



13TH INTERNATIONAL “HIROSHIMA” SYMPOSIUM ON THE DEVELOPMENT AND APPLICATION OF SEMICONDUCTOR TRACKING DETECTORS

**MARTHA - MONOLITHIC ARRAY OF REACH
THROUGH AVALANCHE PHOTO DIODES**

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J. Ninkovic, G. Schaller,
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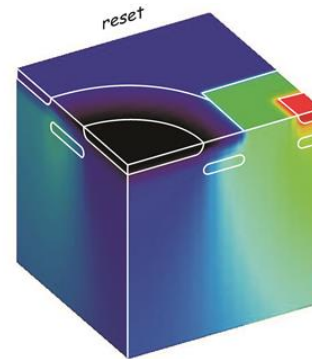
New Building

- IPP Campus Garching
- currently moving



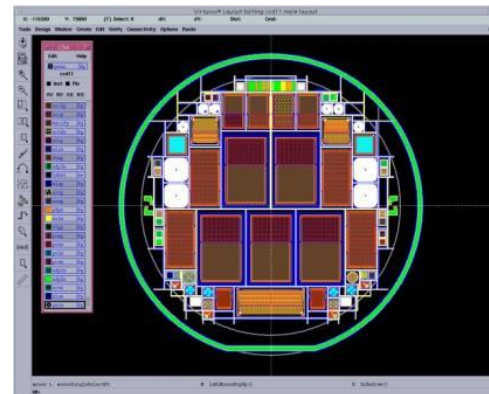
- 1500 m² cleanroom area
- 600 m² ISO3 & ISO4 area
- 6/8 inch silicon process

Central facility of the Max Planck Society
40 scientists, engineers and technicians
+ guest scientists, and students



sensor

- simulation
- design
- fabrication



camera

- design
- assembly
- test



MPG HLL – some examples

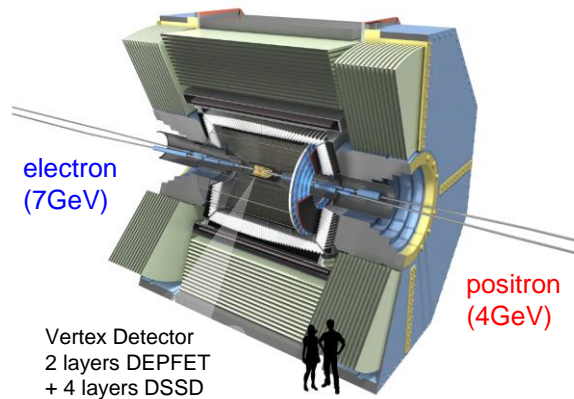


XMM-Newton



pnCCD
X-ray imaging spectroscopy
curtesy ESA

DePFETs at KEK - Japan



DePFET for particle tracking
curtesy Belle2 collaboration

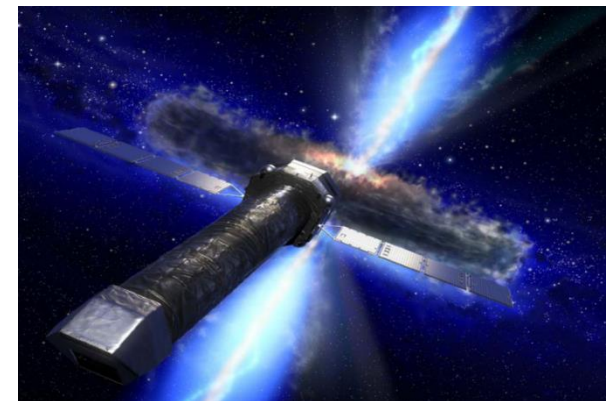
We also produce
-SDD (silicon drift detectors)
-Diodes
-Avalanche Diodes
-Strip Detectors
-etc.

MIXS on BepiColombo



DePFET -planetary science
curtesy ESA

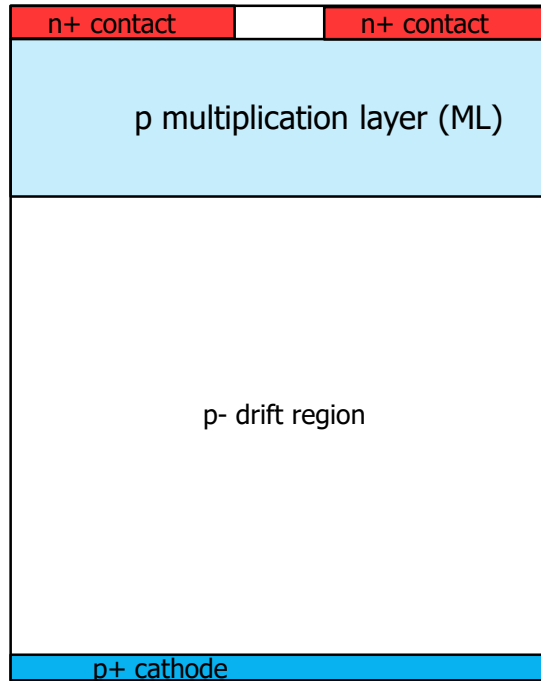
WFI on Athena



DePFET - X-ray imaging spectroscopy
curtesy ESA



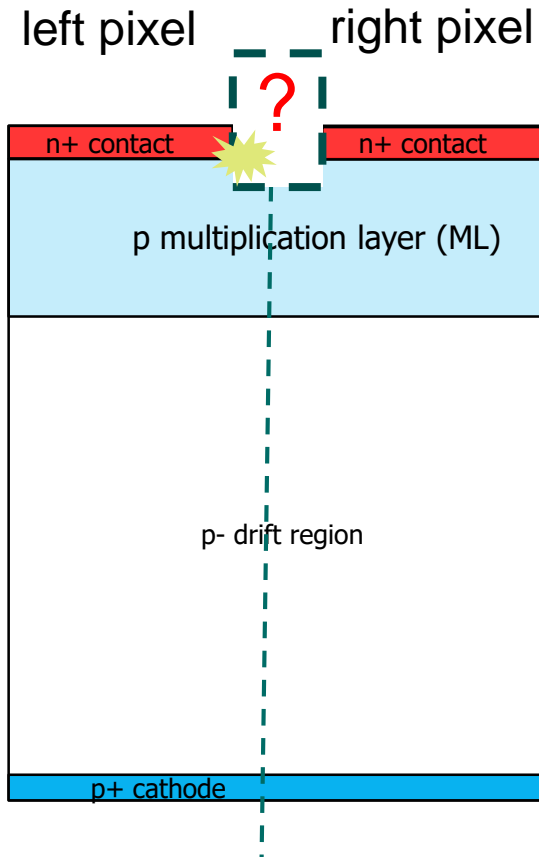
left pixel right pixel



(Soft X-ray) Photon Counting

For applications at FELs

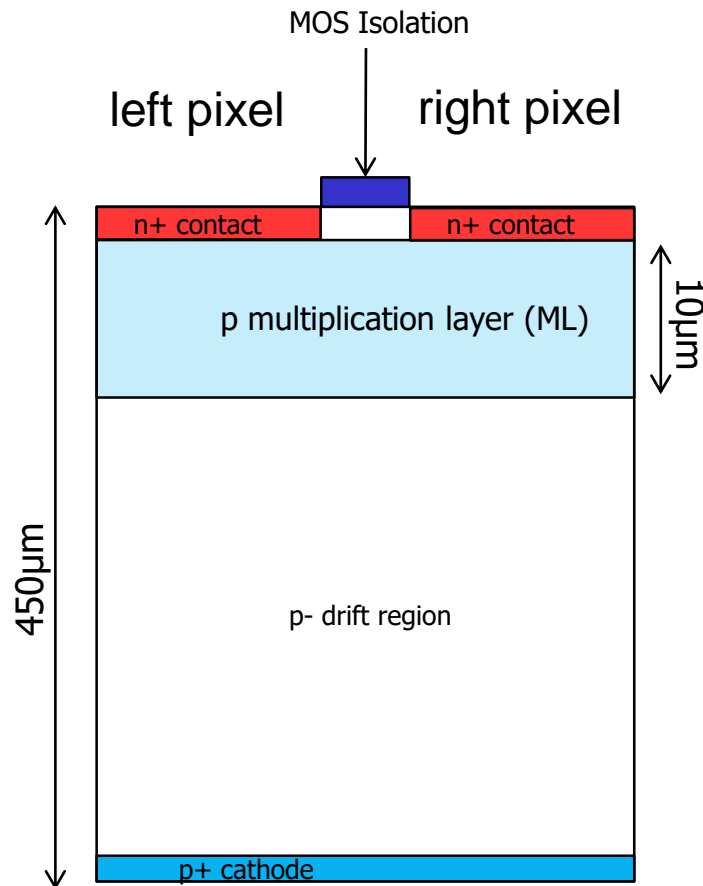
- **(HLL) thin entrance window + avalanche multiplication**
- **homogeneous gain**
- **high k-factor (low excess noise)**



Interpixel isolation requirements

- Isolation
- Suppress edge break down
- Reduction of E-fields at interface (oxide charge up, H-bond cracking)

