R&D of dark matter cryogenic detectors: study of impacts of an aluminium layer as a shield against magnetic fields

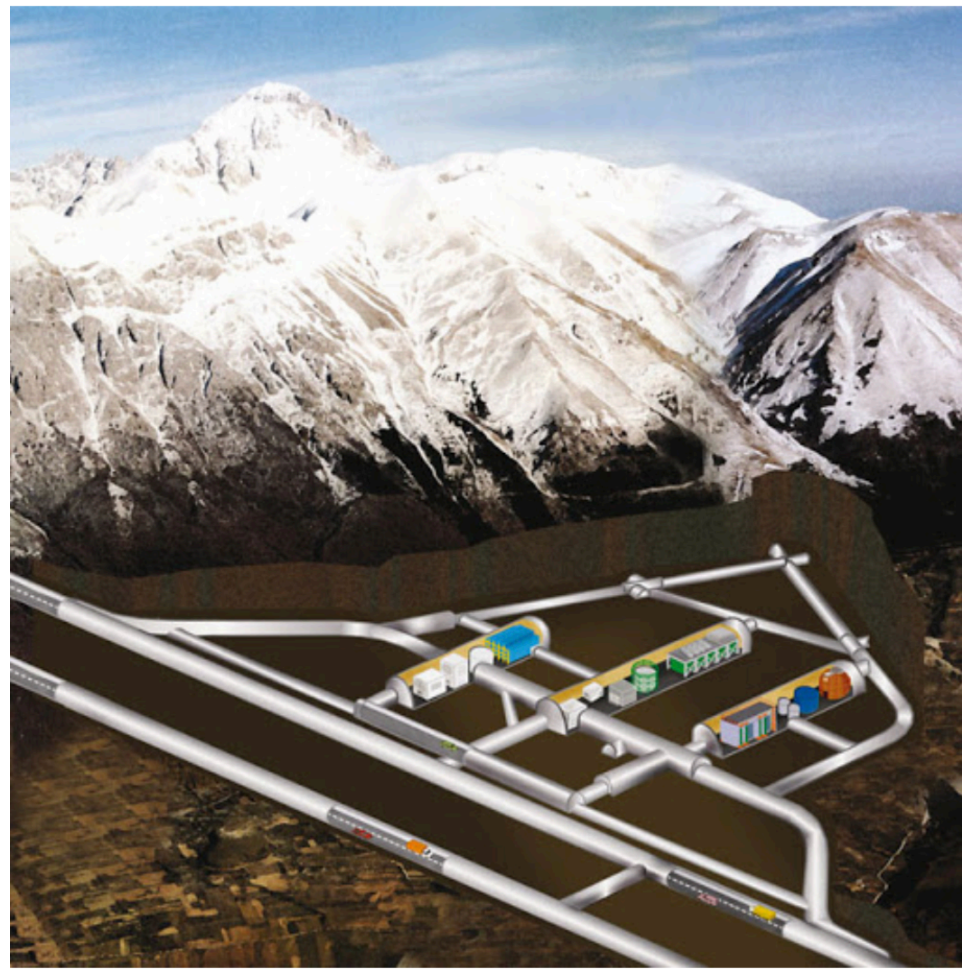
The CRESST Experiment

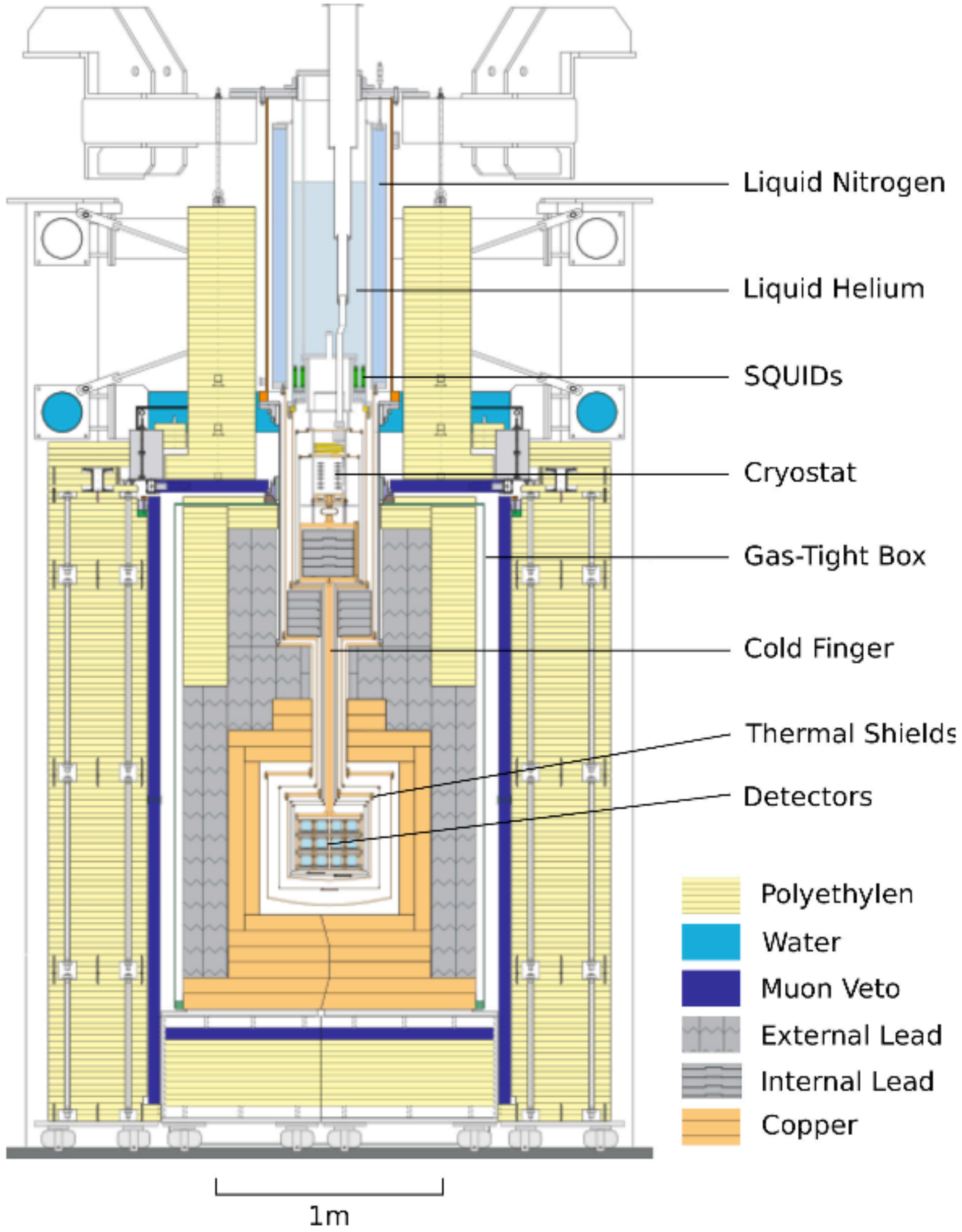
- Cryogenic Rare Event Search with Superconducting Thermometers

- Scope: direct detection of dark matter particles through their scattering off nuclei in cryogenic calorimeters

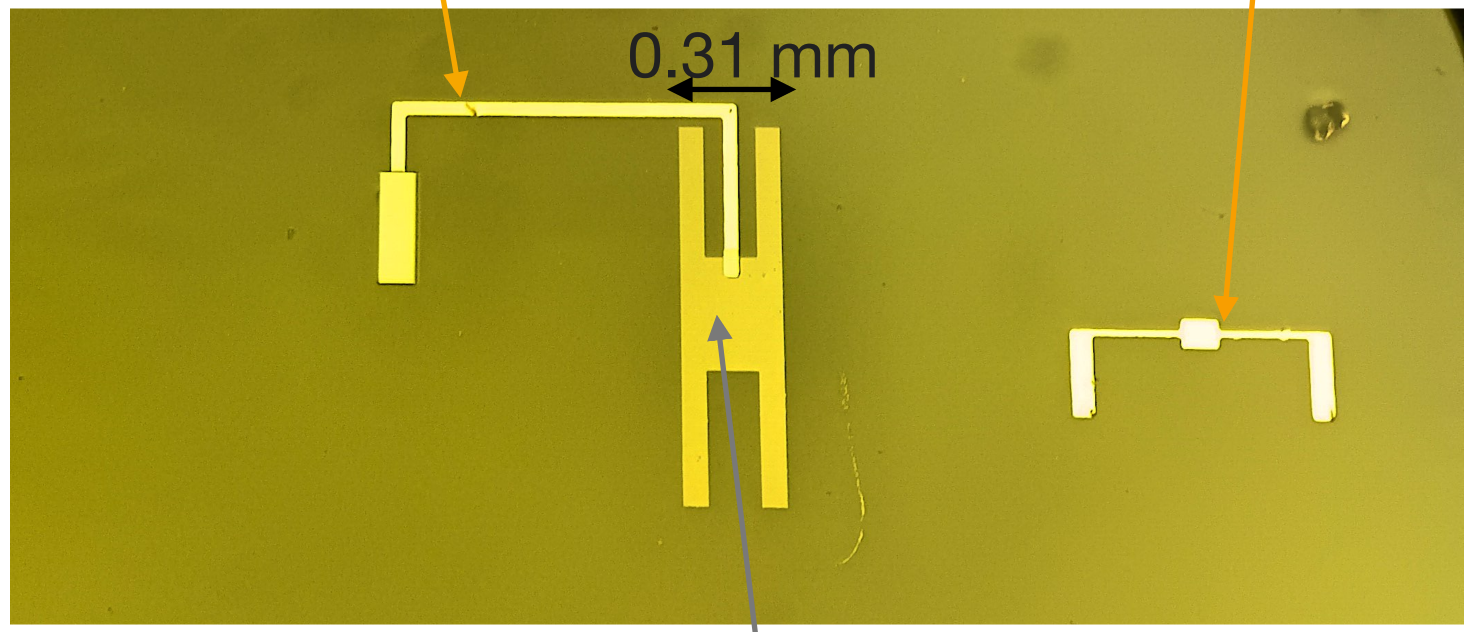
- Situated at the Laboratori Nazionali del Gran Sasso, beneath 1400 meters of rock ~3600 m.w.e.

- The main part of the experimental setup is composed by the shielding





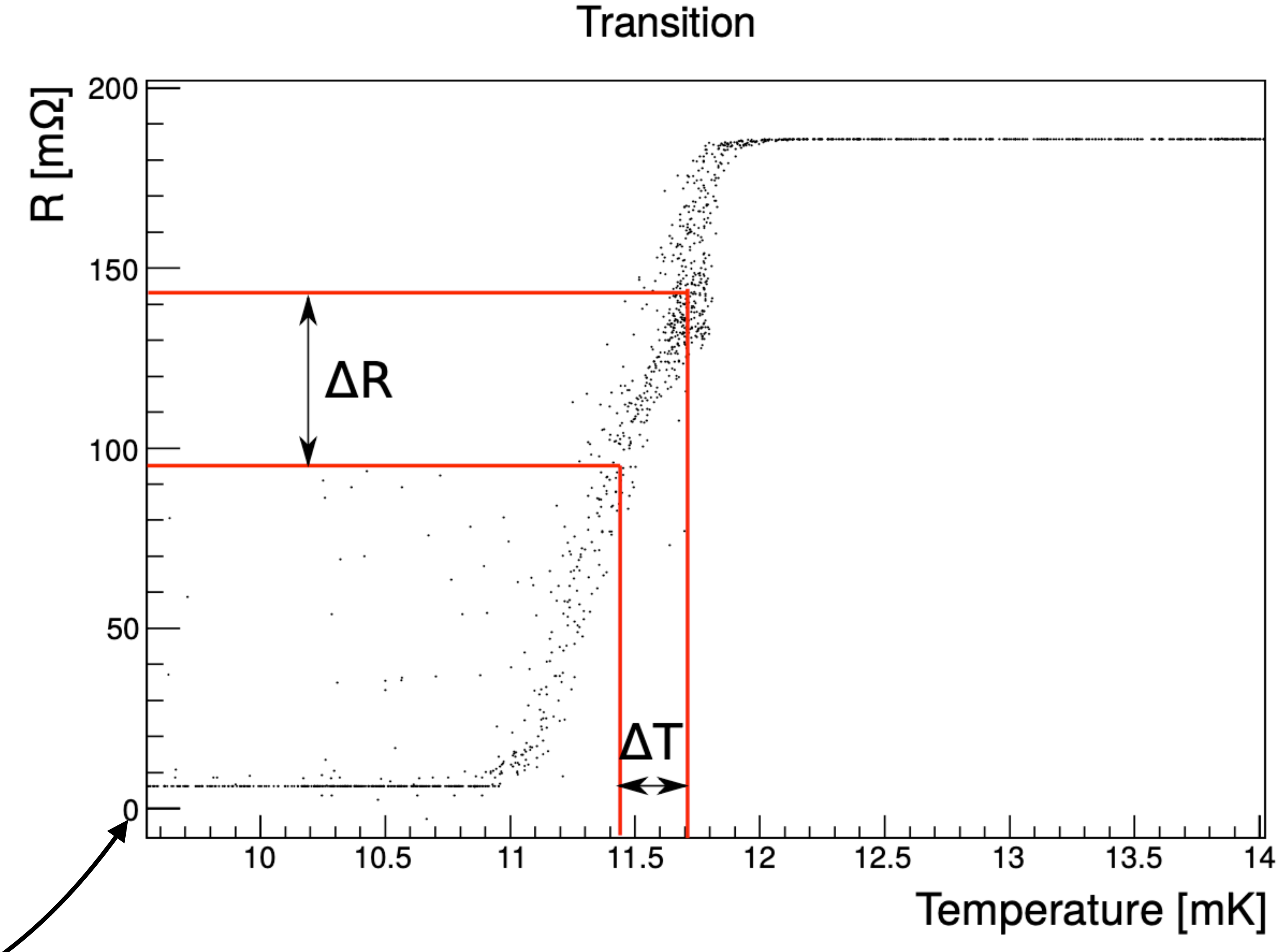
CRESST sensors



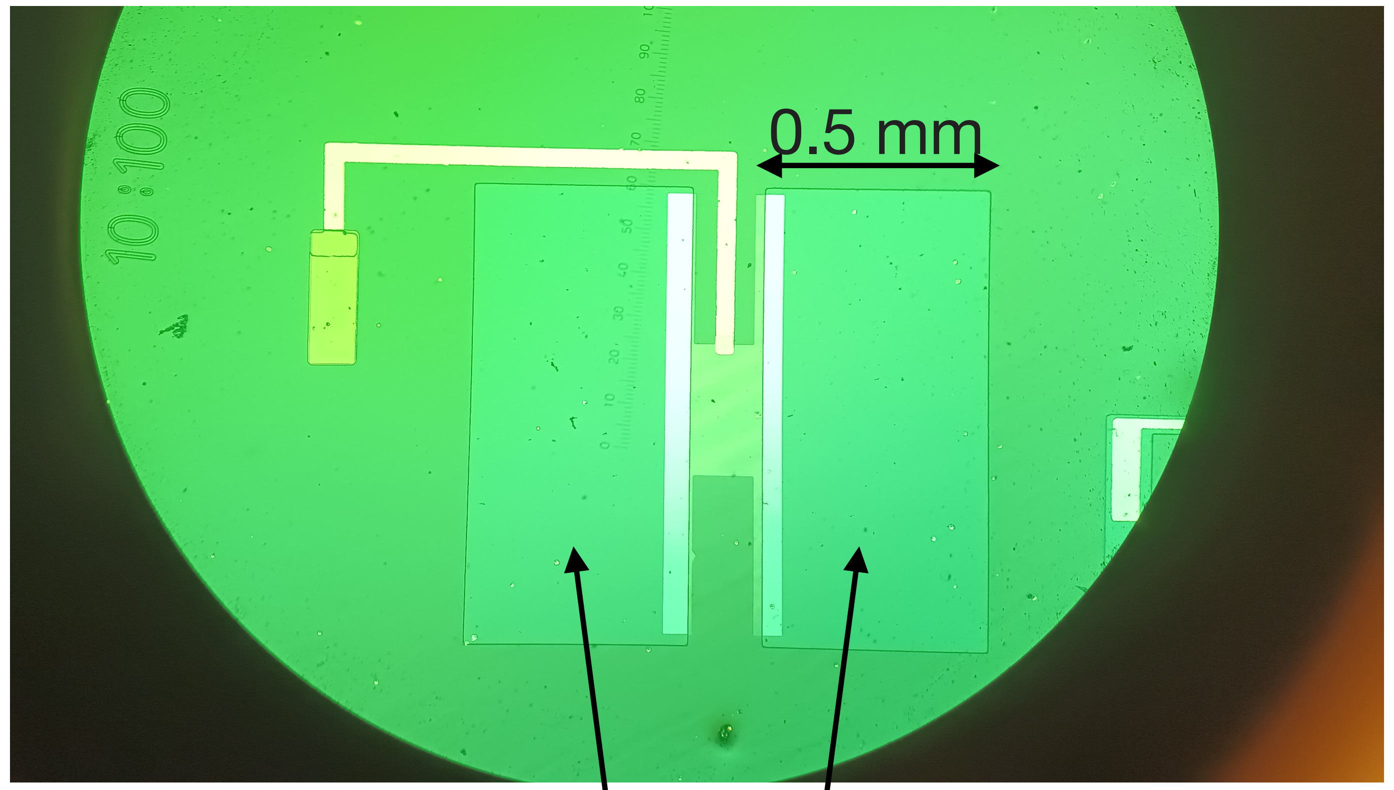
Gold Thermal Link

Gold Heater Pad

Tungsten Tc ~ 15 mK W-TES



Transition Edge Sensor



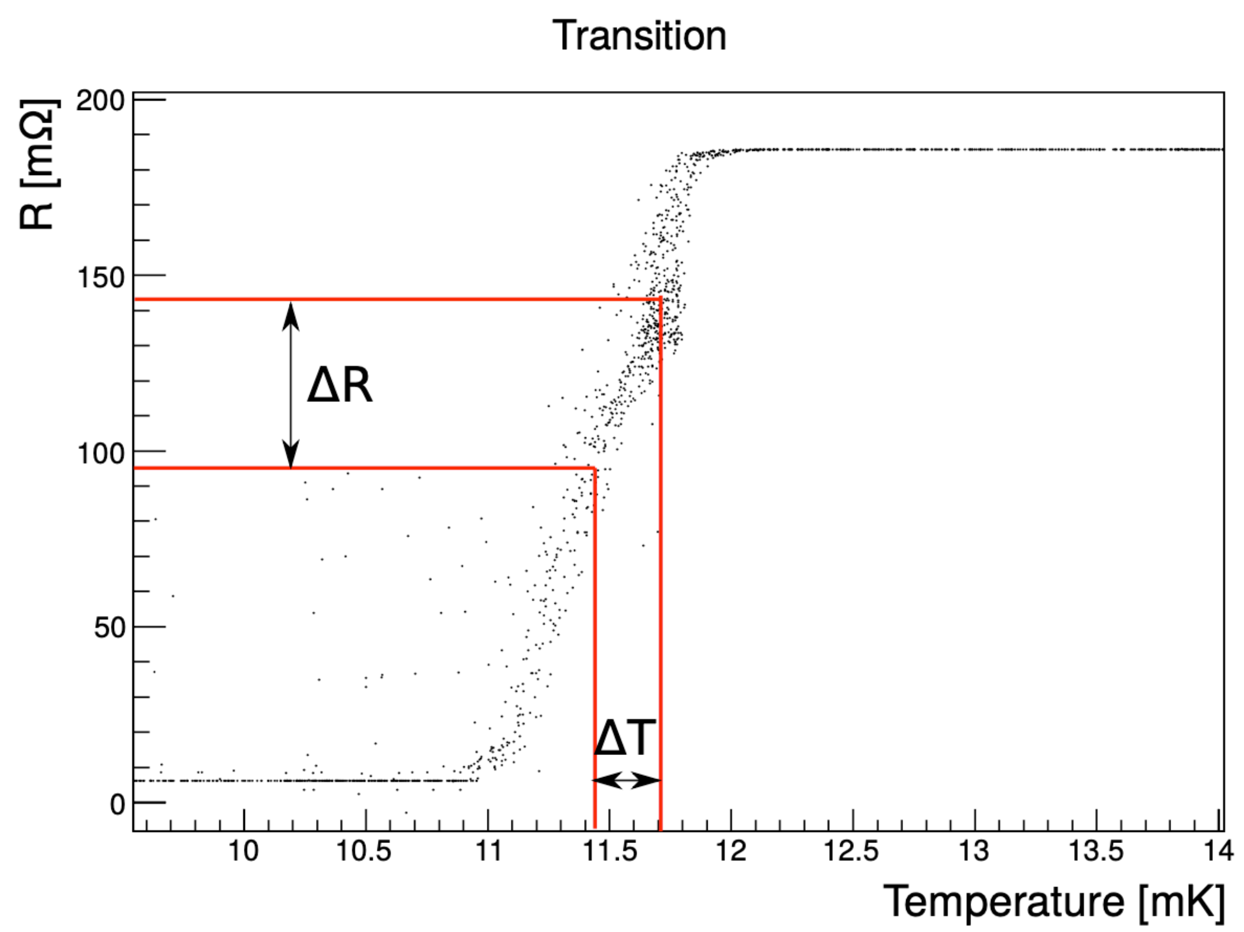
Aluminium Phonon Collectors
Tc~1.2K

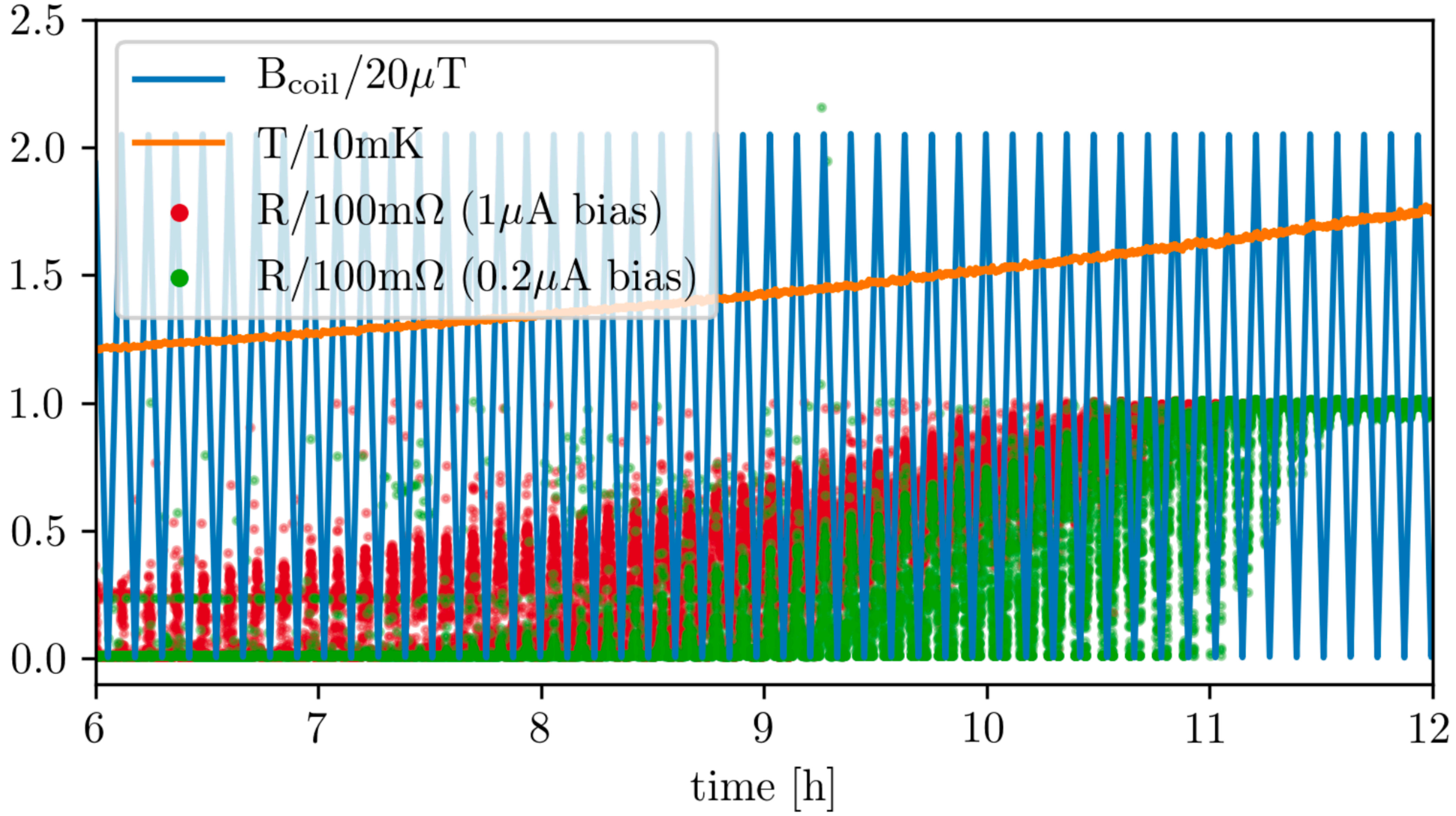
Interaction with energy ~ keV → ~ μK Temperature increase → ~mΩ Resistance variation → Detectable !

