Development of the Next Generation Silicon Sensors for the LHCb experiment

27-29.5. 2025 P4F colloqium

Peter Švihra

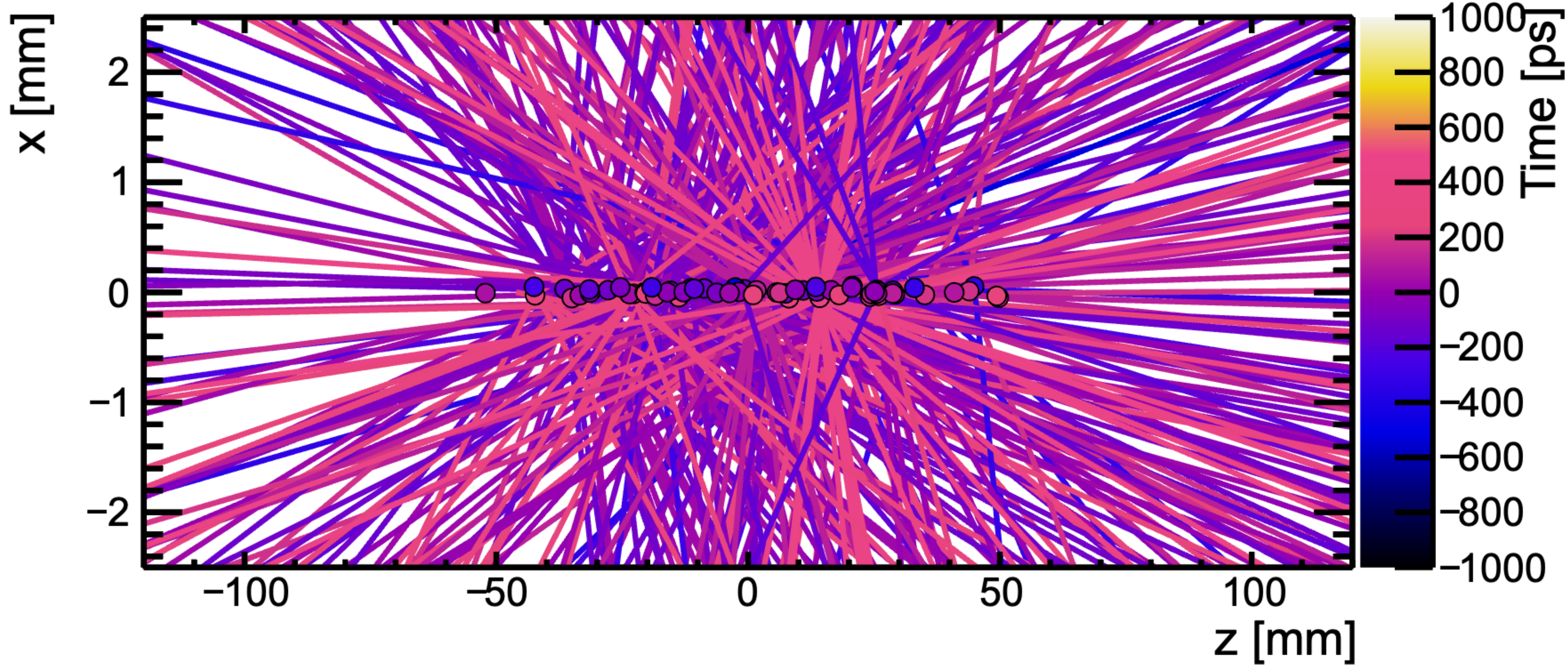
PHYSICS FOR FUTURE

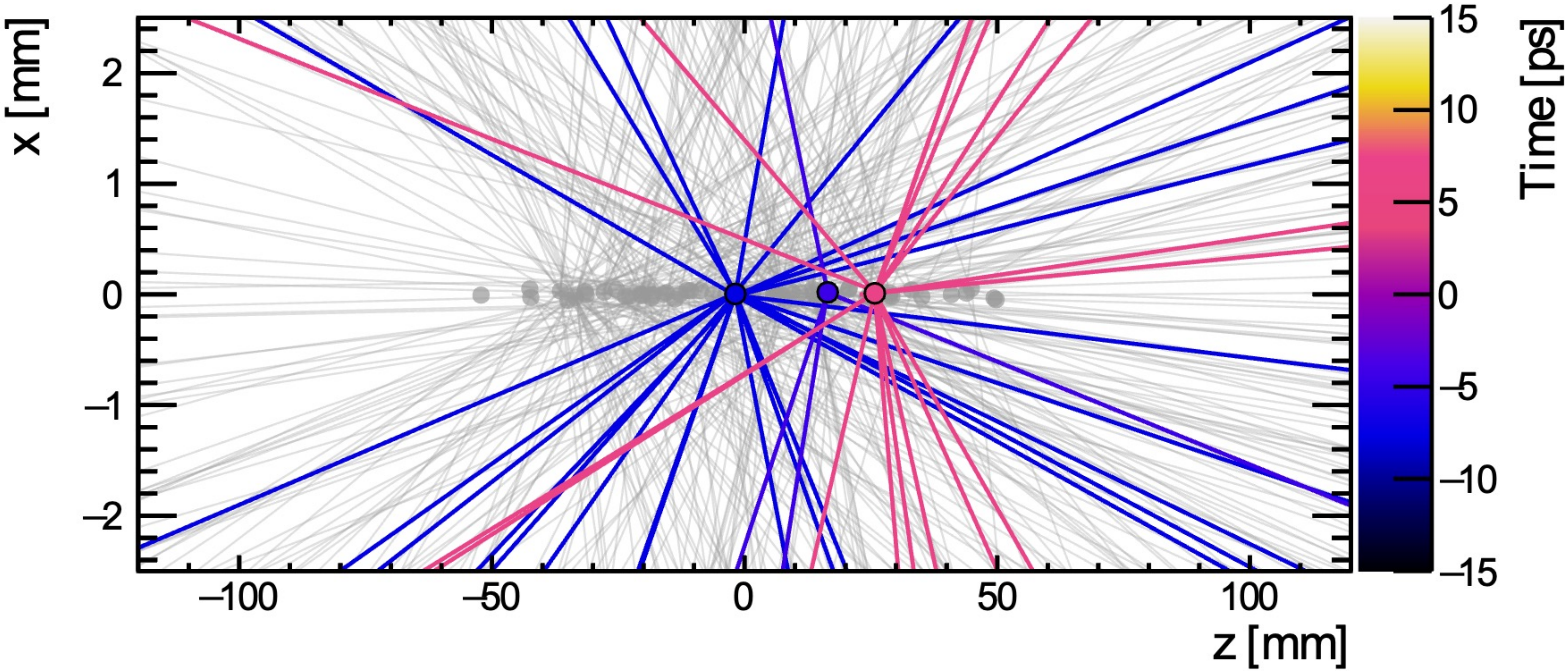
FZU

Co-funded by the European Union

Motivation:
Need for a precise track timing and radiation hardness in HL-LHC experiments

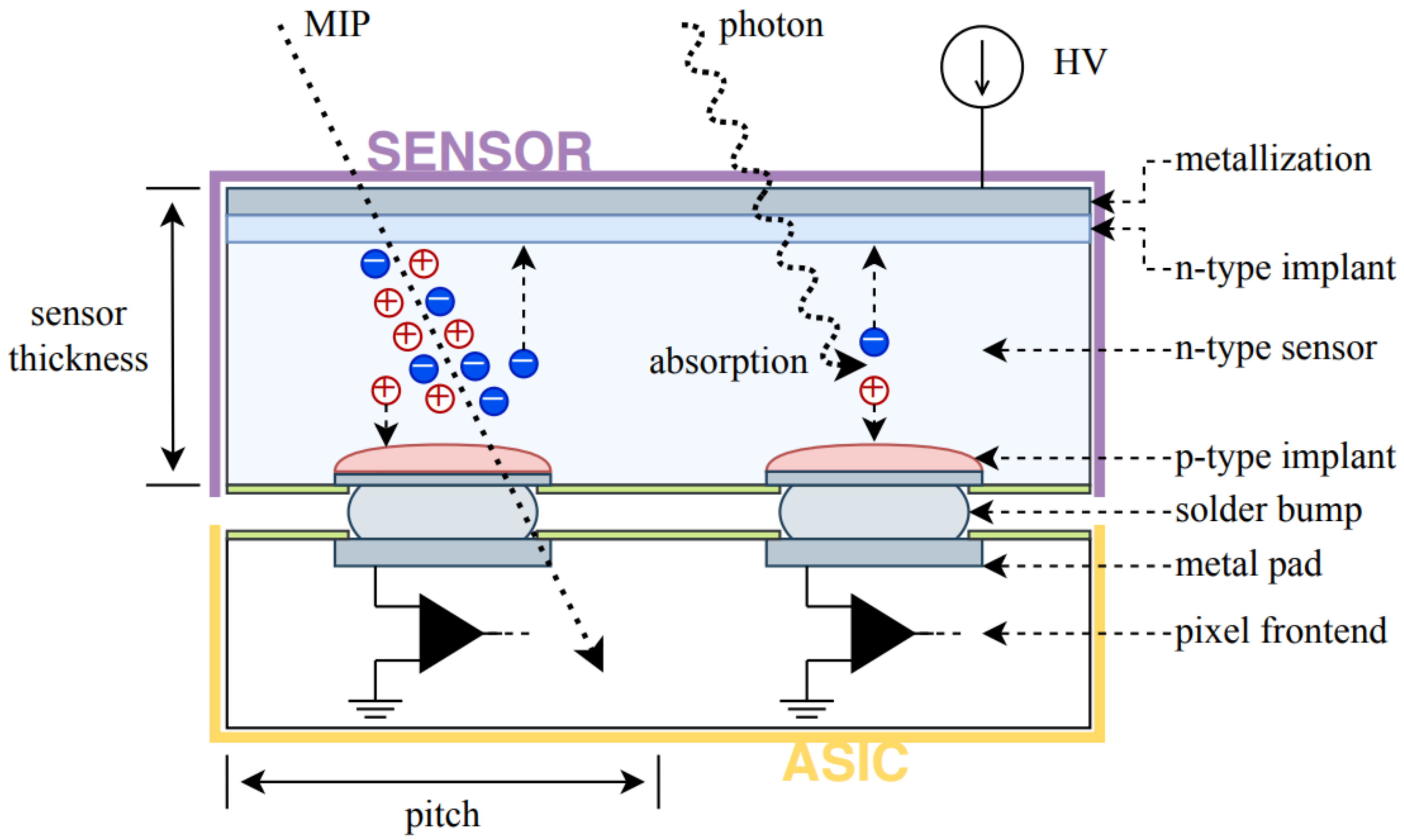
LHCb Upgrade 2 FTDR




x [mm]
2
1
0
−1
−2
−100
−50
0
50
100
z [mm]
15
10
5
0
−5
−10
−15
Time [ps]

Semiconductor detectors – in a nutshell

Hybrid ➔ current predominant detector concept
➔ vertex detection & track-timing



Separate sensor & ASIC ➔ intercon. hybrid detector
➔ sep. R&D and manufacturing process

✓ **Efficiency, spatial and timing resolution**

× **Material budget**

× **Interconnection cost and minimum achievable pitch**

R&D

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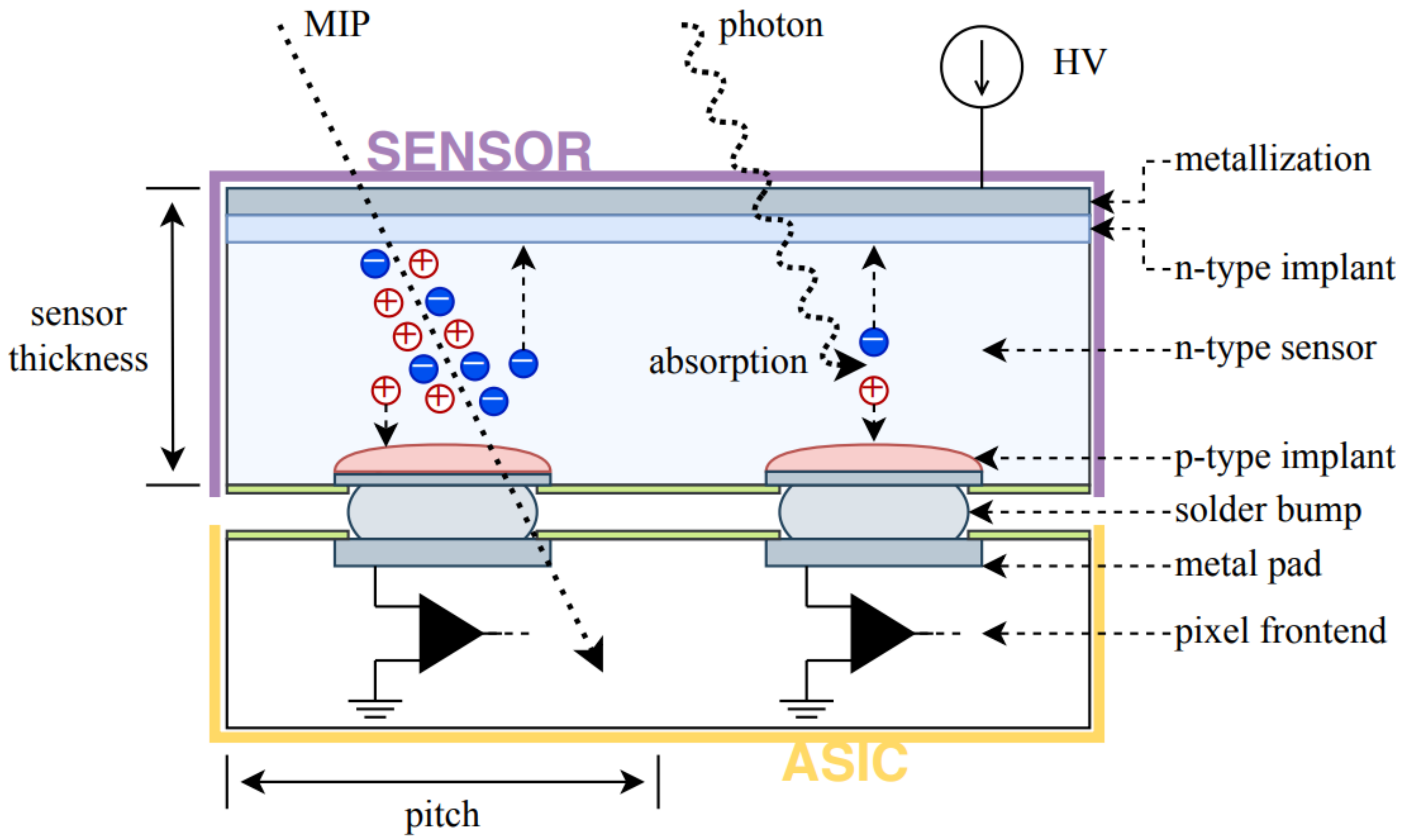

