ÖAW AUSTRIAN ACADEMY OF SCIENCES

MARIETTA BLAU INSTITUTE FOR PARTICLE PHYSICS

First Results from the Second Production of the RD50-SiC-LGAD Common Project

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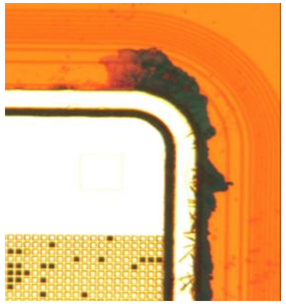
4th DRD3 Week
13.11.2025

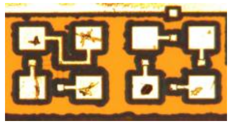
RD50 SiC-LGAD Common Project*

*Contributors:
MBI, CNM, CERN, INFN Perugia, IFCA Santander, NIKHEF

- 2 PiN + 1 LGAD run
- Design by HEPHY (now MBI)
- Production at CNM

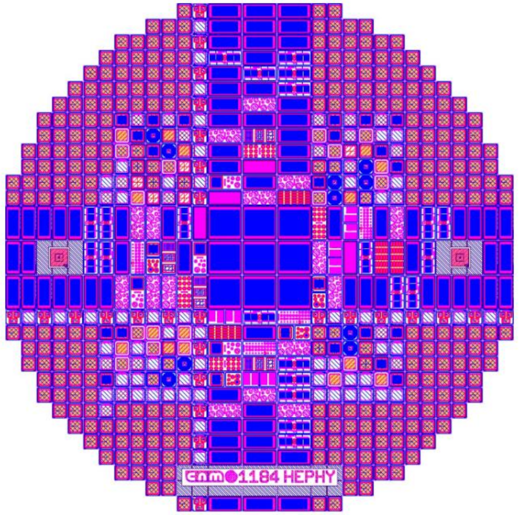
- 1st PiN run (finished 2024):
  - 2x50µm and 1x100µm wafers have been processed
  - Low yield (<30%) due to production issues
  - See talk at 1st DRD3 week



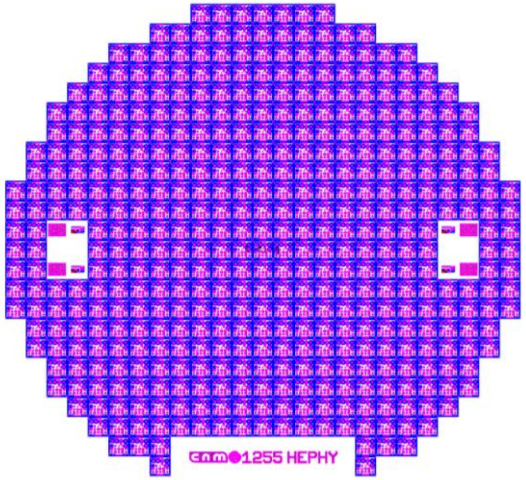


- **2nd PiN run (finished 2025): this presentation**

- LGAD run (upcoming)



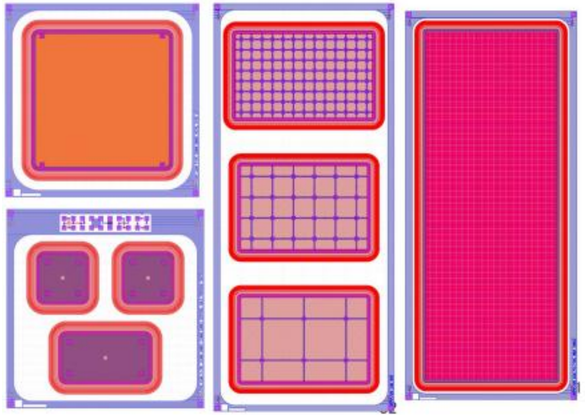
Layout of PiN runs

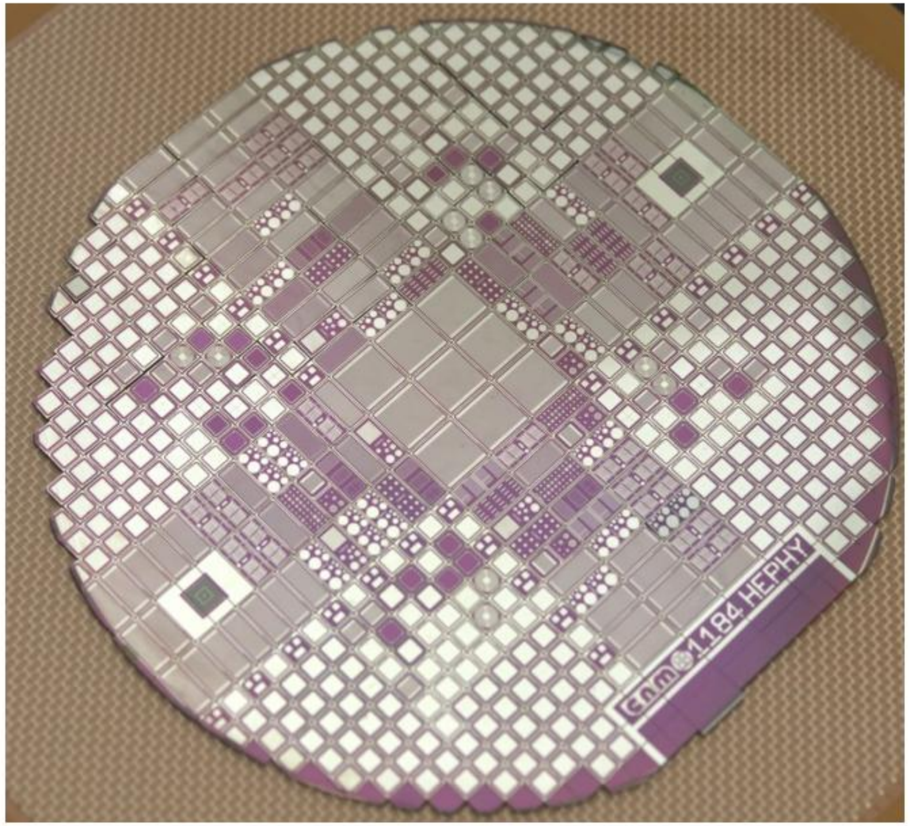


Layout of LGAD run

2nd PiN Production Overview

- Production finished summer 2025 at CNM
- 2 wafers: 1x50µm and 1x100µm epi thickness
- Contents per wafer:
  - 3x3mm^2 diodes (PAD)
  - Small area diodes (<1pF)
  - Segmented strips
  - MOSCAPs
  - Resistive devices
  - ...

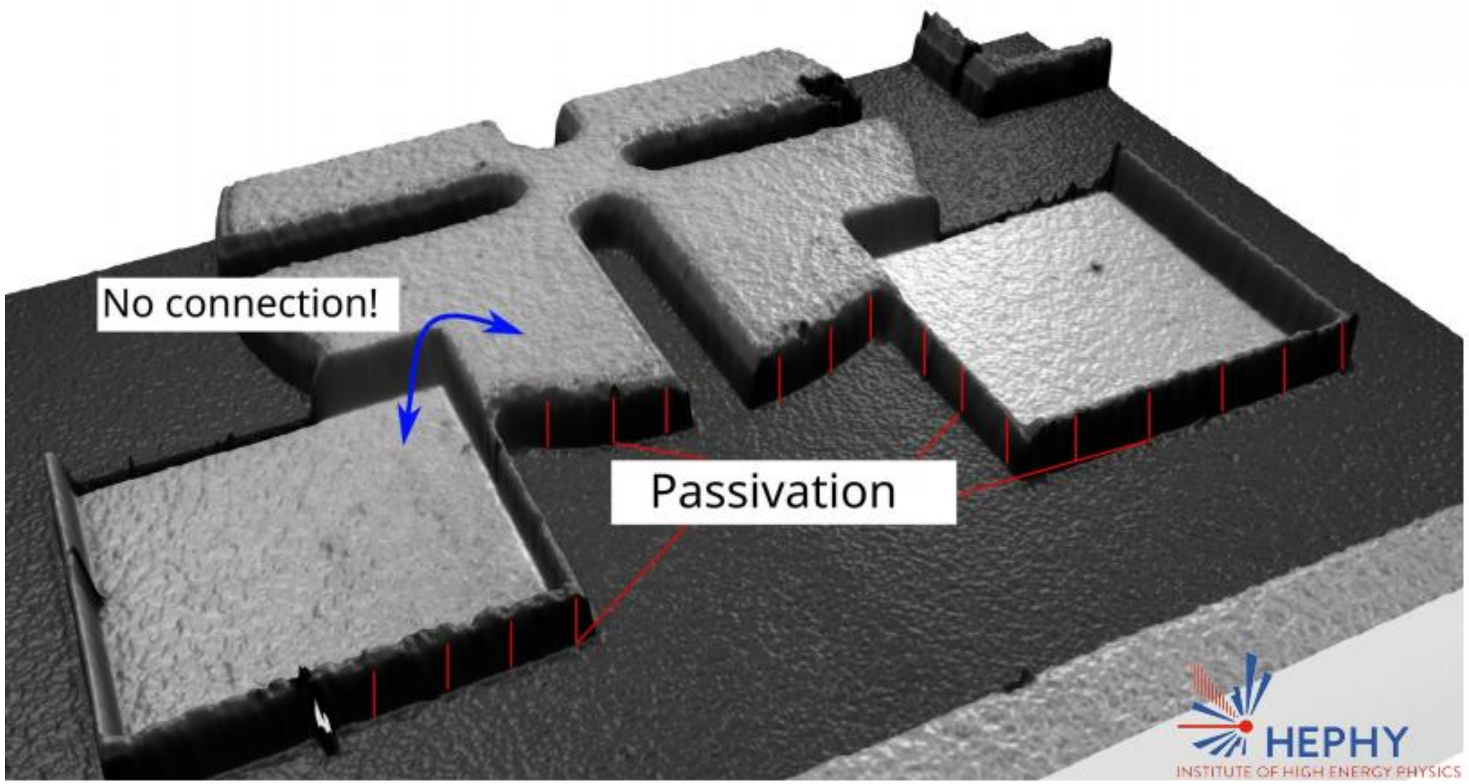


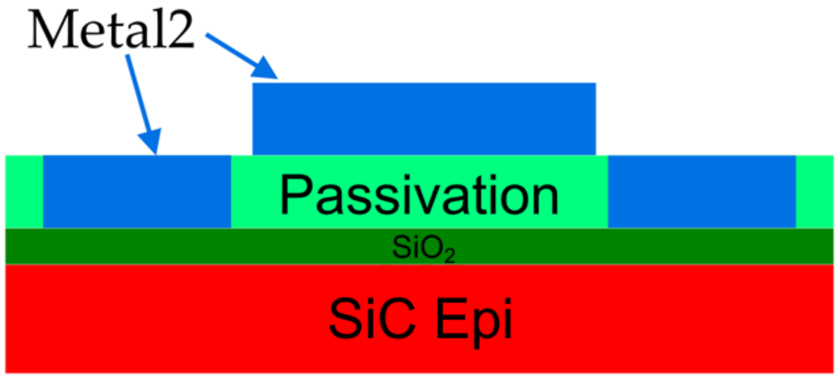


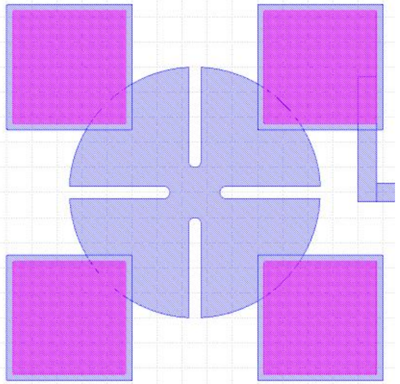
- Process upgraded to mitigate metal outflow
  via addition of 2nd metal layer → successful (yield ~70%)
  But…

