MAX PLANCK
SEMICONDUCTOR
LABORATORY

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

MARTHA - MONOLITHIC ARRAY OF REACH THROUGH AVALANCHE PHOTO DIODES

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

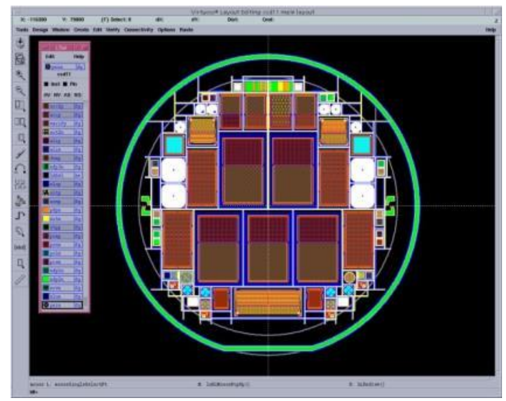
MPG HLL

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

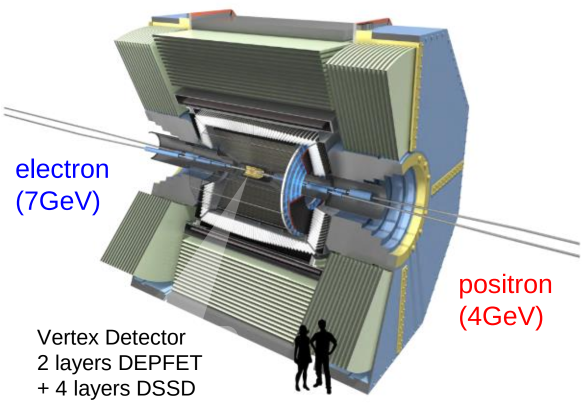
- design
- assembly
- test

MPG HLL – some examples

XMM-Newton

pnCCD
X-ray imaging spectroscopy
curtesy ESA

DePFETs at KEK - Japan



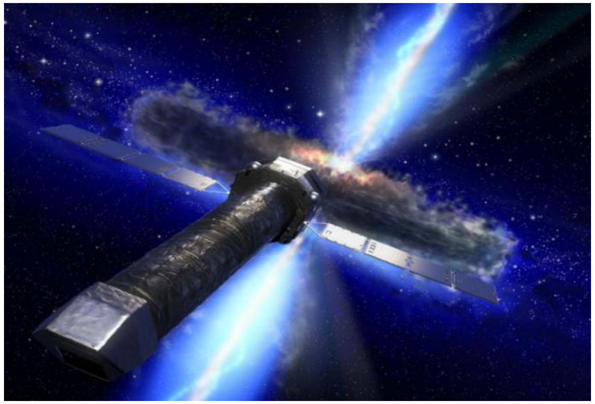
DePFET for particle tracking
curtesy Belle2 collaboration

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

MIXS on BepiColombo

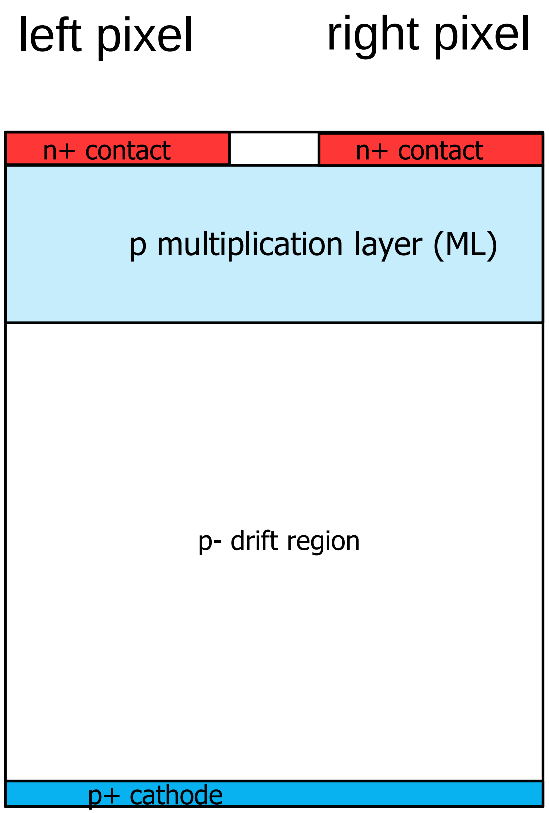
DePFET -planetary science
curtesy ESA

WFI on Athena



DePFET - X-ray imaging spectroscopy
curtesy ESA

MARTHA - APDs FOR SOFT X-RAYS

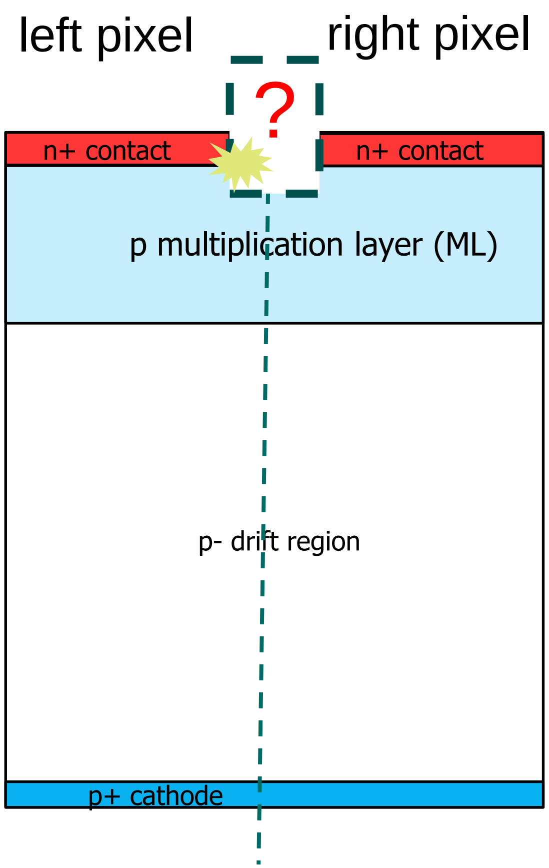


(Soft X-ray) Photon Counting

For applications at FELs

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

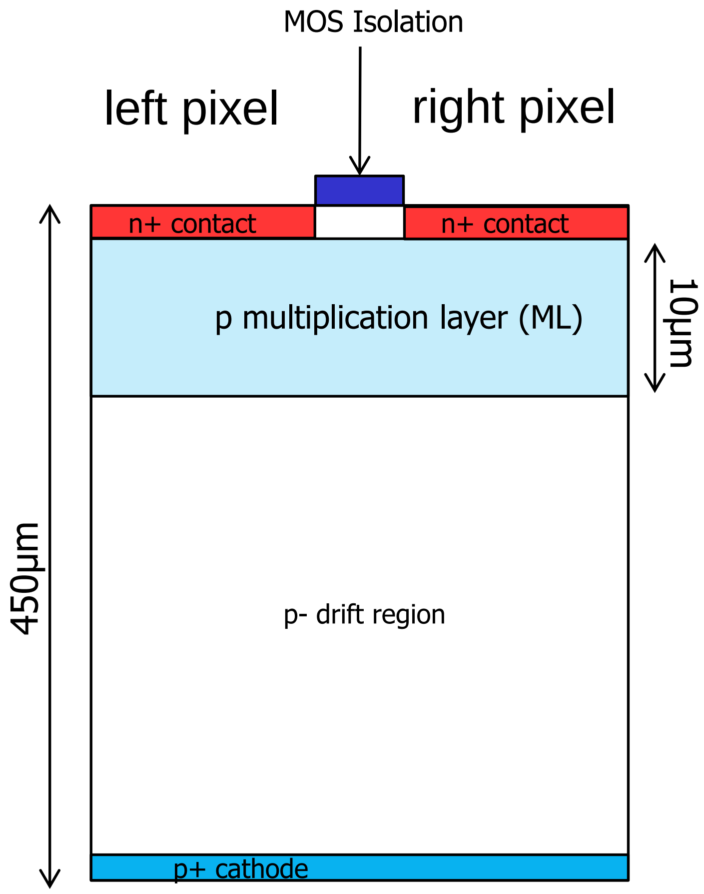
MARTHA - INTERPIXEL ISOLATION



Interpixel isolation requirements

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

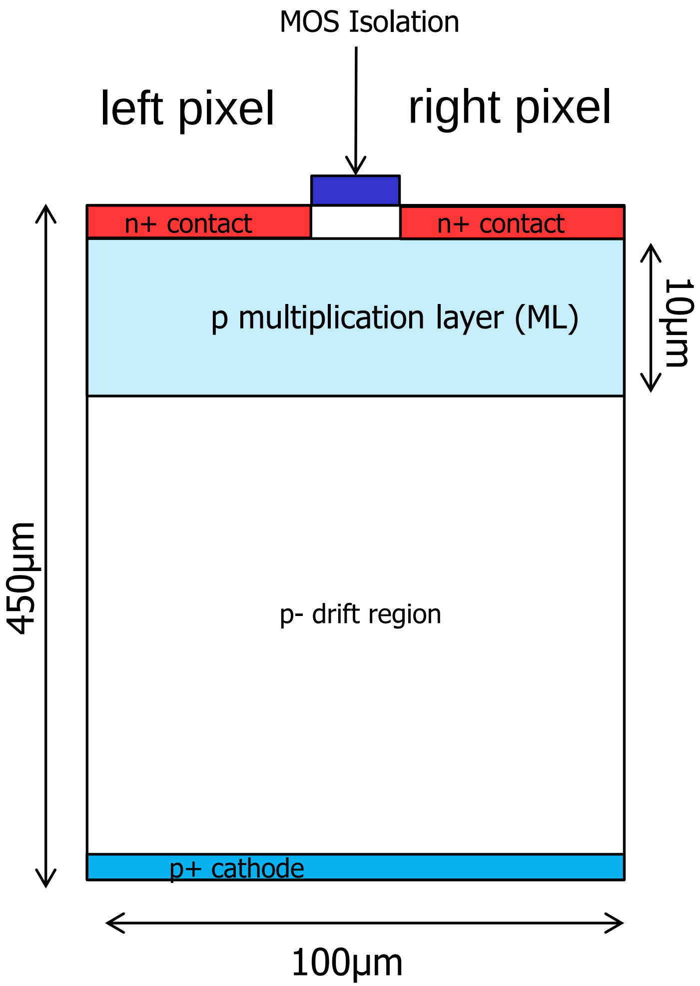
STRIP ARRAY 50µm PITCH (2D SIMULATION)