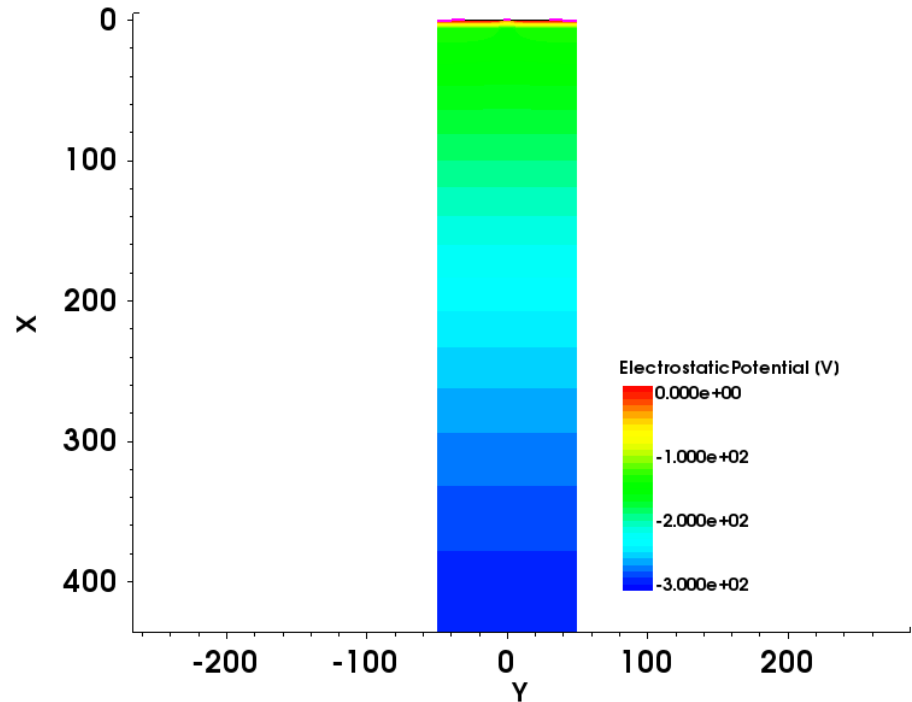
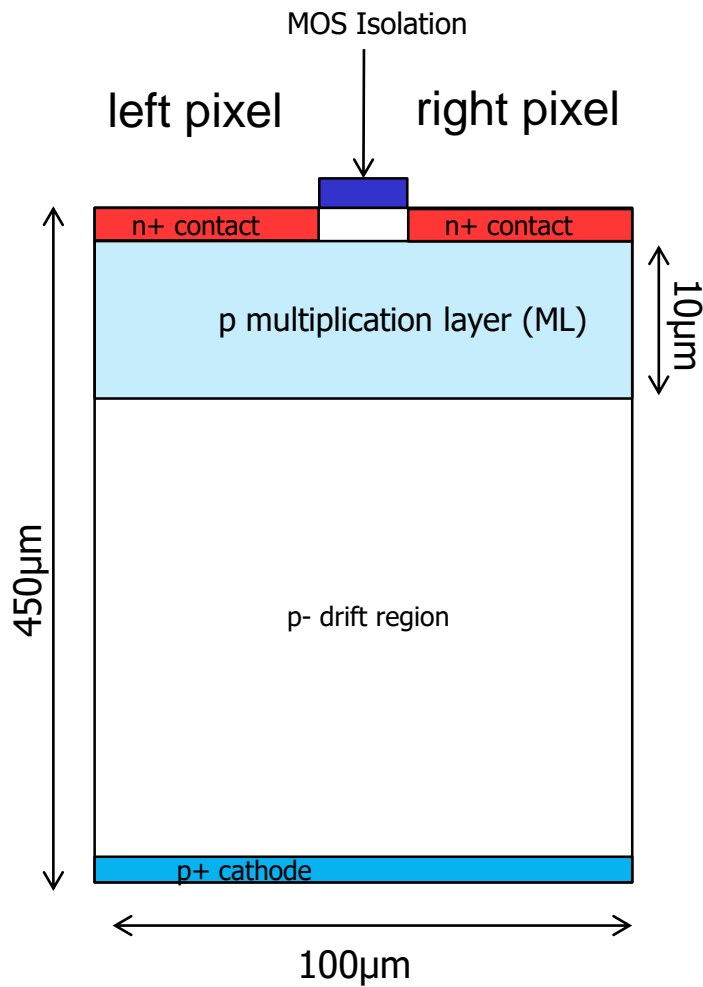
STRIP ARRAY 50 μm PITCH (2D SIMULATION)



- **Reach-through APD**
- **50 μm pitch**
- **MOS isolation**
- **Based on HLL „standard“ technology**

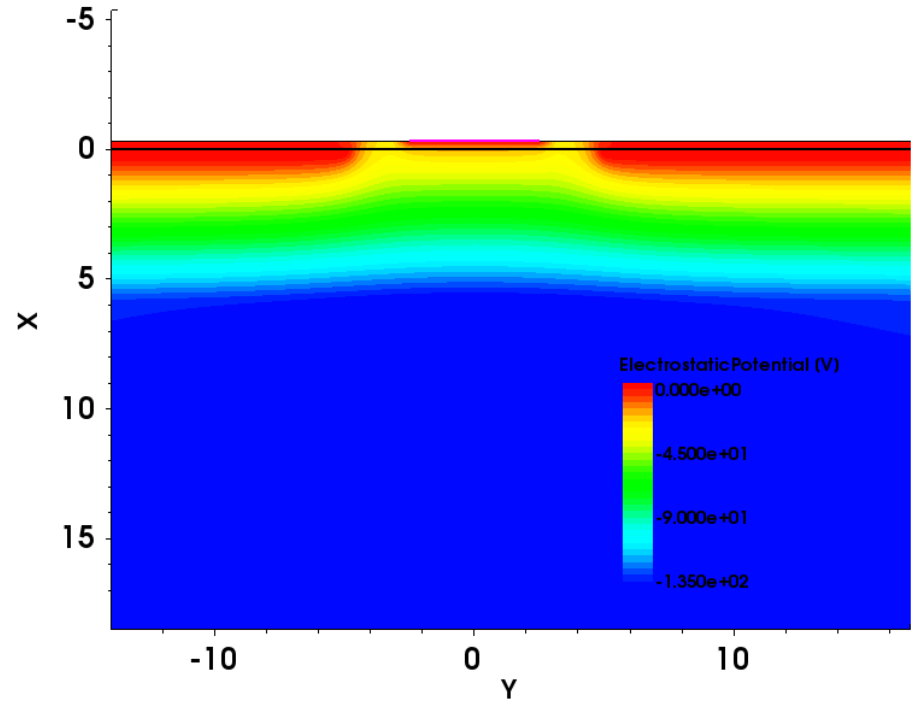
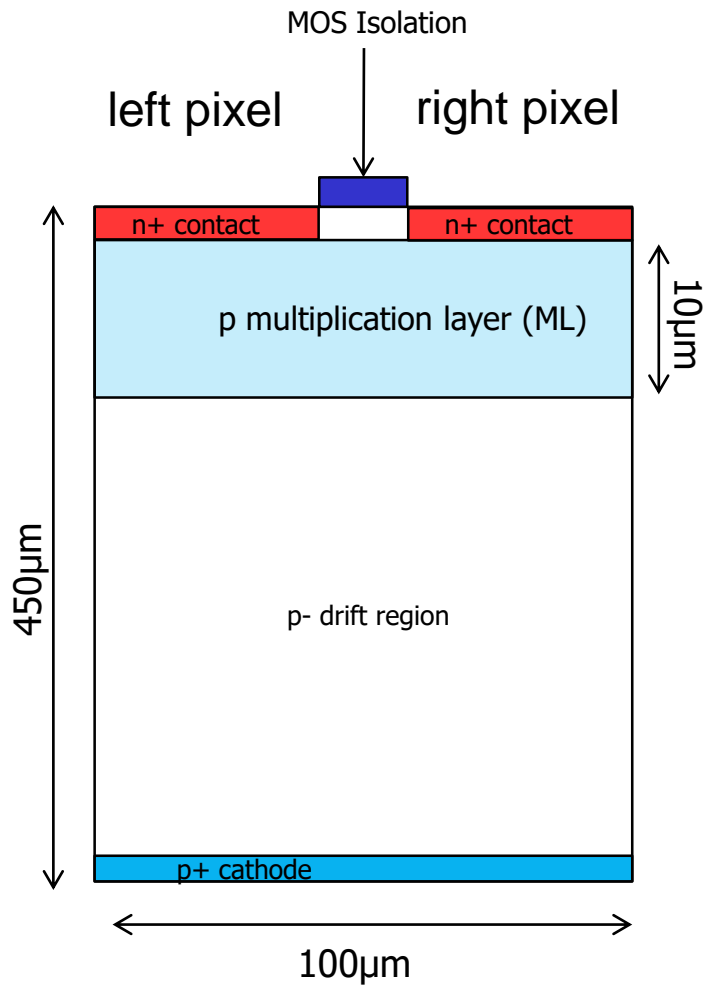
HF region extends over pixel gaps

STRIP ARRAY (2D SIMULATION)



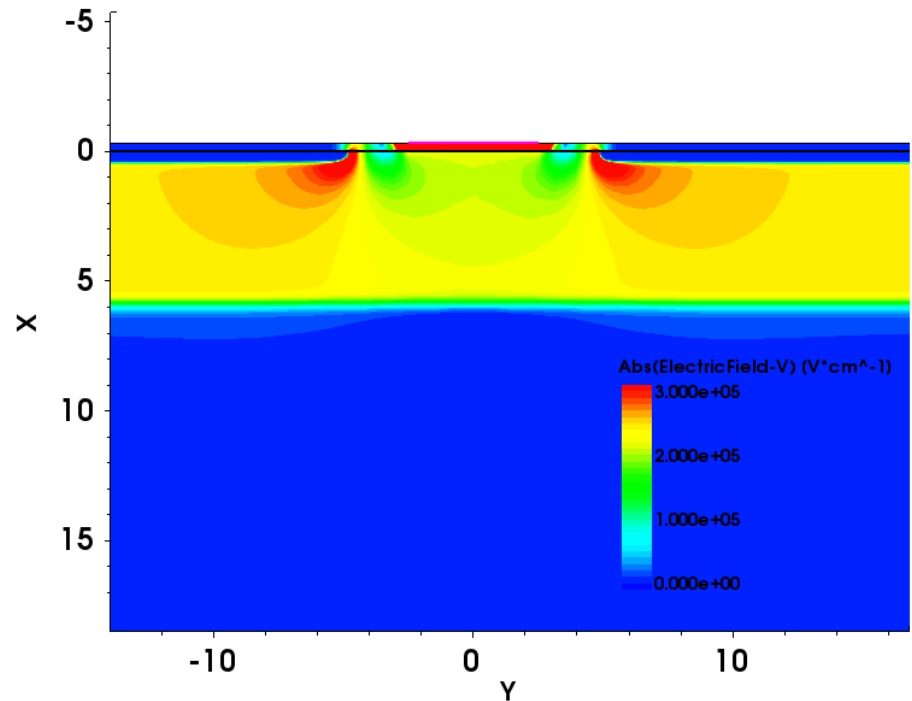
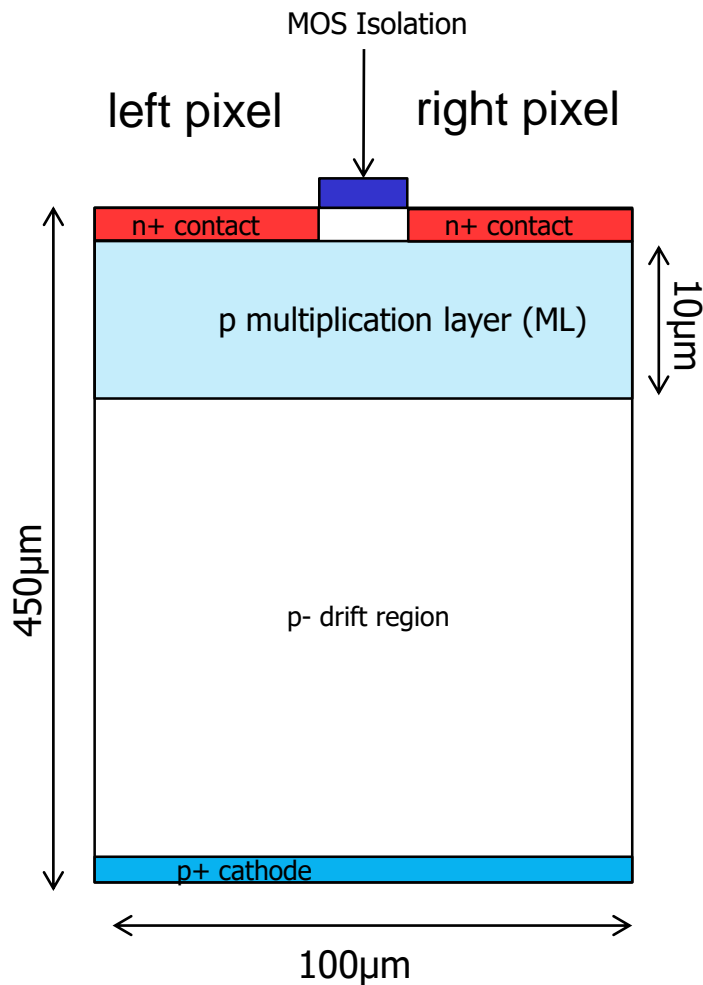
HF region extends over pixel gaps