Passivation Issues

- The top passivation was deposited below the 2nd metal instead above it
- Passivation is only open at the bondpads
- 2nd metal layer is on top of the passivation, which results in a large step-height
  → Bond pads are not electrically connected



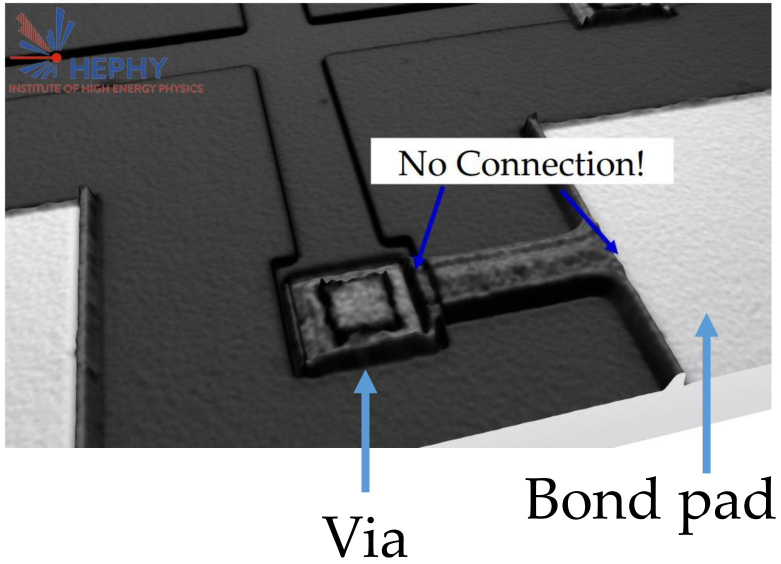




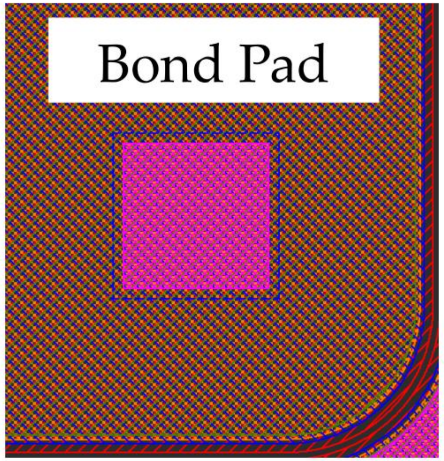
Purple: passivation open

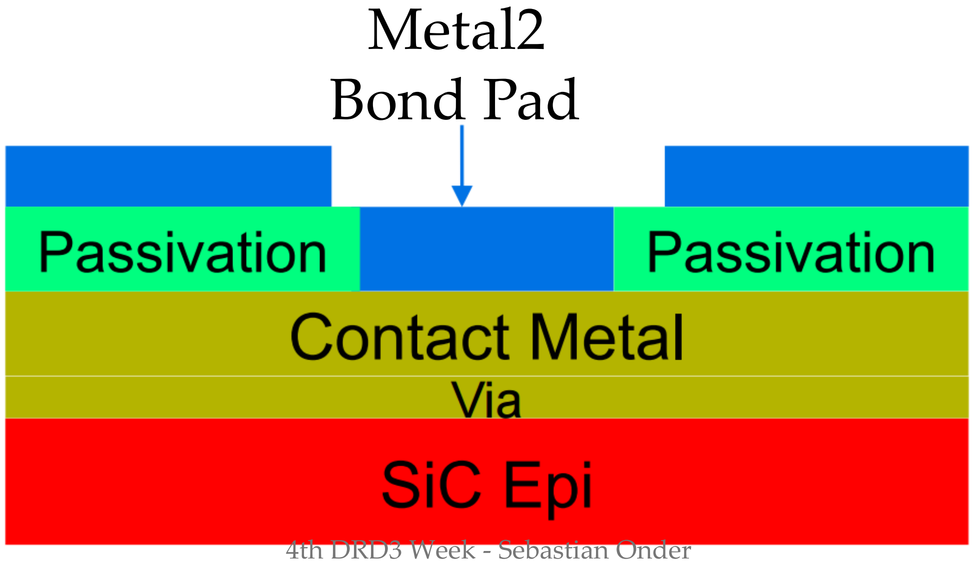
Passivation Issues

- Non-functional devices, e.g. VdP test-structures, MOSFETs
  - Bonding pad placed next to substrate contact
  - Connection from bonding pad to substrate is interrupted



- Functional devices, e.g. 3x3 mm² PAD diodes
  - Passivation is open above substrate contact
  - Connection is ensured by contact metal below passivation ✓





Metal2
Bond Pad

Passivation

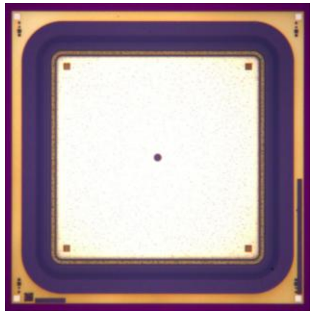
Passivation

Contact Metal

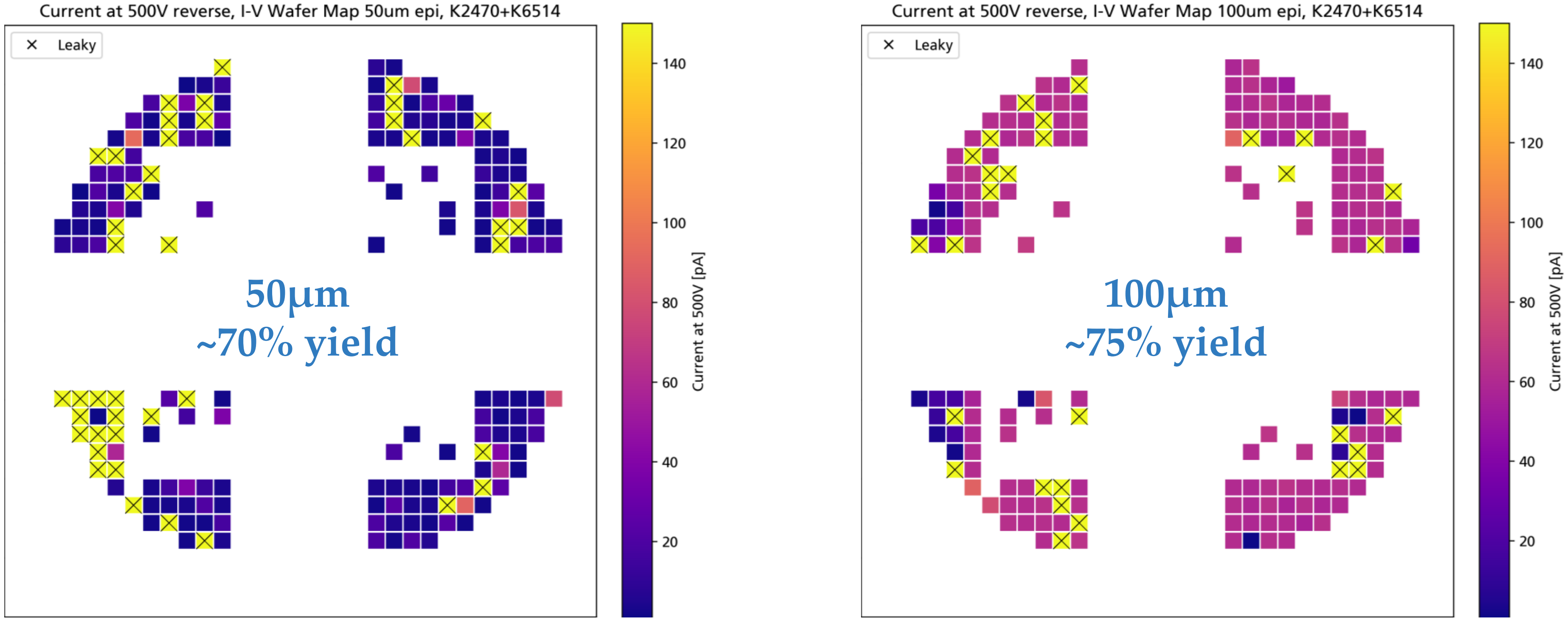
Via

SiC Epi

Wafer Level IV of PADs



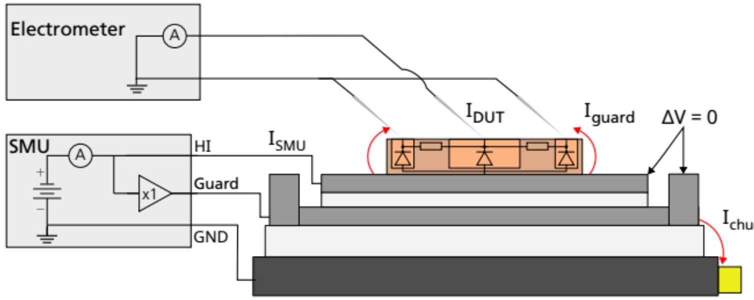
- Results from wafer level testing @ CNM
- MPI TS2000-SE wafer prober + K2470 SMU + K6514 ELM
- Grounded guard ring
- Good devices have 20-50pA leakage current at 500V originating from setup