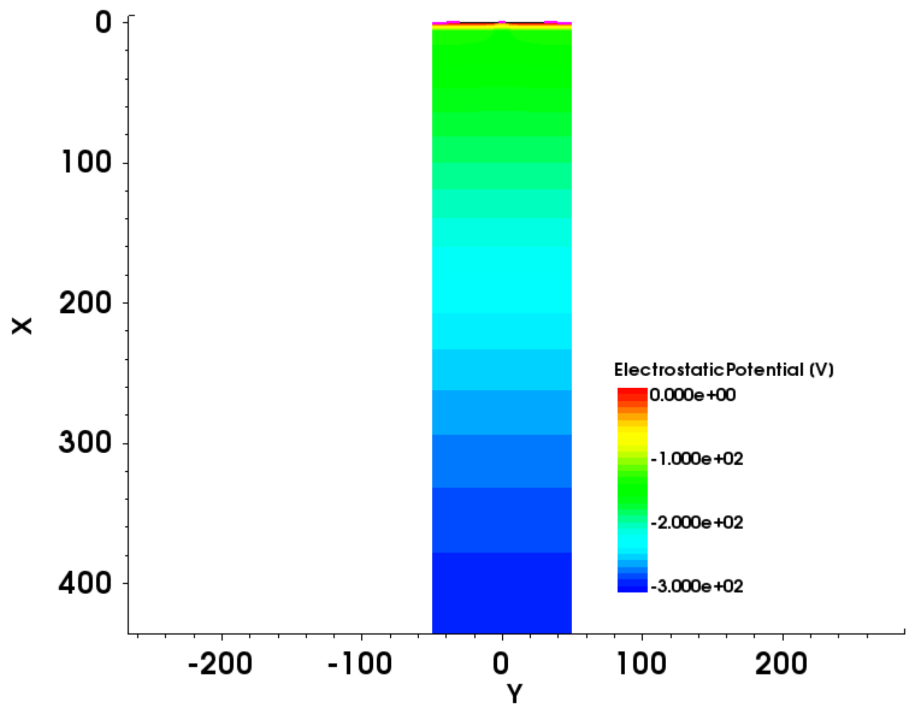


- Reach-through APD
- 50 µm pitch
- MOS isolation
- Based on HLL „standard“ technology

HF region extends over pixel gaps

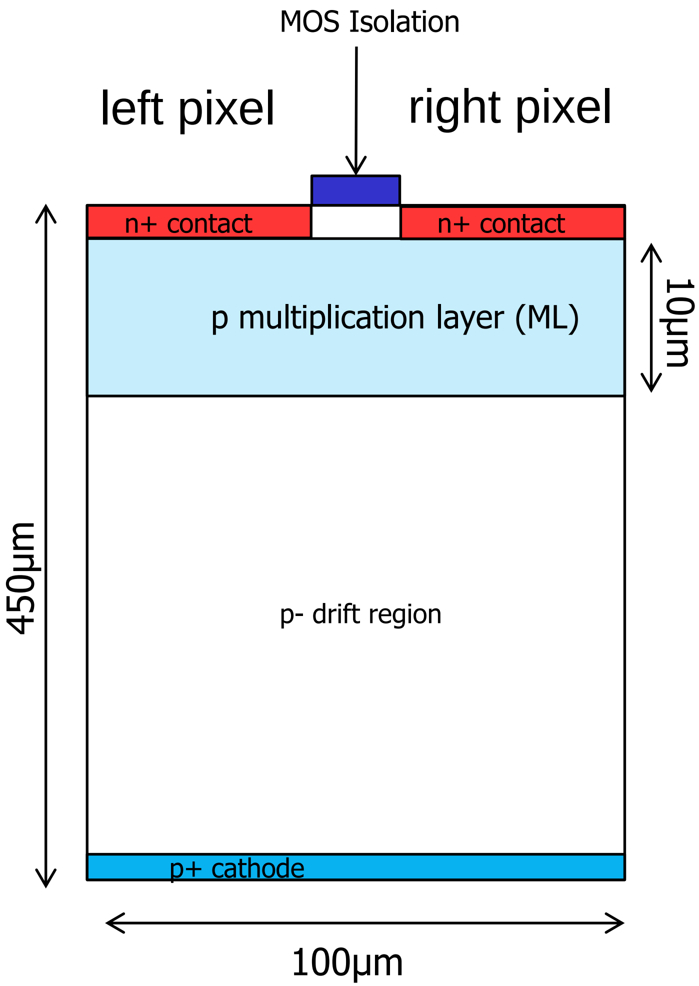
STRIP ARRAY (2D SIMULATION)

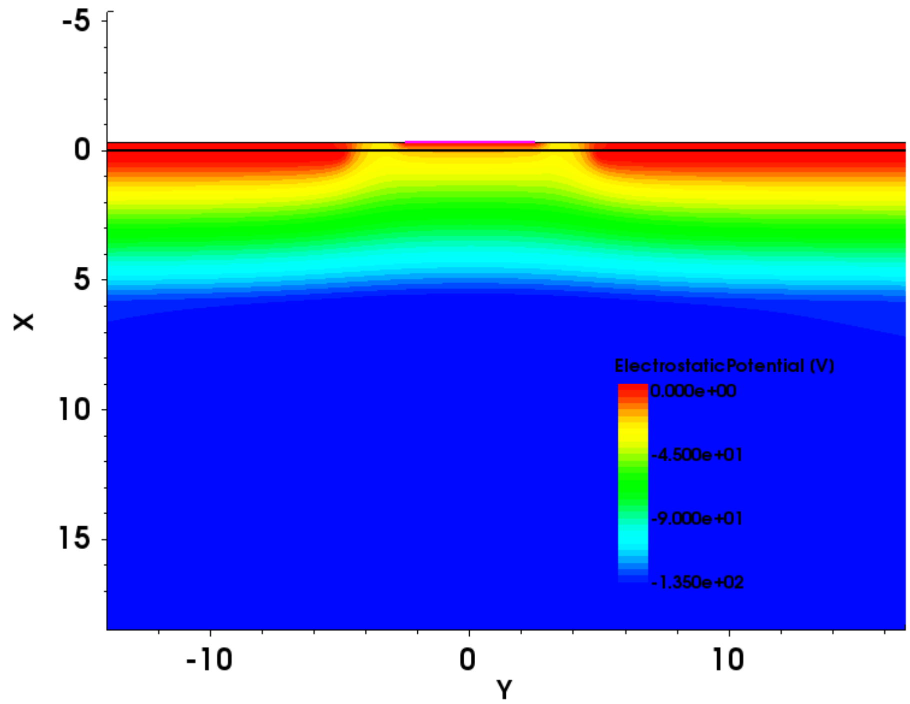




HF region extends over pixel gaps

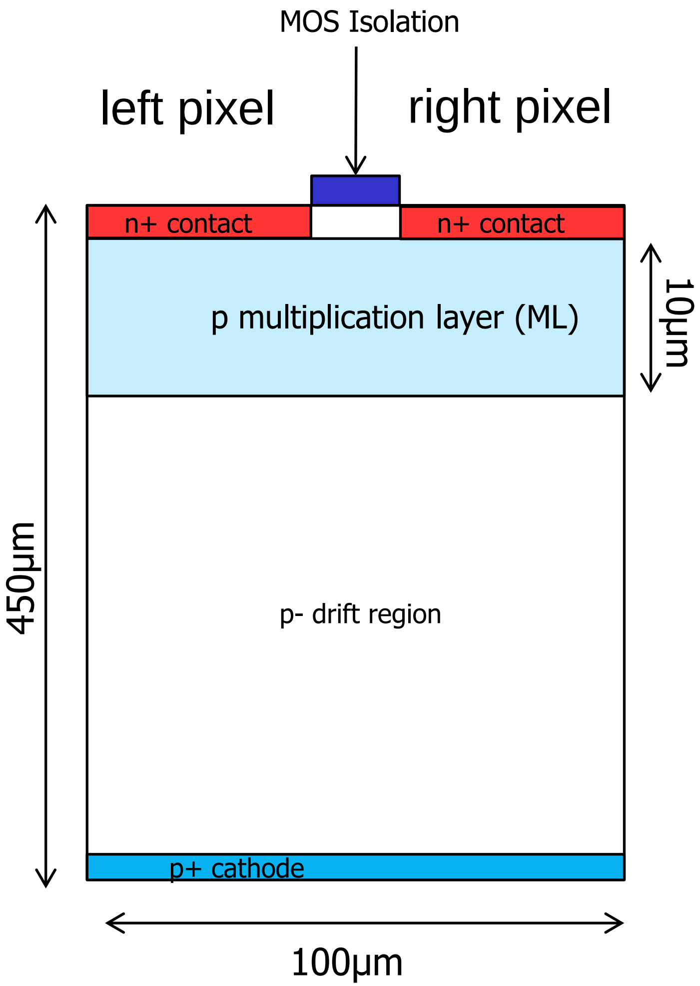
STRIP ARRAY (2D SIMULATION)

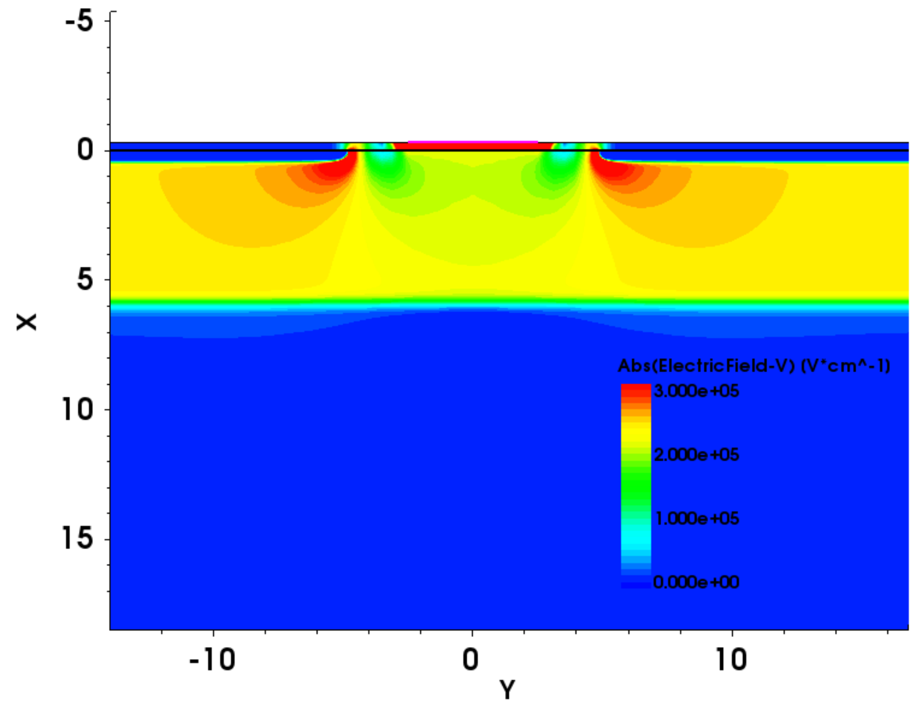




HF region extends over pixel gaps

STRIP ARRAY (2D SIMULATION)



