Investigations of a BiCMOS Pixel Sensor

A close look on its early breakdown

Physikalisches Institut, Universität Heidelberg

Benjamin Weinläder

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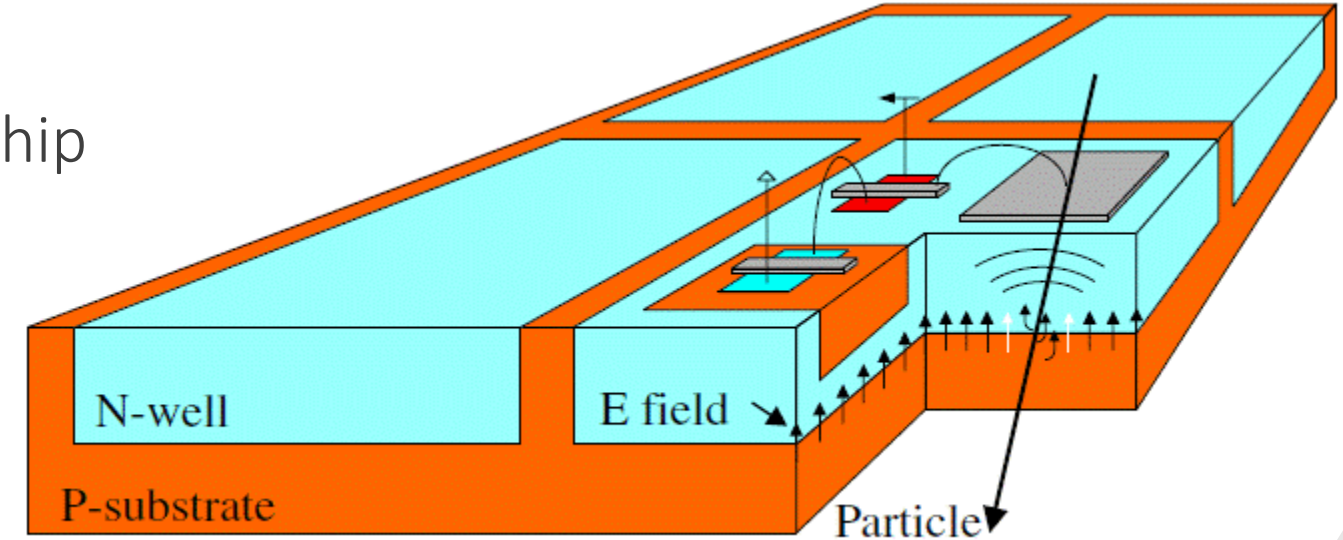
High Voltage – Monolithic Active Pixel Sensors

- detection and readout on one chip
  - in-pixel electronics
- high voltage:
  - fast charge detection via drift
  - large depletion area
- commercially available processes



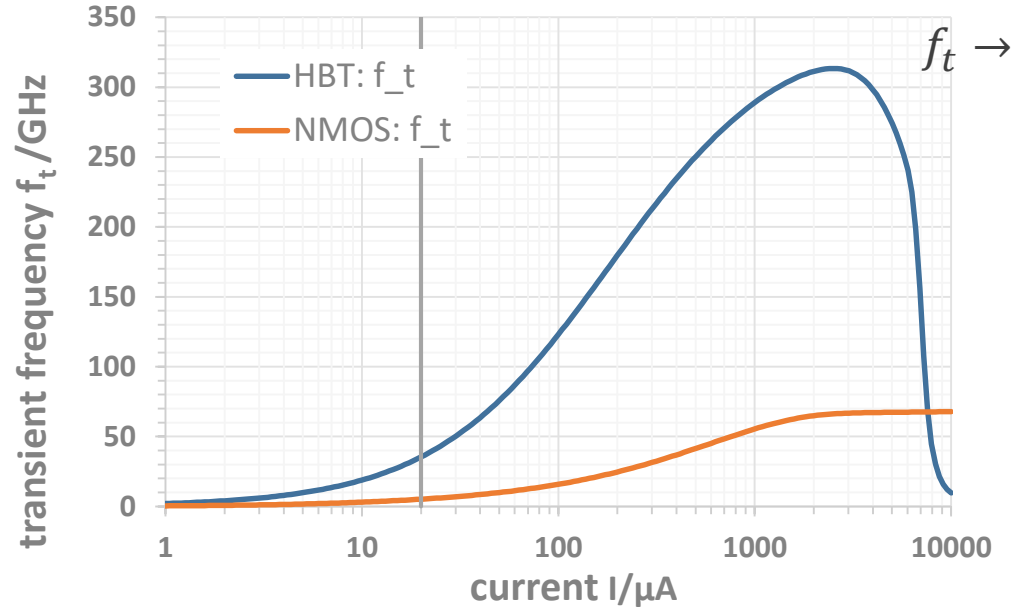
I. Peric, P. Fischer et al.:
NIM A 582 (2007) 87

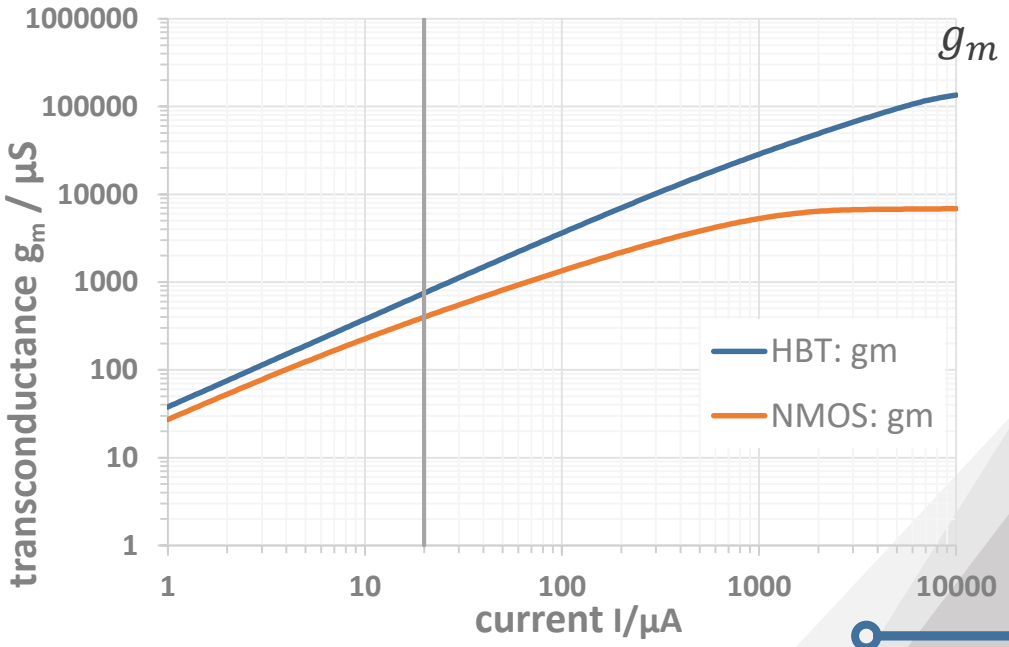
More Information in Section: T147, Thursday 17:30-19:00

BiCMOS Process

- combines bipolar (HBT) and MOS transistors
  - allows to benefit from CMOS logic
- advantages of bipolar transistors:
  - fast switching times
  - large current gain

} scales with current





Idea:

→ build HV-MAPS in a BiCMOS process
→ use single HBT to boost the performance of the in-pixel amplifier
→ achieve very good time resolution

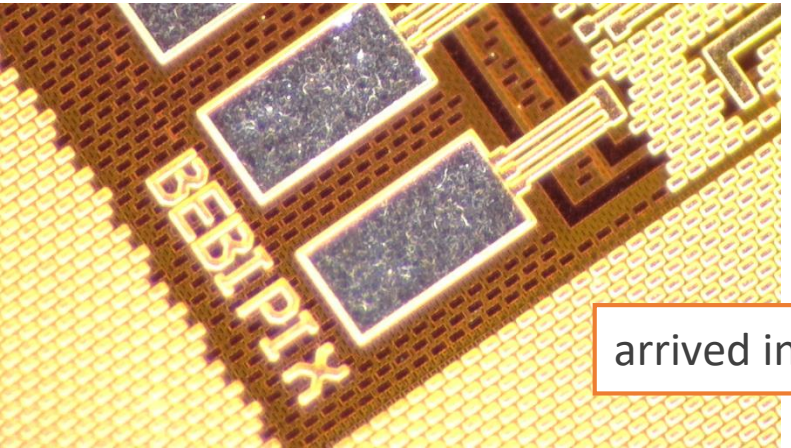
Existing Projects

University of Geneva:

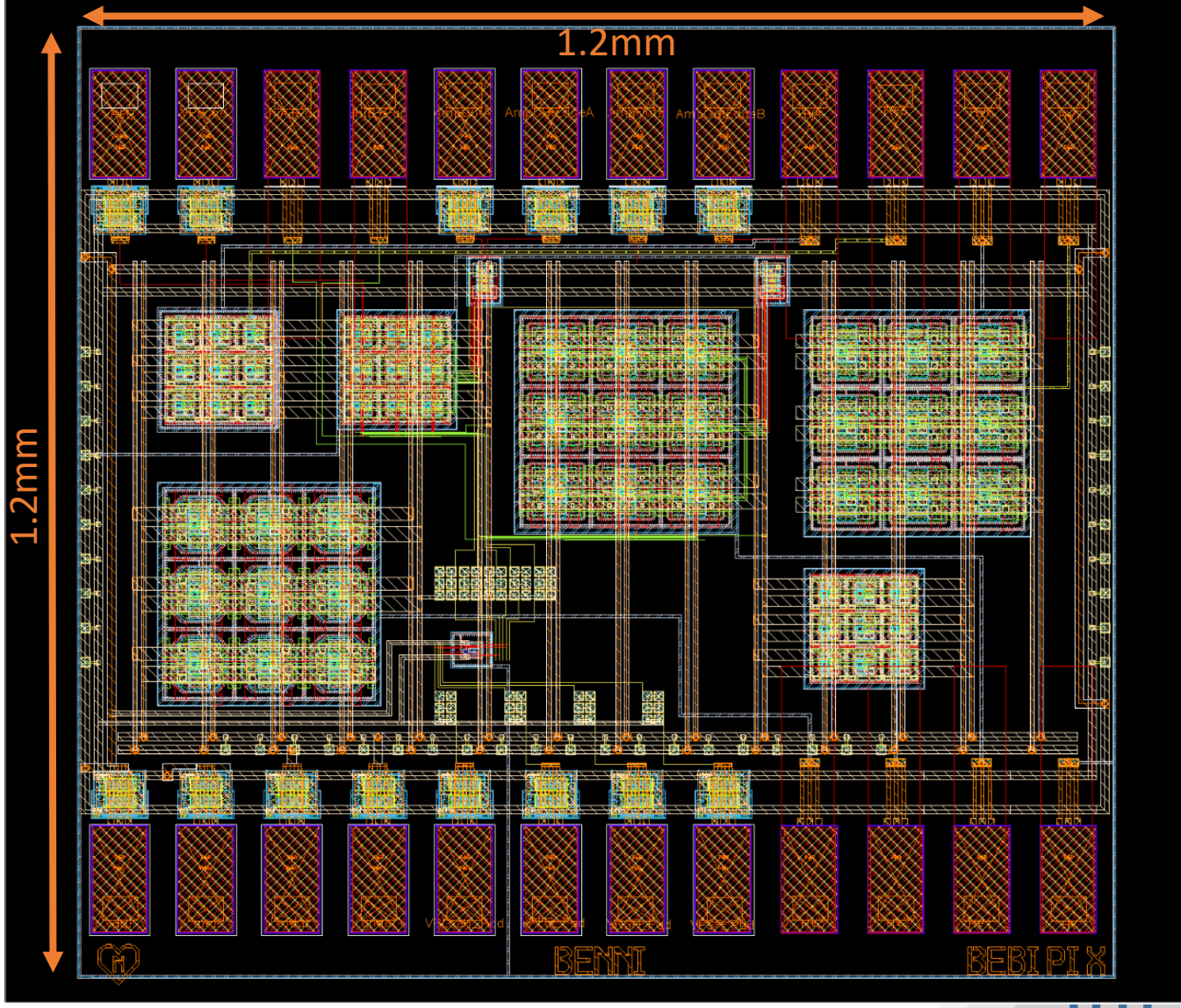
- general R&D chip: G. Iacobucci et al., doi: 10.1088/1748-0221/17/02/P02019
  - hexagonal pixels with $65\mu m$ side
  - time resolution of $\sigma_t \approx 80\ ps\ (I_{preamp} = 20\mu A)$
- ASIC for the FASER experiment: S. Gonzalez-Sevilla, doi: 10.1088/1748-0221/18/02/C02002
  - first test looking good
  - no results for the time resolution published yet

