SiC Studies at CERN:

IV/CV after Extreme Fluences and Establishment of a SiC Source Test Setup with Initial Results

2nd DRD3 week on Solid State Detectors R&D // 2024-12-05

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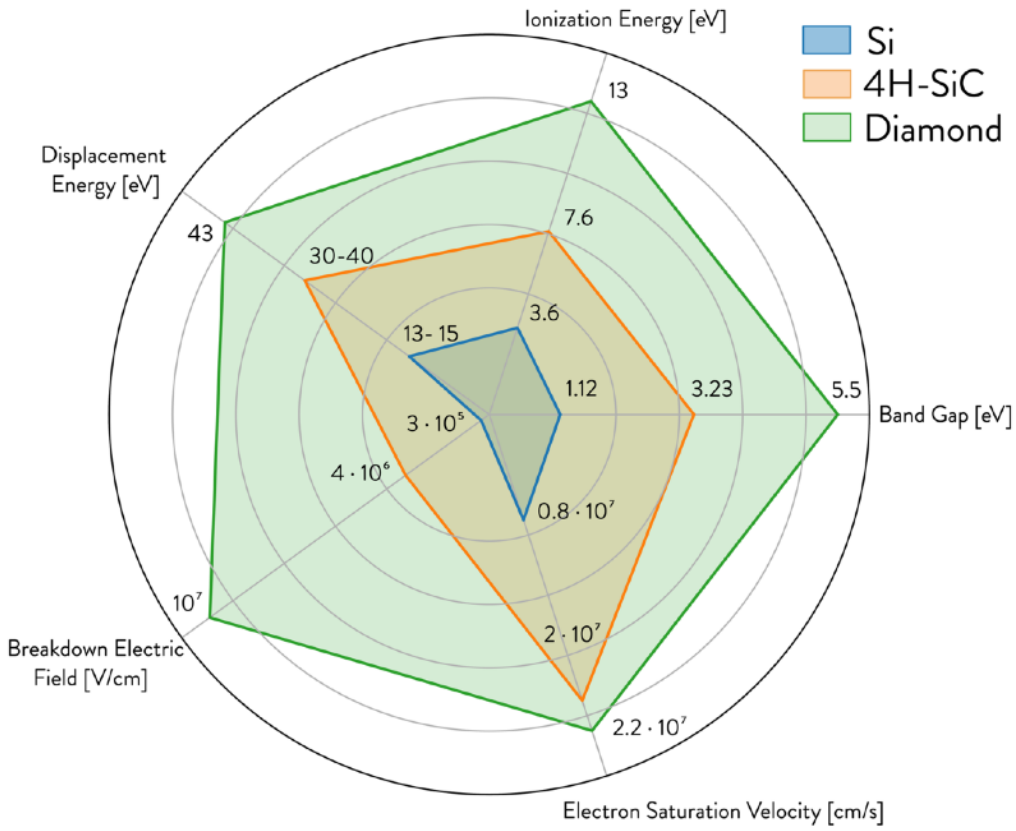
CERN

Reminder: SiC Sensors for HEP

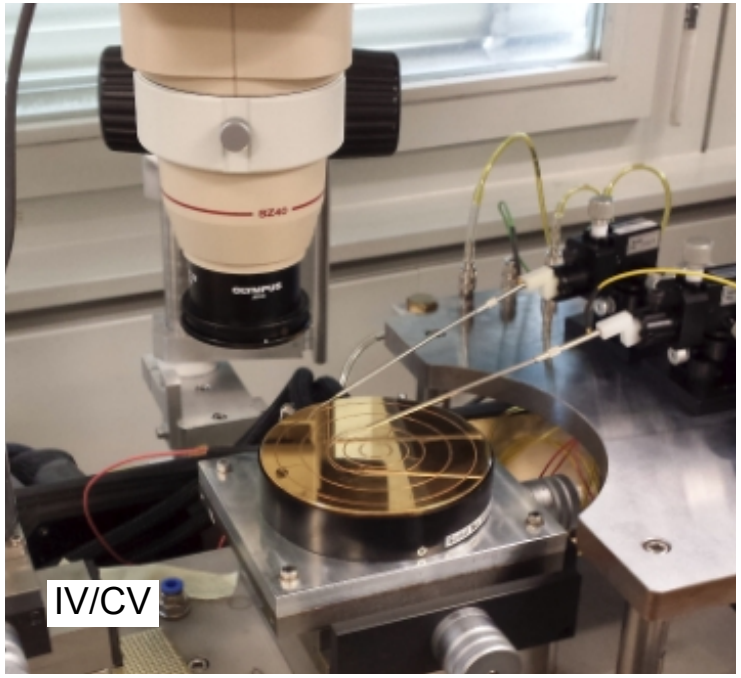
- Wide band gap semiconductor (3.26 eV)
  - + low leakage currents
  - + insensitivity to visible light
  - + high breakdown field and saturation velocity,
  - + potentially higher radiation hardness, no cooling needed after irradiation
  - - high ionisation energy
  - - limitations in epi layer thickness and resistivity
- Material not new but now available in higher quality (mostly) due to renewable energy technologies and automotive

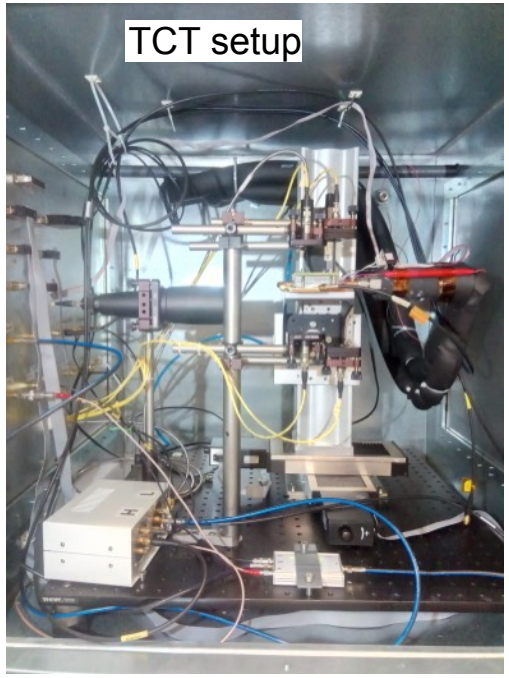


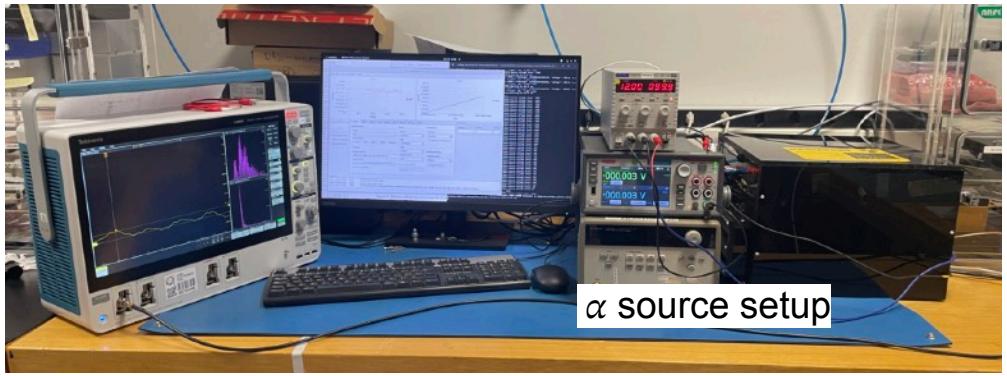
[Front. Phys., 2022]

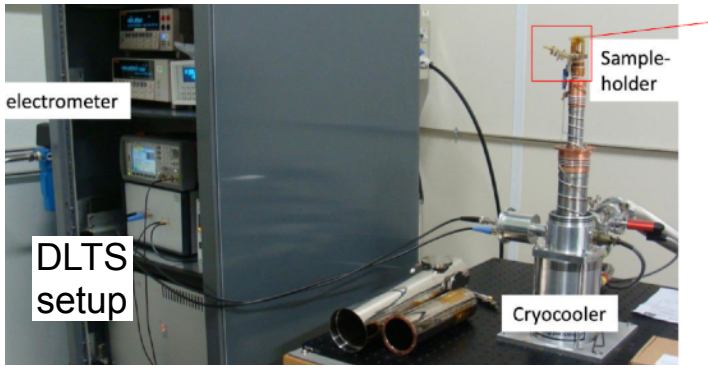
Sensors and setups

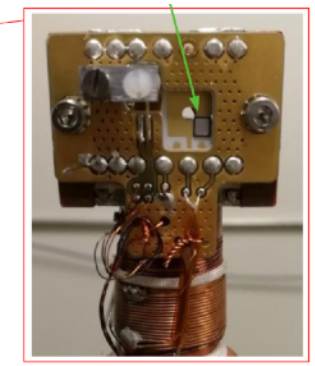
- sensors from RD50 SiC-LGAD common project coordinated by HEPHY [T. Bergauer, 41st RD50 workshop]
- CERN's contribution: characterisation of SiC sensors
- IV/CV measurements + α radiation tests [this talk], (UV-)TCT [E. Arnqvist], Deep Level Transient Spectroscopy (DLTS) + Thermally Simulated Current (TSC) [N. Sorgenfrei, 1st DRD3 week], defect investigations [I. Pintilie, 2nd DRD3 week]





