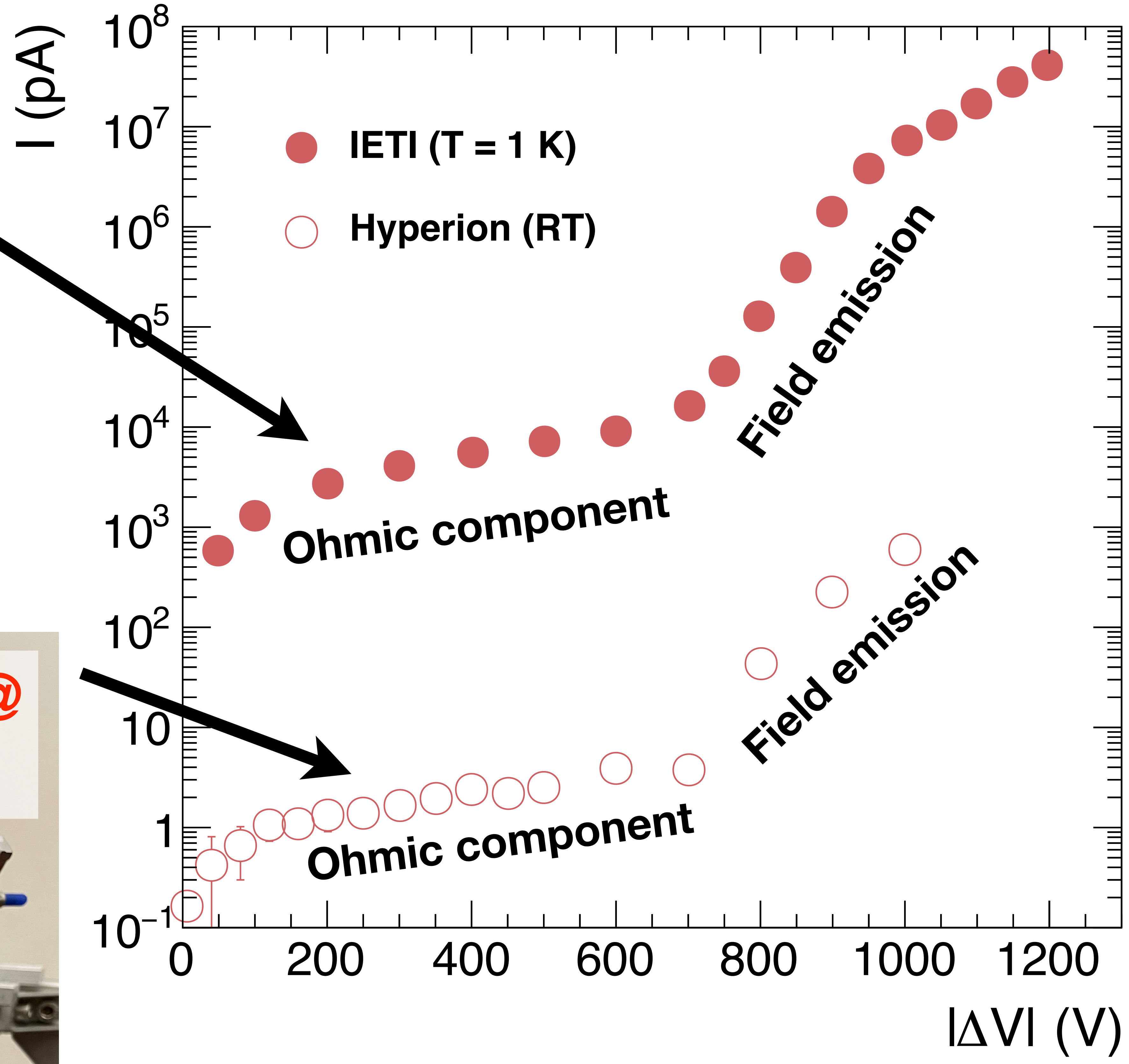
Shown in June

WHOPPER +



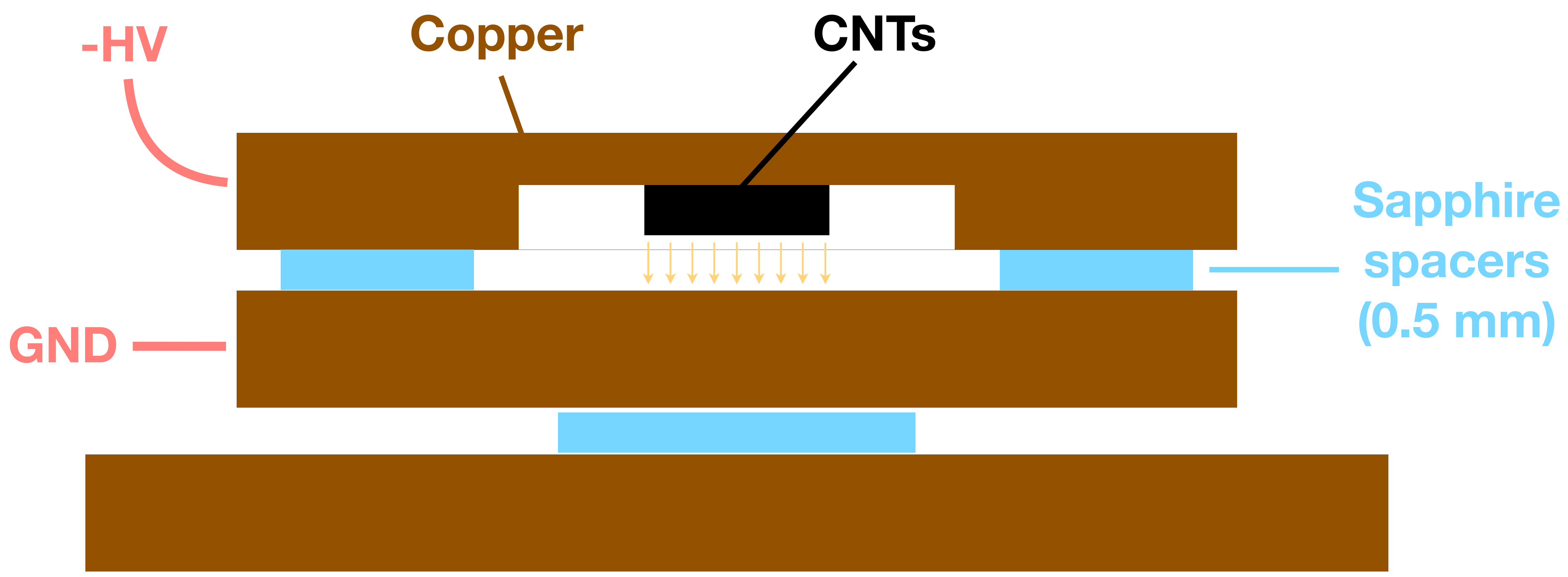
WHOPPER +