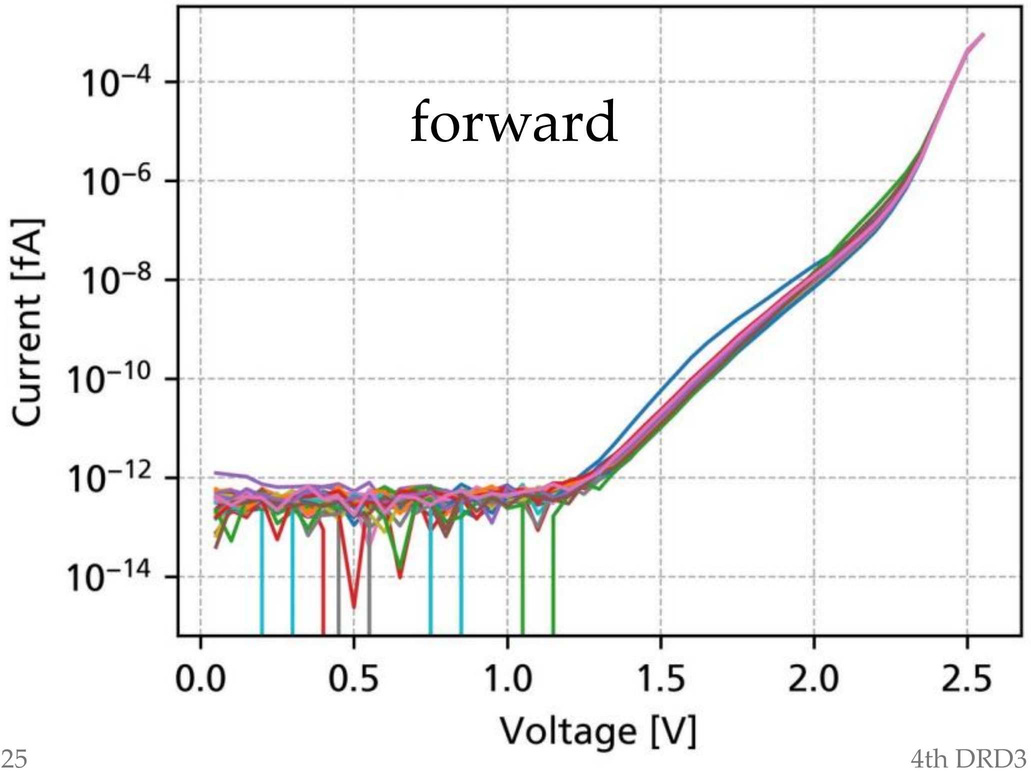


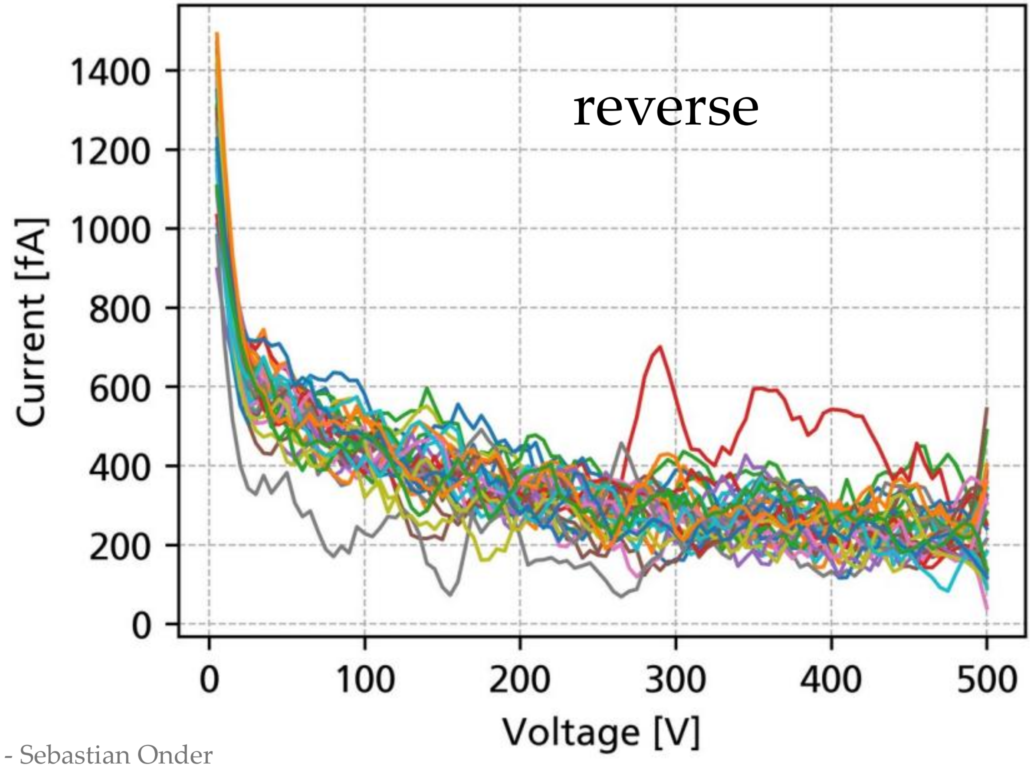
Leaky = leakage current > 750pA

Precision IV Characterization

- Single die IV using guarded chuck (few fA sensitivity) in Vienna
- Leakage currents of good diodes are well below 1 pA
- In reverse bias, only the settling of the probe station etc. is measurable

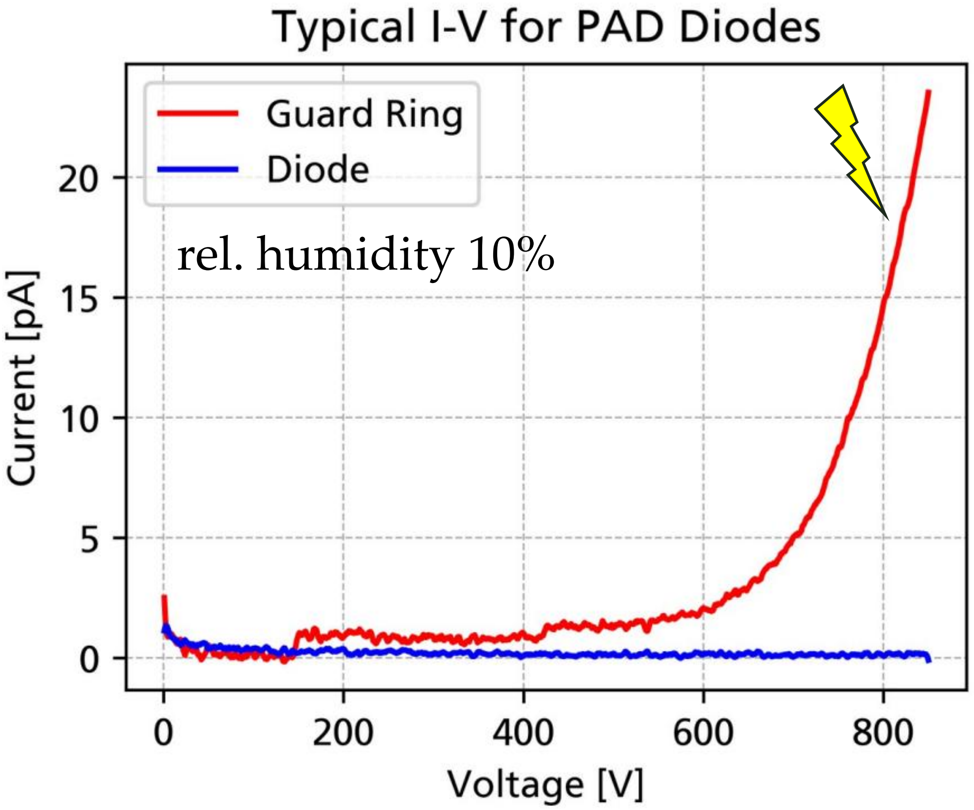


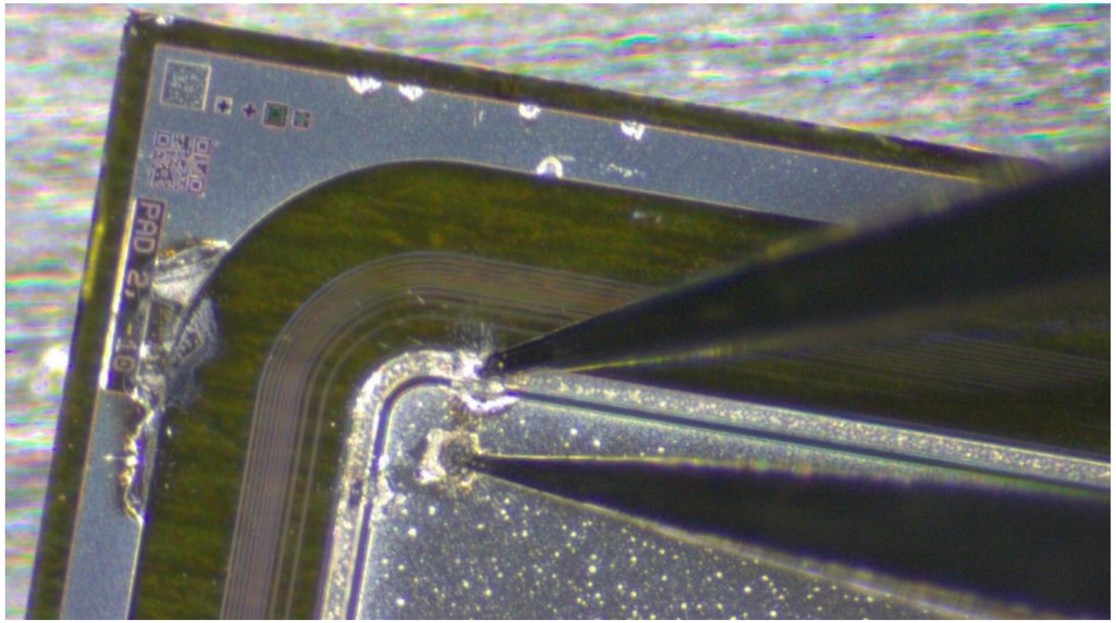




HV Limitations

- Guard ring leakage starts to increase above 400V (consistent among all tested diodes)
- **Destructive breakdowns around 1kV**
- Maybe related to non-passivated metal on top