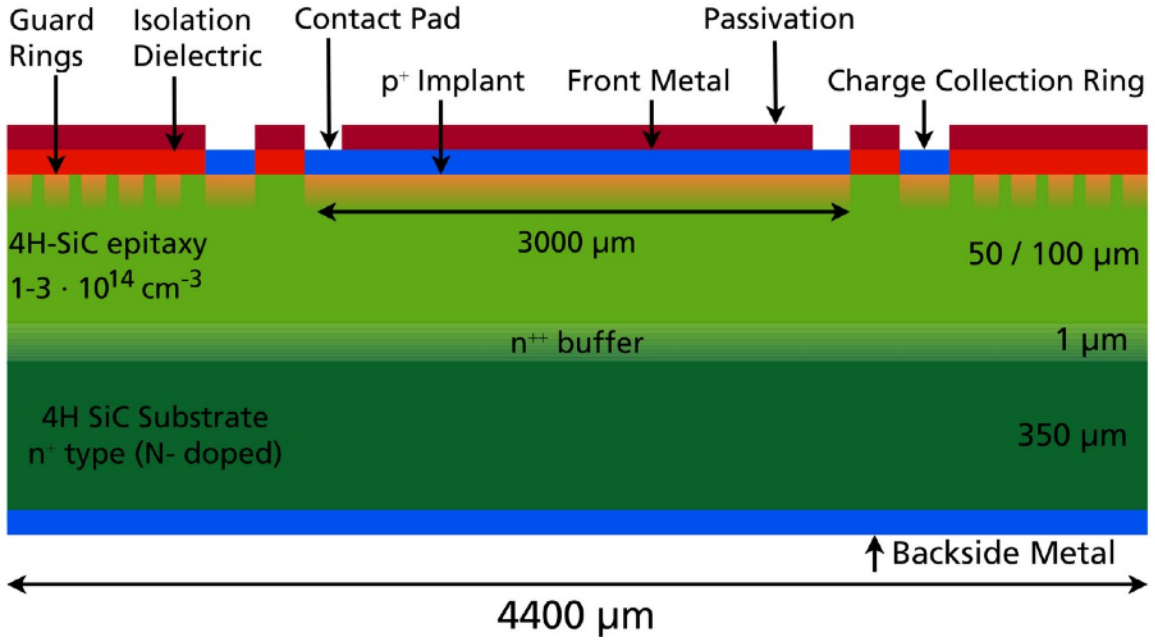






SiC Samples under investigation

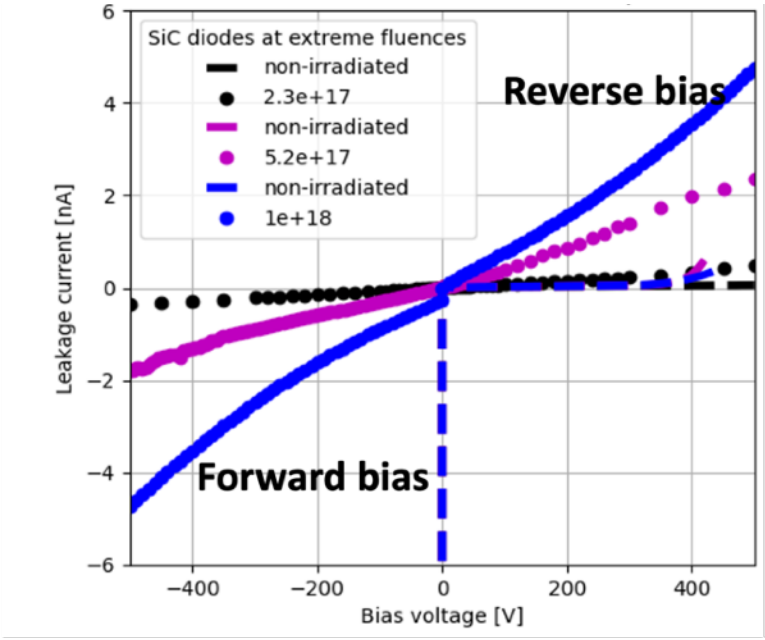
- RD50 Common Project planar run 16886:
  - W2: 50 µm epi pad sensors
  - W4: 100 µm epi pad sensor
  - broken guard ring structure due to the aluminium outflow during processing
  - used for depletion depth or dielectric permittivity estimation, and source tests
- from run 14171 wafer 1:
  - 50 µm epi pad sensor, pre-irradiated to 10^{12} p/cm^2 fluence
  - used for validation of source test setup

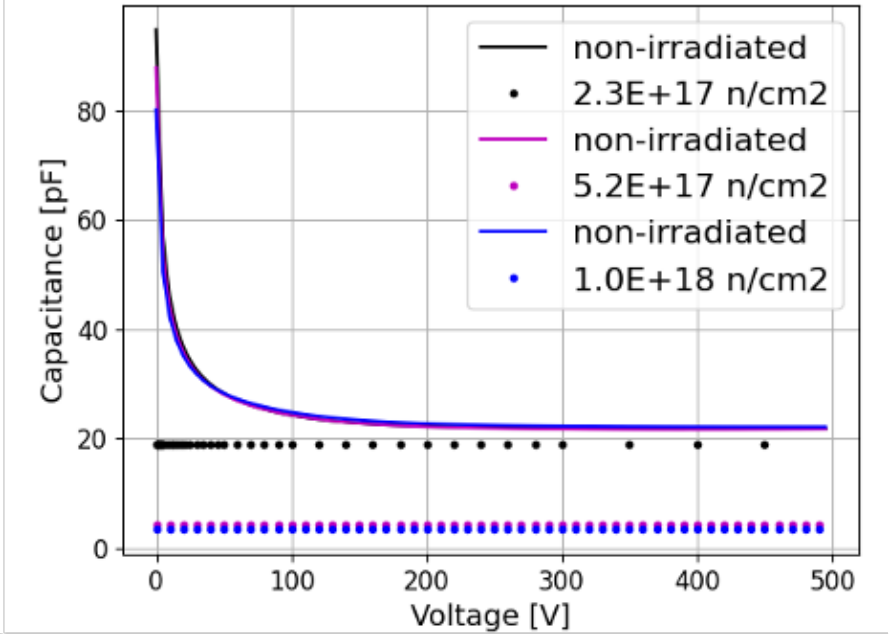


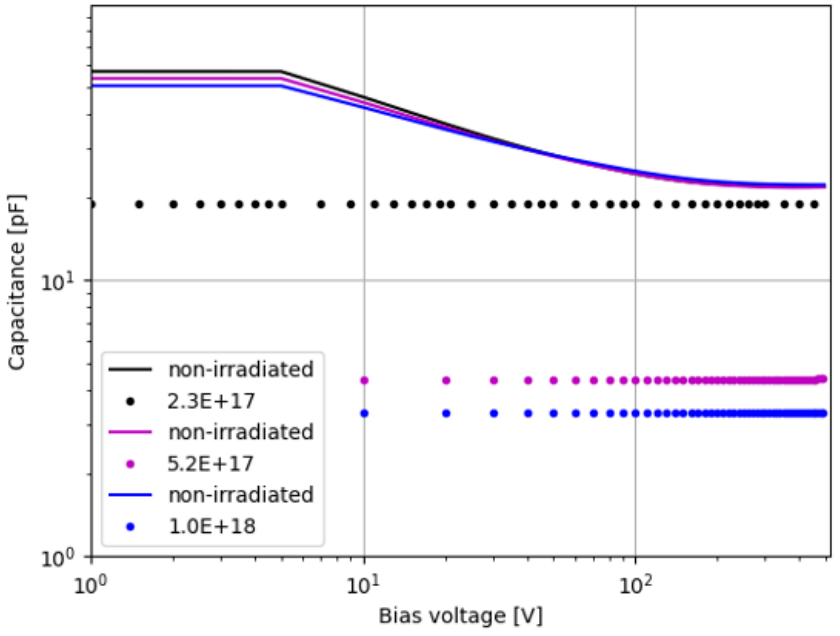
[HEPHY, 1st DRD3 workshop]

Characterisation of samples to extreme fluences: IV/CV

- 3 samples from 16886 wafer 2
- irradiated to extreme fluences [1, 2]: 2.3×10^{17} n_{eq}/cm^2, 5.2×10^{17} n_{eq}/cm^2, 10^{18} n_{eq}/cm^2
- IV/CV reveals → diode character is lost



