Silicon photomultipliers with bulk-integrated quenching resistor: first results of characterization

- SiMPl - **Si**licon **M**ulti**P**ixel **l**ight detector concept
- First results from the prototype production

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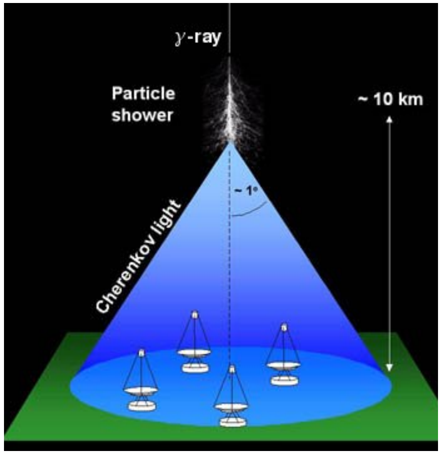
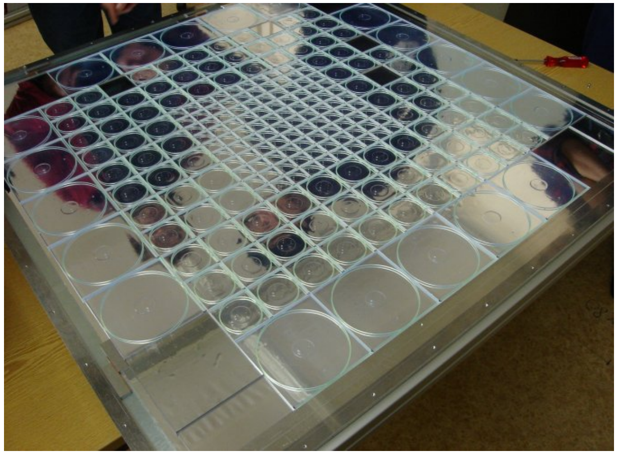
Motivation for novel photon detectors





Low light level camera in
ground-based gamma-ray astronomy

Single tile readout for
high granularity in calorimetry

large number of photon detectors for future experiments and applications

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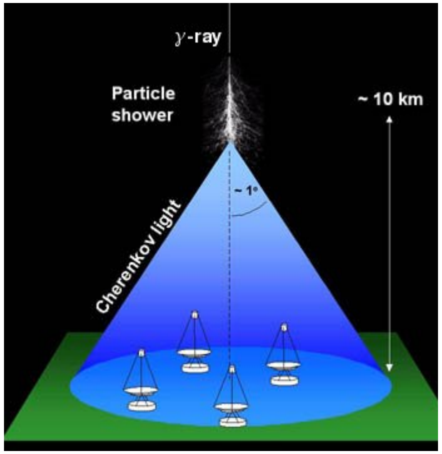

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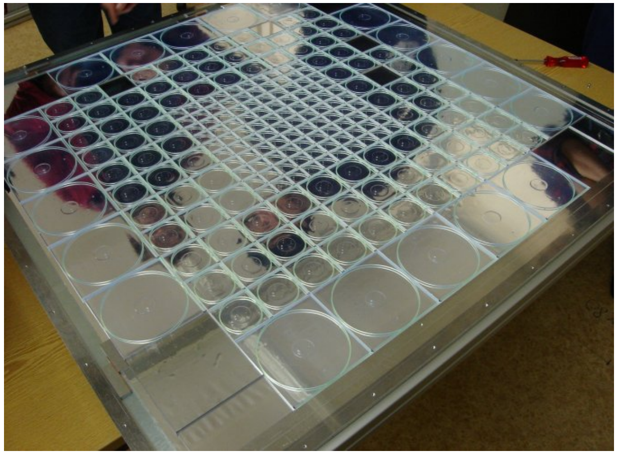


Single tile readout for
high granularity in calorimetry

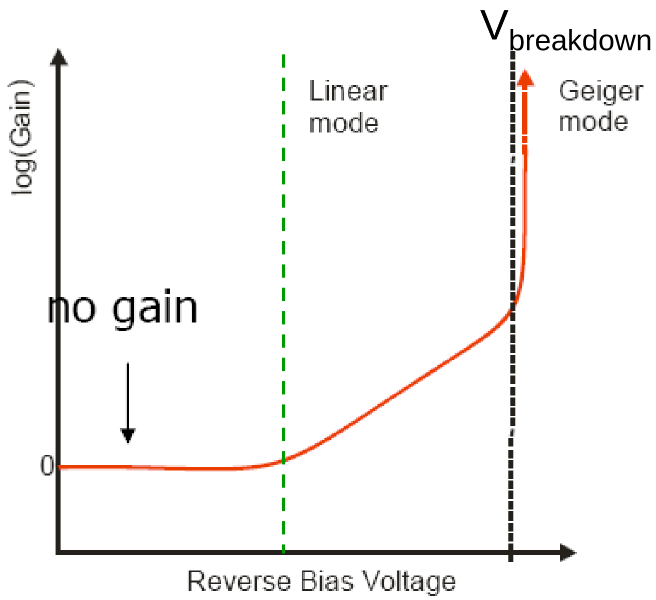
large number of photon detectors for future experiments and applications

Main requirements

- low costs
- low power consumption
- compact and light
- insensitive to magnetic fields
- highest possible detection efficiency
- …

Conventional Silicon Photomultiplier – SiPM

- an array of avalanche photodiodes
  - operated in Geiger mode
  - passive quenching by integrated resistor
  - read out in parallel → signal is sum of all fired cells



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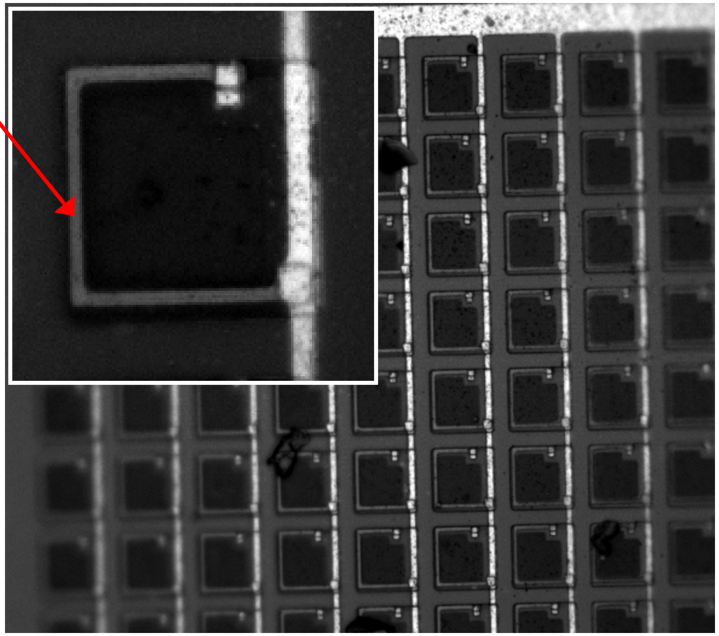