BeBiPix

- small test chip produced in the BiCMOS Process SG13G2 by IHP
- 2 active 3×3 pixel matrices, characterised in simulations
- focusing on a small pixel layout with in-pixel amplifier
- fully analog read-out



arrived in summer 2022



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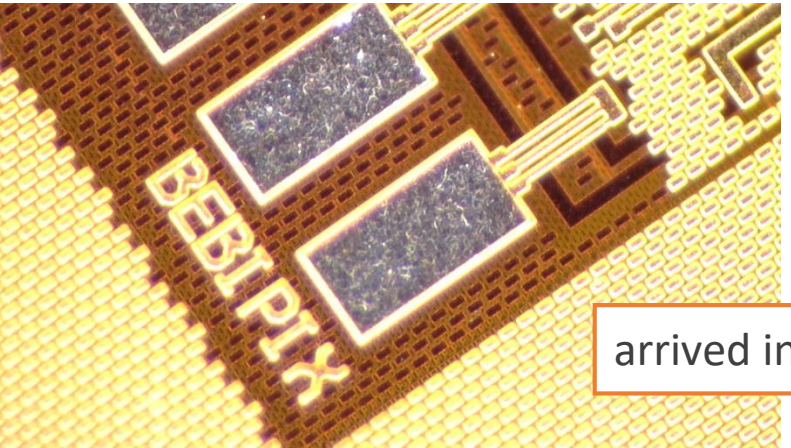

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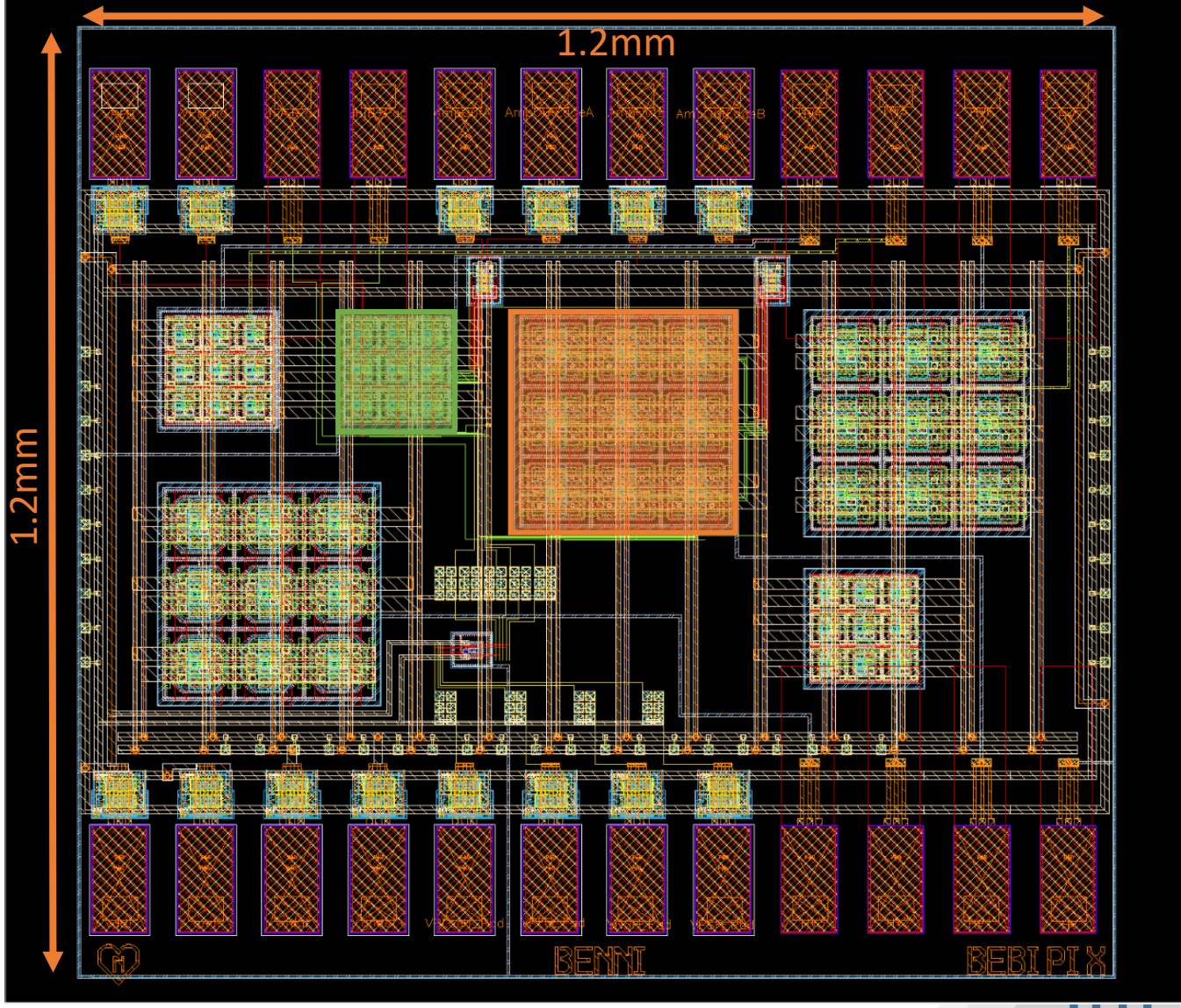


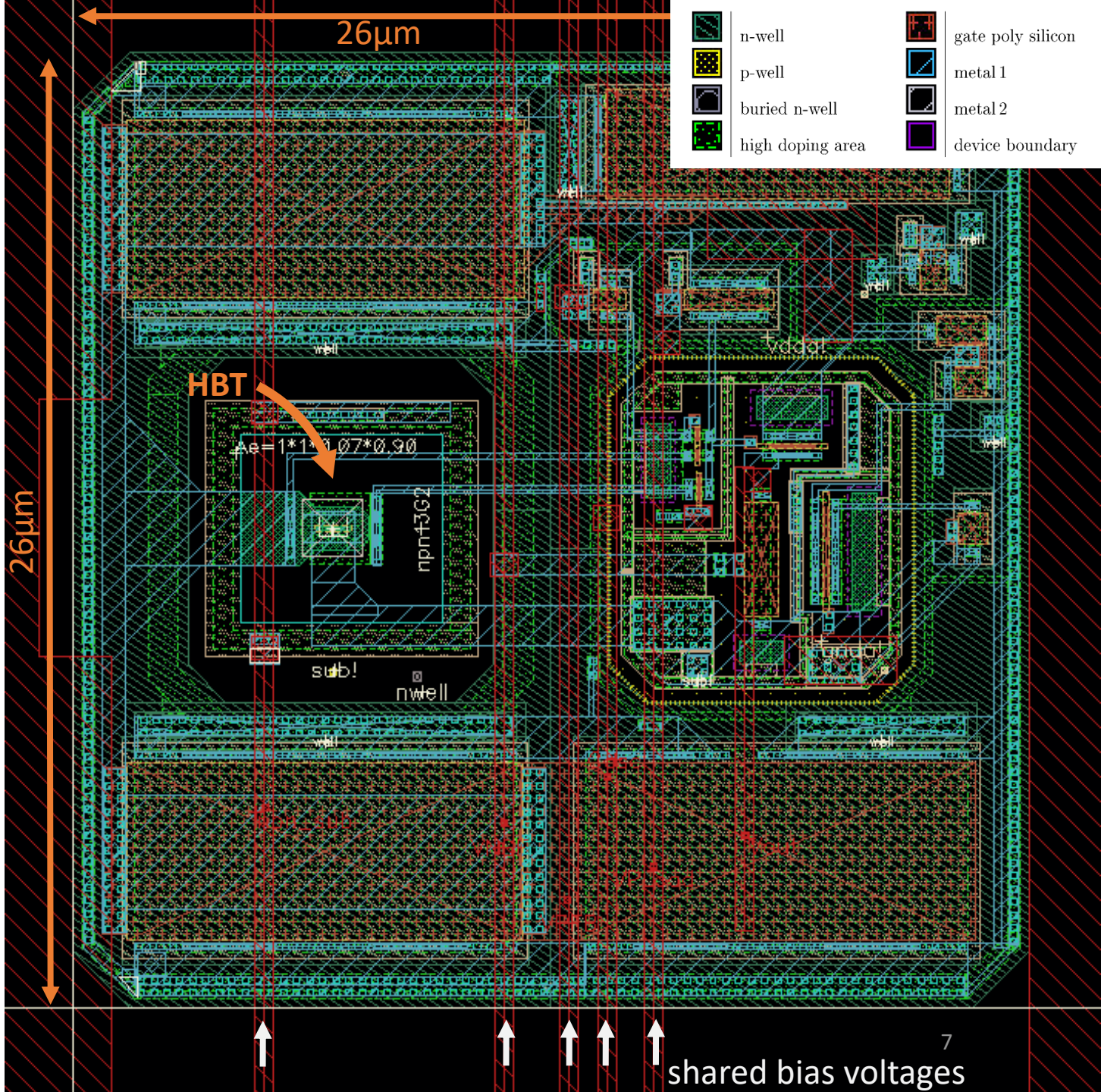
Small Pixel Layout

- implant size $26 \times 26\ \mu m^2$
- pixel size $41 \times 41\ \mu m^2$

Simulation results:

- input signal corresponding $\approx 2800\ e^-$

Amplitude	$149.8 \pm 3.1\ mV$
Rise Time	$741 \pm 340\ ps$
SNR	27 ± 3.9
ToA Jitter	$481 \pm 33\ ps$



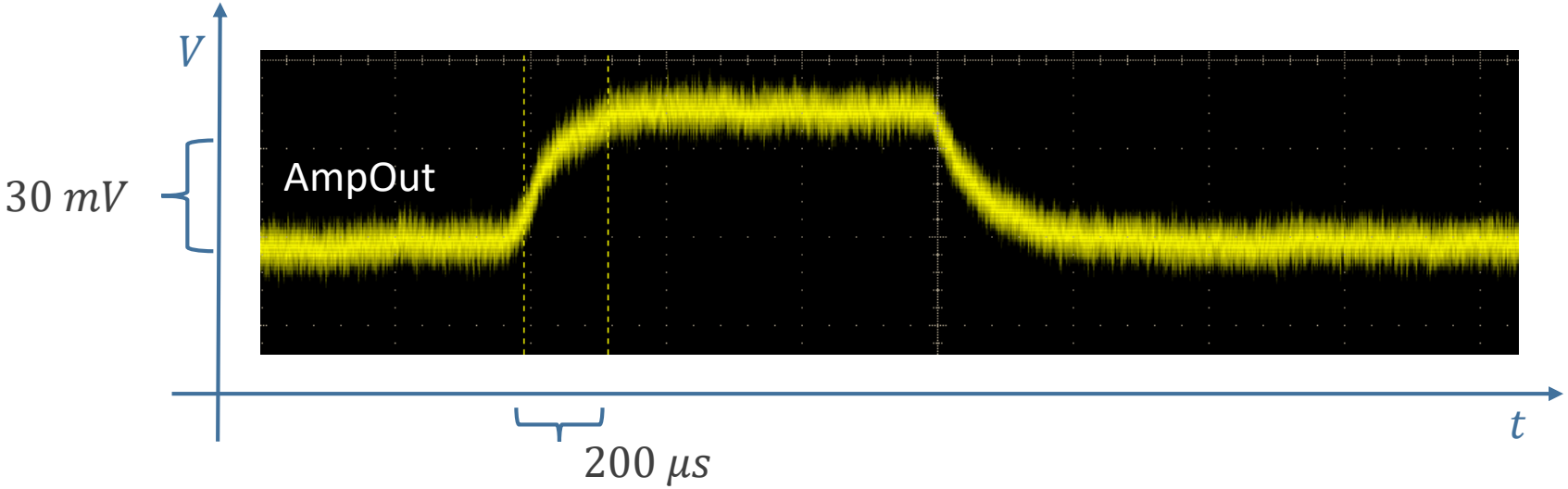
…However

Problem 1: early breakdown

- expected $BDV \approx 90\ V$ from TCad simulation
- measured $BDV \approx 10\ V$

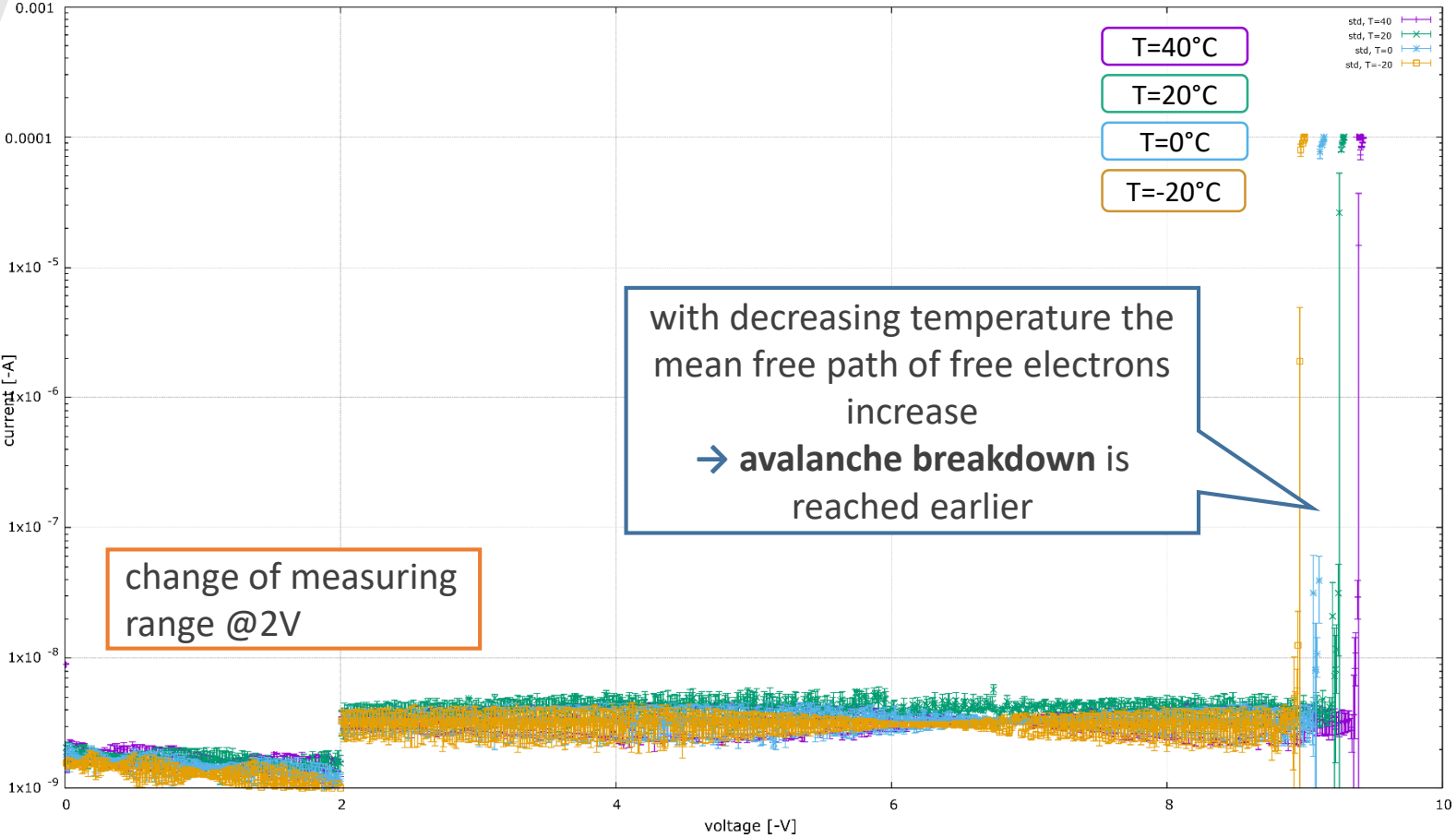
Problem 2: poorly functioning amplifier feedback

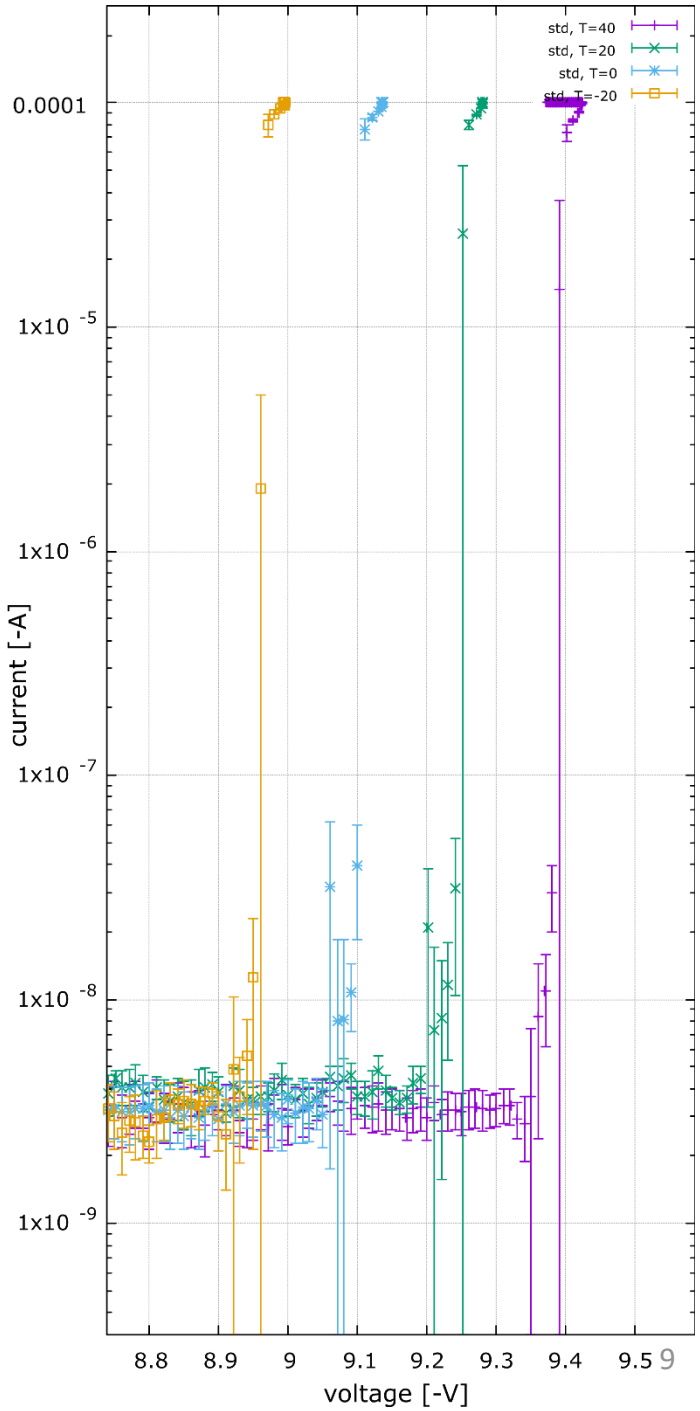
- only slow and large input signals (from red laser) are visible



