Backside Illuminated Drift Silicon Photomultiplier BID-SiPM

Jelena Ninkovic

on behalf of the **BID-SiPM** group*

*MPI for Physics: J. Ninković, C. Merck, R. Mirzoyan, R. Richter, H.G. Moser, A. Otte, M. Teshima, G. Valceanu
*PNSensor: R. Eckhart, G. Lutz, R. Hartmann, P. Holl, C. Koitsch and H. Soltau.

Outline

- Motivation
- Concept of the BID-SiPM
- First measurements of the test structures
- Future plans

Gamma Ray Astronomy

http://wwwmagic.mppmu.mp

Gamma Ray induces electromagnetic cascade

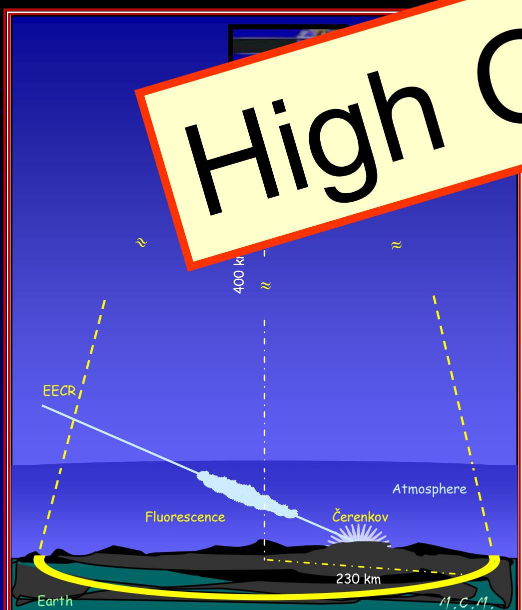
↳ relativistic particle shower in atmosphere

↳ Cherenkov light

fast light flash (n
100 ph … a Ray)

… air Cherenkov telescope

High QE photo sensors!!!