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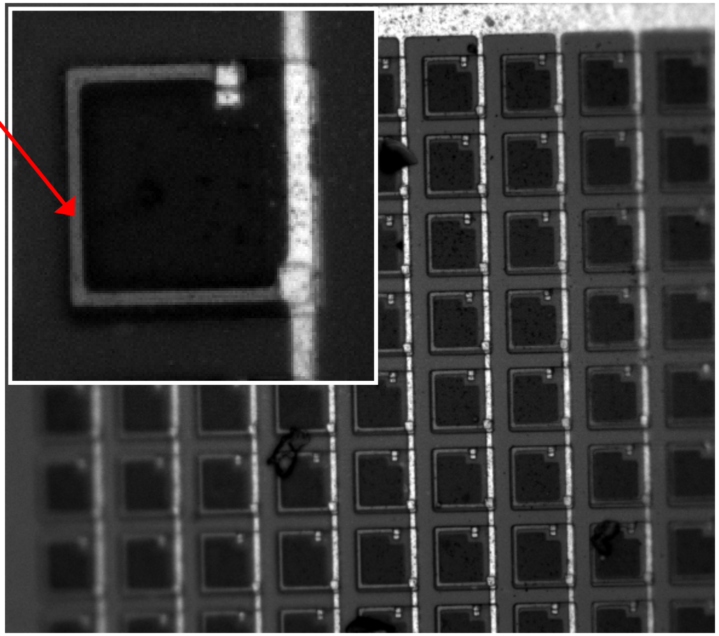
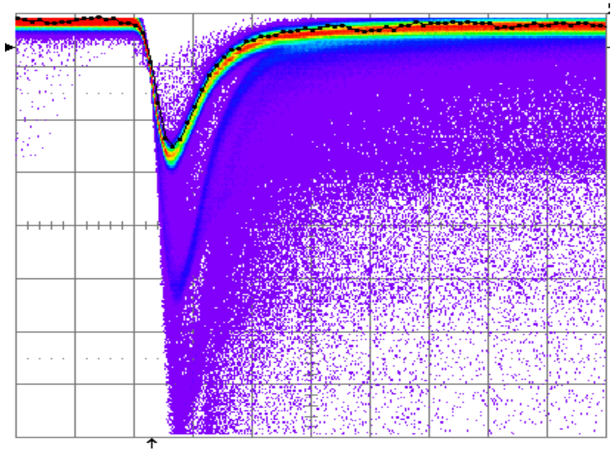
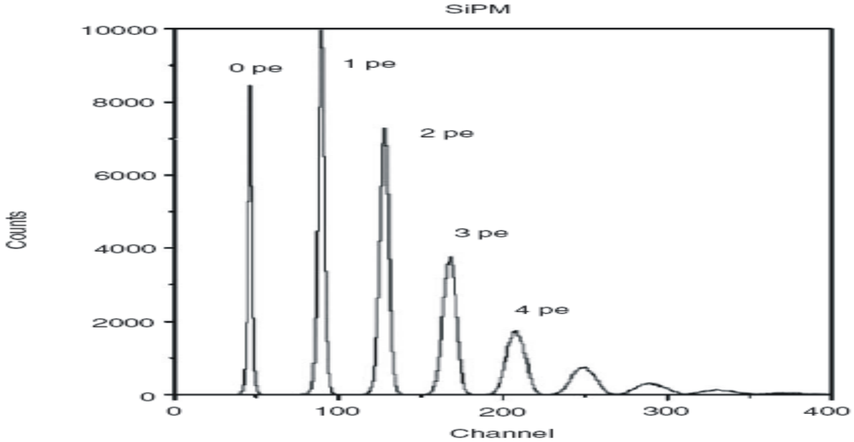
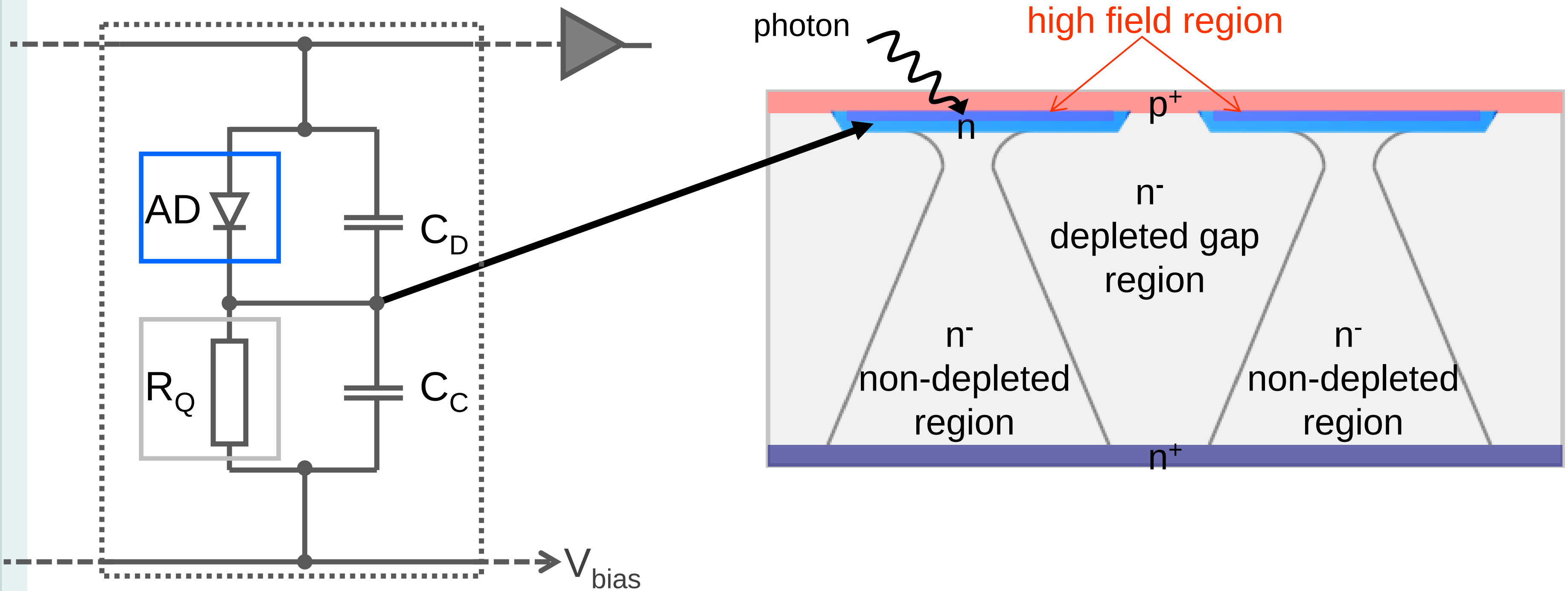