Investigation of the Breakdown

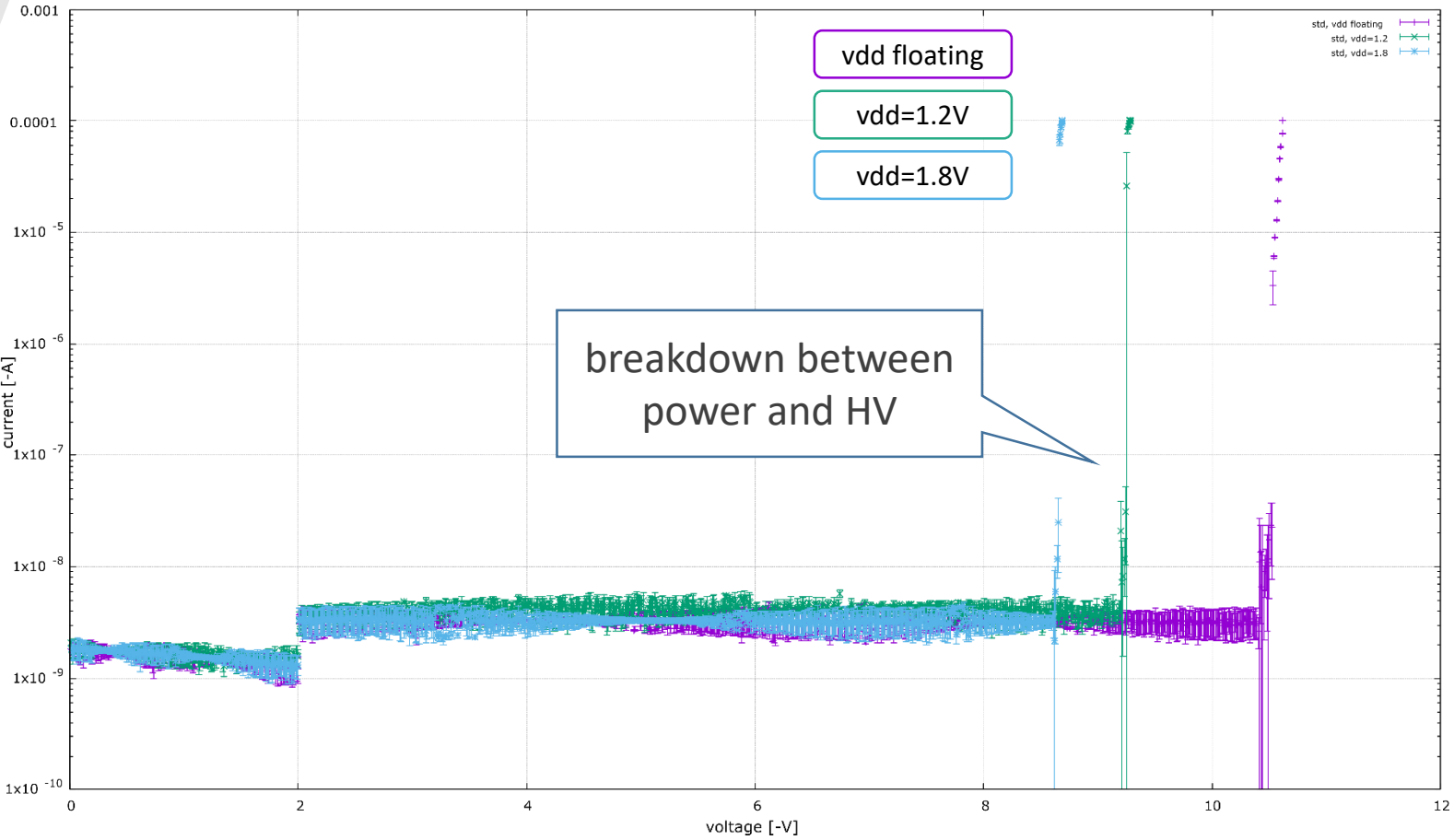
- dependency on temperature

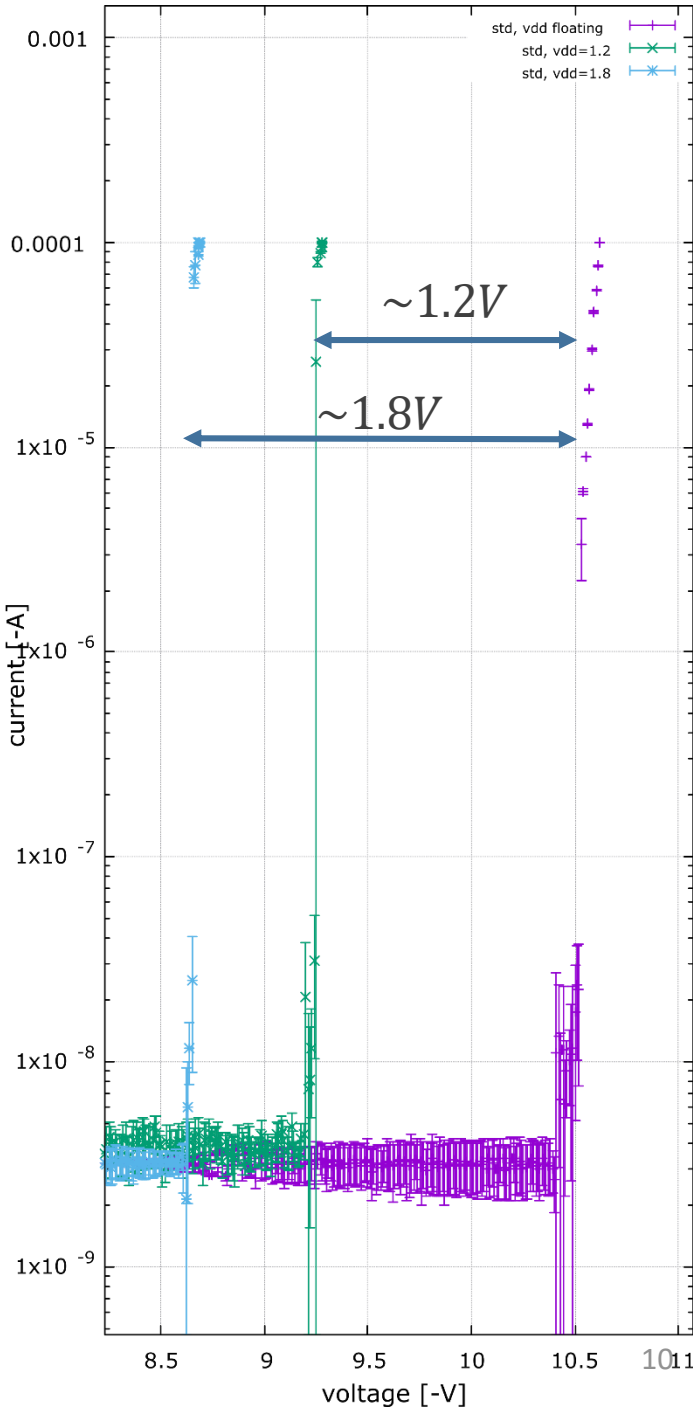




Investigation of the Breakdown

- dependency on vdd-voltage (vdda floating)





Investigation of Breakdown

Light Emission Test (LET)

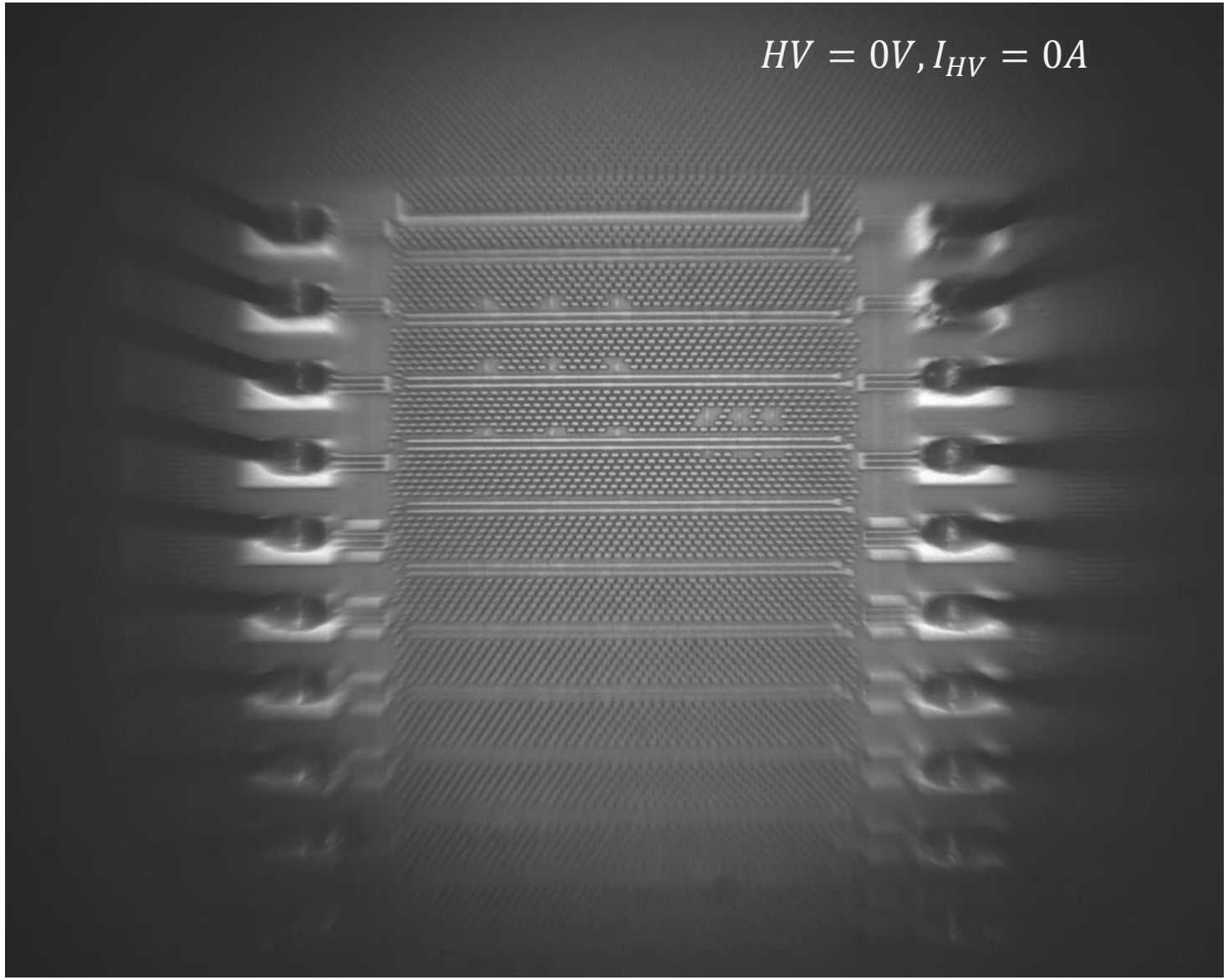
- pn-junctions at avalanche breakdown emits light
  - Intra-band transitions → mostly Bremsstrahlung
  - Inter-band transitions → e-h pair recombination
- light is emitted from localized spots, with highest electrical field
  - increasing current results in an increasing number of spots

→ use CCD camera in light-tight box to capture emission
→ light spots indicate position of the breakdown