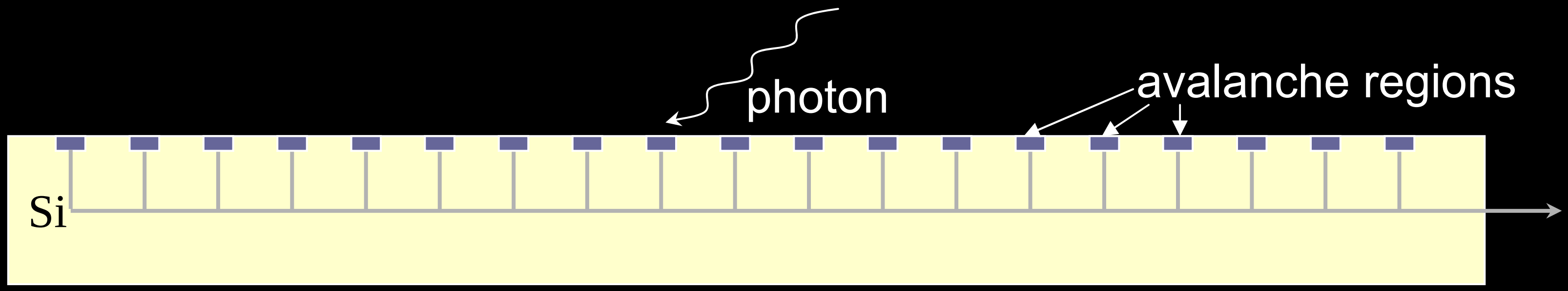


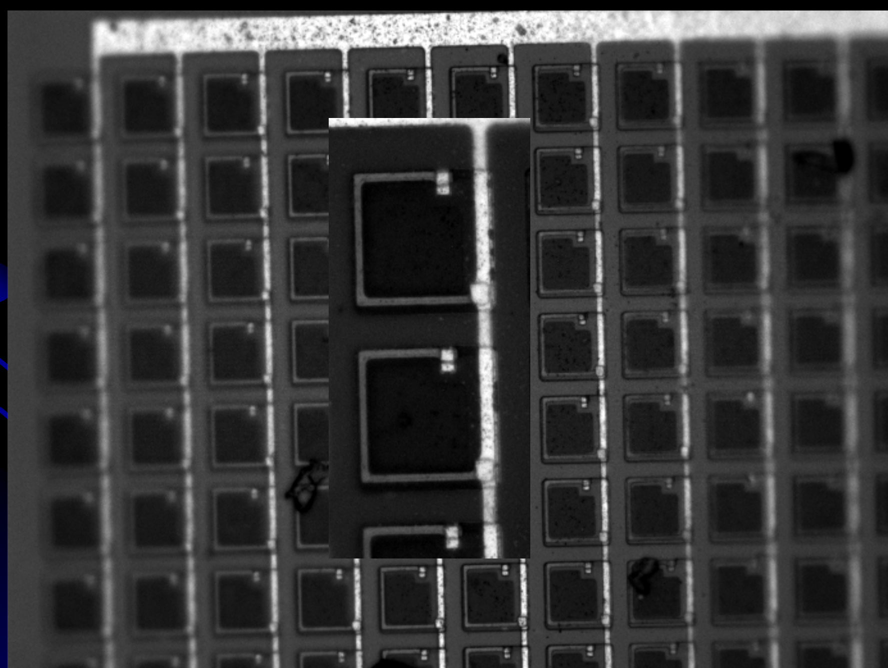
Fluorescence in the atmosphere

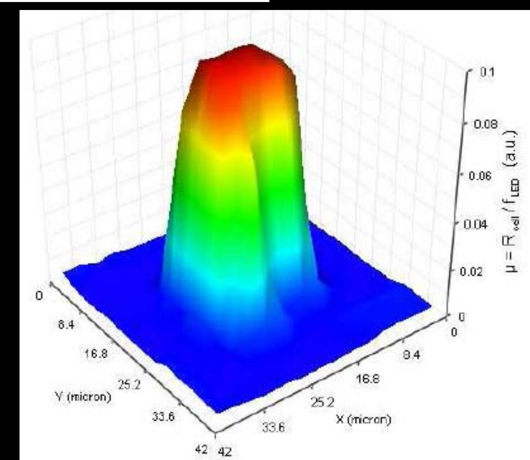
JEM - EUSO

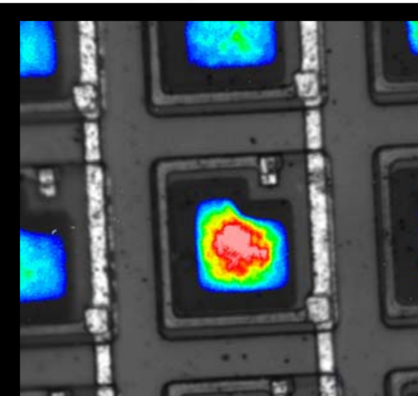
SiPM

Conventional SiPM - an array of avalanche photo diodes operated in Geiger mode



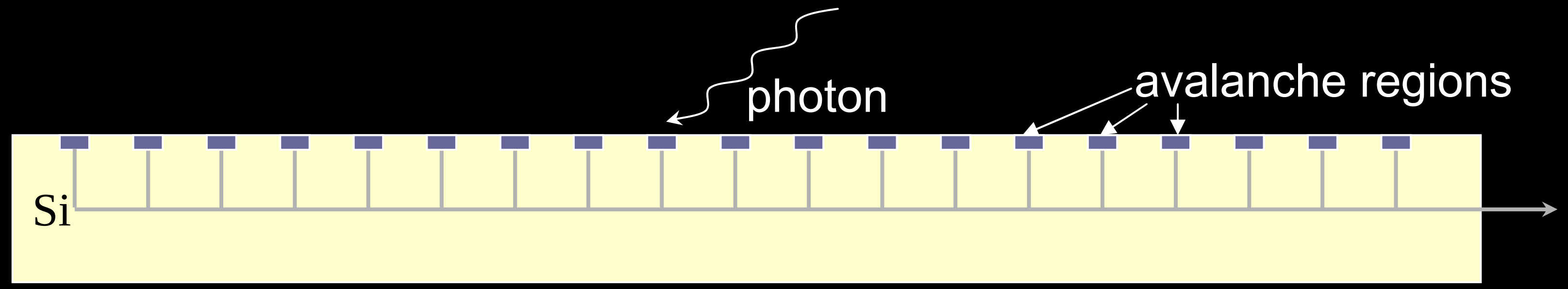




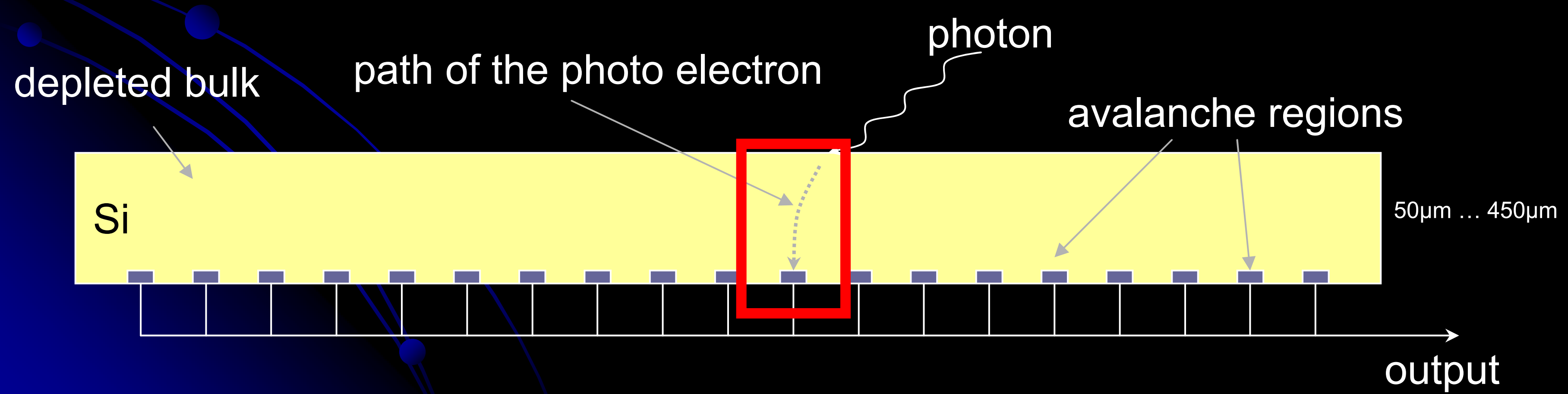


BID-SiPM

Conventional SiPM - an array of avalanche photo diodes operated in Geiger mode

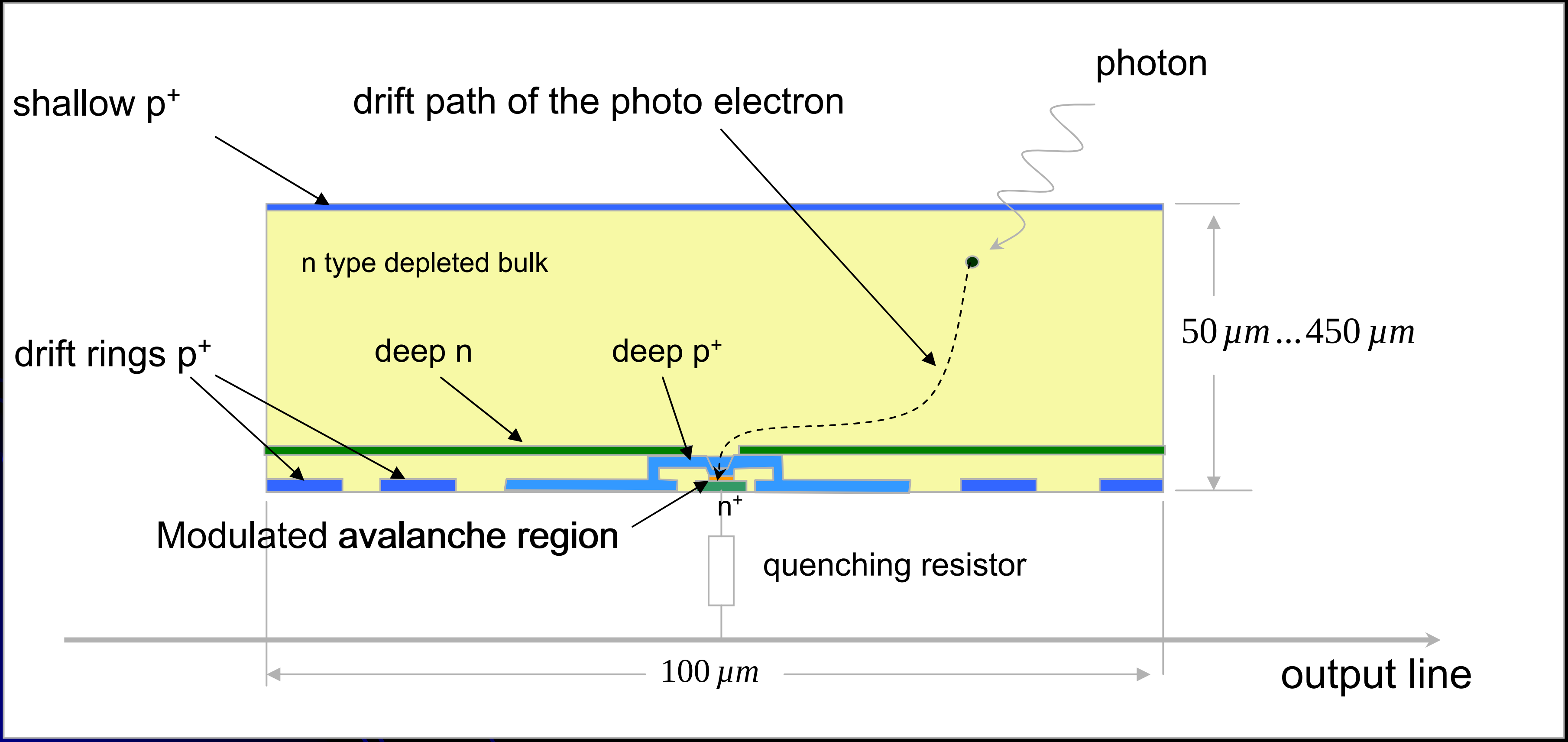


BID SiPM – combined principle of avalanche photodiode and drift diode



BID-SiPM

Zoom to a single cell



G. Lutz et al., IEEE Trans.Nuc. Sci., 52, (2005) 1156-1159.
G. Lutz et al., Proc.Int. Con. New Dev. Photodet., Beaune 2005, to be published in NIM A.

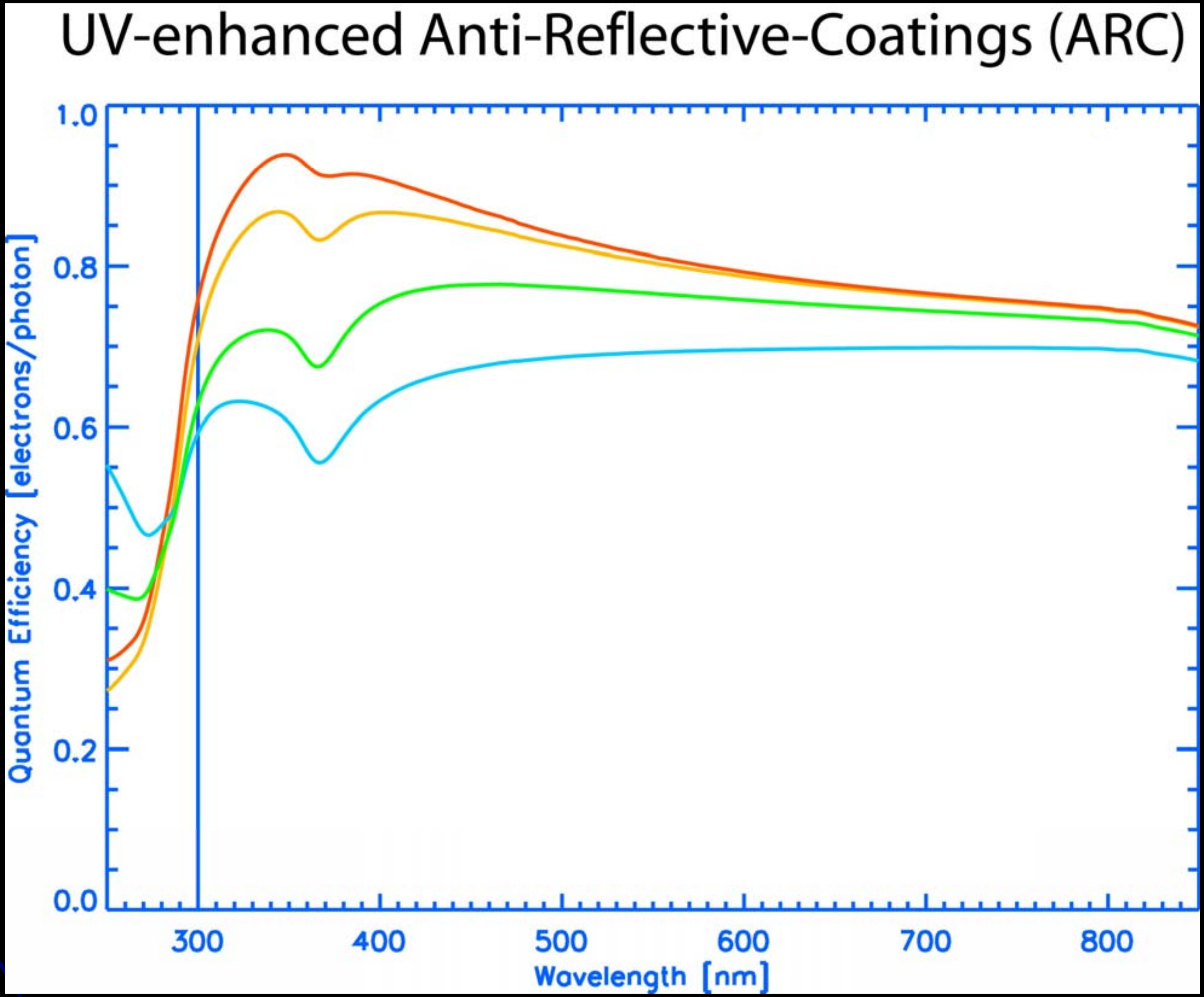
Pro & Con

Advantages:

- Unstructured thin entrance window
- 100% fill factor
- High conversion efficiency (especially at short wavelength)
- Lateral drift field focuses electrons into high field region
- High Geiger efficiency (always electrons trigger breakdown)
- Small diode capacitance (short recovery, reduced x-talk)

BID-SiPM radiation entrance window

Non-structured backside allows engineering of the radiation entrance window



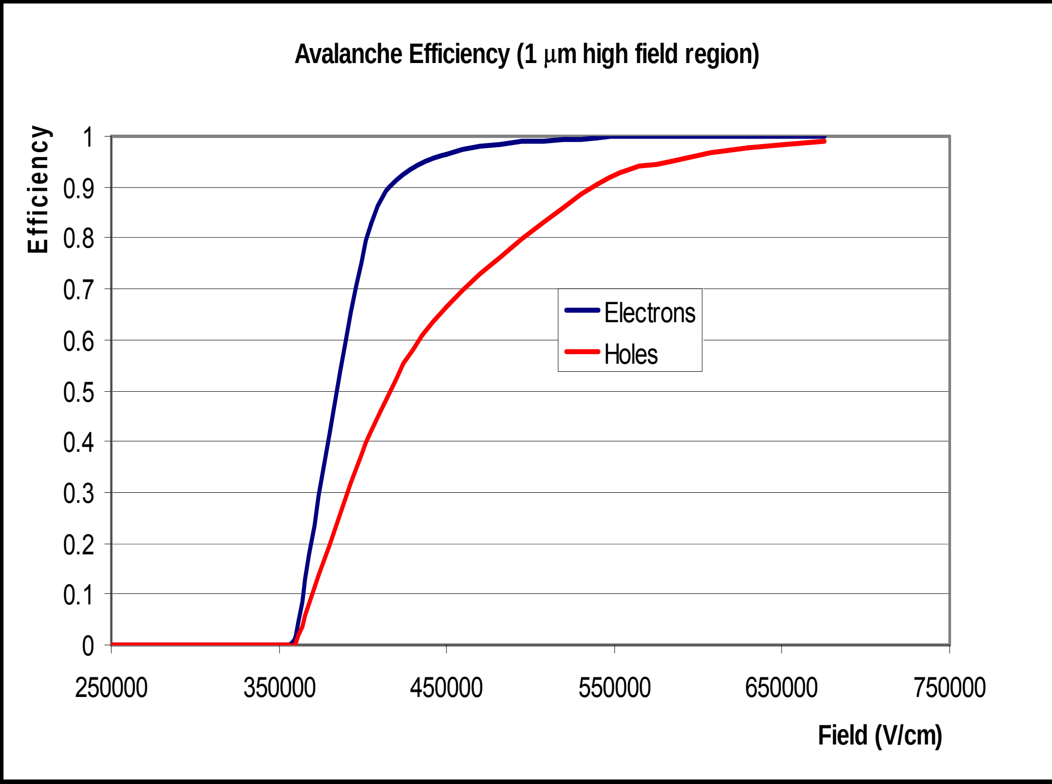
Geiger Efficiency of electrons and holes