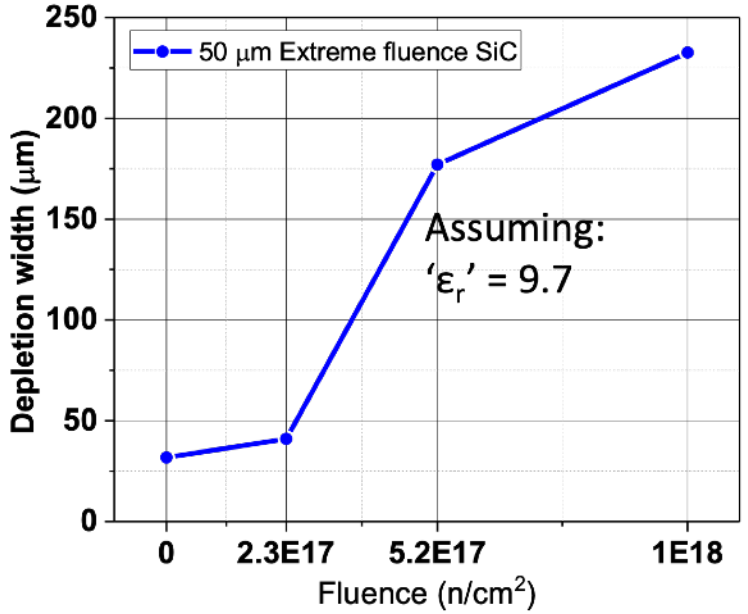


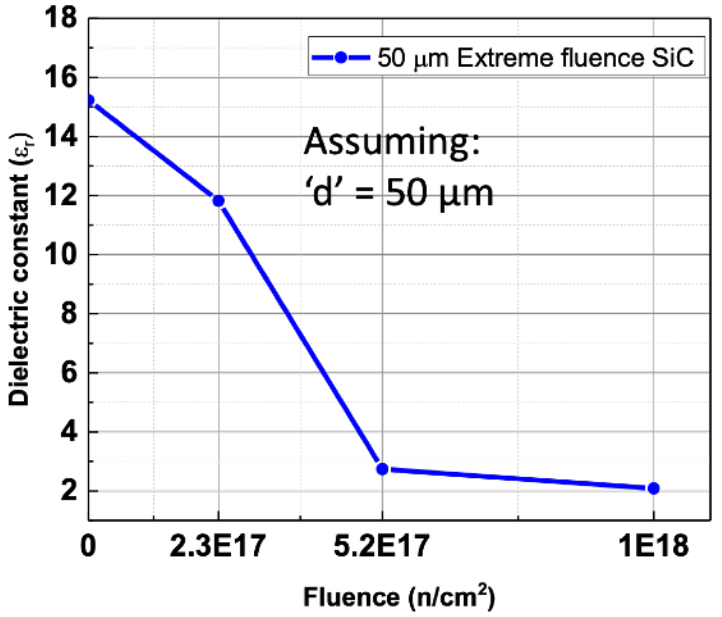


Characterisation of samples to extreme fluences: Depletion depth + dielectric permittivity estimation

$$C = \frac{A\epsilon_0\epsilon_r}{d}$$

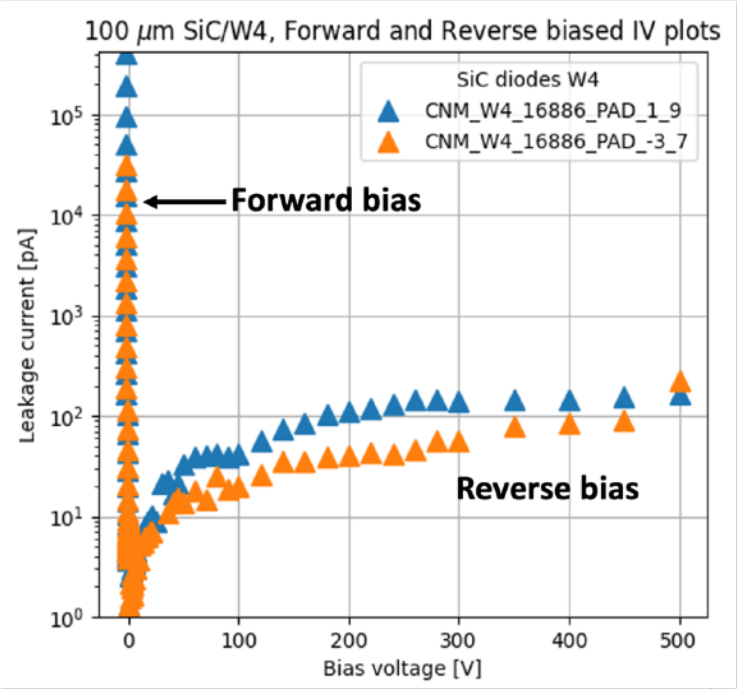
- with A = 0.03 cm^2 very low capacitance values (~3 pF) for extreme fluences implies high depletion width d (~177 µm), extended into the substrate?
  (substrate doping 10^{18} cm^{-3} [P. Gaggl, 42nd RD50 workshop])
- OR change of dielectric permittivity ϵ_r values:
  11.82, 2.74 and 2.08 for irradiated samples?