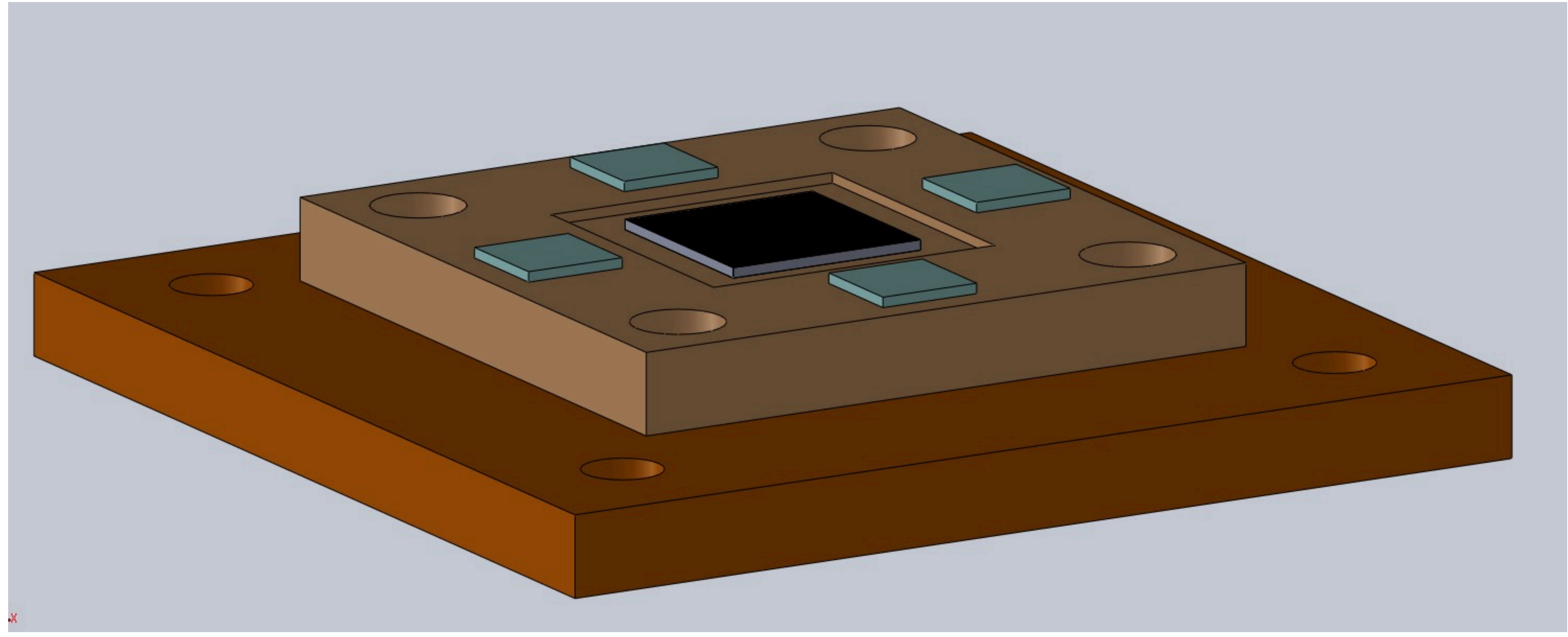




- Large Ohmic component
  - R ~ 10^{14} Ω
  - ×1000 at T ~ 1 K
- **Compatible** with nylon!
  - Need other spacers