SiPM cell components → SiMPI approach

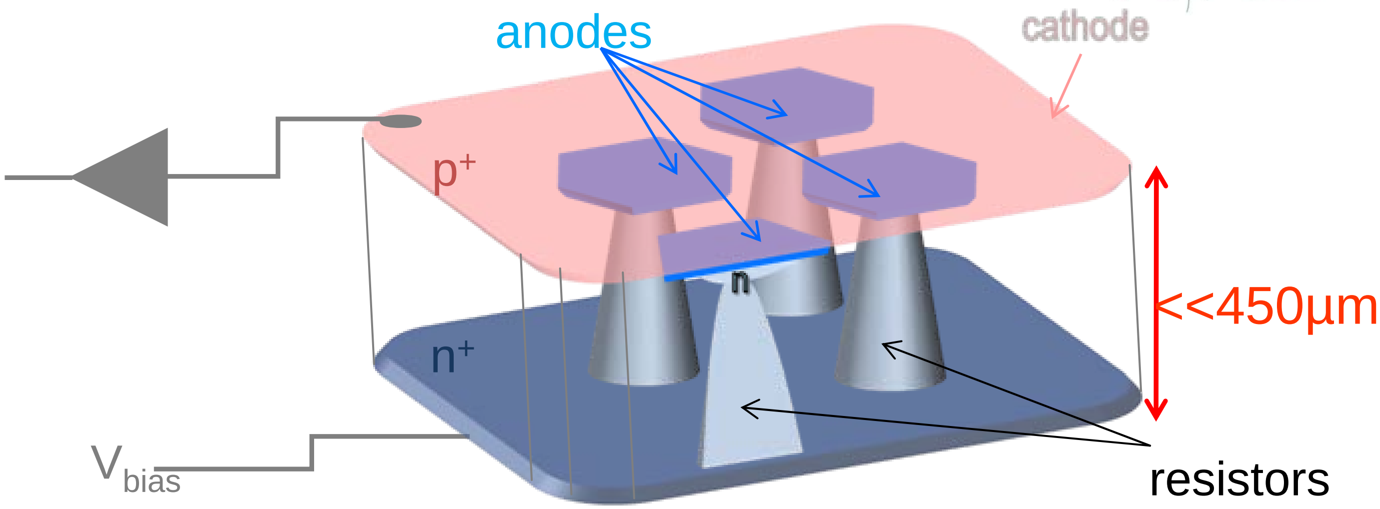


- electrical separation by depleted gap region
- quench resistor formed by non-depleted bulk region

SiPM cell components → SiMPI approach

Resistor matching requires thin wafers !

→ SOI wafers



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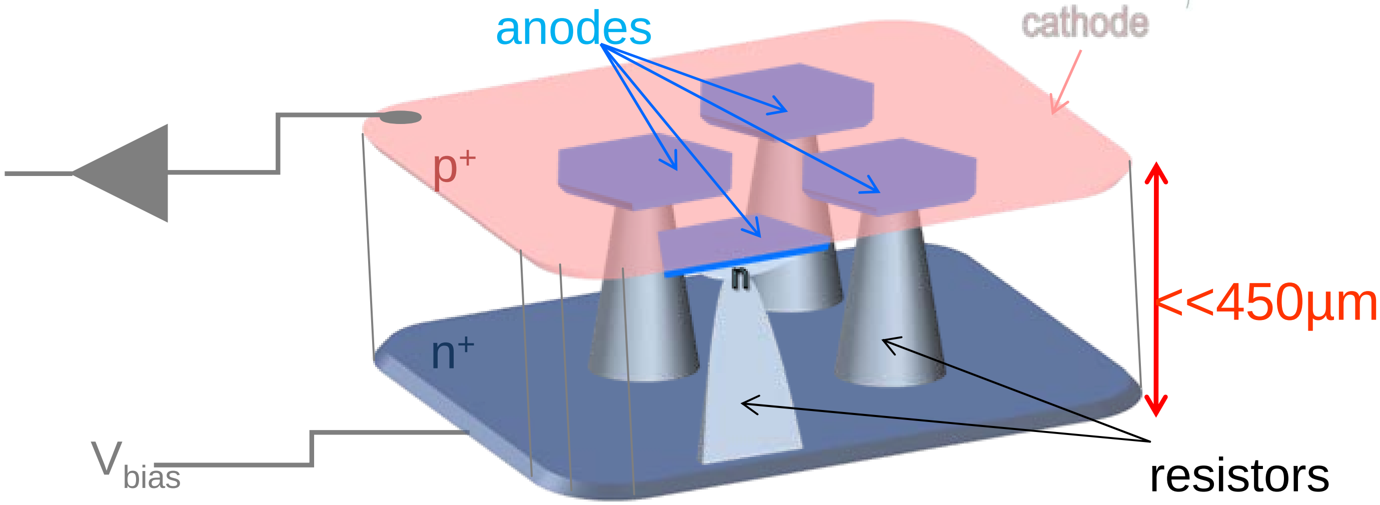

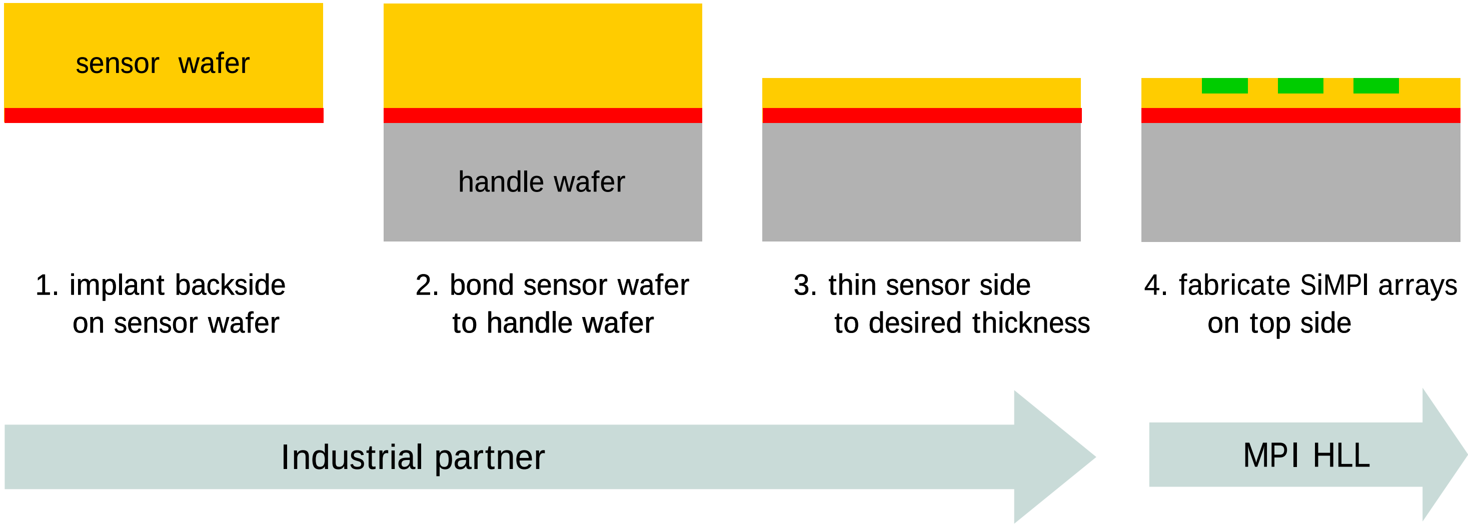

Advantages and Disadvantages

Advantages:

- no need of polysilicon
- no metal necessary within the array → free entrance window for light
- simple technology → lower costs
- inherent diffusion barrier against minorities in the bulk → less optical cross talk