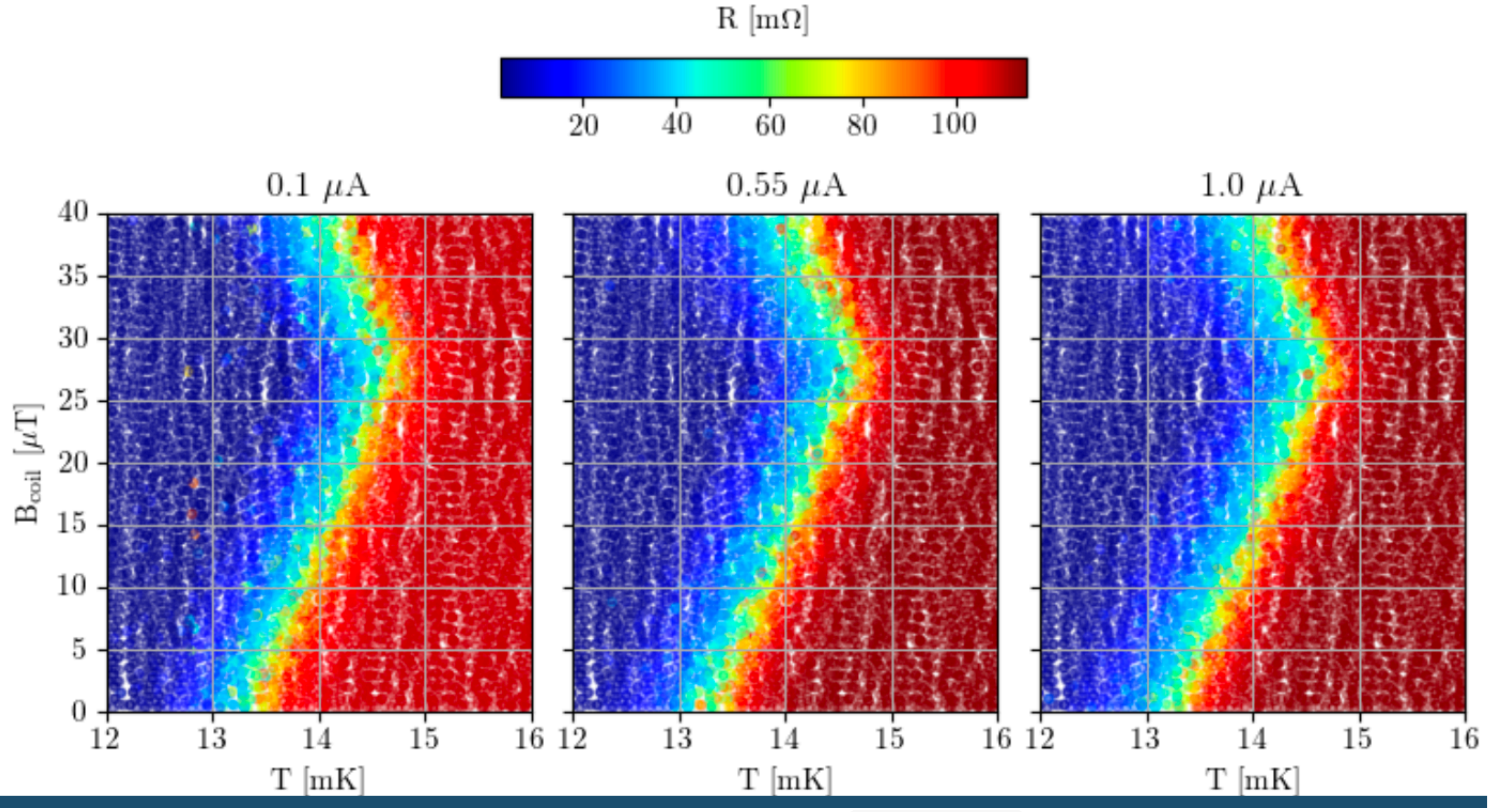
Effects of the B-fields on the TESs

- B-fields change the transition of the TESs and thus also their working point

- Optimisation of the detectors is always tricky due to this phenomenon

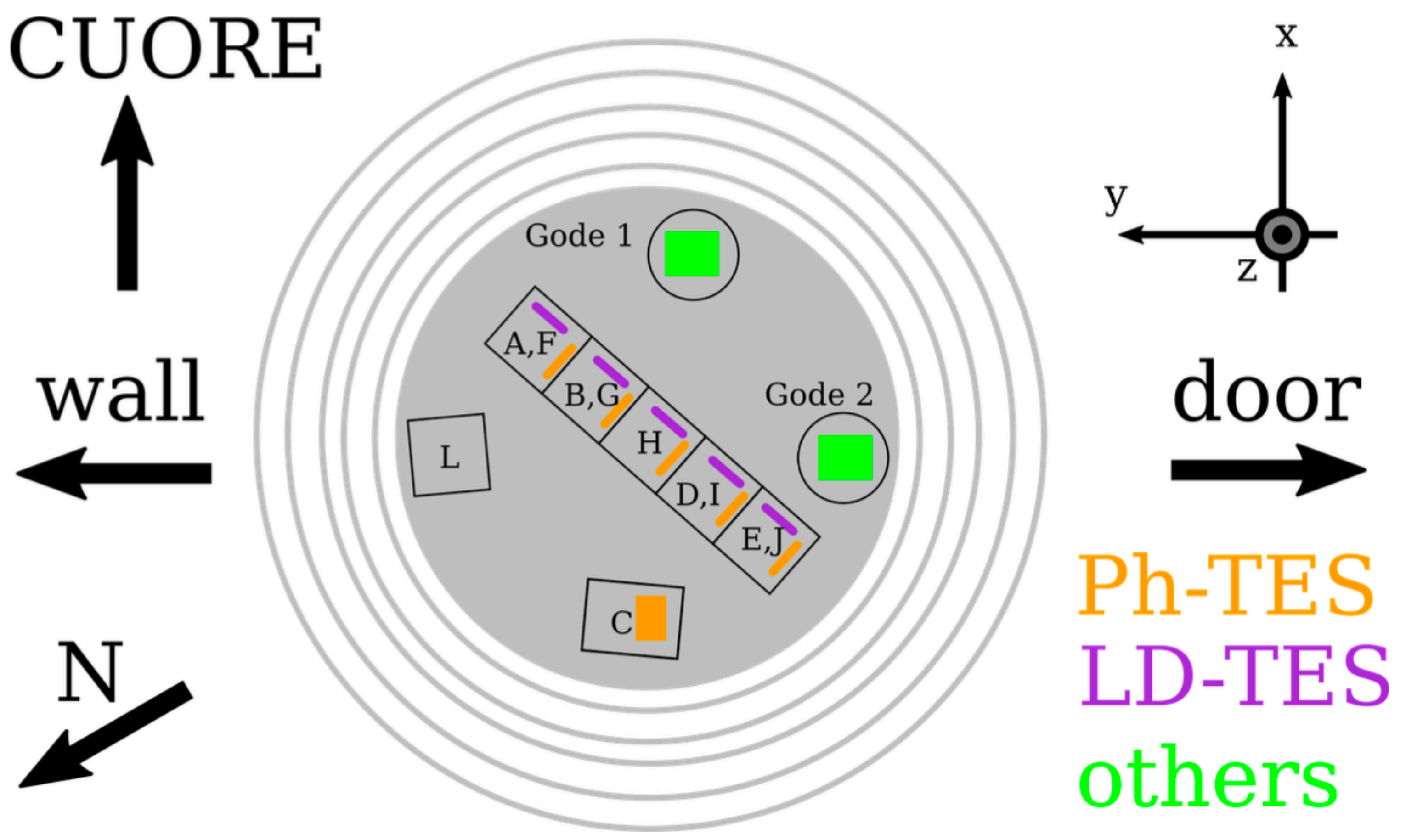


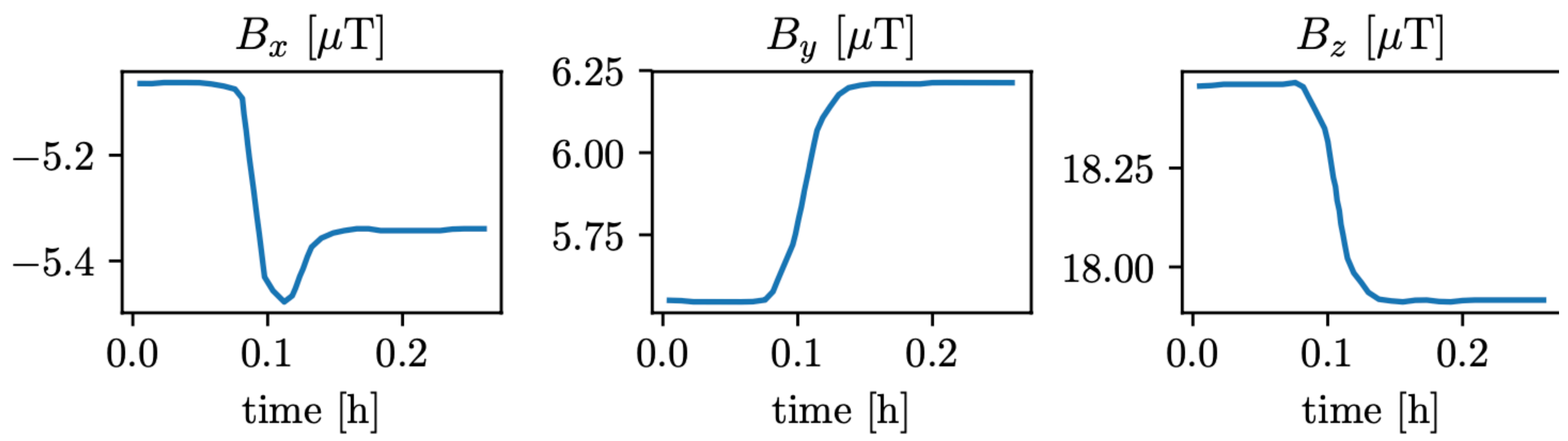


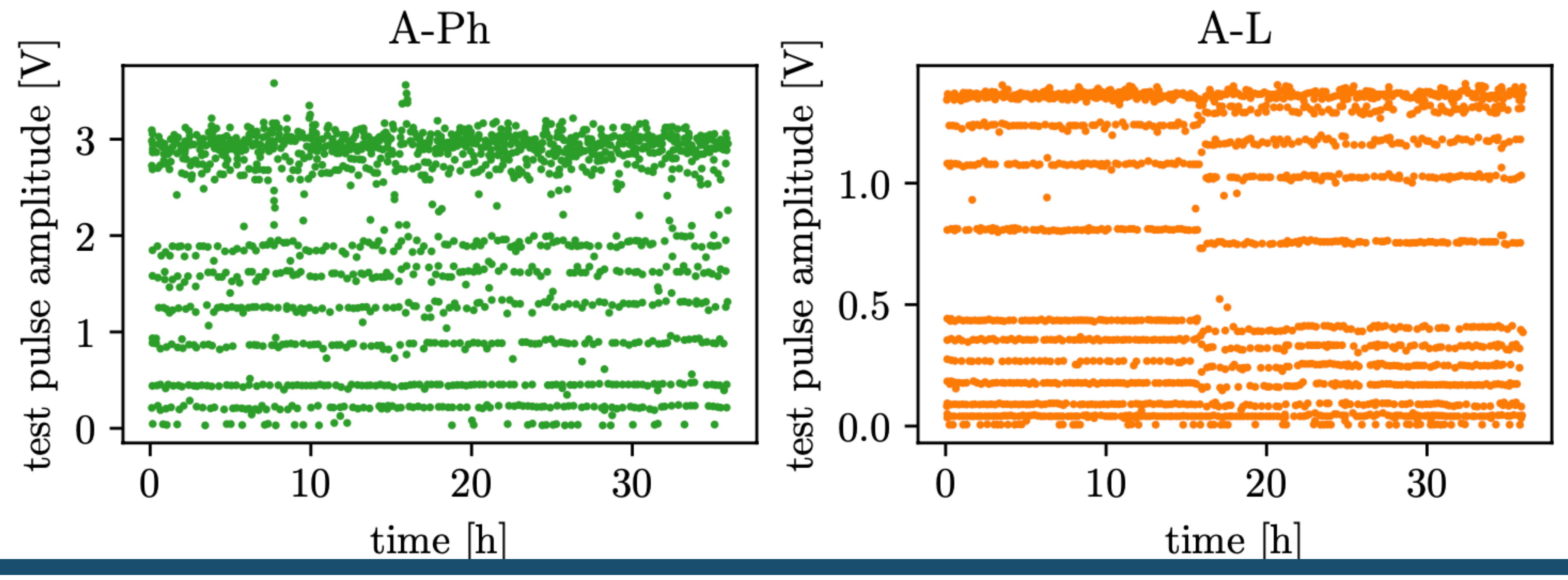


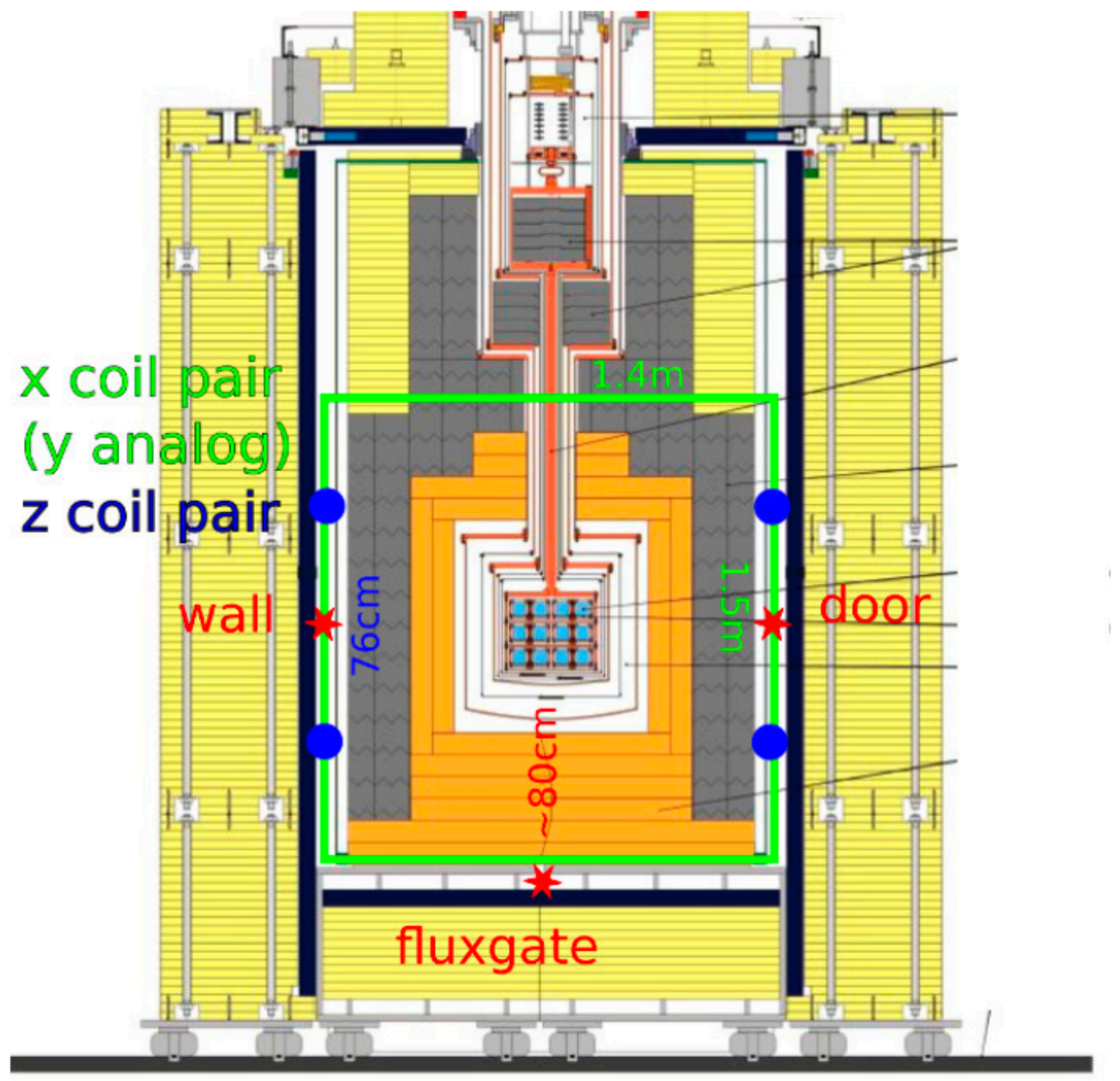
Effect of the B-fields at the LNGS

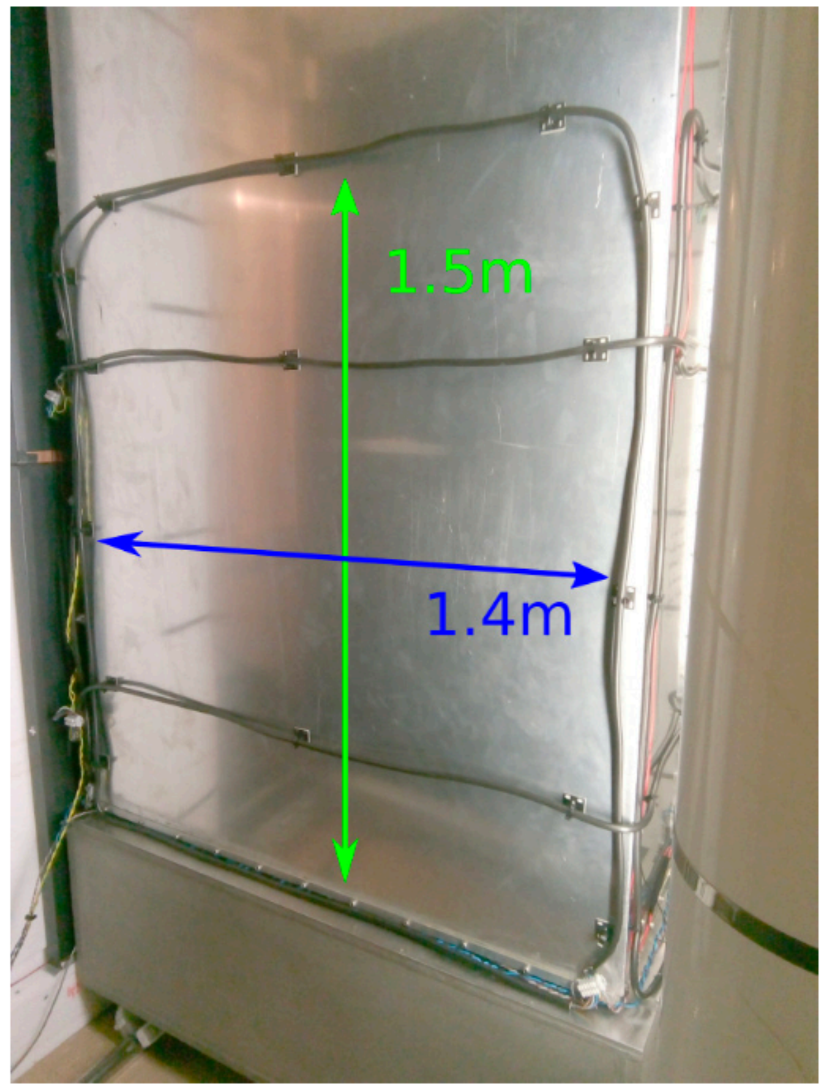
- B-fields measured through magnetometers external to the detector carousel
- Maximum B-field variation @LNGS = 0.5 μT
- System of coils is used to compensate for these effects
- Different detector orientation makes impossible to perform a compensation simultaneously for all of them