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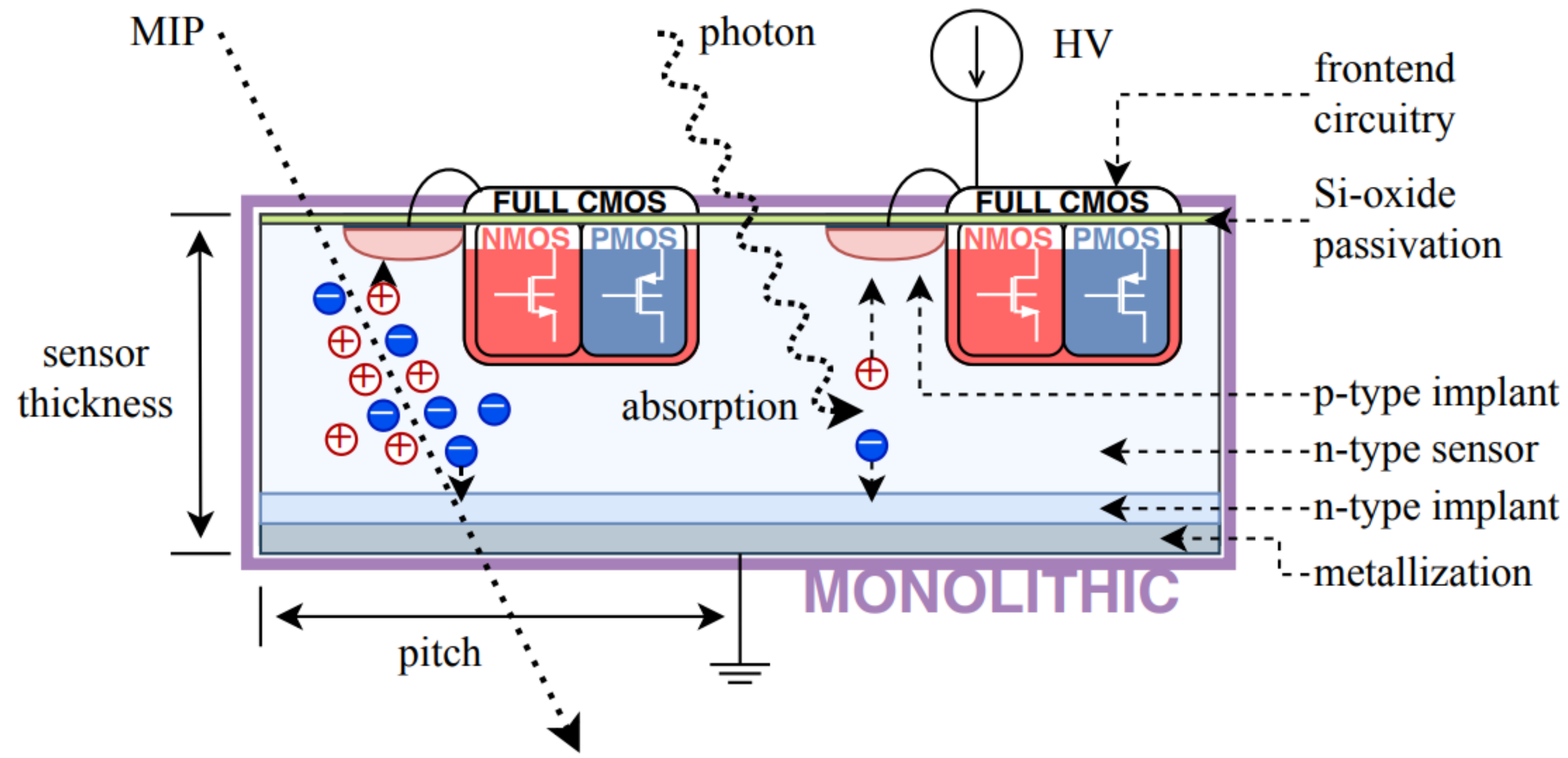
R&D

Monolithic CMOS ➔ future detector concept
➔ vertex detector & tracker



Sensor and readout electronics fully integrated
➔ Adapted industrial manufacturing technologies

✓ Simplified, cost-effective construction

✓ Low capacitance, high signal/noise, low power, low material budget

✕ Complex integration of circuitry in sensor

✕ Complex sensor structures & proprietary design rules

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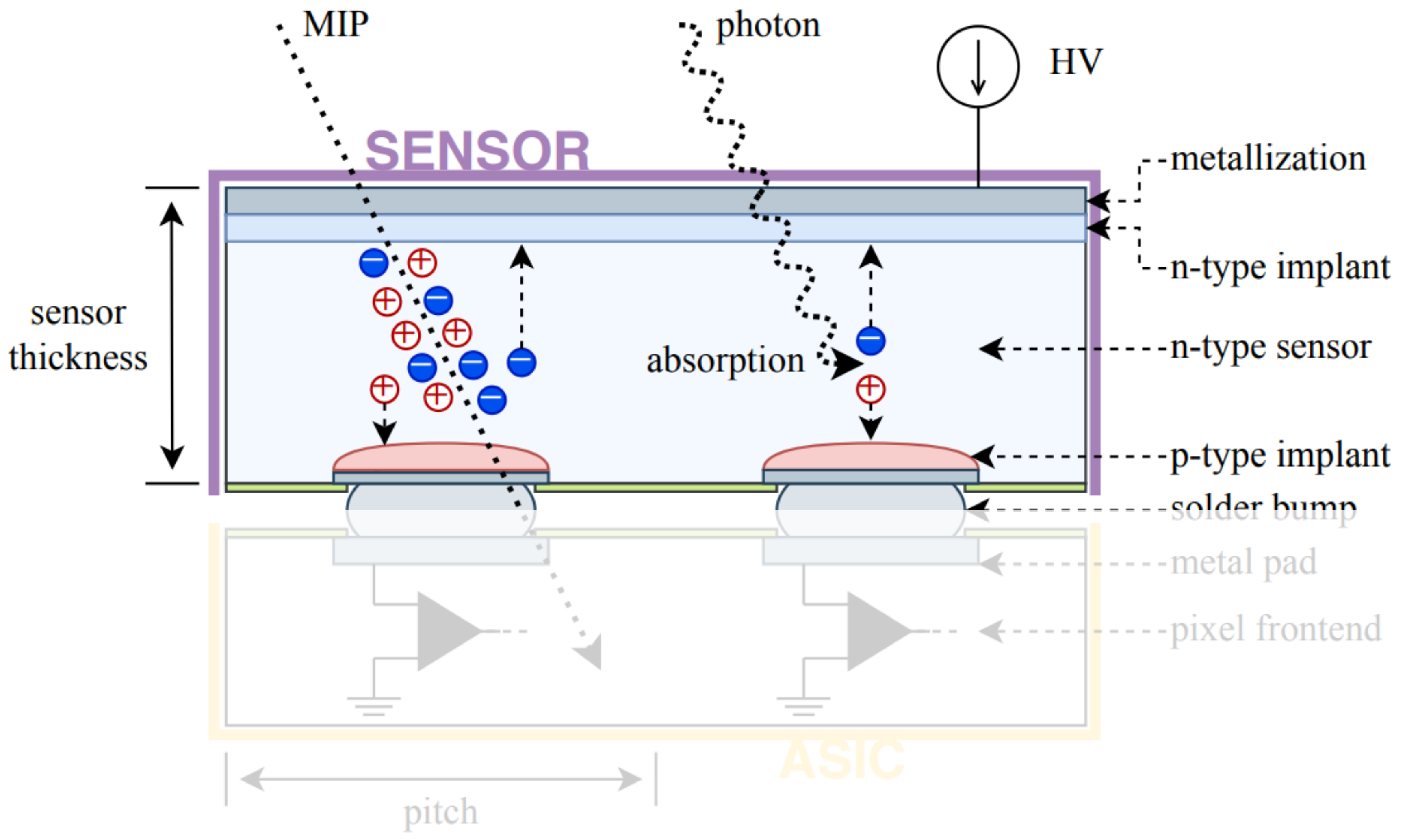

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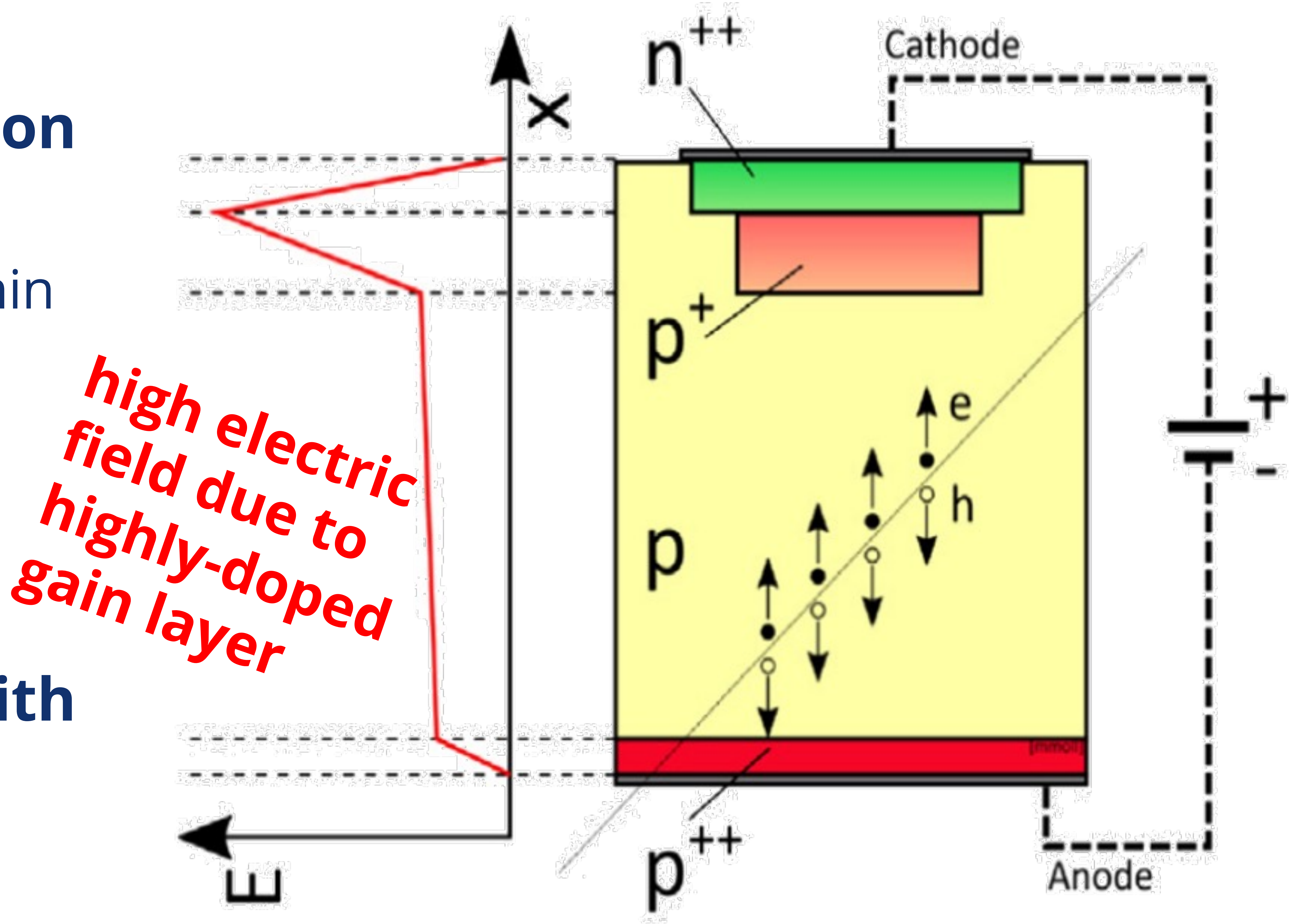
R&D

Low Gain Avalanche Detectors (LGADs)

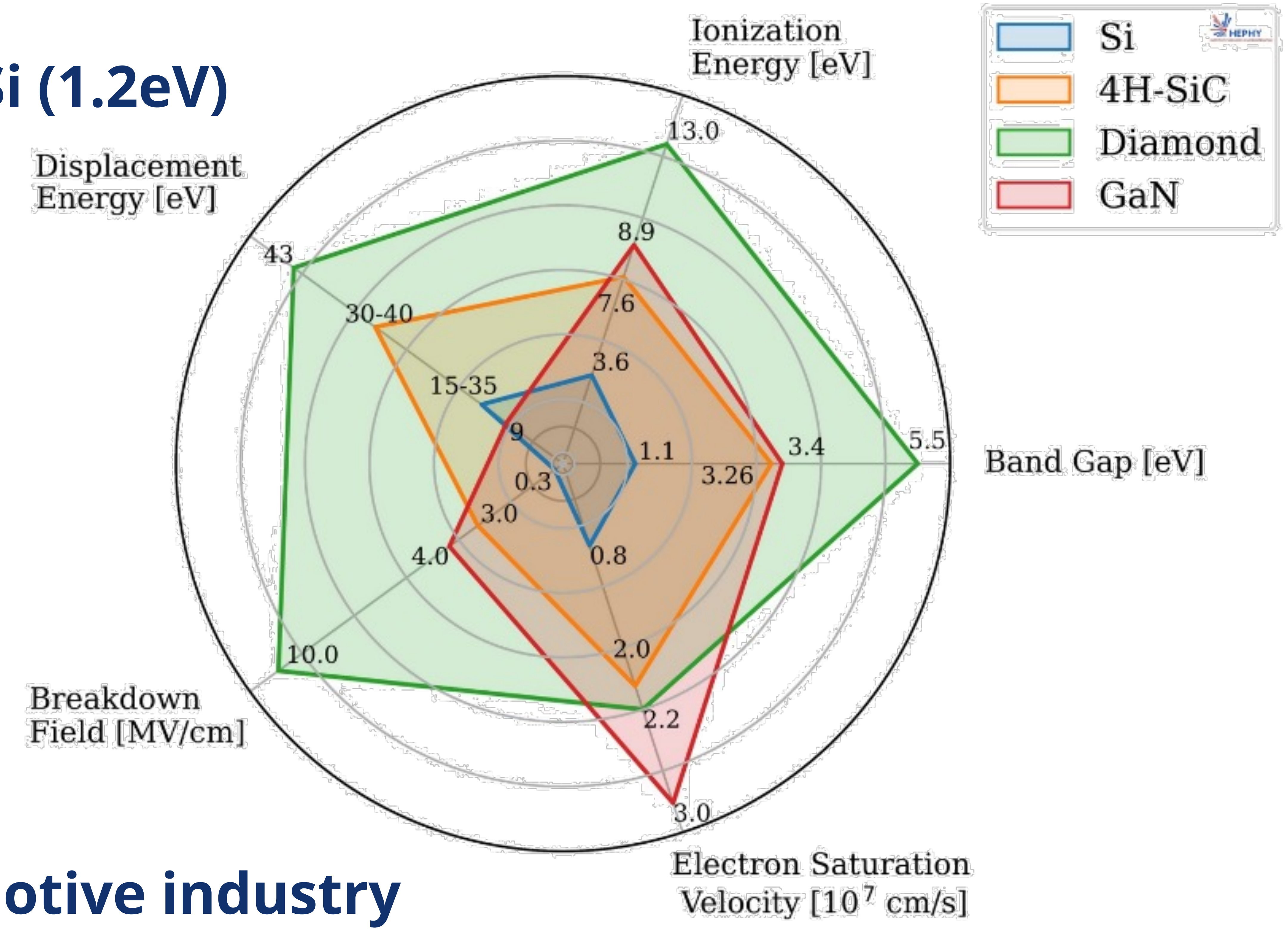
- **Benefits of intrinsic charge multiplication**
  - Improved Signal-to-Noise Ratio
  - Excellent timing capabilities (~ 40 ps) for thin LGADs (~ 50 µm)
  - Low energy X-rays detection (< 5 keV)
- 🔻**Performance degradation with radiation damage**
- **Challenging performance uniformity with small pixels**



LGADs on 4H-SiC silicon carbide:
Future of track-timing detectors?