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mpi halbleiterlabor

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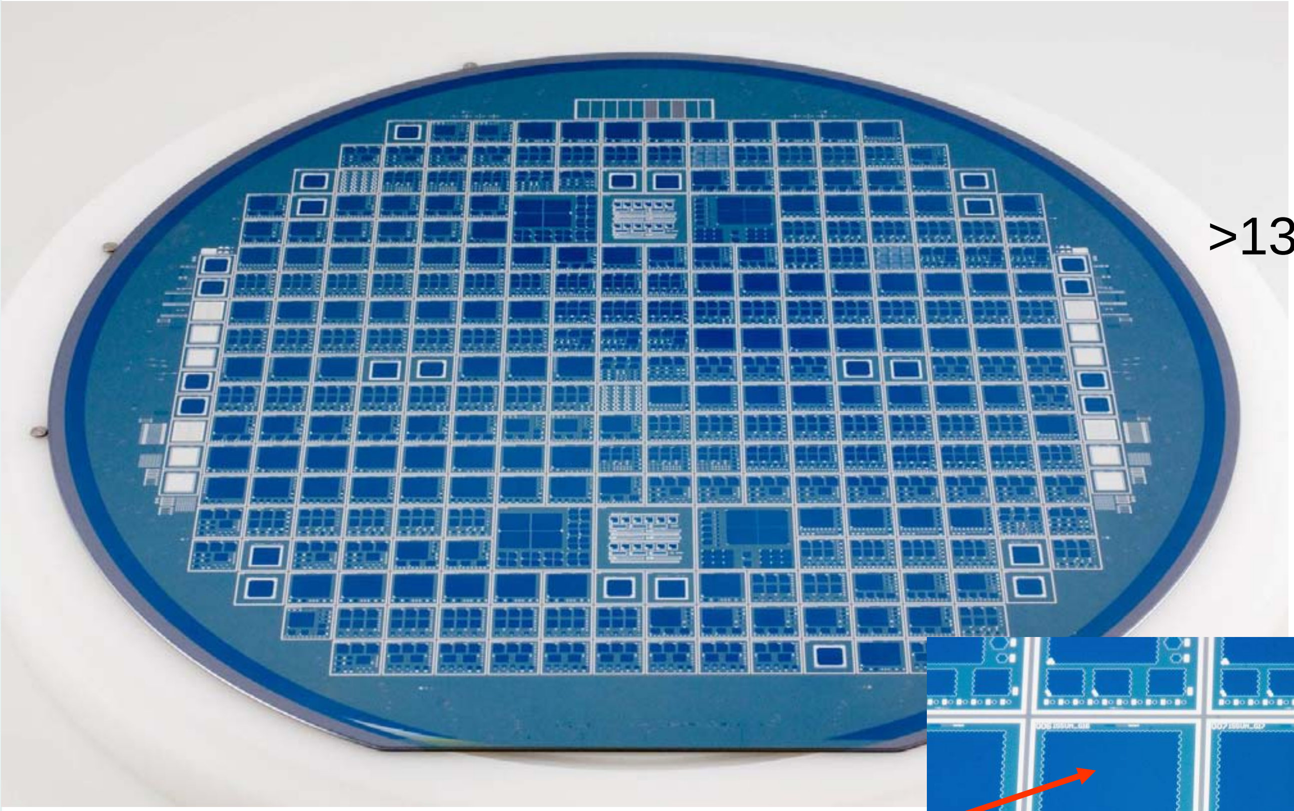
Drawbacks:

- required depth for vertical resistors does not match wafer thickness
- wafer bonding is necessary for big pixel sizes
- significant changes of cell size requires change of the material