Kaikai Xu et al., doi:10.1117/12.2199841

LET Measurement

- exposure of a part of the BeBiPix
- sensor breakdown: $BDV \approx 10.1\,V$
- LED is used to illuminate the sensor



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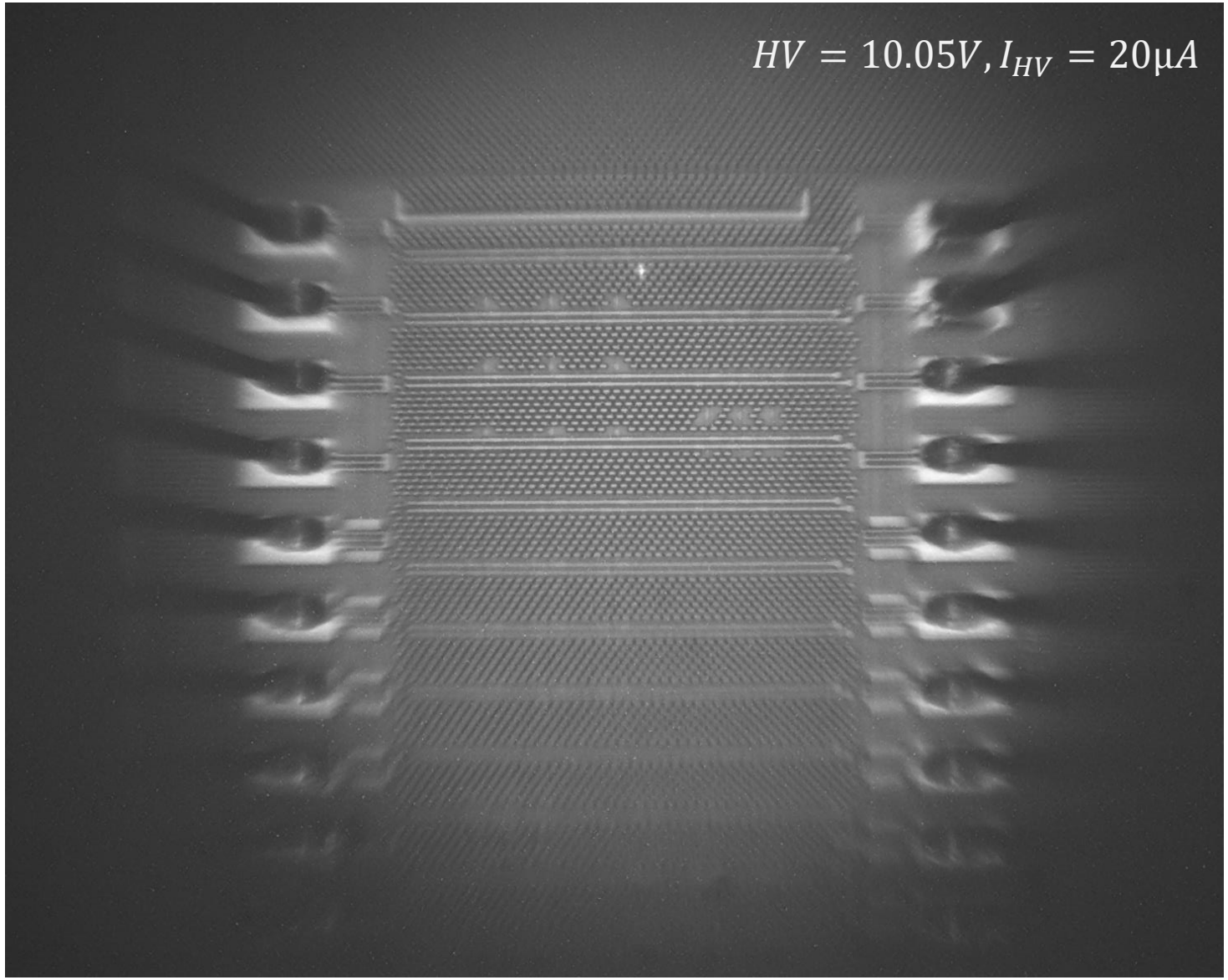

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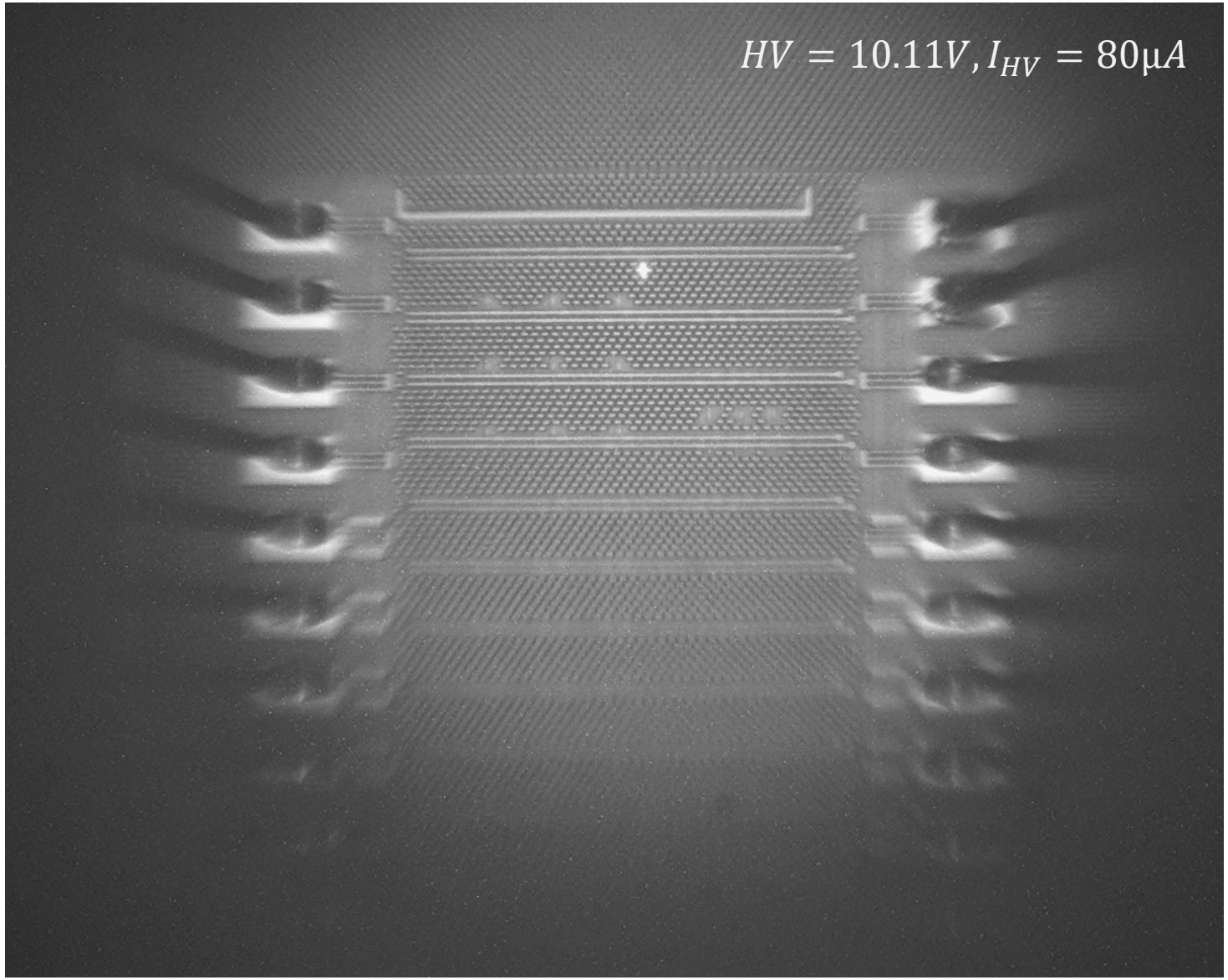