Re-discovery of Silicon-Carbide

- **Wider bandgap of 2.4 < Eg < 3.3 eV compared to Si (1.2eV)**
- **Advantages**
  - Lower dark current
  - Excellent temperature stability (up to 300 °C)
  - High radiation tolerance
  - Material hardness (resistant)
- **Disadvantages**
  - Lower signal (48 e-h pairs/µm
  - Difficult to manufacture
  - Material hardness (hard to dice, easier to shatter)



- **Affordability due to advancements in the automotive industry**

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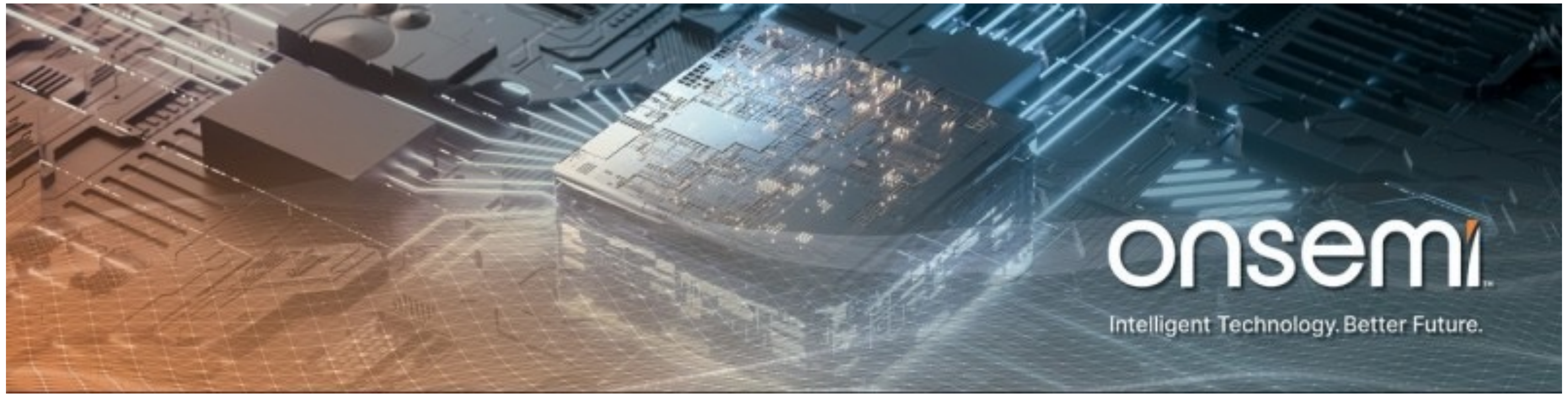
Availability thanks to onsemi

- Silicon sensor manufacturing for ATLAS detector
- New SiC design center in CZ
- Multiple common project developing SiC detectors segmented SiC LGAD



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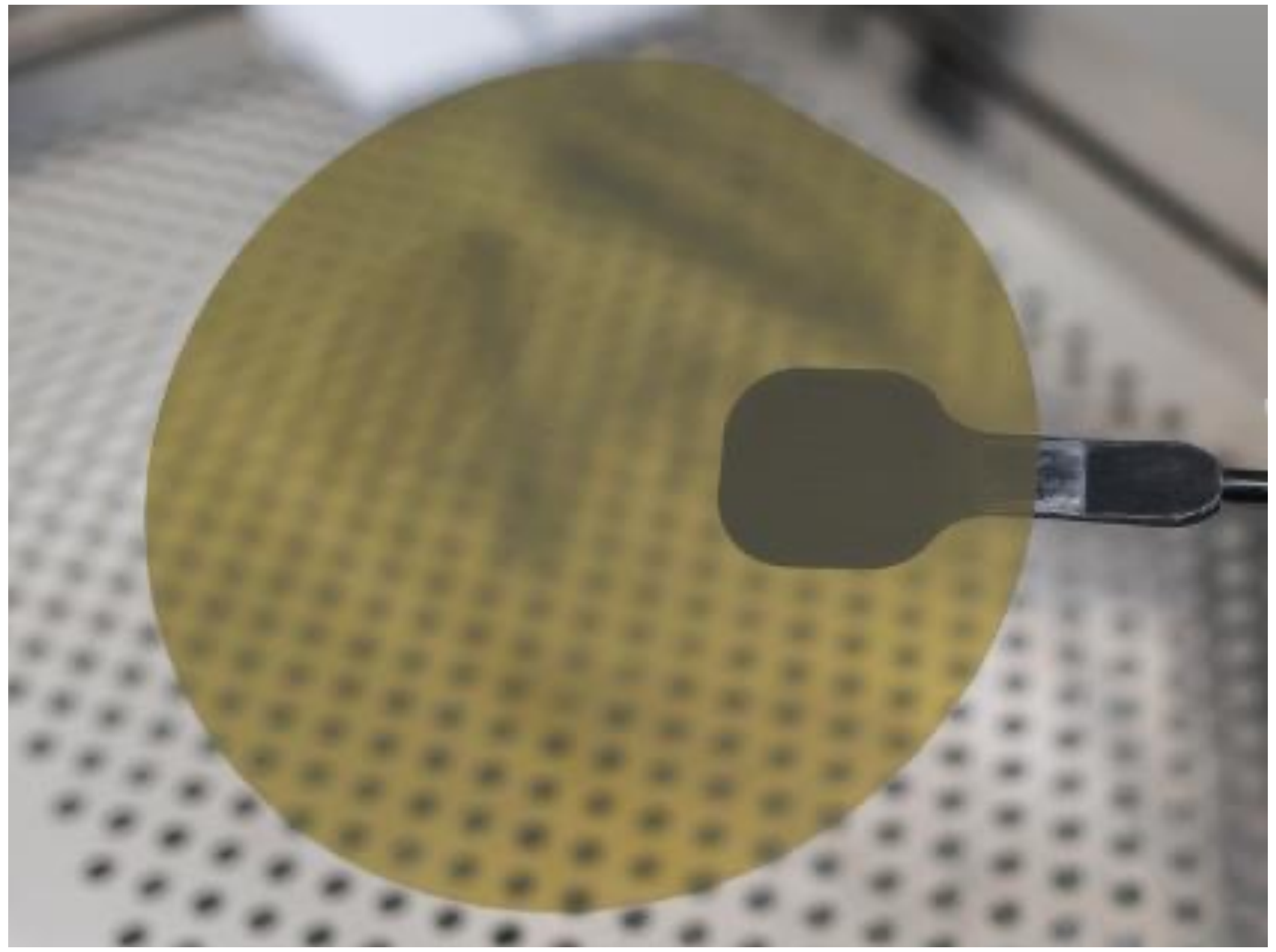
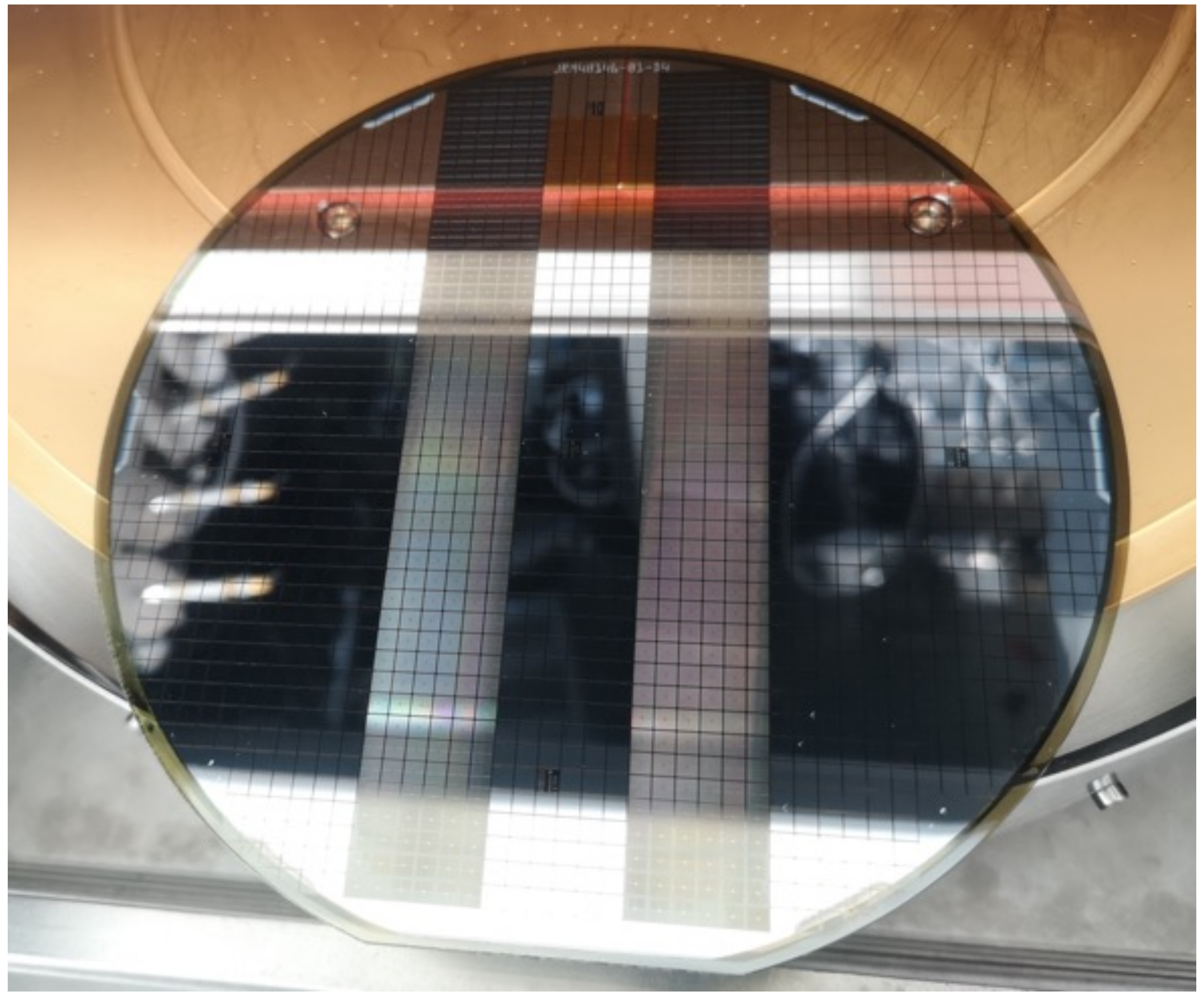
LGADs on SiC – design

