MAX PLANCK SEMICONDUCTOR LABORATORY

VCI2025 - 17th Vienna Conference on Instrumentation

MARTHA – FIRST MEASUREMENT RESULTS

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F. Schopper, J. Treis

MPG HLL

New Building

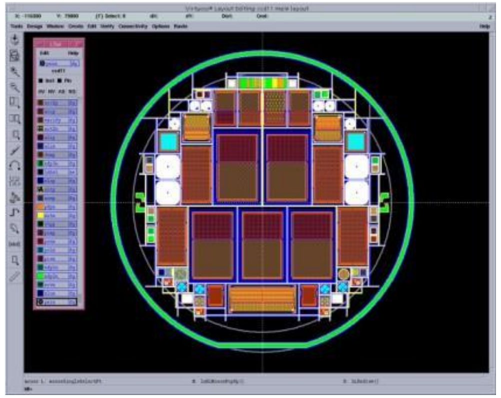
- IPP Campus Garching
- moved recently

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

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

sensor

- simulation
- design
- fabrication



camera

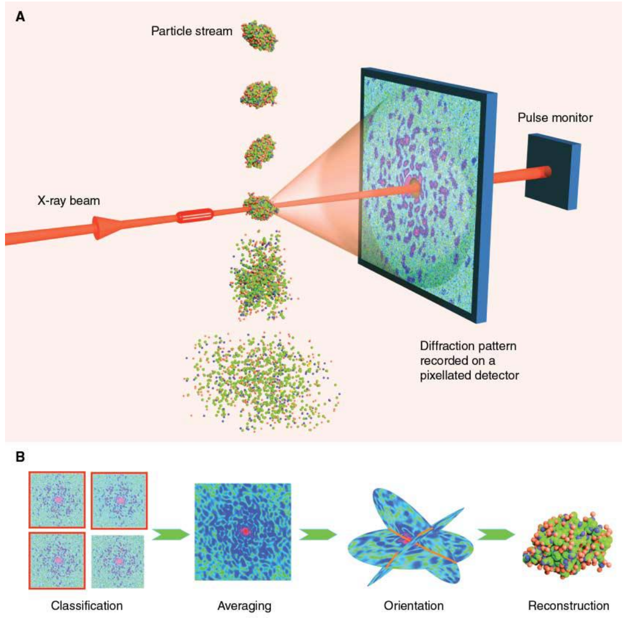
- design
- assembly
- test

MONOLITHIC ARRAY OF REACH THROUGH AVALANCHE DIODES (MARTHA)

being developed for photon science applications

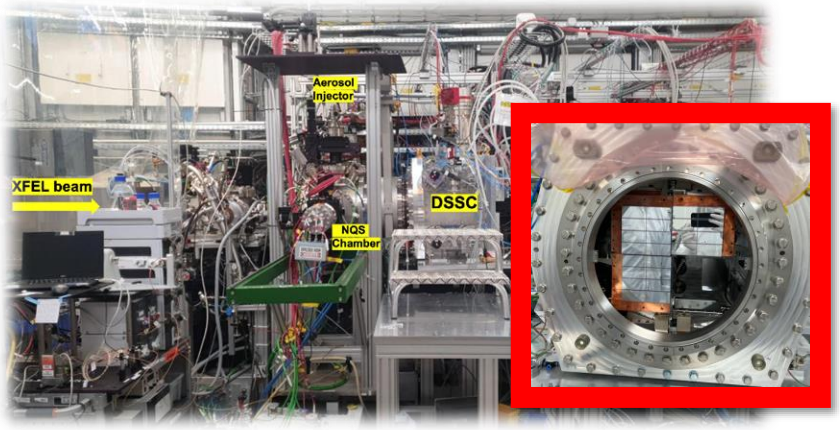
(soft X-ray) Photon Counting

For applications at FELs



K.J. Gaffney and H. Chapman, Science 316, 1444 (2007)