New Design: Mozzarella in Carrozza (MiC) Gun

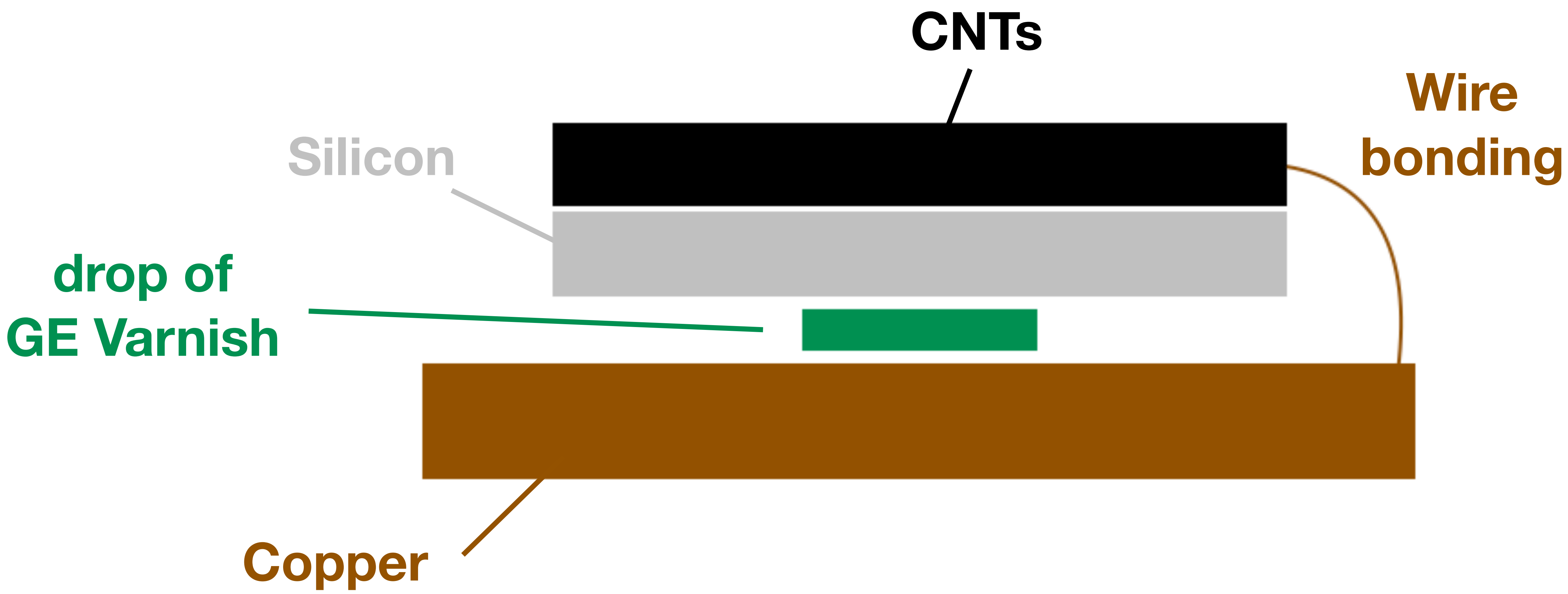


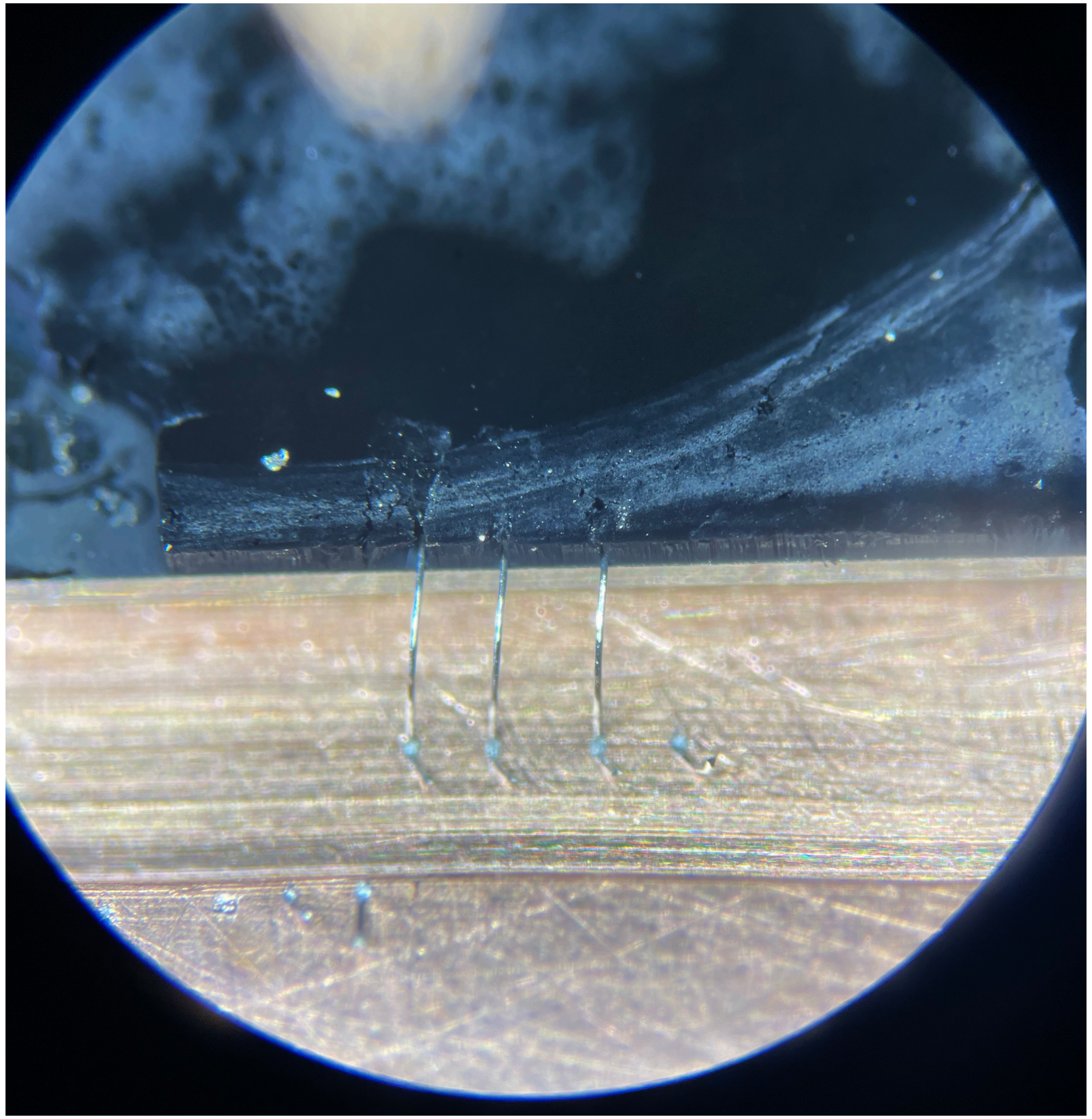


✓ **Sapphire** spacers