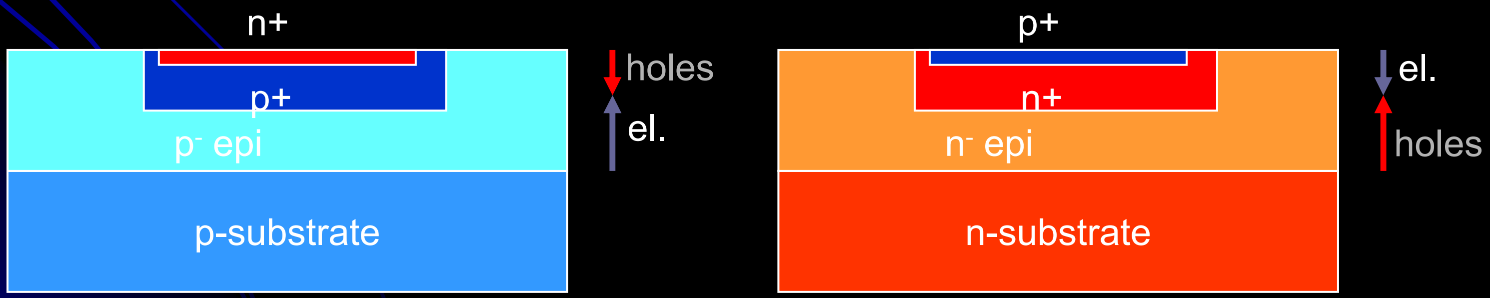
Electrons have a higher probability to trigger an avalanche breakdown then holes

Efficiency depends on depth of photon conversion and hence on the wavelength

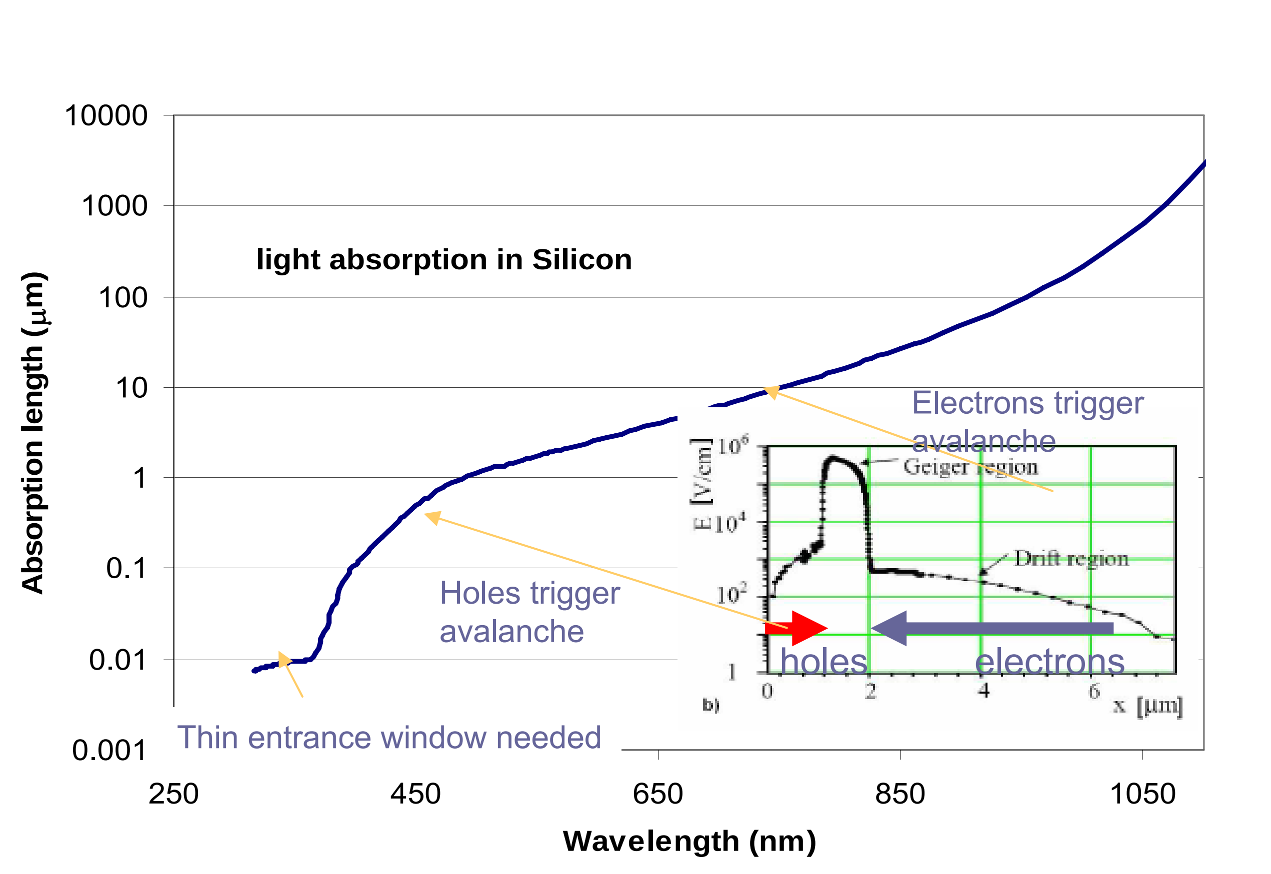
Solutions:
-Increase overvoltage

Or:
- Ensure that only electrons trigger an avalanche





Sensitivity at different wavelengths



Example:
p-substrate

p-substrate: photons < 450 nm: only holes contribute
photons > 700 nm: lost in insensitive bulk

n-substrate: ok for short wavelengths,
hole efficiency dominates for $\lambda > 500$ nm

Back illumination: whole thick (> 50 μm) bulk absorbs photons
design for electron collection

Pro & Con

Advantages:

- Unstructured thin entrance window
- 100% fill factor
- High conversion efficiency (especially at short wavelength)
- Lateral drift field focuses electrons into high field region
- High Geiger efficiency (always electrons trigger breakdown)
- Small diode capacitance (short recovery, reduced x-talk)

Disadvantages:

- Large volume for thermal generated currents (→increased dark rate)
  - Maintain low leakage currents
  - Cooling
  - Thinning (< 50 μm instead of 450 μm)
- Large volume for internal photon conversion (→increases x-talk)
  - Lower gain (small diode capacitance helps)
  - Thinning (< 50 μm instead of 450 μm)

Possible show stopper!

- Electron drift increases time jitter
  - Small pixels,
  - Increased mobility at low temperature <2 ns possible

Design of Devices

Hexagonal Cells

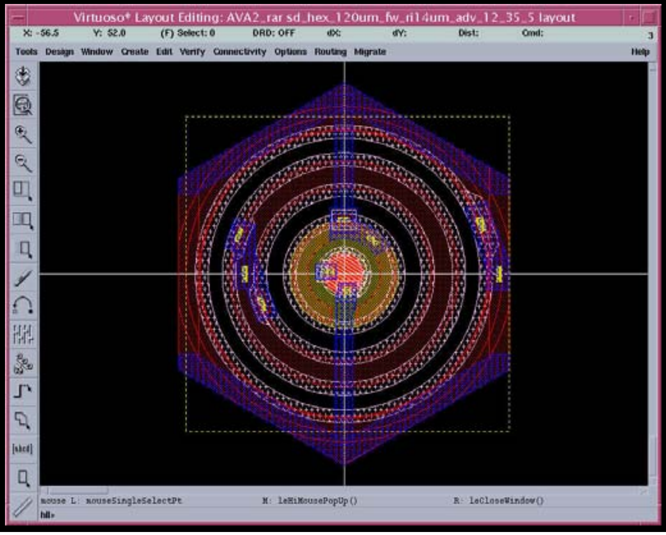
100-200 μm diameter
3 drift rings

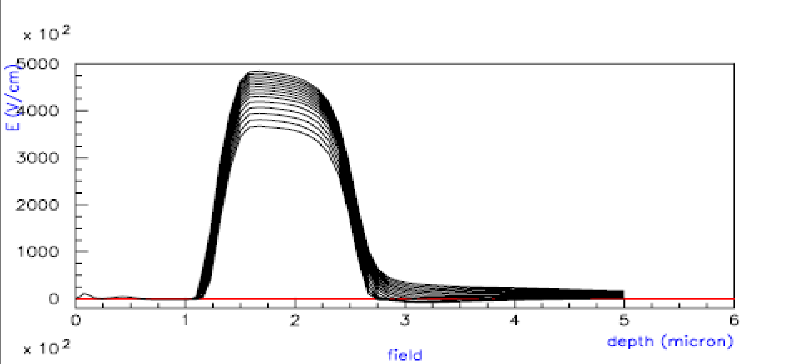
Central HF region with 8 μm diameter

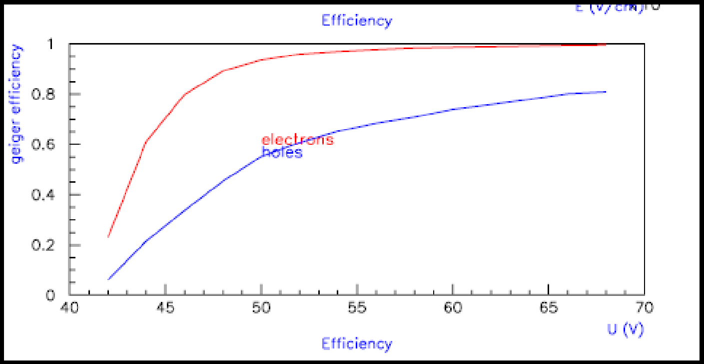
Capacitance ~ 12 fF
Gain: O(10^5)
~ 1 μm depth

95% Geiger efficiency
@ 8V overvoltage (electrons)