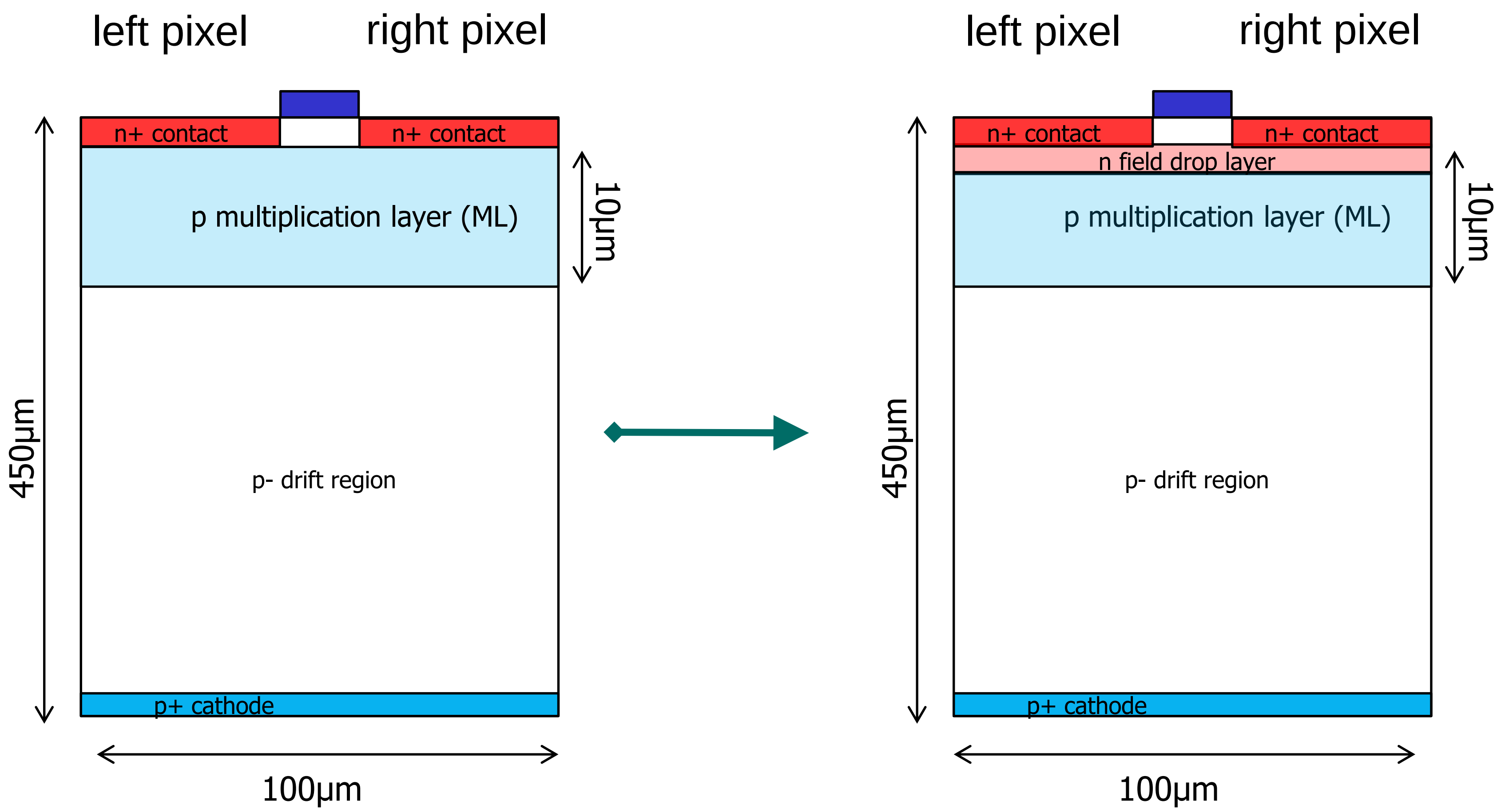


HF region extends over pixel gaps

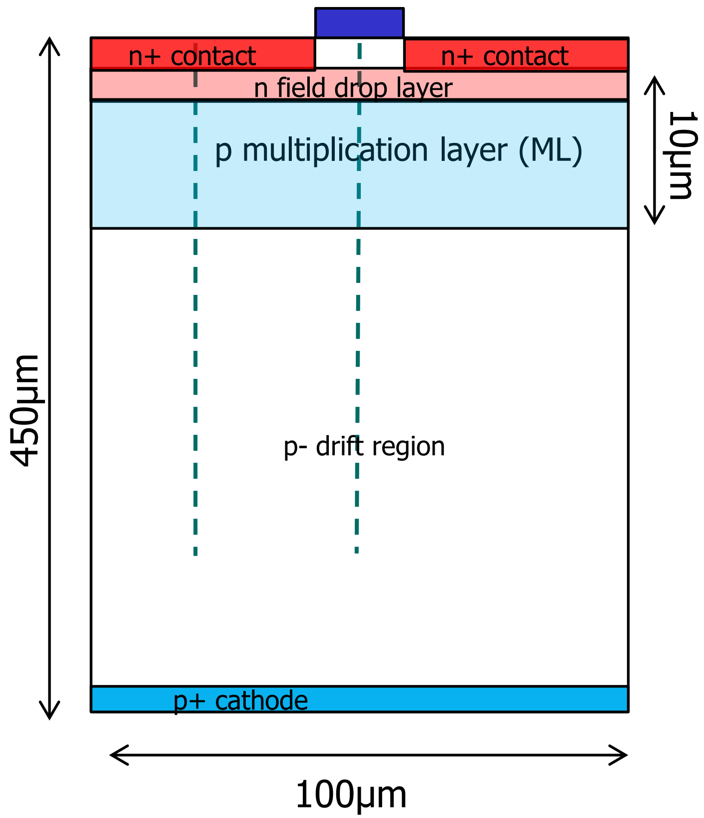
Avalanche (breakdown) at edges

Approach not usable

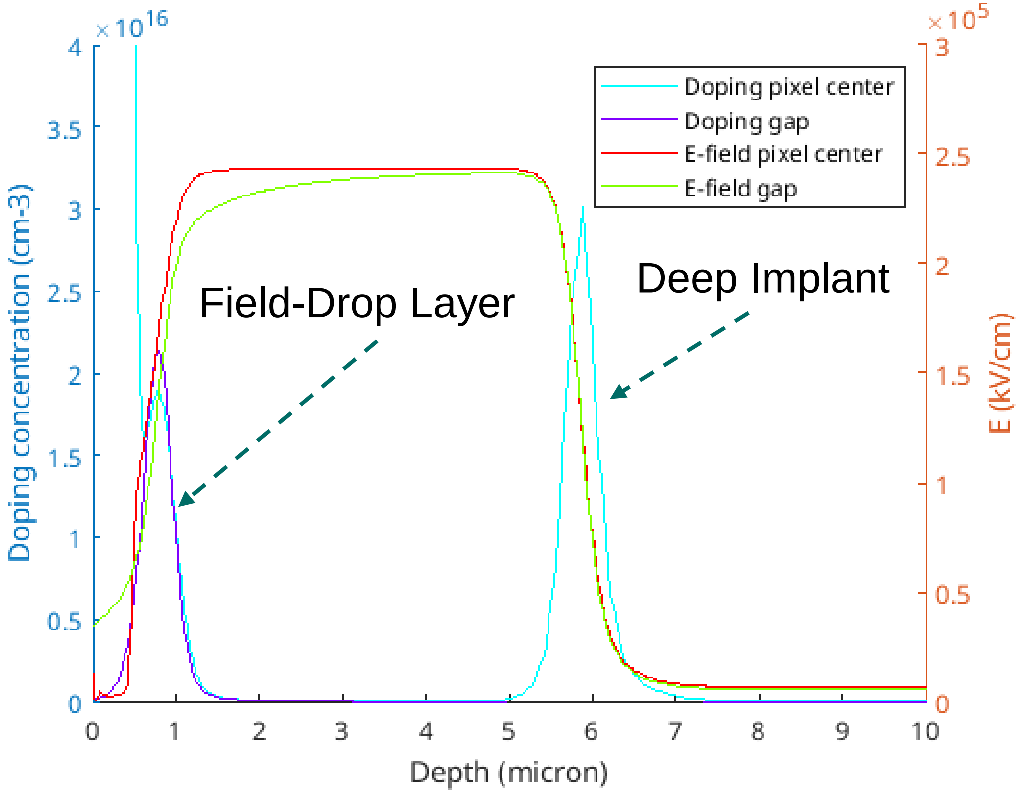
2D SIMULATION
EDGE BREAKDOWN SUPPRESSION



EDGE BREAKDOWN SUPPRESSION



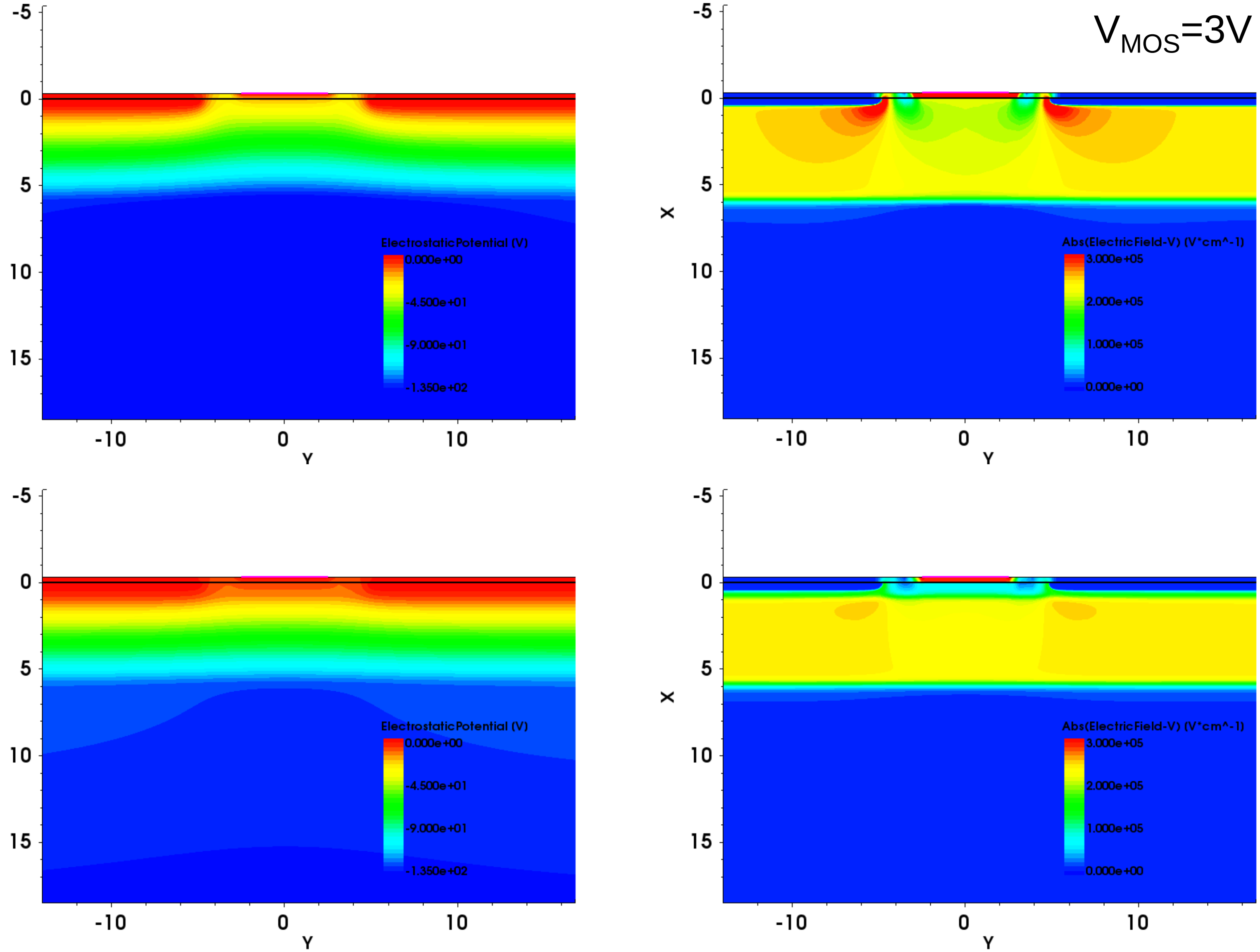
deep implant (6 µm)