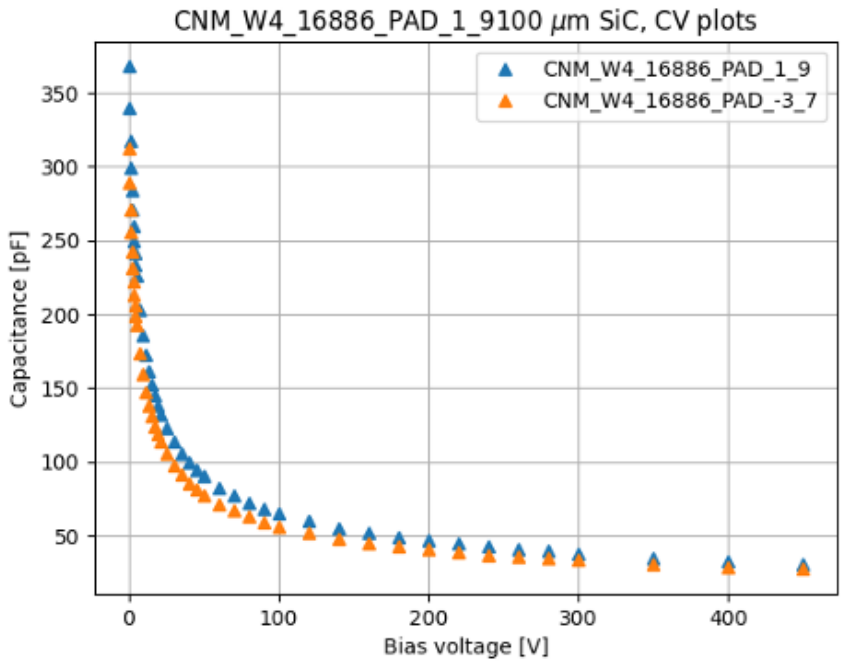


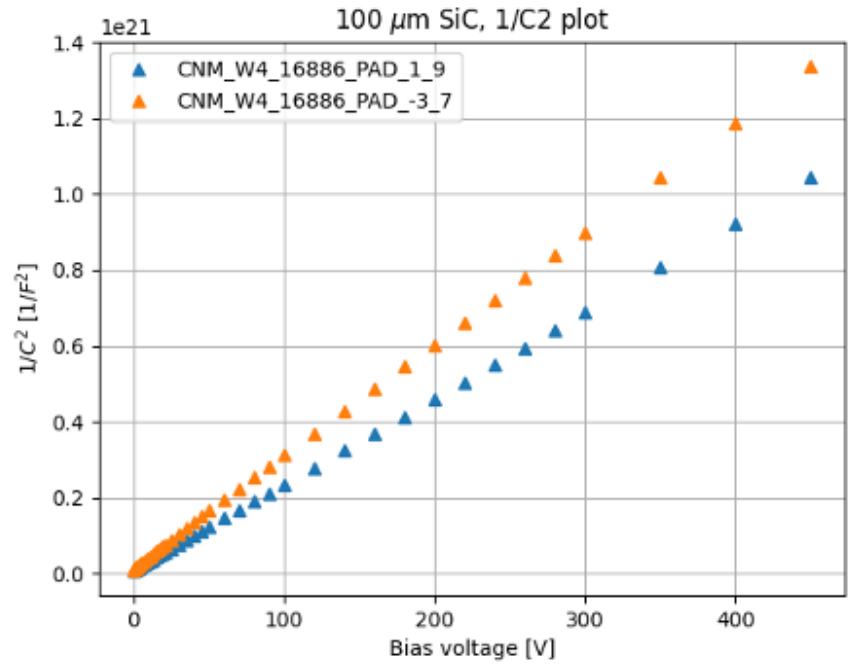


IV/CV of samples for source tests

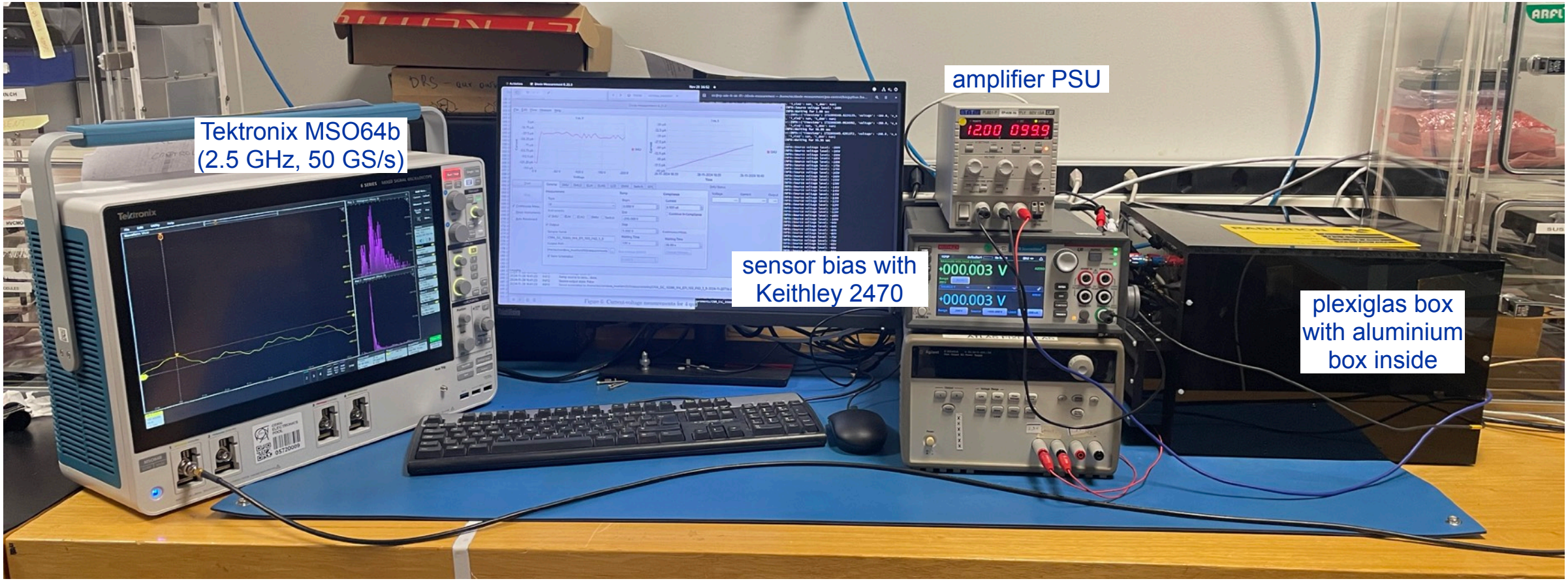
- samples from 16886 W4
- initial electrical characterisation:
  - IV shows diode character with variations in leakage current
  - CV and $1/C^2$ revealed: samples not fully depleted at 500 V bias voltage (limit of source setup)







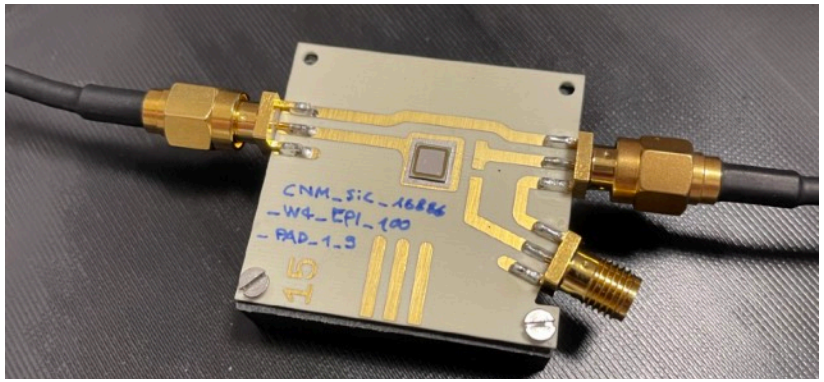
New Source Test Setup for SiC

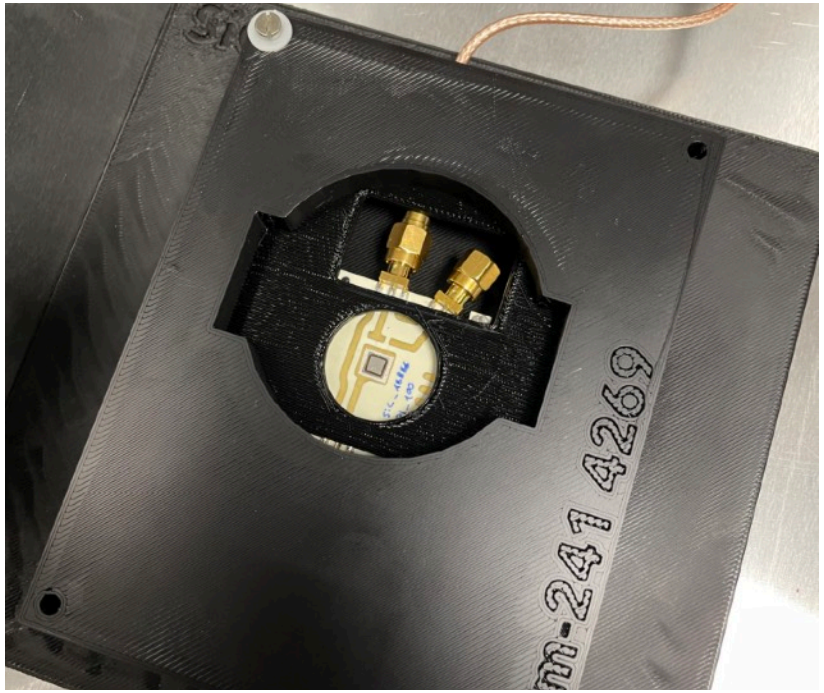


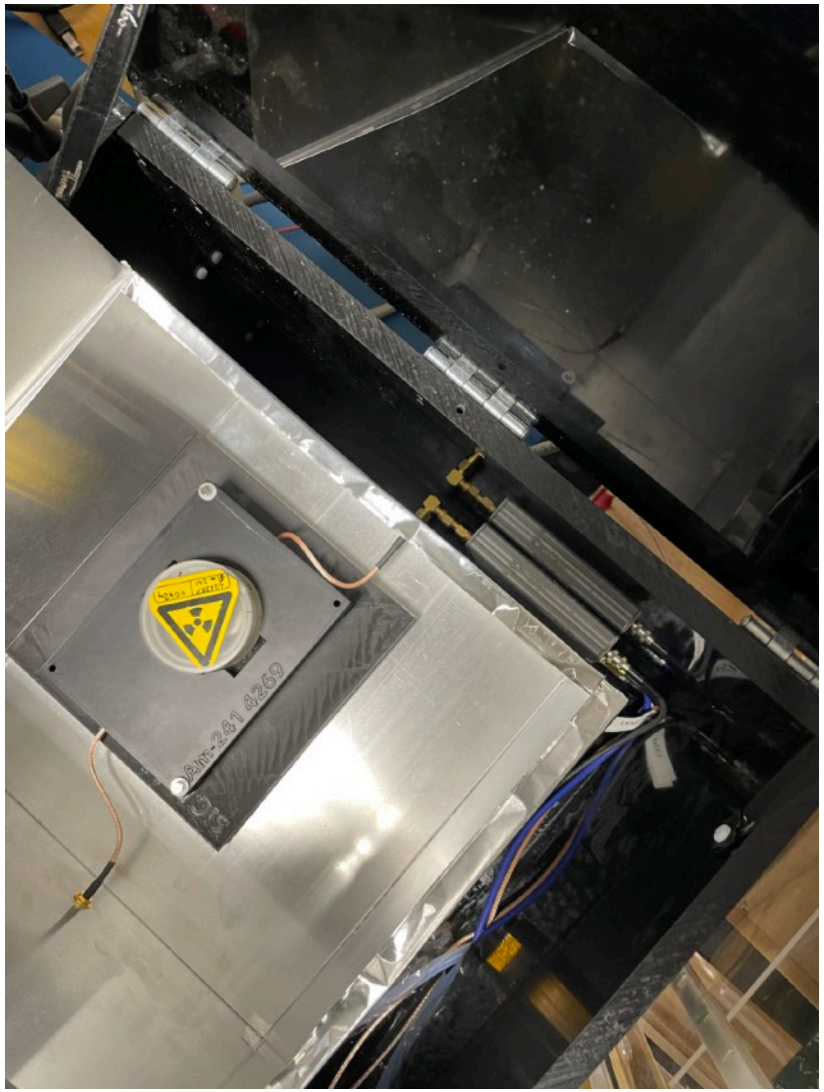
- Cividec C2-HV as amplifier (40 dB)