STRIP ARRAY (2D SIMULATION)



HF region extends over pixel gaps

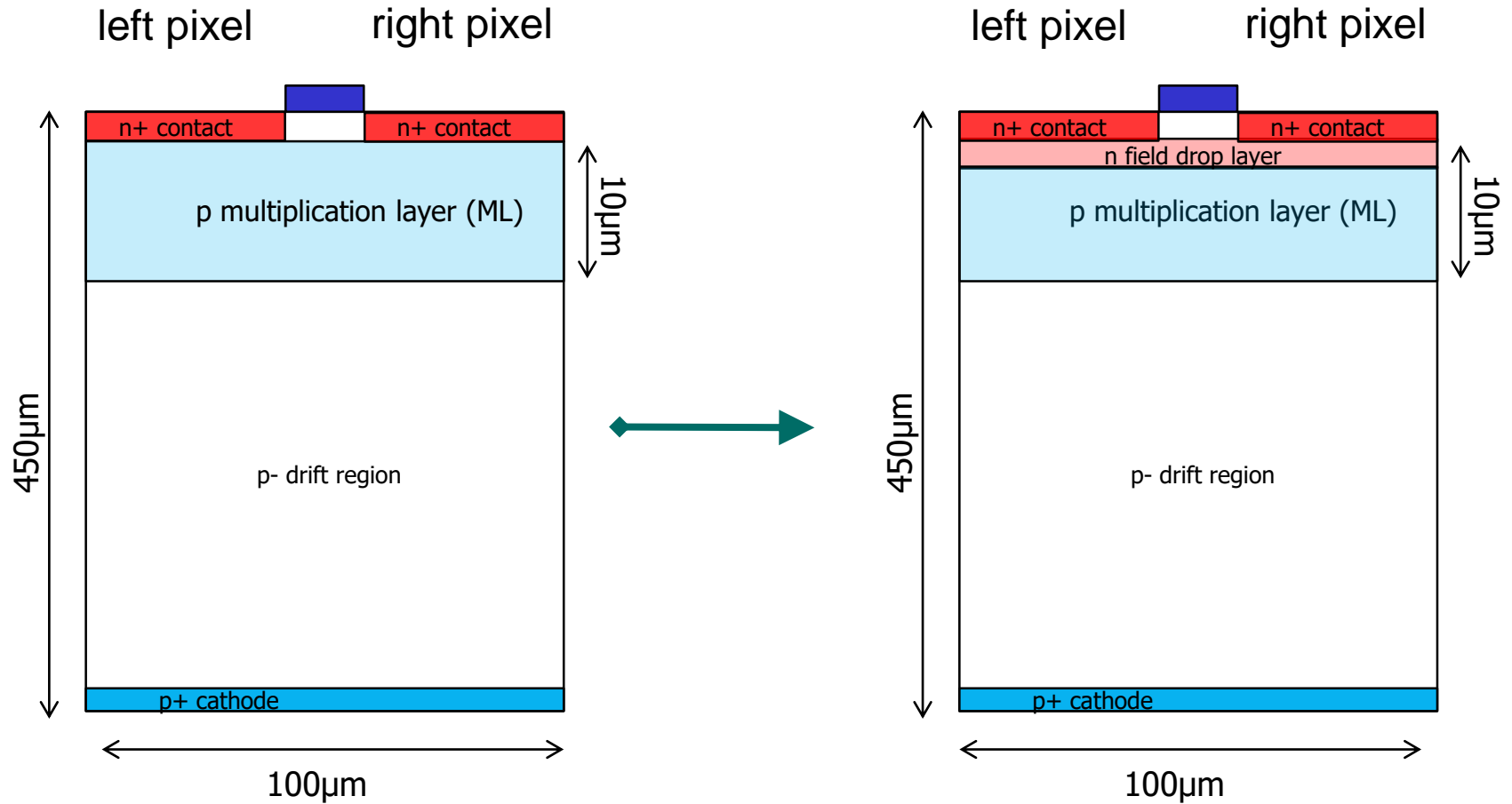
STRIP ARRAY (2D SIMULATION)



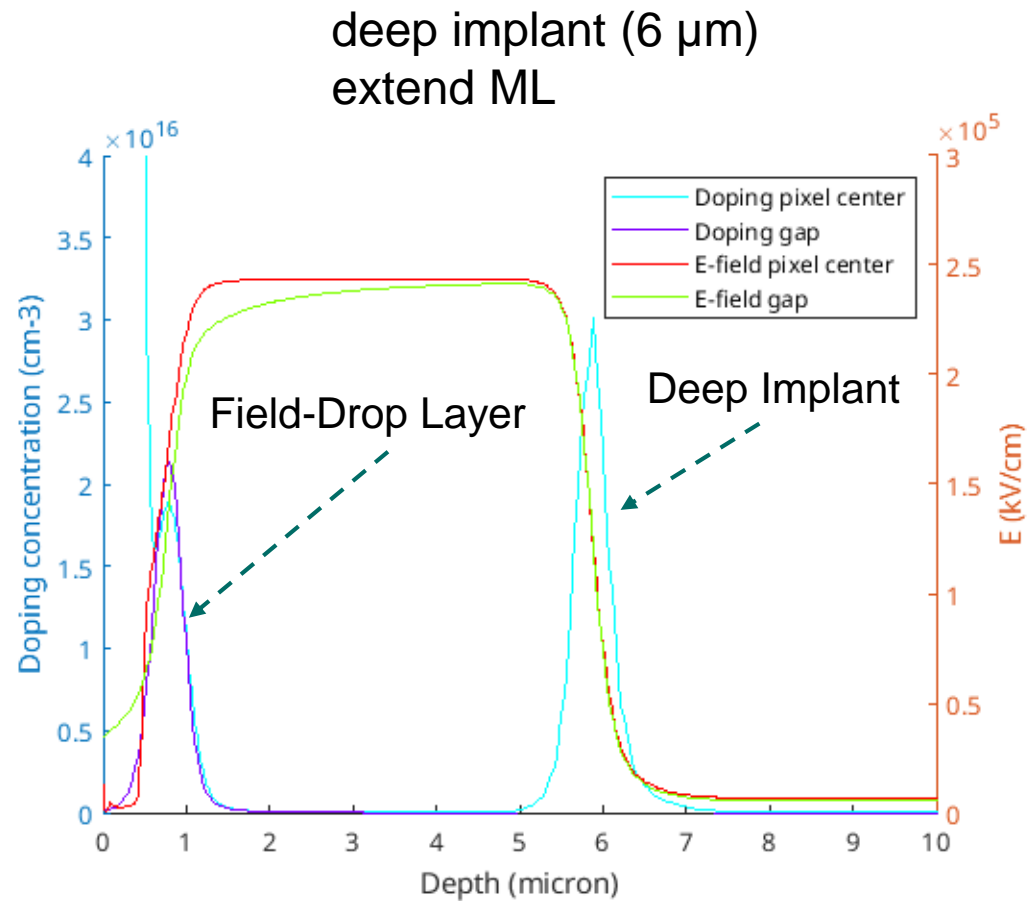
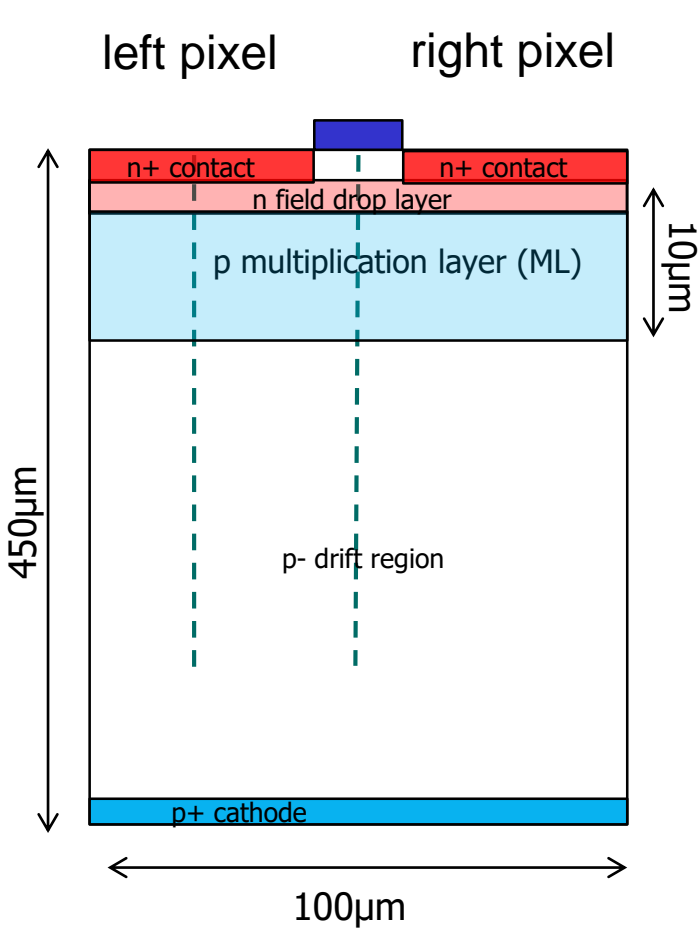
HF region extends over pixel gaps