extend ML



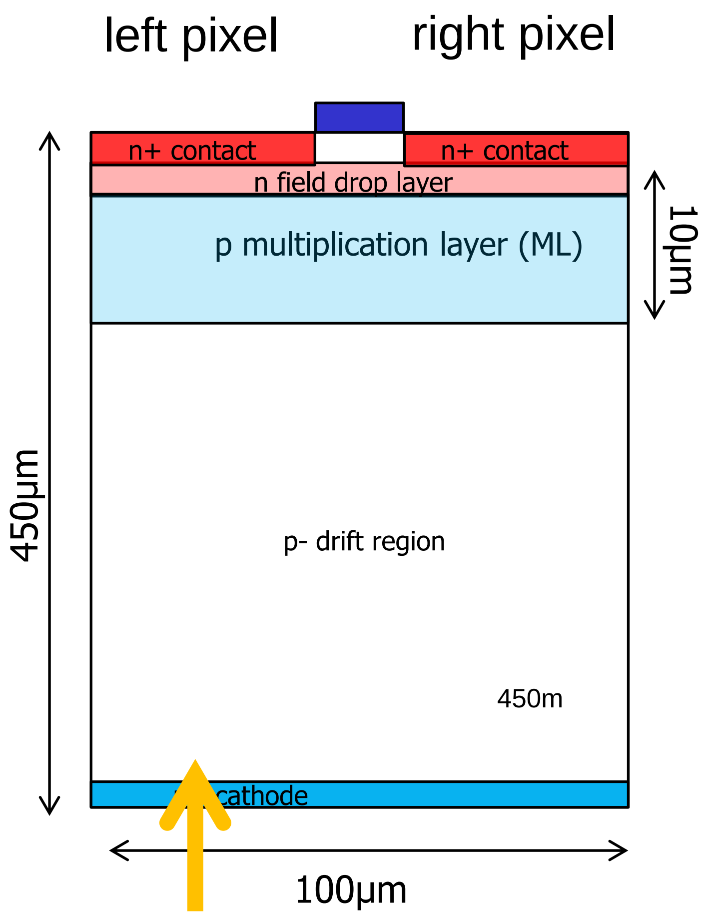
2D SIMULATION
EDGE BREAKDOWN SUPPRESSION

HF region extends over pixel gaps

HF region and field drop layer extend over pixel gaps

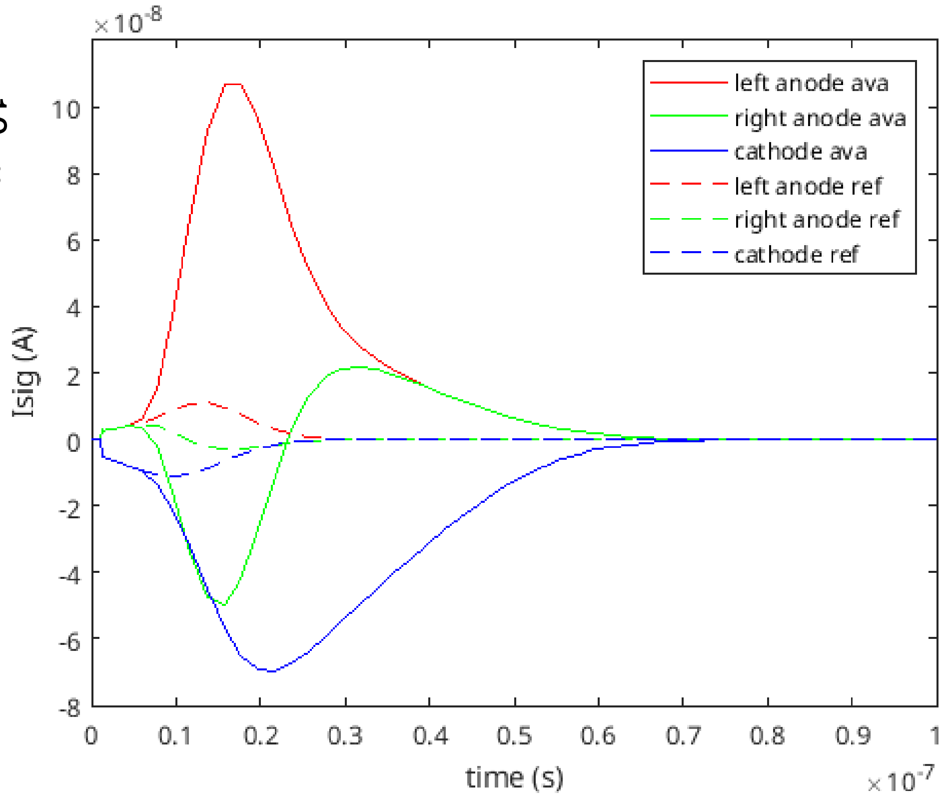


SIMULATED SIGNAL EVOLUTION (CURRENT)



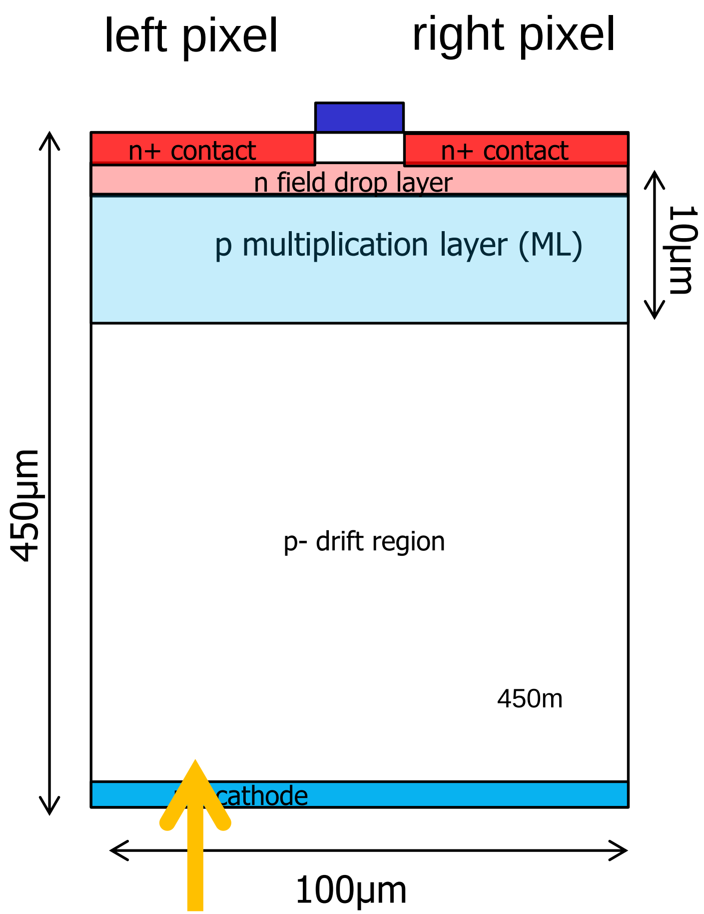
generate test charge
Qtest = 1.3×10^{-16} C