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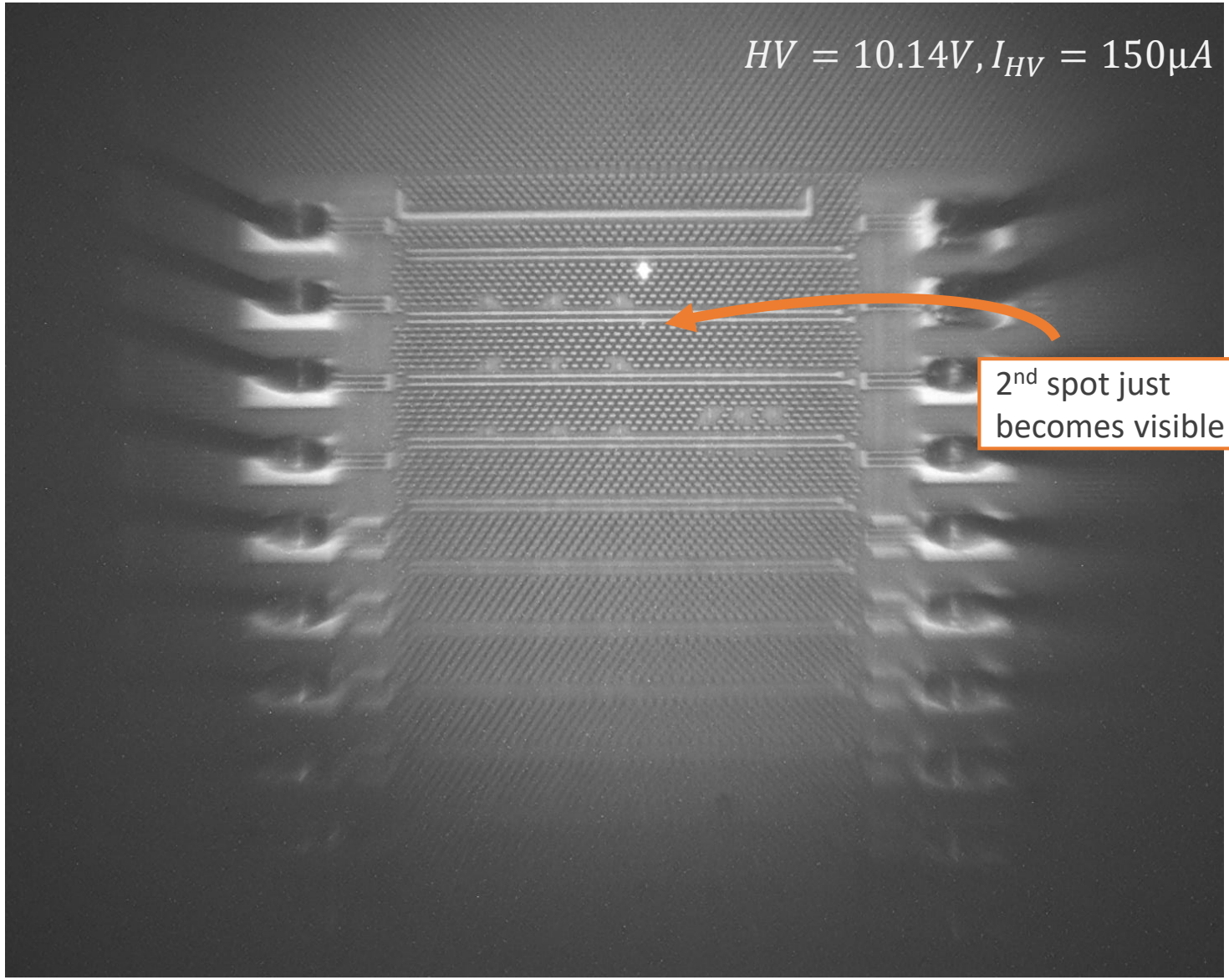
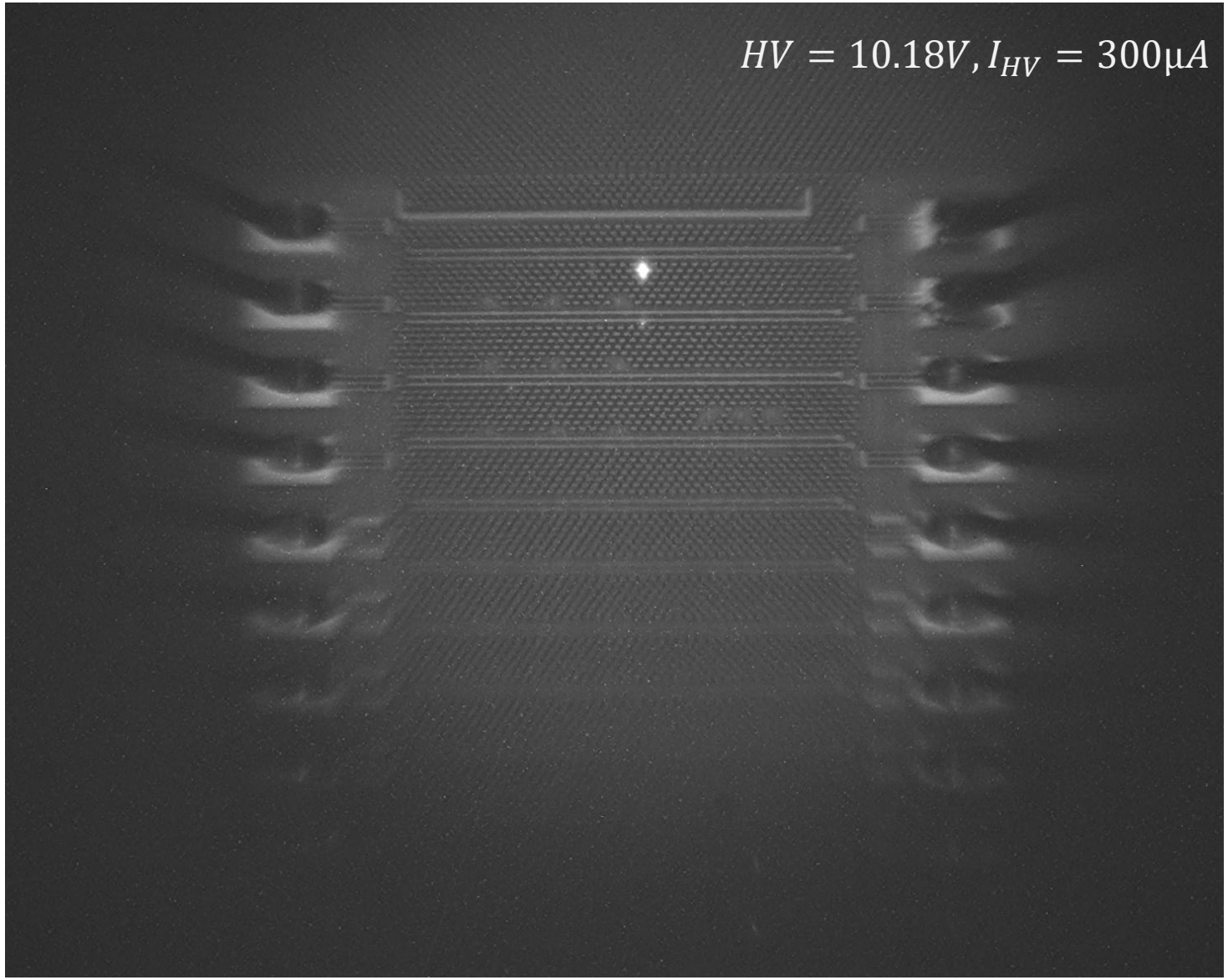


LET Measurement

- exposure of a part of the BeBiPix
- sensor breakdown: $BDV \approx 10.1\,V$
- dim LED
- 10min exposer

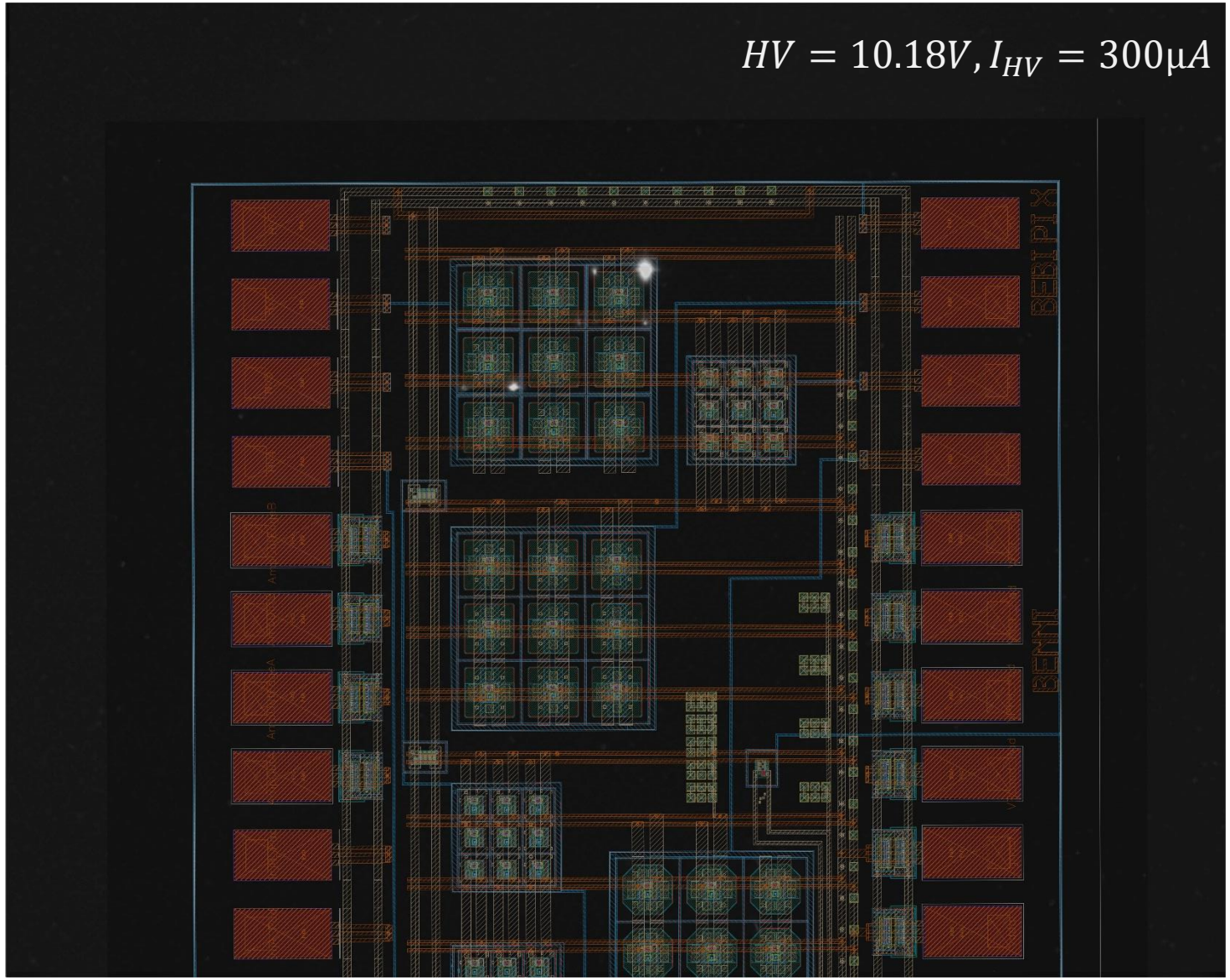


LET Measurement

- exposure of a part of the BeBiPix
- sensor breakdown: $BDV \approx 10.1\ V$
- without LED
- 30min exposure

LET Measurement

- exposure of a part of the BeBiPix
- sensor breakdown: $BDV \approx 10.1\,V$
- overlay layout