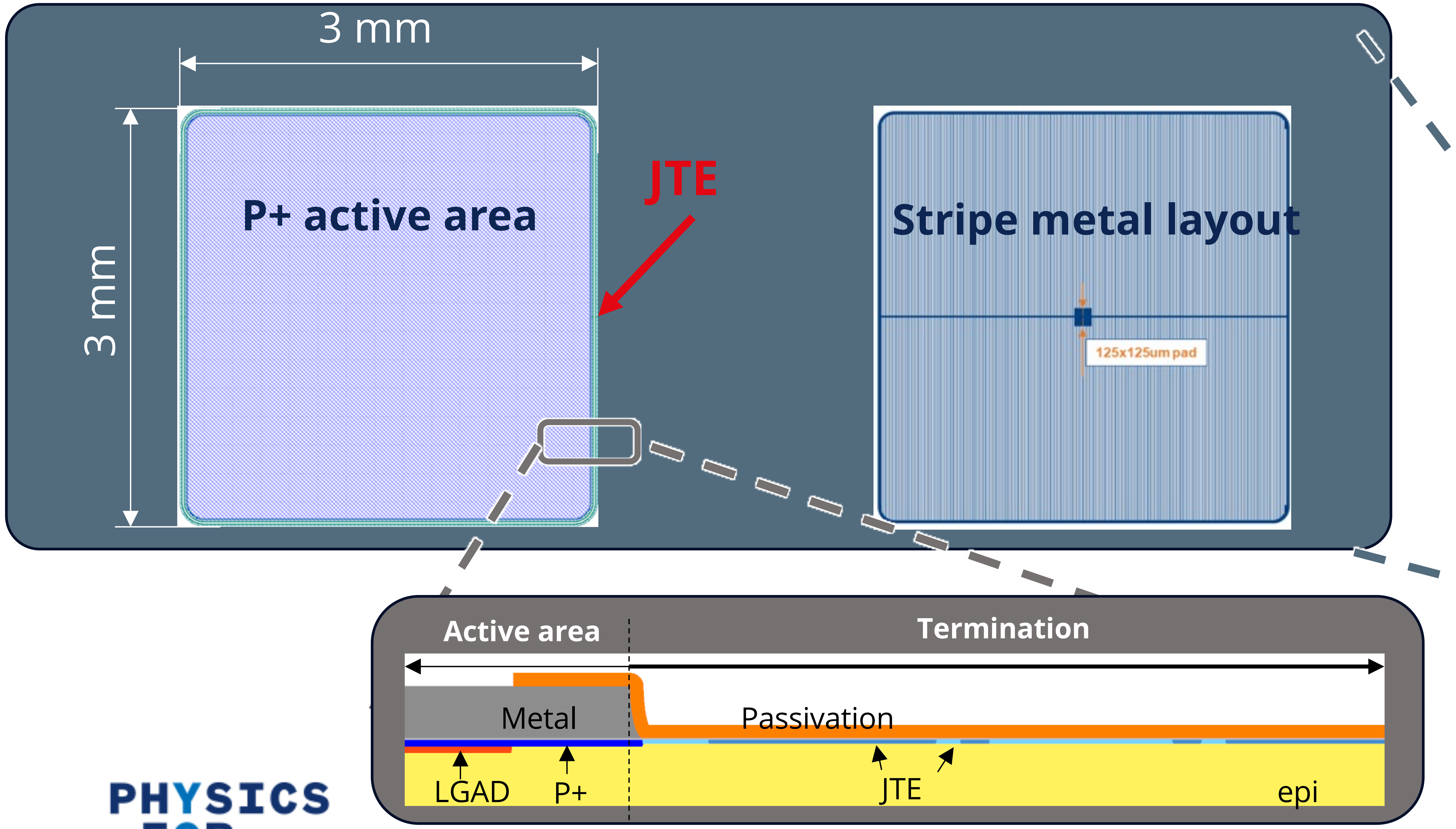
- Diode 3 x 3 mm2 used for R&D
- Comparison no-gain and LGAD
- 30-100 µm EPI grown on 4H-SiC substrate
- n-type bulk

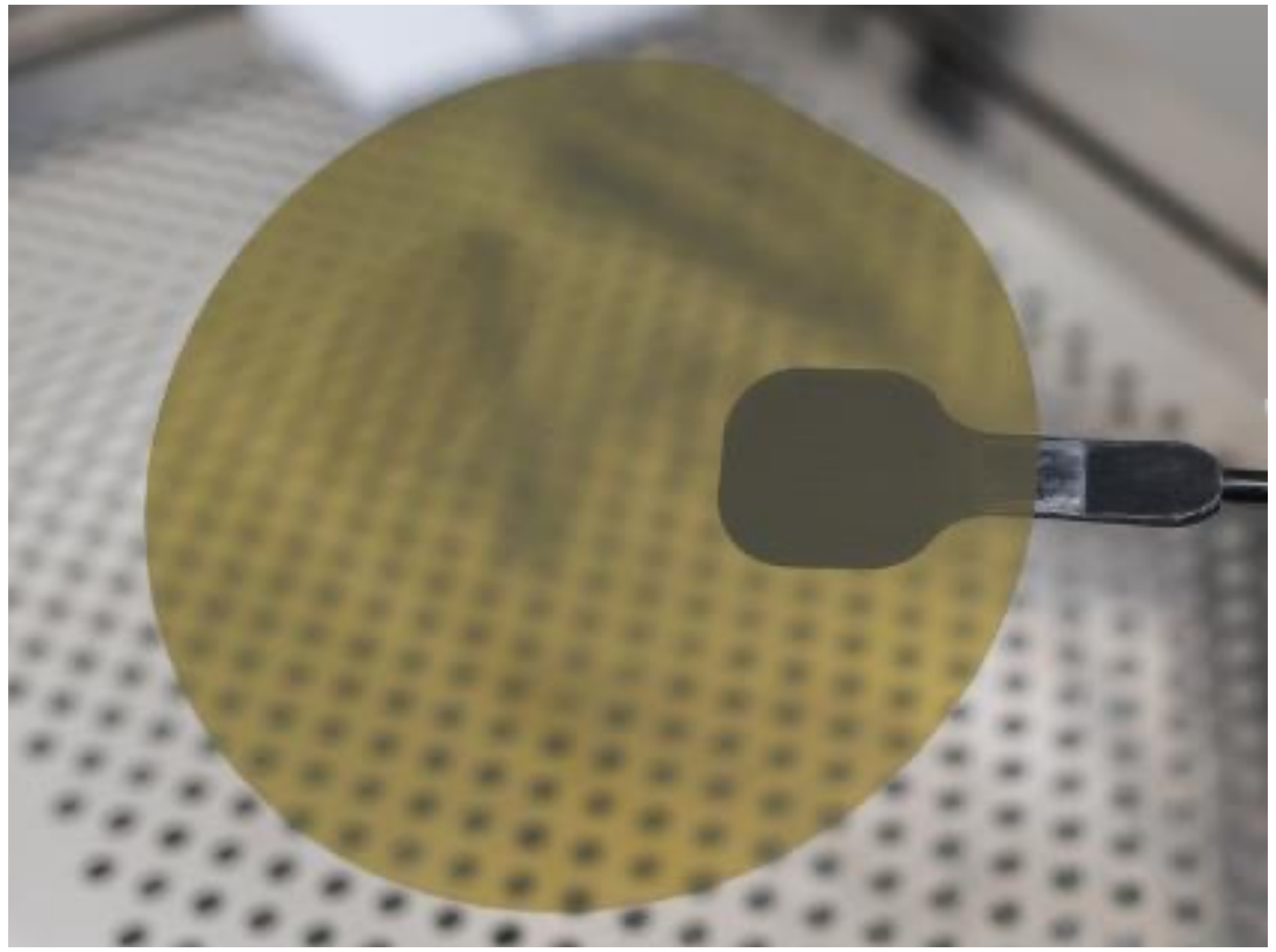


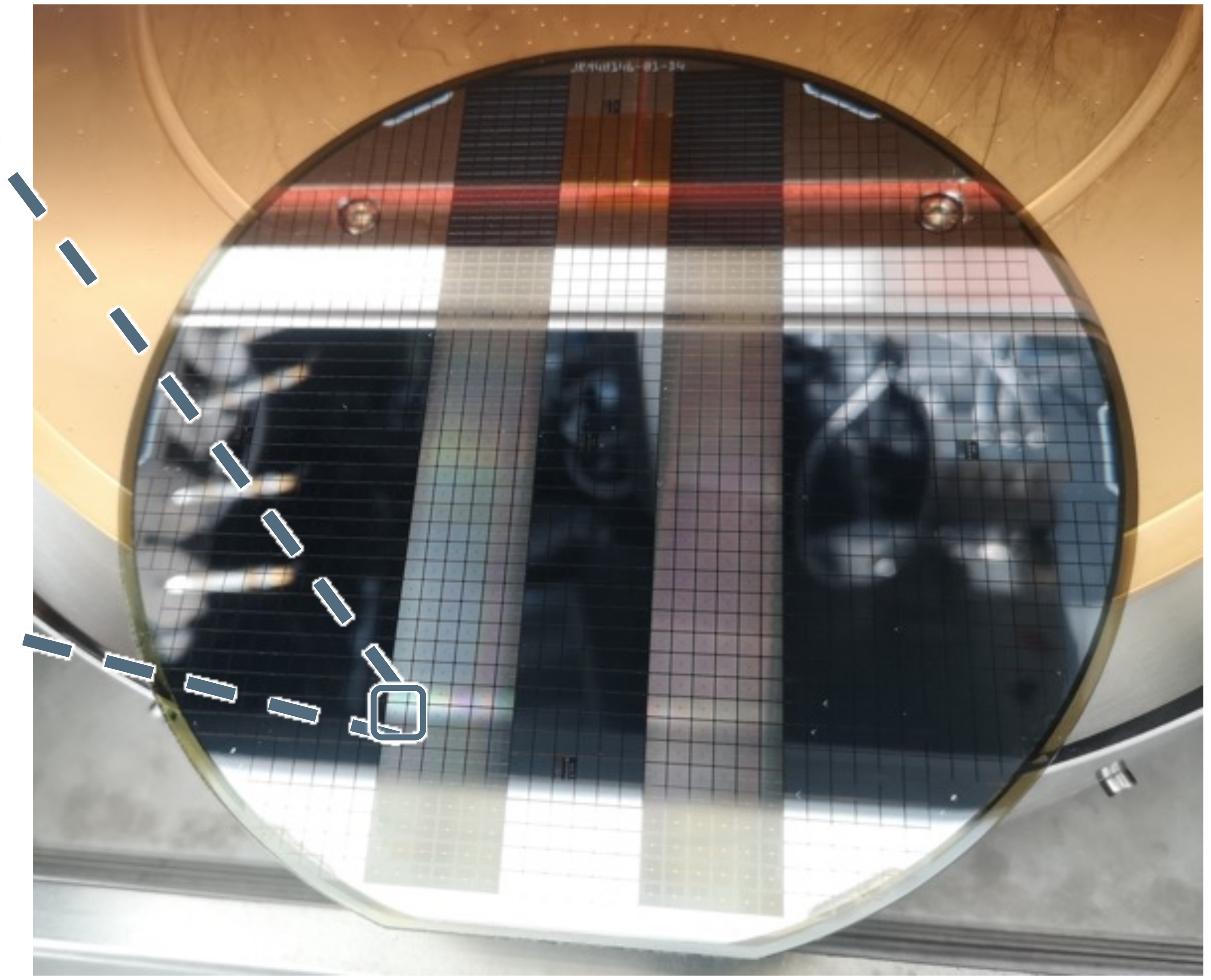


LGADs on SiC – design

- **Diode 3 x 3 mm2 used for R&D**







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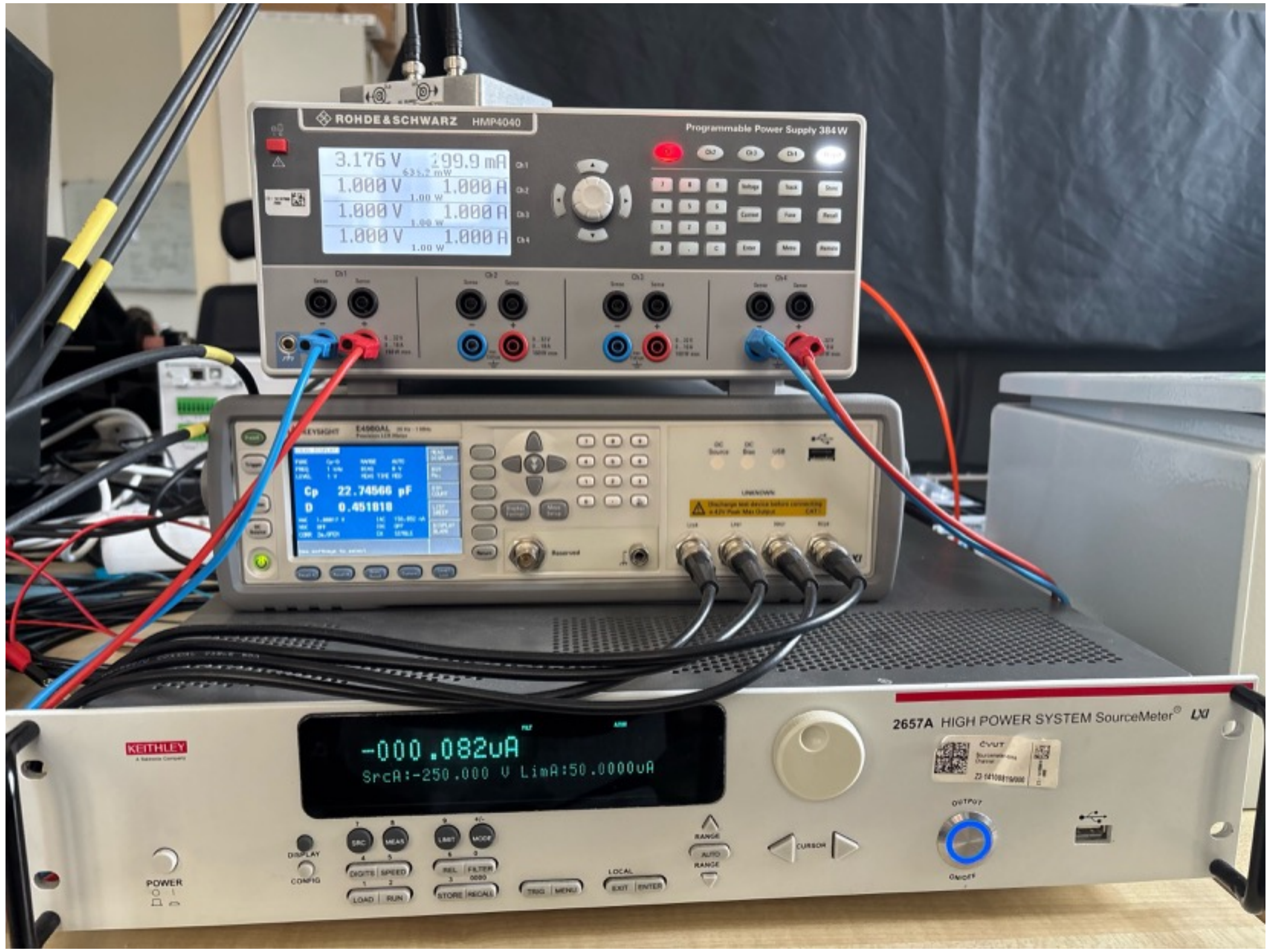
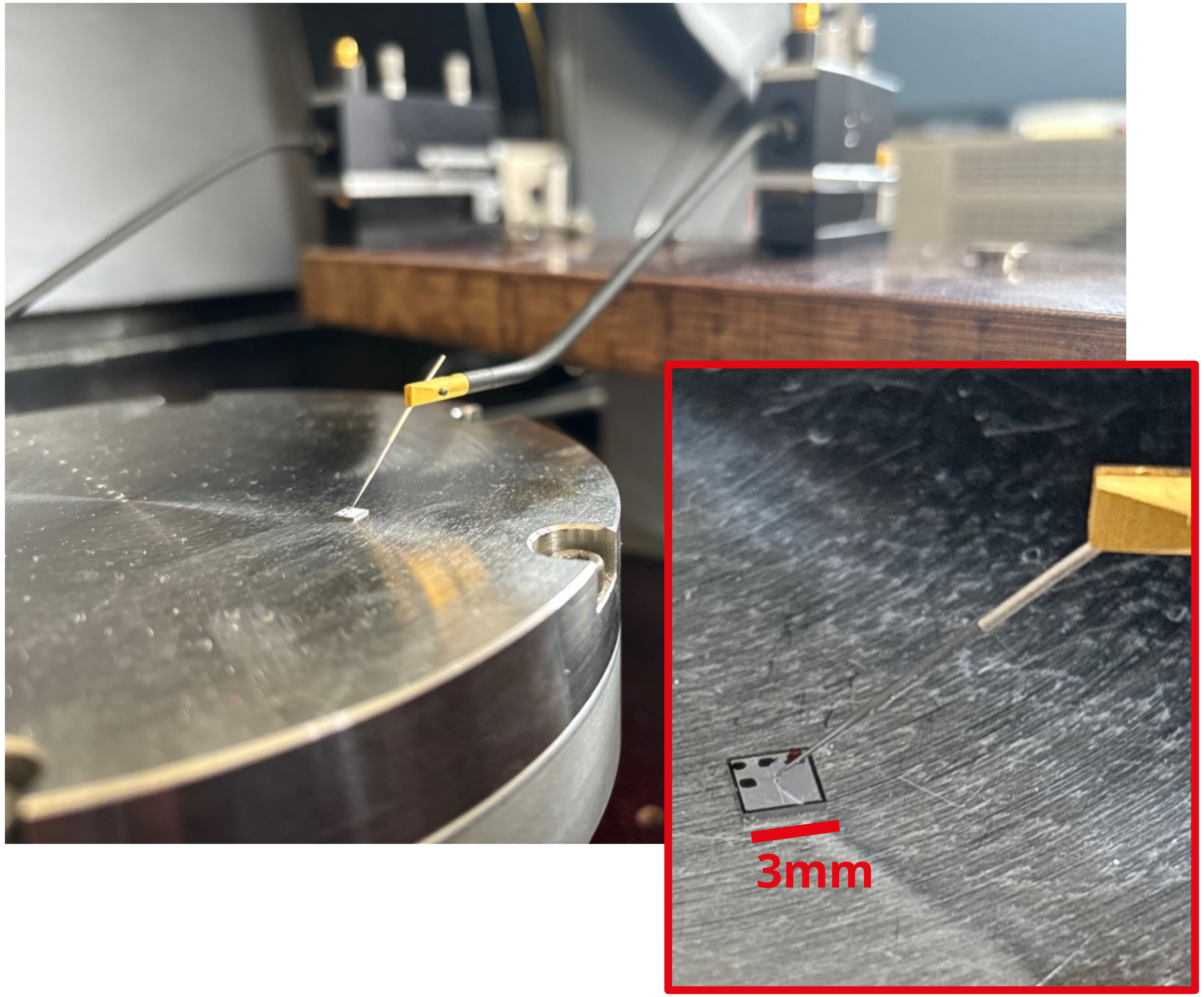
Electrical characterisation