Avalanche (breakdown) at edges
Approach not usable

2D SIMULATION EDGE BREAKDOWN SUPPRESSION



EDGE BREAKDOWN SUPPRESSION

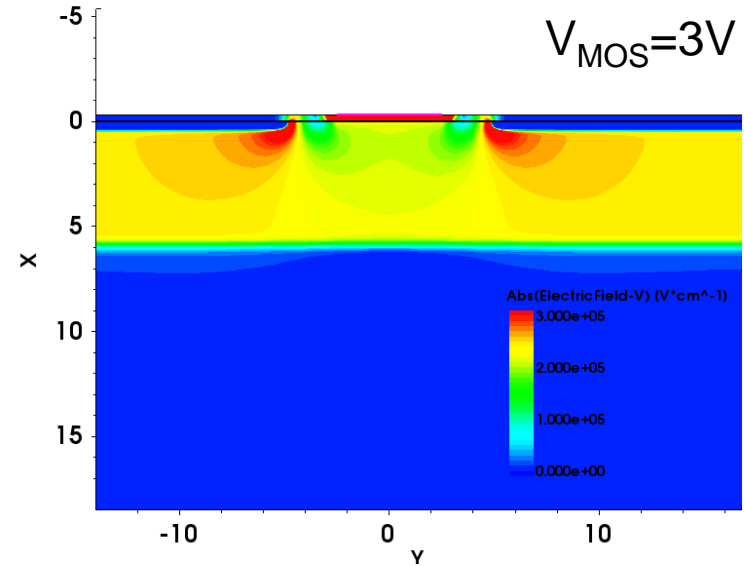
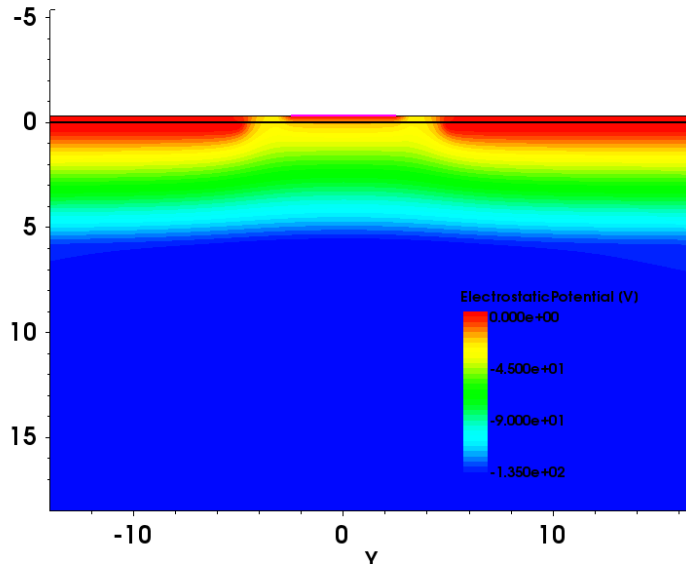


2D SIMULATION EDGE BREAKDOWN SUPPRESSION

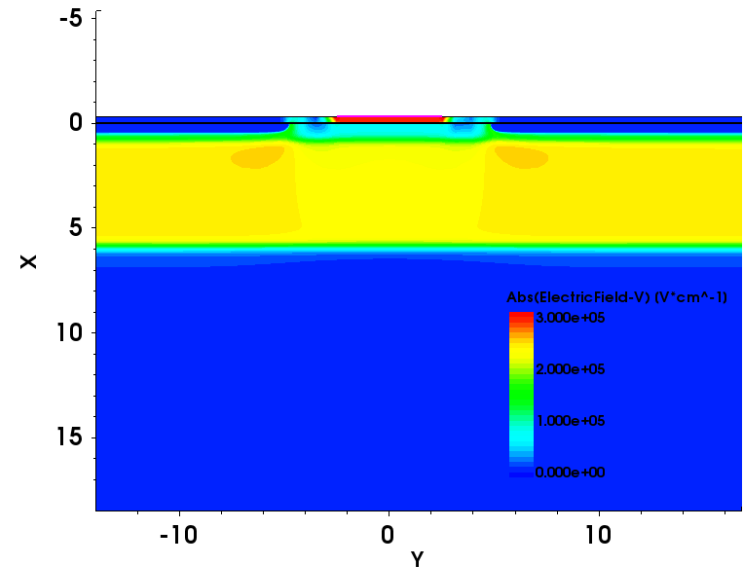
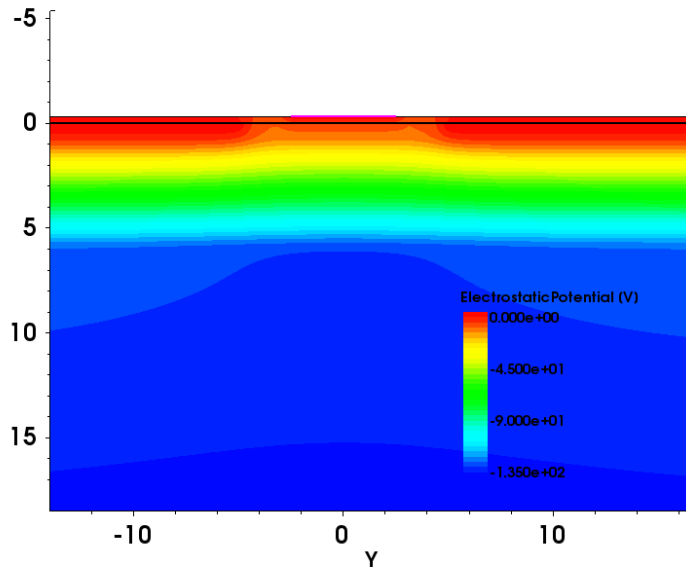


$V_{MOS}=3V$

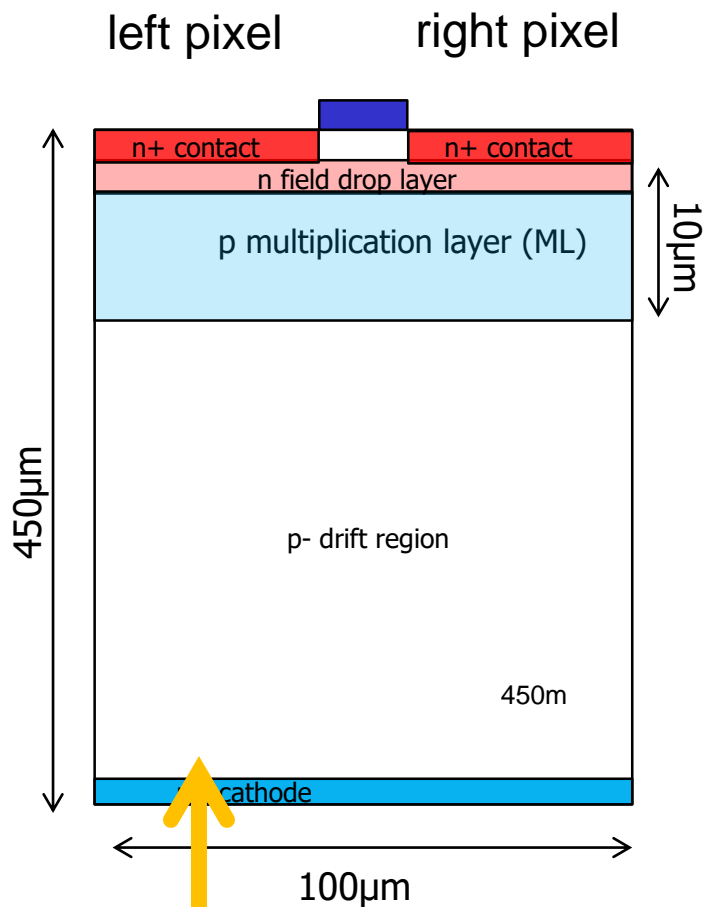
HF region
extends over \times
pixel gaps



HF region and
field drop layer
extend over
pixel gaps

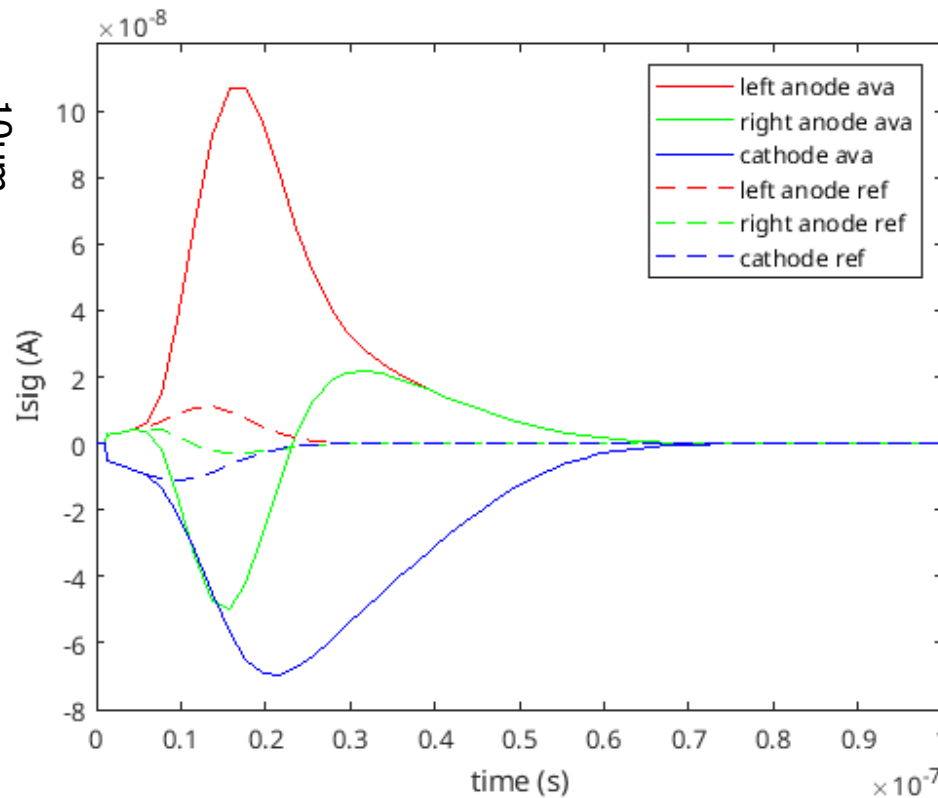


SIMULATED SIGNAL EVOLUTION (CURRENT)



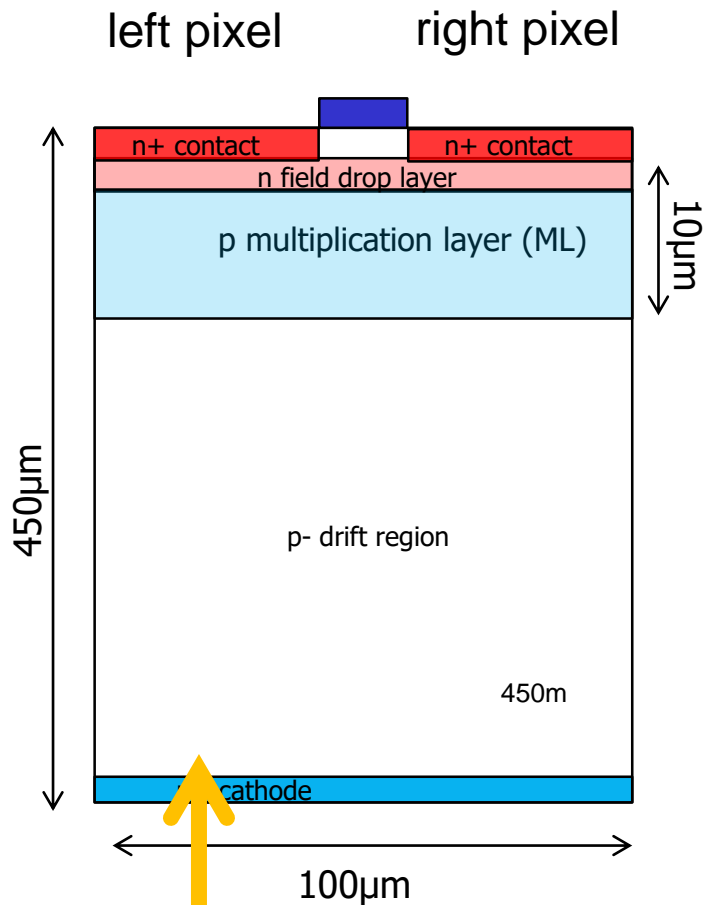
generate test charge
 $Q_{test} = 1.3 \times 10^{-16} \text{ C}$