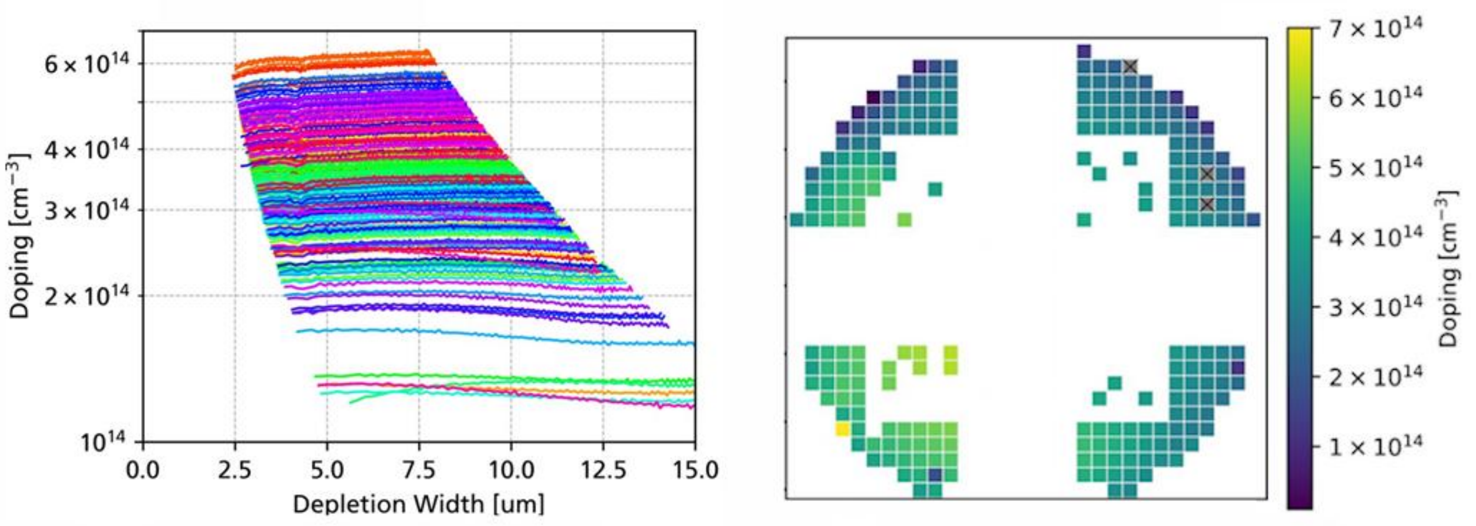


Doping of PAD diodes

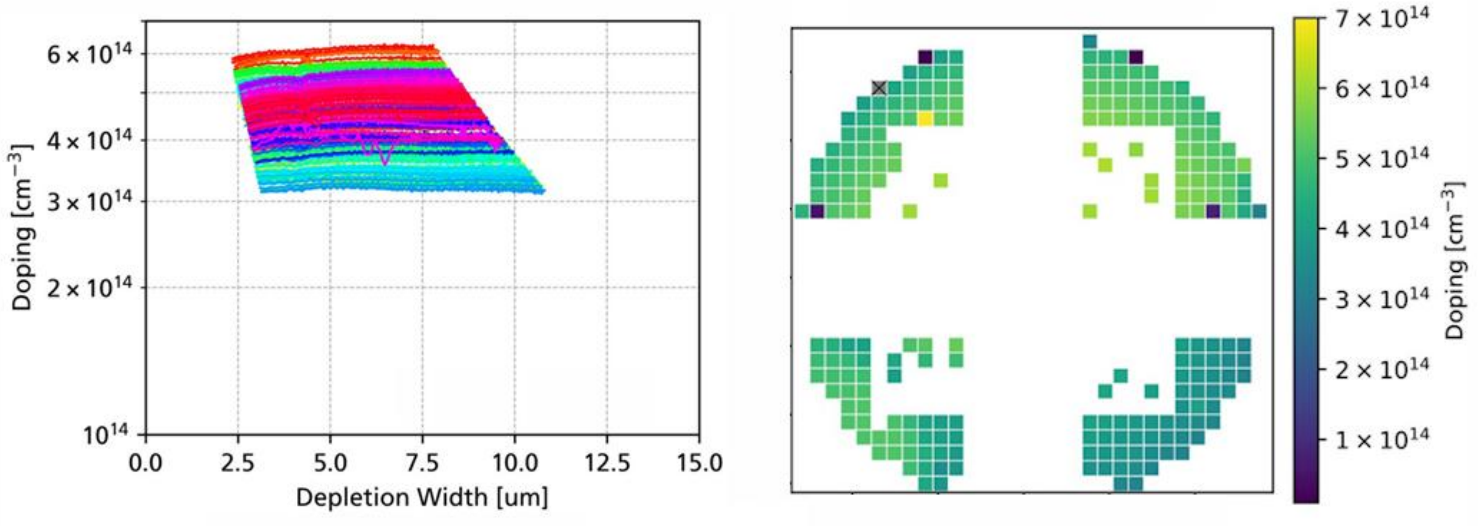
- From CV with K4200A SCS up to 40V
- Target doping: 1.5e14 cm^{-3}
- **Average observed doping: ~4e14 cm^{-3}**
- Full depletion with 4e14 cm^{-3}:
  - $V_{dep} \approx$ 900V for 50µm epi
  - $V_{dep} \approx$ 3.4 kV for 100µm epi

⇒ Diodes can not be fully depleted easily considering HV limits (850V)

50µm



100µm

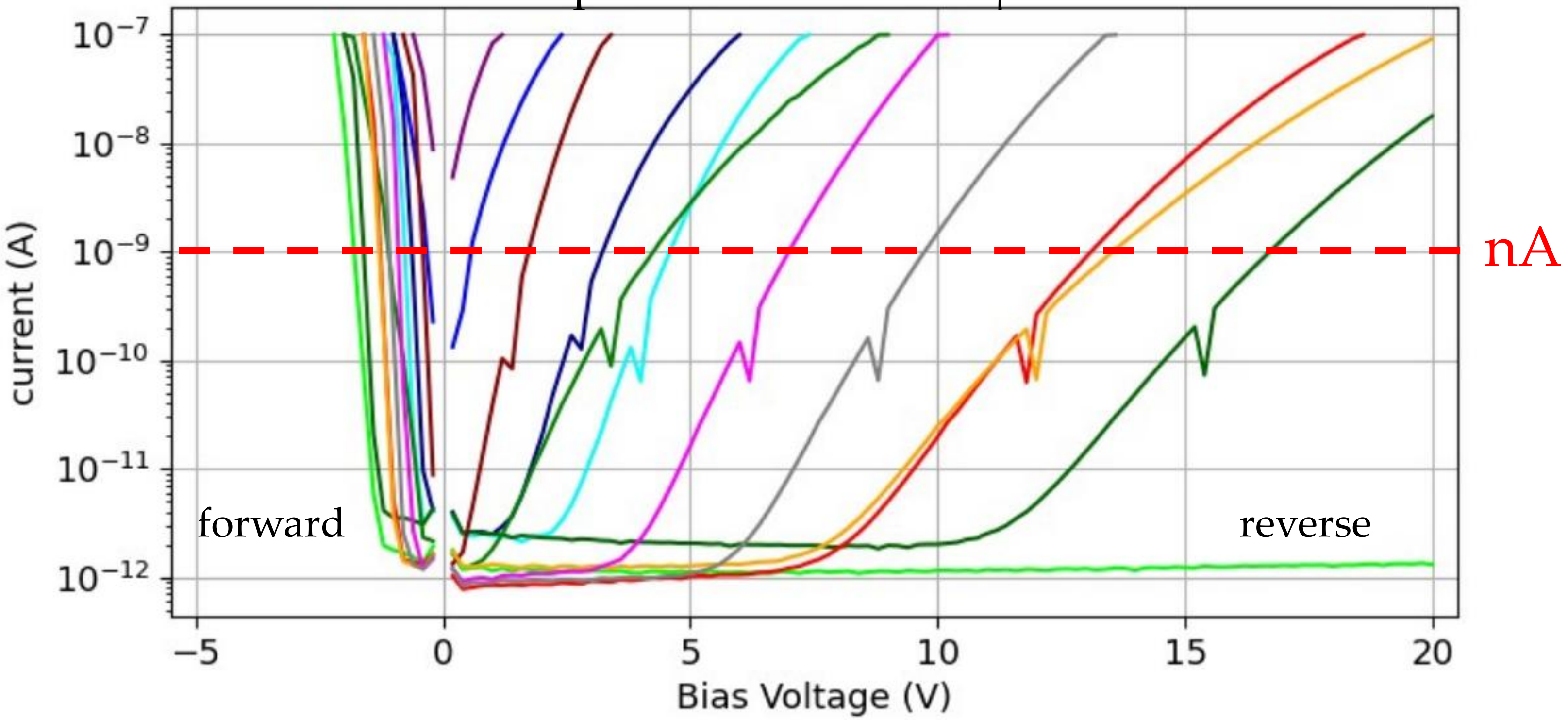


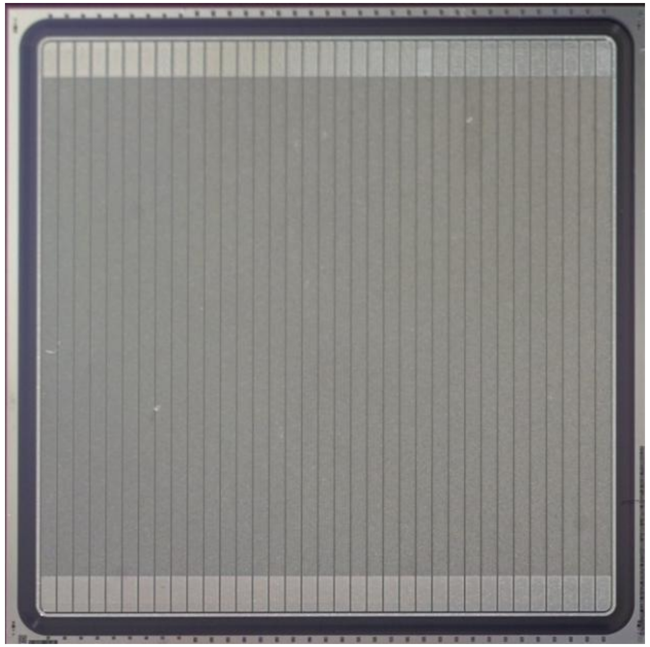
Strip Sensors

- All strip sensors show **excessive leakage currents (> 1nA)** already below $V_{bias} \approx 20V$
  - Guard ring and neighboring strips grounded