Source Test Setup

- base plate with elevated stand for sample PCBs
- source holder:
  - cut-out for source and its opening window
  - offset adjusted for sensor centre
  - minimal distance to sensor (4 to 7 mm depending on source container)
- amplifier as close as possible







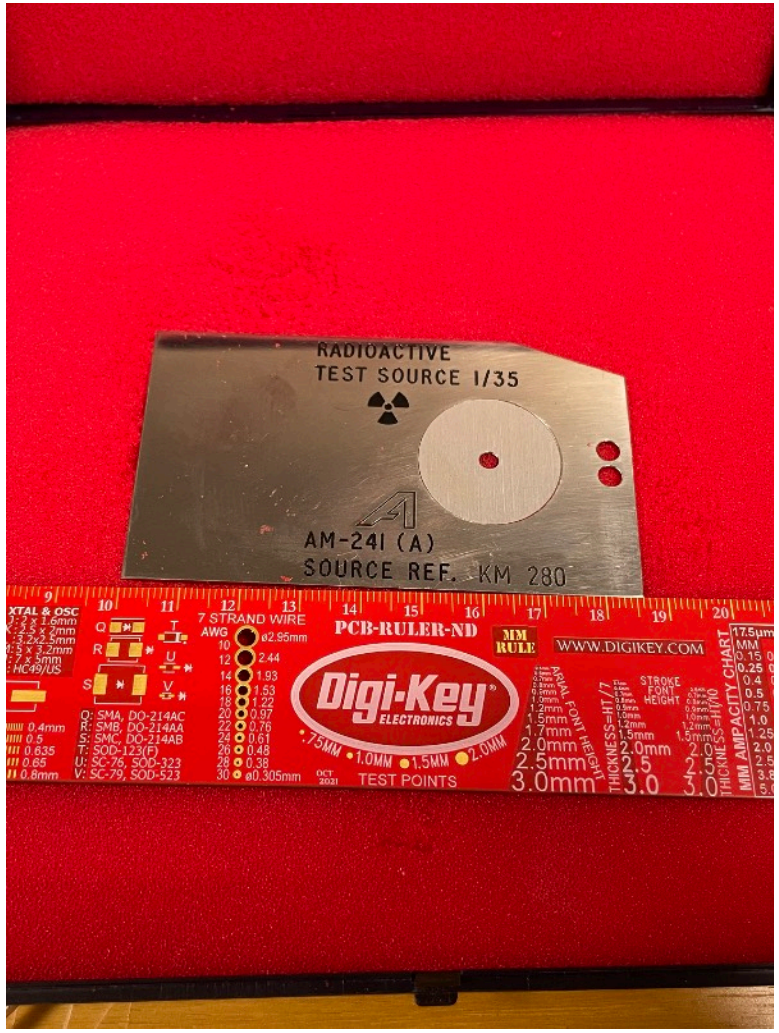
Source Test Setup: sources

- used Am241 α sources:
  - 39 kBq activity (id 4269)
  - < 1 kBq activity (id 4061)
- Am241 emission spectra:

energy [keV]	rel. intensity
5388	0.0166
5443.8	0.131
5482.56	0.848

- expecting ~4700 keV due to loss in air [A. Gsponer et. al.]

source 4061

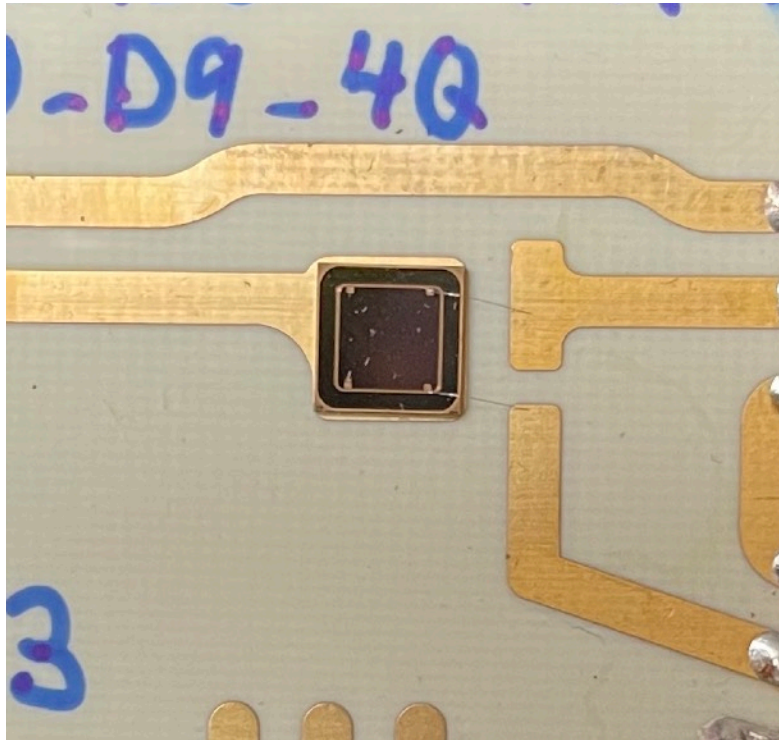


source holder bridge with source 4269

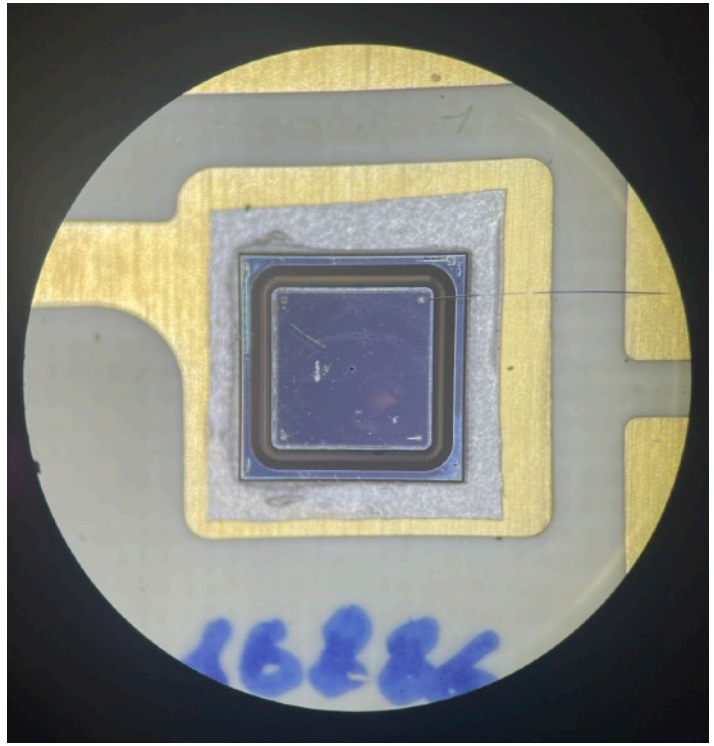
Source Test Setup: samples

- sample to verify setup:
  - 50 µm epi pad sensor
  - segmented in 4 identical quadrants
  - irradiated to low dose of 10^{13} p/cm^2
- sample from latest run (16886 W4):
  - 100 µm epi pad sensor
  - not segmented, not irradiated
  - first bonded sample from latest run