solid - with avalanche
dashed - without avalanche



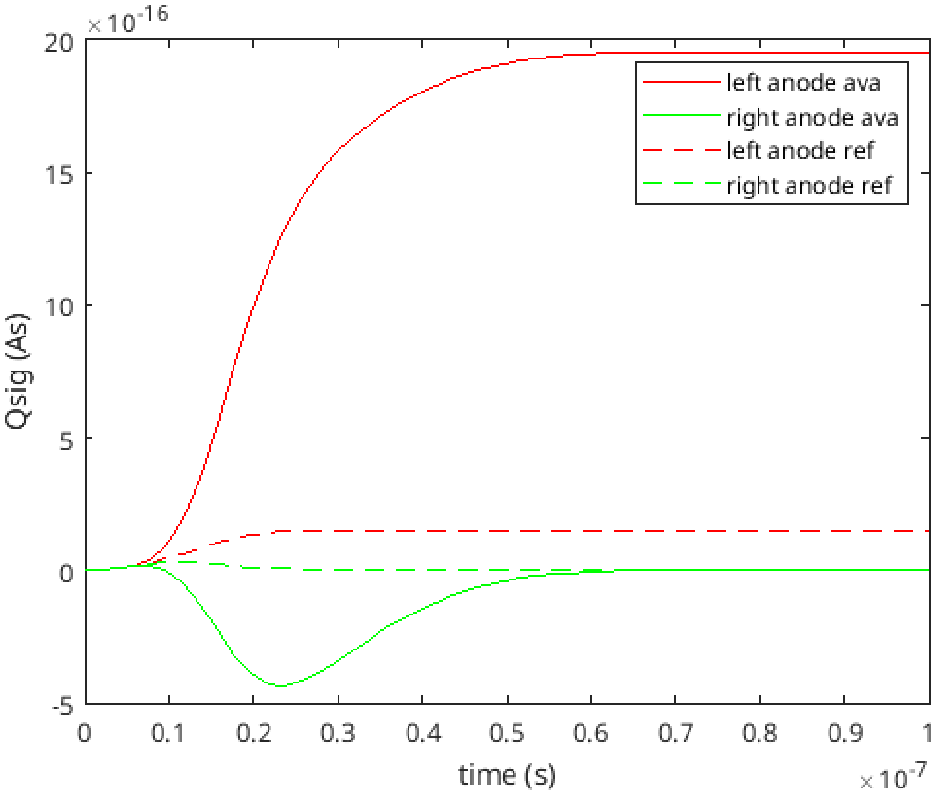
full signal formed faster in reference structure (generated drift to backside)
‘anti cross talk‘

SIMULATED SIGNAL EVOLUTION (CHARGE)



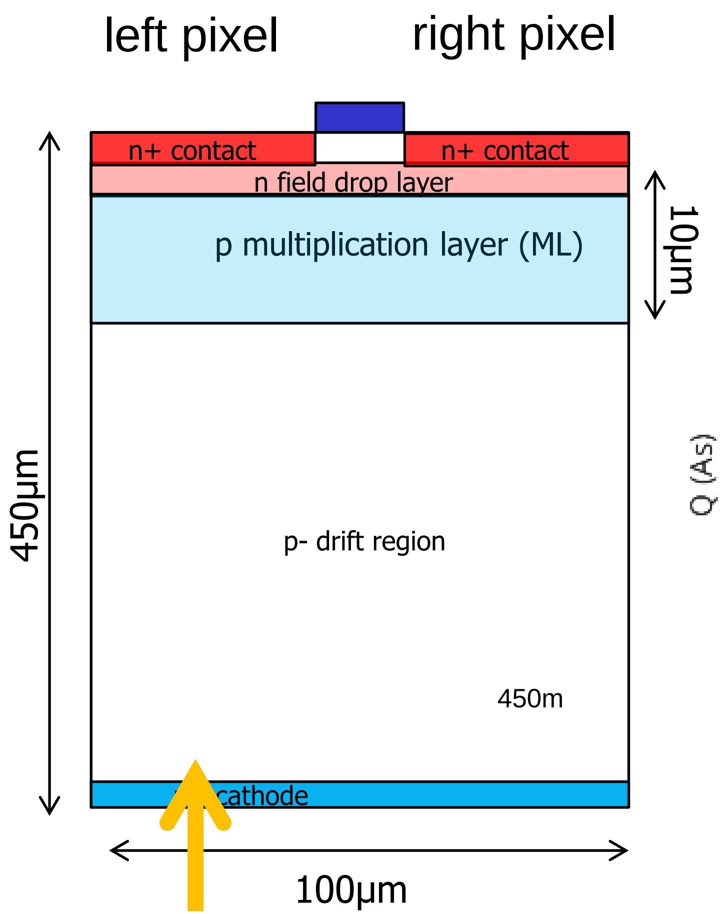
generate test charge
Qtest = $1.3x10^{-16}$ C