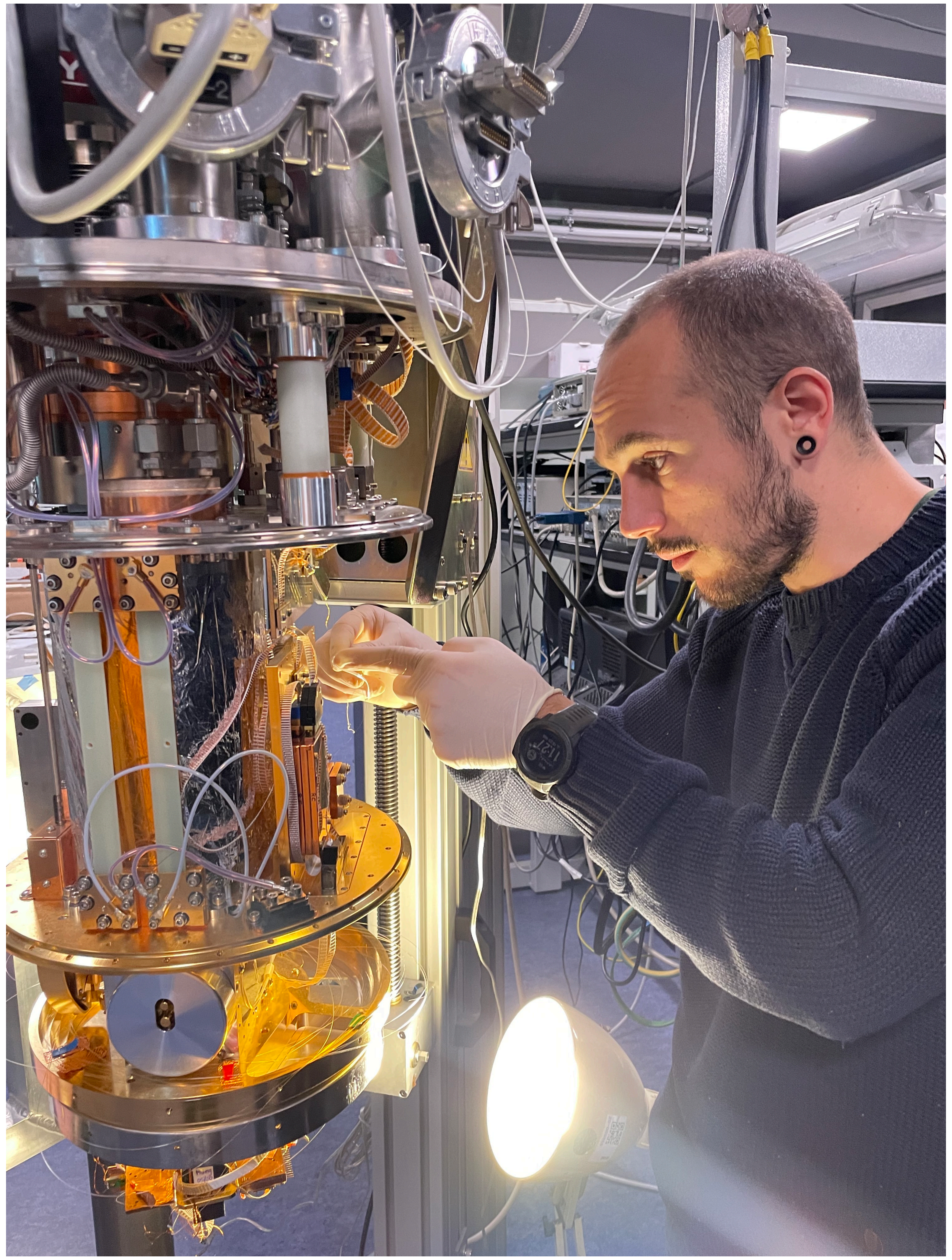
✓ **Improved** mechanical stability

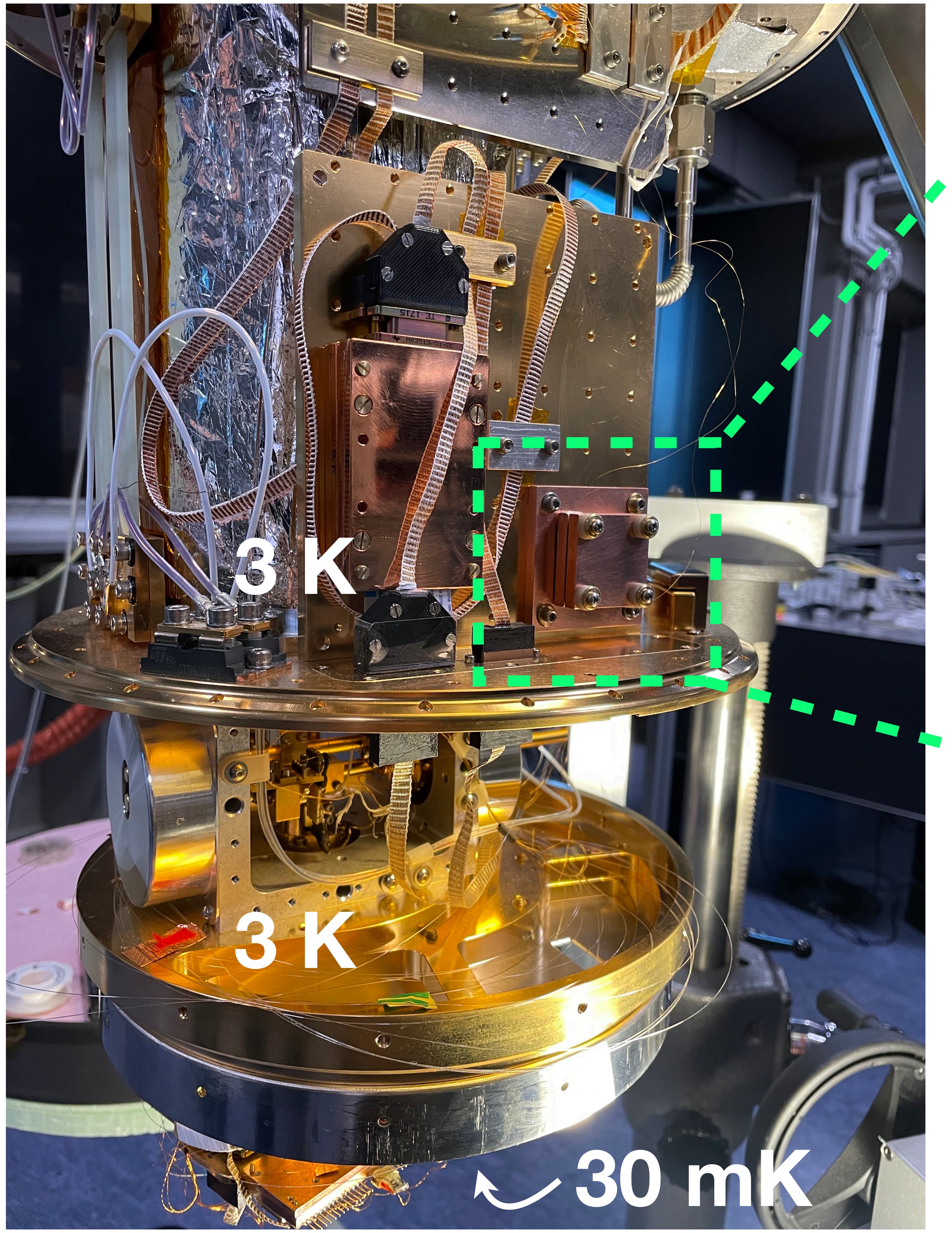
Electrical Contact with Wire Bonding on Nanotubes