CNM_SiC_14171-1_50_D9_4Q

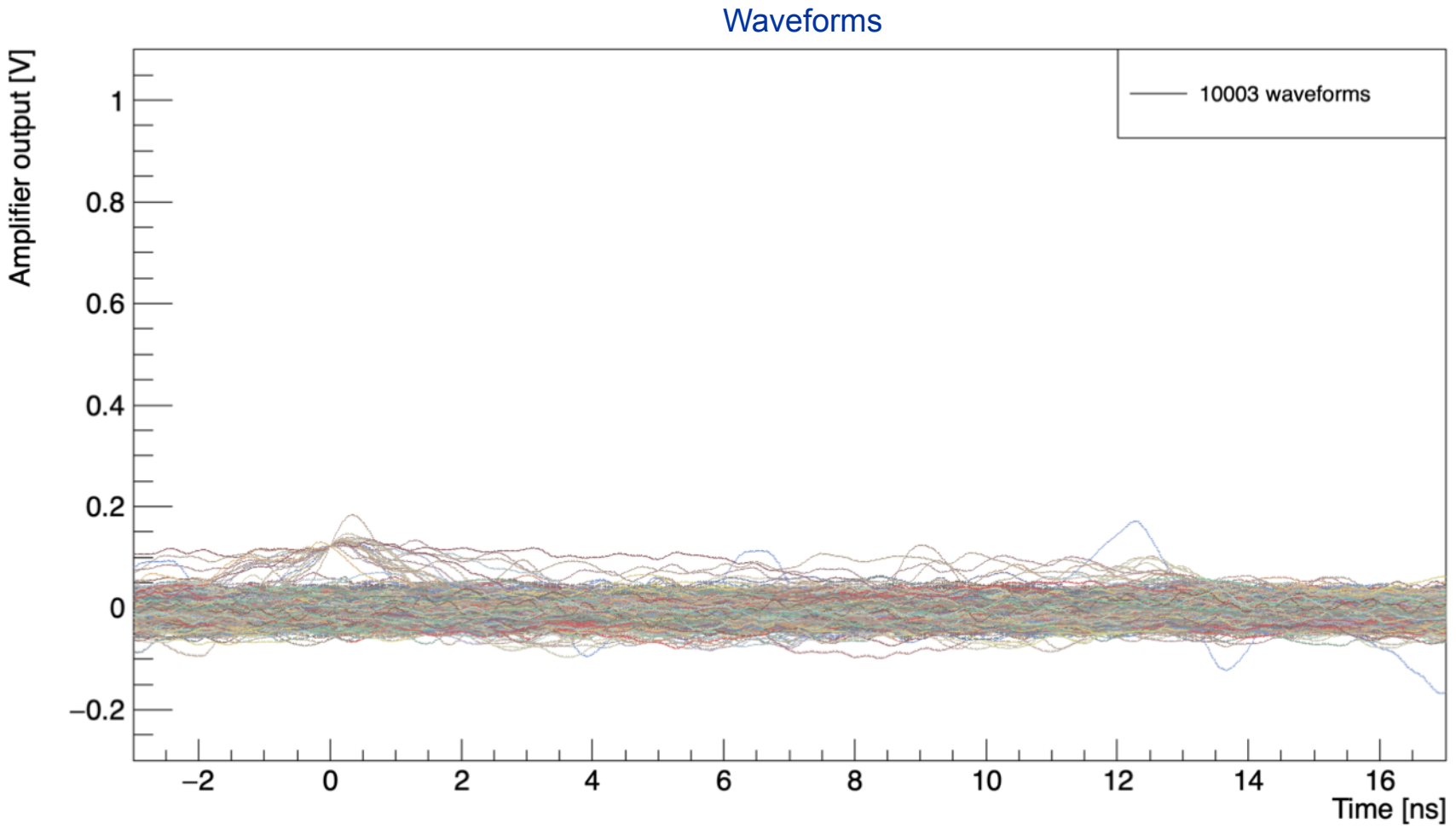


CNM_SiC_16886_W4_EPI_100_PAD_1_9



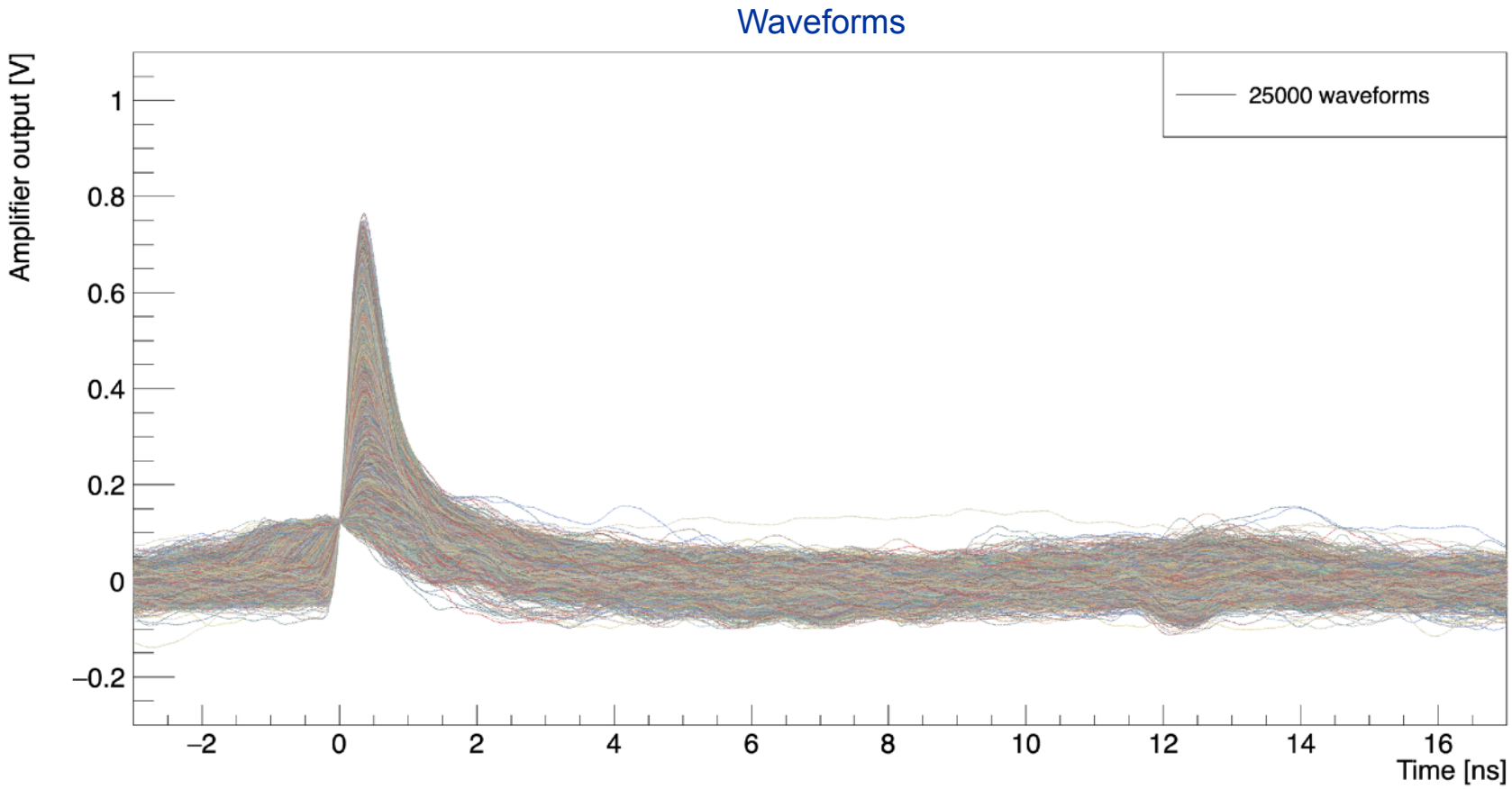
Source Test: Background Measurement

- sample used: 14171 W1
- HV bias 500 V
- rate O(10 Hz)
- several sources of noise identified and mitigated:
  - remote control commands of Keithley 2470
  - automatic triggering of local current measurement of Keithley 2470
- further tests with EMI shielded box in preparation