vertical ‘resistor‘ is a JFET → parabolic IV → longer recovery times

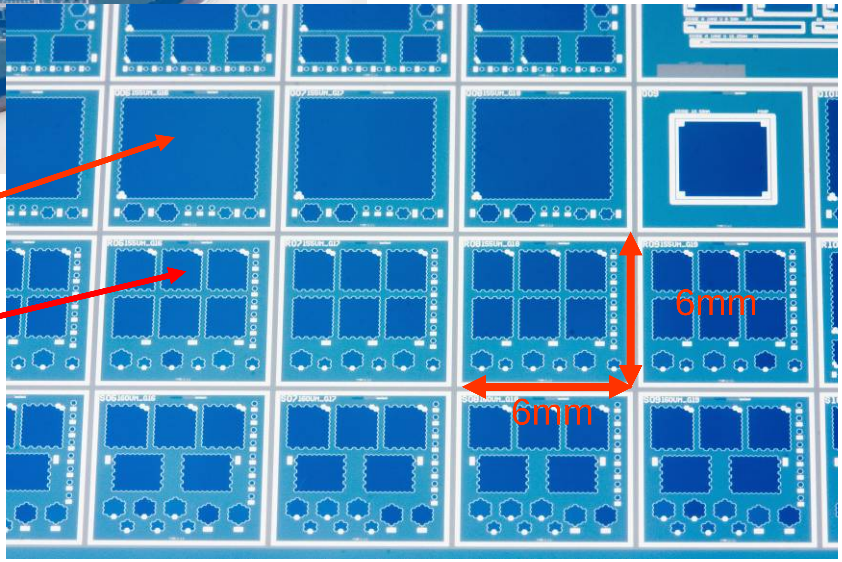
Prototype production



>130 different chips

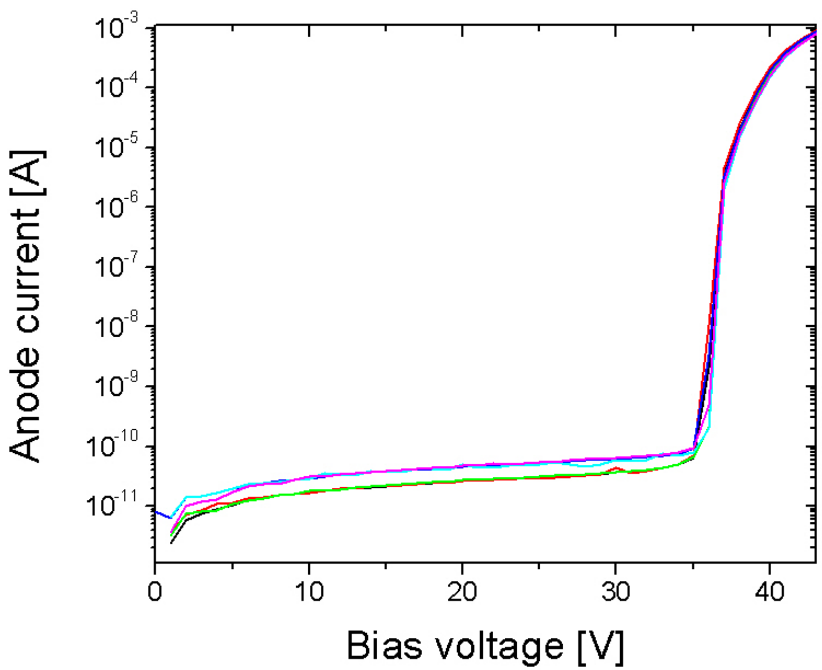
30x30 arrays

10x10 arrays



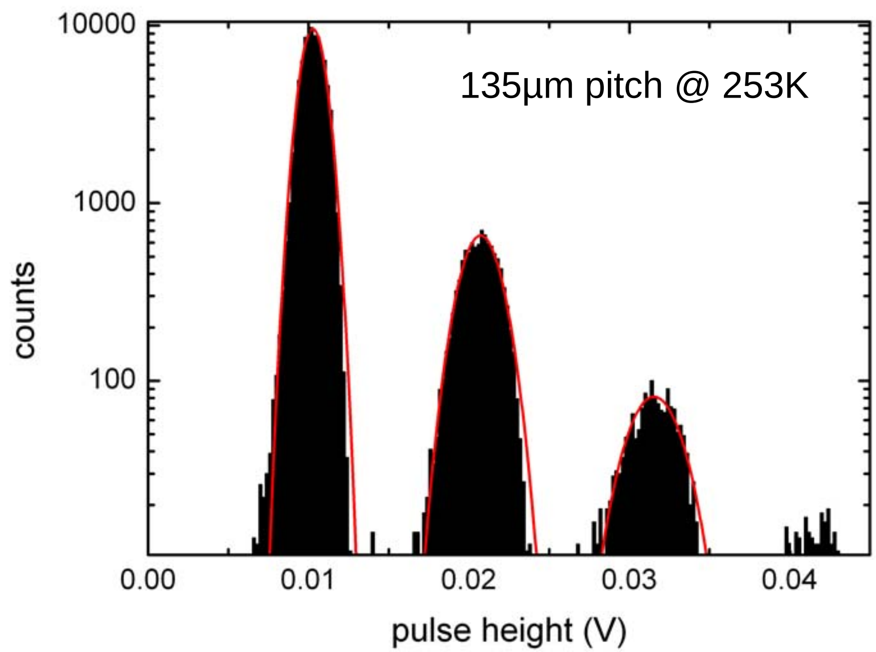
Results

Static measurements



6 (10x10) arrays placed over
6mm distance