→ Destructive tests planned to find source of leakage

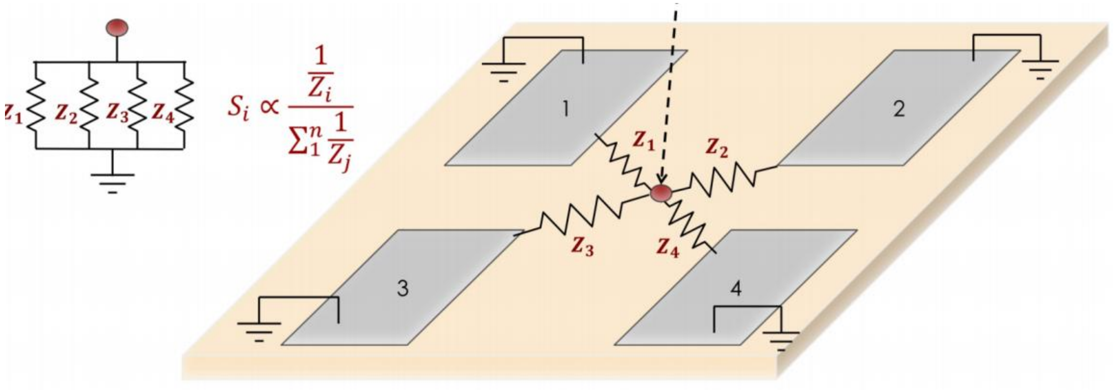
Example IV-curves on 100µm wafer



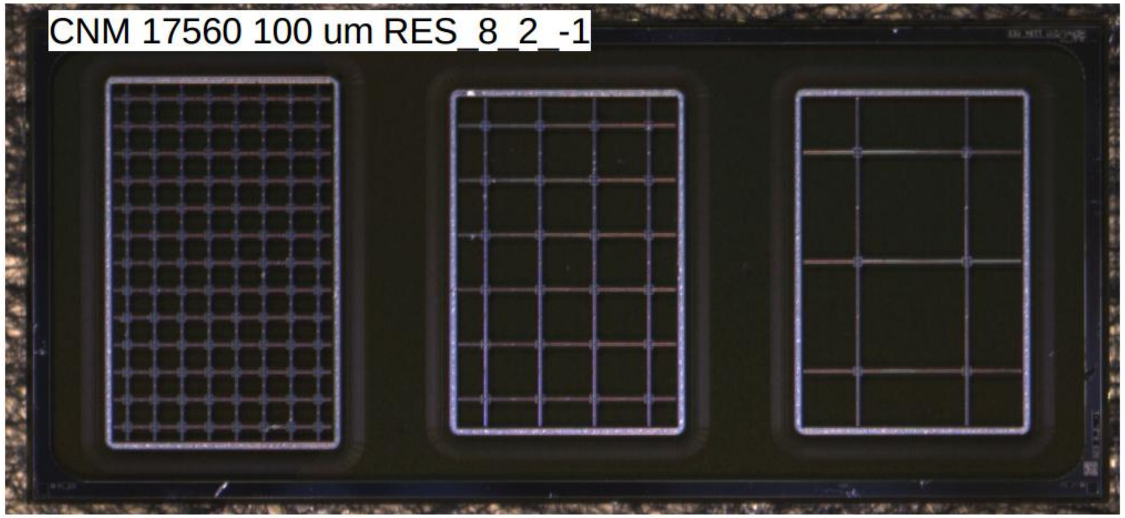


DC Resistive SiC Devices

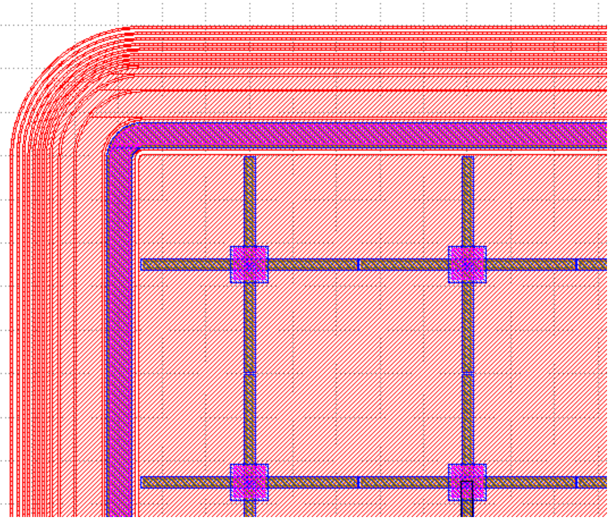
- Implant over entire area of device with a specified sheet resistivity
- Multiple readout electrodes form current divider relative to particle position
  ⇒ charge sharing & 2D position resolution



Adapted from: N. Cartiglia, INFN Torino, Resistive Silicon Detector, LCWS2021



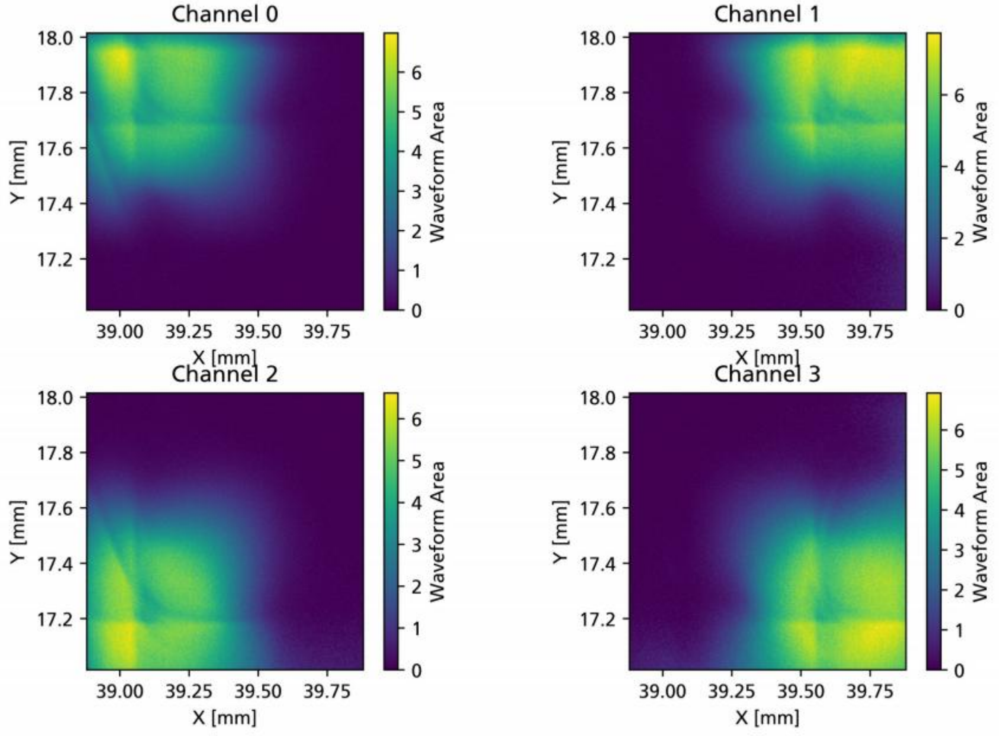
250µm 500µm pitch 1000µm

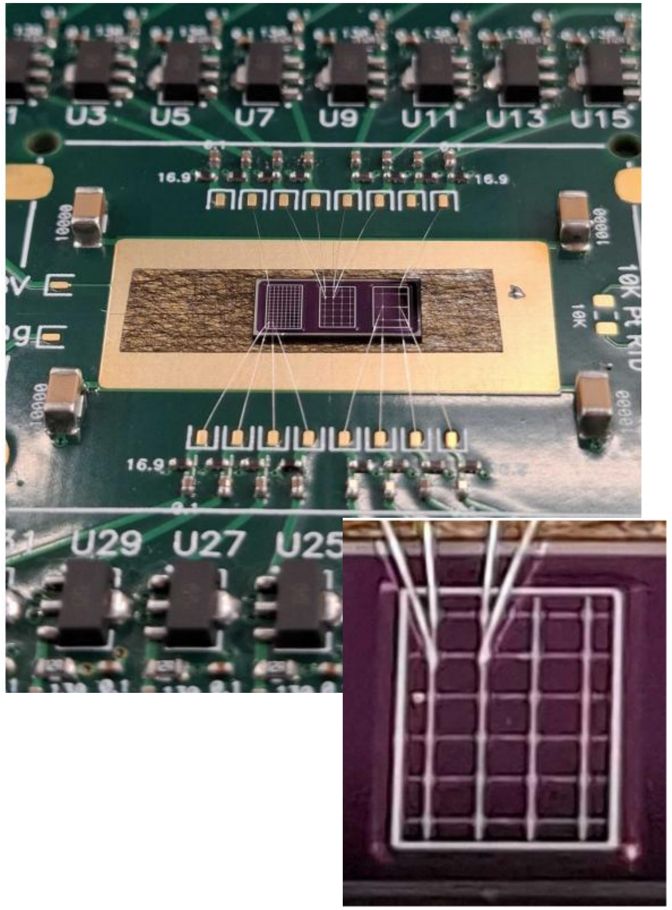


DC-coupled

Sensor Mapping

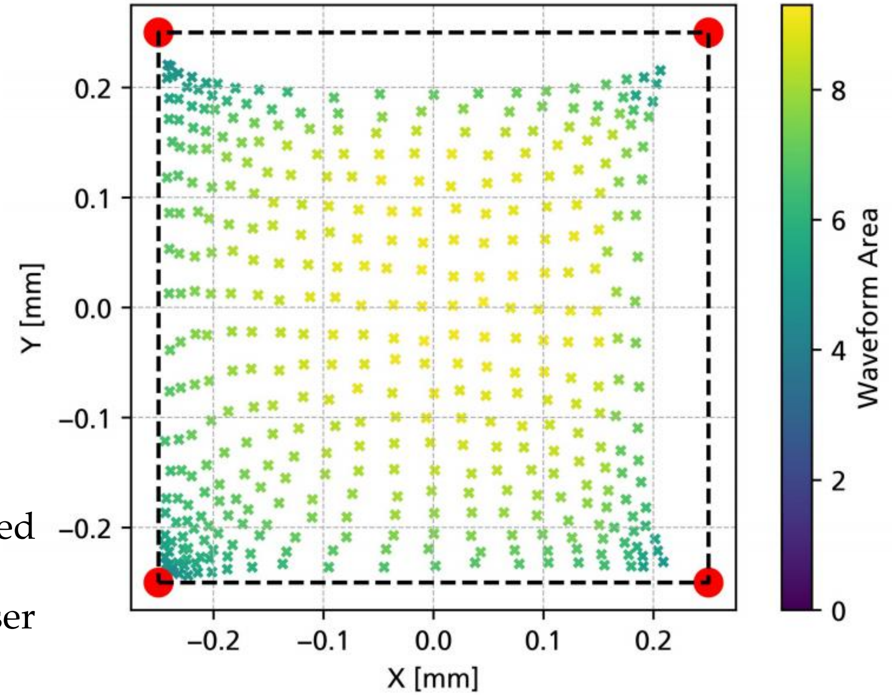
- Results for 50µm epi + 500µm pitch @ V_{bias}= 600V
- Readout by 16ch FNAL board + CAEN digitizer
- X-Y scans using UV-laser, record waveforms on 4 channels
- Collected signal in individual channels is position dependent ⇒ charge sharing



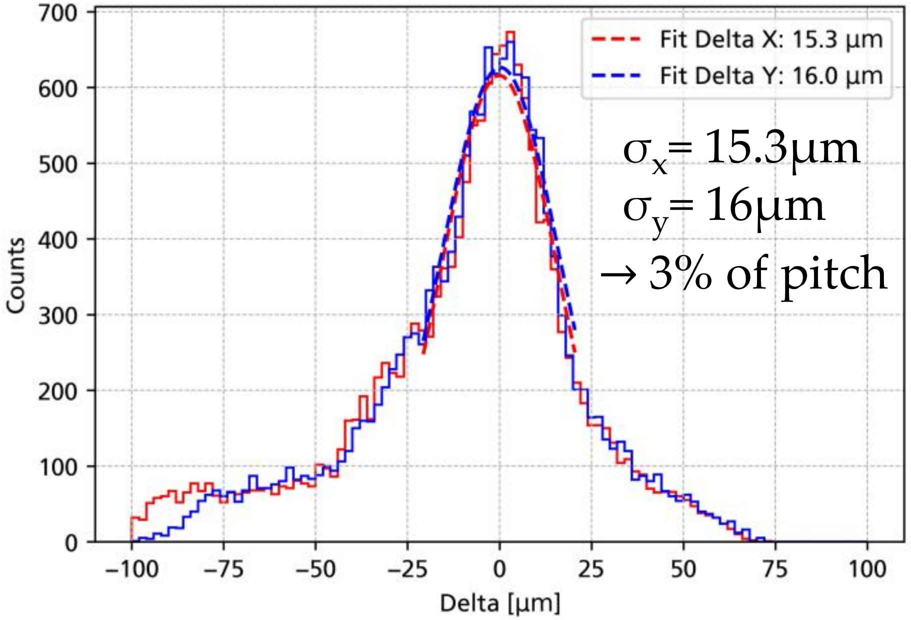


Position Reconstruction

1. Simple reconstruction: average of readout electrode position weighted by fraction of charge collected by each electrode
2. Position residuals Δx, Δy determined by difference of reconstructed and actual laser position
3. Histogram position residuals and fit to determine spatial resolution



Reconstructed positions skewed towards corner (electronics, laser focus?)