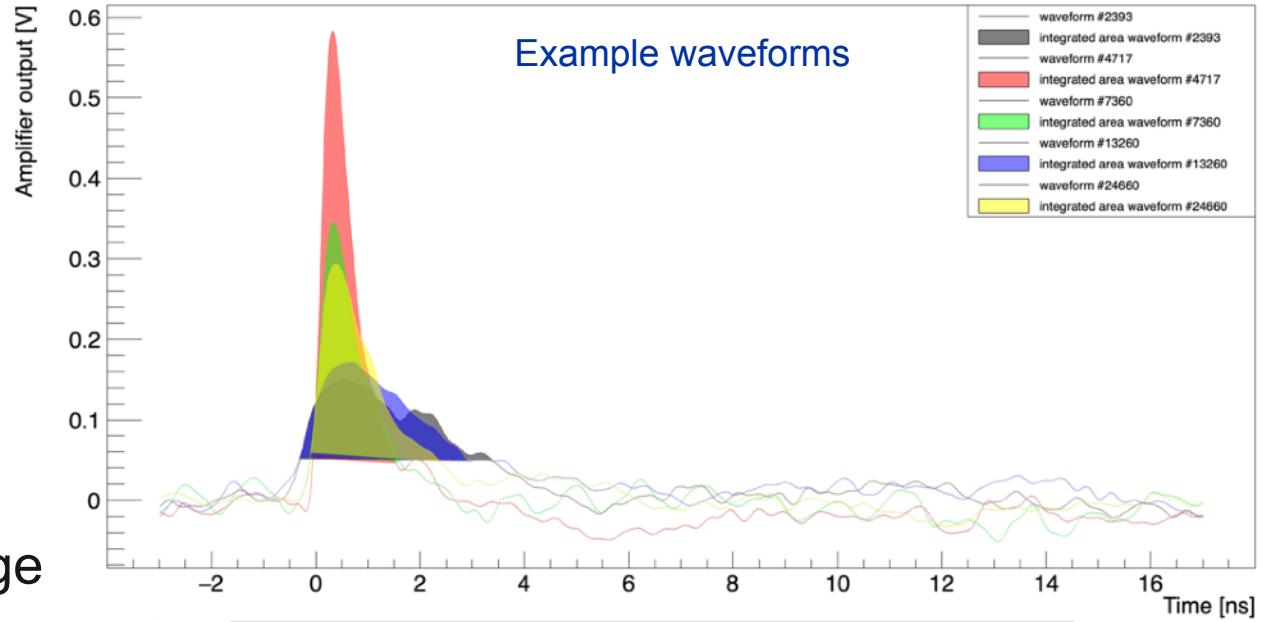
Source Test: First Results

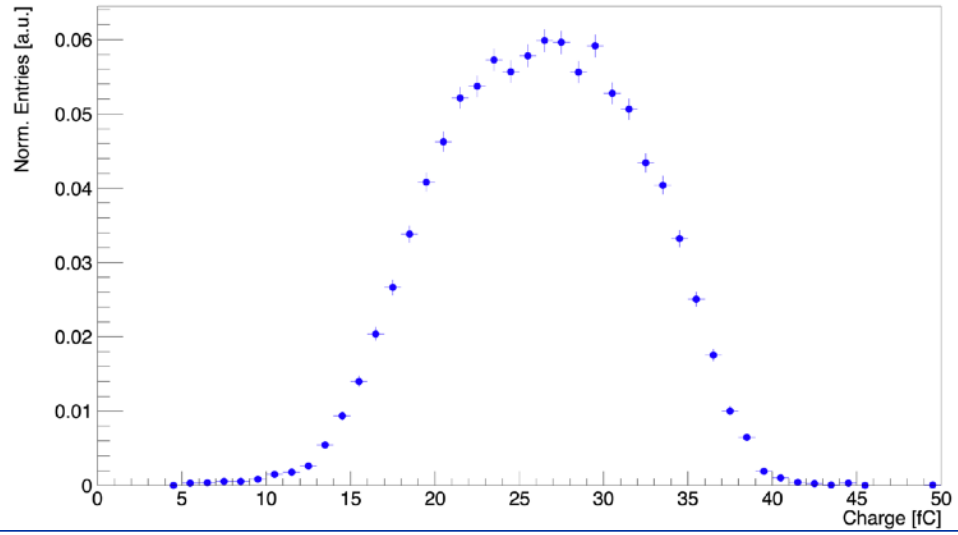
- sample used: 14171 W1
- HV bias 500 V
- 25000 acquisitions per measurement cycle
- trigger rates at 100 mV:
  - Am241 4269: 10 to 20 Hz
  - Am241 4061: < 1 Hz
- α detection feasible



Source Test: Analysis of Waveforms

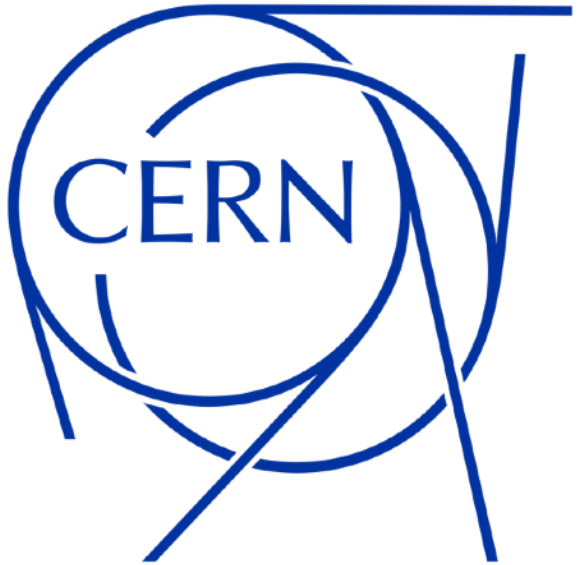
- several analysis functions implemented so far:
  - peak detection
  - FWHM
  - rise- and fall time
  - area → charge
- preliminary normalised histograms for charge collection
  - assuming resistivity of 20 Ωcm [A. Gsponer et. al.]
  - charge values comparable of what to expect with SiC ionisation energy 7.83 eV [A. Gsponer et. al.]: $Q \approx 96$ fC
  - reduced measured charge possible due to loss in air, weakly irradiated sample





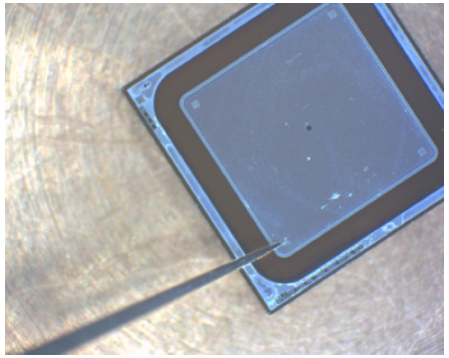
Conclusions and Outlook

- progress in electrical characterisations of SiC sensors from RD50 common project at CERN
- first characterisation after extreme fluences up to 10^{18} n_{eq}/cm^2
  - IV/CV measurements reveal diode character lost
  - low capacitance after irradiation points to an extension of the electric field into the substrate or a change of the dielectric constant
- setup for source test functional and initial measurements of SiC sensors performed
  - noise was reduced by basic Faraday cage
  - evaluation of results ongoing, further investigation with latest bonded sample
- next steps:
  - three-photon-absorption TCT to measure the depletion depth [I. Vila Alvarez, 2nd DRD3 week]
  - study of radiation induced degradation of charge collection efficiency (with Am241 source)
  - further noise reduction with improved faraday cage
  - comparison at different bias voltages and source distances
  - analysis deploying correlation of measured parameters