Drift field extends into bulk

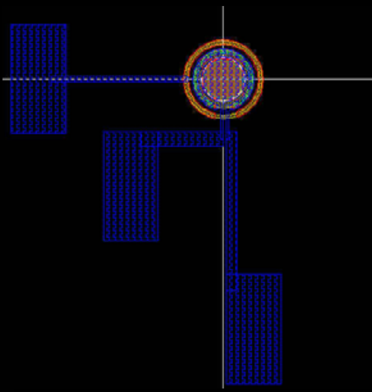


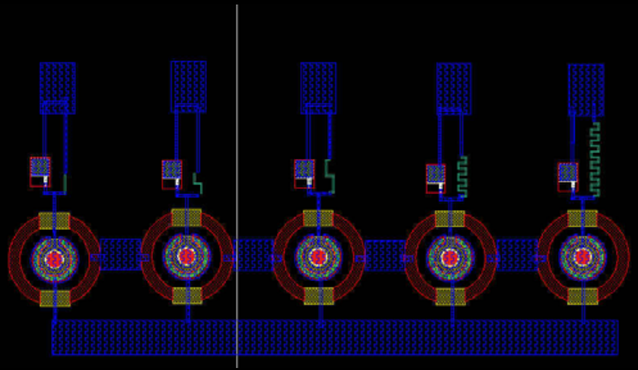




Test structure production in 2005/06

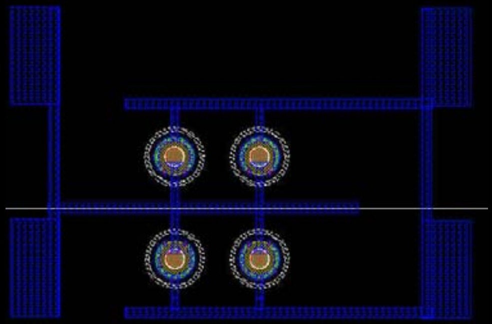
-> fix parameters of avalanche cell (radius, depth, resistor values…)
-> no backside illumination yet

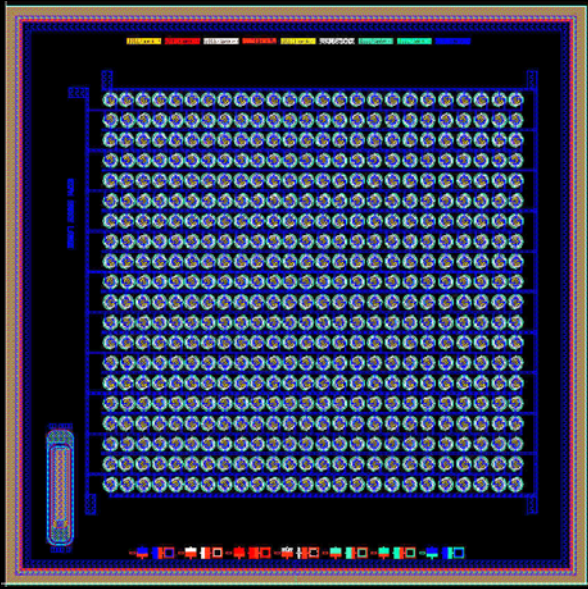


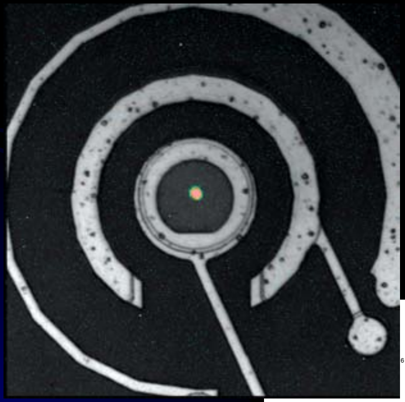


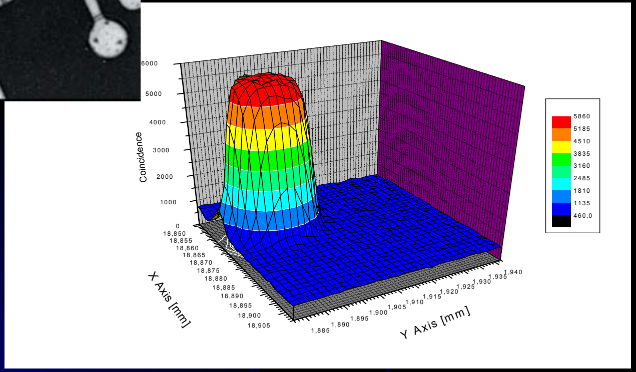
Single pixel structures
Small arrays
Large arrays (20 x 25 pixel 180 μm pitch)
HF diameter: 5-25 μm