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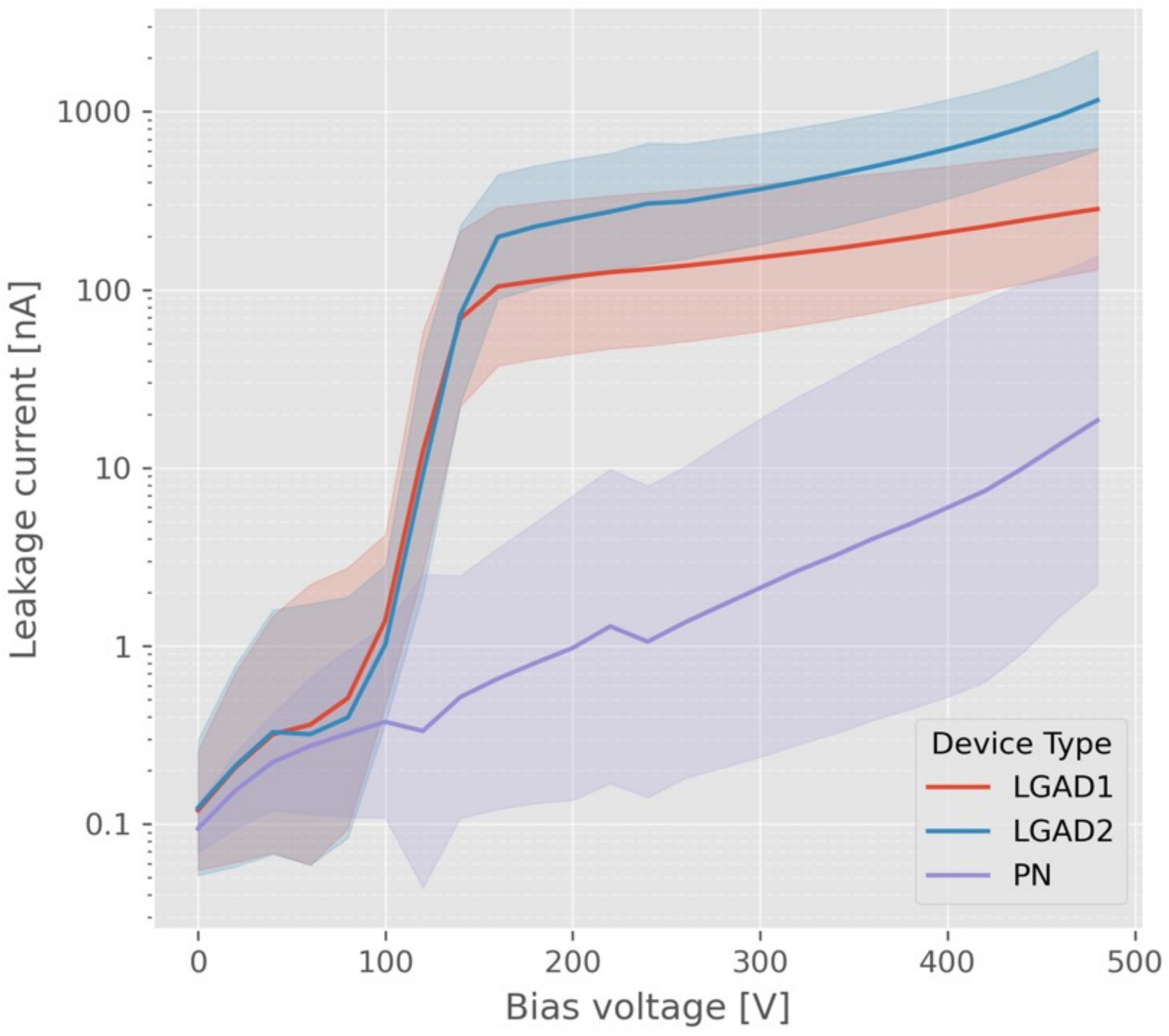
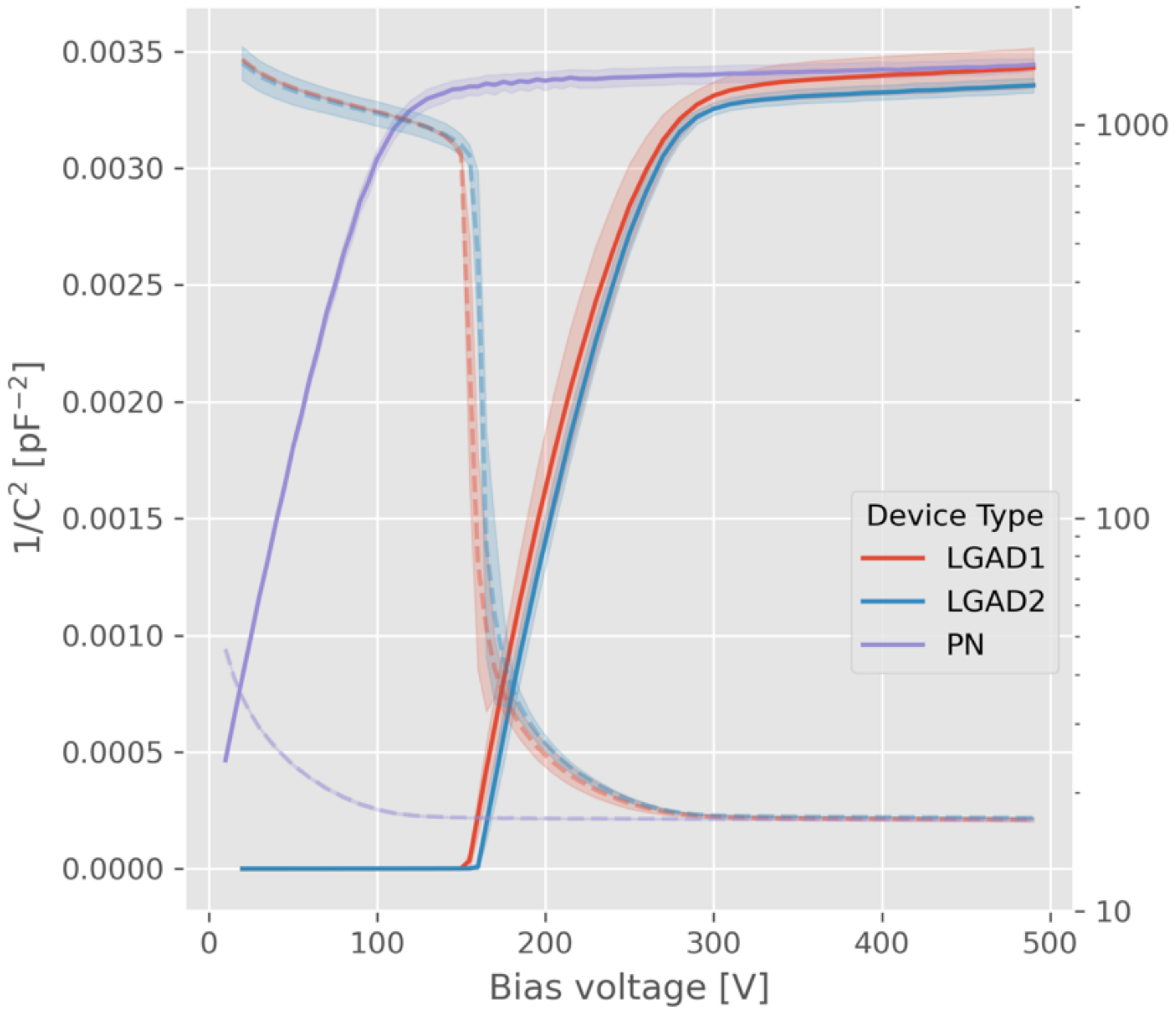
Electrical characterisation – results