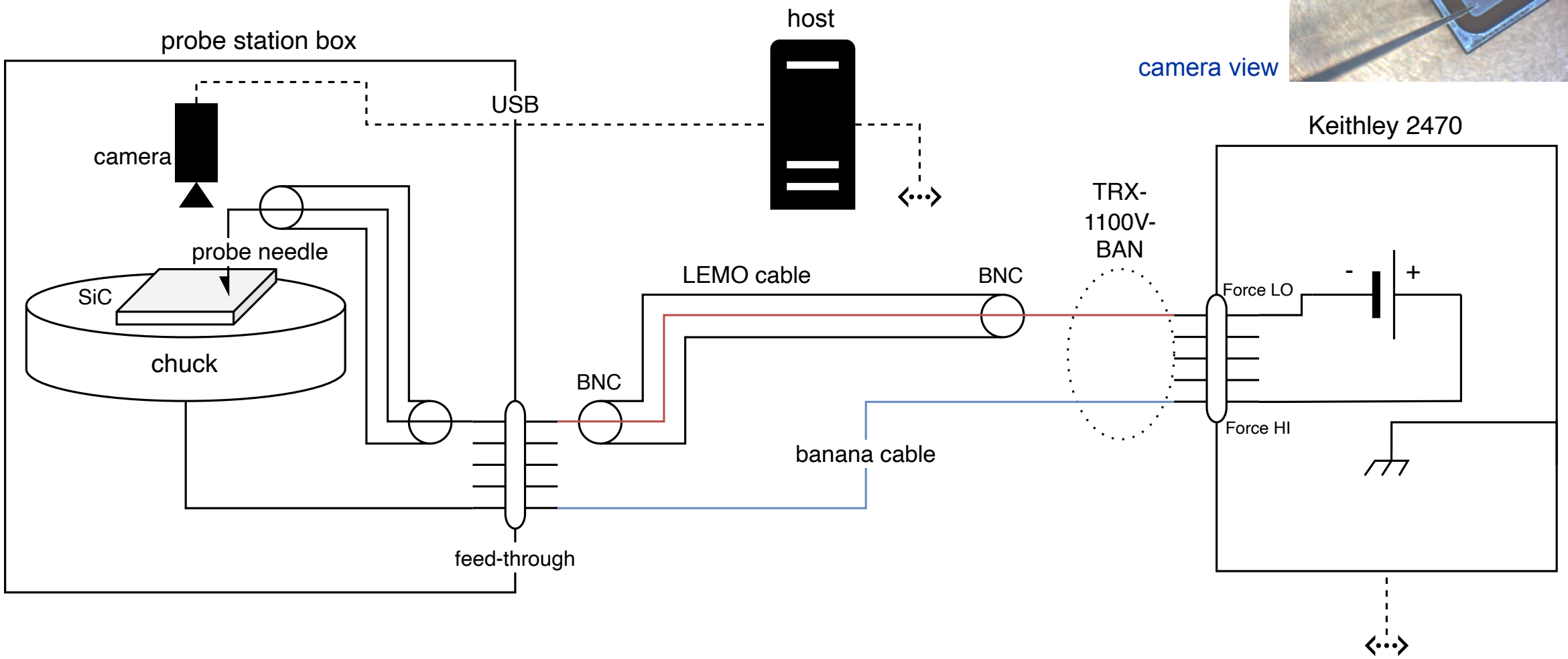


Backup

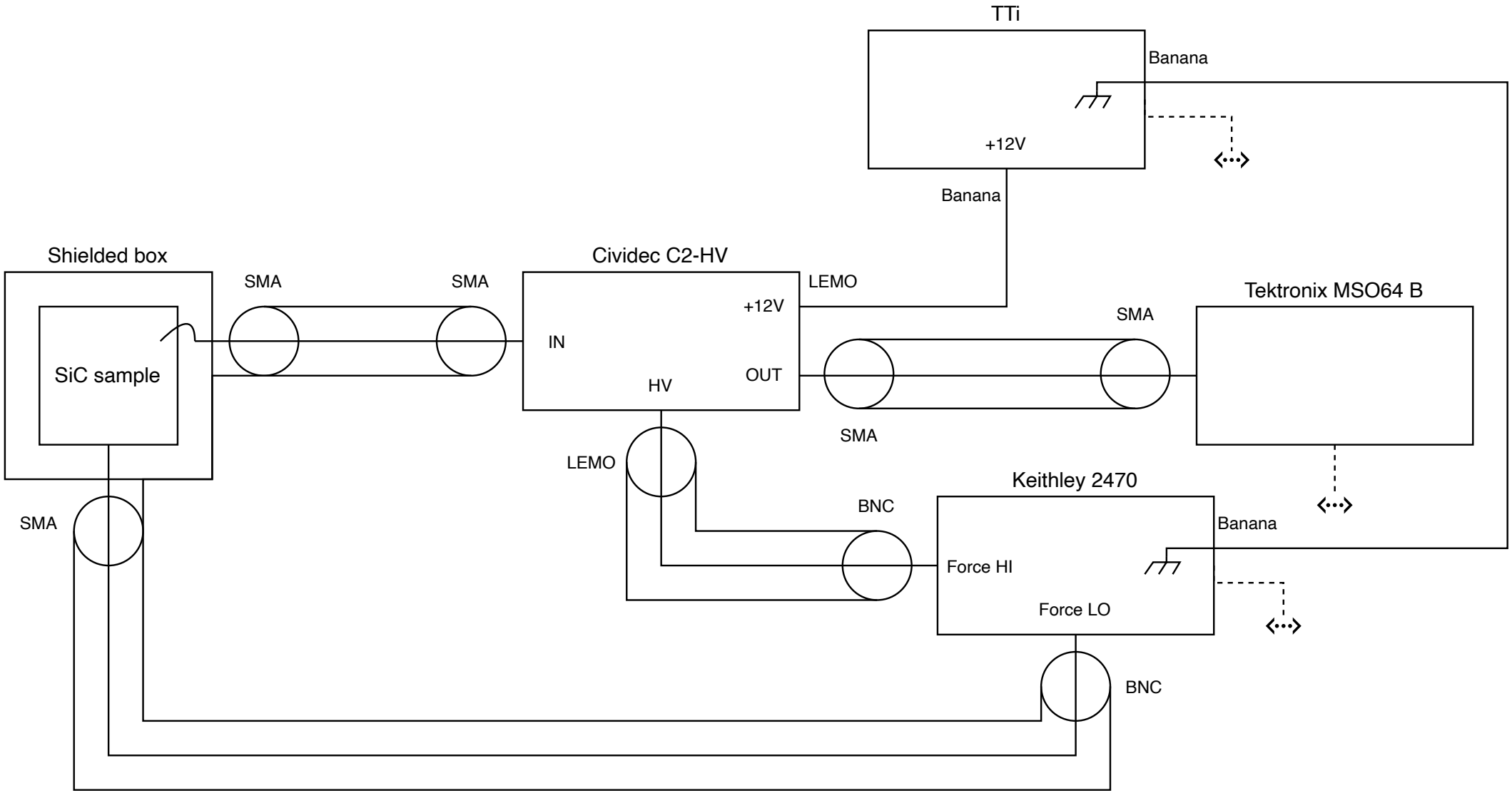
Probe Station CERN EP-ADE-TK



camera view



Source Test Setup CERN EP-ADE-TK



Cividec C2-HV data sheet

Parameters:	
Type:	Current amplifier
Analog bandwidth:	1 MHz - 2 GHz
Gain:	40 dB
Input coupling:	AC coupled (1 nF @ 1 kV)
Input impedance:	50 Ω
Input protection:	IEC61000-4-2 (±8 kV, 2 A for 1 μs)
Input polarity:	Bipolar
Output polarity:	Non-inverting, bipolar
Linear output voltage range:	±1 V
Output impedance:	50 Ω
Equivalent input current noise (rms):	0.4 μA

Power supplies:	
Supply voltage:	+12 V, 100 mA
Bias-Tee:	Included with low-pass filter
Maximum HV voltage:	±500 V

Housing:	
Box size:	85 mm x 55 mm x 15 mm
Box material:	Aluminium with extra RF shielding
Signal input and output connectors:	SMA female
12 V power connector:	Lemo ERA.0S.302.CLL
Detector bias voltage connector:	Lemo ERA.00.250.NTL

Keithley 2470 specs

Specifications

Voltage Specifications [1, 2]

	Source			Measure [3]		
Range [4]	Resolution	Accuracy [5] 23 °C ± 5 °C, 1 Year ±(% setting + volts)	Noise (RMS) <10 Hz	Resolution	Input Resistance	Accuracy 23 °C ± 5 °C, 1 Year ±(% reading + volts)
200.0000 mV	5 µV	0.015% + 200 µV	2 µV	100 nV	> 10 GΩ	0.012% + 200 µV
2.000000 V	50 µV	0.020% + 300 µV	10 µV	1 µV	> 10 GΩ	0.012% + 300 µV
20.00000 V	500 µV	0.015% + 2.4 mV	100 µV	10 µV	> 10 GΩ	0.015% + 1 mV
200.0000 V	5 mV	0.015% + 24 mV	1 mV	100 µV	> 10 GΩ	0.015% + 10 mV
1000.000 V	50 mV	0.02% + 100 mV	20 mV	10 mV	> 10 GΩ	0.015% + 50 mV

Temperature Coefficient

20 V and 1000 V ranges: ±(0.15 × accuracy specification)/°C, 0 °C to 18 °C and 28 °C to 50 °C.
200 mV and 2 V ranges: ±(0.30 × accuracy specification)/°C, 0 °C to 18 °C and 28 °C to 50 °C.

Current Specifications [1, 2]

	Source			Measure [3]		
Range [4]	Resolution	Accuracy [5] 23 °C ± 5 °C, 1 Year ±(% setting + amps)	Noise (RMS) <10 Hz	Resolution	Voltage Burden	Accuracy 23 °C ± 5 °C, 1 Year ±(% reading + amps)
10.00000 nA [6]	500 fA	0.100% + 200 pA	500 fA	10 fA	< 100 µV	0.10% + 250 pA
100.0000 nA [6]	5 pA	0.060% + 250 pA	500 fA	100 fA	< 100 µV	0.060% + 300 pA
1.000000 µA	50 pA	0.025% + 400 pA	5 pA	1 pA	< 100 µV	0.025% + 300 pA
10.00000 µA	500 pA	0.025% + 1.5 nA	40 pA	10 pA	< 100 µV	0.025% + 700 pA
100.0000 µA	5 nA	0.020% + 15 nA	400 pA	100 pA	< 100 µV	0.02% + 6 nA
1.000000 mA	50 nA	0.020% + 150 nA	5 nA	1 nA	< 100 µV	0.02% + 60 nA
10.00000 mA	500 nA	0.020% + 1.5 µA	40 nA	10 nA	< 100 µV	0.02% + 600 nA
100.0000 mA	5 µA	0.025% + 15 µA	100 nA	100 nA	< 100 µV	0.025% + 6 µA
1.000000 A	50 µA	0.067% + 900 µA	10 µA	1 µA	< 100 µV	0.03% + 500 µA

Temperature Coefficient ±(0.15 × accuracy specification)/°C, 0 °C to 18 °C and 28 °C to 50 °C

Notes

1. Speed = 1 PLC.
2. All specifications are guaranteed with output ON.
3. Accuracies apply to 2-wire and 4-wire modes when properly zeroed. For the 200 mV and 1 A ranges, the voltage burden may exceed the specification in 2-wire mode.
4. Maximum display and programmming ranges are 5% overrange for voltage, except for the 1000 V range, which is 10% overrange (1100 V), and 5% overrange for current (for example, 1.05 A on the 1 A range).
5. For sink mode, 1 µA to 100 mA range, accuracy is ±(0.5% + offset × 3). For 1 A range, accuracy is ±(0.15 × accuracy specification)/°C on 20 V and 1000 V ranges ±(1.5% + offset × 3).
6. Rear-panel triaxial connections only.

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