σ_x= 15.3µm
σ_y= 16µm
→ 3% of pitch

Summary & Outlook

- PAD diode yield increased (50µm: 70%, 100µm: 75%) over first production
- Processing issues:
  - Top passivation processed below 2nd metal layer
  - HV limited to < 900V + doping ~4e14/cm³ ⇒ full depletion is difficult (50µm) to impossible (100µm)
- Strip sensors exhibit excessive leakage (>1nA below 20V bias)
- 500µm pitch resistive devices measured to have spatial resolution of ~15-16µm

- Upcoming & ongoing activities:
  - Proton (CERN IRRAD, KIT) and Neutron (JSI) irradiations
  - Detailed MOSCAP characterization before/after irradiation to develop surface damage model (in cooperation with INFN Perugia)
  - Resume laser characterization of resistive devices and consider doing a test beam
  - …

Thank you!

7th Allpix^2 User Workshop

28 - 30 April 2026
MBI-ÖAW, Vienna, Austria

Abstract Deadline: **23 March 2026**
Registration Deadline: **15 April 2026**

Organisers
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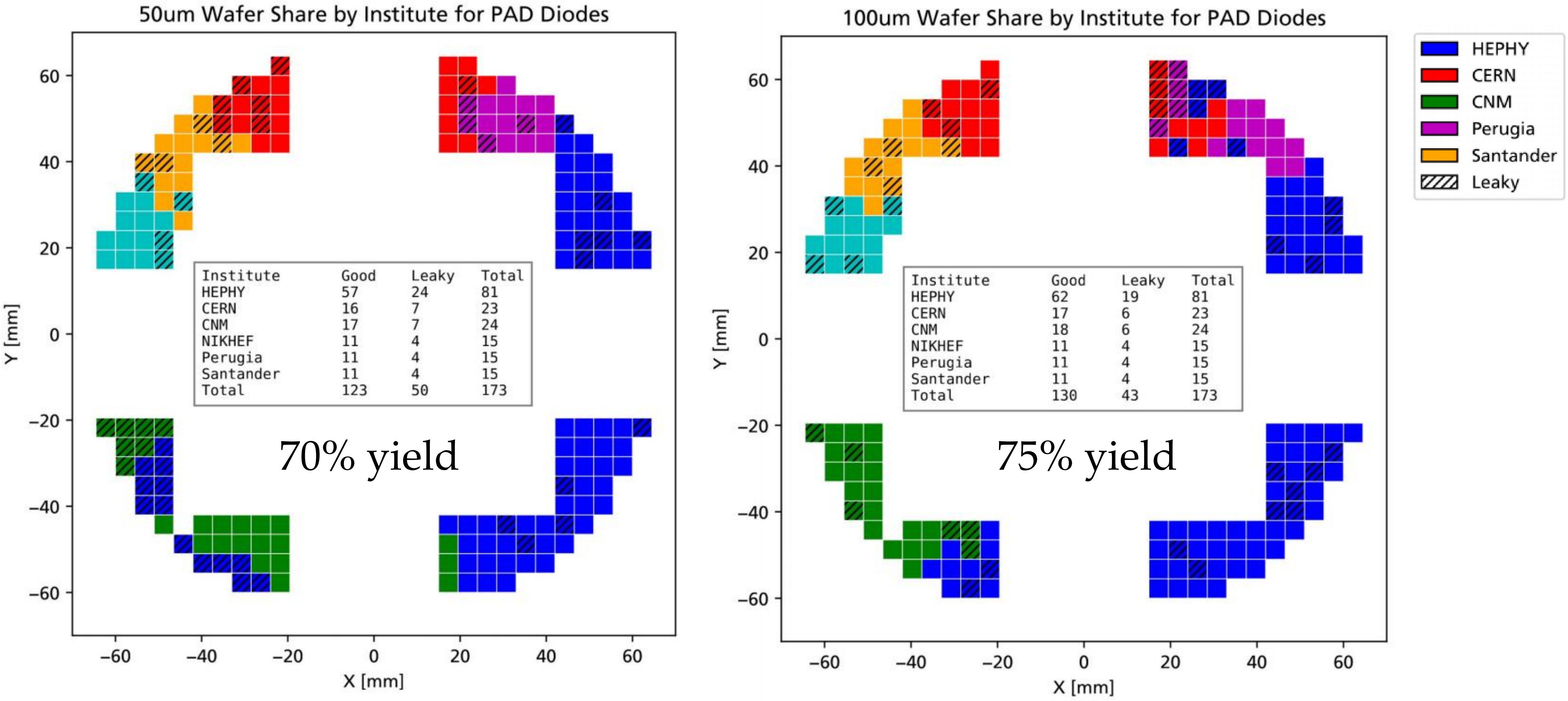
Back Up

PAD Yield and Distribution



Institute	Good	Leaky	Total
HEPHY	57	24	81
CERN	16	7	23
CNM	17	7	24
NIKHEF	11	4	15
Perugia	11	4	15
Santander	11	4	15
Total	123	50	173

70% yield

Institute	Good	Leaky	Total
HEPHY	62	19	81
CERN	17	6	23
CNM	18	6	24
NIKHEF	11	4	15
Perugia	11	4	15
Santander	11	4	15
Total	130	43	173

75% yield

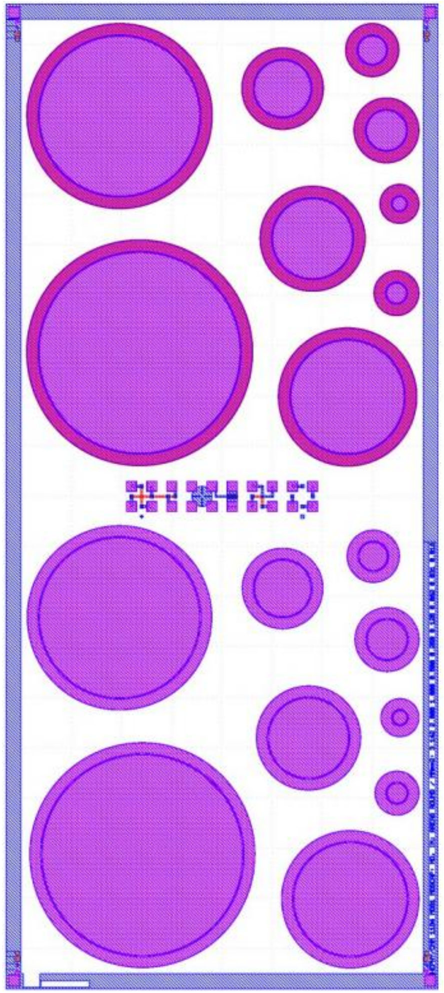
MOSCAP Overview

- MOSCAP structures to study SiO2/4H-SiC interface states pre-/post irradiation

- 4 different flavours:
  - MOS-NO: no p-implant
  - MOS-IN: p-implant under guard ring
  - MOS-IOH: p-implant under guard ring and slight overlap to pad
  - MOS-FI: p-implant covers pad and guard

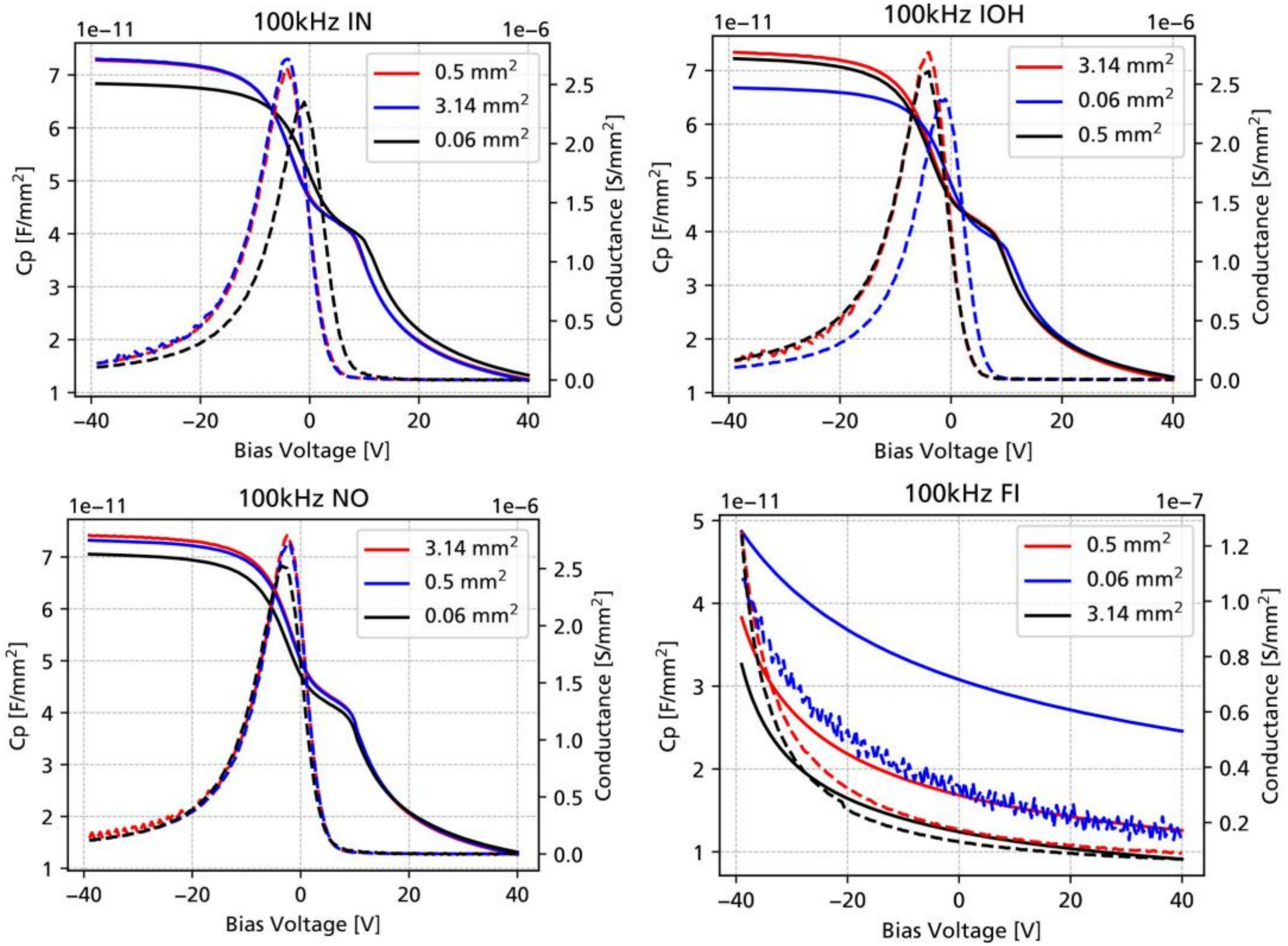
- 9 different sizes per flavour

- Initial assessment using high-frequency and quasi-static CV measurements using Keithly 4200a semiconductor analyzer