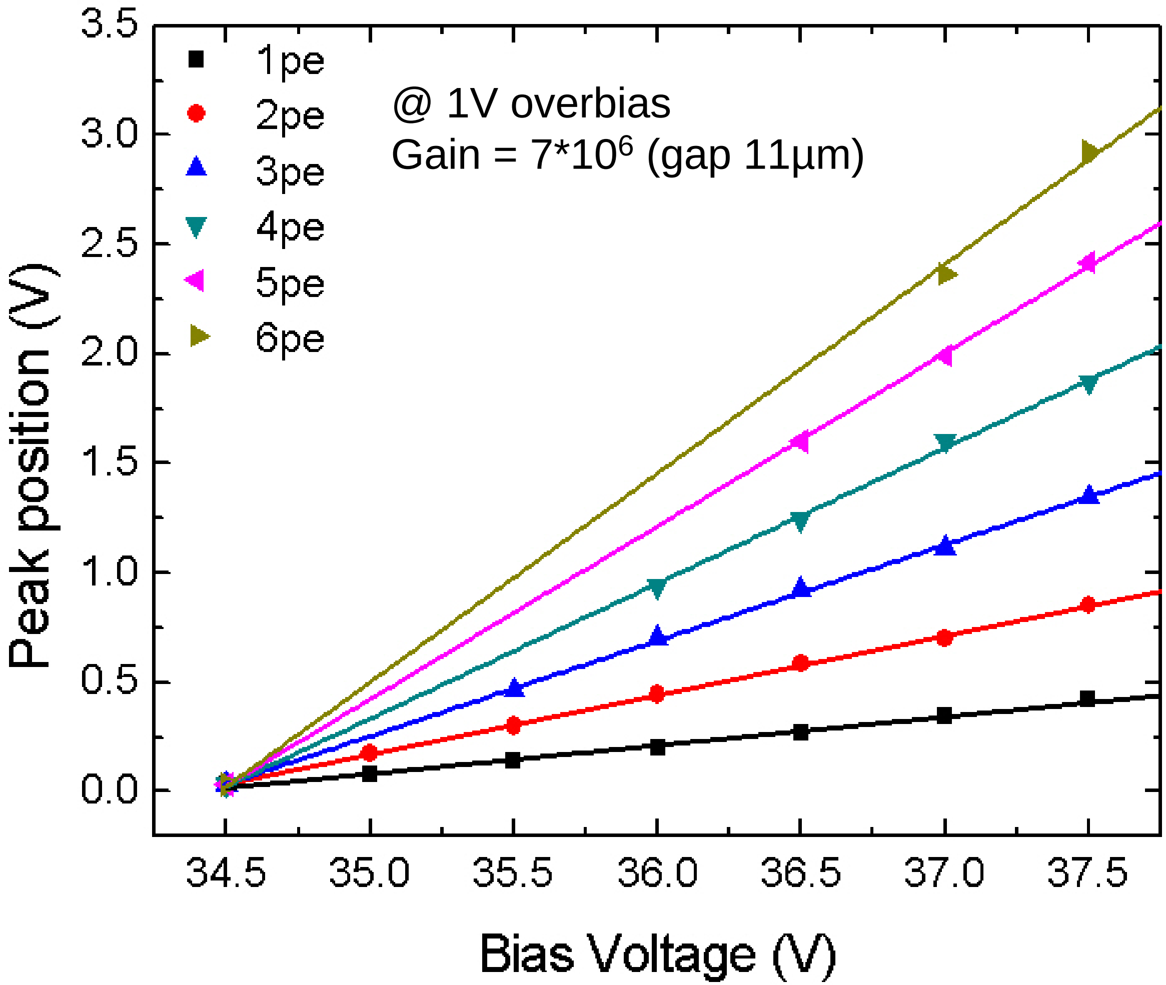
Dynamic measurements



clear peak separation

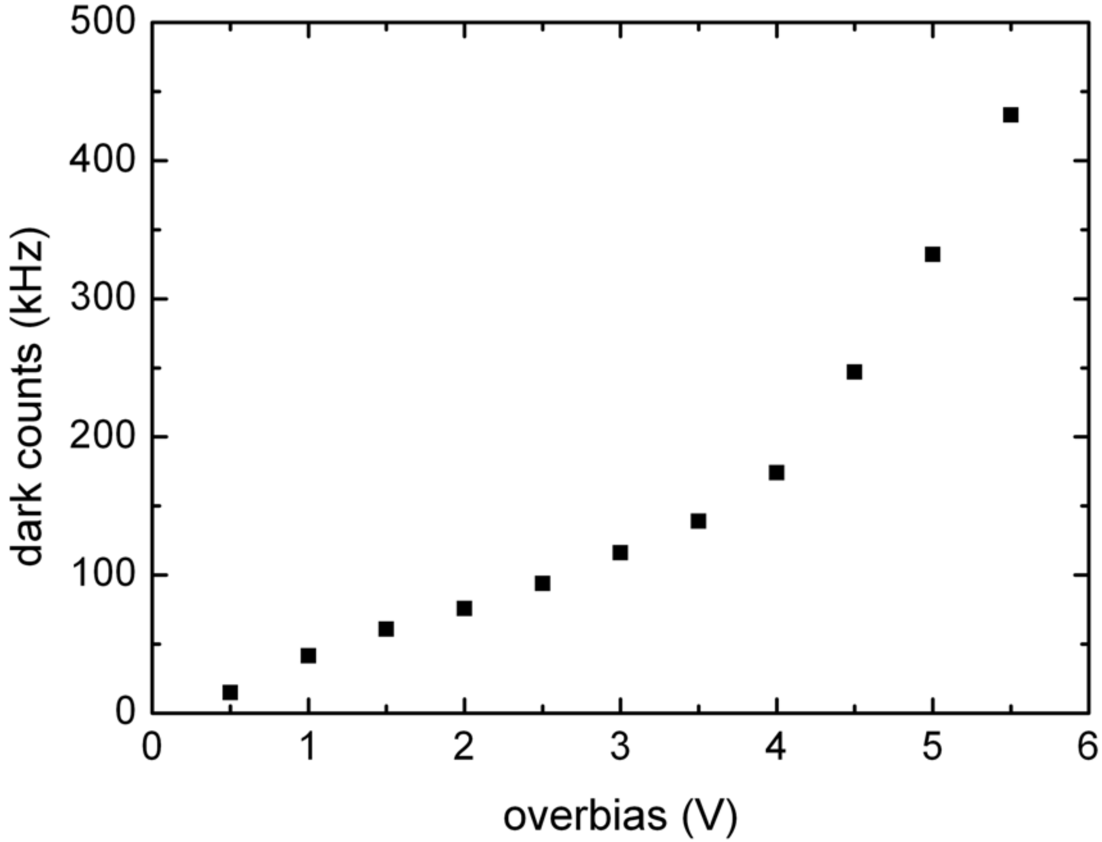
Gain linearity

10x10 array of 130µm pitch @ -30°C



Dark rate

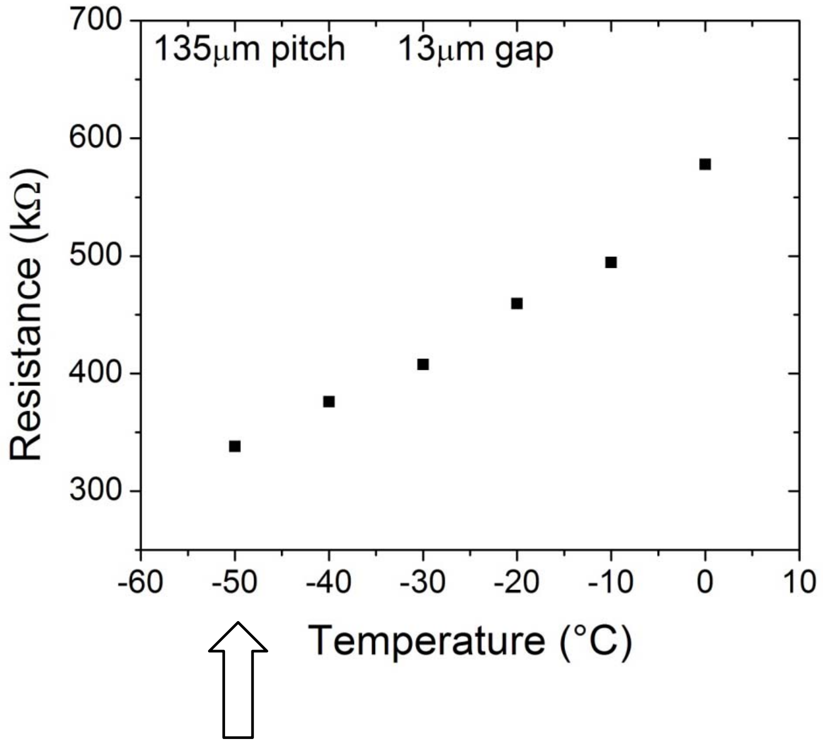
Due to the non optimal process sequence of the high field processing ~10MHz @300K for 4V overbias