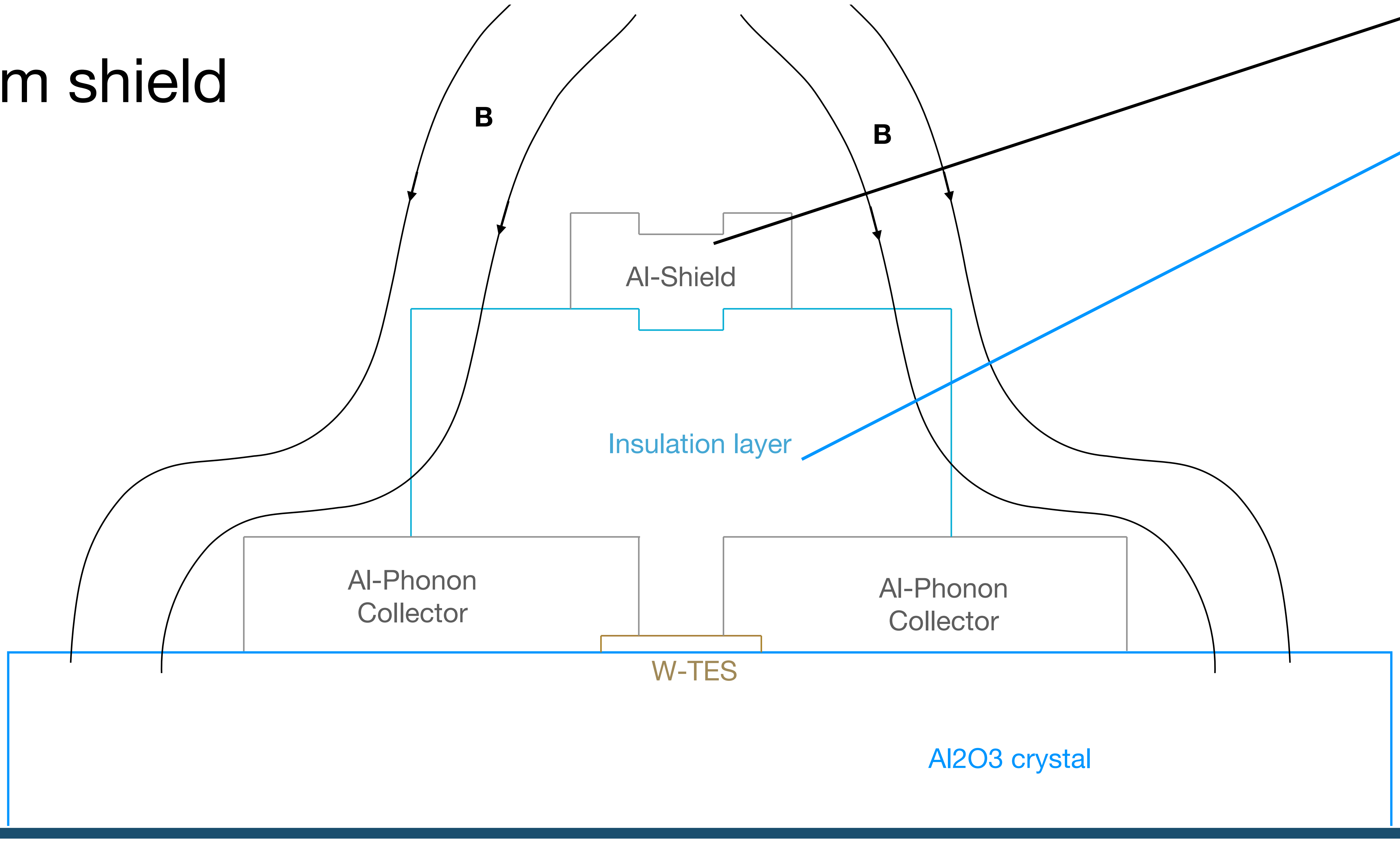


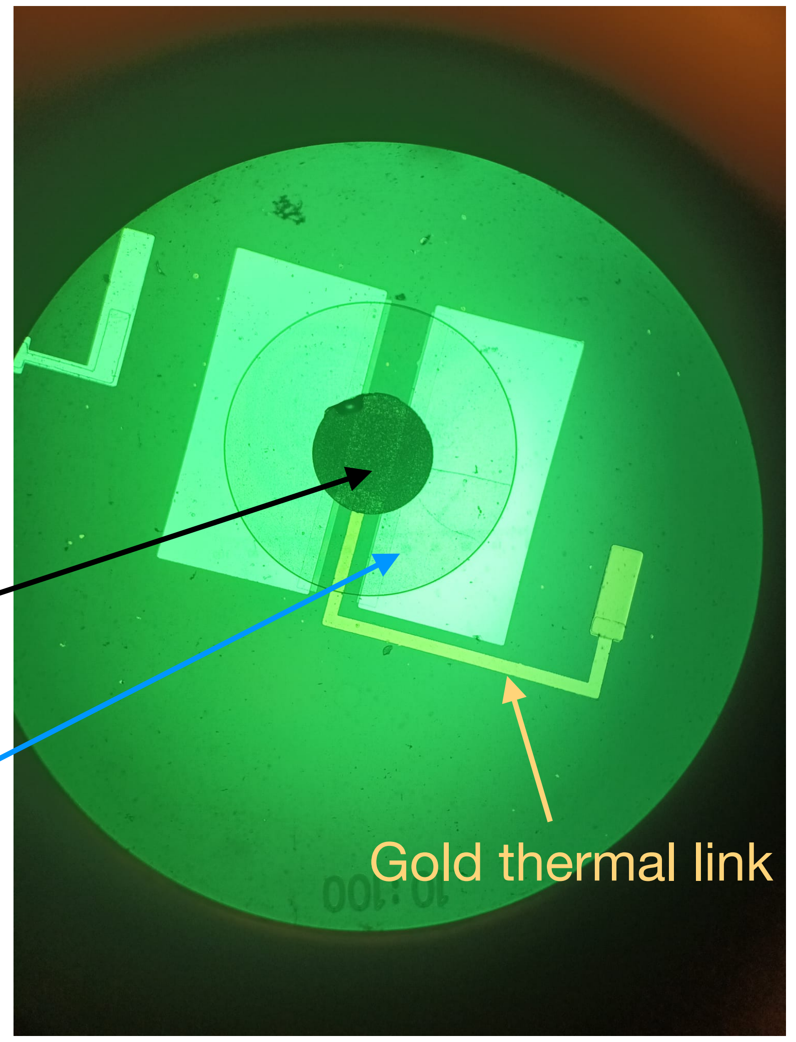




New samples design

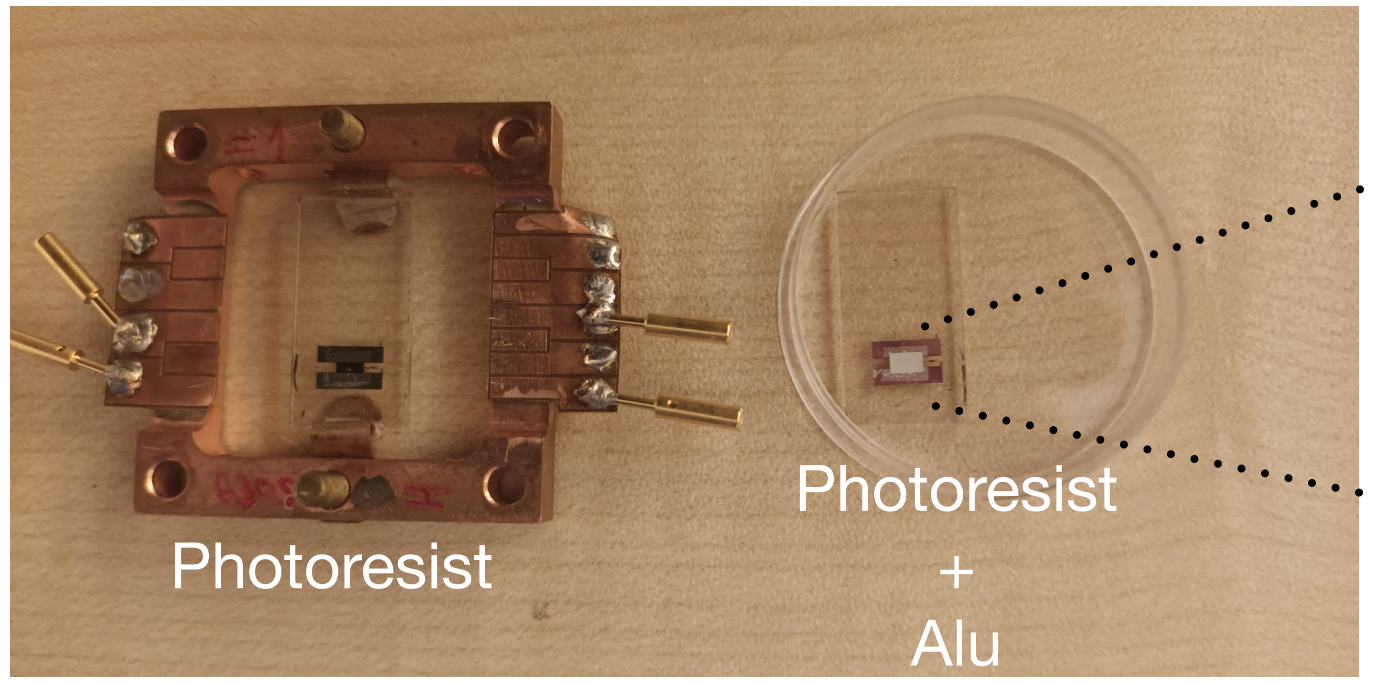
- The idea: exploiting the Meissner Effect of superconductors
- Classical H-TES design: tungsten sensor + two Al phonon collectors
- Insulation layer made of KMSF photoresist
- Sputtered Aluminium shield

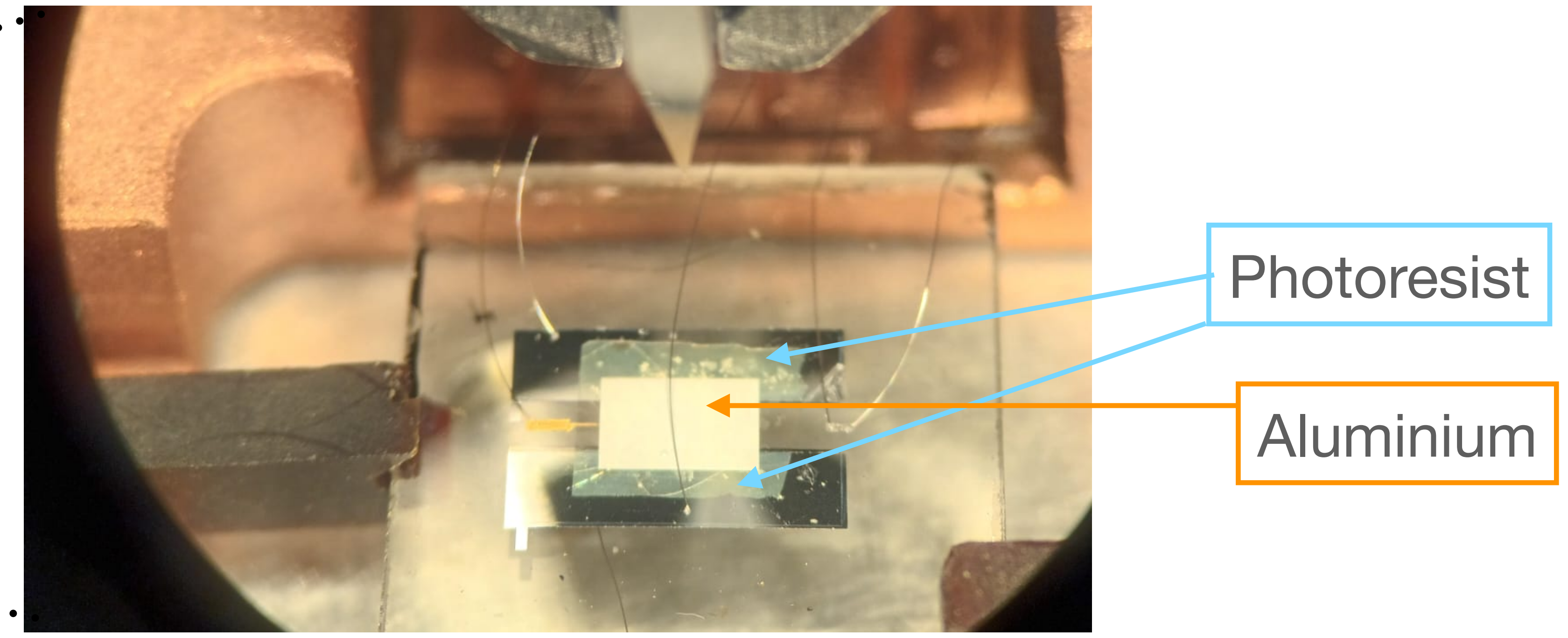




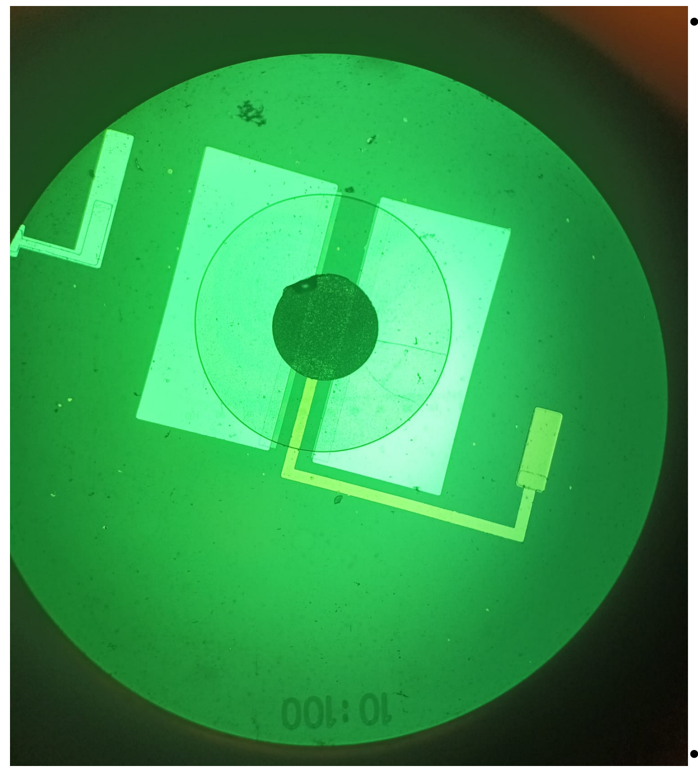
The two configurations

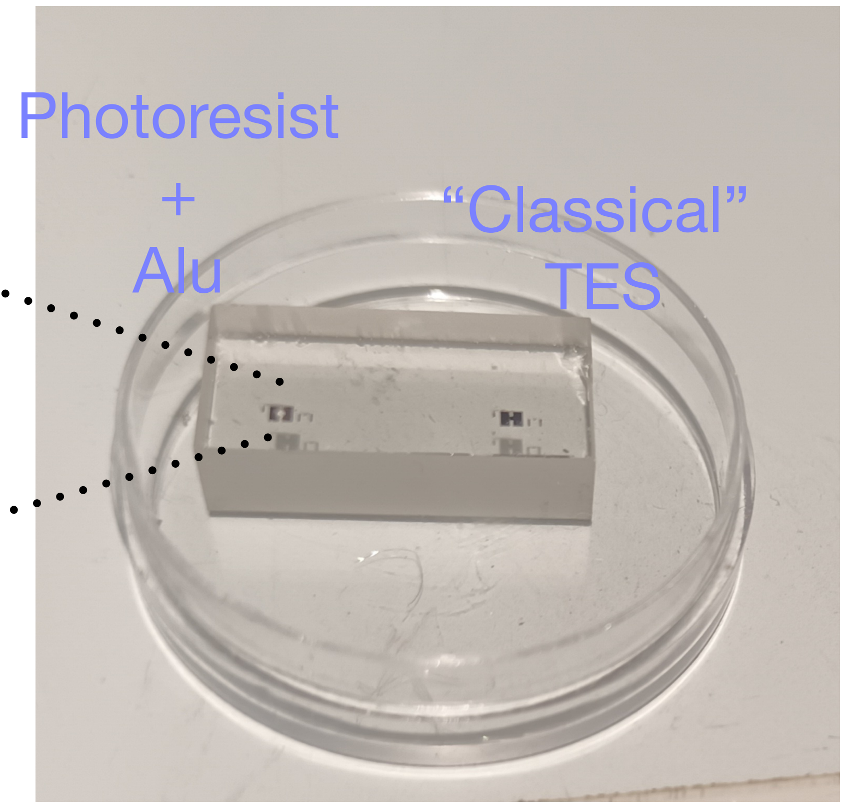
- Two sputtered TESs on two different sapphire substrates: one with the dielectric layer only, the other with also the Al shield





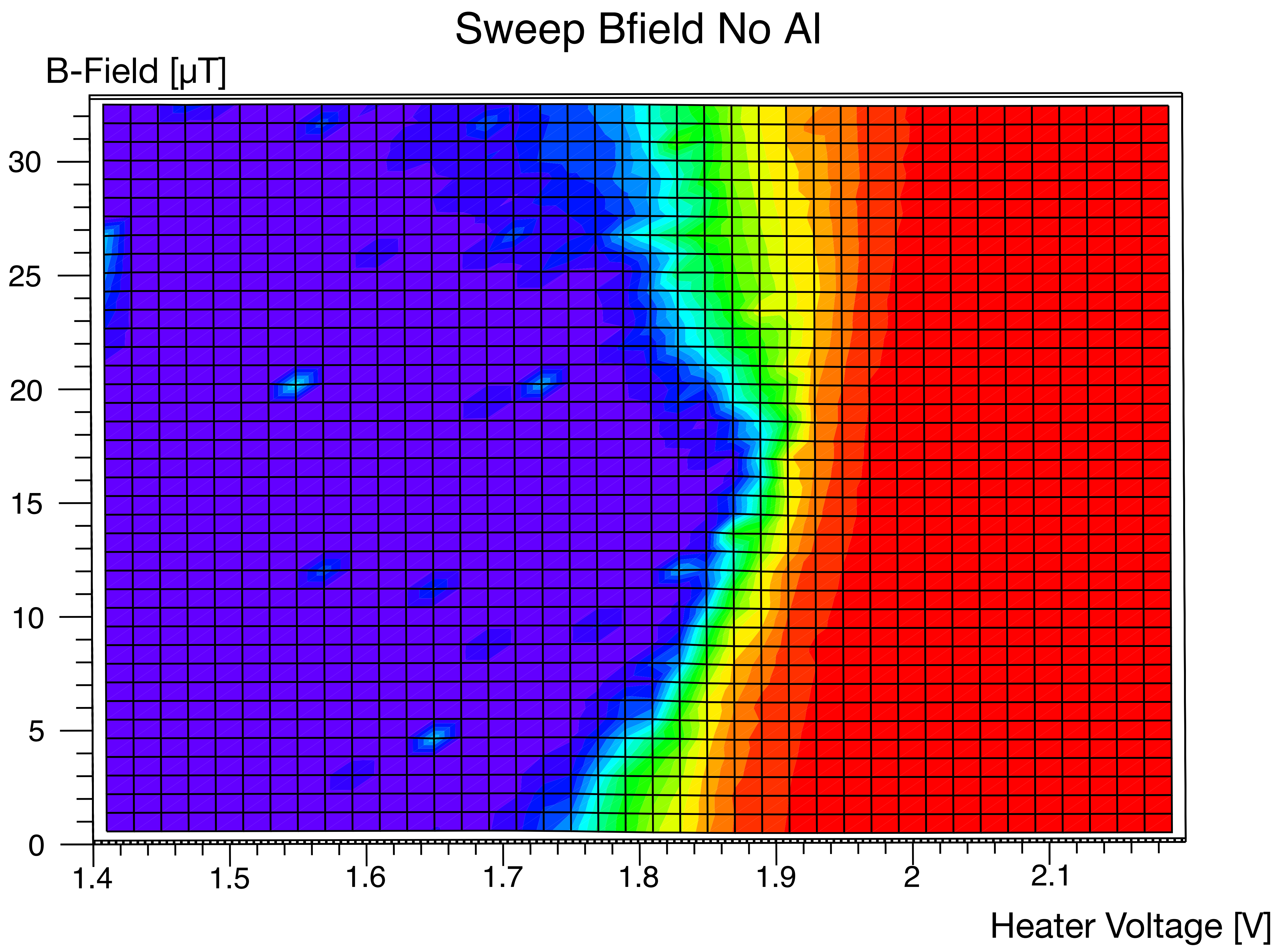
- Two evaporated TESs on the same crystal: one without additional layers, the other with photoresist and Al shield

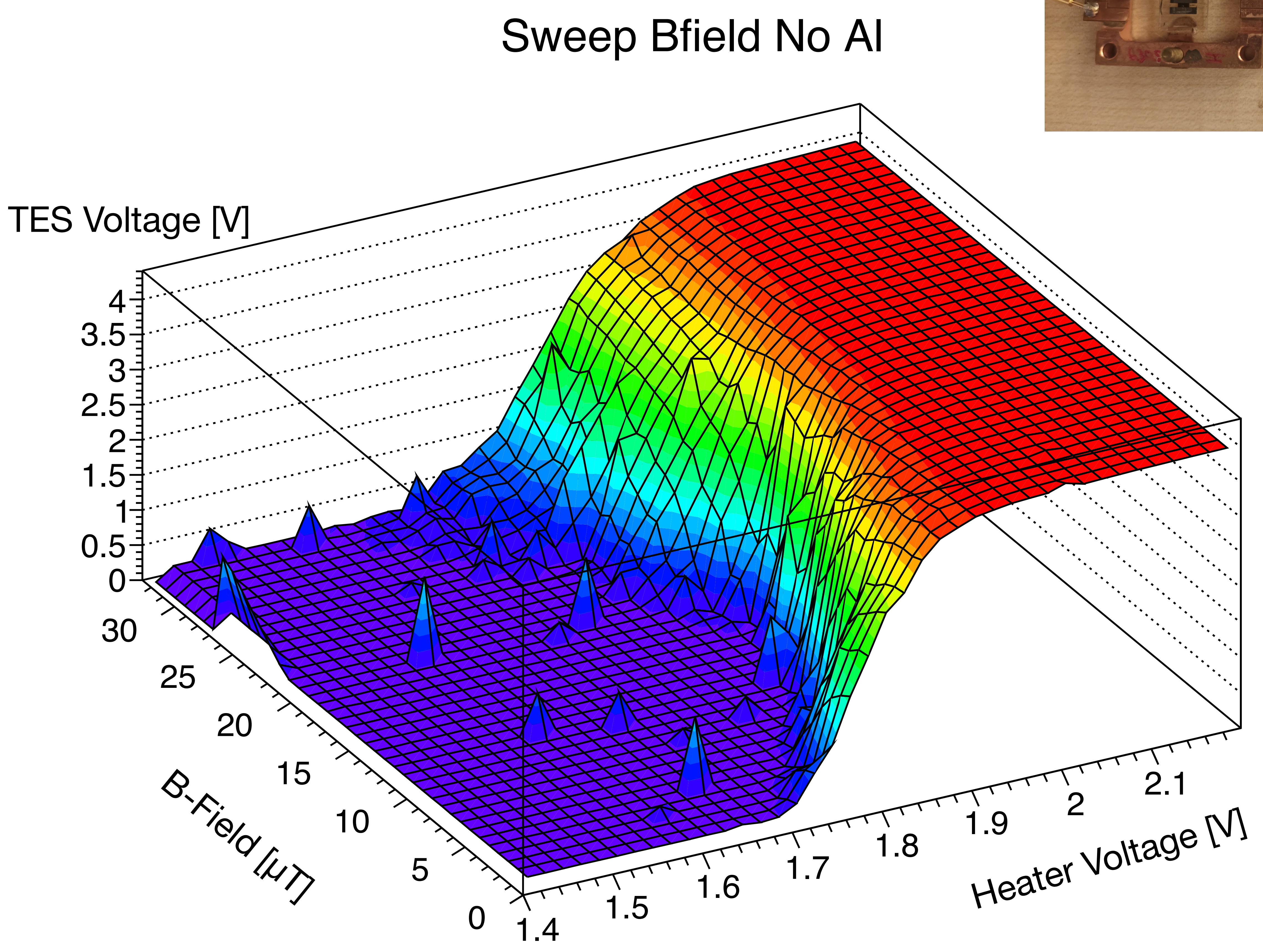


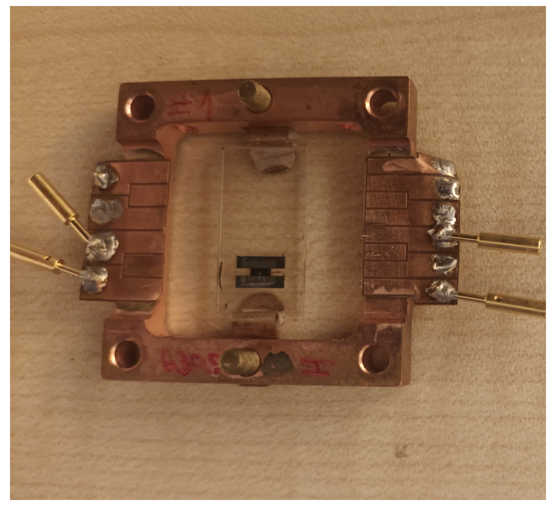


First configuration: transition with increasing B-field

- Non-shielded TES' transition shows a clear dependence on the field

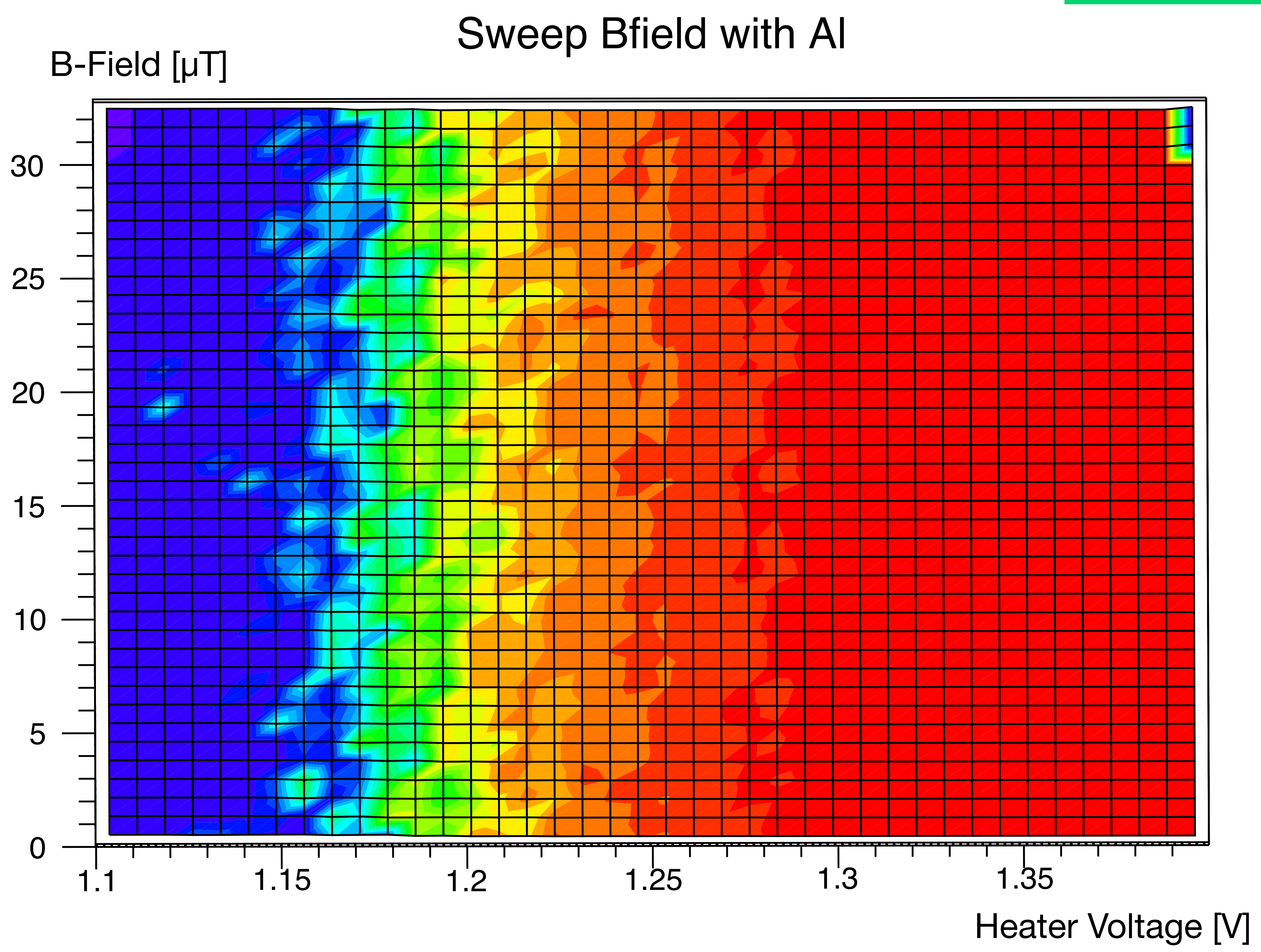


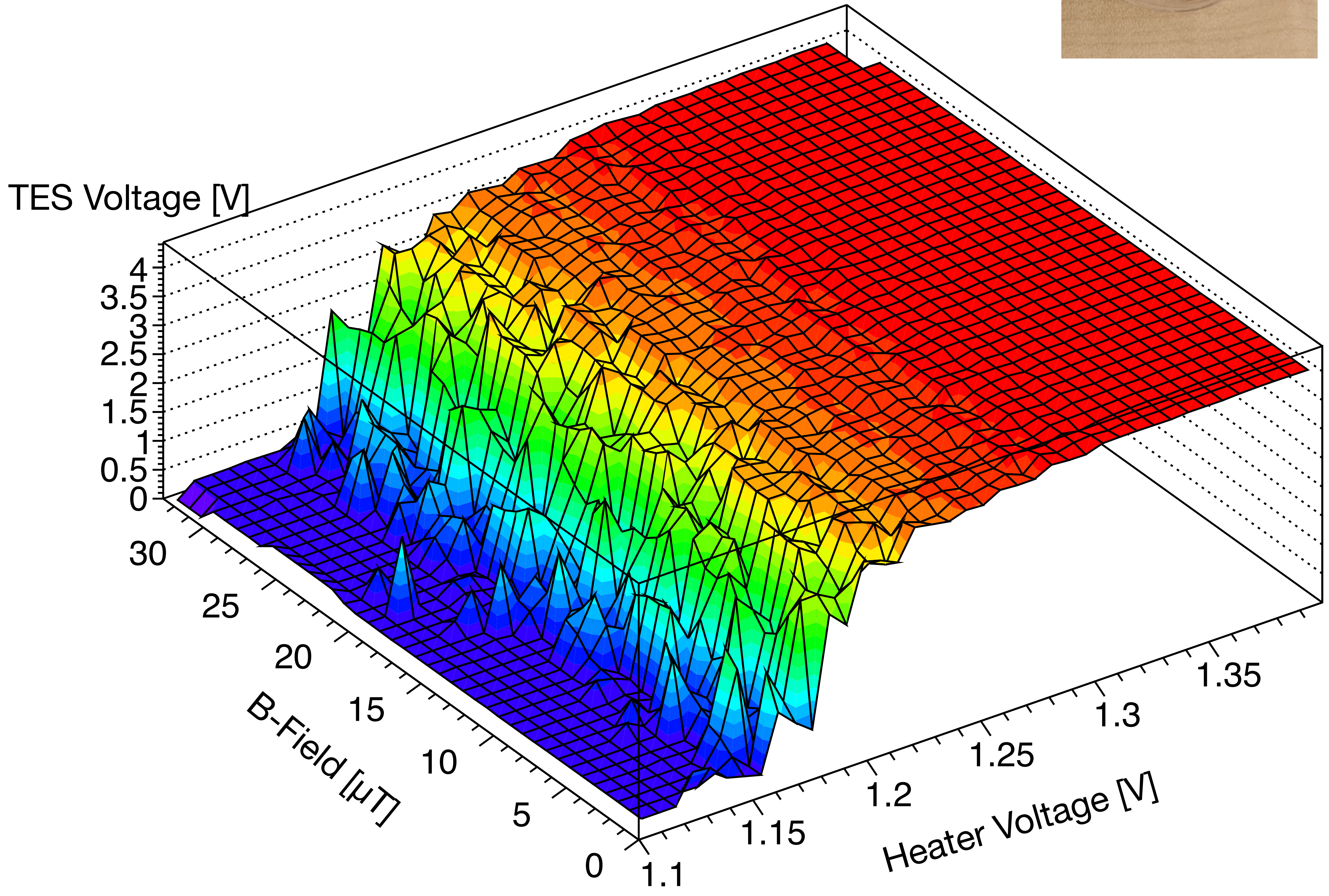


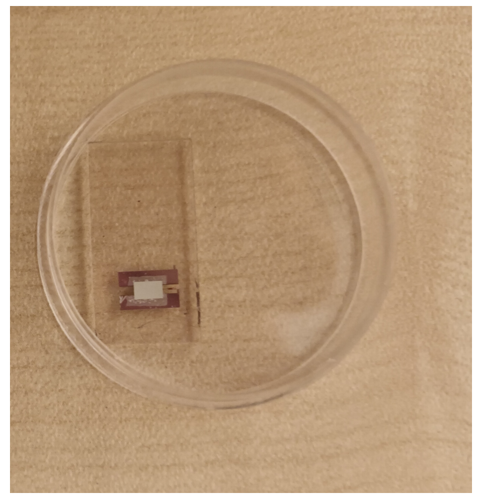


First configuration: transition with increasing B-field

The Shield worked !!!