MOSCAP HF-CV

- Measurements with 100kHz and floating guard ring
  ⇒ similar results for IN, IOH and NO
- Accumulation, depletion, inversion clearly visible
- „knee“ around 10V
- FI behaves essentially like a PiN diode
- From accumulation:
  ⇒ $C_{ox} = 7.3 \text{nF/cm}^2 \approx 470 \text{nm SiO}_2$



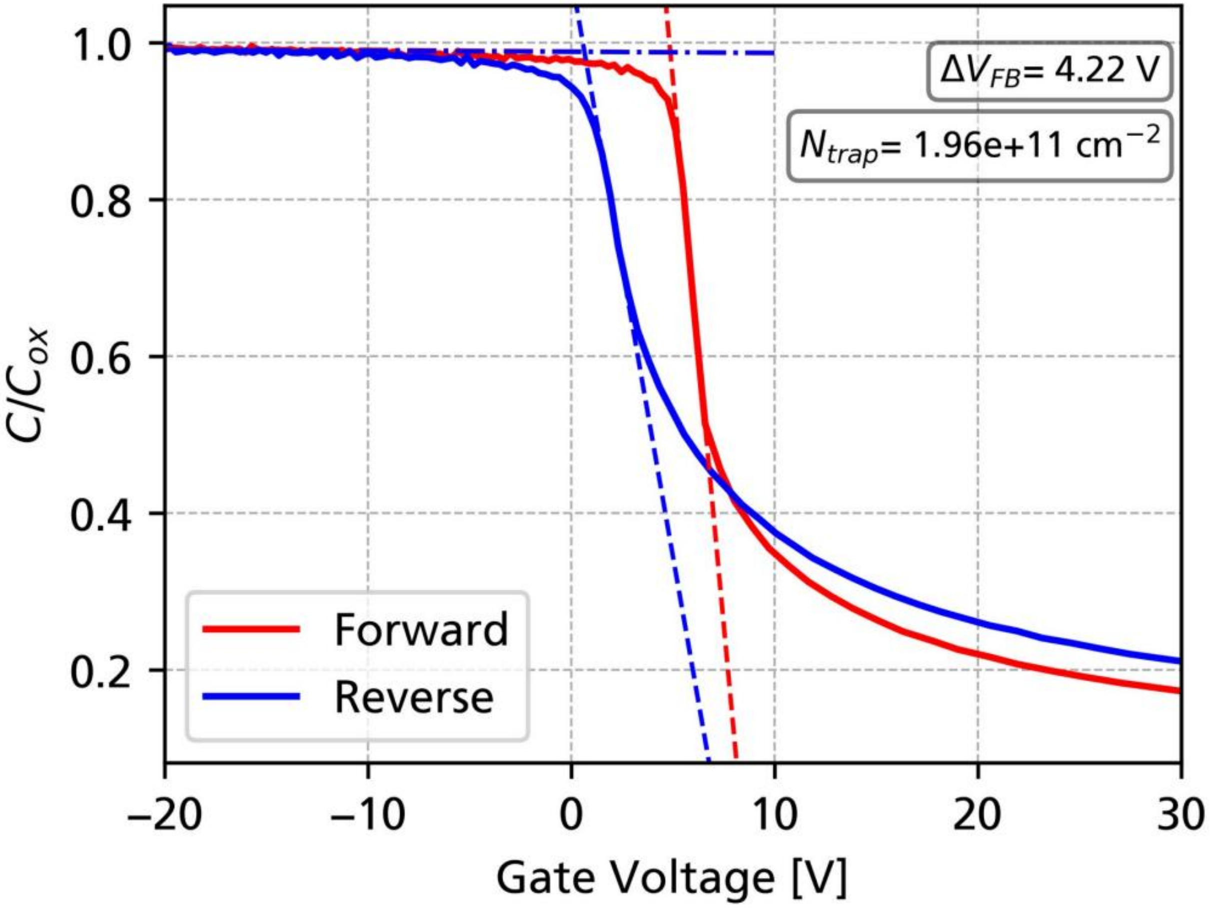
MOSCAP QS-CV

- Force-I QS-CV on MOS-NO (no p-implant) using K4200A-SCS:
  - Force current: 10pA
  - Sweep between -40V and +40V and back

- Clear hysteresis visible
- Flatband voltage shift of ~4.2V
  ⇒ significant concentration of border traps N ≈ 2e11/cm²

- Next step:
  - try to reduce hysteresis with measurement parameters
  - Apply HF-LF method to derive interface state density
  - Irradiate with X-rays (Perugia)

MOS-NO, 3.14 mm², QSCV



Irradiations

- We target statistics → large sample size, wide fluence range
- Neutrons:
  - 18 dies currently at JSI for irradiation to 2.3e17, 5.2e17, 1e18 $n_{eq,Si}/cm^2$ (6 samples per fluence)
  - Plan to irradiate 6-8 dies per fluence with 1e13-1e16 $n_{eq,Si}/cm^2$

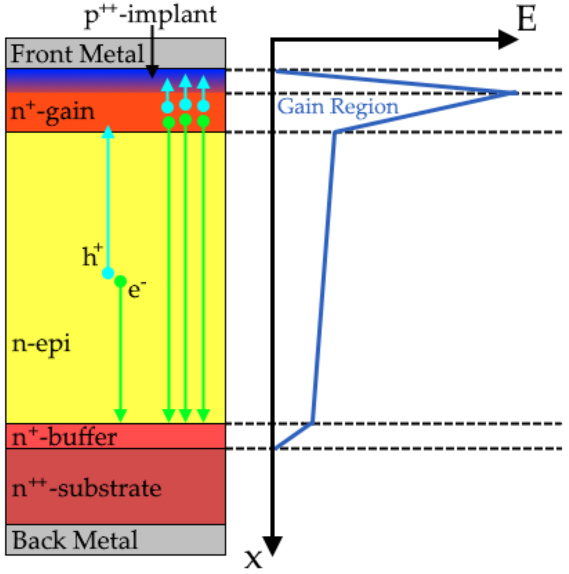
- Irradiations using protons:
  - 64 dies currently at CERN IRRAD for 8 fluences between 1e13-5e15 $protons_{24GeV}/cm^2$
  - Plan to irradiate ~20 dies with 23MeV protons at KIT (together with INFN Perugia)

- In total >100 dies irradiated using protons and neutrons

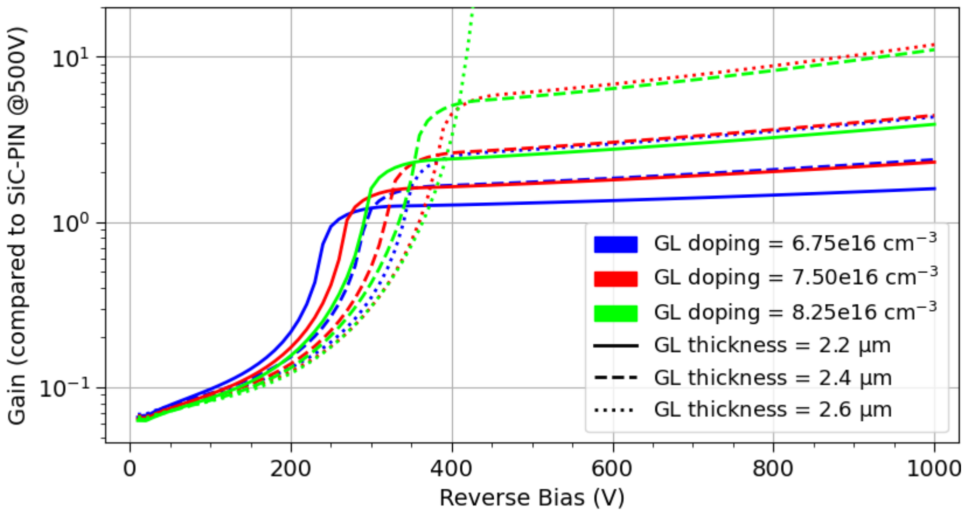
4H-SiC LGAD Simulation & Design

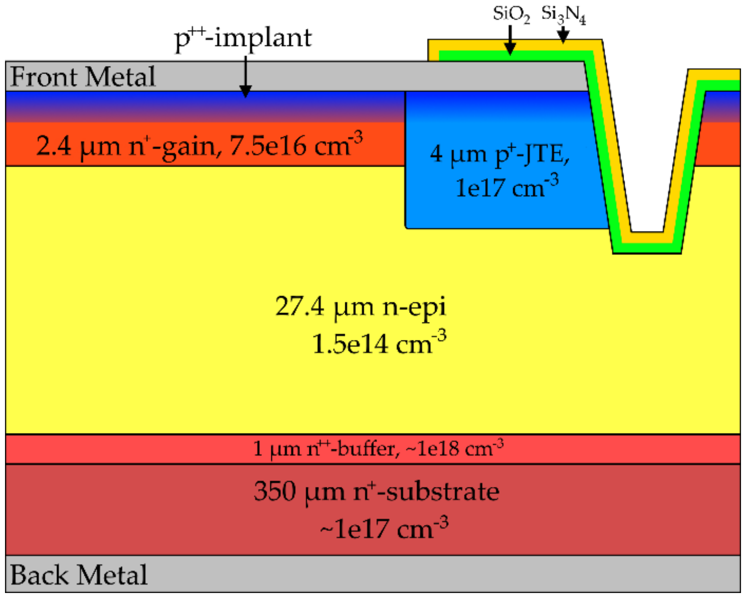
- Active layer <100μm and wide band-gap ⇒ 4H-SiC signal yield smaller than Si
- ⇒ 4H-SiC Low Gain Avalanche Diode with internal amplification

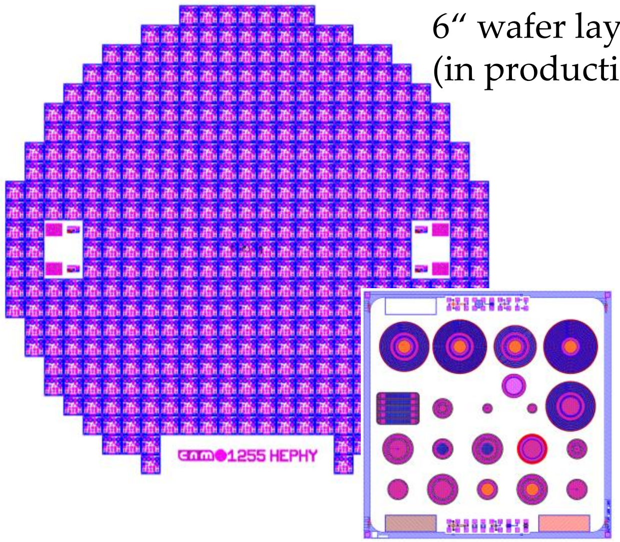
- Epitaxially grown gain layer on 30 μm epi, $V_{FD} < 600V$
- Edge termination using trench + JTE combination
- Gain of 1-10 within error margin of gain layer thickness / doping