solid - with avalanche
 dashed - without avalanche



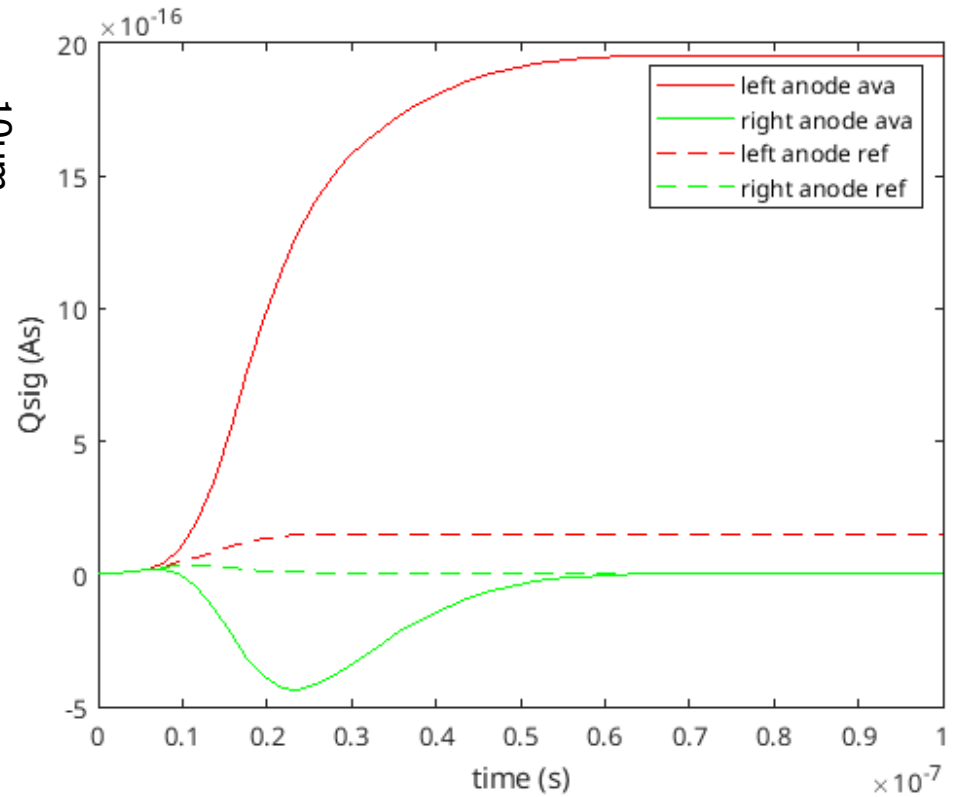
full signal formed faster in reference structure
 (generated drift to backside)
 ‘anti cross talk’

SIMULATED SIGNAL EVOLUTION (CHARGE)



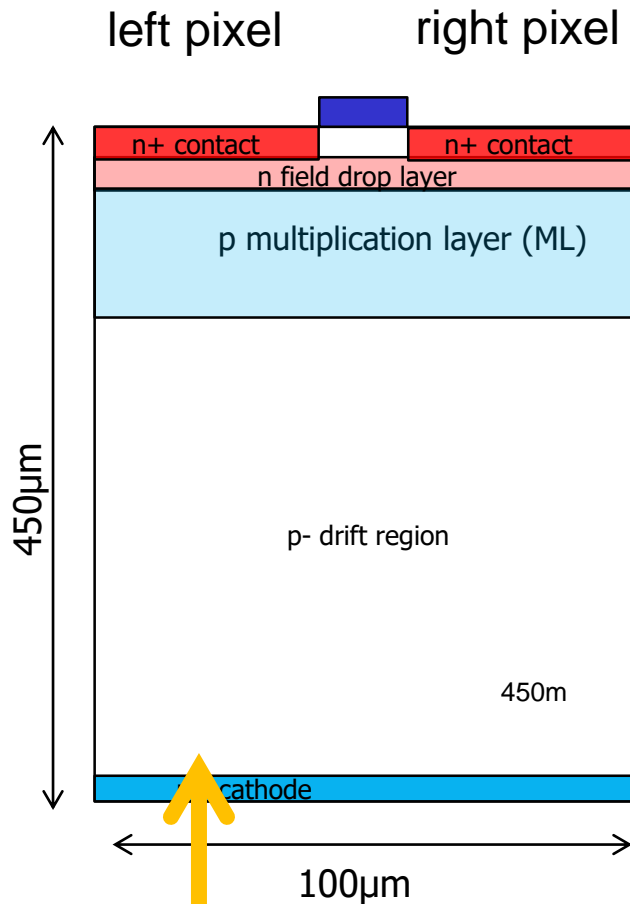
generate test charge
 $Q_{test} = 1.3 \times 10^{-16} \text{ C}$