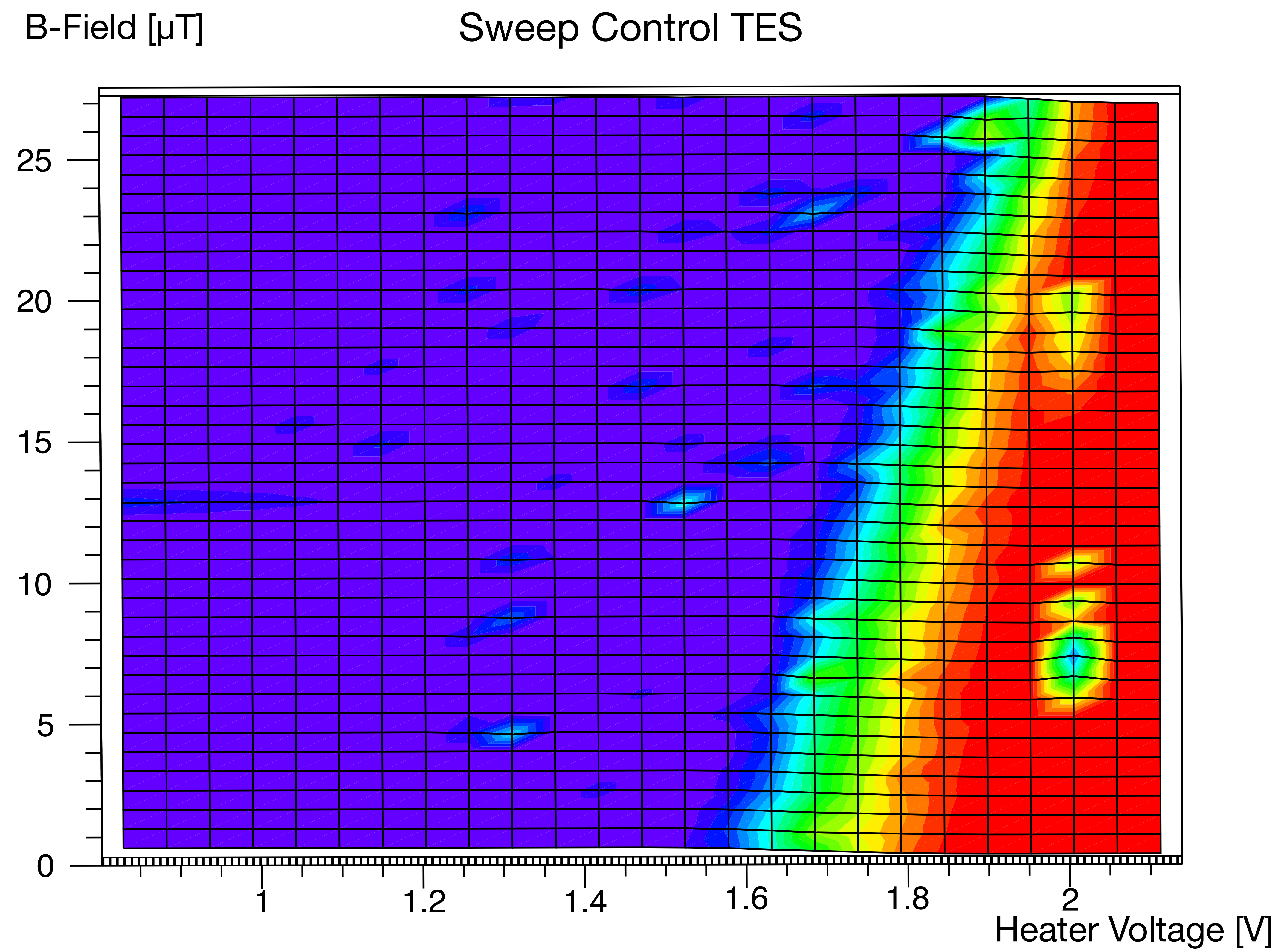


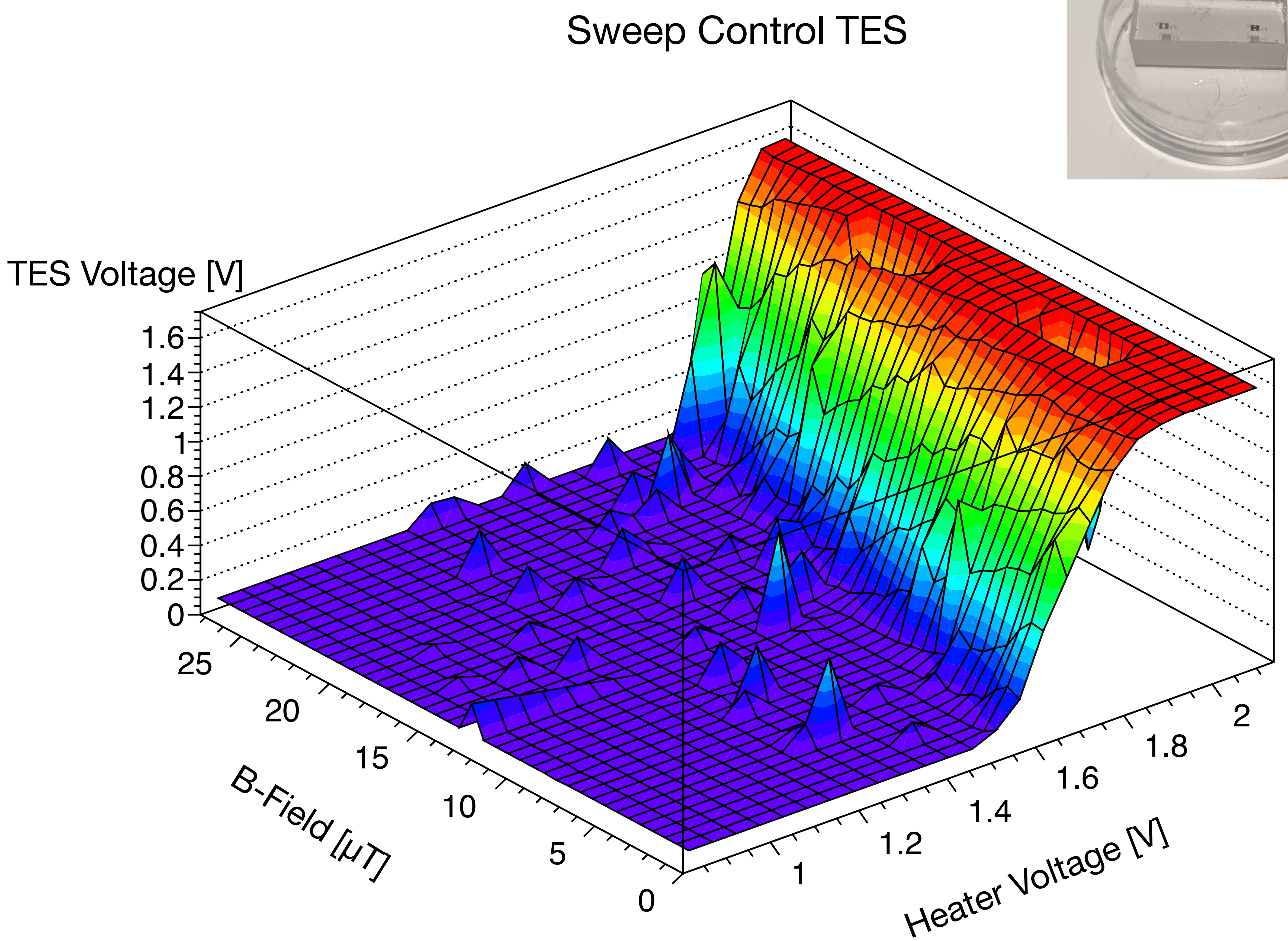


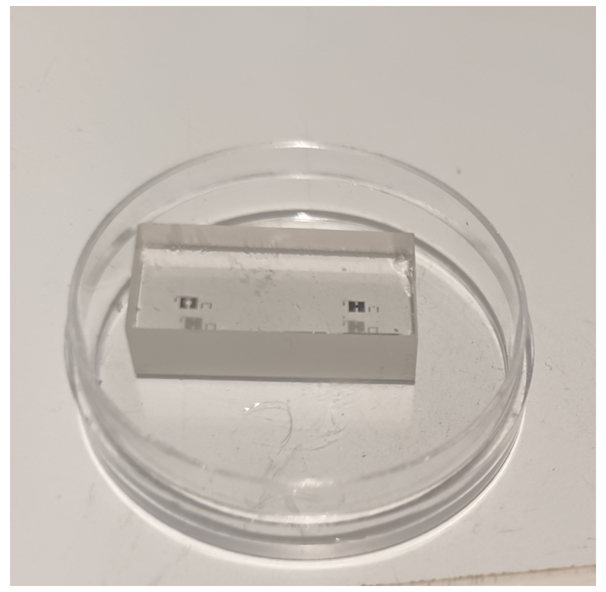


Second configuration: Transition with increasing B-field

- This sample has neither the photoresist nor the Alu-Shield

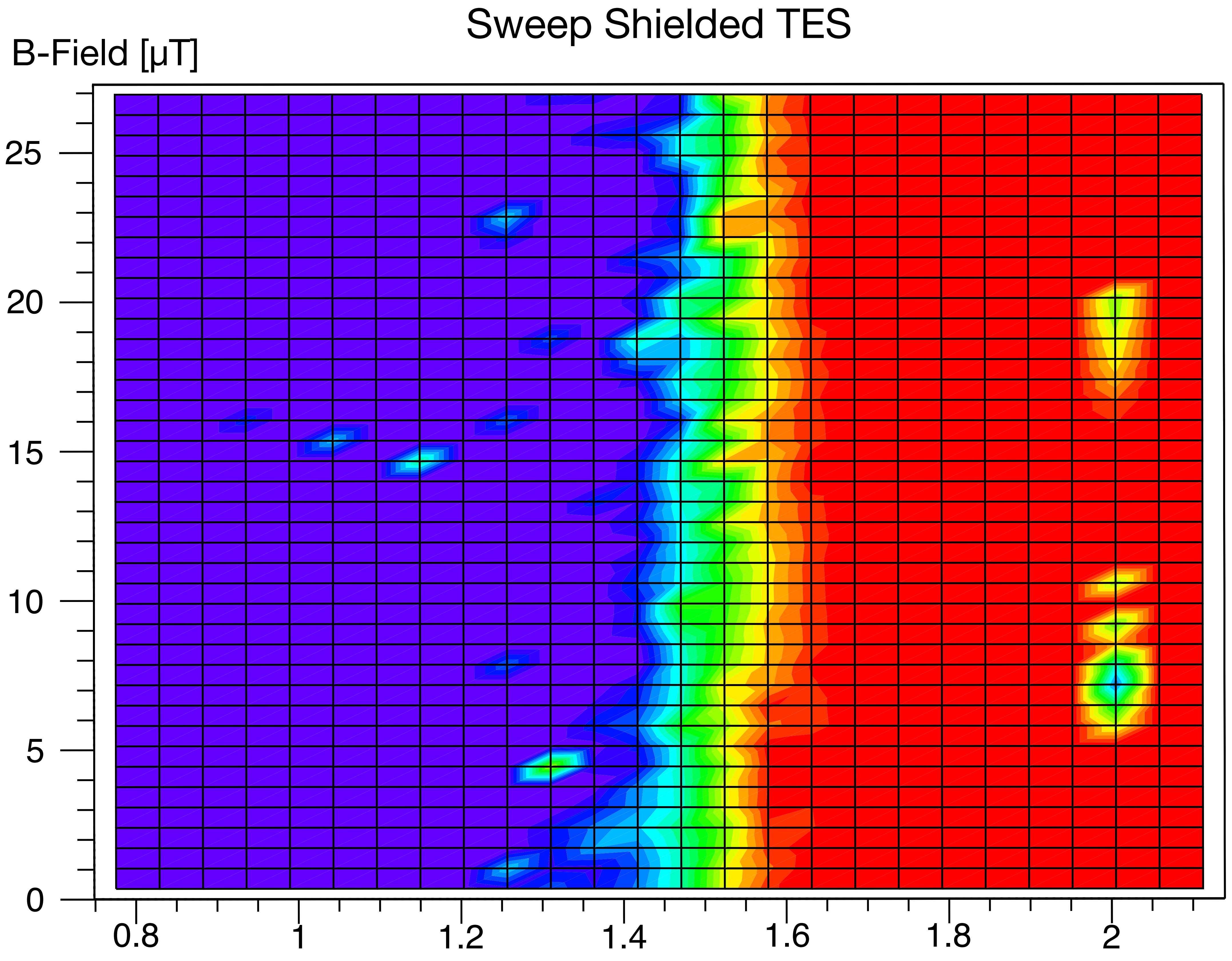


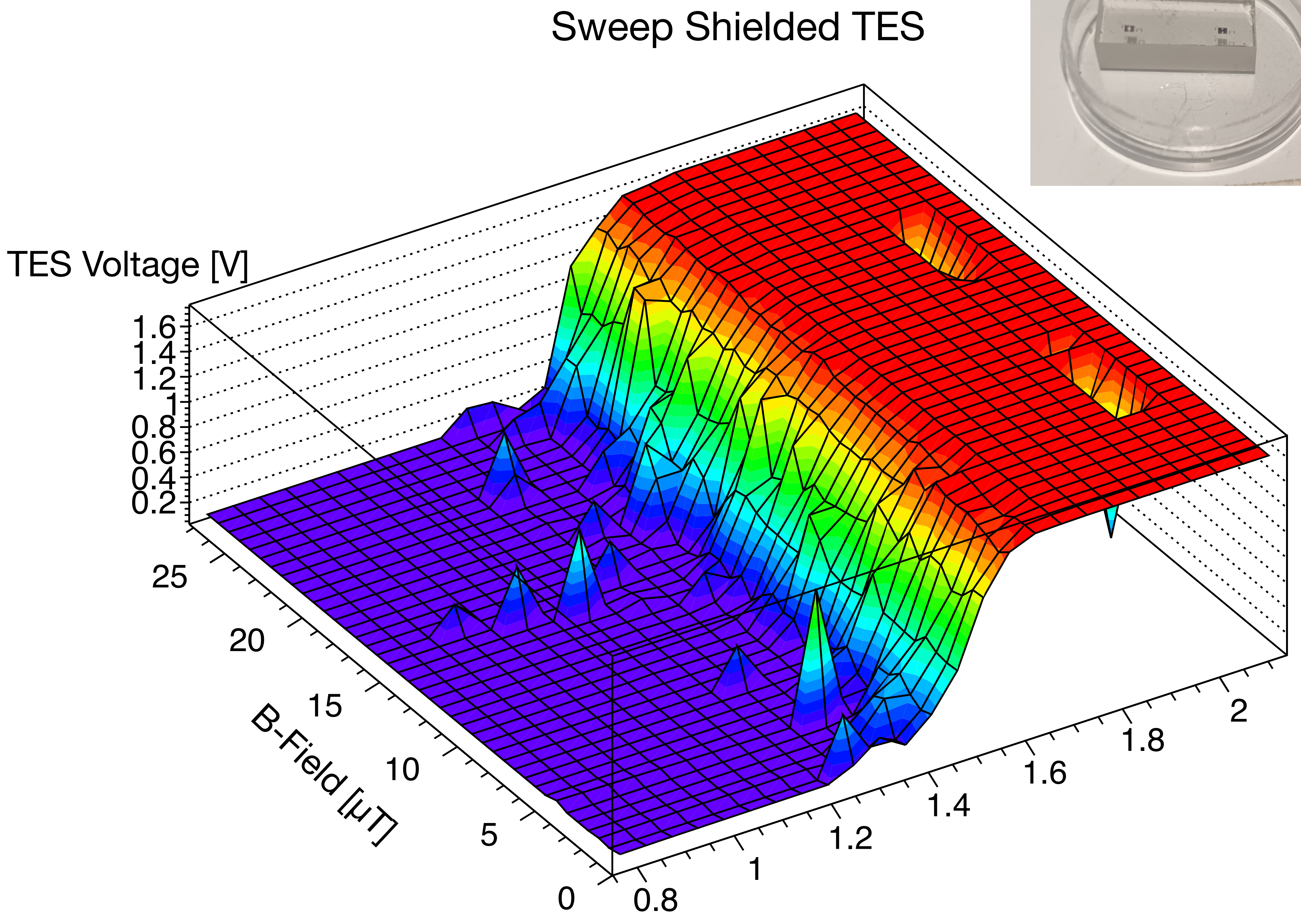


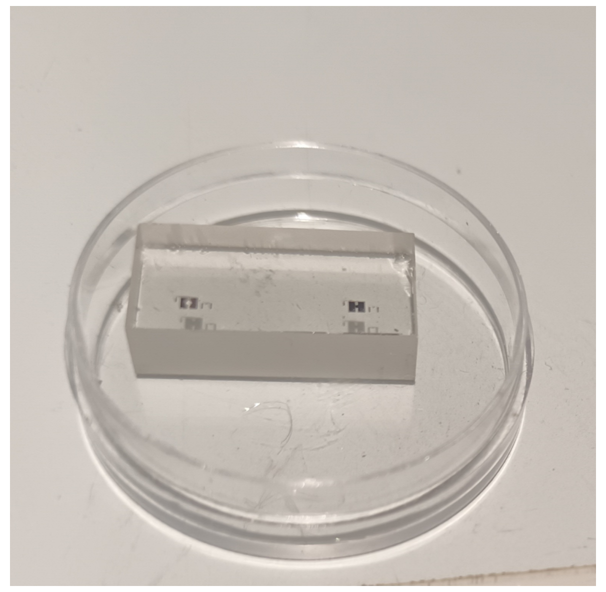


Second configuration: Transition with increasing B-field

- This sample has both the photoresist and the Alu-Shield

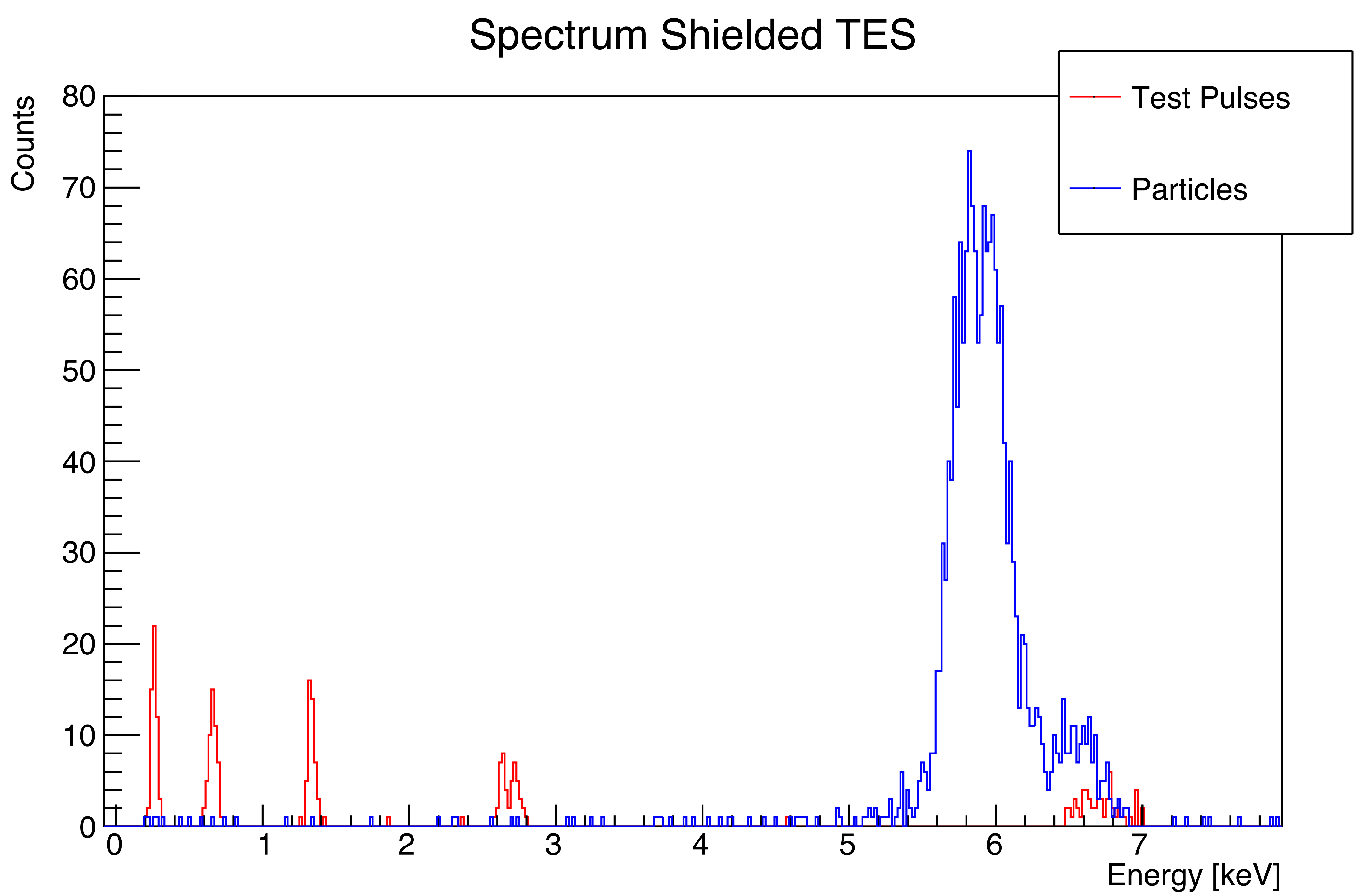




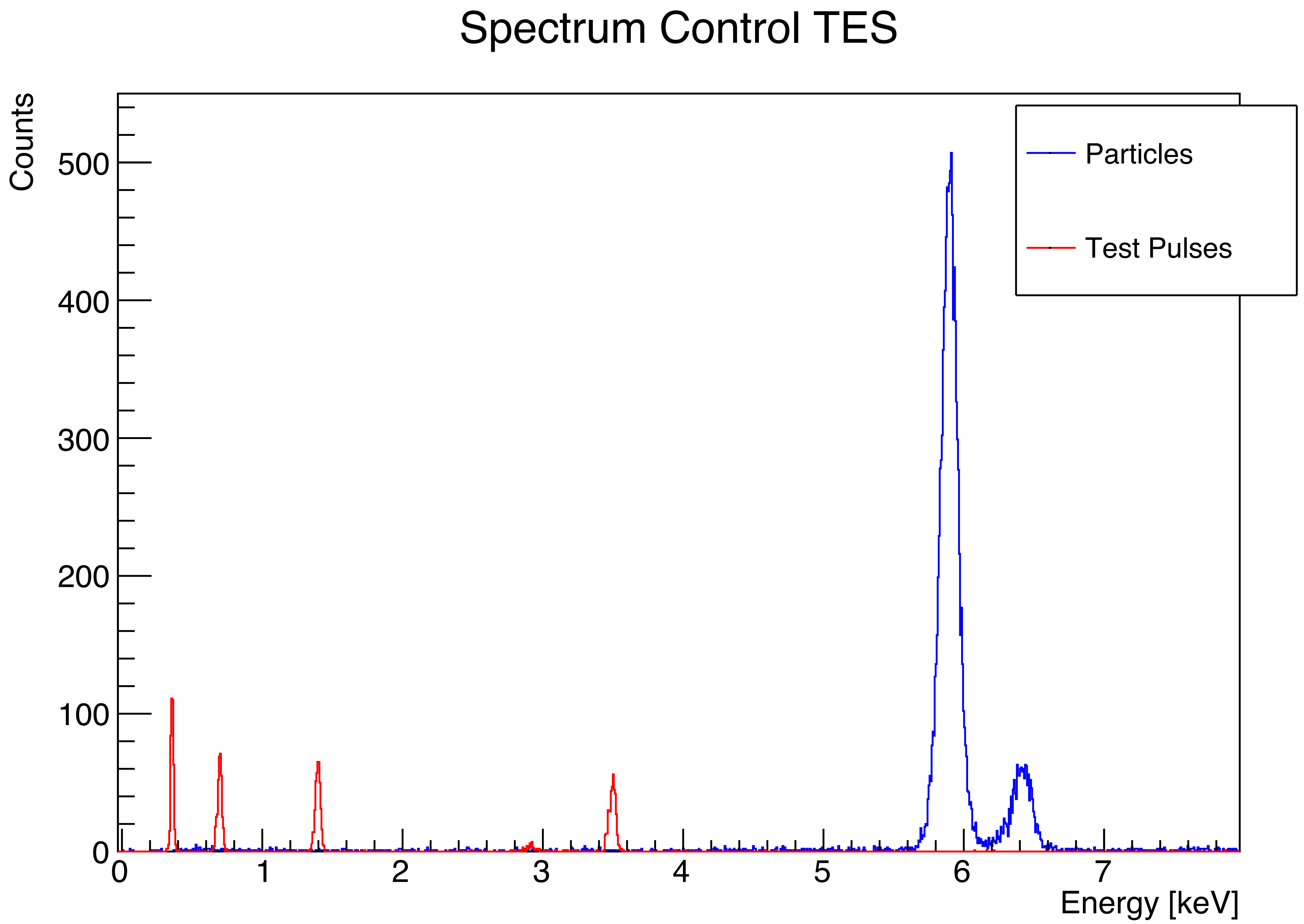


Spectra of the two detectors

- Goal: resolve the ^{55}Fe peaks to perform the calibration (two X-rays peaks at 5.89 keV and 6.49 keV)
- Due to its instability, the data cleaning greatly reduced the data set for the shielded sensor