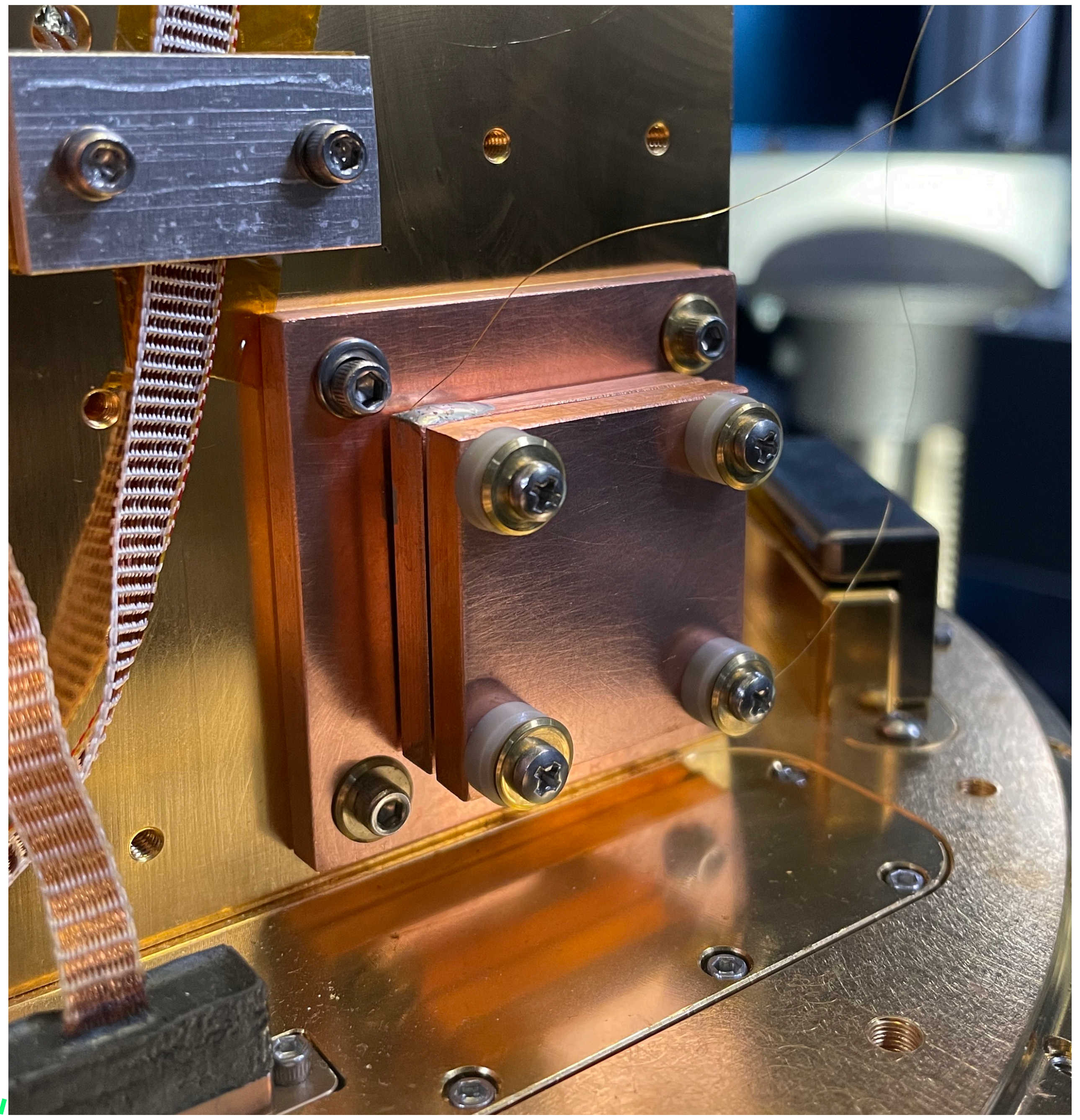




Installing MiC Gun Inside INRiM Cryostat

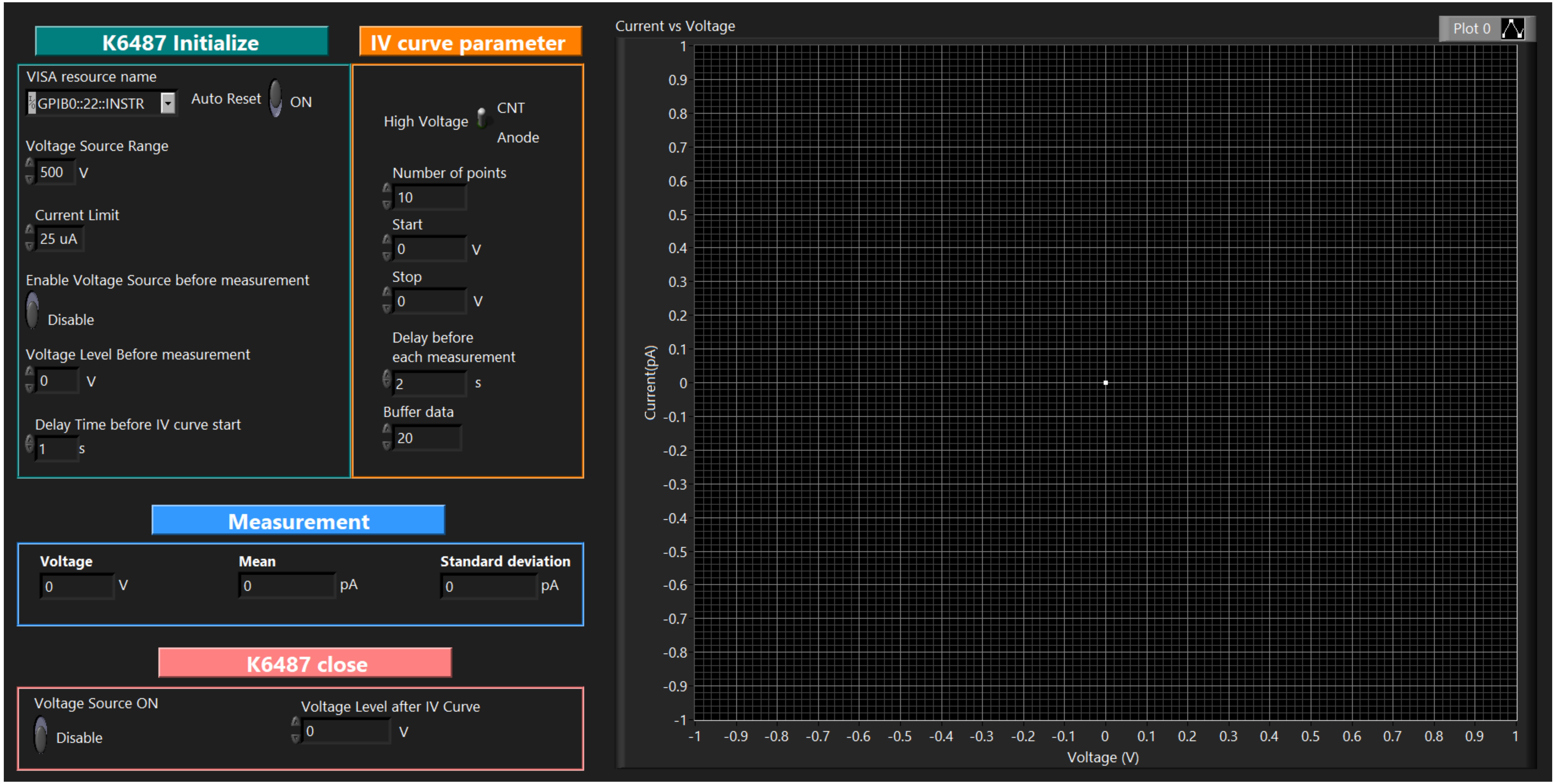