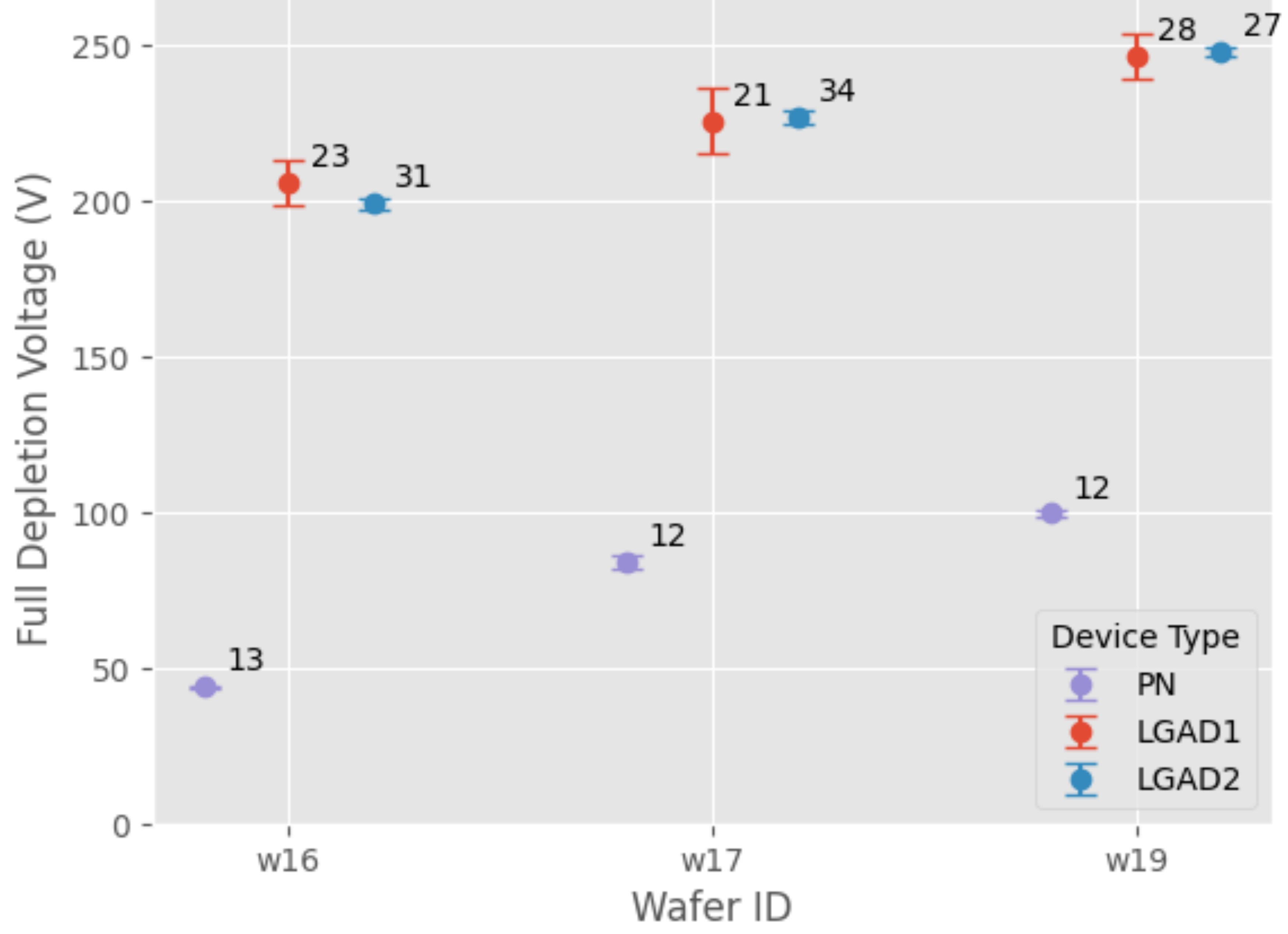
Current-Voltage



Current-Capacitance



Full depletion



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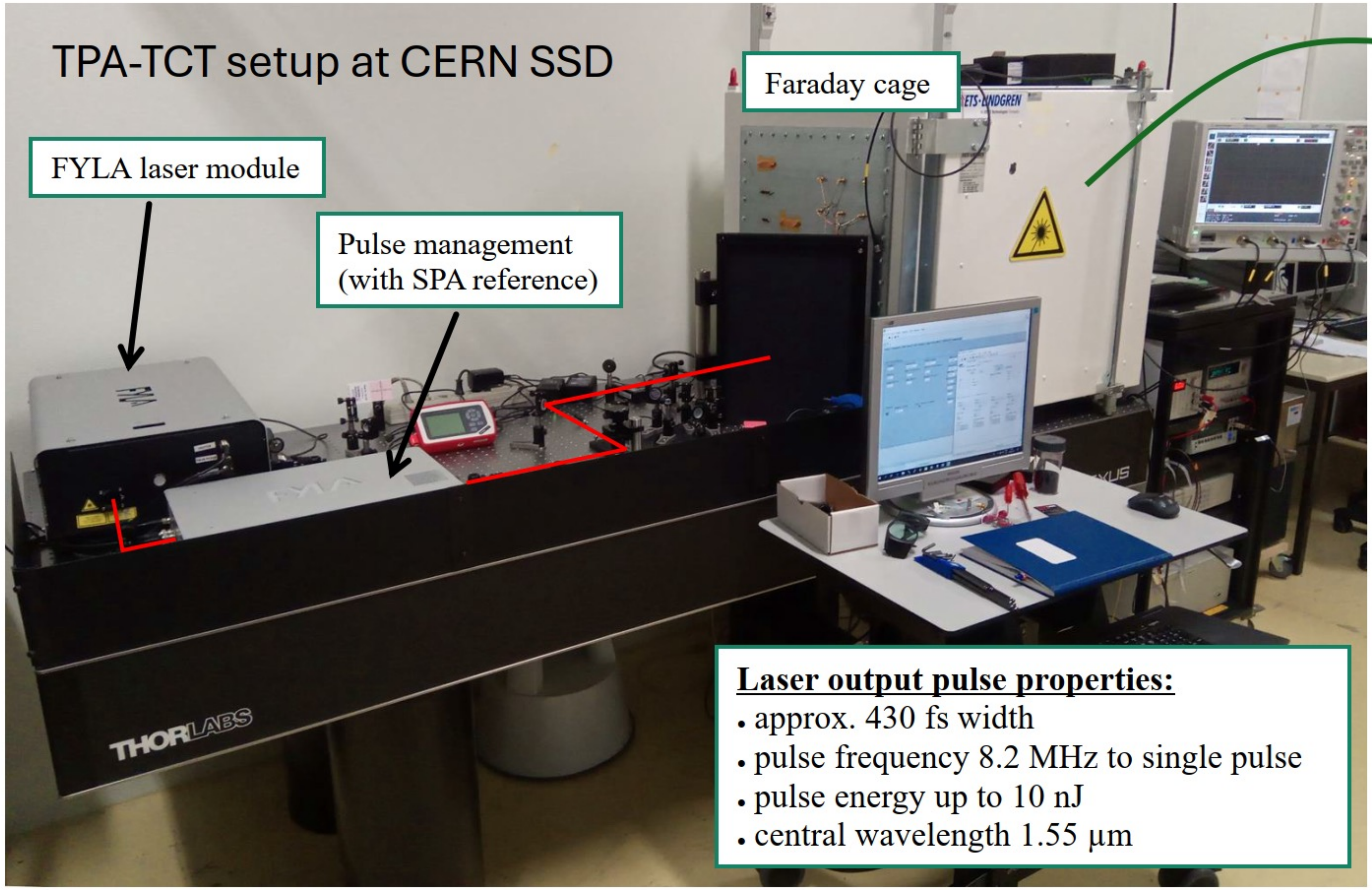
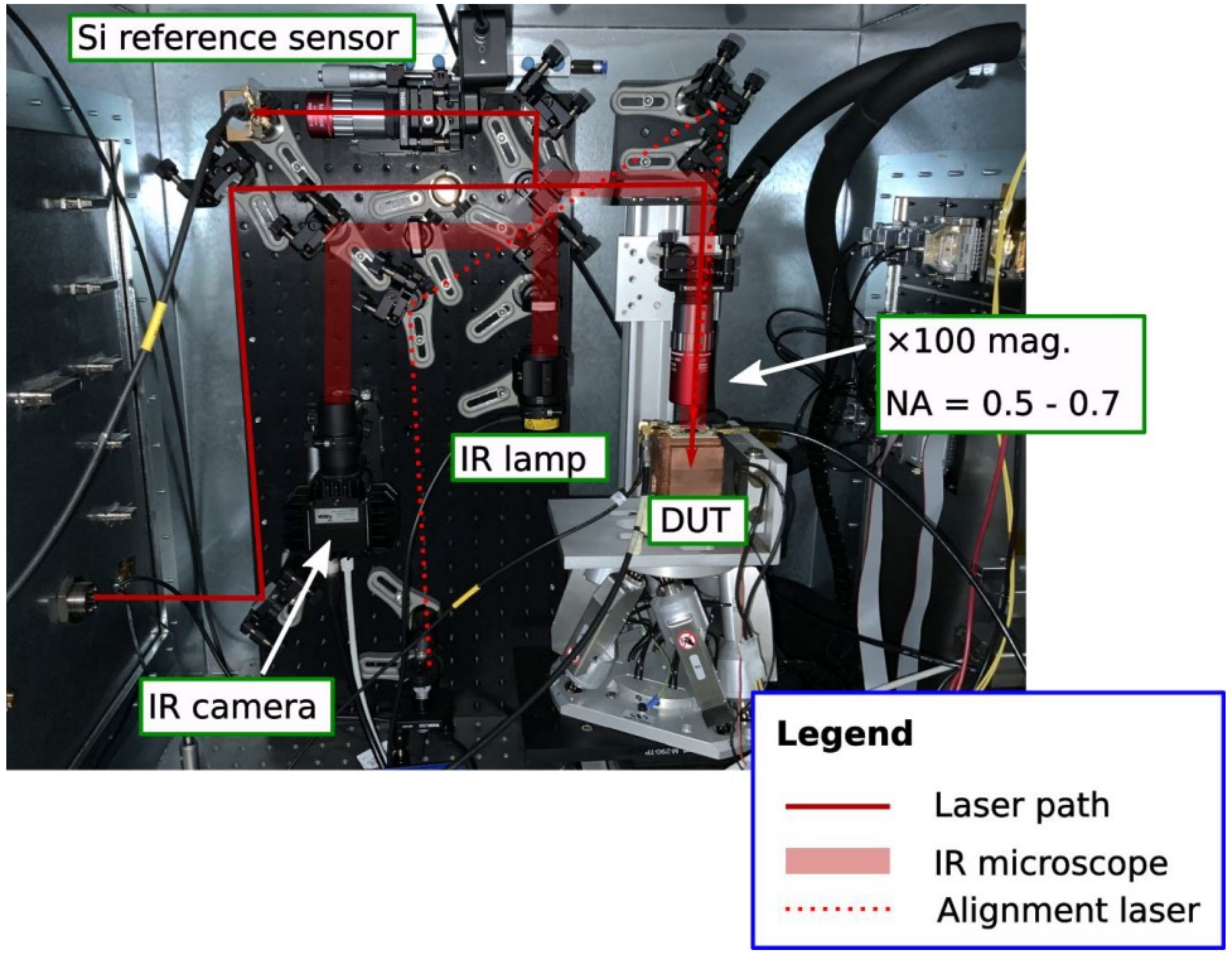
Transient Current Technique (TCT)



Inside the Faraday cage



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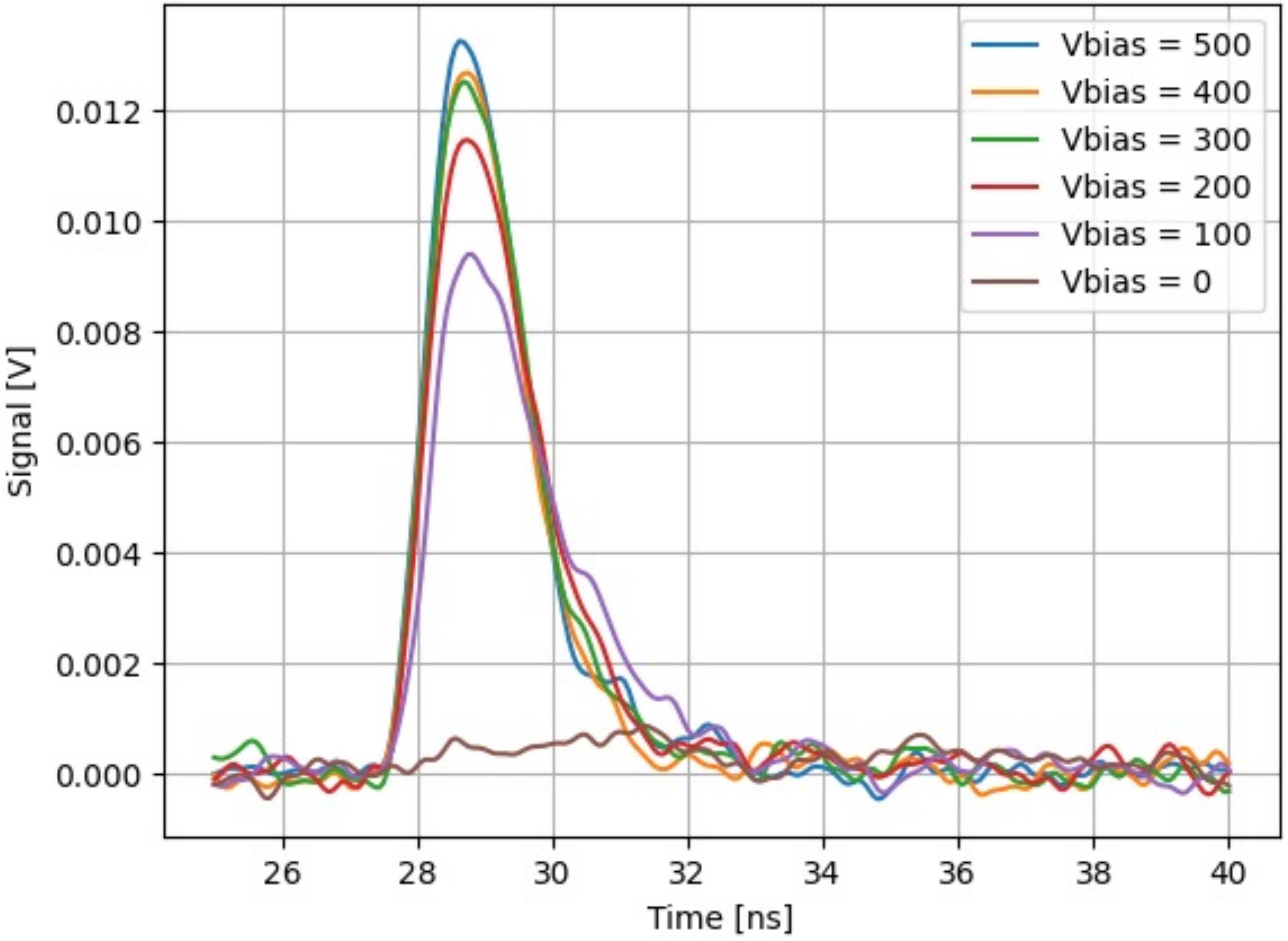
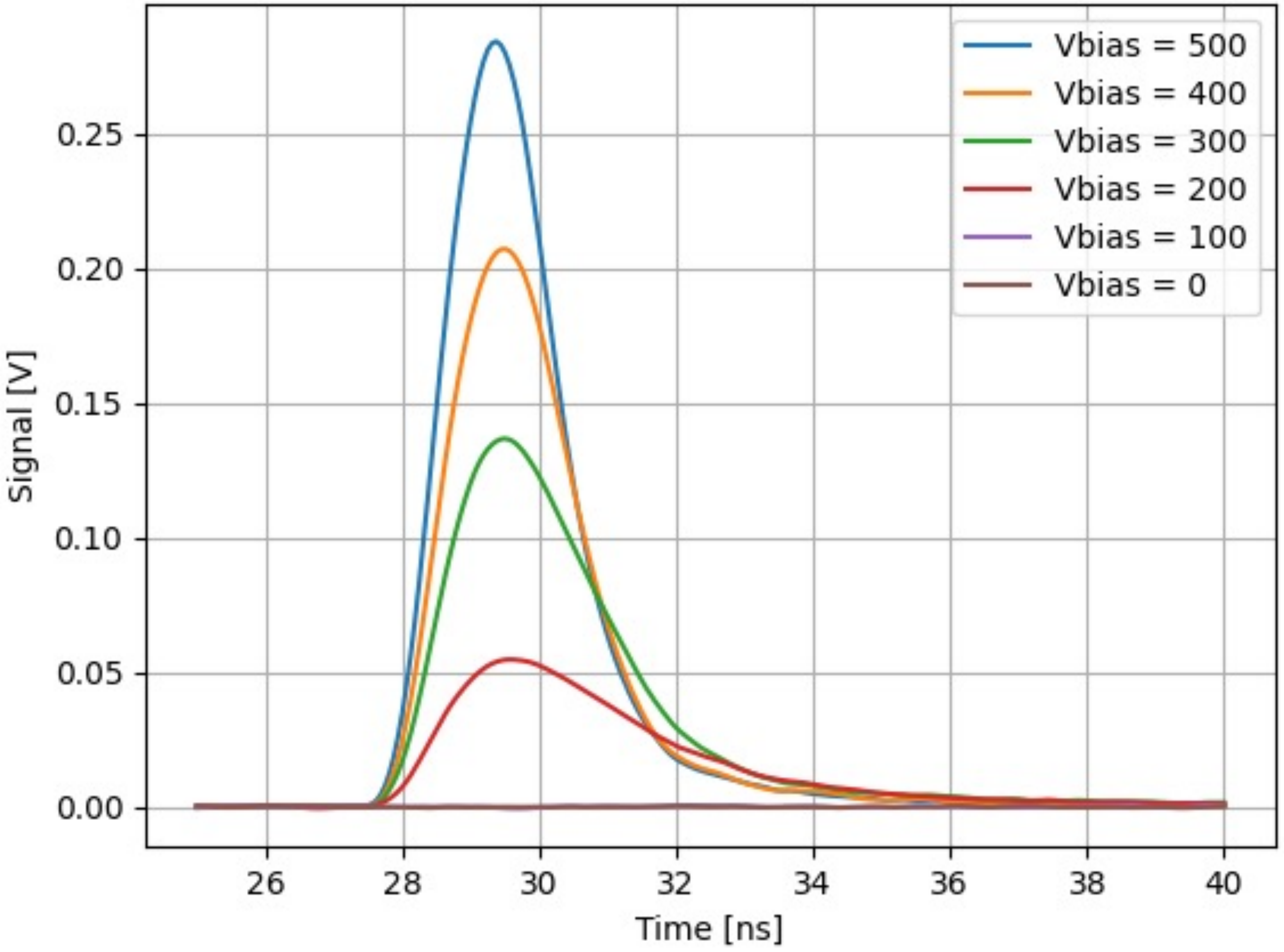
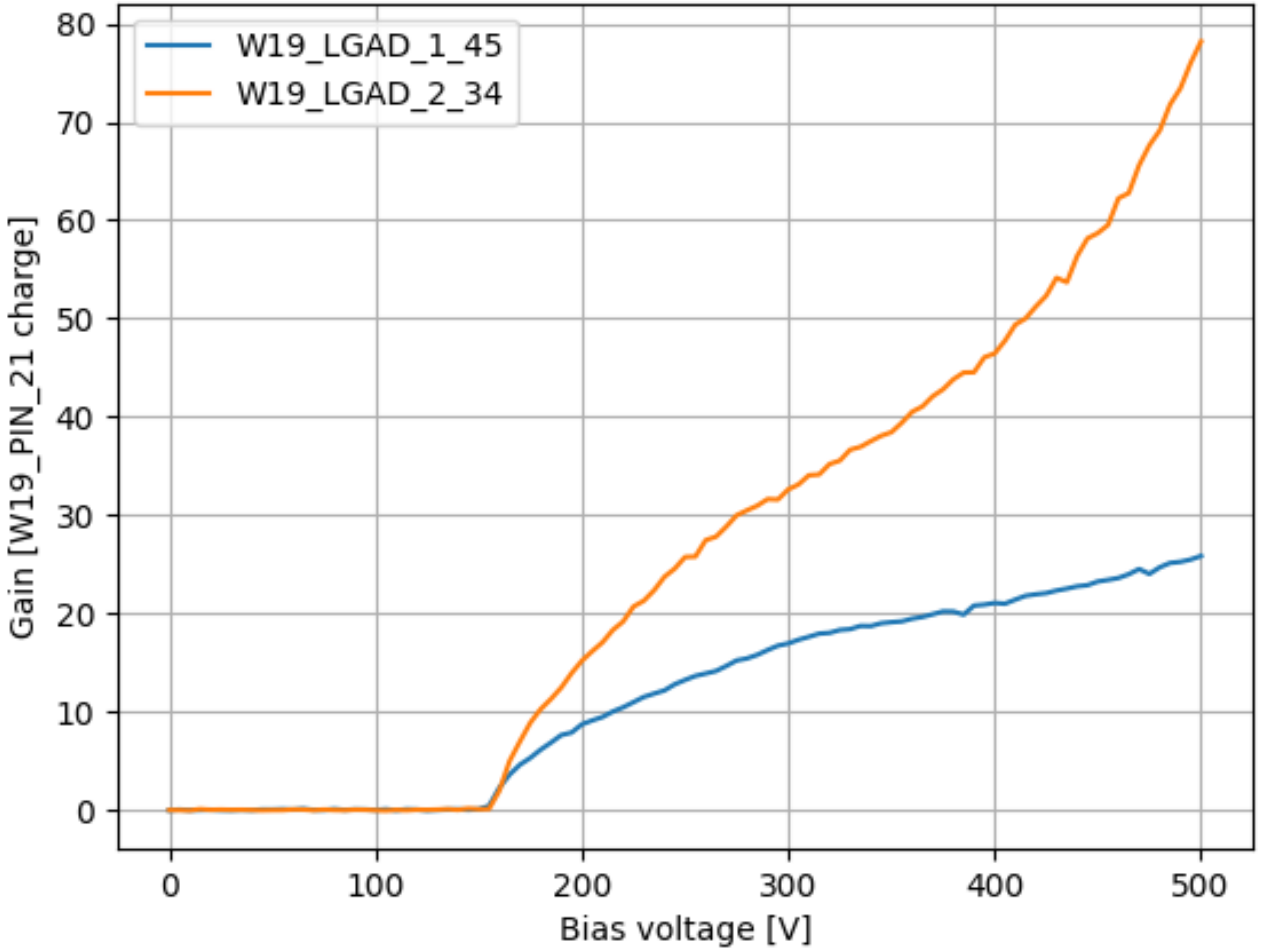
Transient Current Technique (TCT) – results