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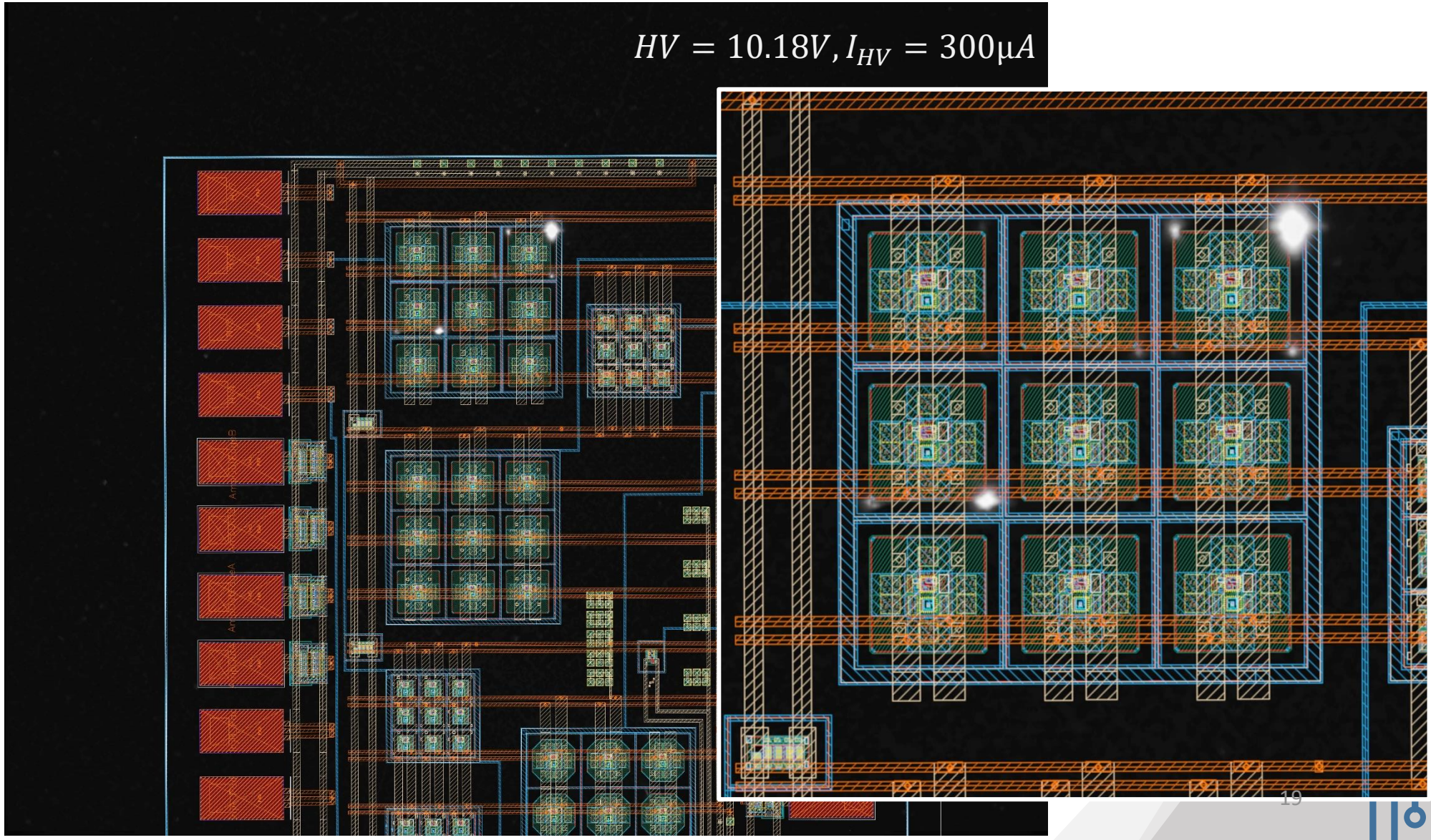
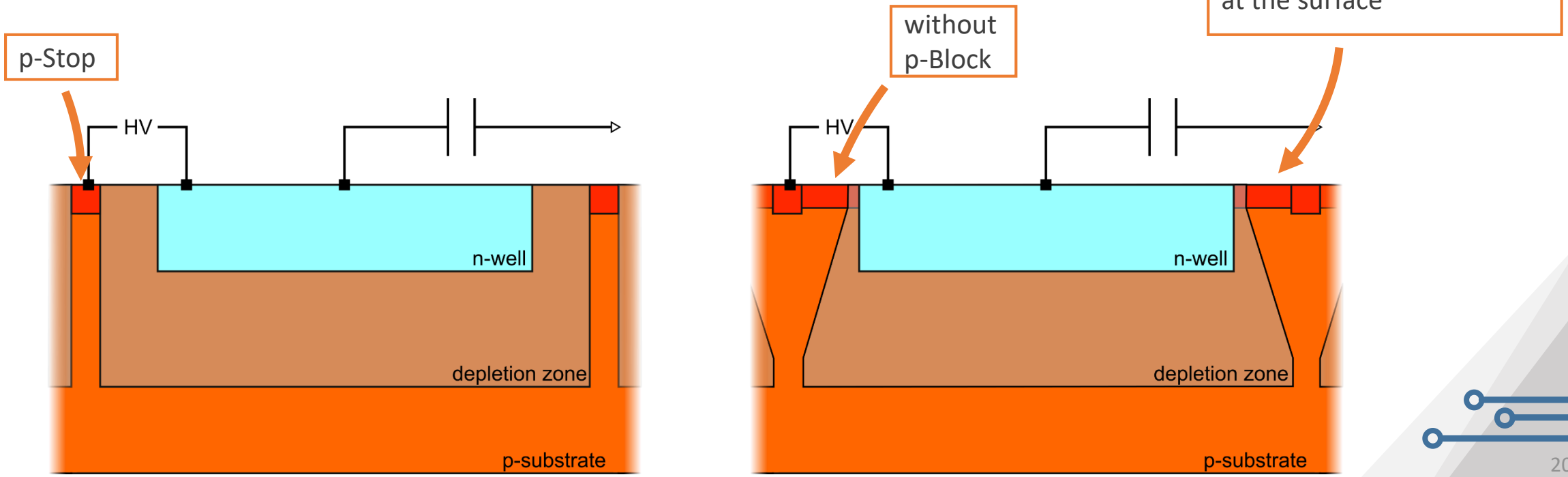
- overlay layout



Early Breakdown

Most possible reason:

- p-Block layer was forgotten in layout
- manufacturer places p-doping by default

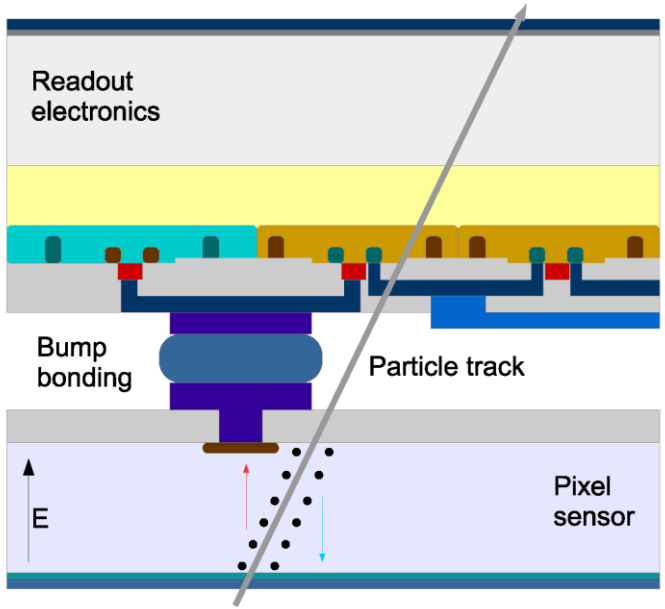


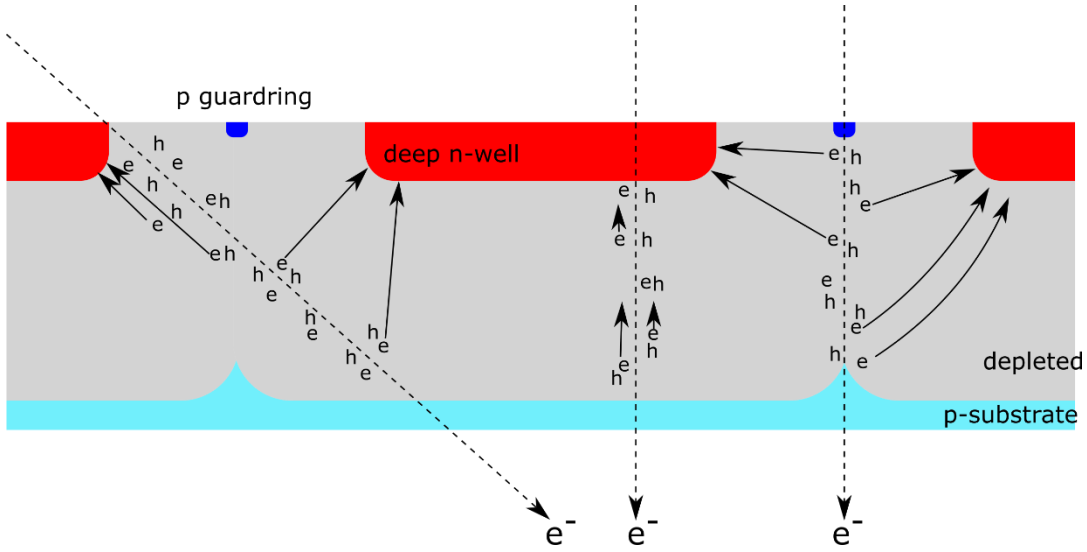
Summary

- combination of a BiCMOS Process with HV-MAPS is a promising concept
  - simulation showed good results for the timing
- BeBiPix has still several problems:
  - early breakdown
  - poorly functioning amplifier-feedback: only slow signals visible
- next steps:
  - use TCT-setup to investigate Signal response further

Back up

Hybrid vs HV-MAPS

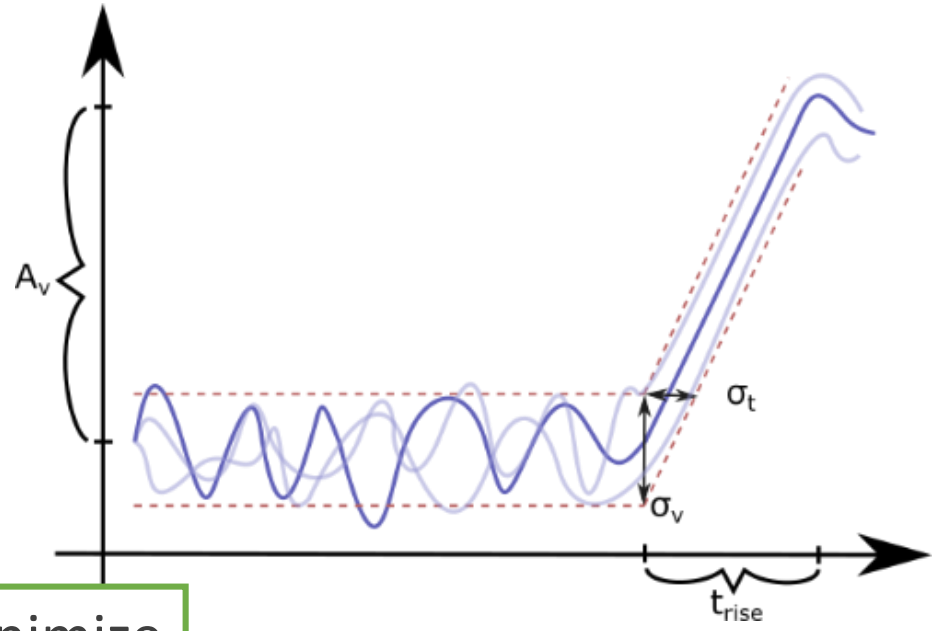




Marco-Hernandez, doi:10.3390/instruments4040036

Advantages of BiCMOS

- $\frac{\sigma_t}{\sigma_v} \approx \frac{t_{rise}}{A_v} \rightarrow \sigma_t \approx \frac{t_{rise}}{SNR}$
- comparison MOSFET and HBT:
  - τ = integration/measuring time