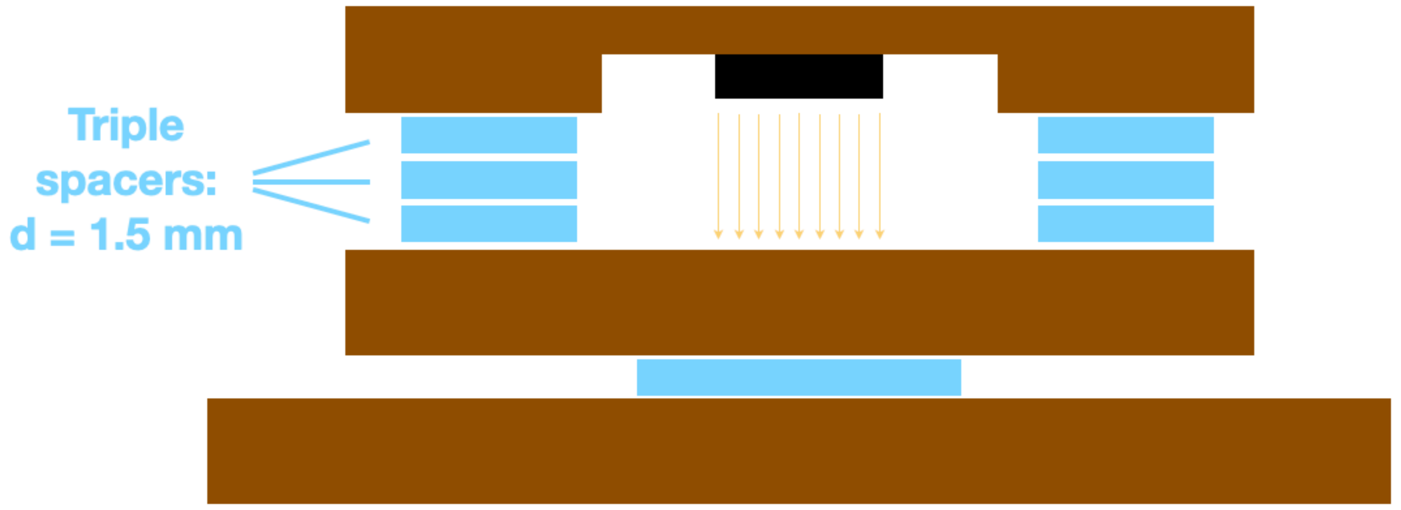




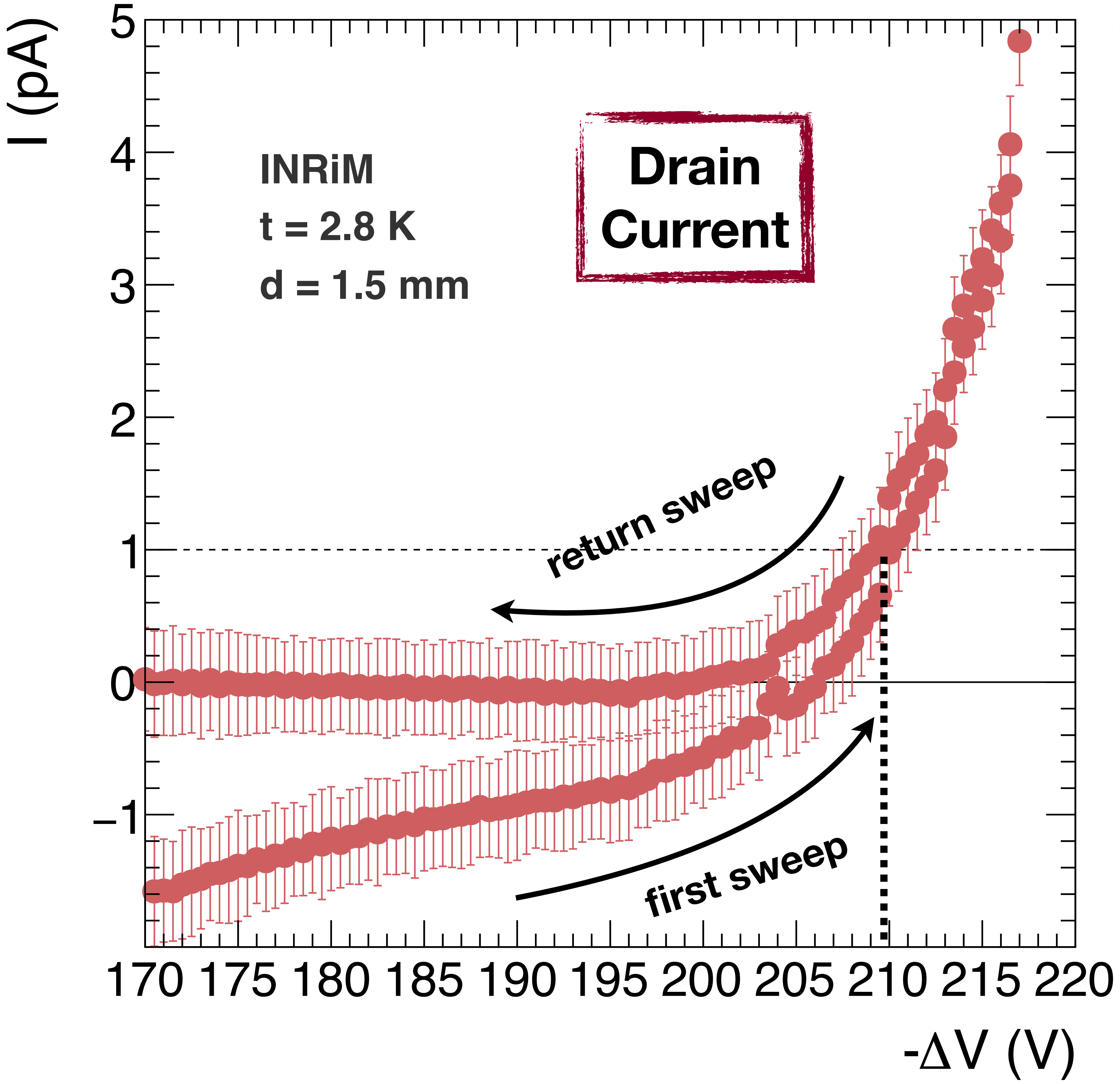
Can reach 30 mK in only 18 hours!