- for example at the EU-XFEL

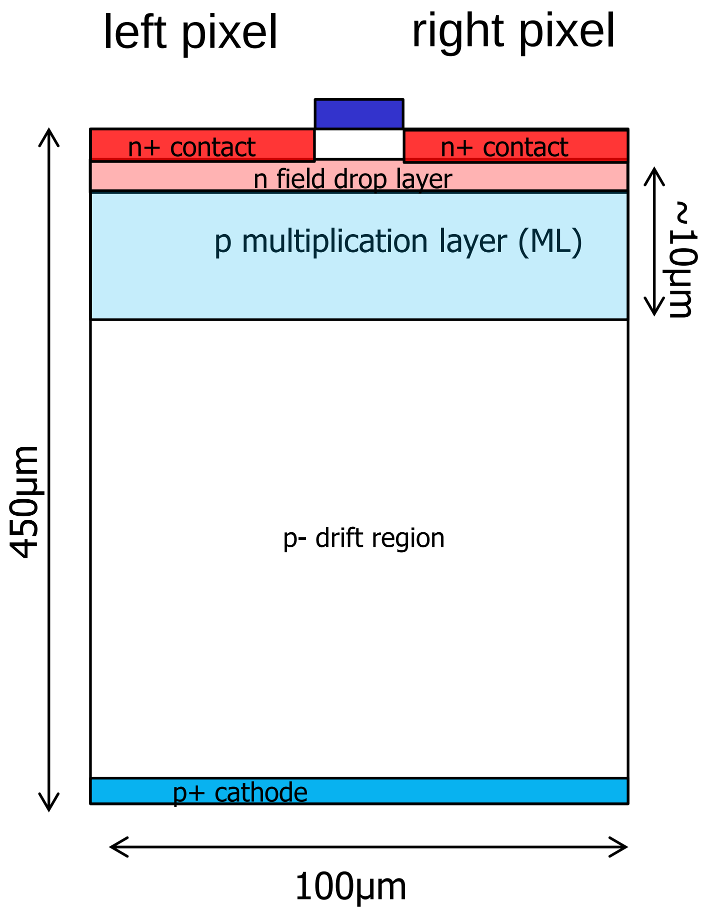


MiniSDD DSSC camera @ the SQS experiment at the EU-XFEL
with curtesy of Matteo Porro, XFEL