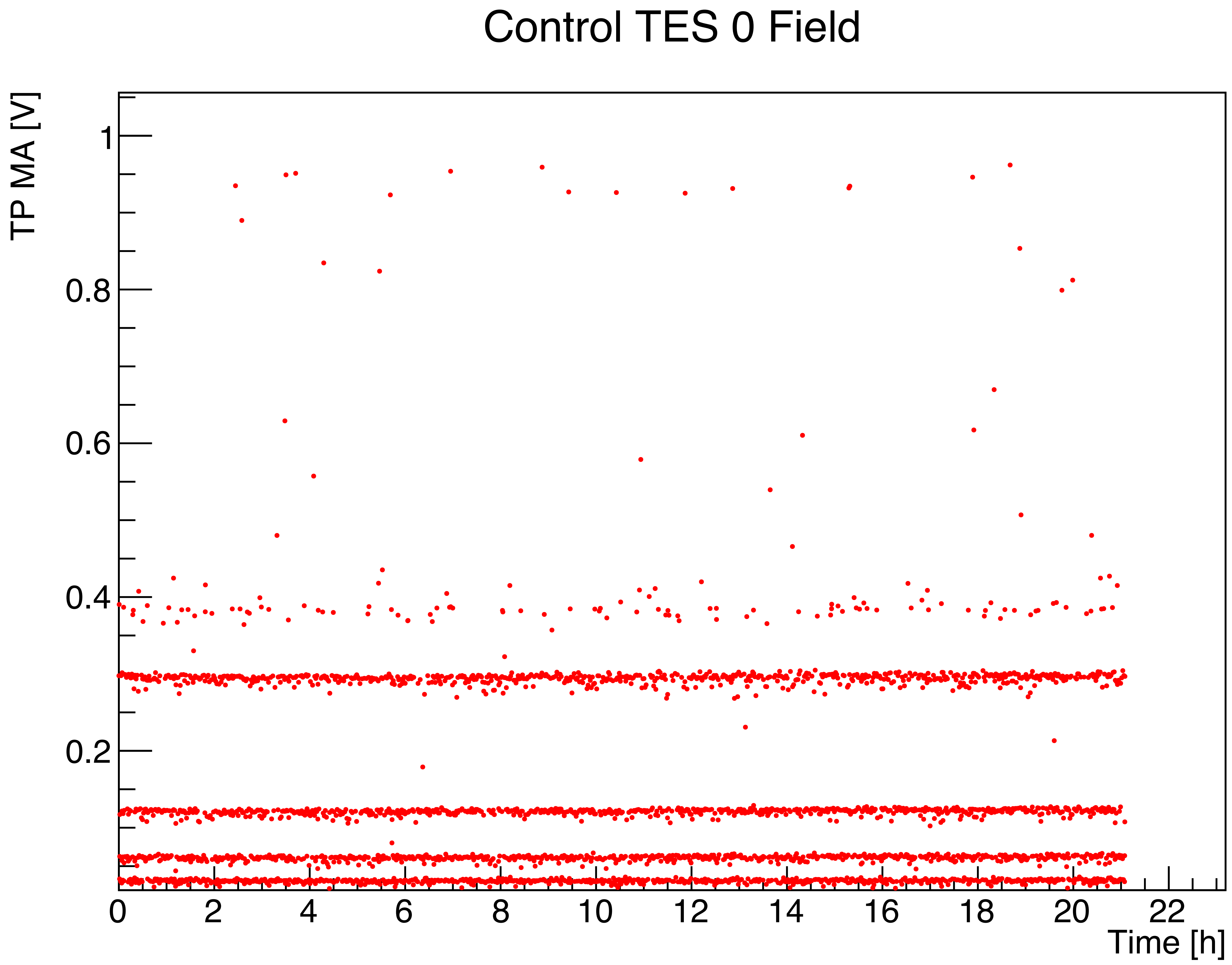
BL Resolution Shield= (28 ± 2)eV

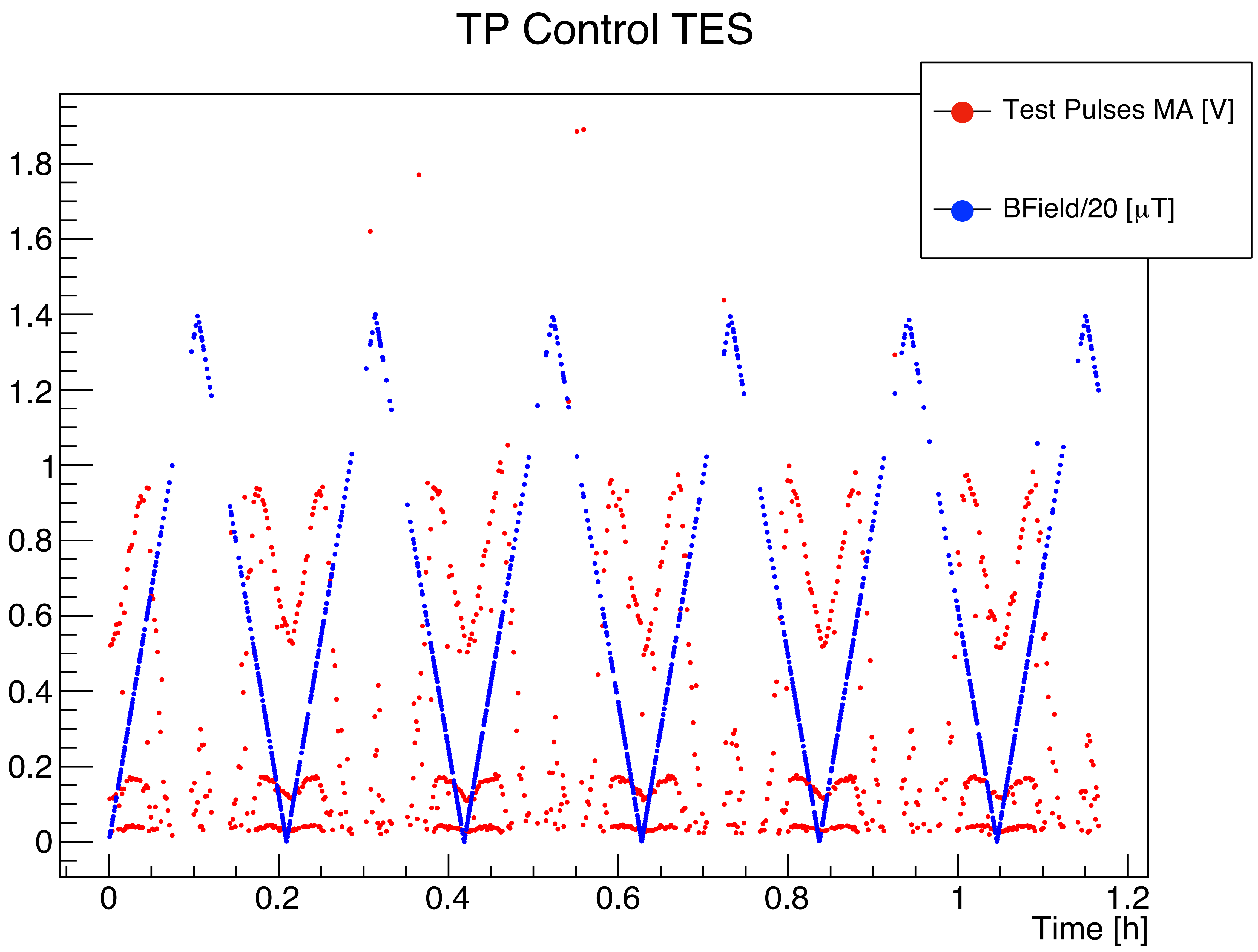


BL Resolution Control = (19 ± 5)eV

Comparison between the performance of the two TESs: Test Pulses

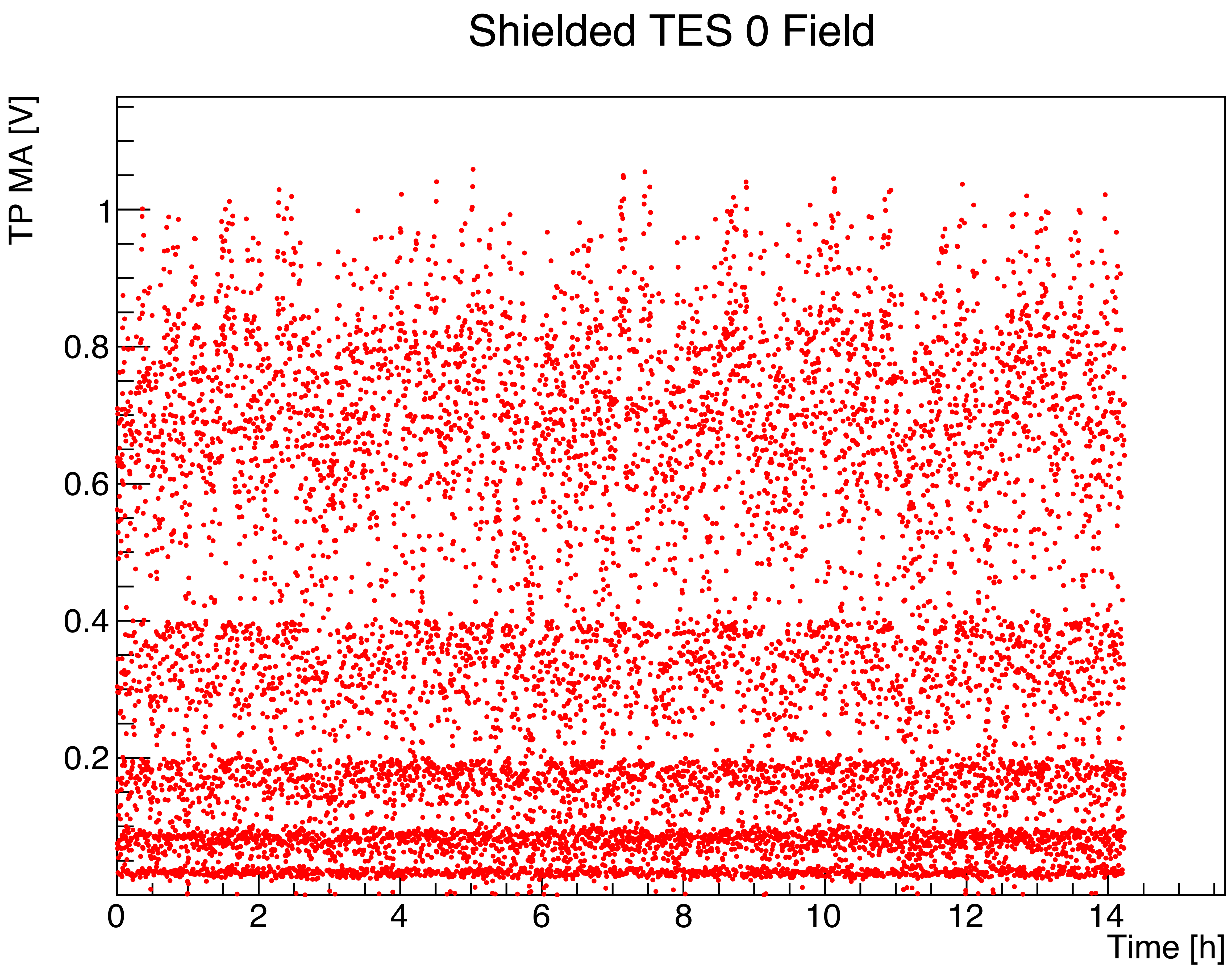
- Variation of the magnetic field from 0 μT to 27.3 μT

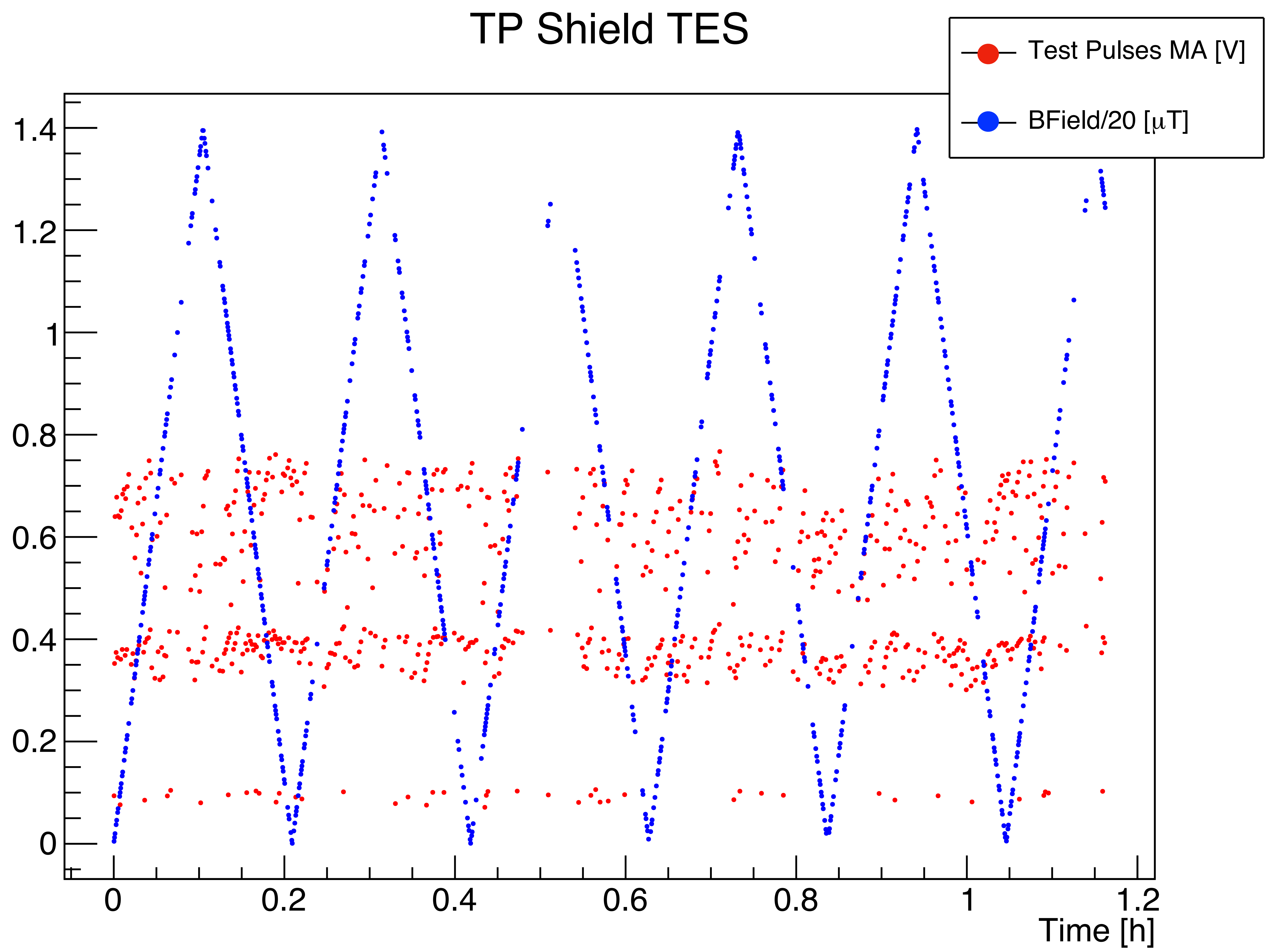




Comparison between the performance of the two TESs: Test Pulses

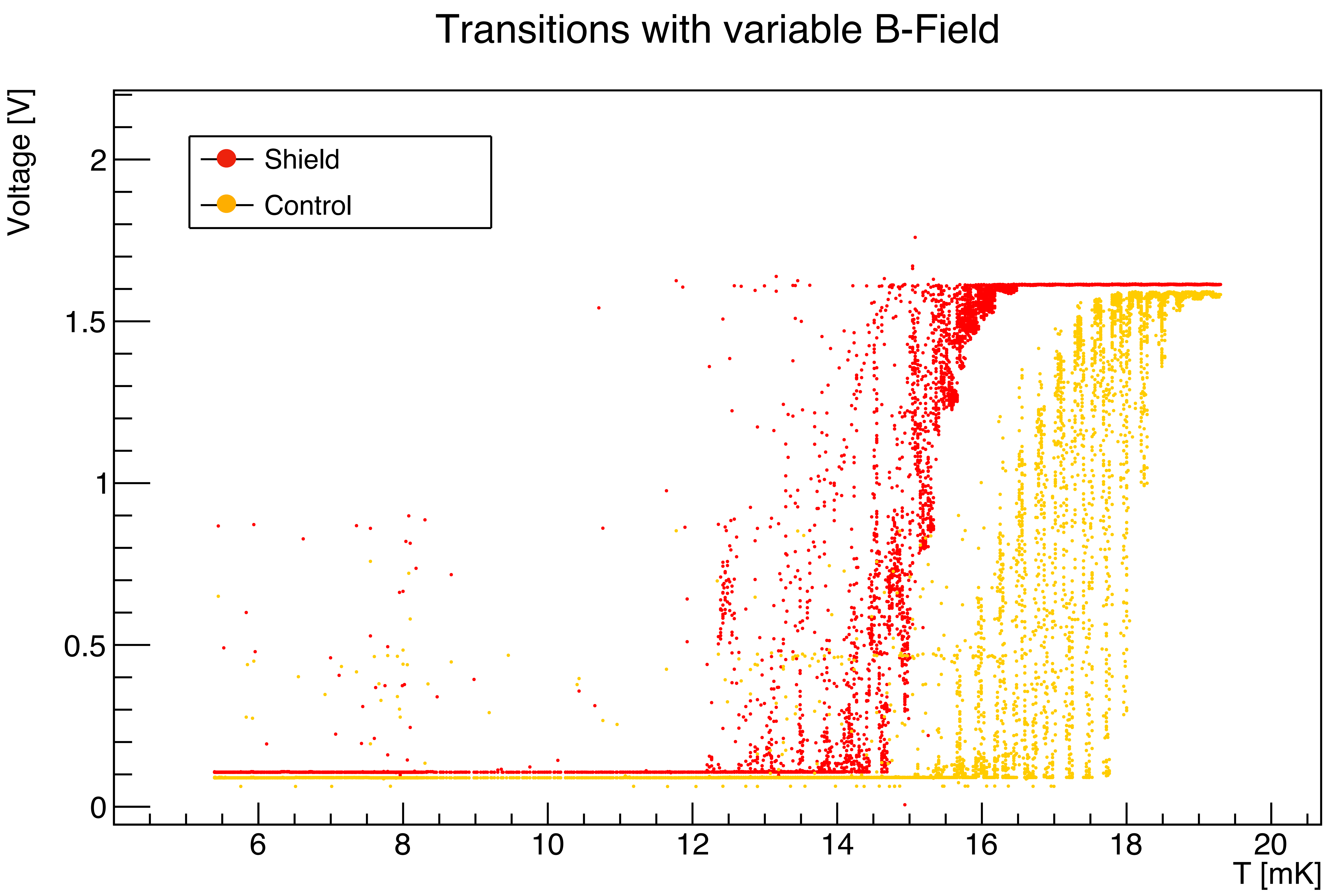
- Variation of the magnetic field from 0 μT to 27.3 μT