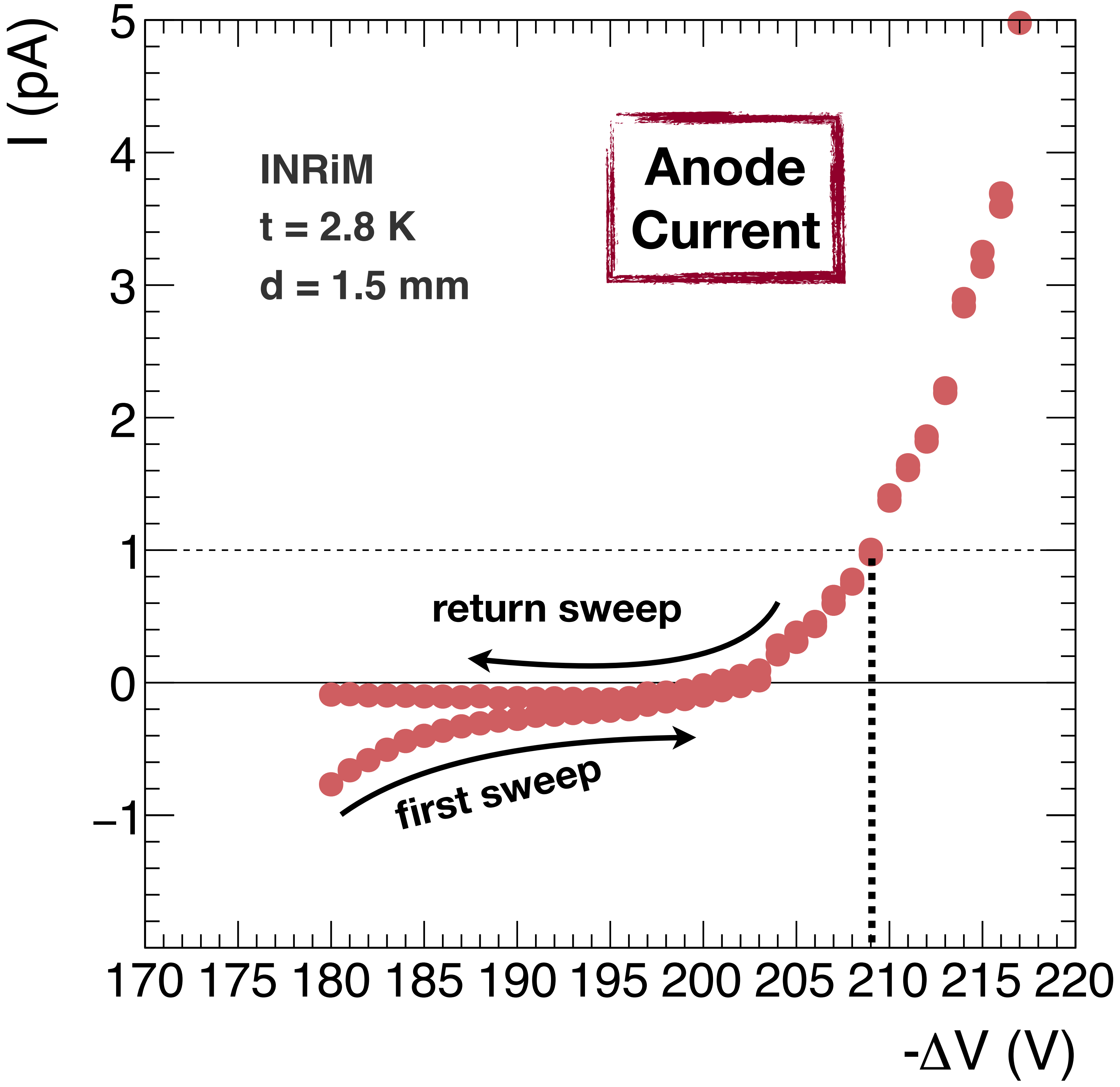
Fully Automatized Data Acquisition with LabView