solid - with avalanche
dashed - without avalanche



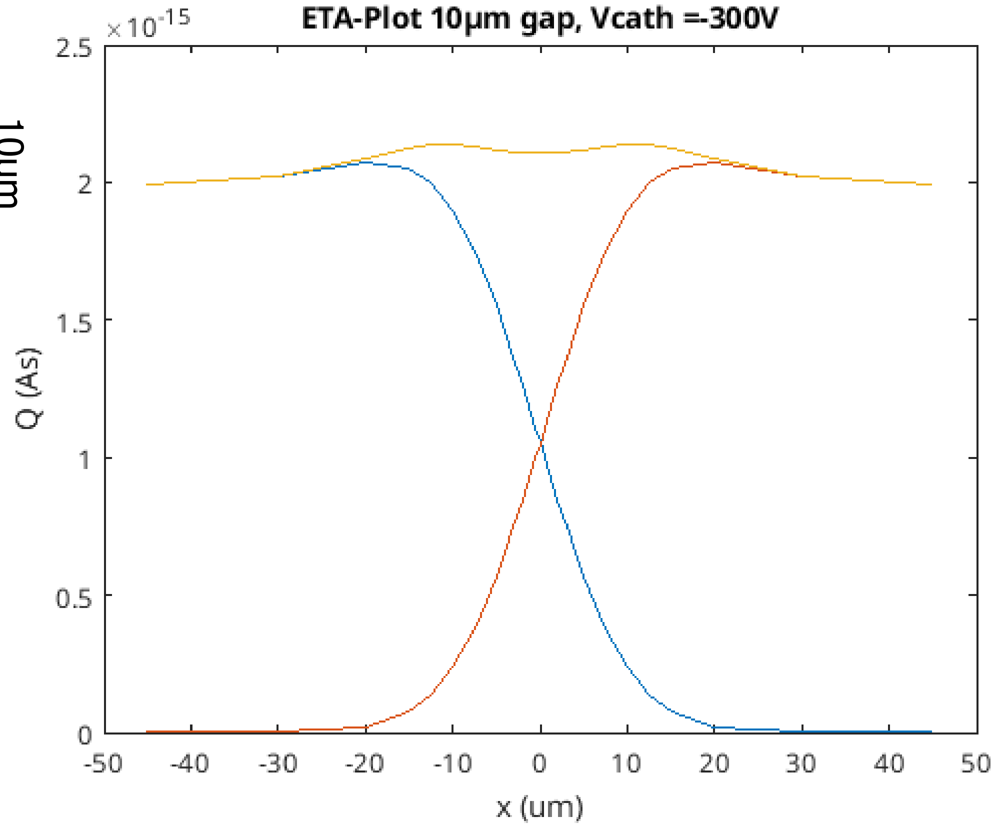
-> M = 14.8

GAIN IN THE GAP REGION

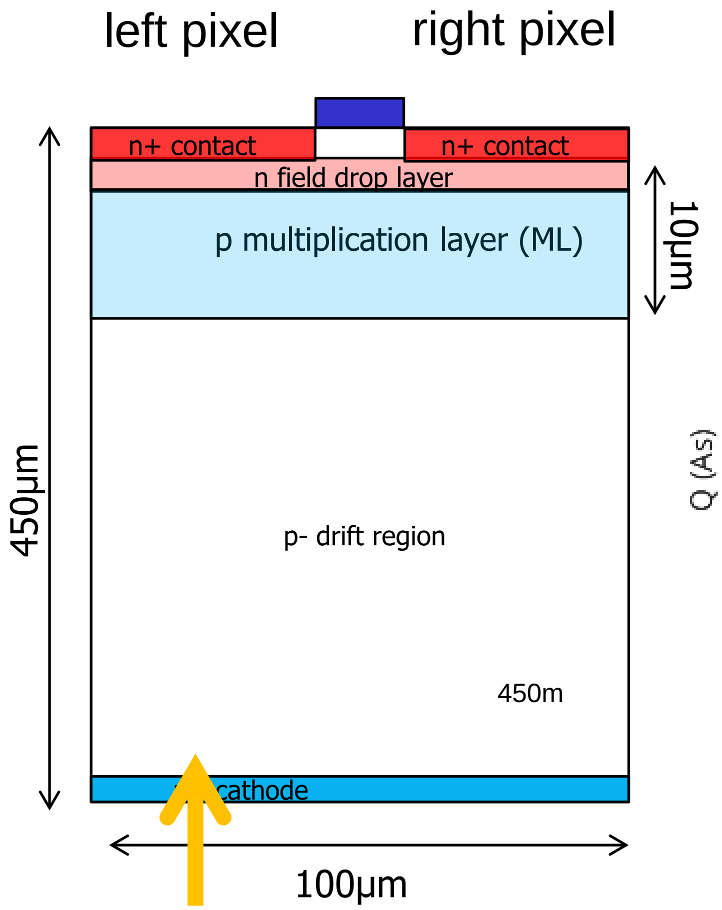


generate test charge
Qtest = 1.3×10^{-16} C

variation of injection position in x

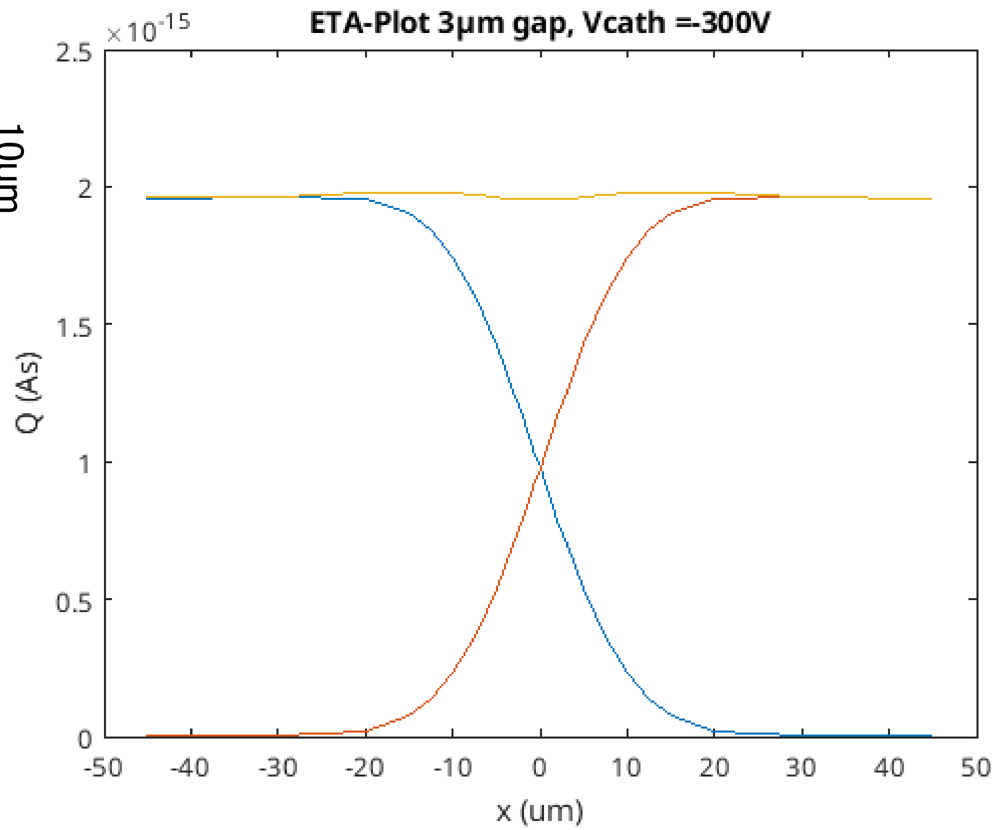


GAIN IN THE GAP REGION



generate test charge
Qtest = 1.3x10^{-16} C

variation of injection position in x

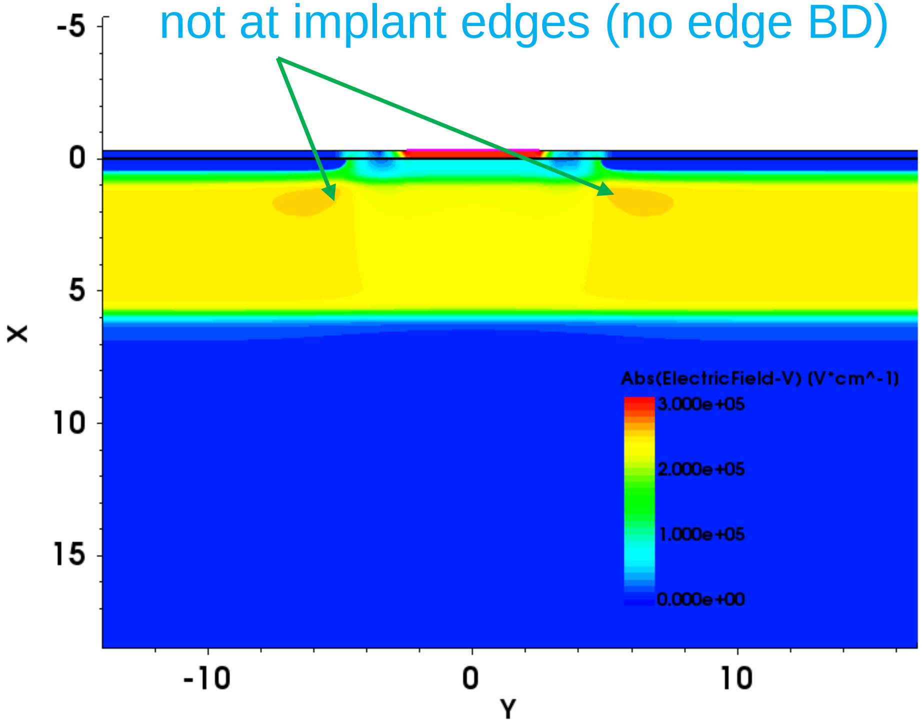


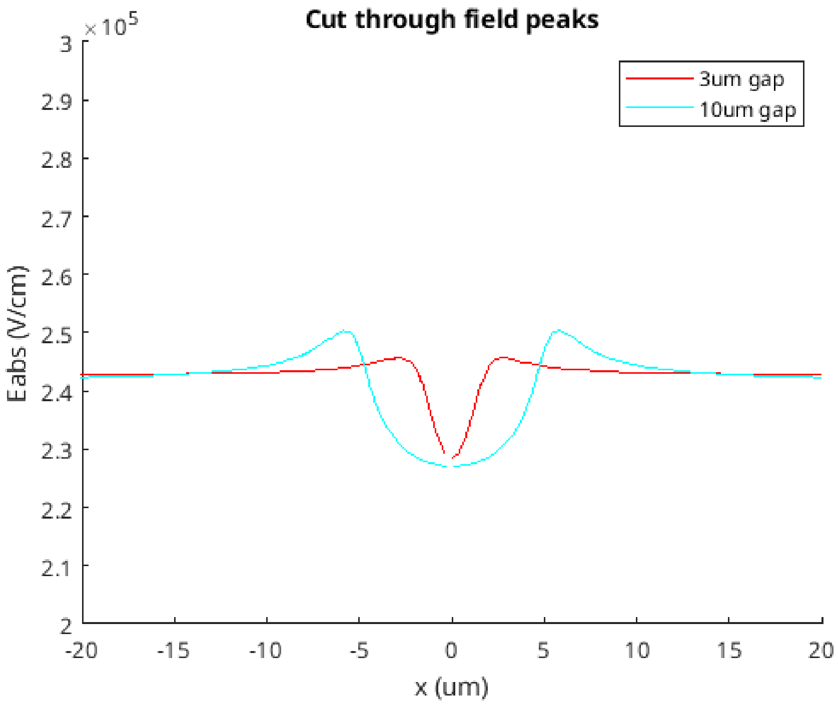
reduce gap size
reduce gain inhomogeneity

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

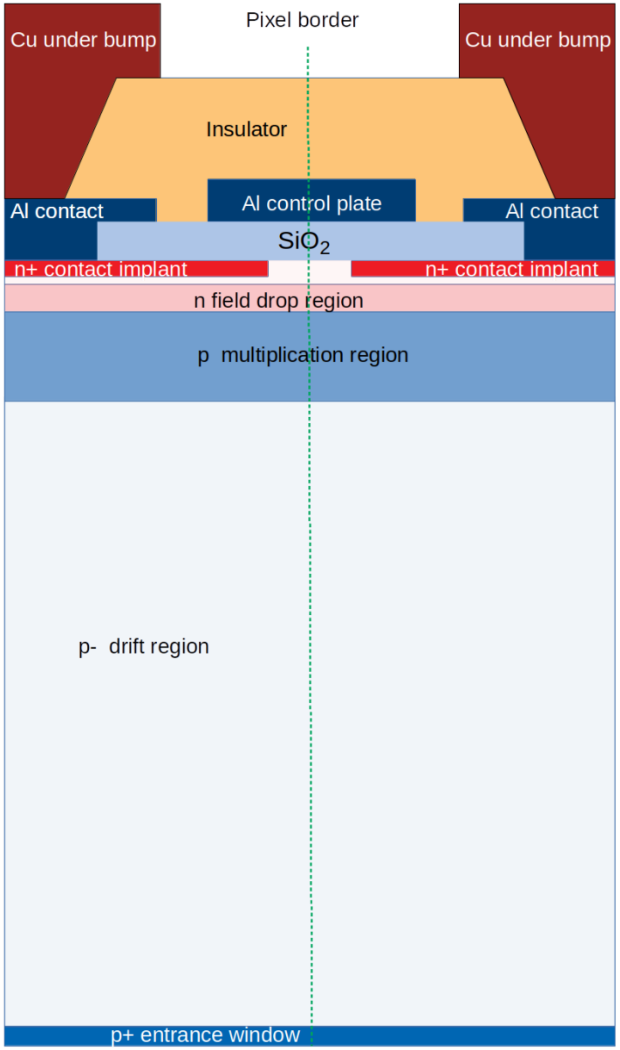
field peaks

not at implant edges (no edge BD)





FINAL ARRAY



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:

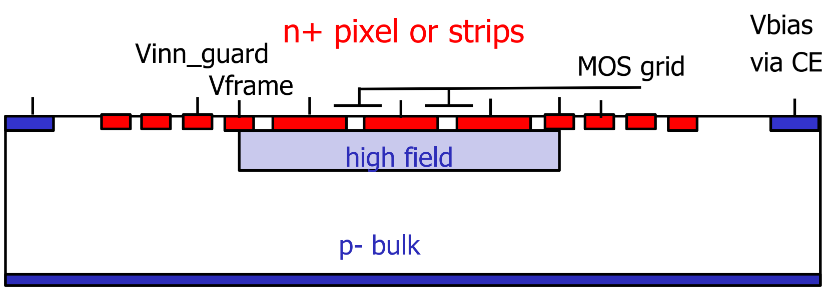
Leading edge trigger: <50ps

Full signal formation 50ns (450µm)