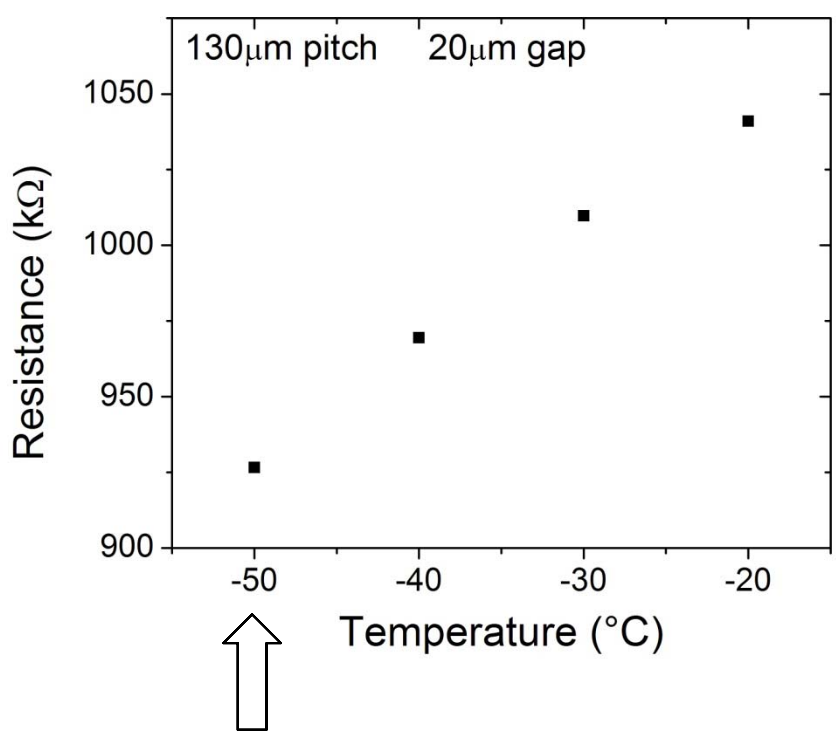


Normal operation up to 4.5V overbias @227K

Resistor behavior

Resistor value designed for room temperature operation



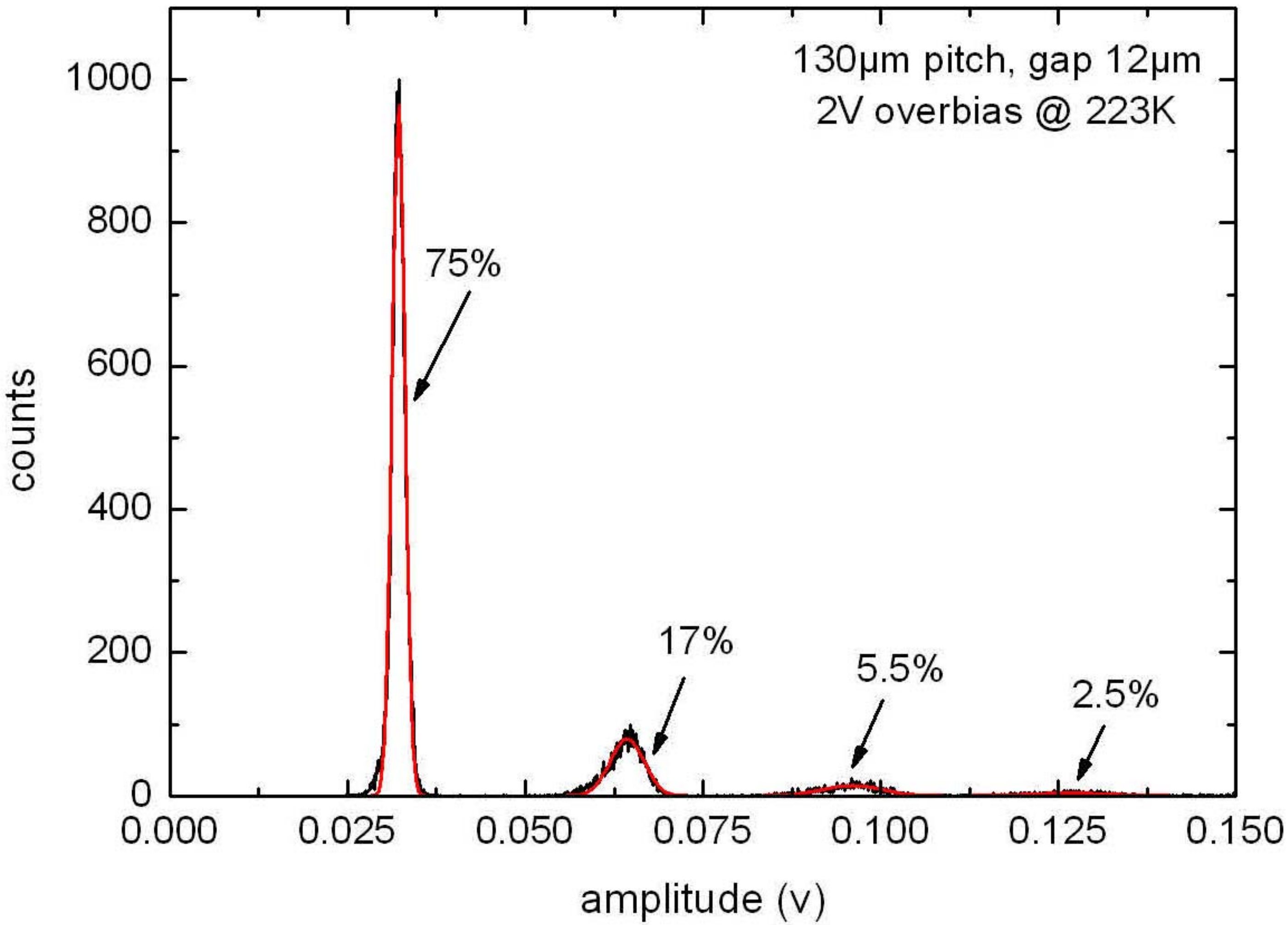


350kΩ @ -50°C

920kΩ @ -50°C

→ limitation of operation range (non-quenching)

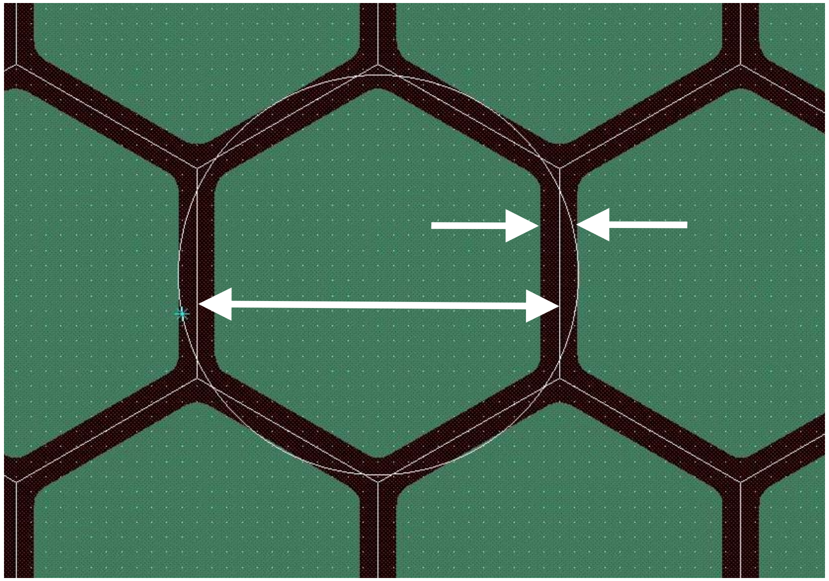
Cross Talk

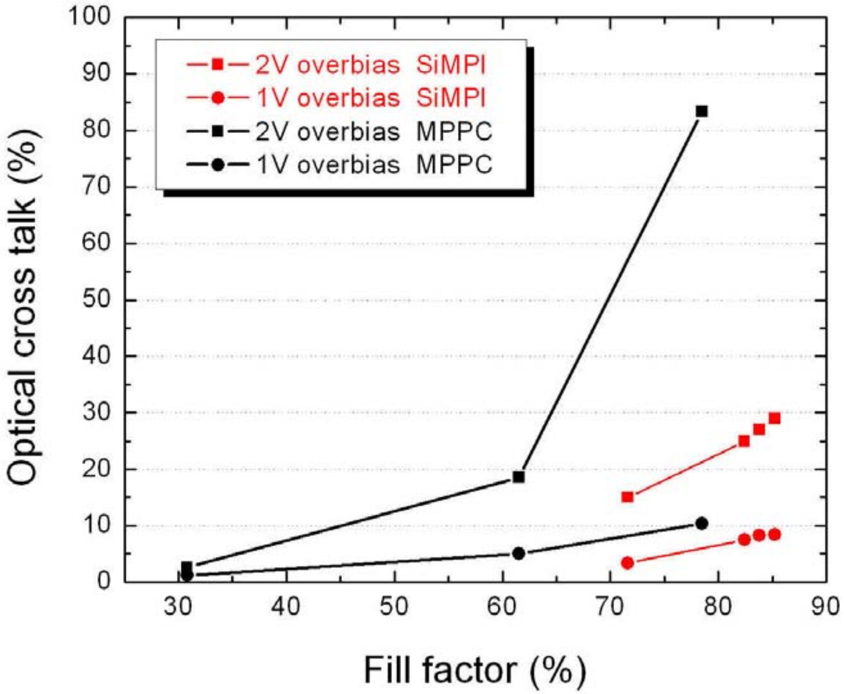


NOTE: no optical barriers for cross talk suppression implemented

Dark Rate & Cross Talk

Pitch / Gap	Fill factor	Cross talk (2V V_{ob})
130µm / 10µm	85.2%	29%
130µm / 11µm	83.8%	27%
130µm / 12µm	82.4%	25%
130µm / 20µm	71.6%	15%





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Photon Detection Efficiency estimation:

- Optical entrance window: 90% @400nm
- Geiger efficiency : 50% @ 2V overbias

Pitch / Gap	Fill factor	PDE
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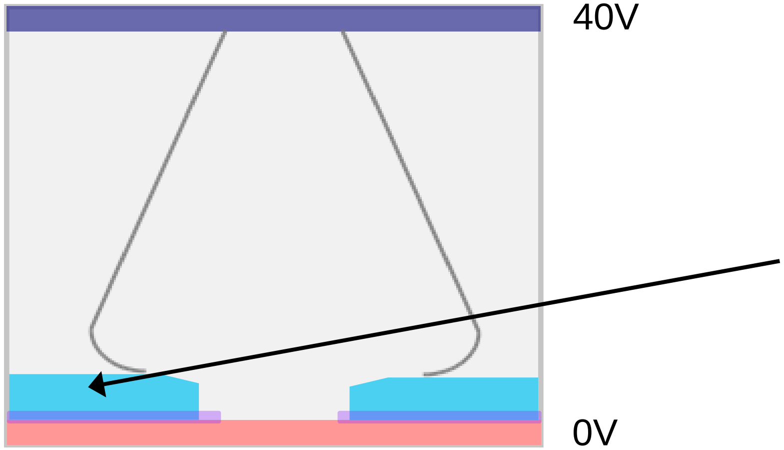
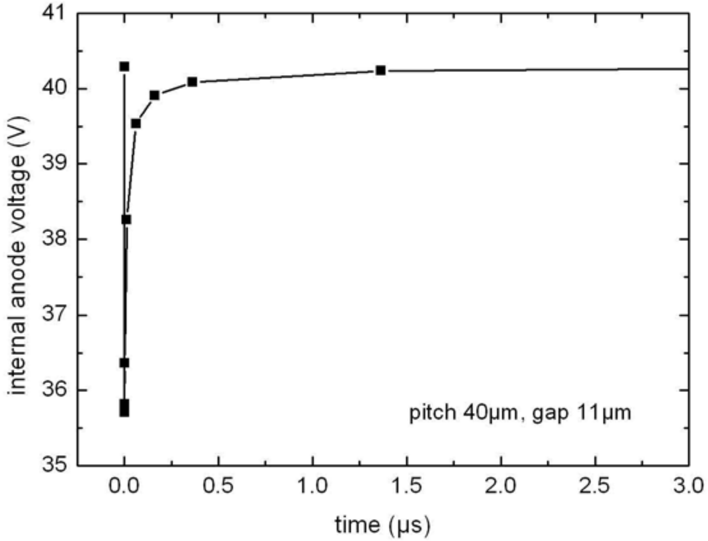
Photon Detection Efficiency estimation:

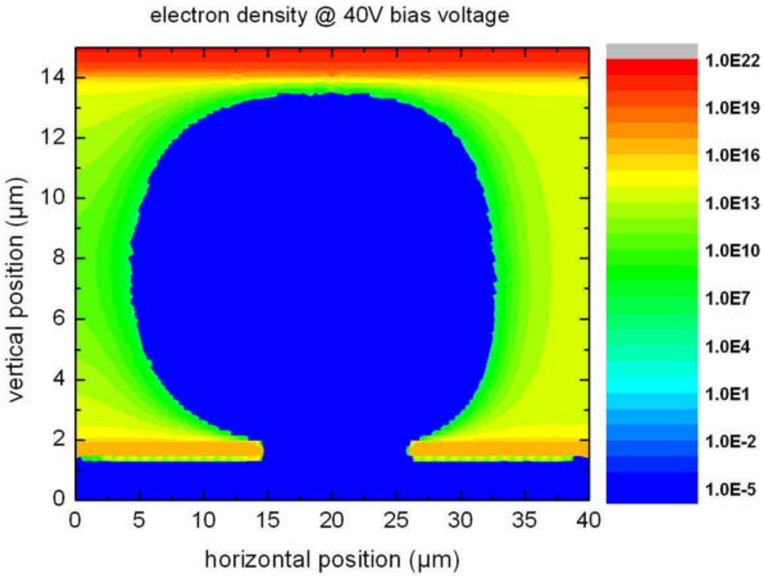
- Optical entrance window: 90% @400nm
- Geiger efficiency : 50% @ 2V overbias   90% @ 6V overbias

Pitch / Gap	Fill factor	PDE	
130µm / 10µm	85.2%	39%	69%
130µm / 11µm	83.8%	38%	68%
130µm / 12µm	82.4%	37%	67%
130µm / 20µm	71.6%	32%	58%

Simulations for small pixels







- small pixel for high dynamic range
- simulation for resistor value estimation
- fill factor of 60% achievable (40µm pitch)
- recovery time of about 0.7 µs

Summary & Outlook

New detector concept for silicon photomultipliers with quench resistors, integrated into the silicon bulk - SiMPI detector

- quench resistor adjustment comes with wafer bonding technique (for small pixels an epitaxial layer is also suitable)
- No polysilicon resistors and metal necessary within the entrance window
- Geometrical fill factor is given by the need of cross talk suppression only
- Very simple process → cost reduction in mass production

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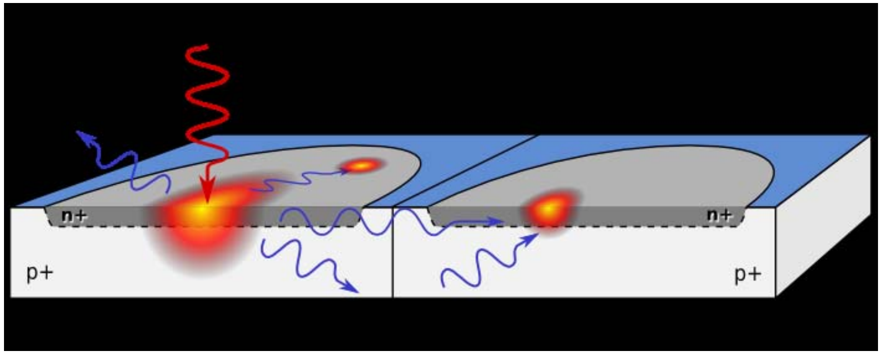
Prototype production finished – quenching works , first measurements very promising, functional devices with very high fill factor

Further studies of the produced sensors (geometry dependence characteristics, PDE, …) are ongoing

New production for dark rate reduction and first simulations for small pixels

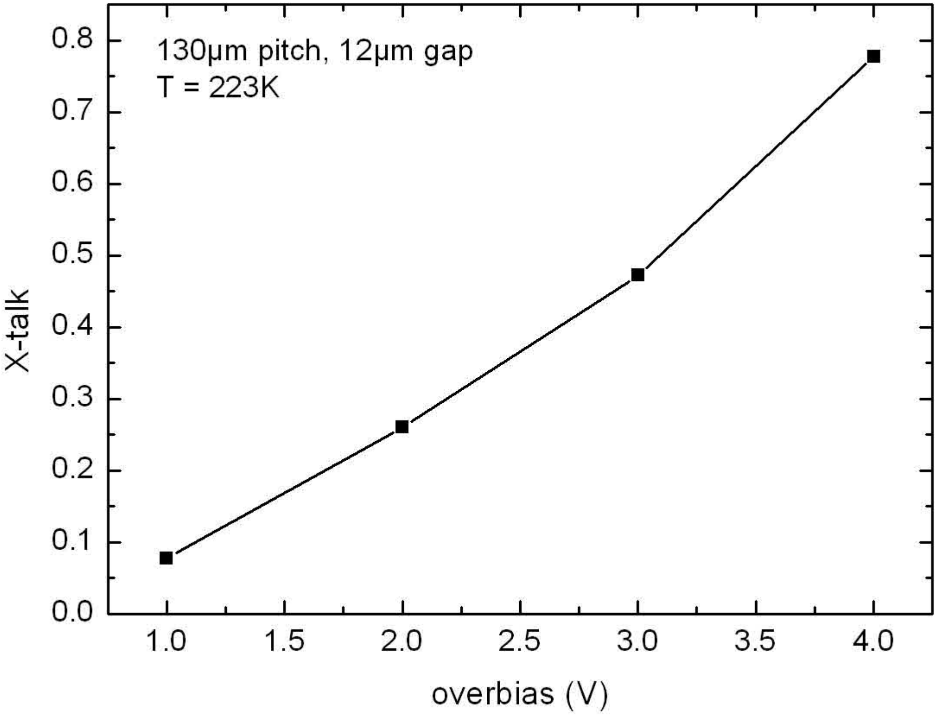
Thank you for your attention!

Cross Talk



Crosstalk depends on:

- Fill factor (80% for SiMPl)
- Gain (10^7 at 2V overbias)
- Geiger efficiency (ca. 1 @ 15% overbias)



Optical cross talk suppression