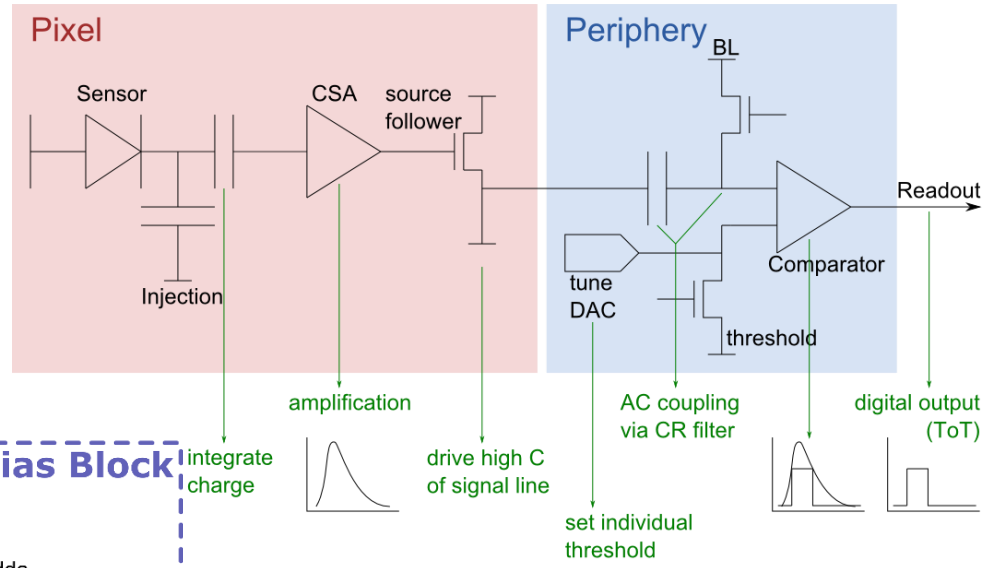
$\sim\tau \rightarrow$ minimize

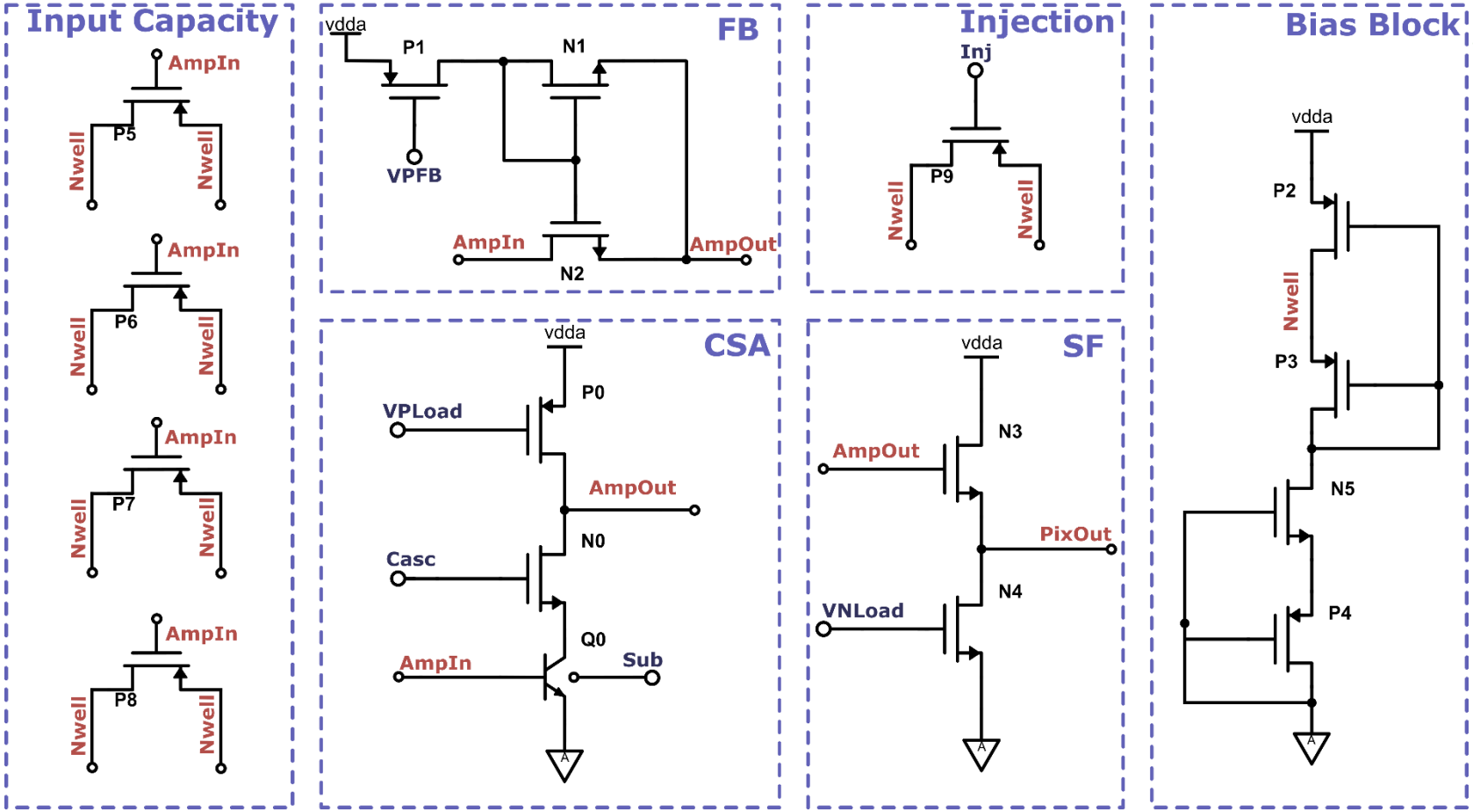
Noise: $$ENC^2 \sim \frac{a}{2\tau} C_{in}^2 + \frac{\tau}{2} b + 2c C_{in}^2$$

	MOSFET	BJT
a	therm. noise	shot noise
b	shot noise (leakage current)	shot noise (leakage current)
c	$1/f$-noise	-

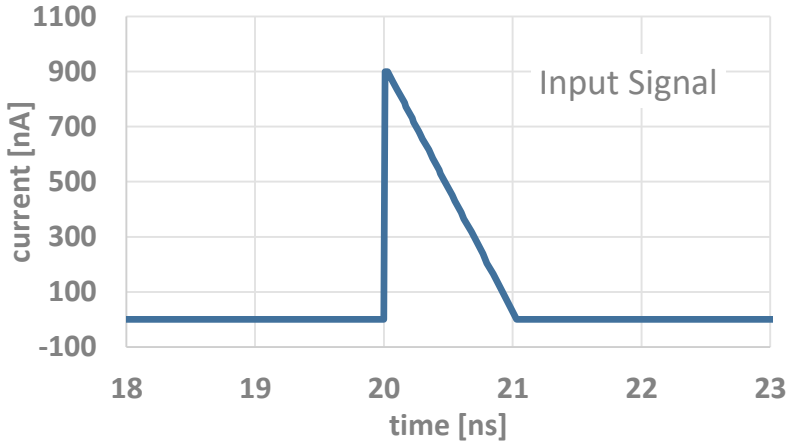
$\sim \frac{R_B}{\beta} \rightarrow$ minimize

BeBiPix Pixel Schematics

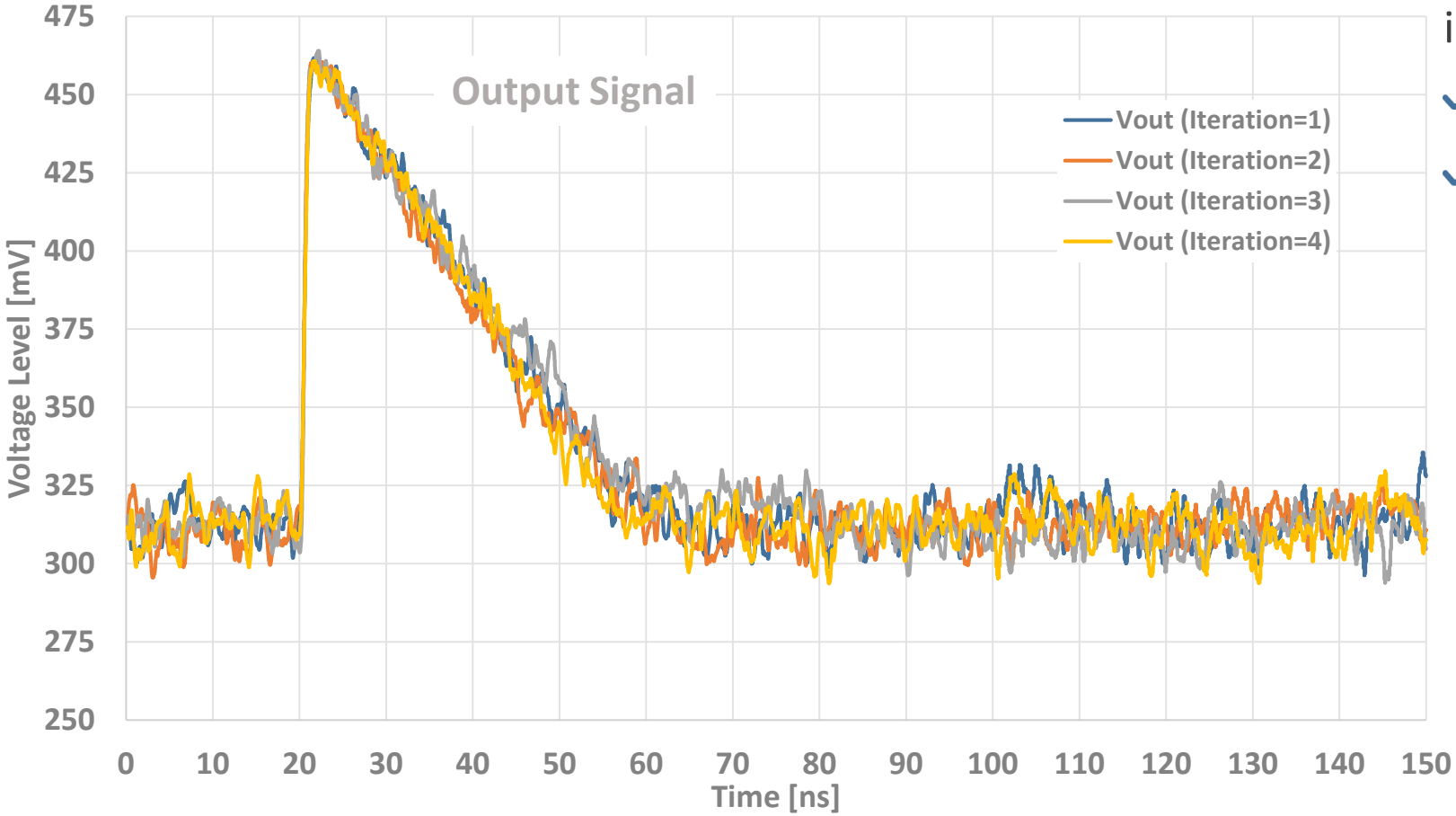




Simulation results



- Transient simulation with noise



input signal:

- corresponding to a MIP
- Parameter:
  - $Q_{sig} \approx 0.45fC \approx 2800\, e^-$
  - $t_{rise} = 10ps, t_{fall} = 1ns$

Transient Simulation – influence of noise

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Rise Time	$741 \pm 340\ ps$
SNR	27 ± 3.9
ToA	$481 \pm 33\ ps$