Successfully tested



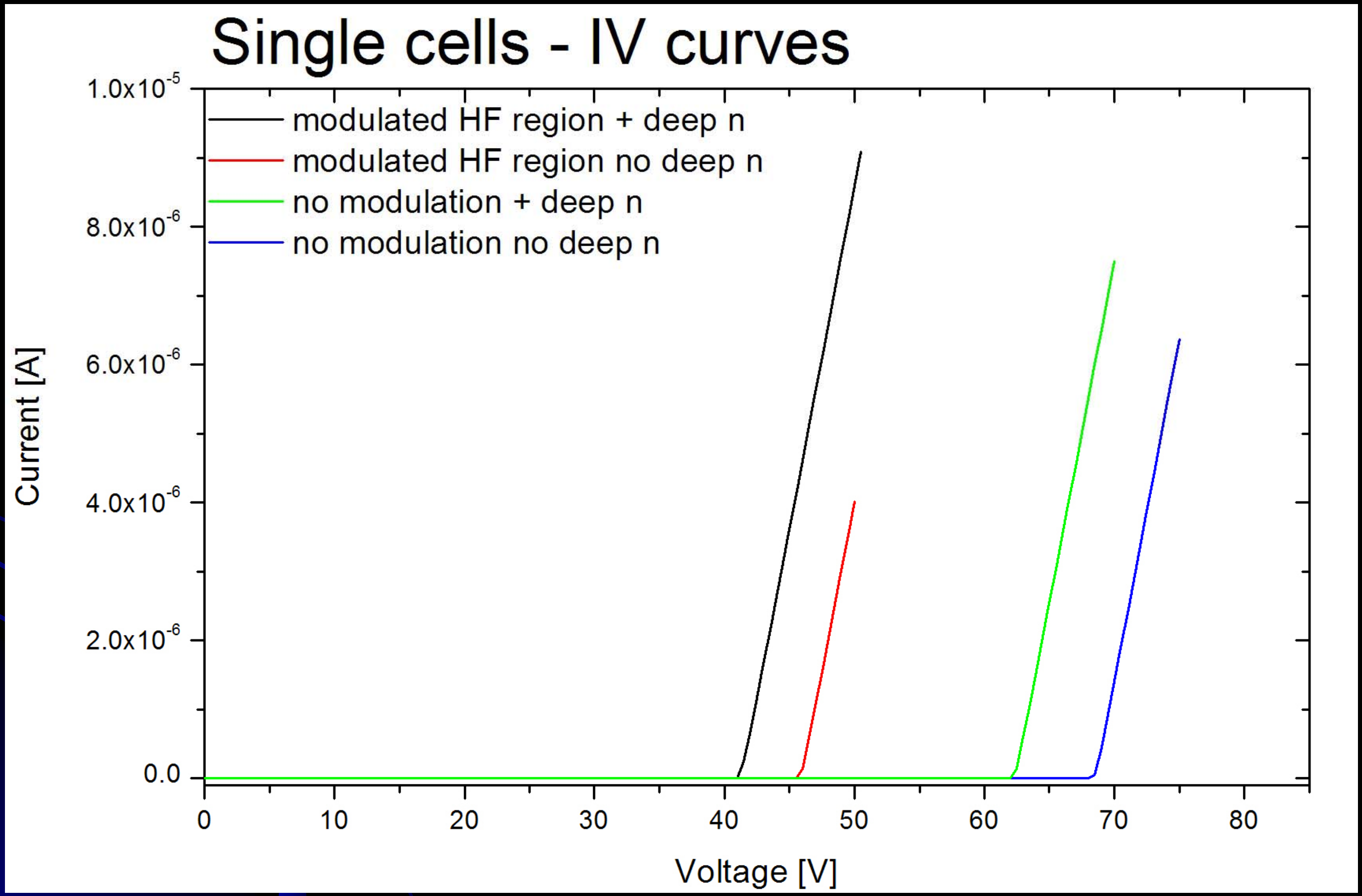






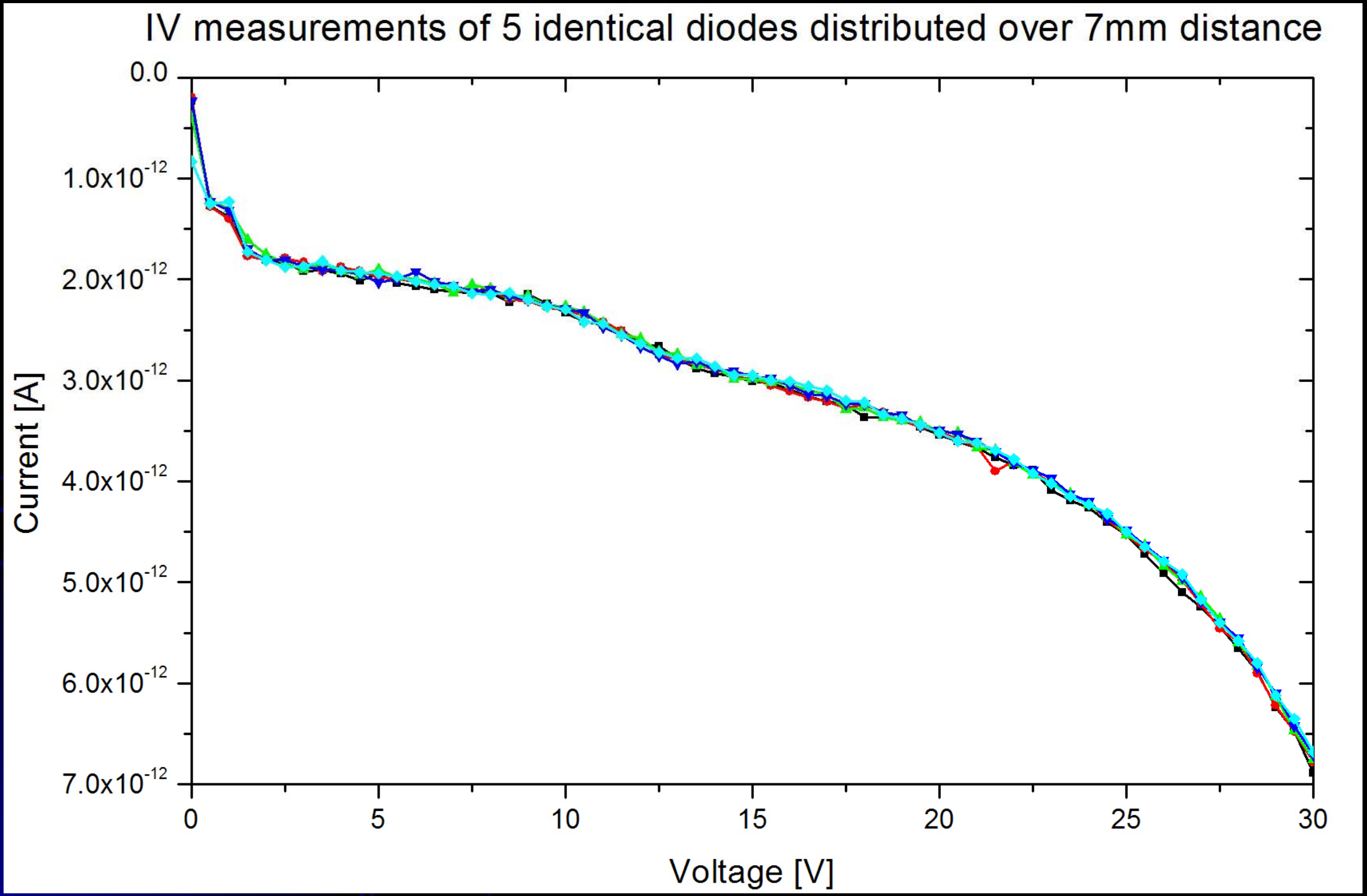
Test structures

Breakdown voltage were expected from simulations



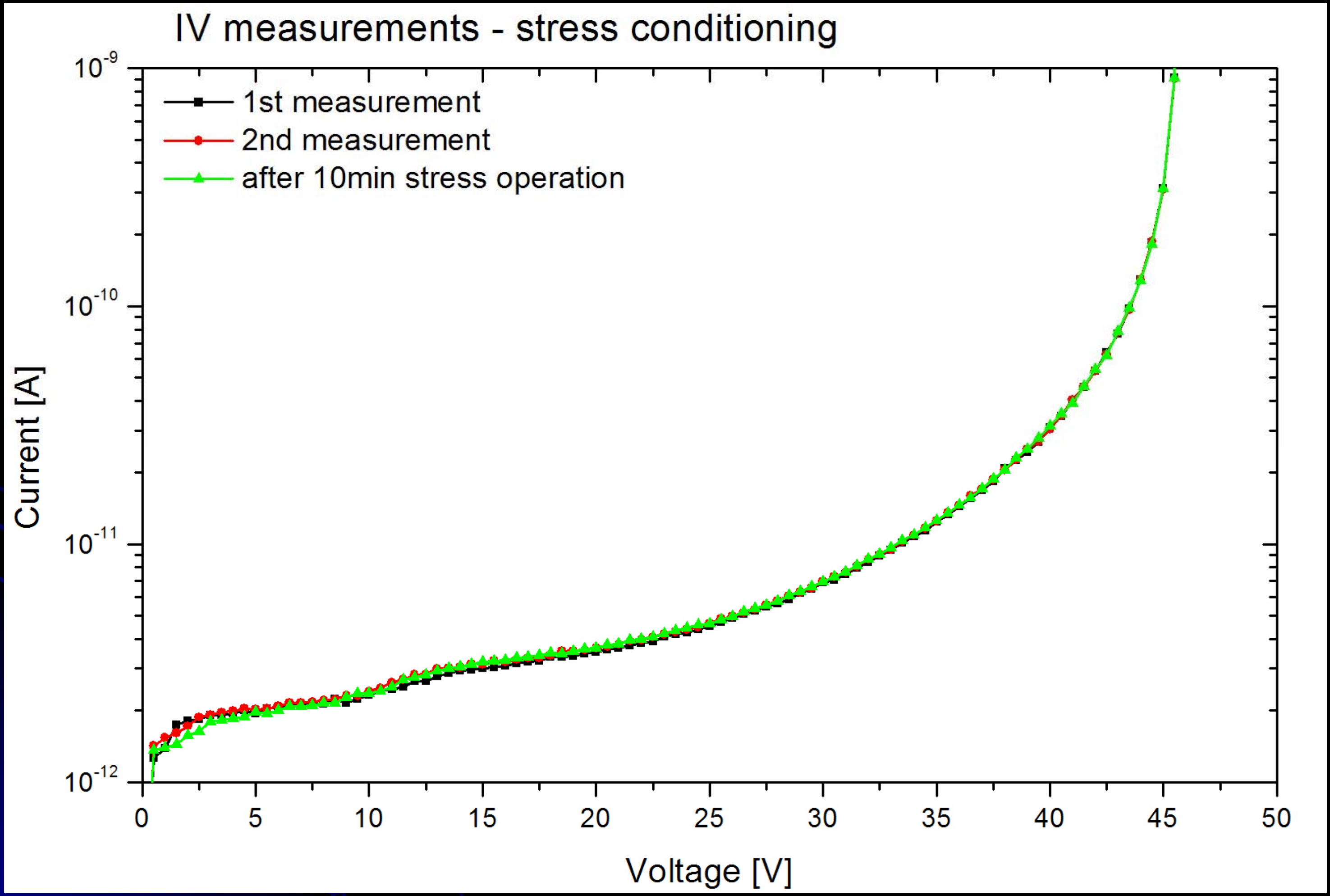
Test structures

- Homogeneity



Test structures

- Stress conditioning

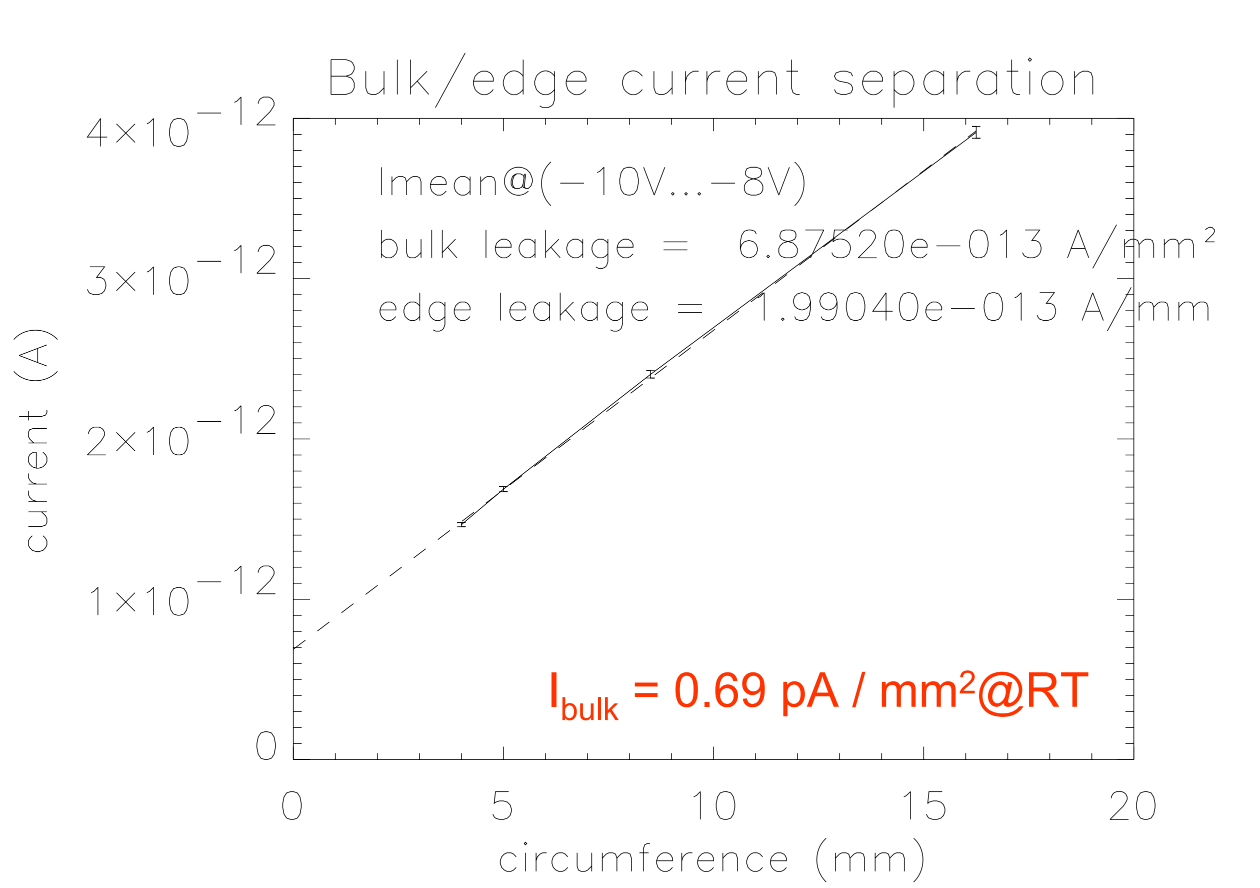


Test structures

Separation of centre and edge currents

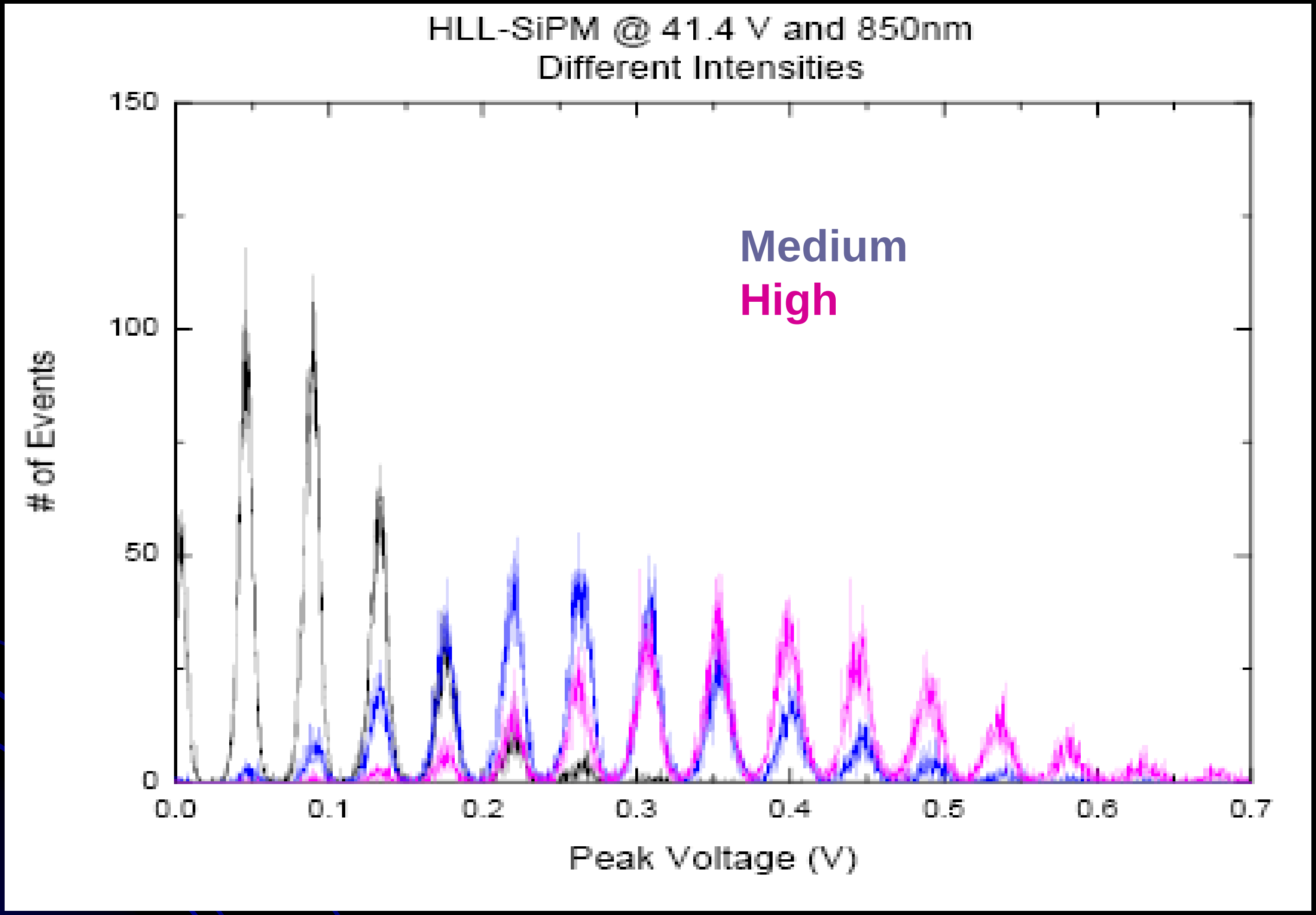
Measurement of many diodes with same area but different circumference allows separation of the bulk leakage current
I@0mm → Ibulk