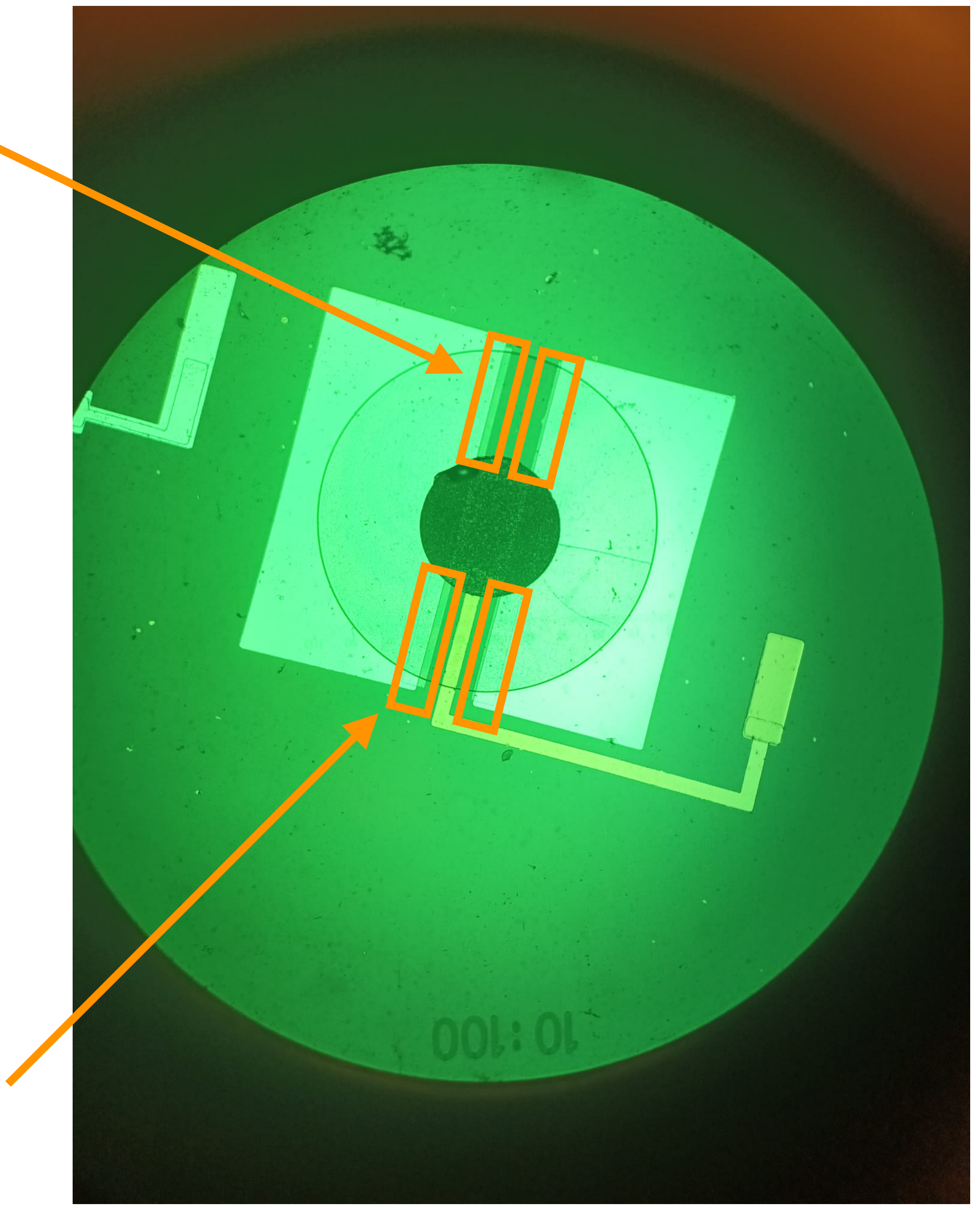
Transition with fast variable field

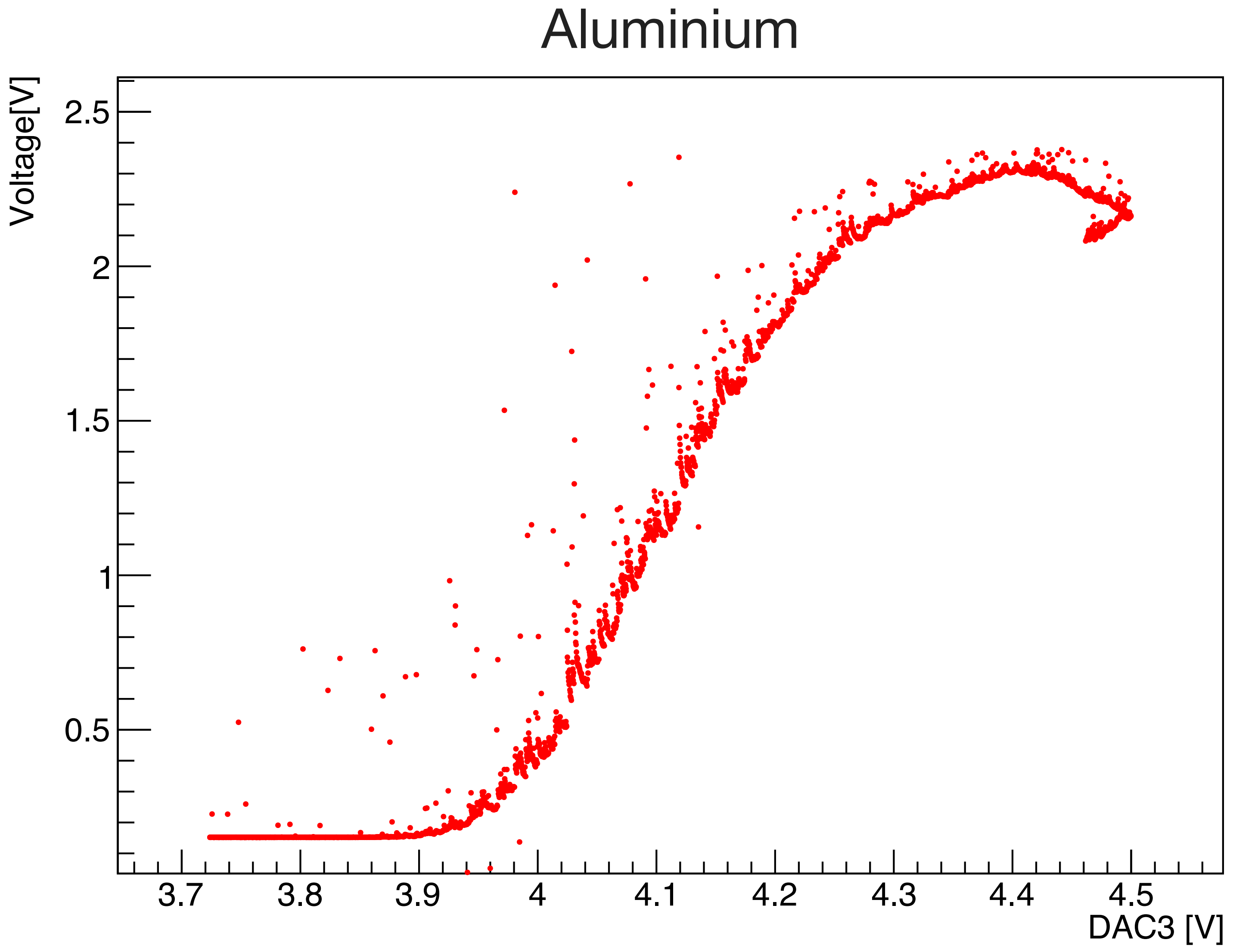
- Field was swept from 0 to 27.3 μT
- Both TESs show a dependence on this variation
- Shielded TES has a weaker dependence on field variations
- Control TES has a broader transition

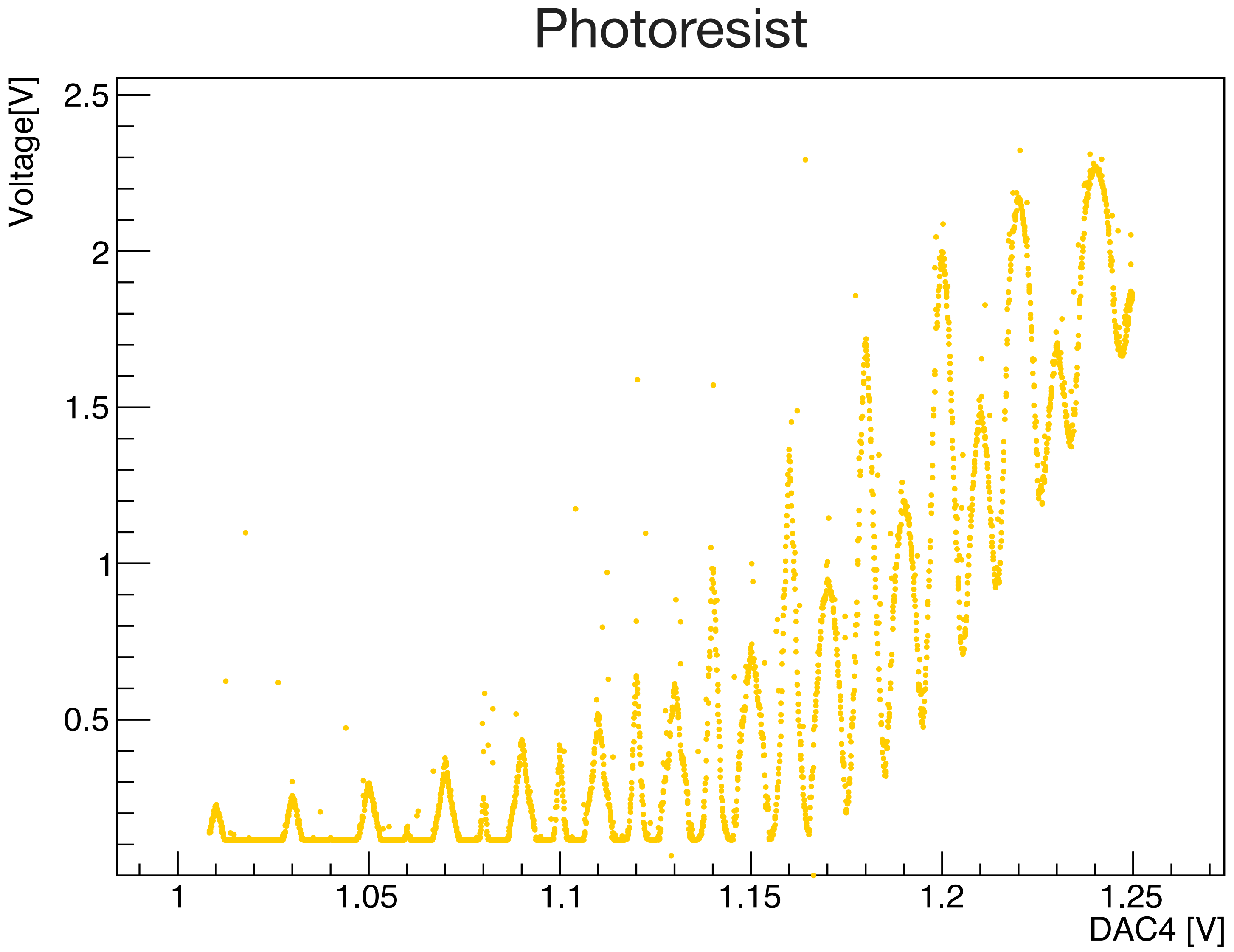


Hypothesis

- Some parts of the sensor are not covered by the aluminium shield
- The same thing is also valid for the detector in the first configuration
- The same test was therefore performed also for the other detector: a very similar result was obtained

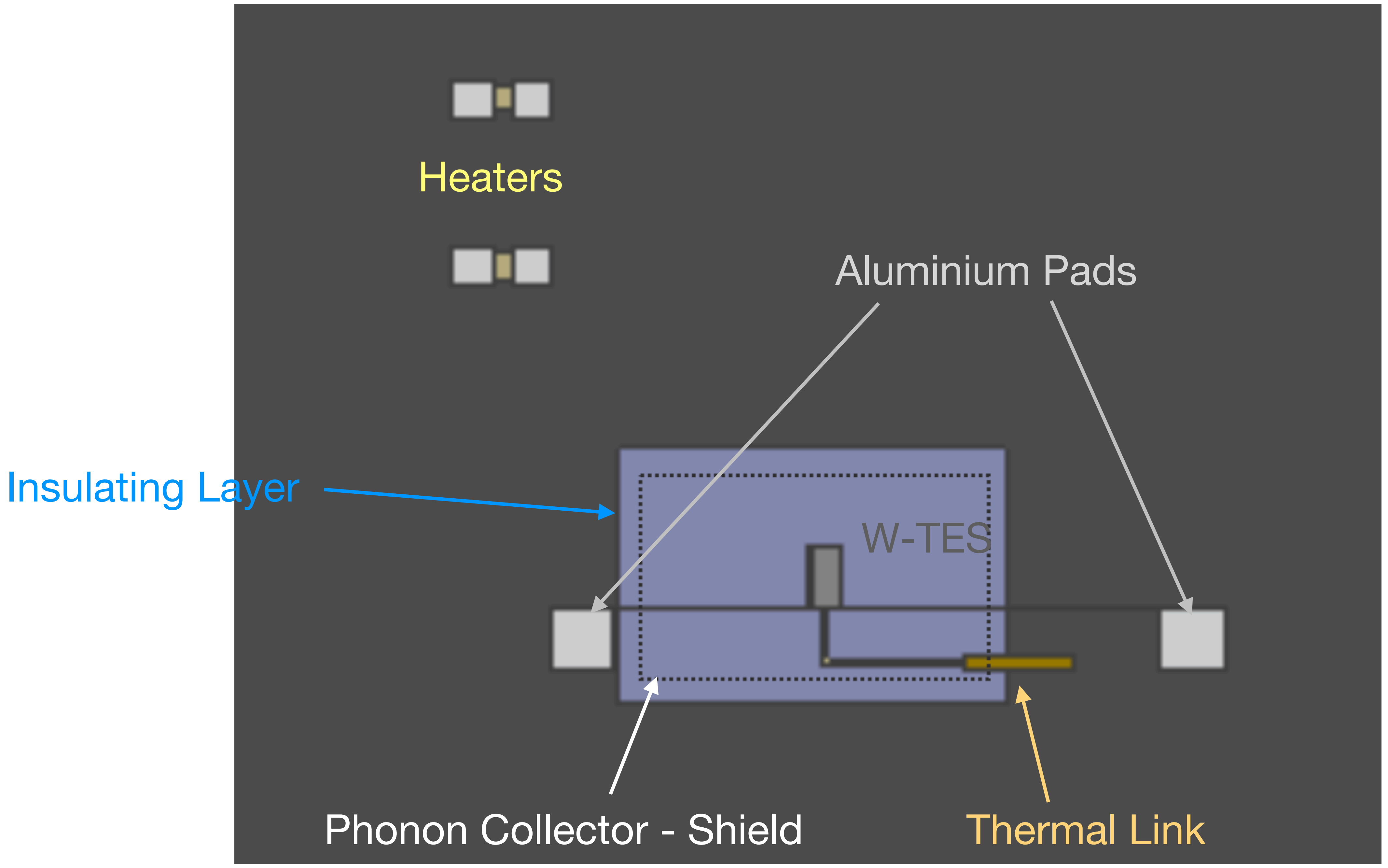


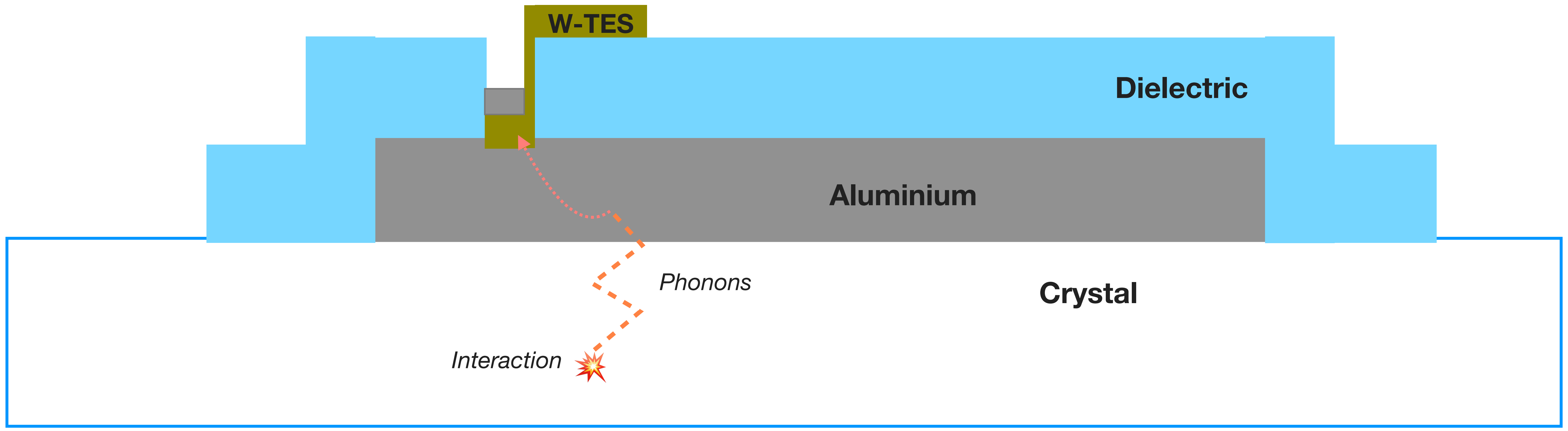




Possible solution

- Use of the phonon collectors with the dual function of shield and phonon collectors





Summary and outlook

- Attempt to build a magnetic shield, adding an insulation layer and an aluminium film to the standard detectors

- The response of the shielded sensor in the presence of external variable magnetic fields is much more stable than the non-shielded one

- In the second configuration it was not possible to make a definitive comparison between the two due to the instability of the shielded sensor

Future Steps:

- New sensors need to be produced in order to accumulate statistics and understand if the shield actually reduces their stability

- Attempt to build the TES on top of the insulation layer to use the aluminium with the dual function of shield and phonon collector

THANKS FOR YOUR ATTENTION

BACK UP SLIDES

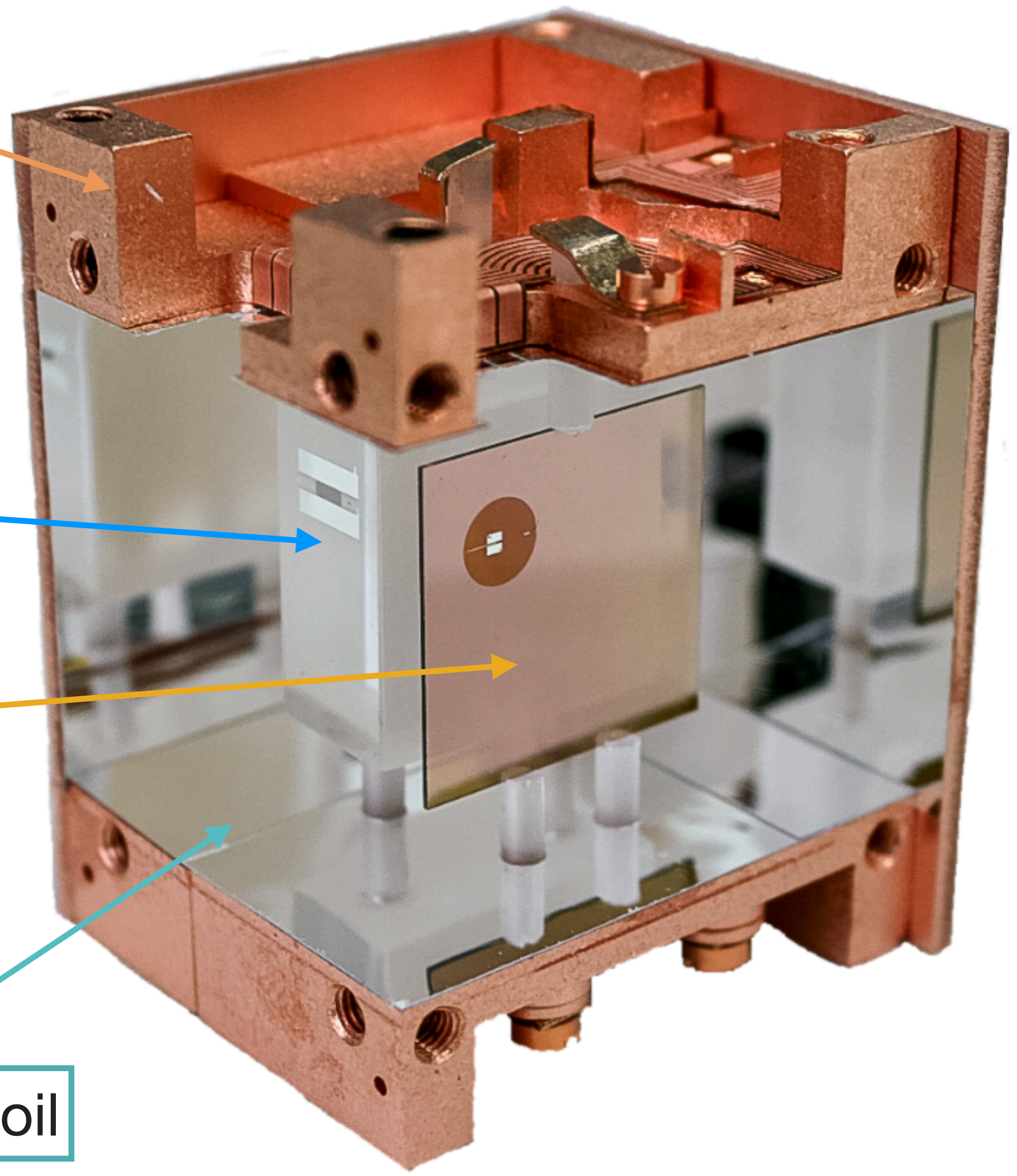
CRESST detectors

- Incident particles deposit energy in the crystal in the form of:
  - Lattice excitation
  - Scintillation light

Two detectors

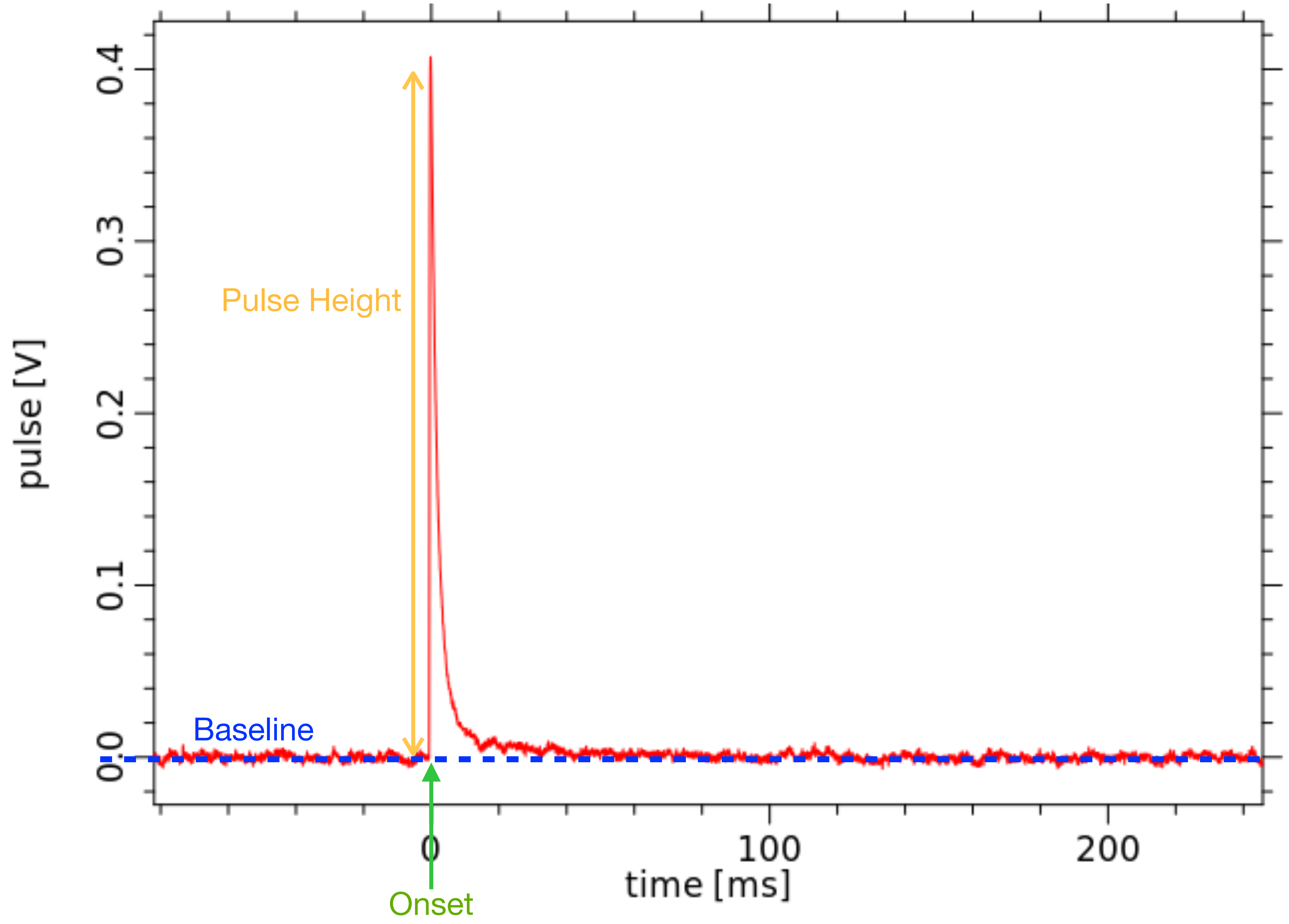
- Phonon detector
  - $CaWO_4$ scintillating crystal
  - Detects the phonon signal (~90%)
- Light detector
  - Silicon on Sapphire substrate
  - Detects the light signal (few %)