In discussion

- application at other FELs
- fast timing applications

THE MARTHA CONCEPT



- reach-through APD
- 50 µm pitch

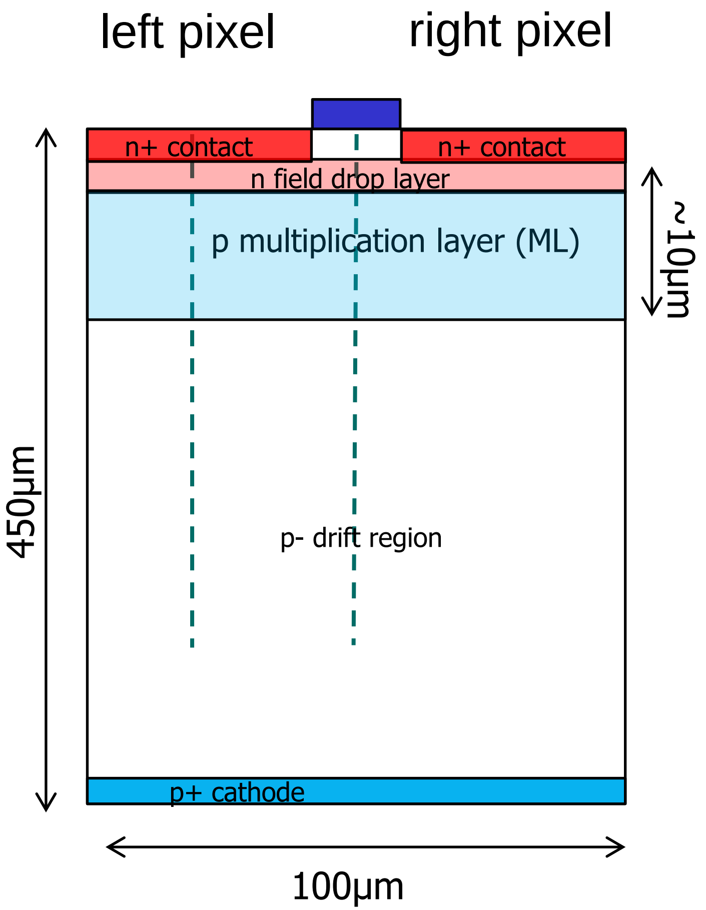
based on HLL „standard“ technology

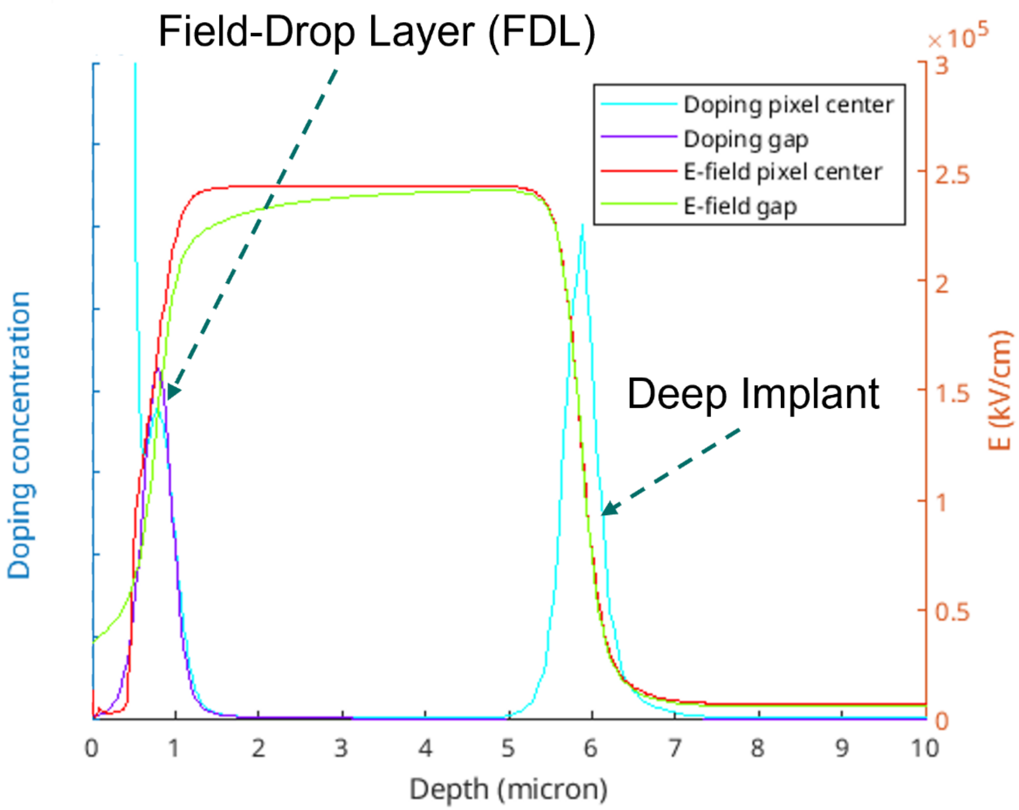
- (HLL) thin entrance window + avalanche multiplication
- homogeneous gain

interpixel isolation requirements

- suppress edge break down
- reduction of E-fields at interface (oxide charge up, H-bond cracking)

2D SIMULATION - ELECTRIC FIELD





deep Implant

- **extended ML**
- **lower field**
- **low k-factor**
- **low excess noise**

FDL:

- **shift Max E-Field**
- **prevent breakdown**

2D SIMULATION - ELECTRIC FIELD

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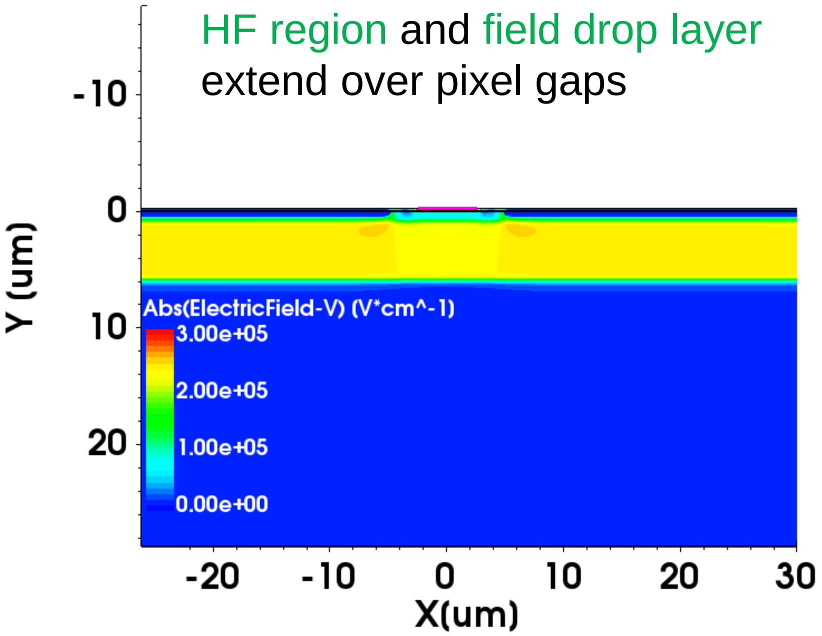
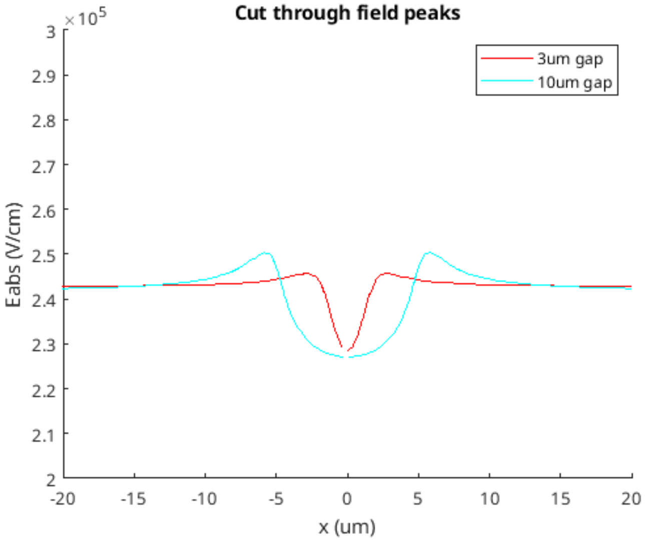
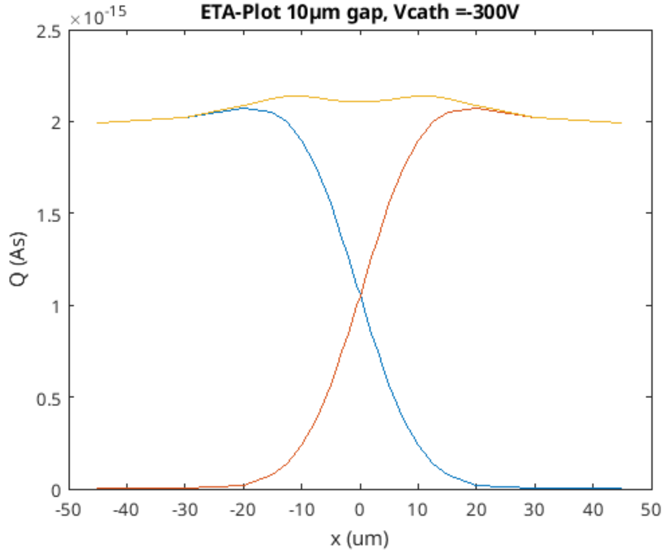
HF region and field drop layer extend over pixel gaps