TCAD simulation of SiC-LGAD gain

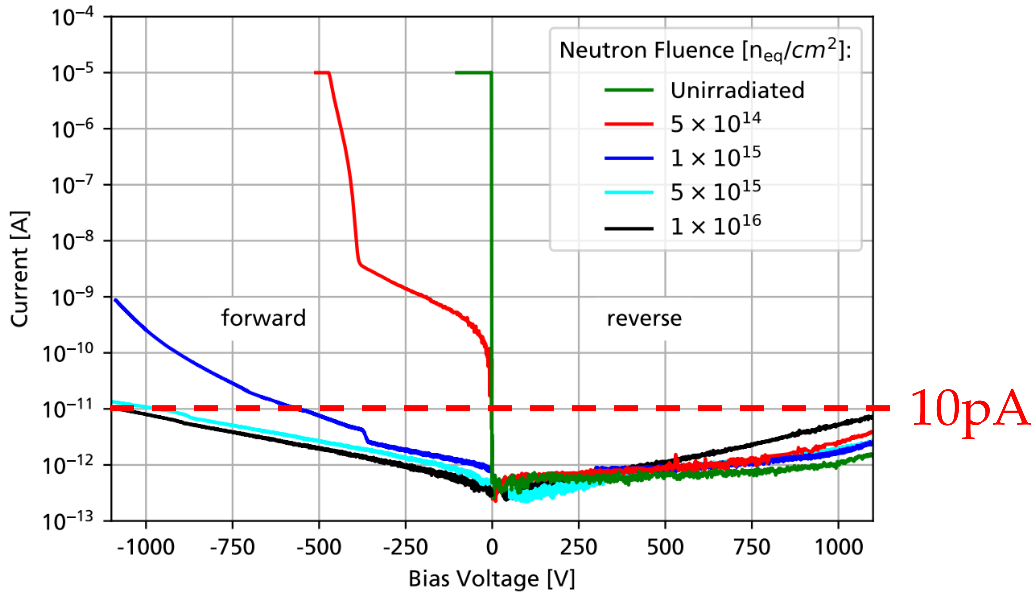


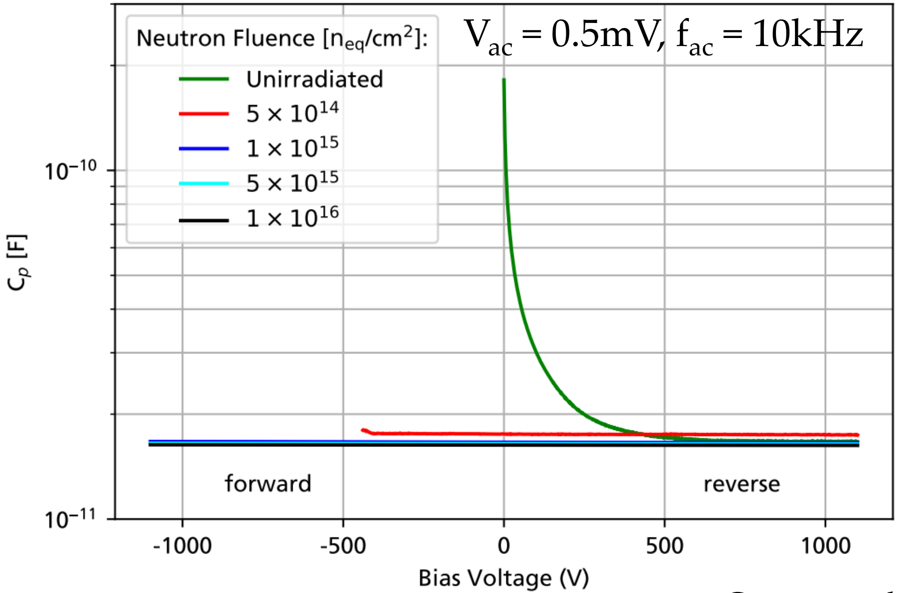




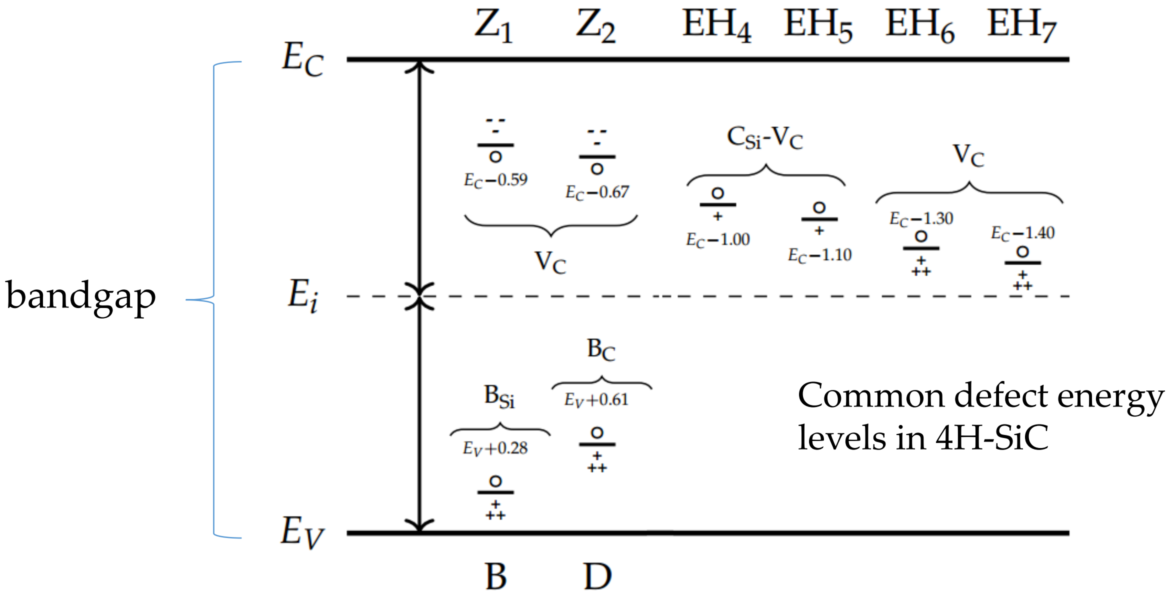
6" wafer layout
(in production)

I-V and C-V pre/post Irradiation





- Negligible increase of reverse current (10 pA vs. >100nA in Si)
- Forward current reduced, rectification properties lost
- C-V flatlines: free electrons from donor atoms captured by lattice defects (trapping)

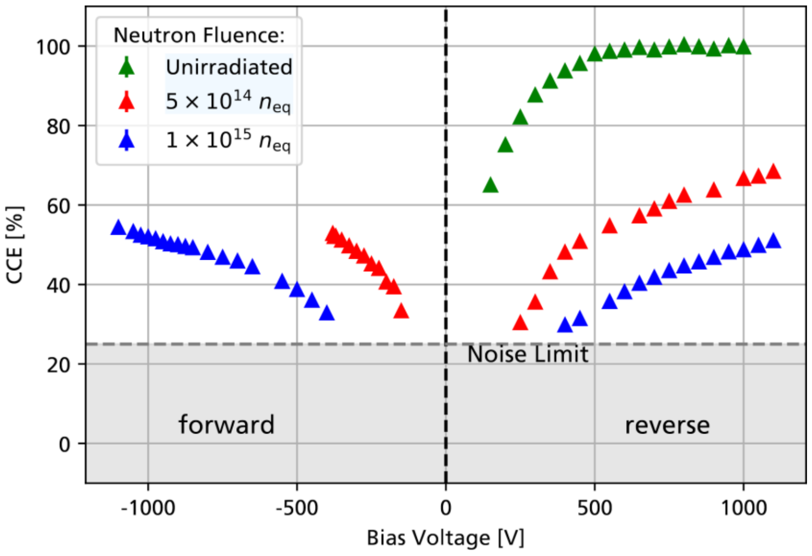


Common defect energy levels in 4H-SiC

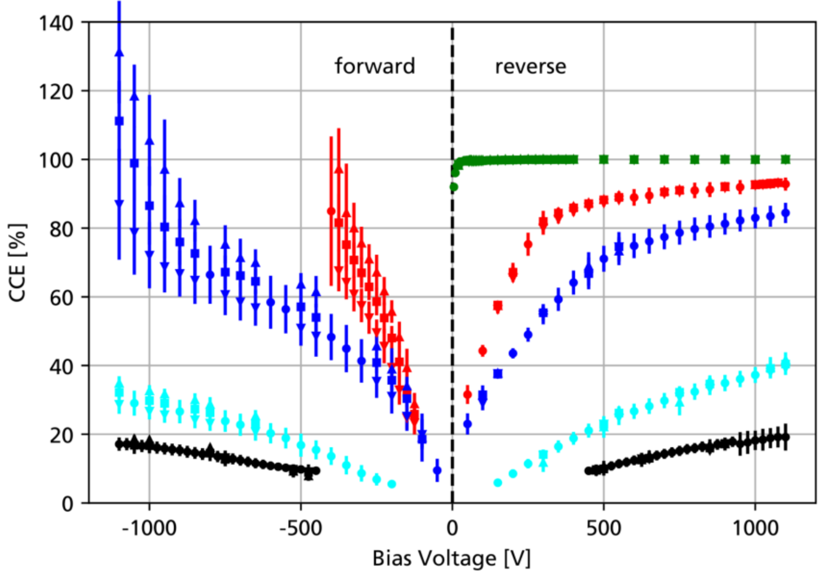
Gsponer et al. “Neutron radiation induced effects in 4H-SiC PiN diodes”, Journal of Instrumentation 18 (2023), p. C11027.

CCE after Irradiation

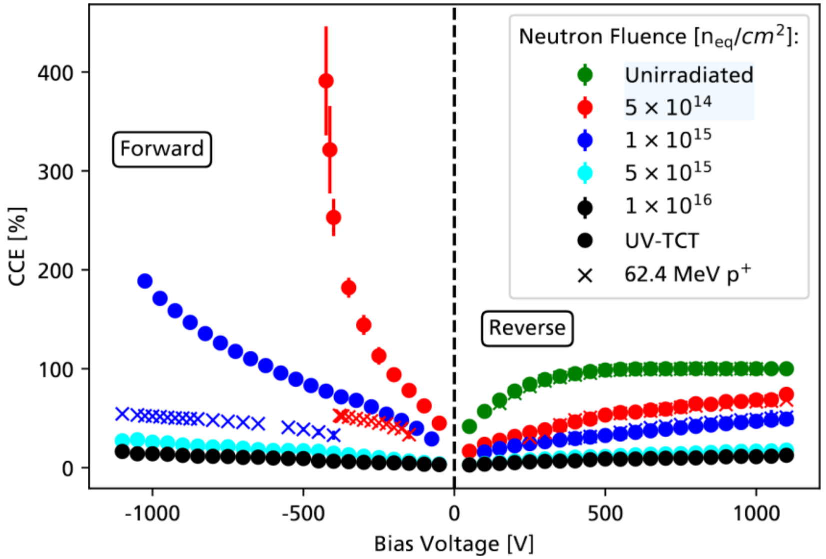
- Reduced forward current allows operation of detector in forward and reverse bias
- Higher CCE in forward direction (electron collection)
- For α particles and UV-TCT : CCE surpasses 100% in forward!



62.4 MeV protons



α particles



SPA-UV-TCT