Constant area: 1mm²
Different circumferences:
4mm (6x)
5mm (3x)
8.5mm (3x)
16.25mm (2x)



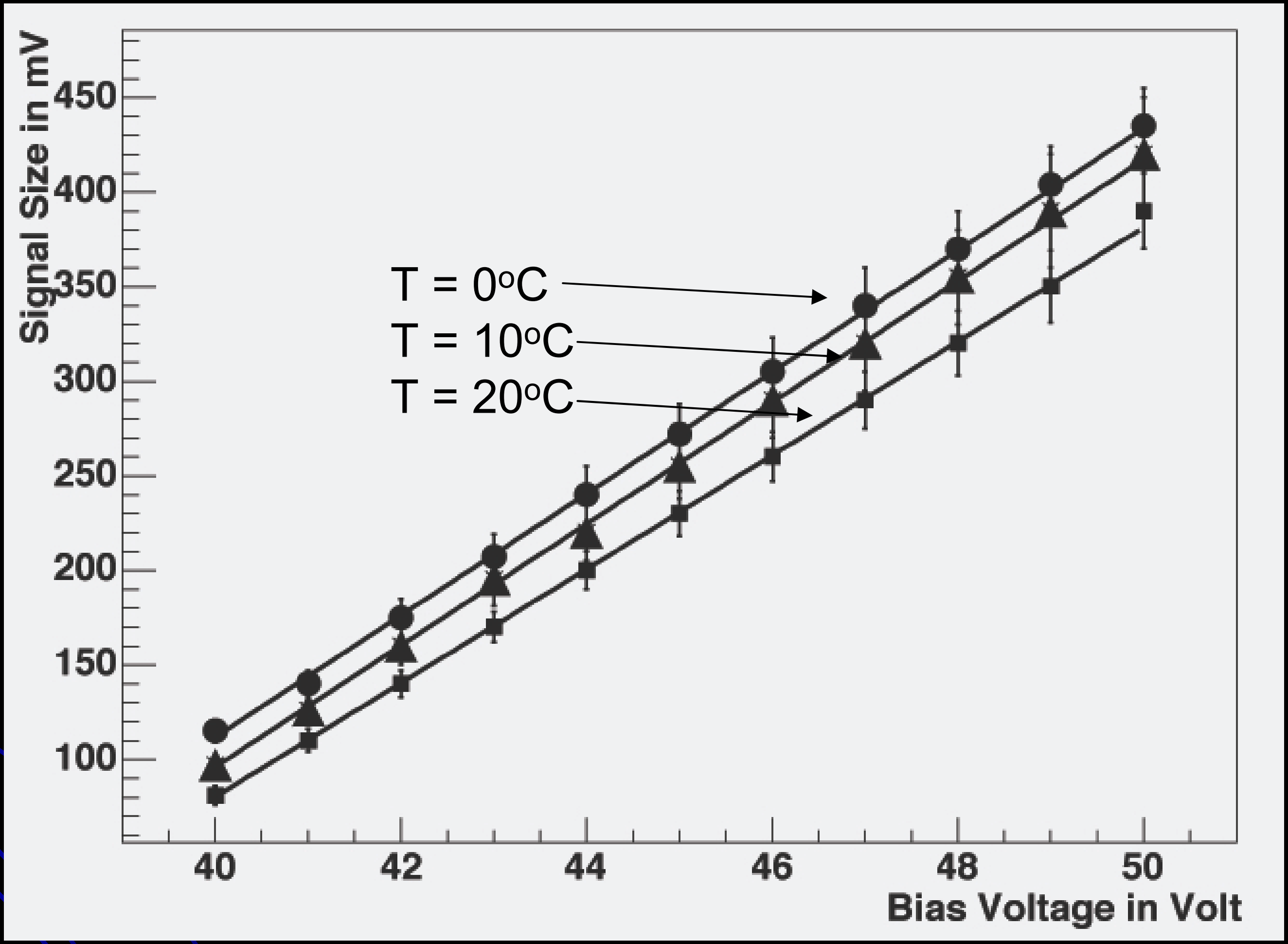
I_{bulk} = 0.69 pA / mm^2@RT

Results: Test Structures



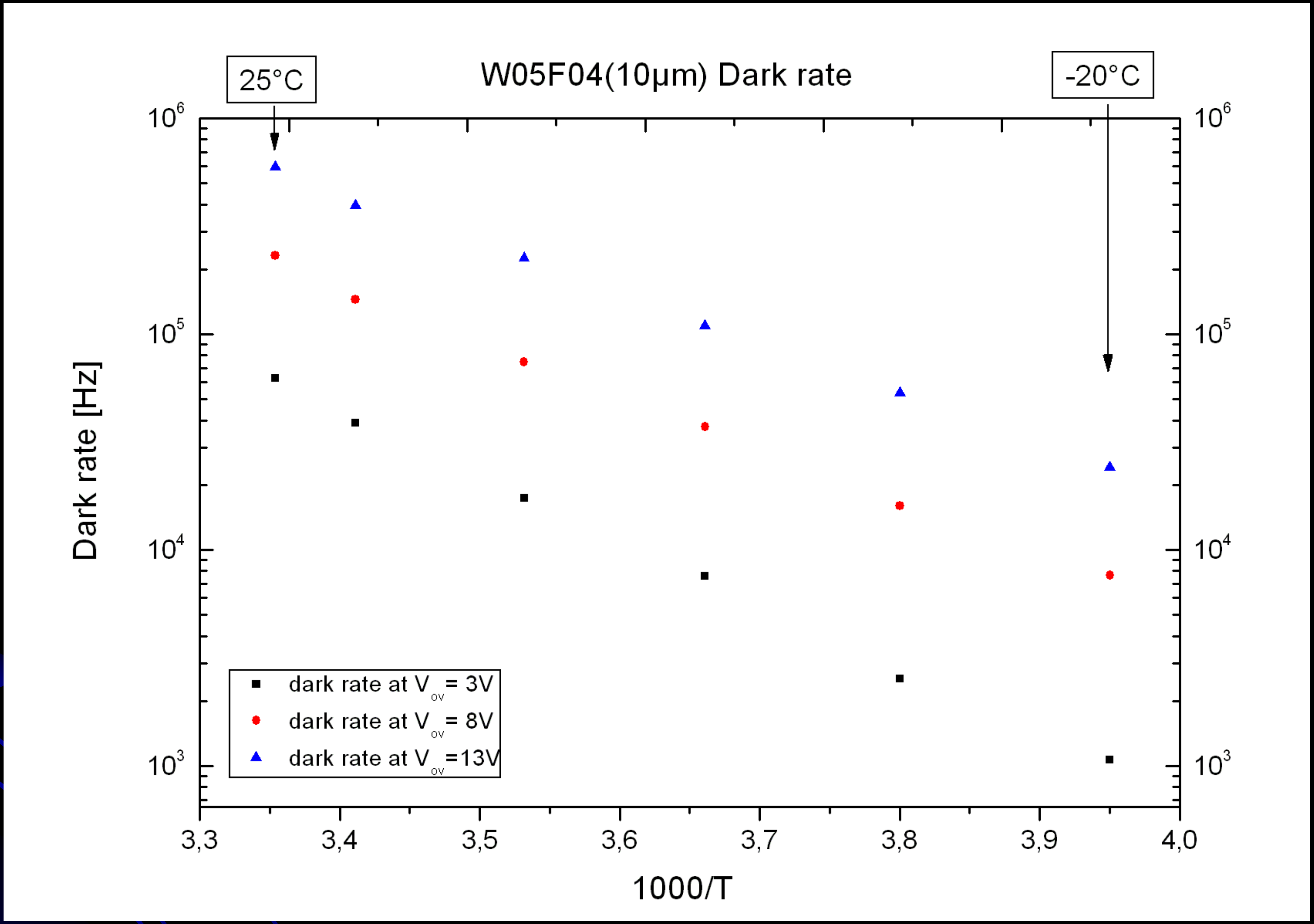
Results with light pulses from a laser (< 1 ns):
Photoelectron peaks clearly resolved up to large n(photon)
RMS of single photoelectron signal ~ 5%

Results: Test Structures



Gain proportional to overvoltage
Breakdown voltage in good agreement with device simulations