Particle discrimination

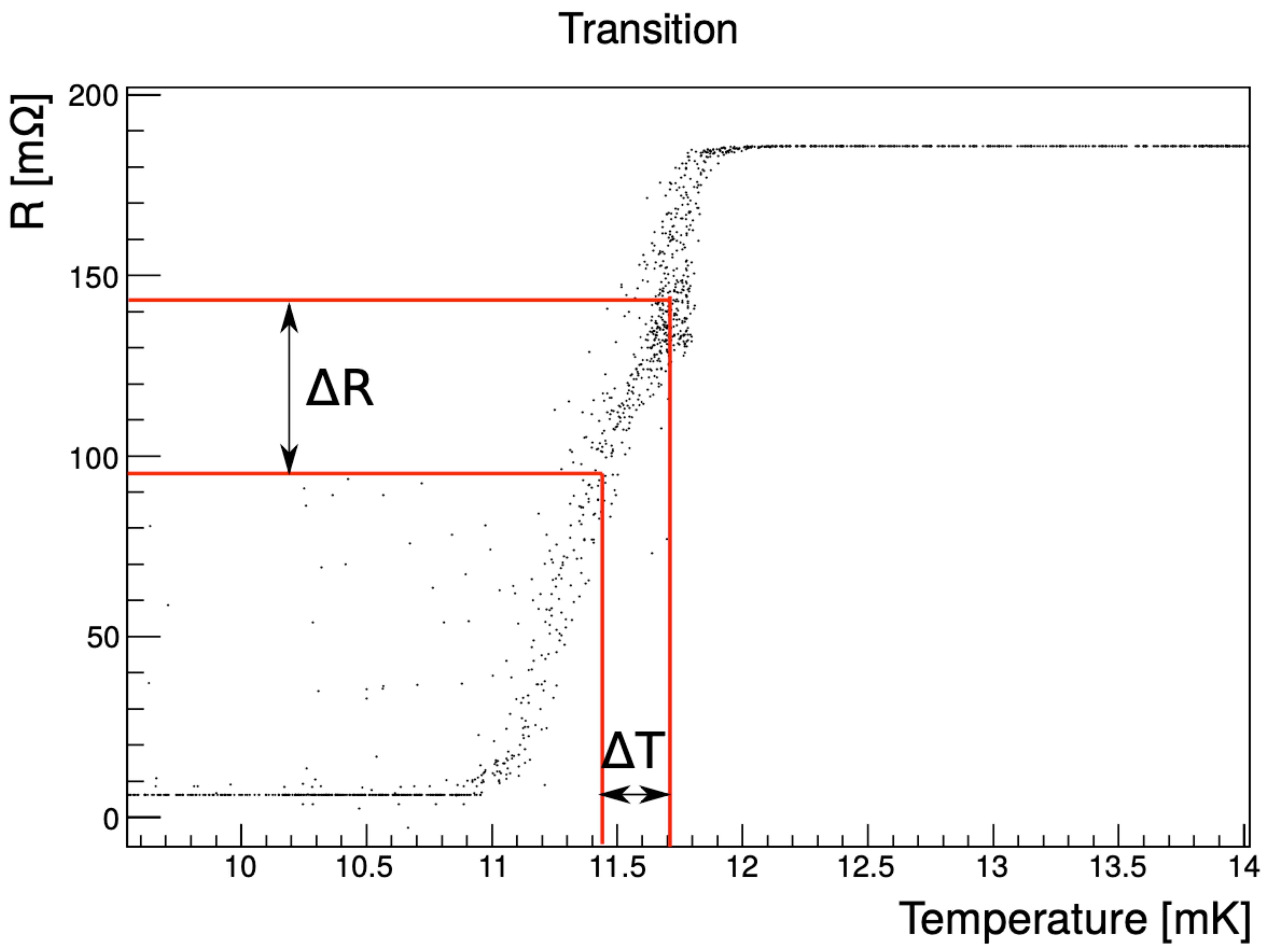


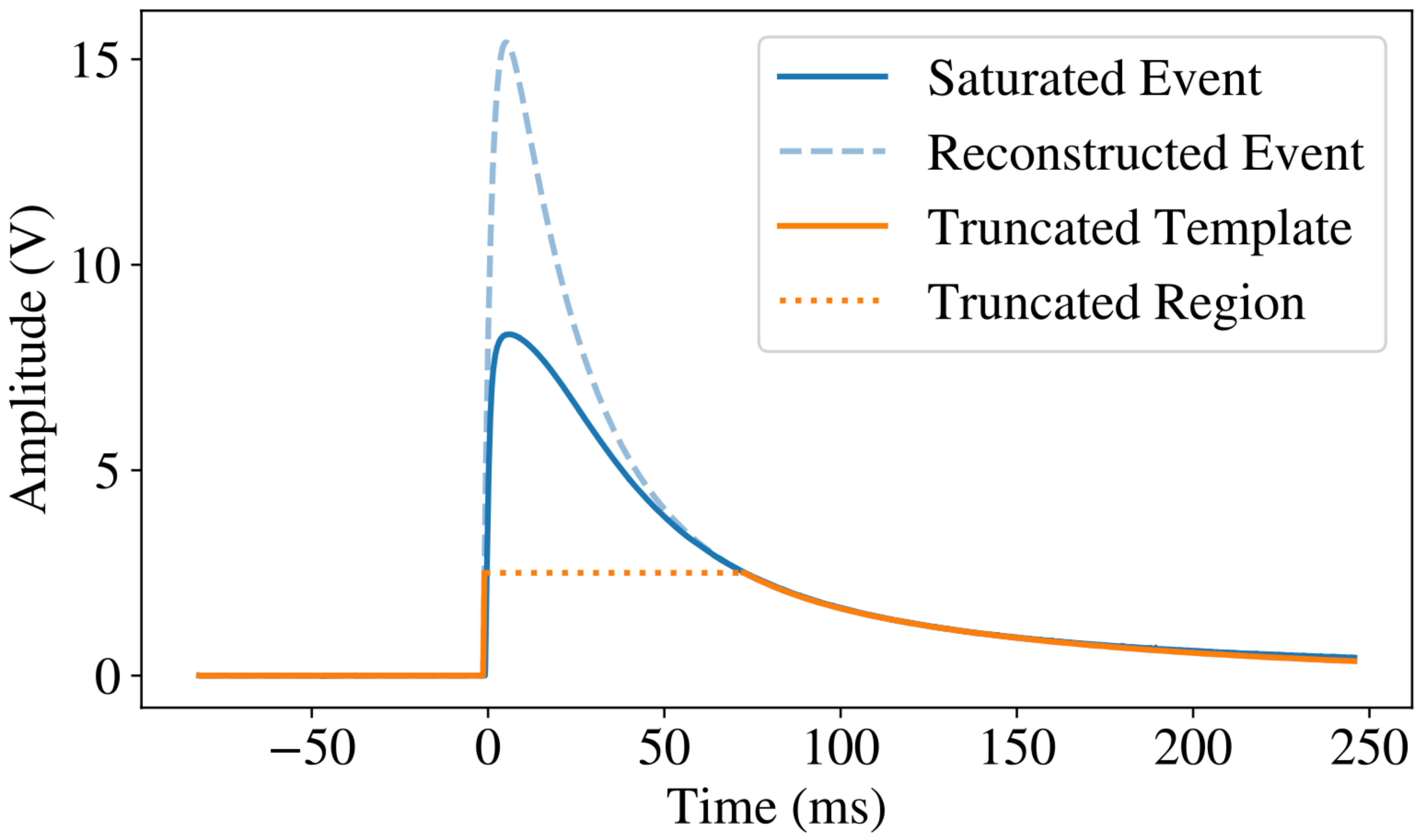
Calibration of the two sensors: data cleaning

- For the calibration of the sensors, a ^{55}Fe source is used (two X-rays peaks at 5.89 keV and 6.49 keV)
- To have a reliable energy estimation of the pulses, the dataset must be cleaned removing events with distortions
- The pulse amplitude is therefore estimated using appropriate analysis techniques (truncated fit)



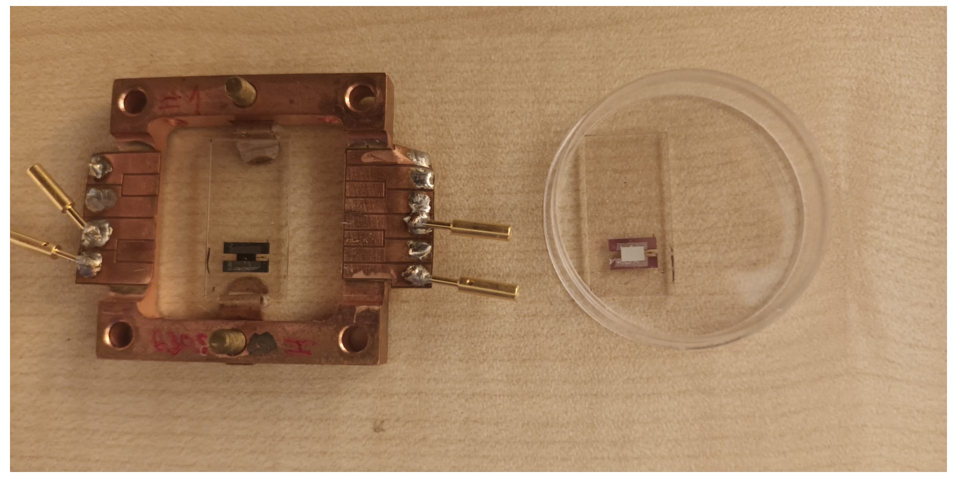
Truncated fit

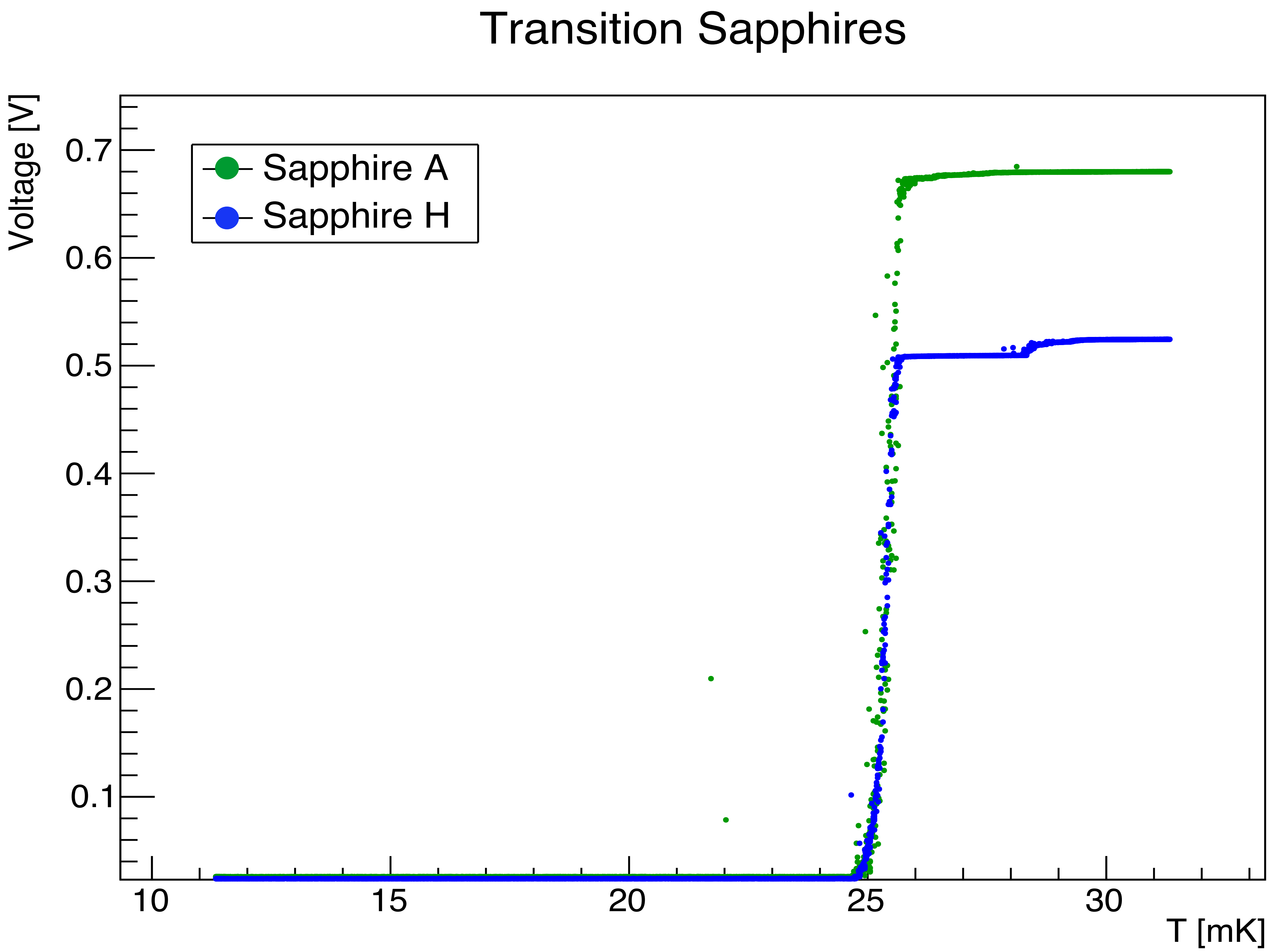


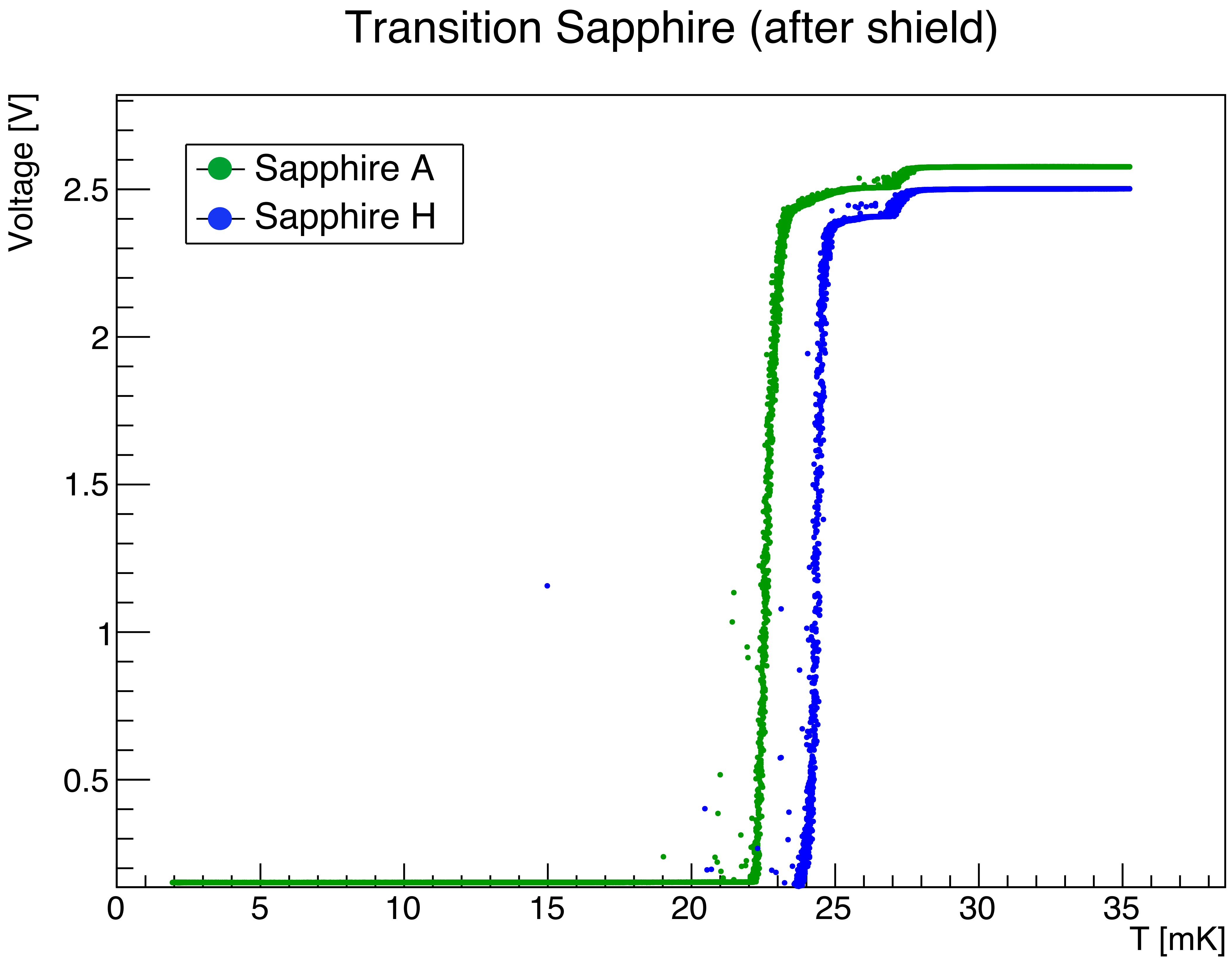


Side Effects: shift in the transition temperature

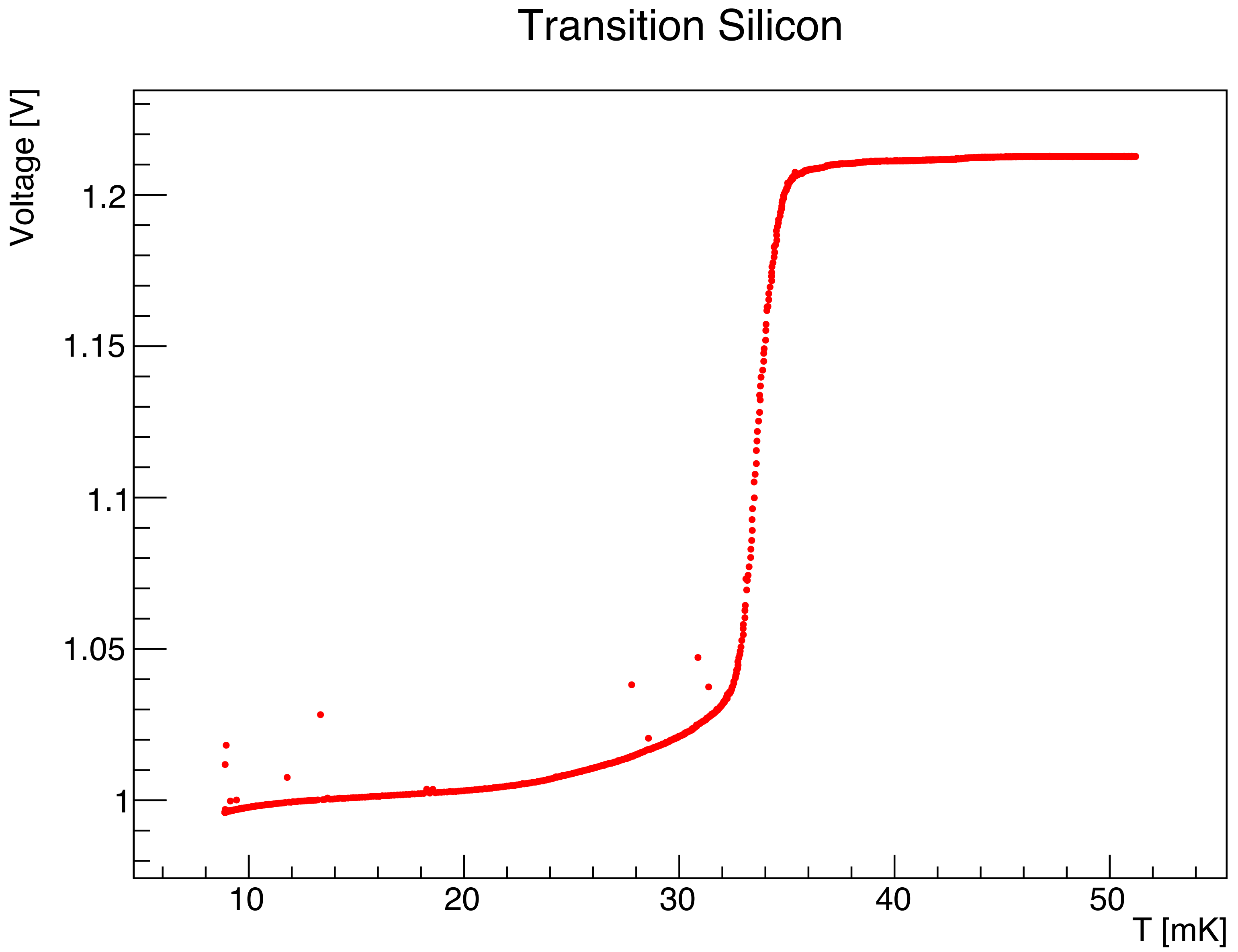
- Sapphire A: sample with both layers
- Sapphire H: sample with insulation layer only