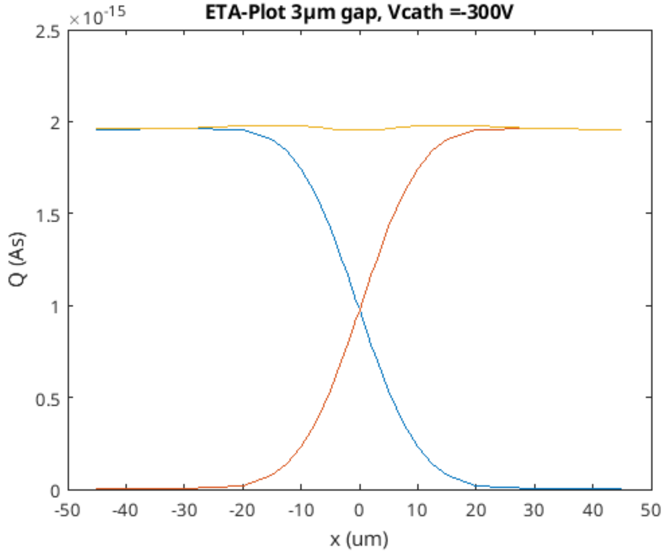




Electric field

„overshot“ at gap corners





amplified signal

gain also in gap region

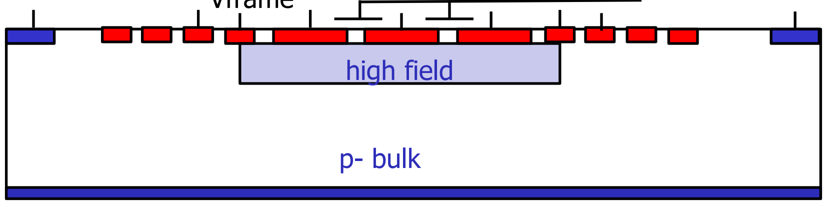
field „overshot“ leads to gain variation

overshot depends on gap size

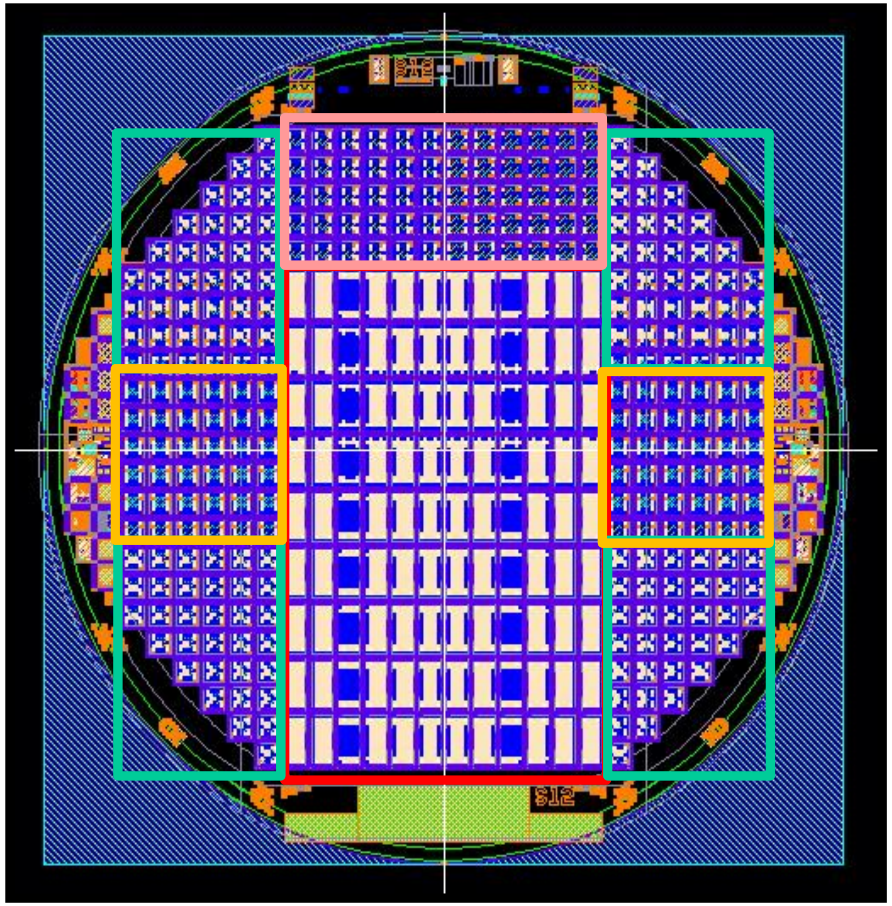
(and operation conditions)