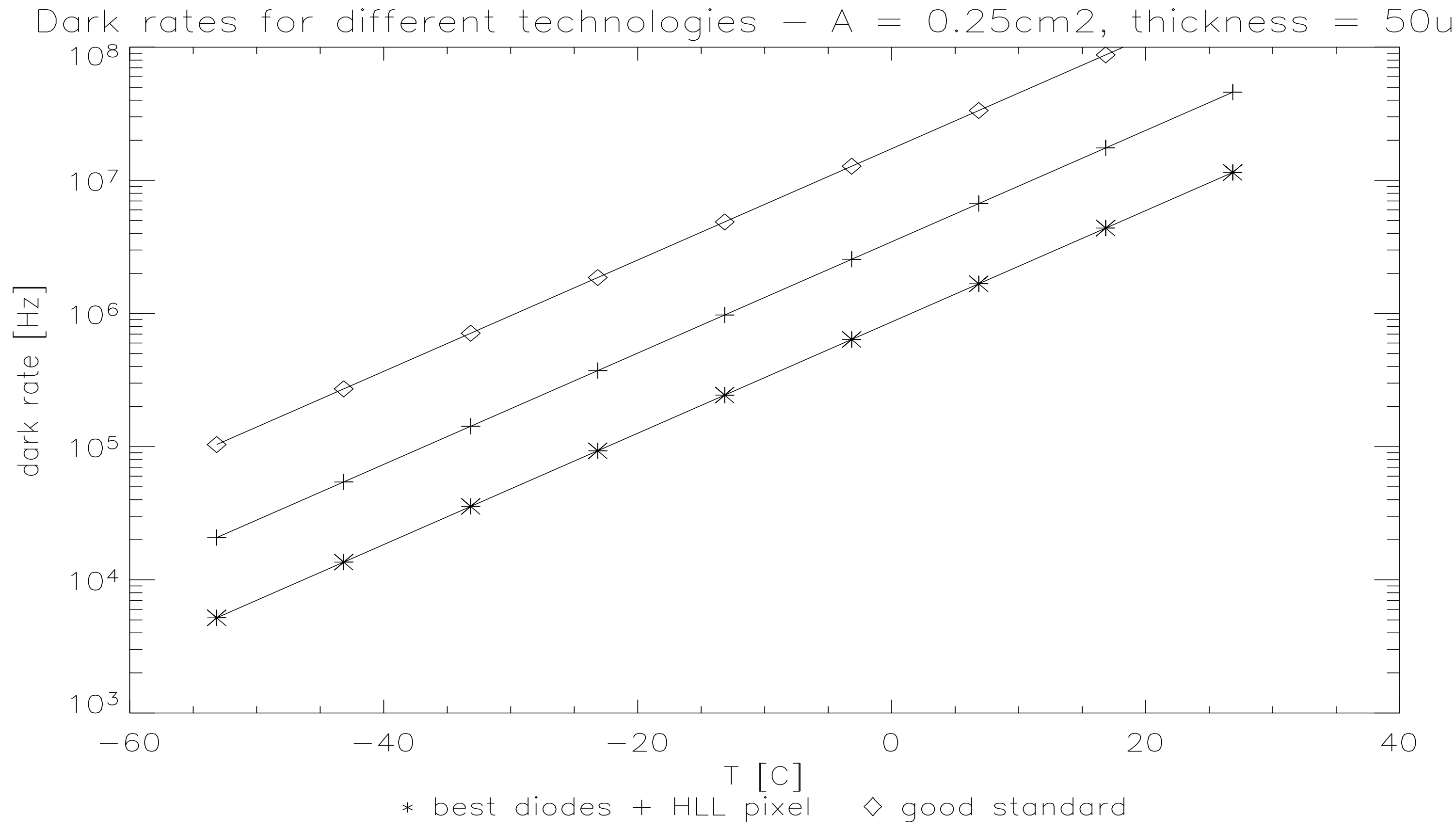
Test Structures



Dark rate mainly from highly doped HF region:
For a 5 x 5 mm^2 matrix with 500 pixels: ~0.2 MHz @ 20^{o}C (8V)

Leakage Currents and Dark Rates

Back side illuminated: bulk leakage current dominates:



For devices thinned to 50 μm: **~10MHz @ 20ºC**

Cooling needed: **~ 1 MHz @ 0ºC**

Cross Talk Studies

Dark spectrum of 25 μm arrays

x-talk heavily suppressed due to small HF region and large pitch

Background due to pile up (suppressed by cooling to -20 C)

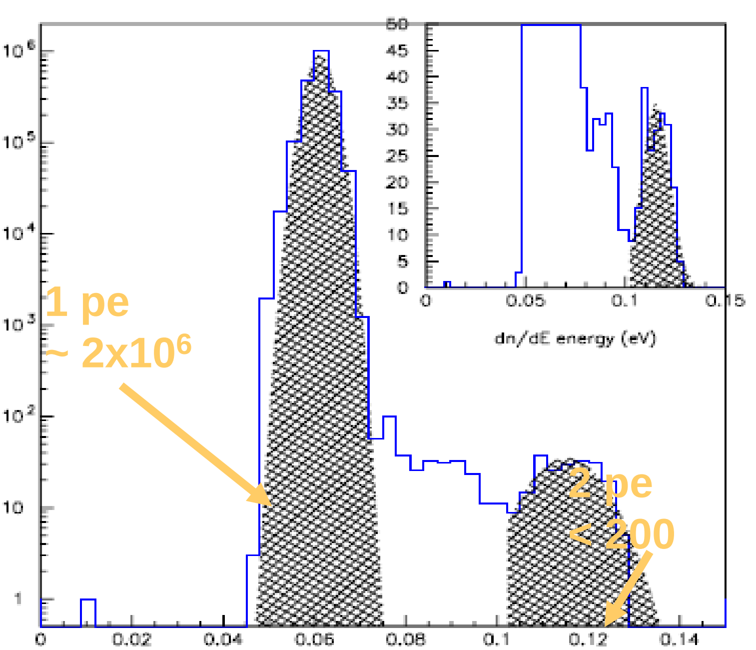
2pe signal clearly visible:

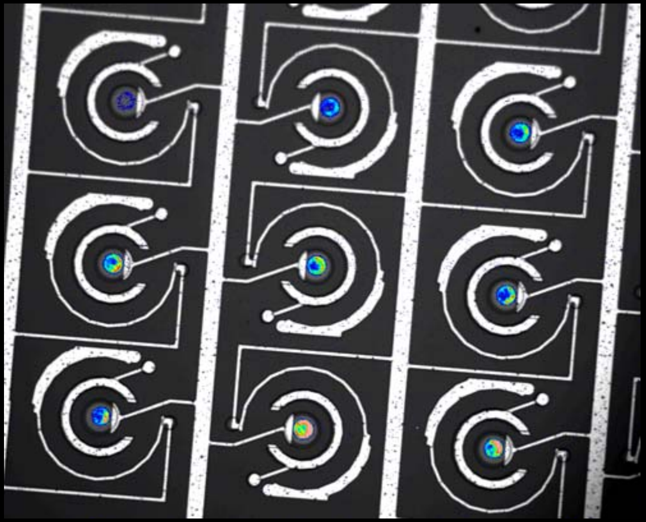
Probability for x-talk ~ 10^{-4} (@*V ΔU)

For backside illumination:

Bulk is sensitive to cross-talk photons

Use MC to extrapolated to full structure





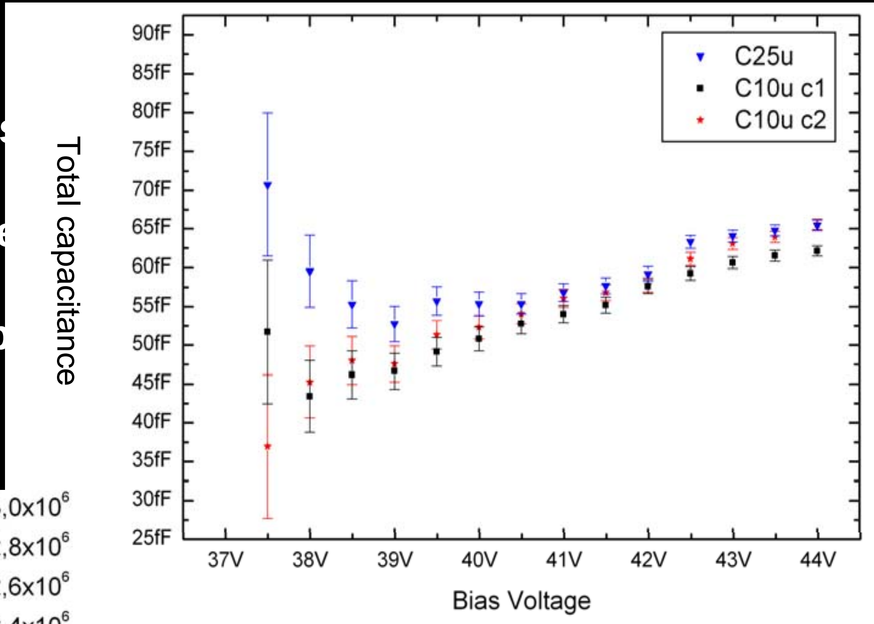
Results

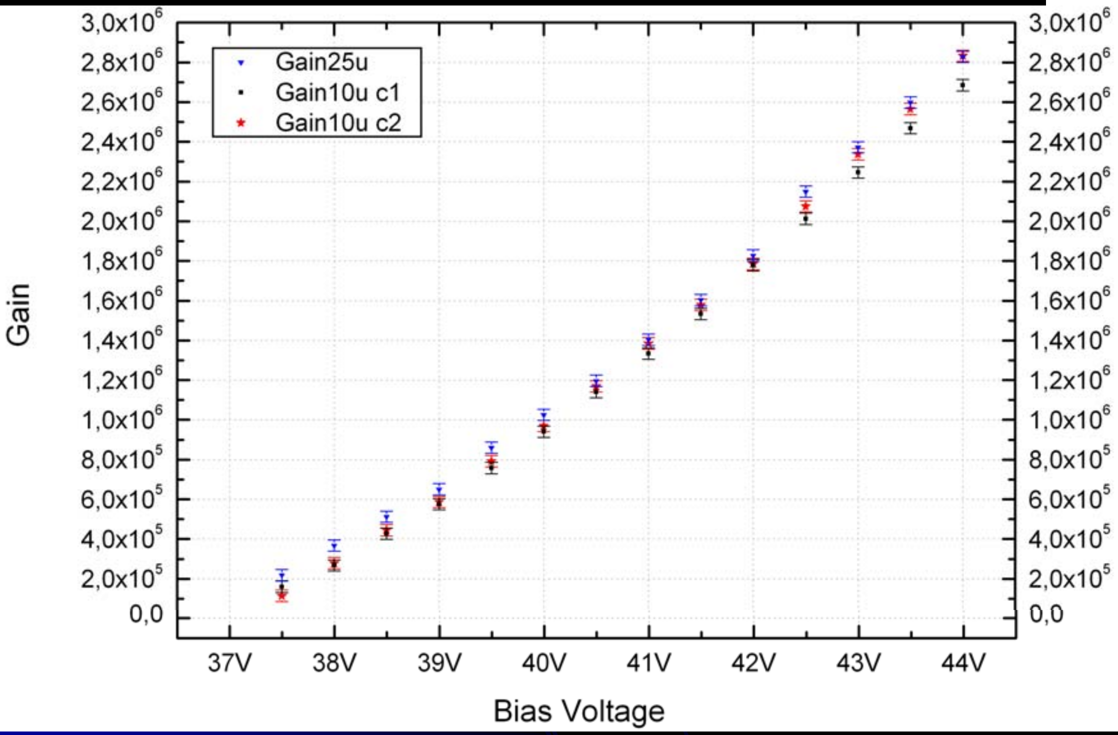
Cross talk measured with test structures implies