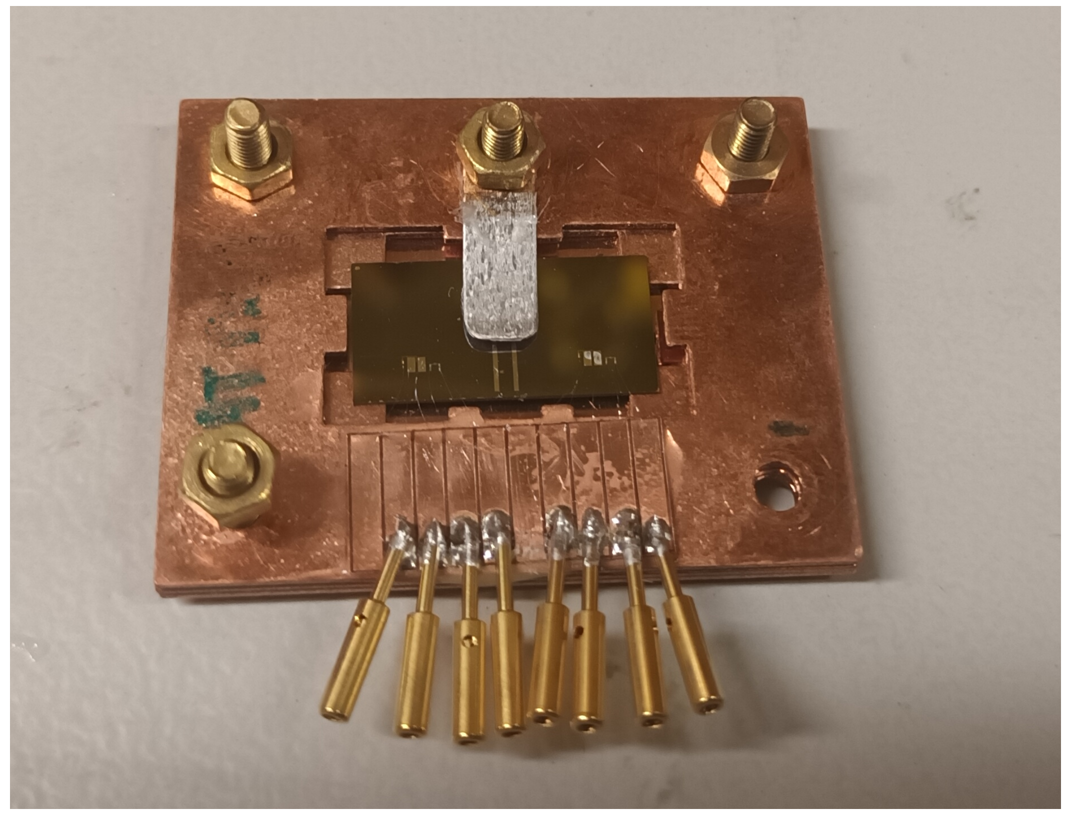


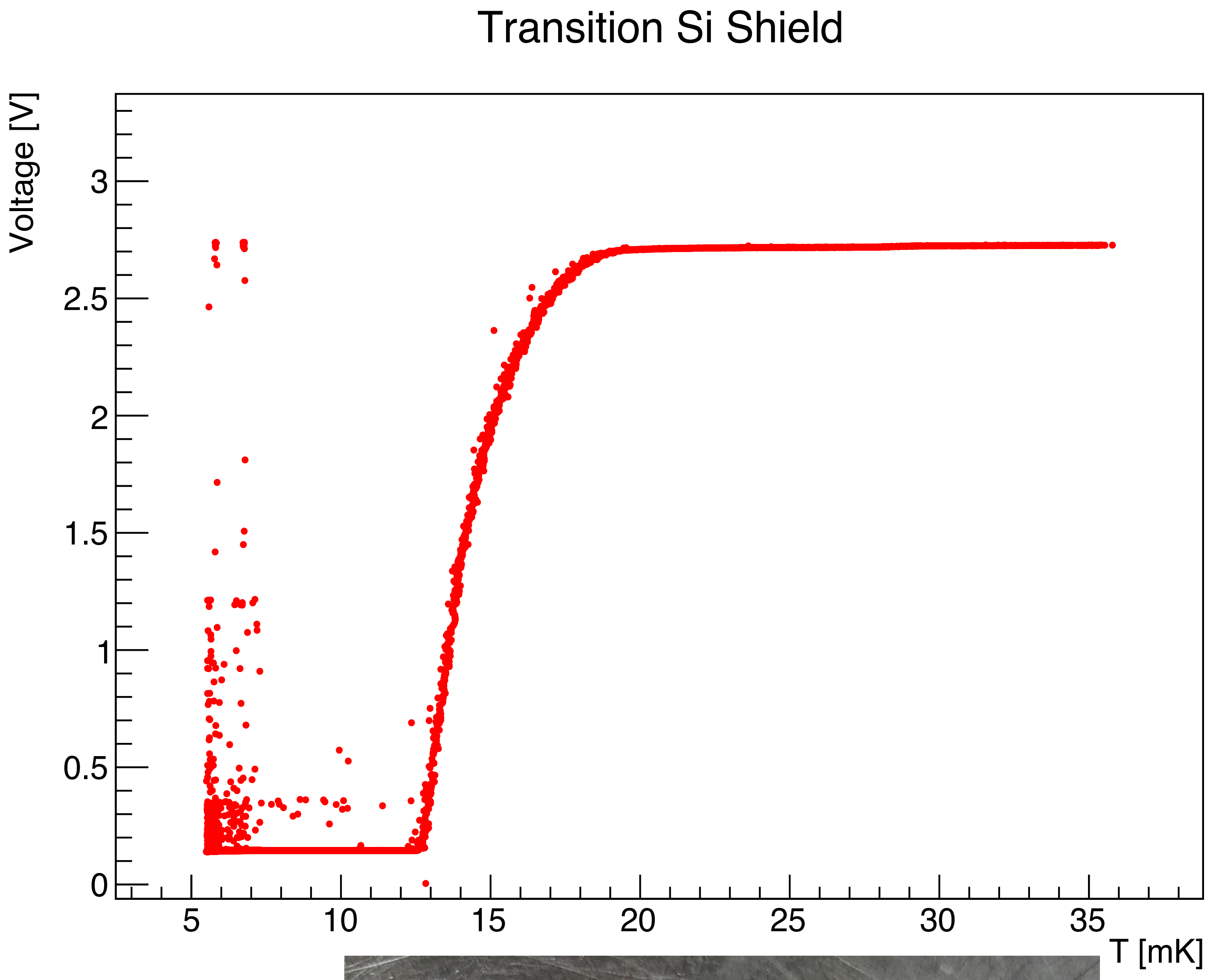


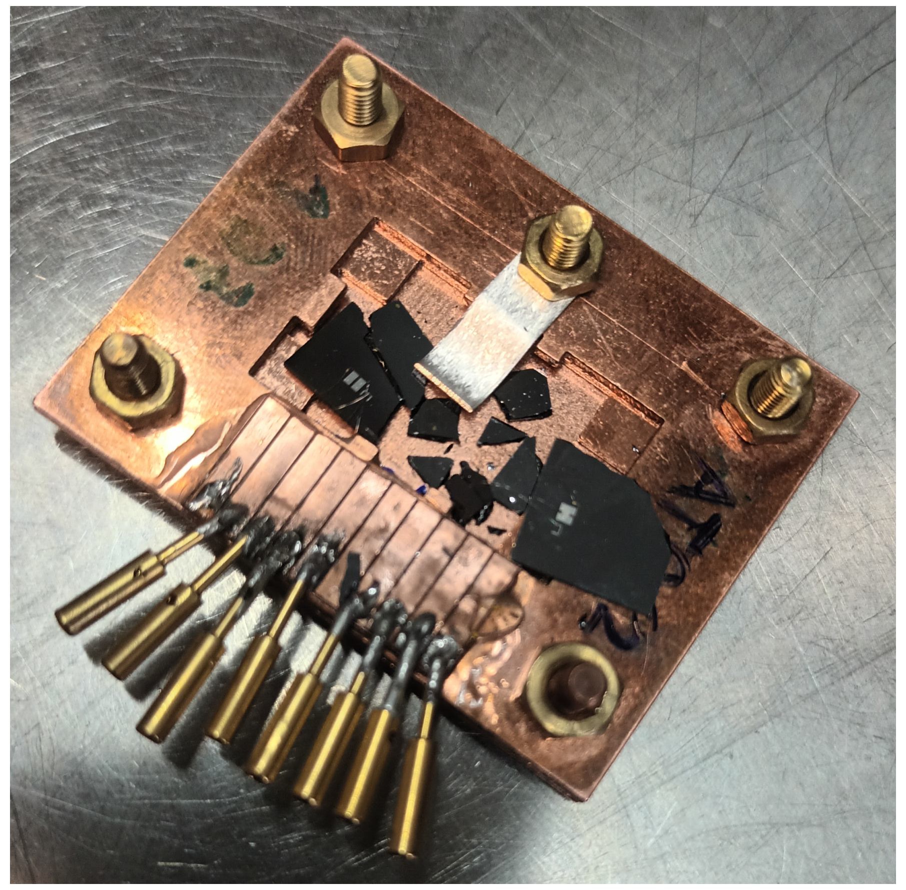


Silicon samples

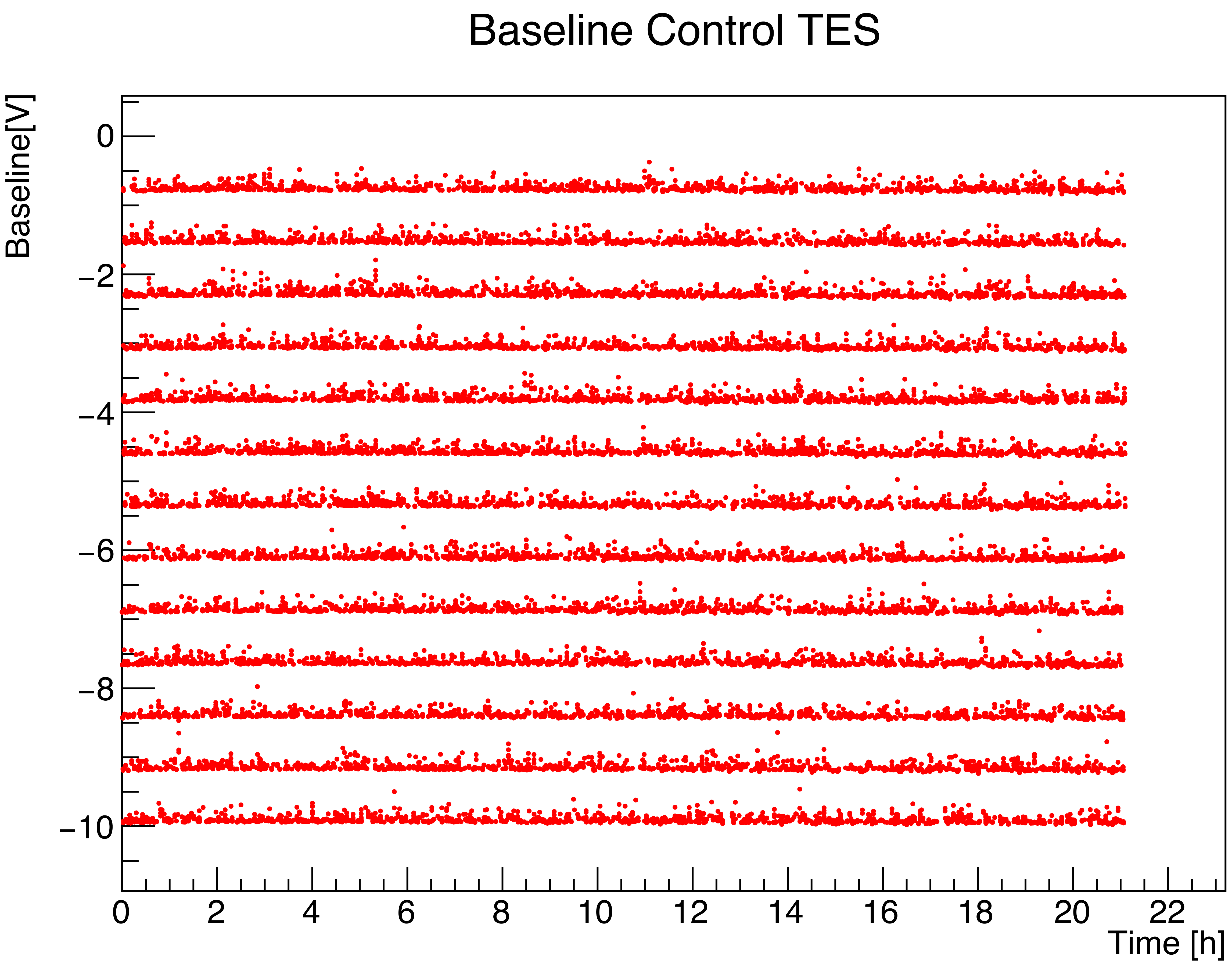


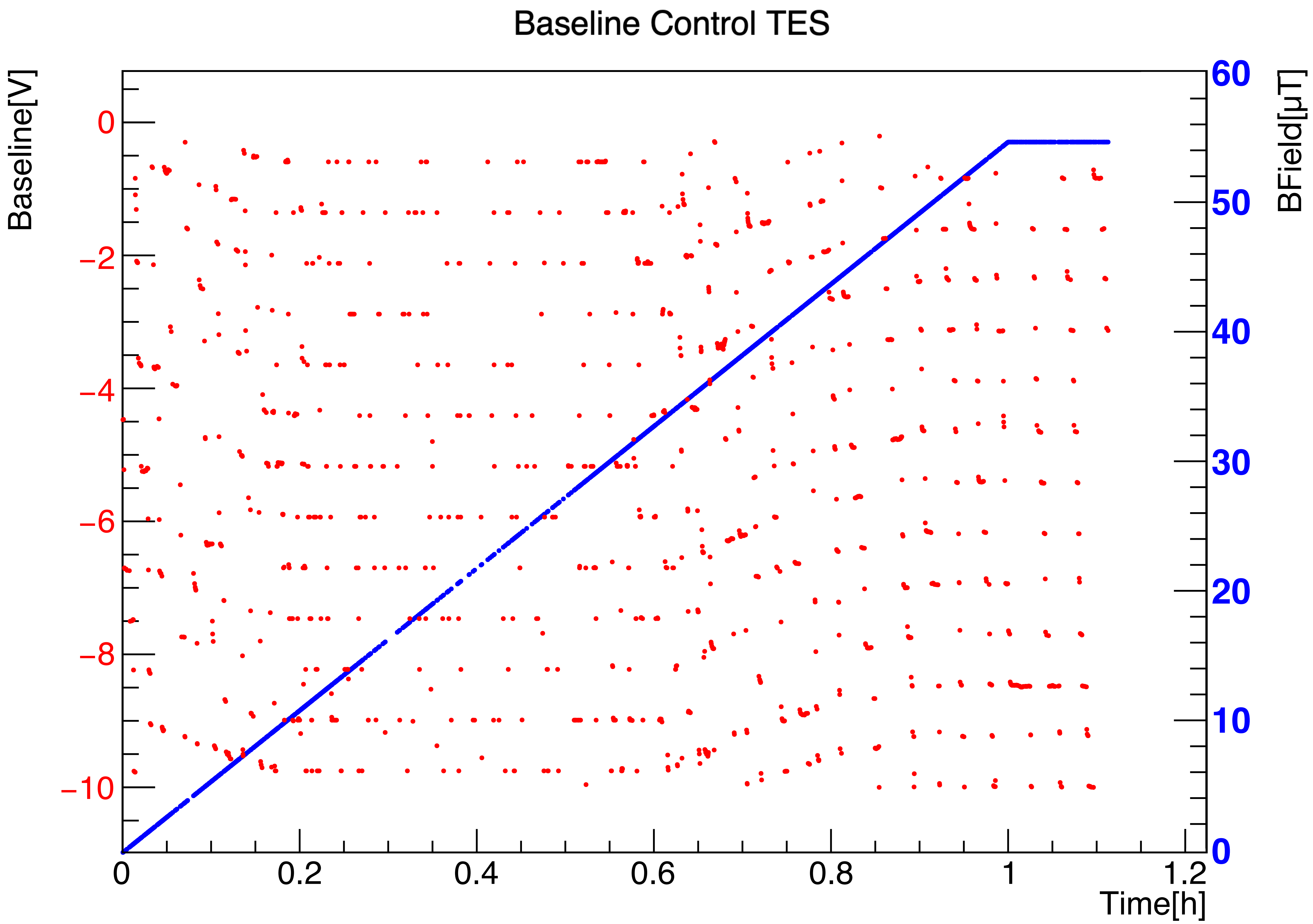




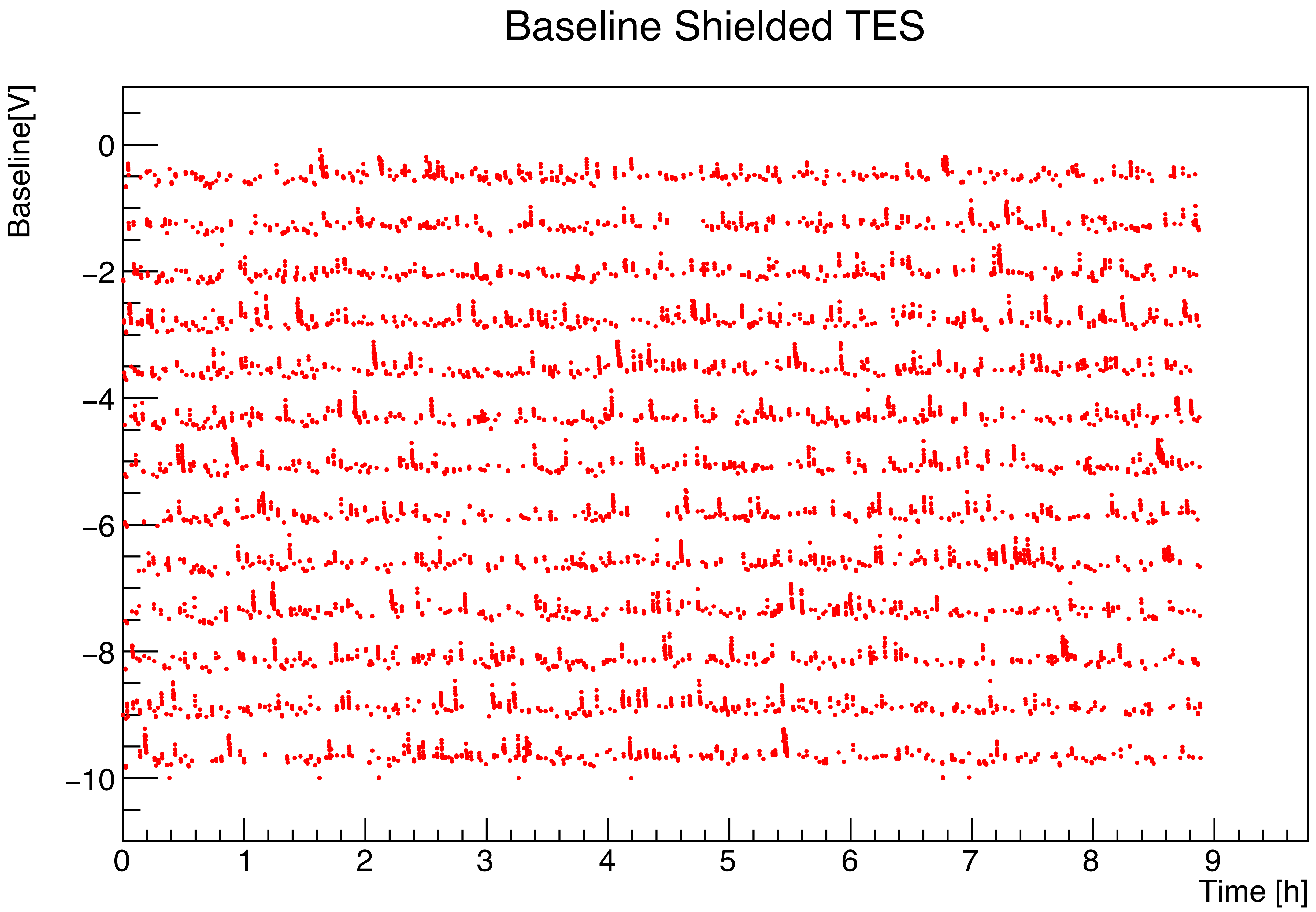


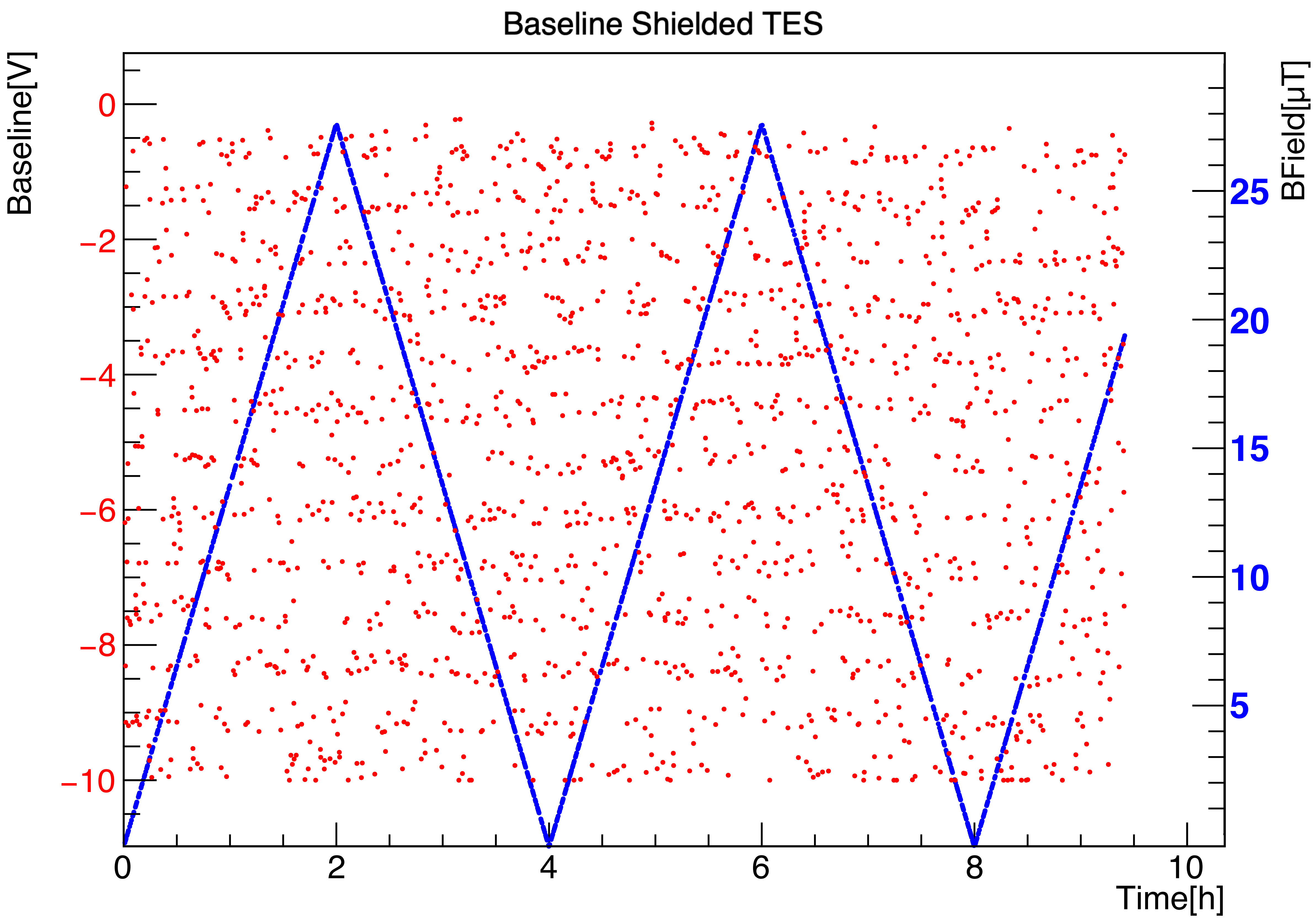
Comparison between the performance of the two TESs: Baseline



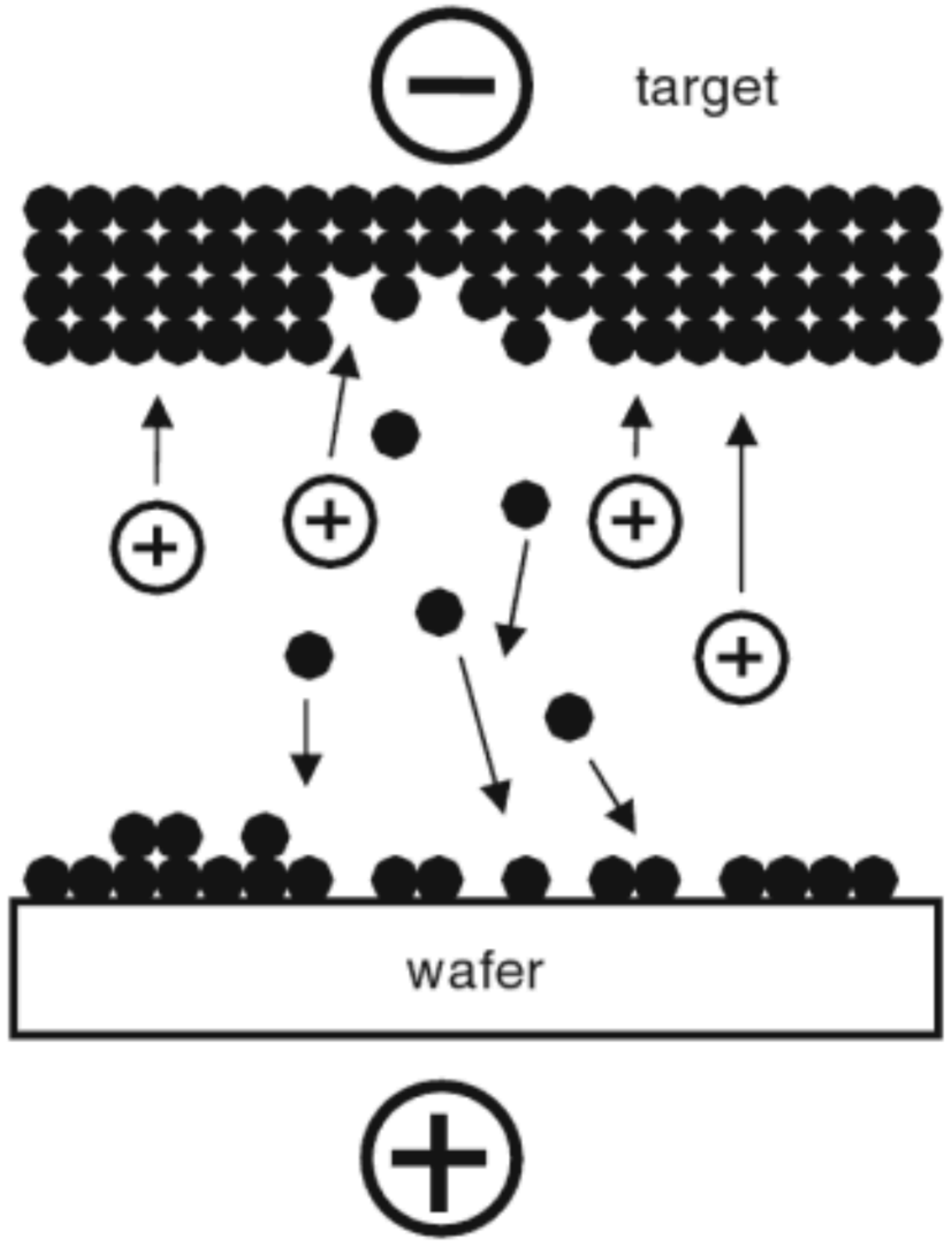


Comparison between the performance of the two TESs: Baseline

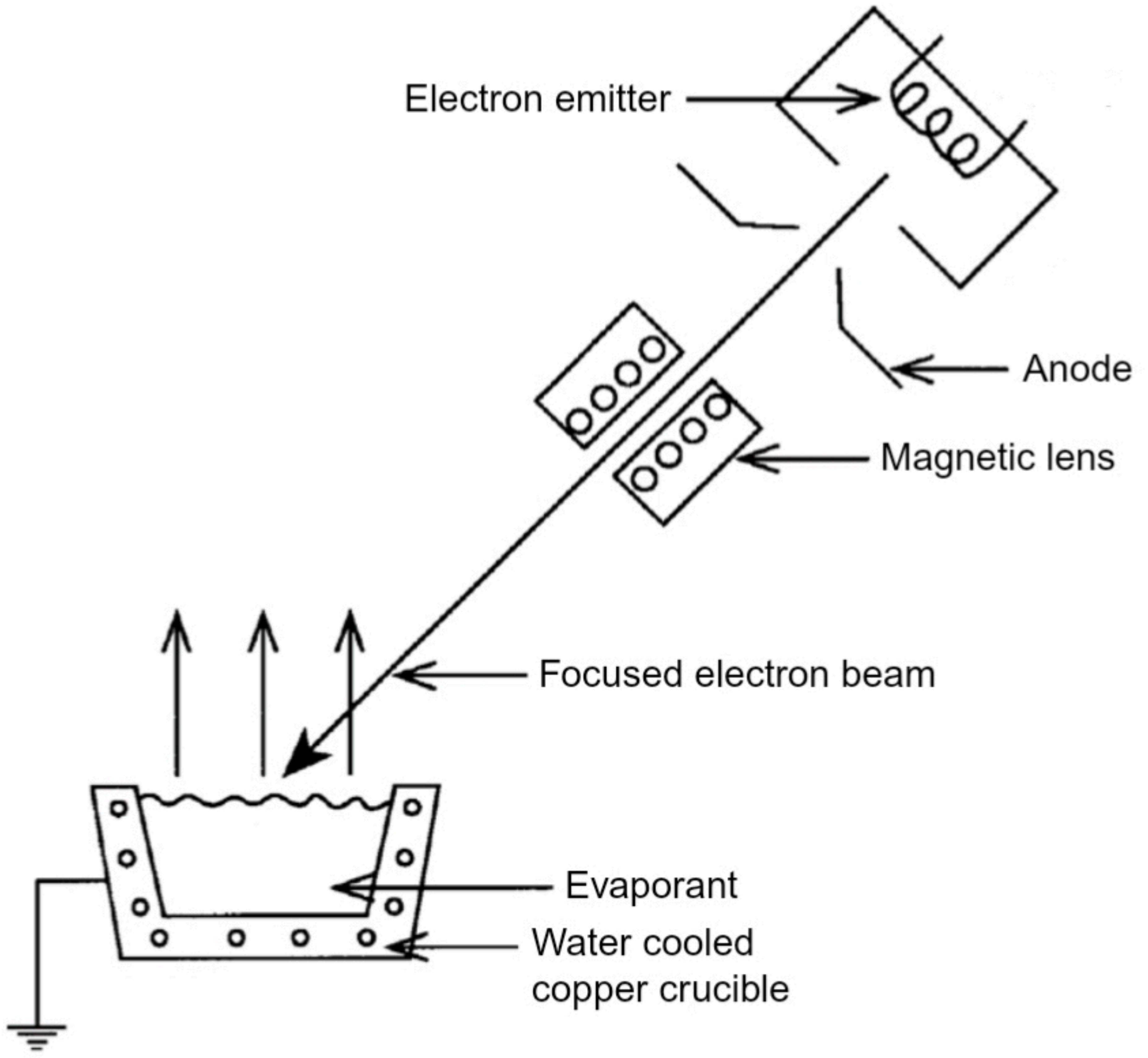




Deposition Techniques



Sputtering



Evaporation