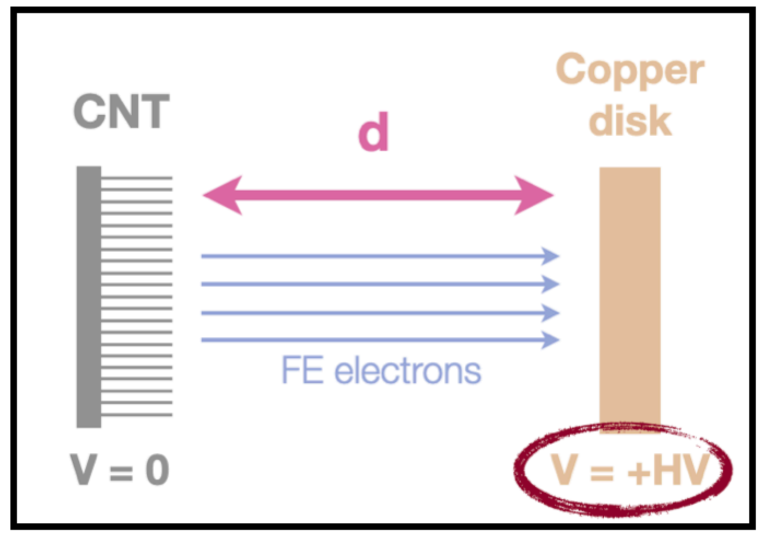


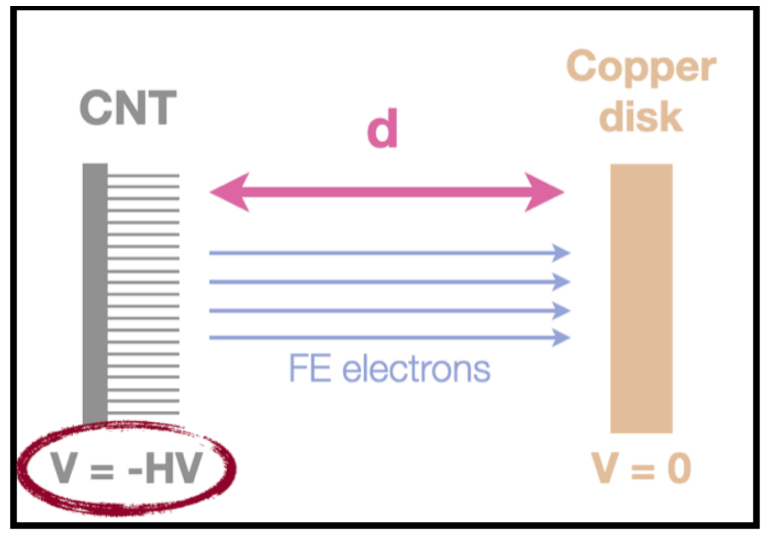
Stable Emission at 2.8 K





- No Ohmic leak!
  - Sapphire doing its job
- Return sweep preferable
- Anode current: less noise
  - σ(anode) ~ 0.04 pA
  - σ(drain) ~ 0.4 pA
- 1 pA @ 210 V (d = 1.5 mm)
  - 1 pA @ 70 V (d = 0.5 mm) ?

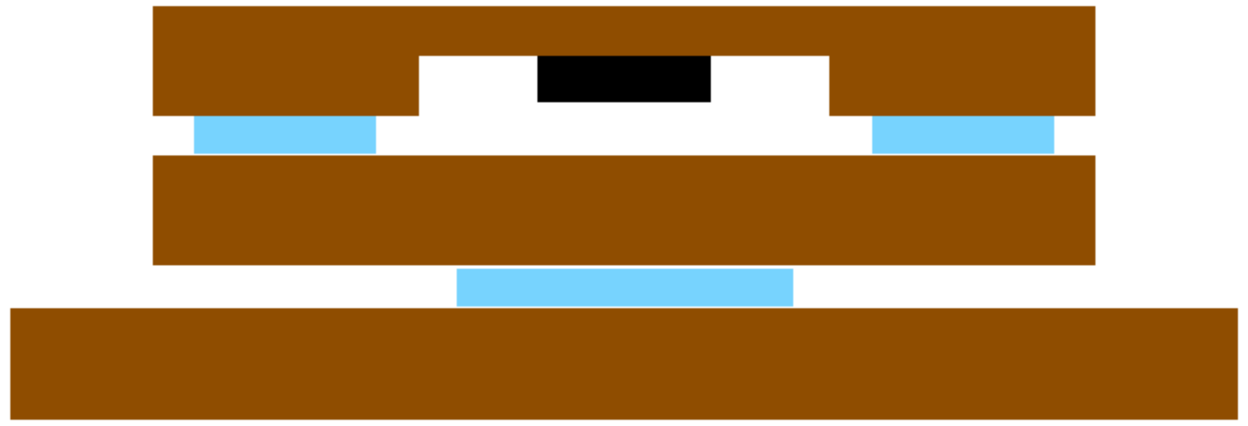




Next Steps

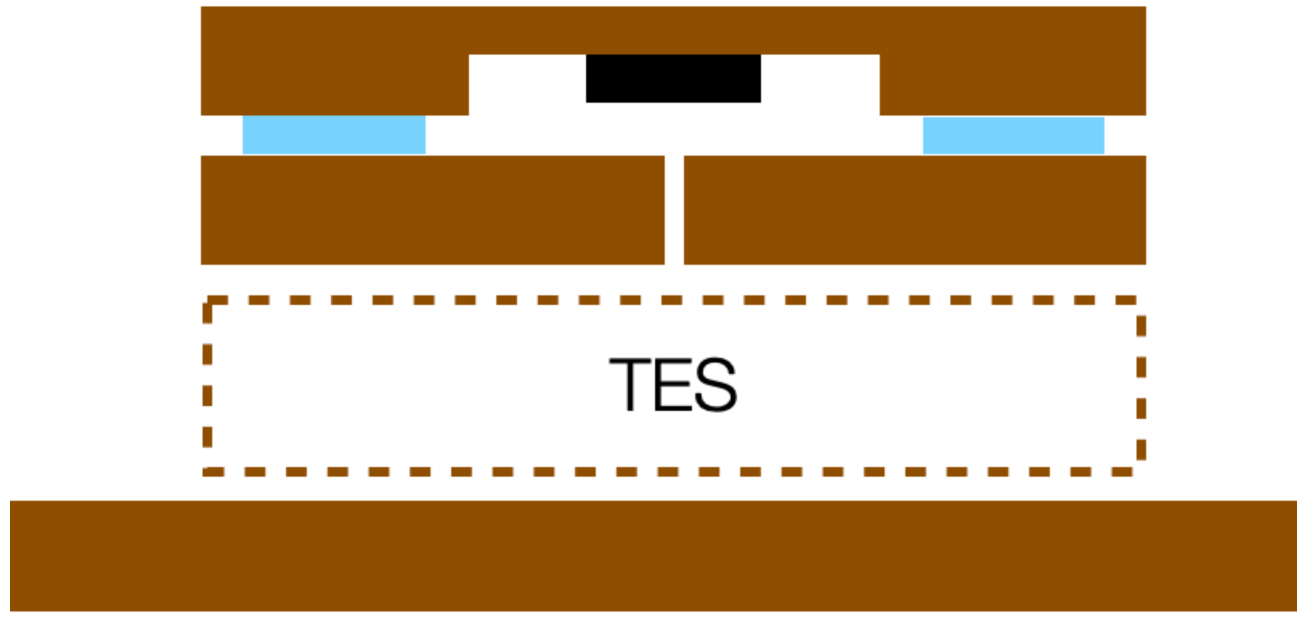
- Fully characterize field emission at 2.8 K
  - d = 0.5, 1.0, 1.5 mm
  - Measure CNTs with different etchings

O(1) month



- Move setup to 30 mK plate
  - Repeat characterization
  - Couple to TES
  - Measure electrons with TES

O(6) months



This design can be tested with MCPs first

Conclusions

- Studying CNT **field emission** as possible cold electron source for TES calibration
  - Need I ~ 1 pA and E_e = 100 eV
  - Need to operate at cryo temperatures
- New 'mozzarella in carrozza' CNT gun design, significant **improvement** wrt Whopper
  - Sapphire spacers have **eliminated** Ohmic leak
- First measurements in INRiM cryostat: **stable** emission at 2.7 K, σ(I) ~ 0.04 pA
  - **Fully automatized** data acquisition
  - Measuring 1 pA @ 210 V for d = 1.5 mm → should imply 1 pA @ ~70 V for d = 0.5 mm
  - **Target in sight**: expect to have results before end of the year