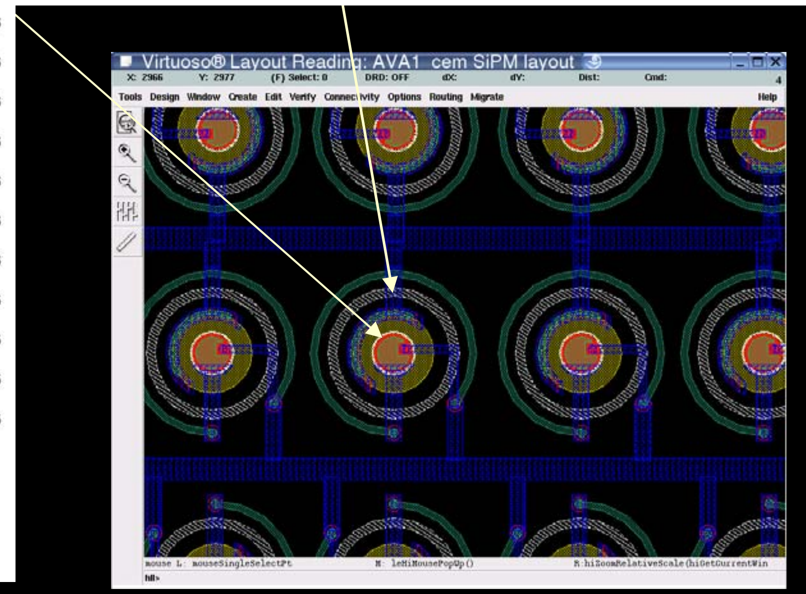
~54 photons (E>1.14 eV) per avalanche

For a backside illuminated device with 100 μm p

cross-talk probability: 99.99%



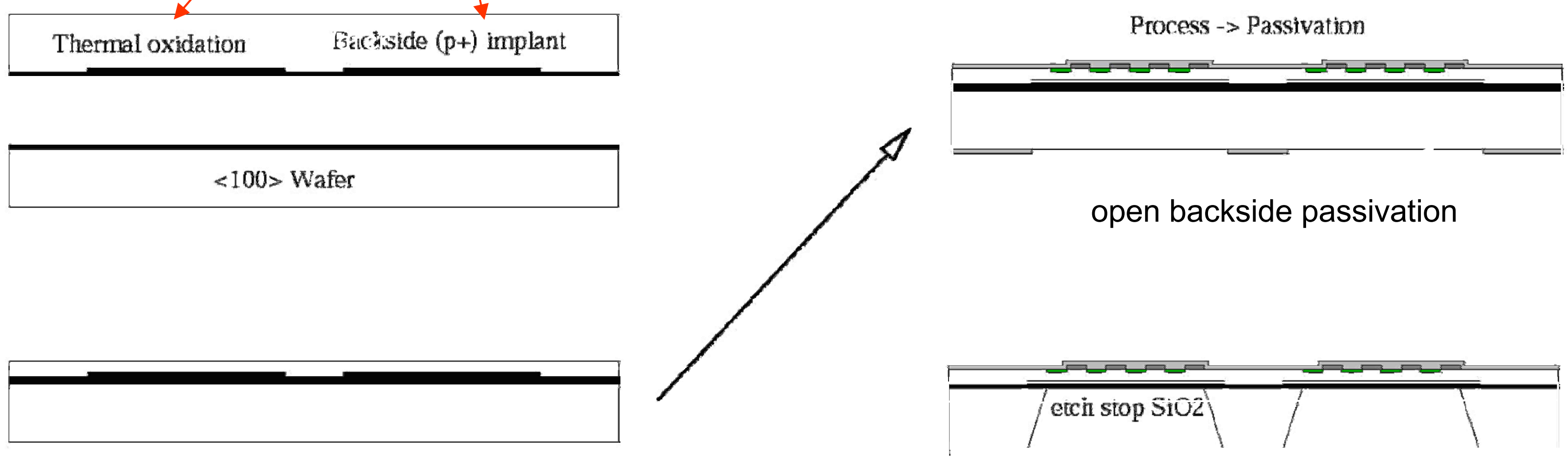




Processing of thin detectors (50 μm)

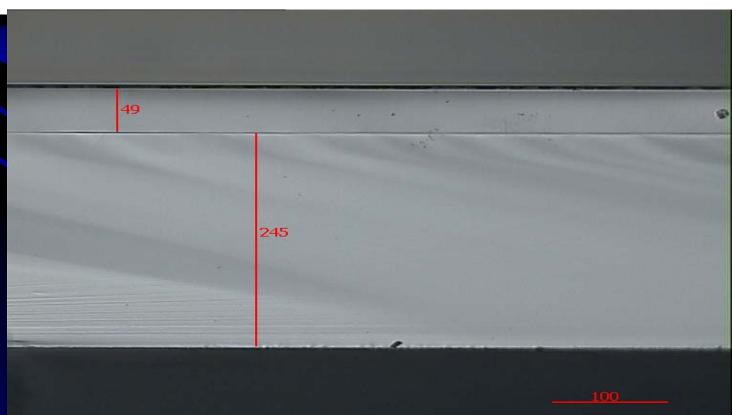
a) oxidation and back side implant of top wafer

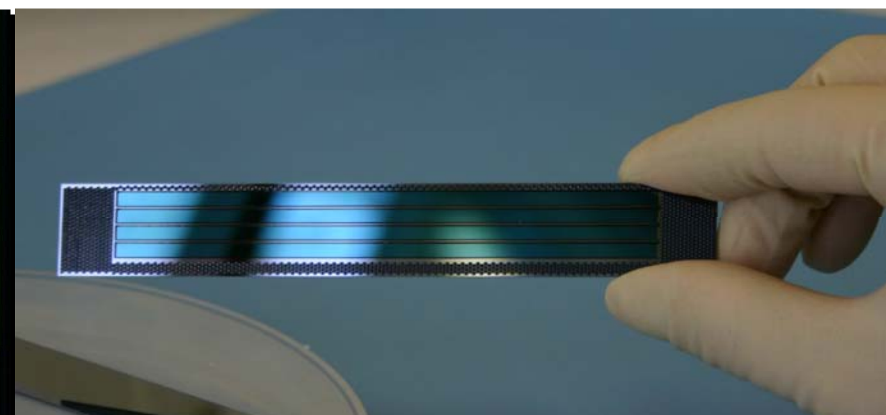
c) process ➔ passivation



b) wafer bonding and grinding/polishing of top wafer

d) deep etching opens "windows" in handle wafer

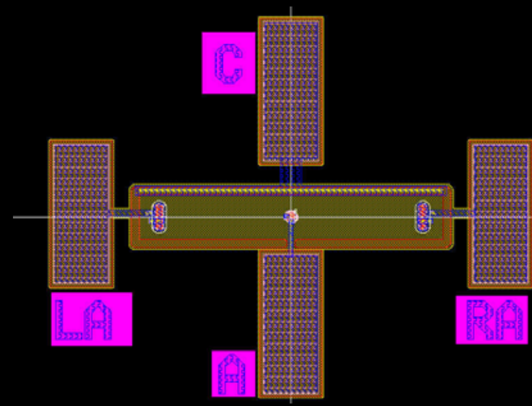


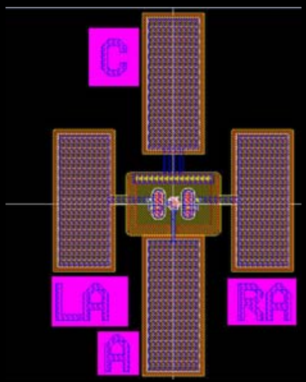


Successfully tested with MOS diodes (keep low leakage current ~ 100 pA/cm^2)

Next steps …

production of fully functional backside illuminated drift SiPMs:

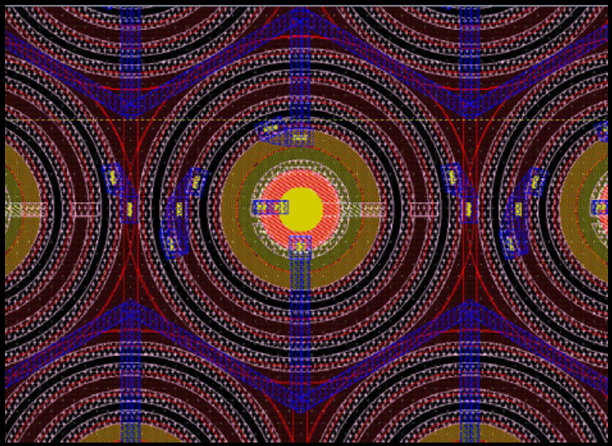


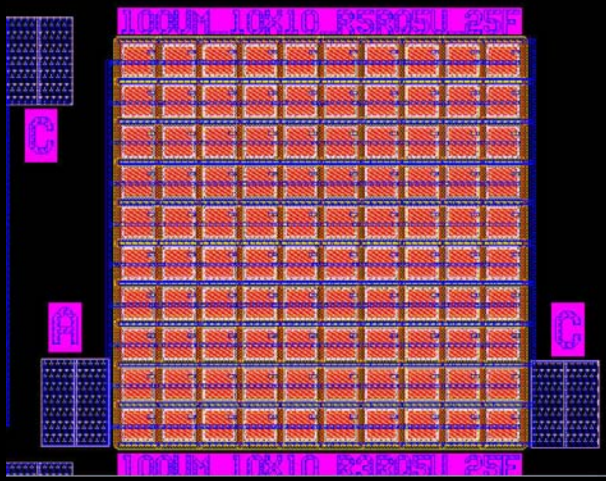


-> including drift rings
-> double sided processing,
   deplete bulk

Finished: End 2007

Various test structures
(single pixels, small arrays)





Arrays:
30 x 31 pixel
Diameter HF region: < 8 μm
Pitch: 100, 120, 150, 200 μm
Area: 3x3 mm^2 – 6x6 mm^2

In addition: some front illuminated arrays

Thanks