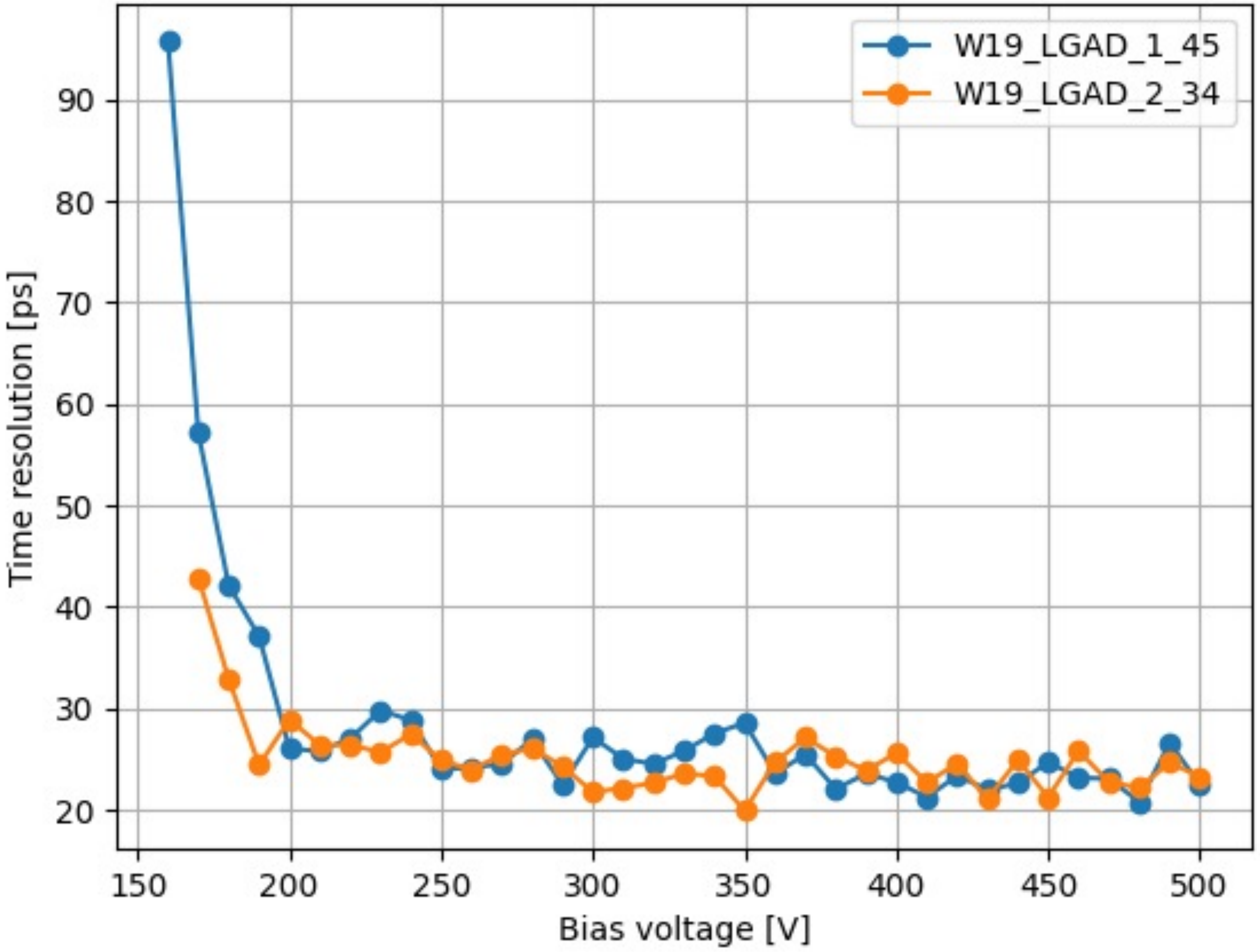




Clear difference of gain on signal response!

Transient Current Technique (TCT) – results





Gain in range of 10-80, non-calibrated signal response down to 20ps

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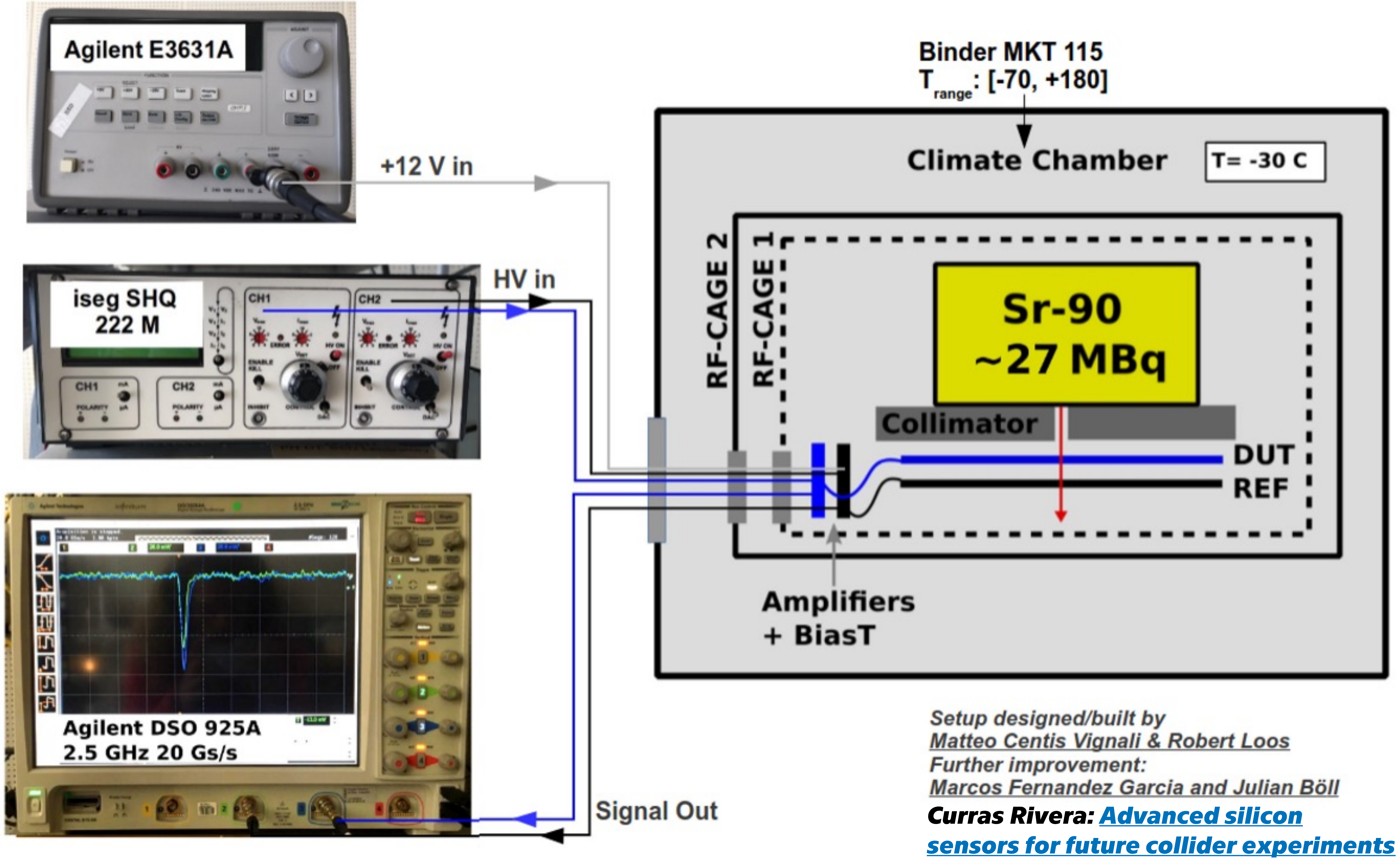
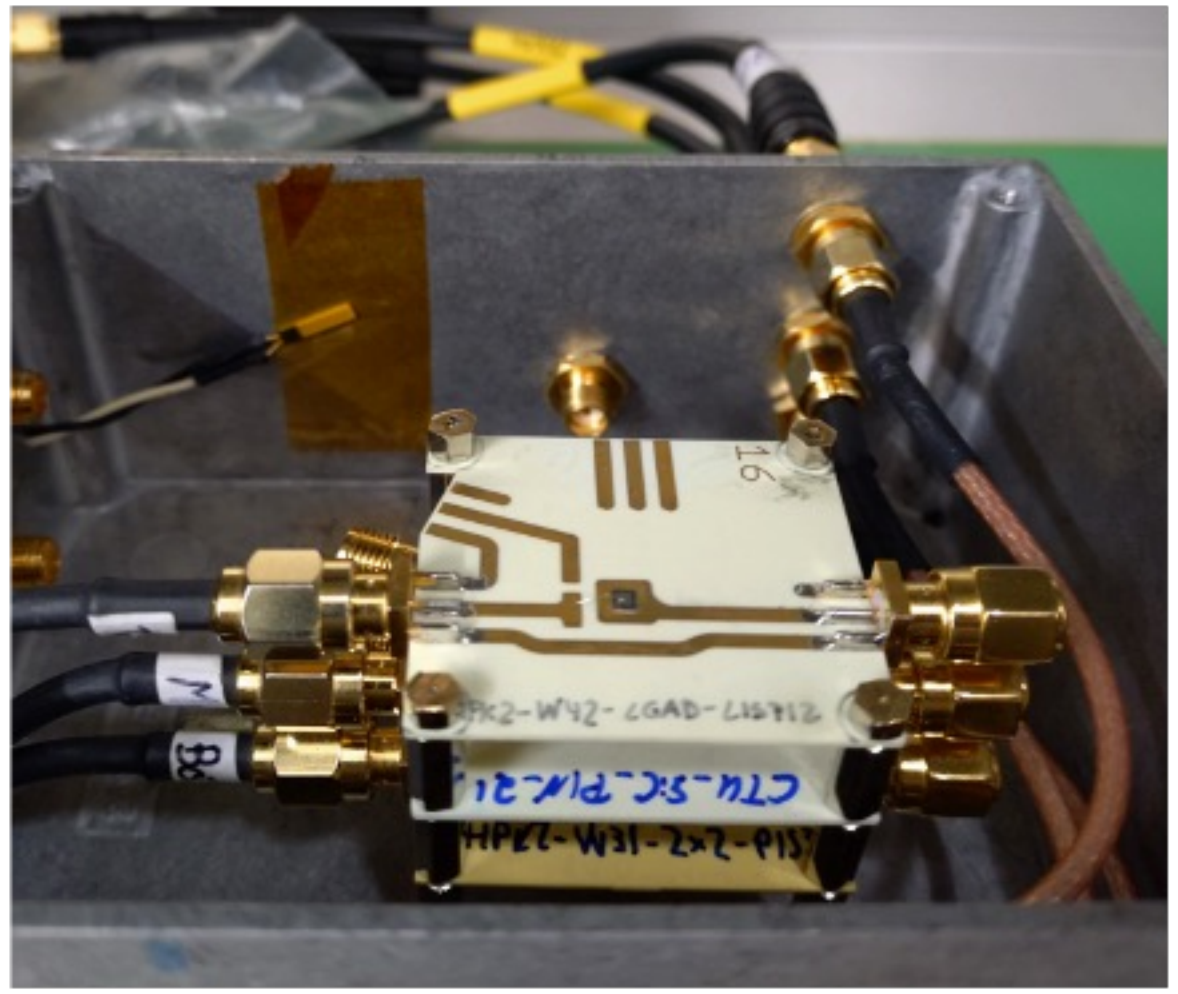
Beta-source tests