solid - with avalanche
dashed - without avalanche



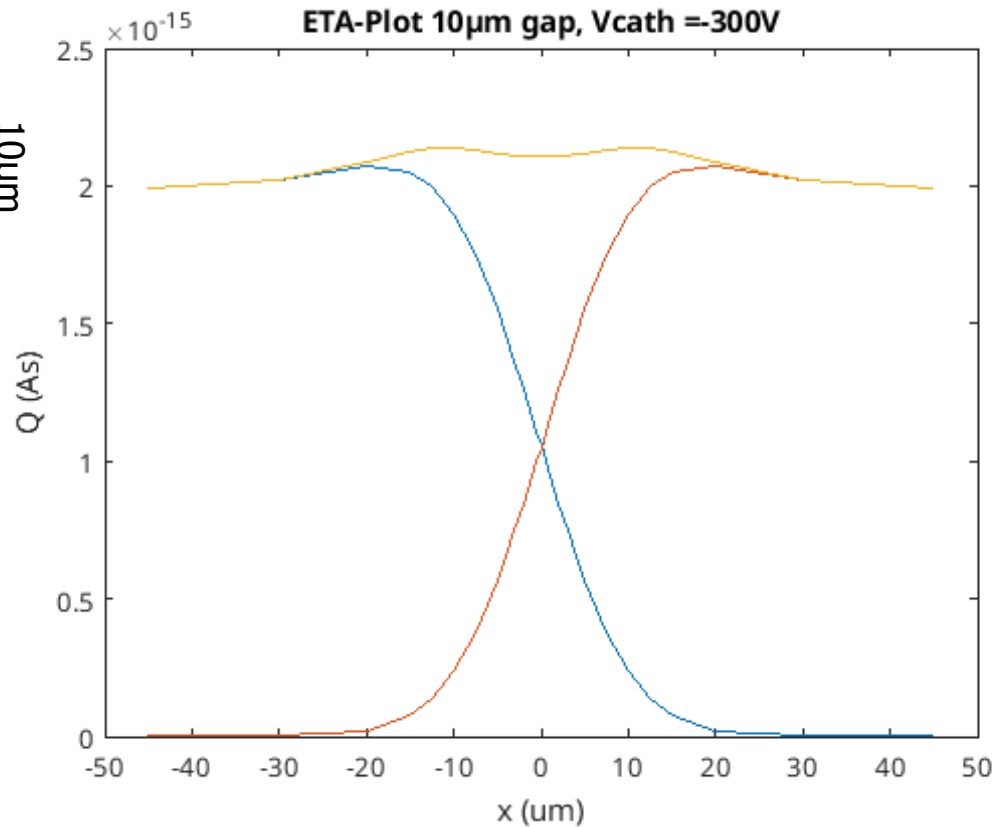
-> $M = 14.8$

GAIN IN THE GAP REGION

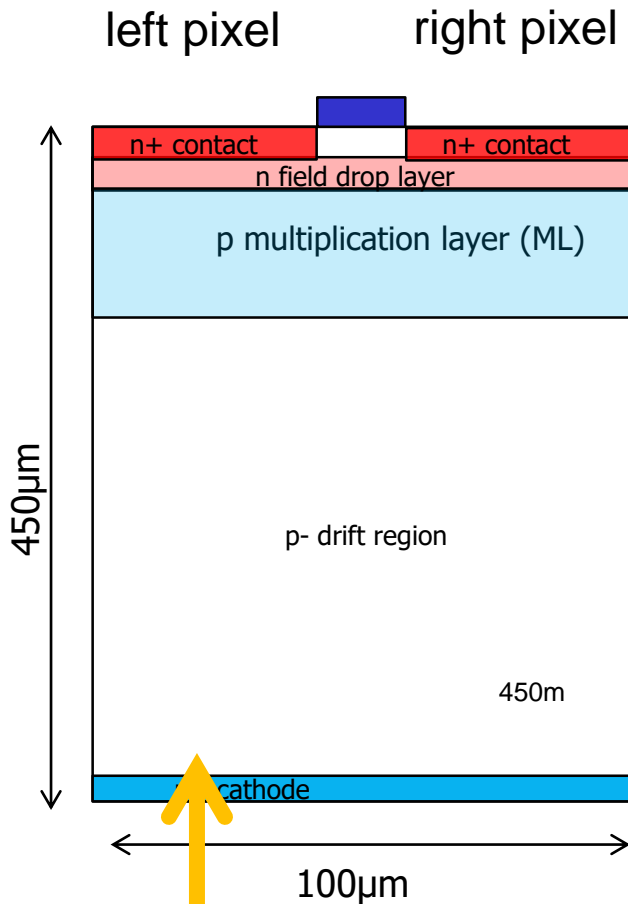


$Q_{\text{test}} = 1.3 \times 10^{-16} \text{ C}$

variation of injection position in x

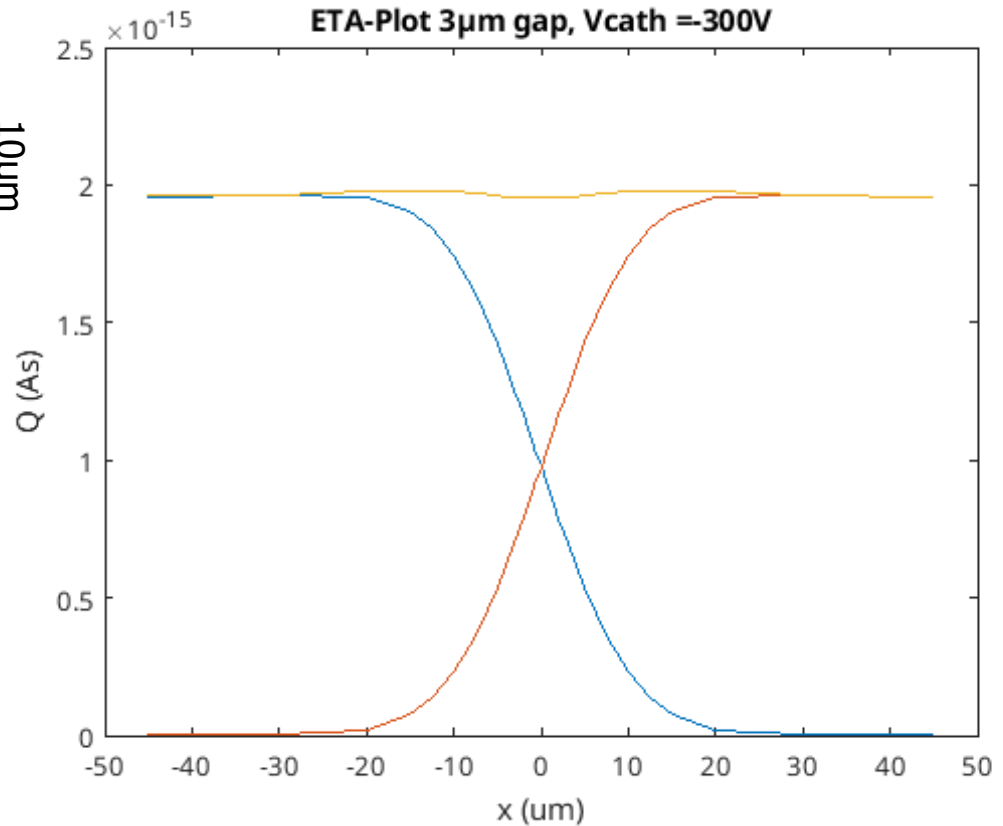


GAIN IN THE GAP REGION



generate test charge
 $Q_{\text{test}} = 1.3 \times 10^{-16} \text{ C}$

variation of injection position in x



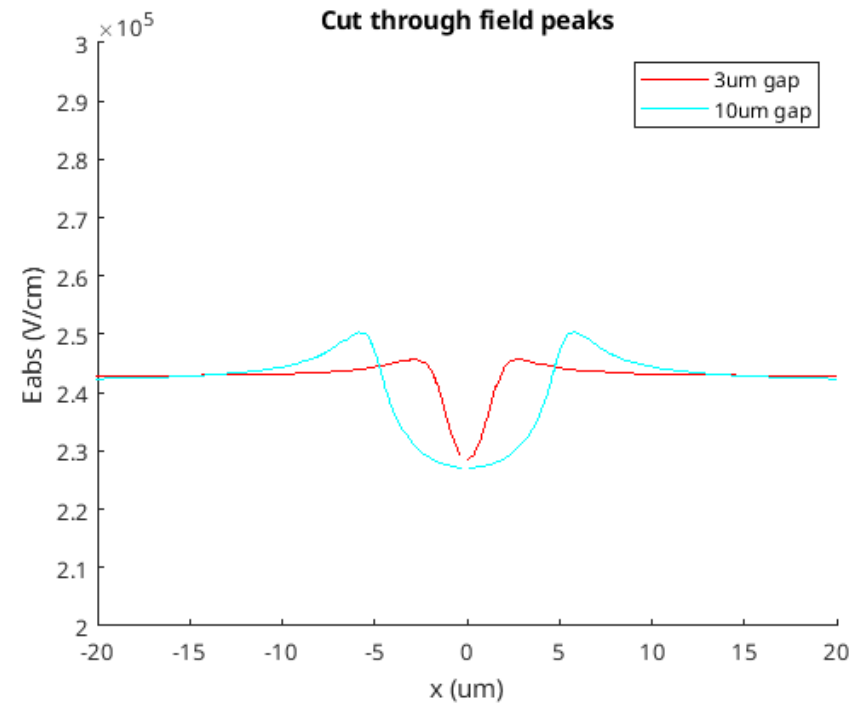
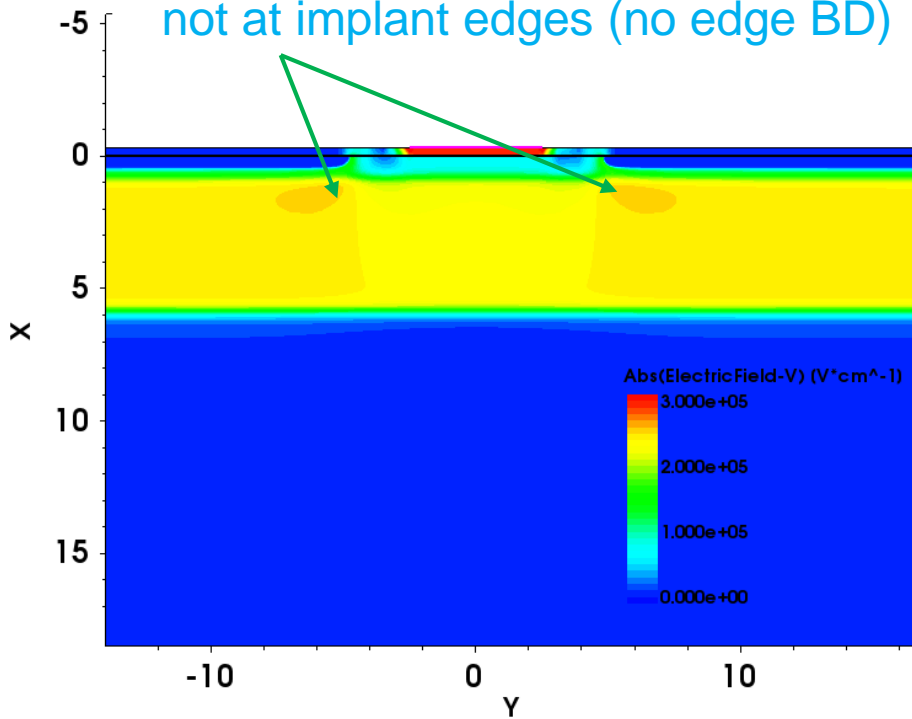
reduce gap size
 reduce gain inhomogeneity

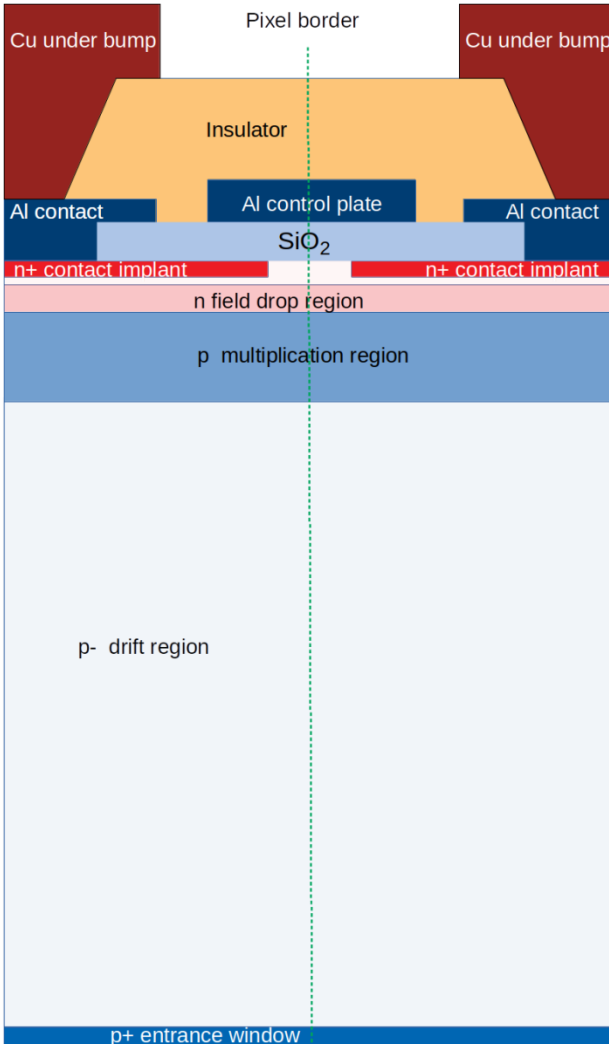
WHAT HAPPENS IN THE GAP REGION? GAP LOSS GETS 'COMPENSATED'



field peaks

not at implant edges (no edge BD)





Expected features

Gain up to 20

Collection efficiencies: > 99%

Pixel pitch: given by bump bond technology and ro electronics space consumption (ATLAS 50μm)

Position resolution: $\ll \frac{pitch}{\sqrt{12}}$

Time resolution:

Leading edge trigger: <50ps

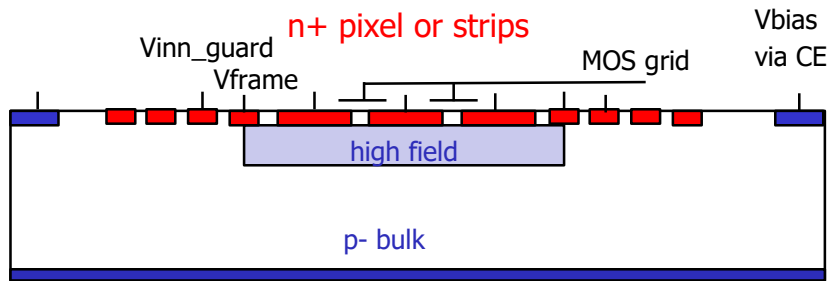
Full signal formation 50ns (450μm)

PROTOTYPE PRODUCTION



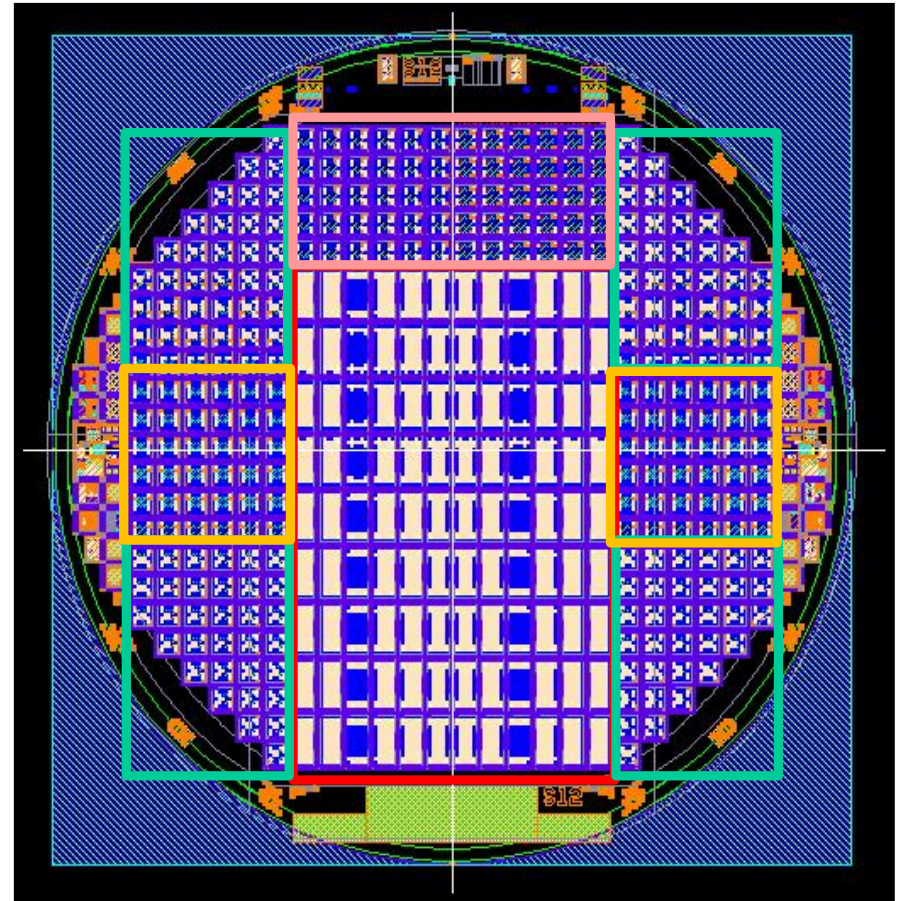
Aims

- proof of principle
- Efficiency, gain, cross talk, noise
- find reliable narrow guard ring structure (in view of buttable arrays)