PROTOTYPE PRODUCTION

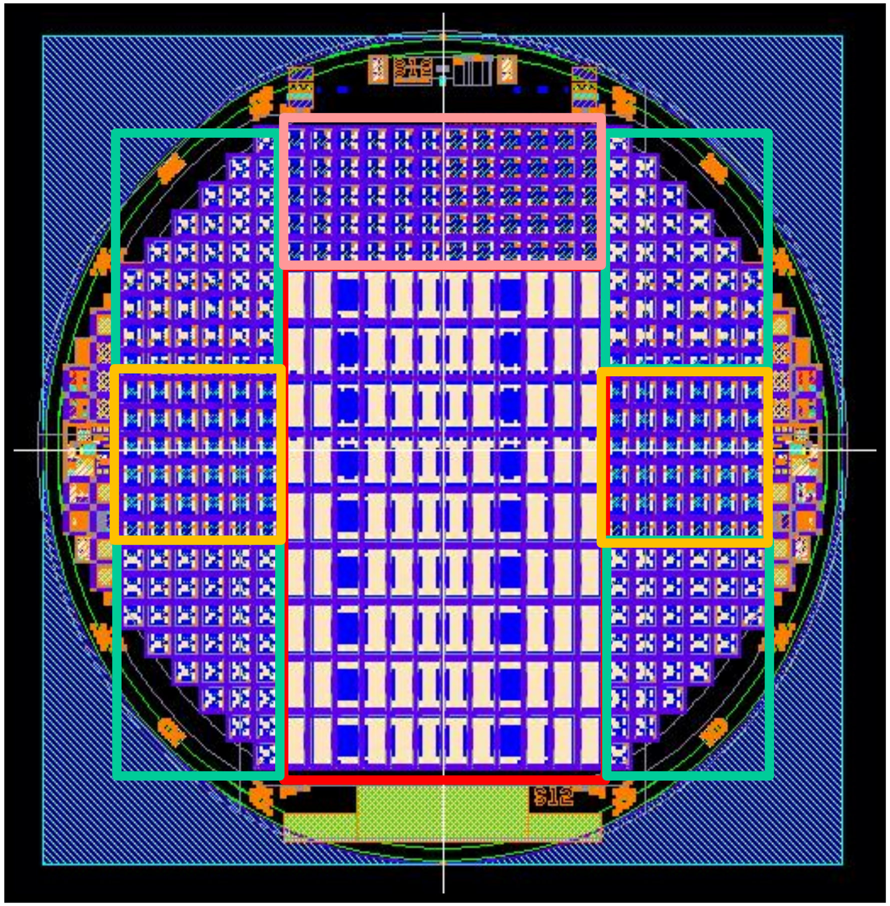
Aims

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



backside p+ entrace window
non structured, no Al

Pixel Strips Diodes MGR Diodes



production finished
tests started

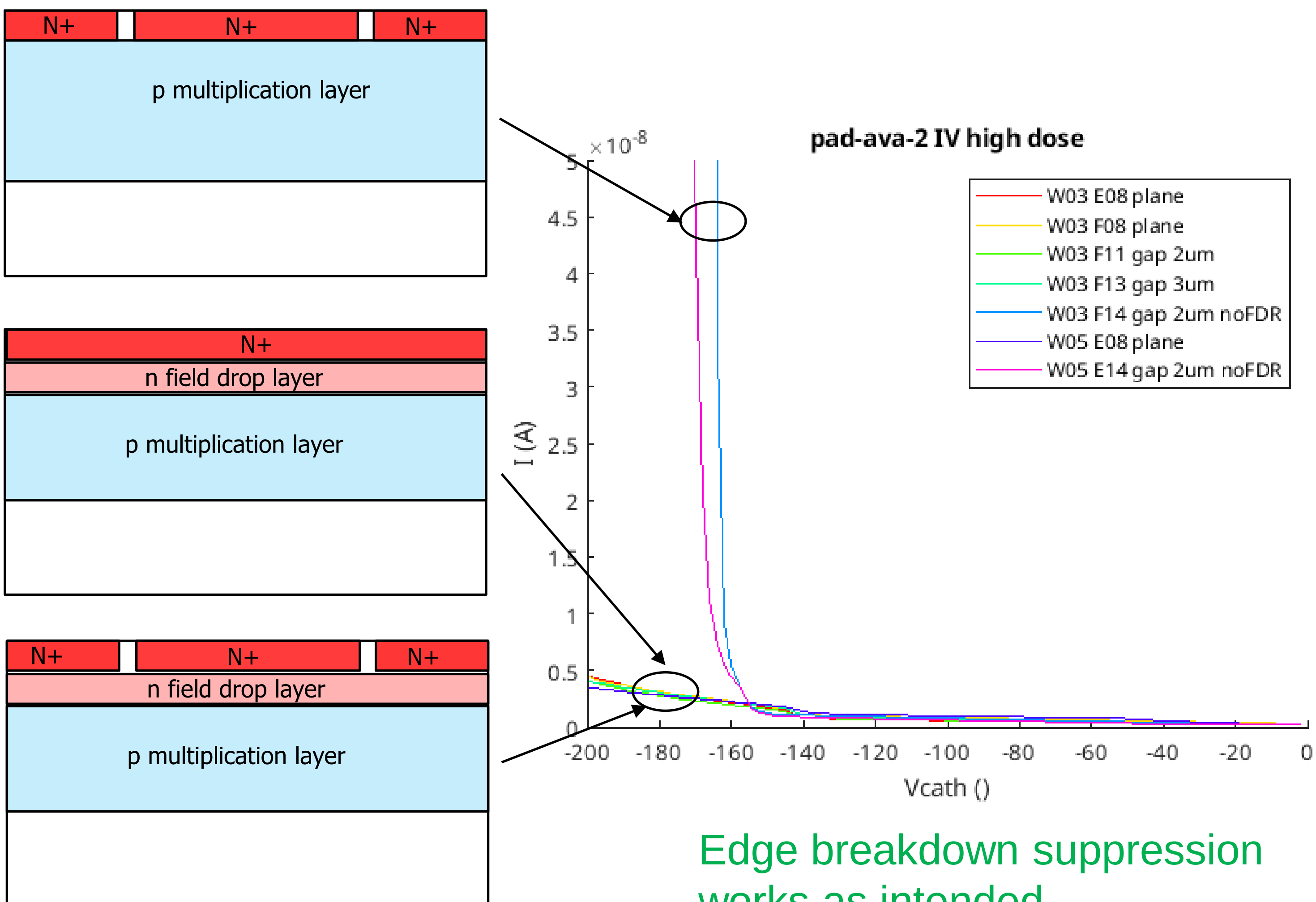
APD DIODES WITH AND WITHOUT GAPS

diodes 2x2mm²

diode with gaps but without FDL

plane diode

diode with gaps and FDL

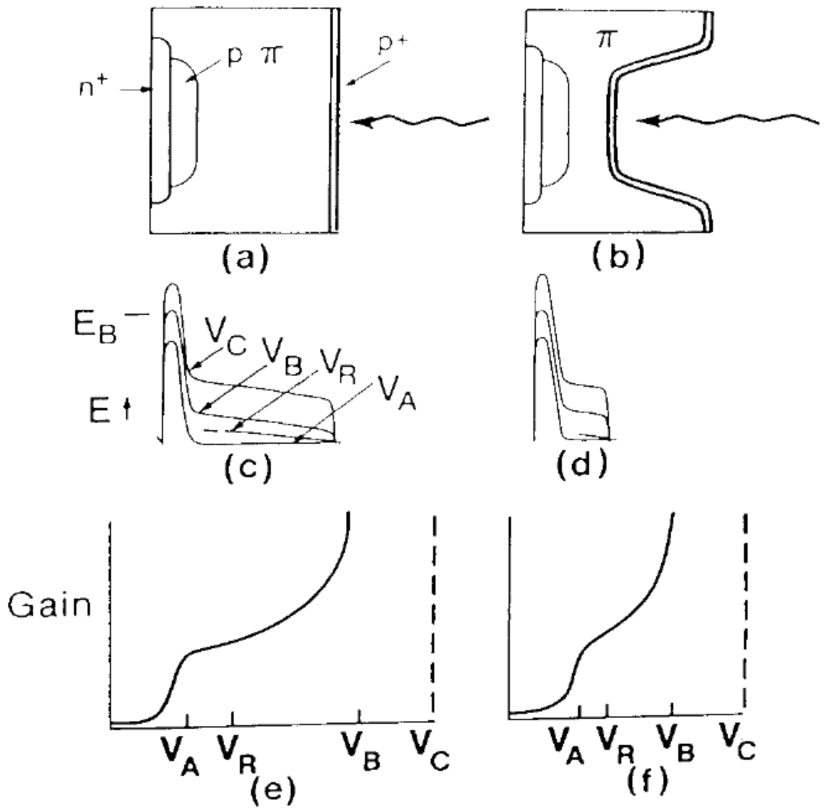


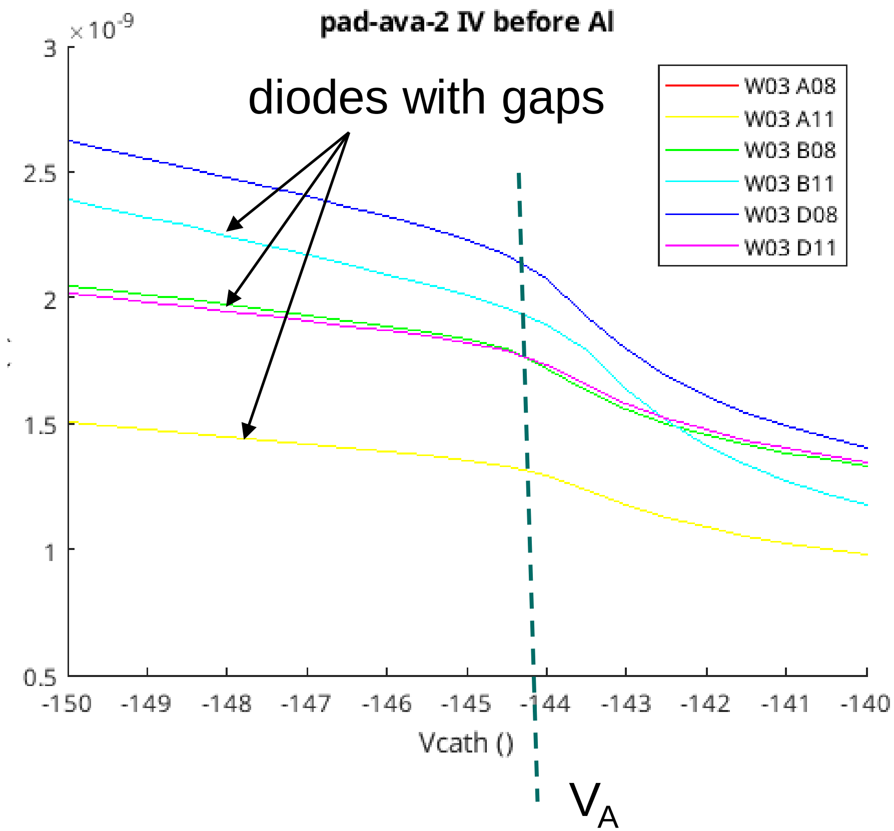
Edge breakdown suppression works as intended

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)