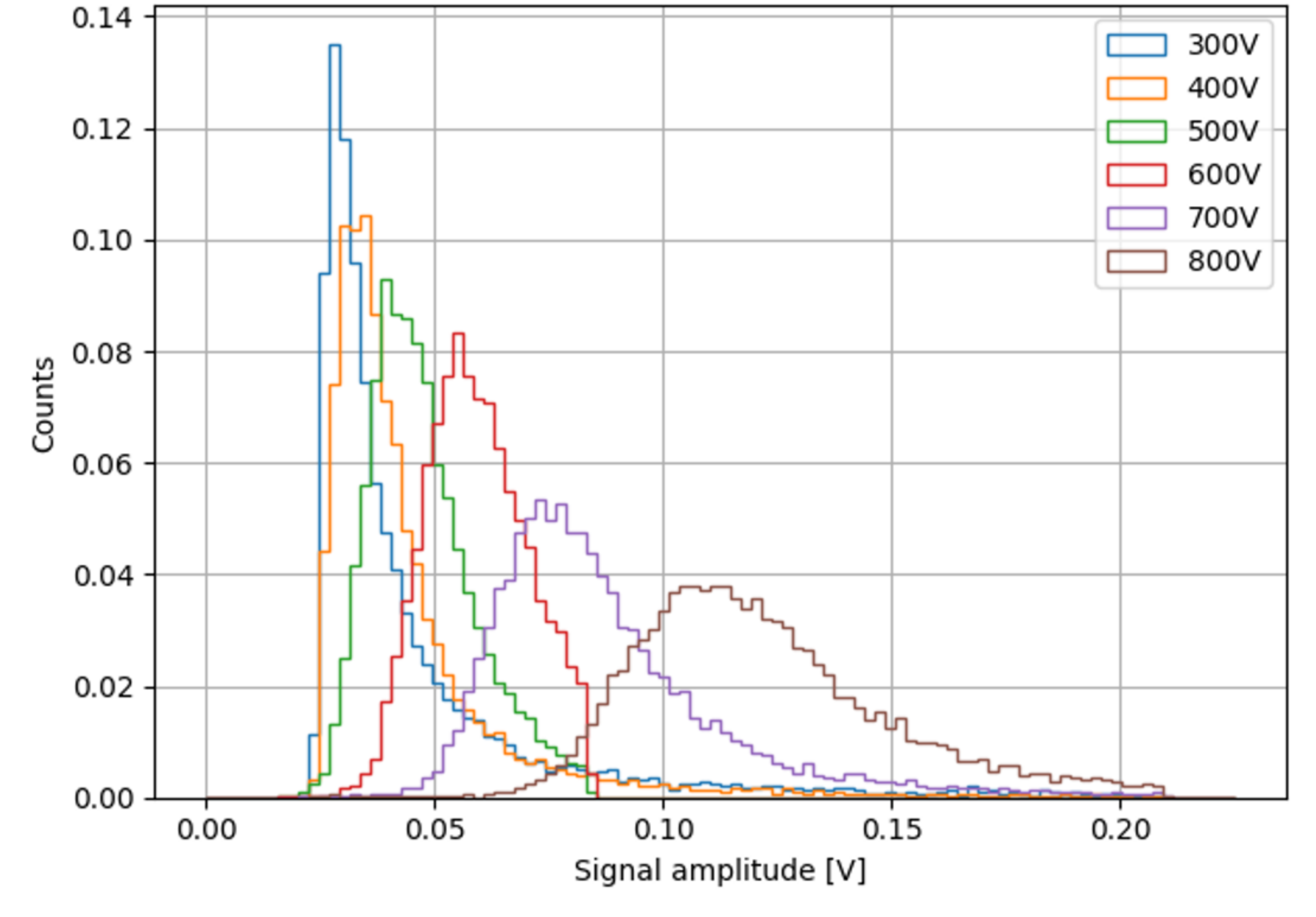
Setup designed/built by
Matteo Centis Vignali & Robert Loos
Further improvement:
Marcos Fernandez Garcia and Julian Böll

Curras Rivera:** **Advanced silicon sensors for future collider experiments



- **Each sensor individually read out with current sensitive amplifiers**
- **Triple coincidence for the oscilloscope trigger**

Beta-source tests – results



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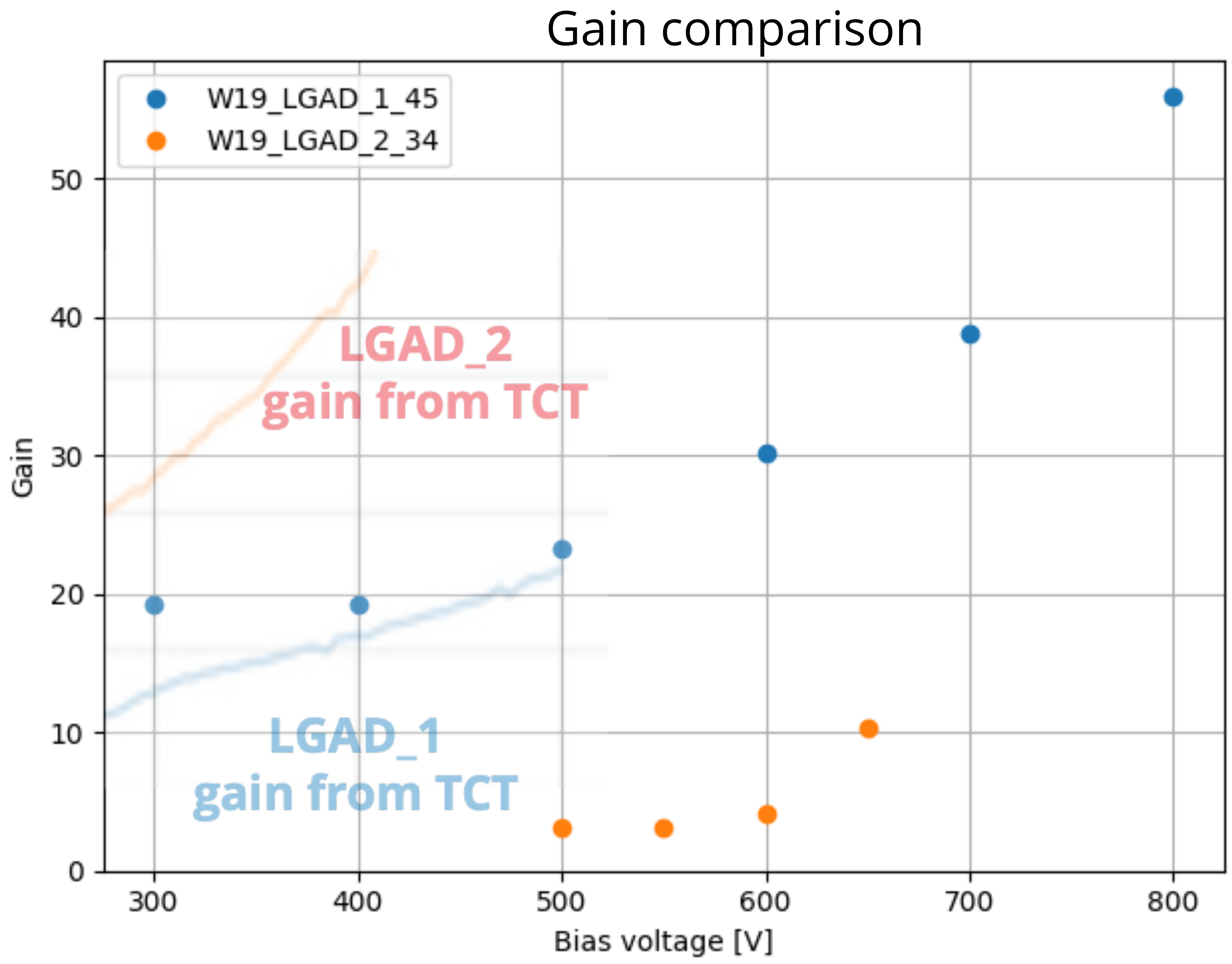

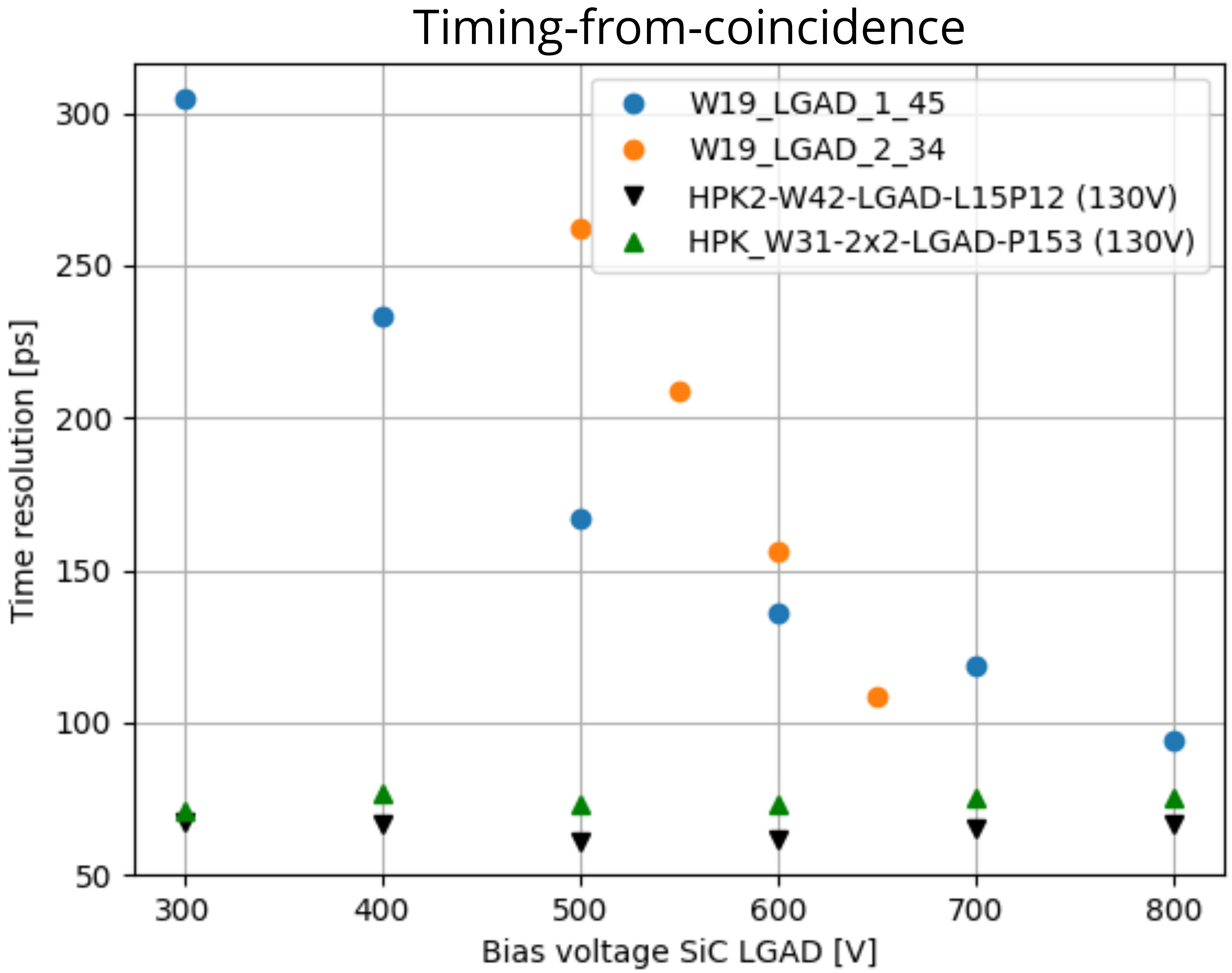

LGAD1 matches TCT calculated gain, particle detection down to 100 ps!!

Future of track-timing detectors..?

- **LGADs provide improved timing**
  - Reduces pile-up
  - Not as radiation hard on normal silicon
- **SiC as an alternative**
  - Radiation hard ? - **to be investigated!**
  - On a path to reach the same performance
  - UV detectors ?
  - … R&D still necessary but promising!

Two papers under review:
https://arxiv.org/abs/2503.07490
https://arxiv.org/abs/2504.09264

FORTE url: FORTE

PHYSICS FOR FUTURE url: P4F

onsemi url: OnSemi

FZU Institute of Physics of the Czech Academy of Sciences url: FZU

CTU CZECH TECHNICAL UNIVERSITY IN PRAGUE CAPADS FNSPE CTU url: CAPADS

Thank you for your attention

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