backside p+ entrance window
non structured, no Al

Pixel Strips Diodes MGR Diodes



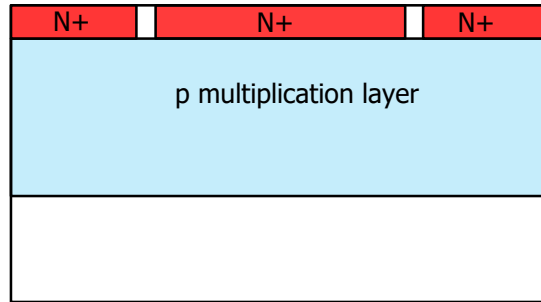
production finished
tests started

APD DIODES WITH AND WITHOUT GAPS

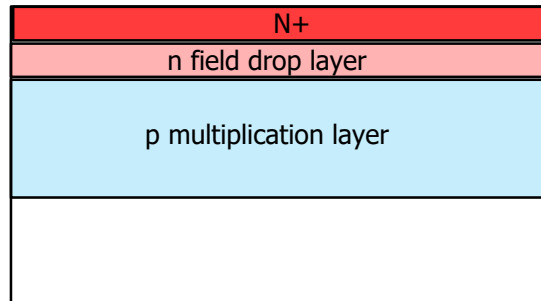


diodes 2x2mm²

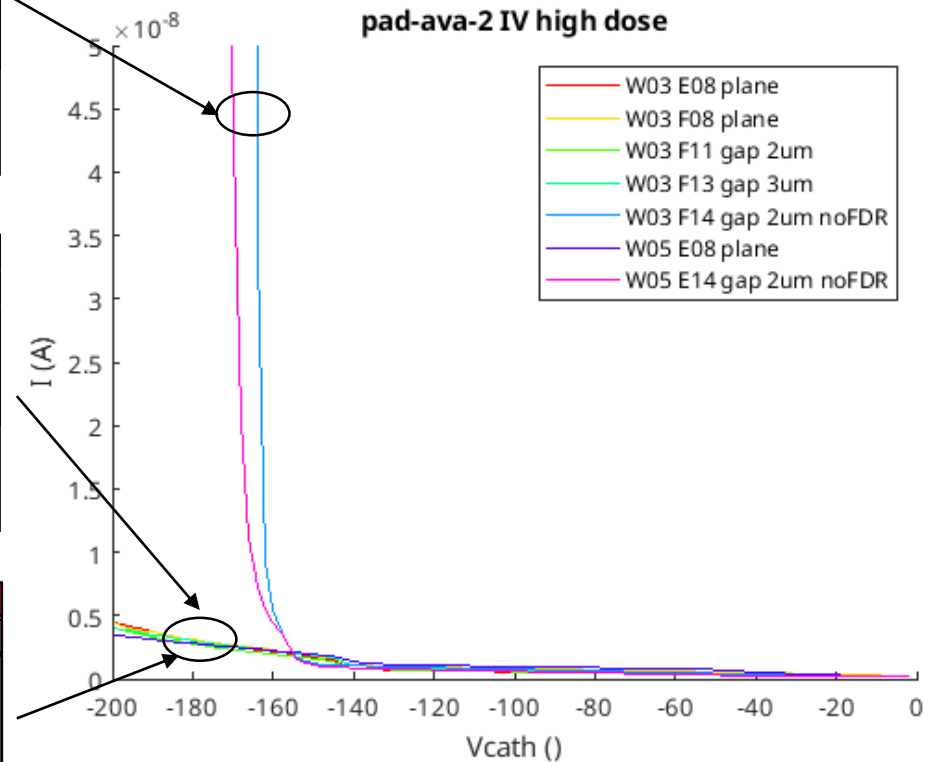
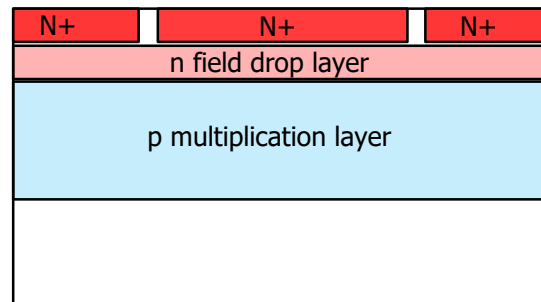
diode with gaps
but without FDL



plane diode



diode with gaps
and FDL



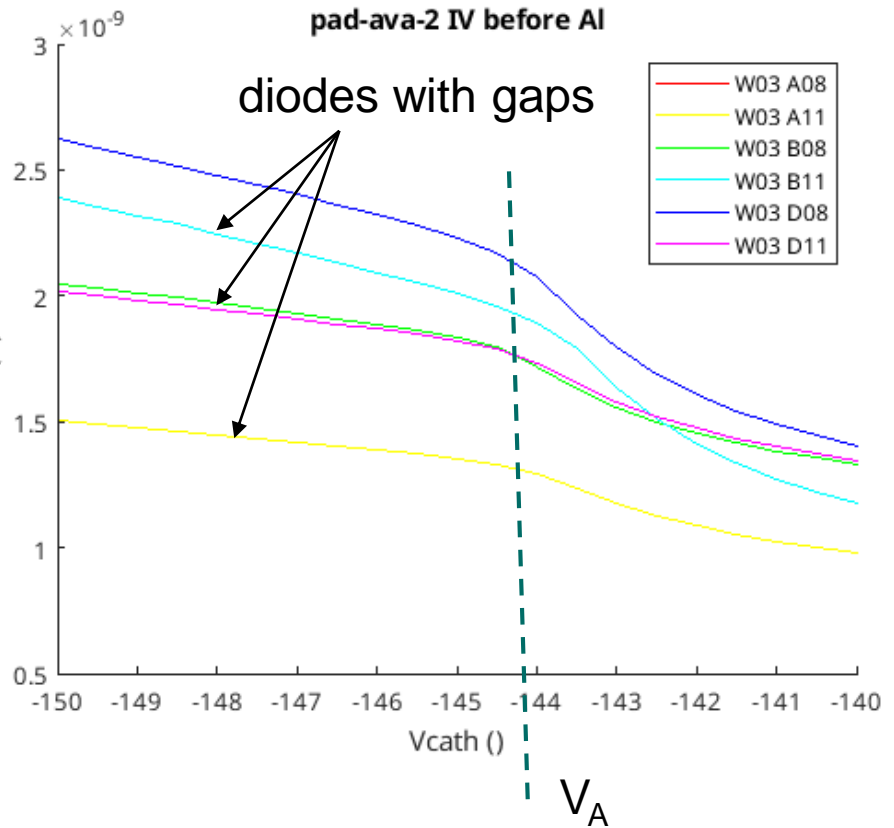
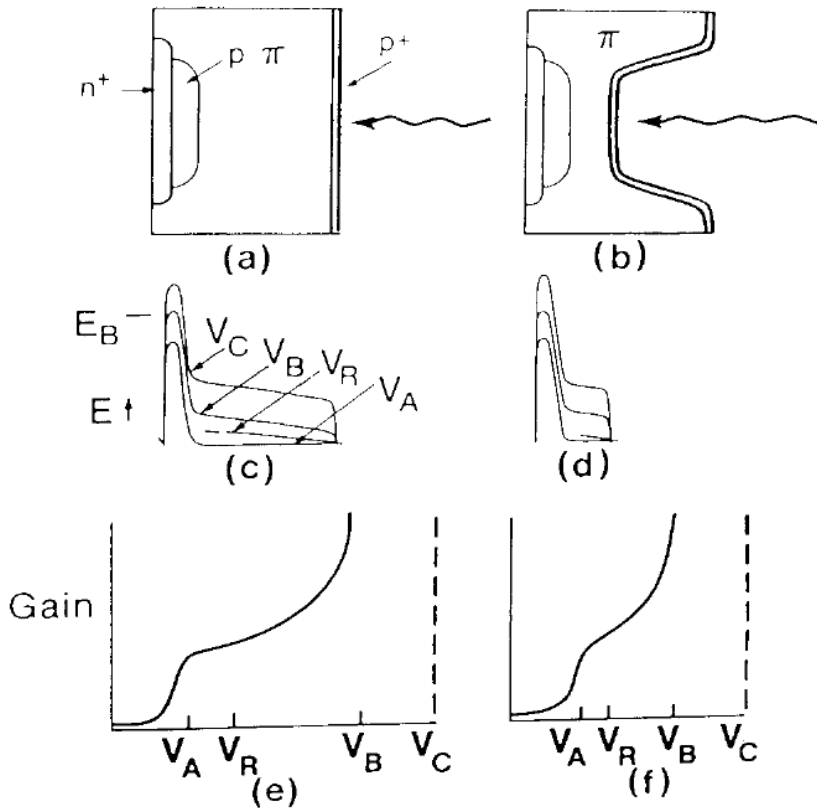
Edge breakdown suppression
works as intended

HOMOGENEITY OF HIGH ENERGY IMPLANTATION (MULTIPLICATION REGION)



Typical Reach-Through APD IVs

R. J. McIntyre, 1985



point of inflection V_A
 p multiplication region fully depleted

no difference between diodes and gap diodes
 (preliminary)