SUMMARY

MARTHA – a new approach for an APD pixel array

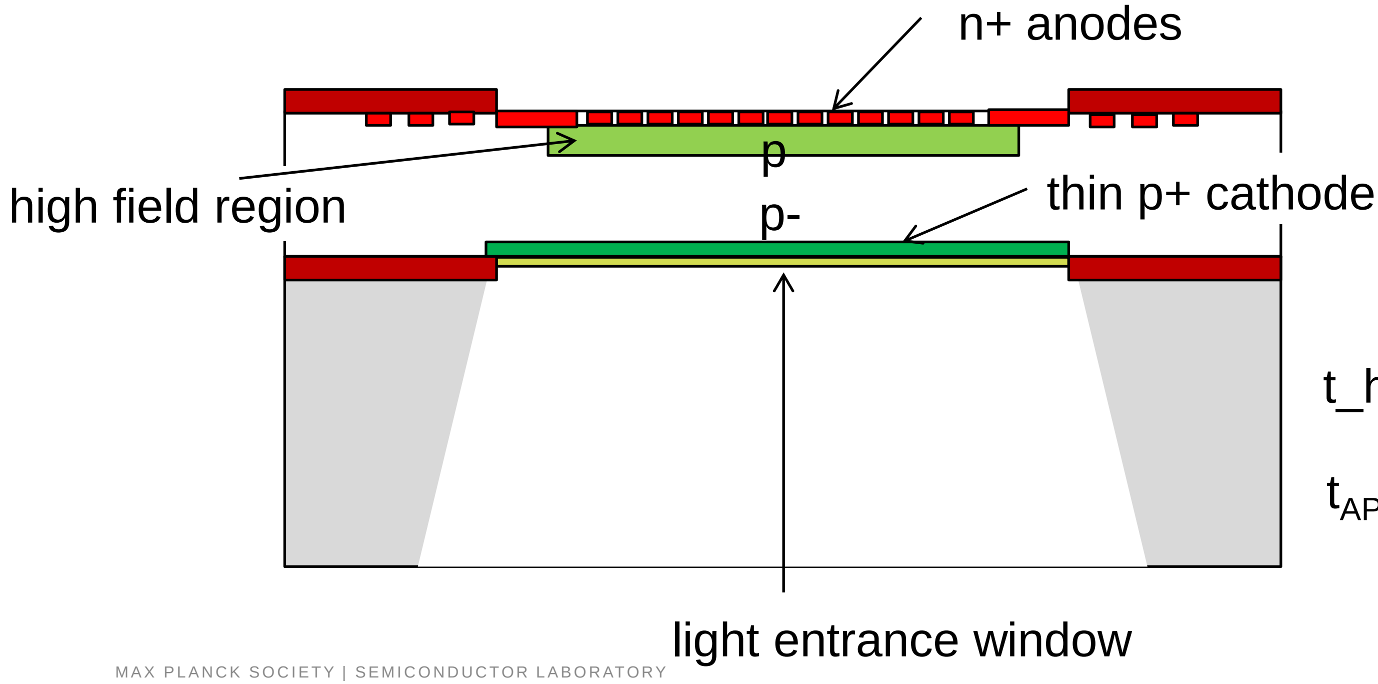
- operated in RT proportional mode
- no inter pixel dead space
- suitable for large pixel arrays
- low excess noise due to HE high field implantation
- First prototyping – small APD arrays and strips
- will be tested further soon

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**



t_handle_wafer ≈ 400µm

$t_{APD} \gtrsim 20\mu m$

THANKS FOR YOUR ATTENTION

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

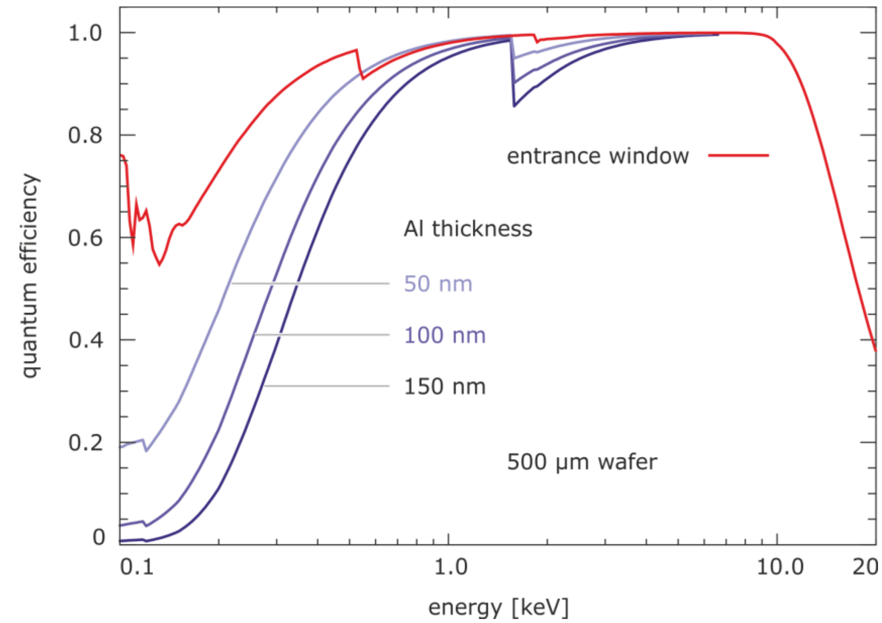
BACKUP SLIDES

PIXEL CAPACITY

expected pixel capacity

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

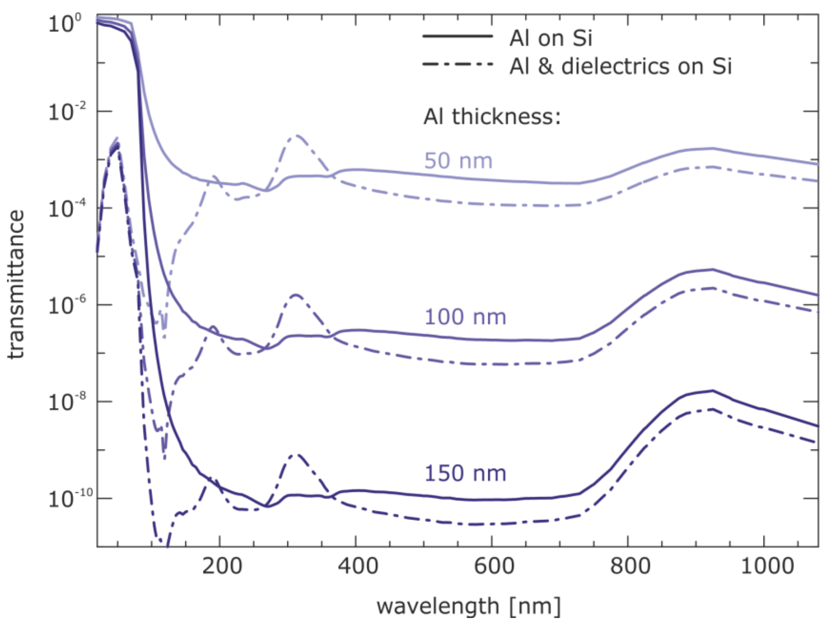
HLL THIN ENTRANCE WINDOW



fully depleted
sensitive over the complete bulk
thickness 50 .. 450 .. 1000 µm
thin, non-structured entrance window
QE > 90% for 0.3 keV < E < 15 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



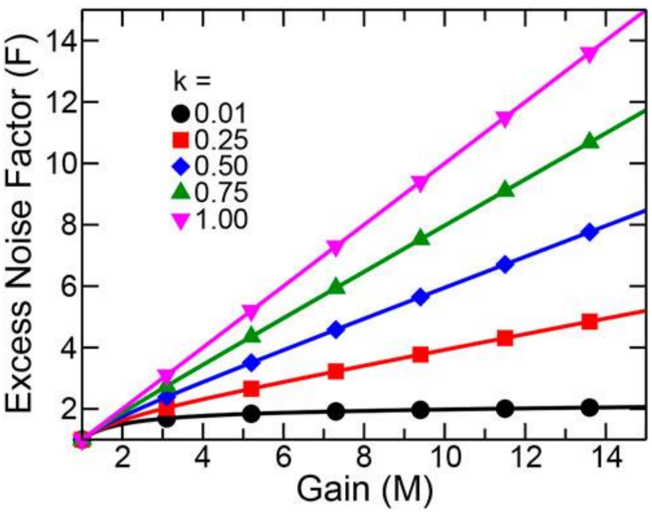
OPTIMIZATION FOR SOFT X-RAY DETECTION (LOW EXCESS NOISE)

Excess noise factor

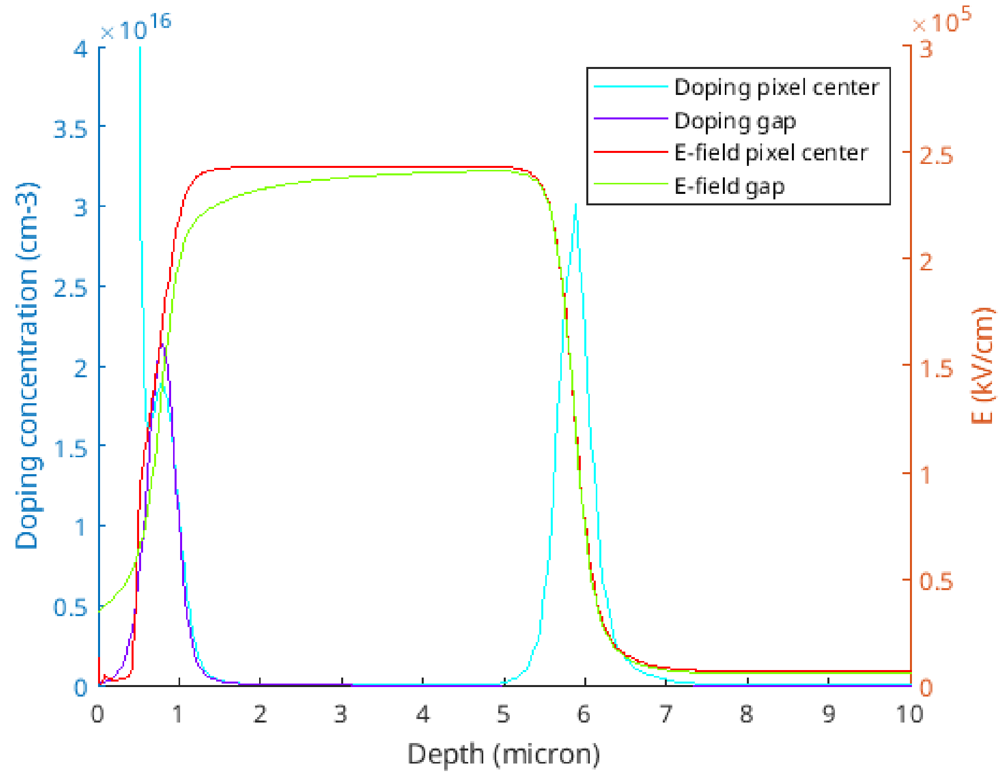
$$F = M * k + (2 - \frac{1}{M})(1 - k)$$

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

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!

MPG HLL

At present
Siemens Campus Neuperlach Munich

- $1000m^2$ of clean room area
- $330m^2$ of ISO3 area
- Full 6 inch silicon process line

New building
IPP Campus Garching
in autumn 2023 – move started

- $1500m^2$ of clean room area
- $600m^2$ 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