MARTHA – a new approach for an APD pixel array

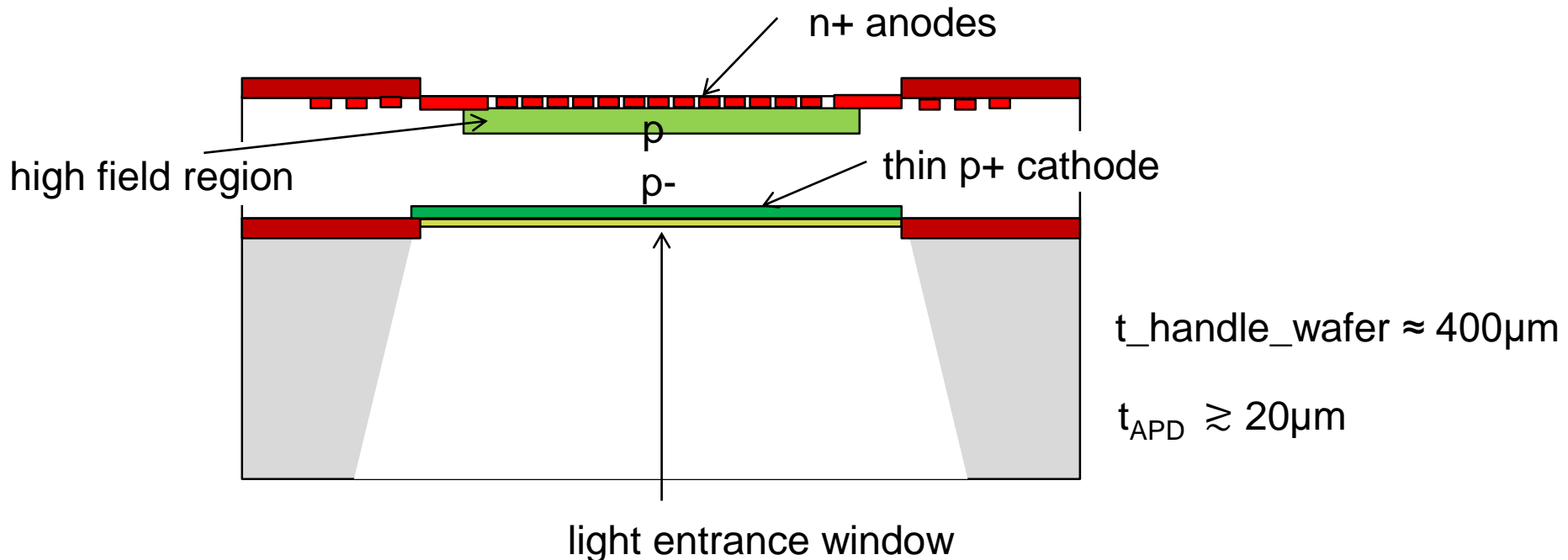
- operated in RT proportional mode
- no inter pixel dead space
- suitable for large pixel arrays
- low excess noise due to HE high field implantation
- First prototyping – small APD arrays and strips
- **will be tested further soon**

OUTLOOK



next steps:

- proof of concept measurements (started)
- discussions with potential users and ASIC designers
- MARTHA sensors can also be produced on thinned wafers
 - improved timing capabilities





THANKS FOR YOUR ATTENTION

R. Richter, A. Bähr, J. Damore,
Ch. Koffmane, R. Lehmann,
J. Ninkovic, G. Schaller,
M. Schnecke, F. Schopper, J. Treis



BACKUP SLIDES

PIXEL CAPACITY



expected pixel capacity

- 50um Pixel 3um gap: ca. 35fF
- 50um Pixel 10um gap: ca. 20fF

HLL THIN ENTRANCE WINDOW



fully depleted

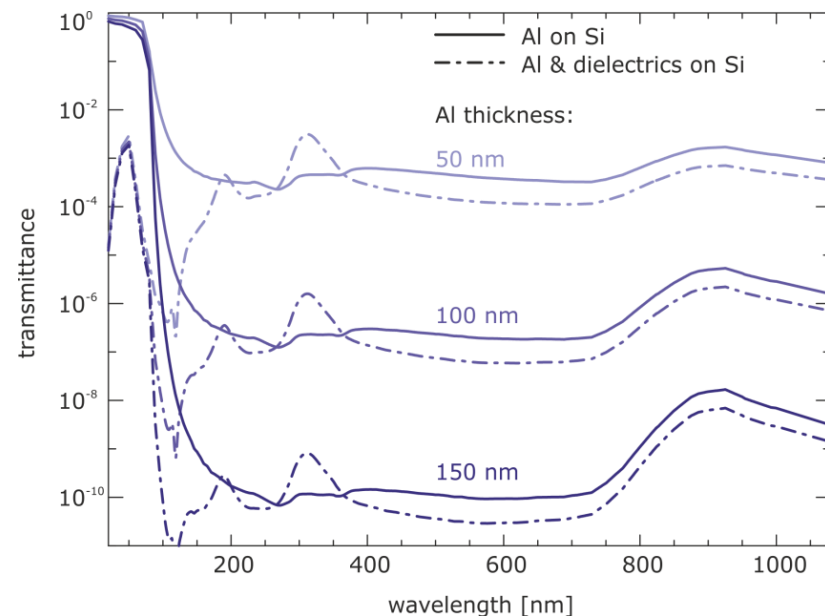
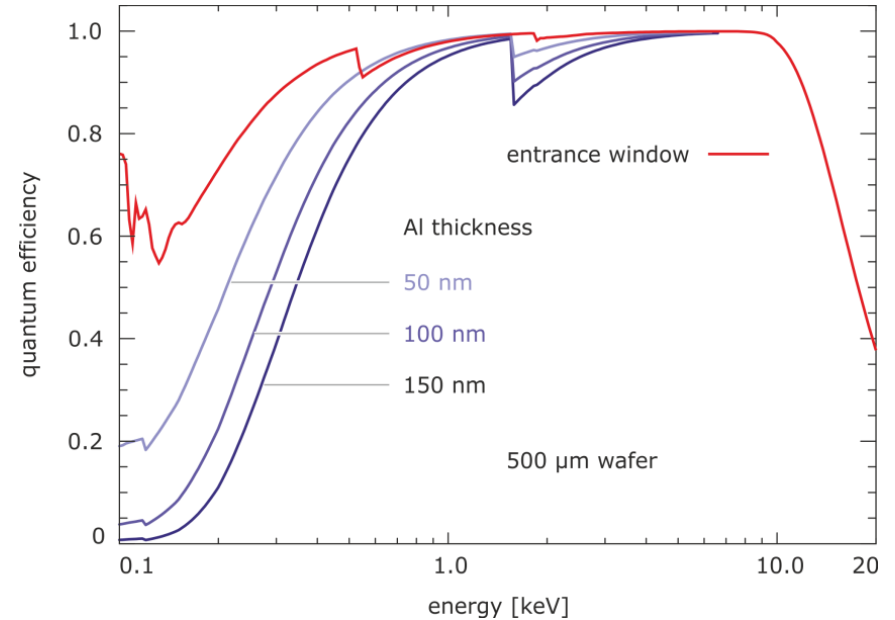
sensitive over the complete bulk
thickness 50 .. 450 .. 1000 μm
thin, non-structured entrance window
QE > 90% for $0.3 \text{ keV} < E < 15 \text{ keV}$
radhart @ soft X-rays (self shielding)

backside irradiation

100 % fill factor
optional light (& UV) filter

integrated first amplifier

low noise
fast readout
emi robust



OPTIMIZATION FOR SOFT X-RAY DETECTION (LOW EXCESS NOISE)

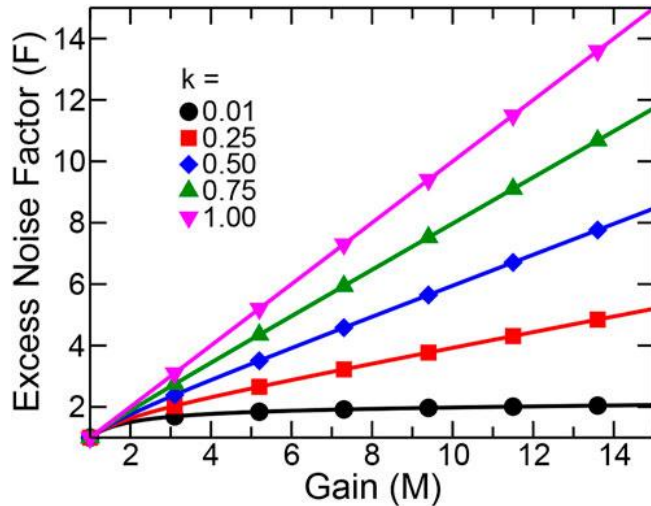


Excess noise factor

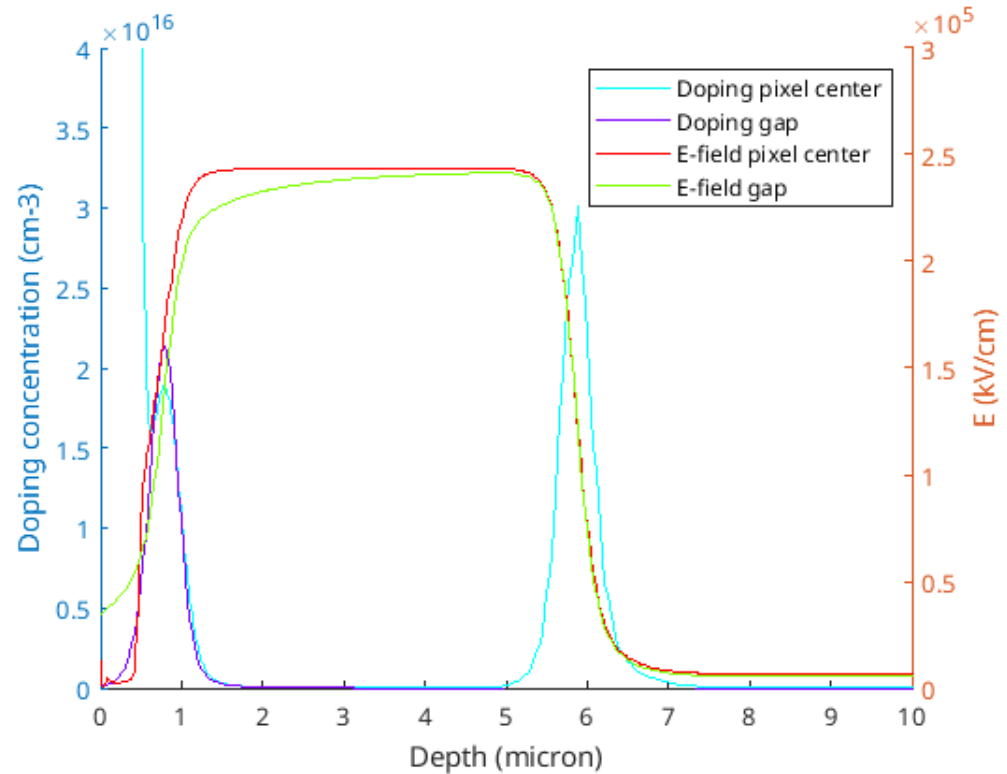
$$F = M * k + (2 - \frac{1}{M}) (1 - k)$$

$$k = \frac{\alpha_h}{\alpha_e} < 1$$

deep implant (6 μm)
extend ML



A. Pilotto et. al. (2022)



The lower E the lower k
the lower the noise **but** the lower gain!

At present
Siemens Campus Neuperlach Munich



- 1000m² of clean room area
- 330m² of ISO3 area
- Full 6 inch silicon process line

New building
IPP Campus Garching
in autumn 2023 – move started



- 1500m² of clean room area
- 600m² of ISO3 & ISO4 area
- 8 inch silicon process line

Central facility of the Max Planck Society
40 scientists, engineers and technicians
+ guest scientists, and students