PROTOTYPE PRODUCTION – FINAL LAYOUT

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

MULTI PURPOSE MEASUREMENT SETUP

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static measurements

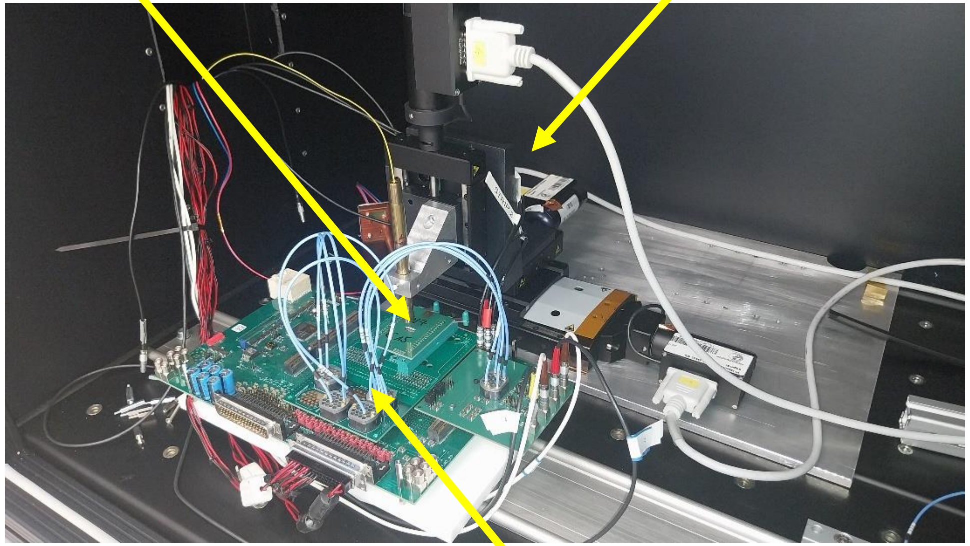
- **Keithley Parameter Analyzer 4200A**

dynamic measurements

- **4 channel transimpedance amplifier PCB**
- **Lecroy Oscilloscope**

x-y-z stage + laser

DUT



flexible connections to different redout electronics

FIRST MEASUREMENTS

two wafers with different dose for HE implant

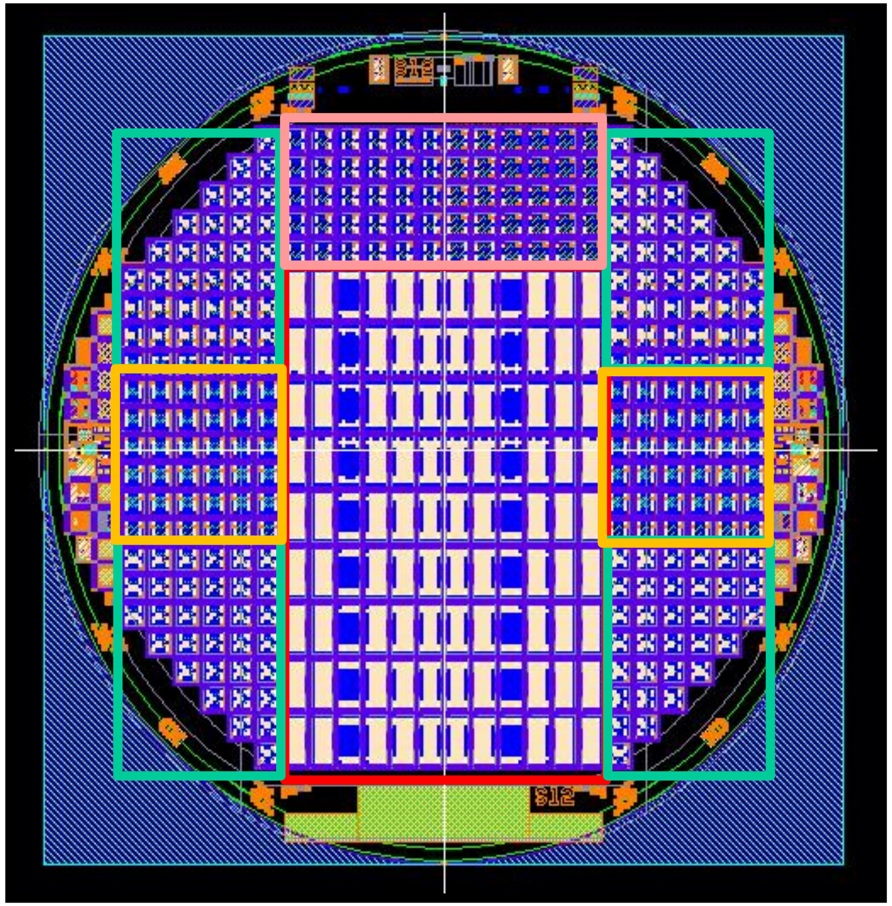
- **high gain**
- **low gain**

Measurements on Diodes with HE implant and FDL

- **gain**
- **homogeneity over wafer**
- **(linearity)**

Measurements on strips

- **behavior in gap regions**
- **homogeneity over small scales**



Pixel Strips Diodes MGR Diodes

GAIN OF FIRST PROTOTYPE(S)

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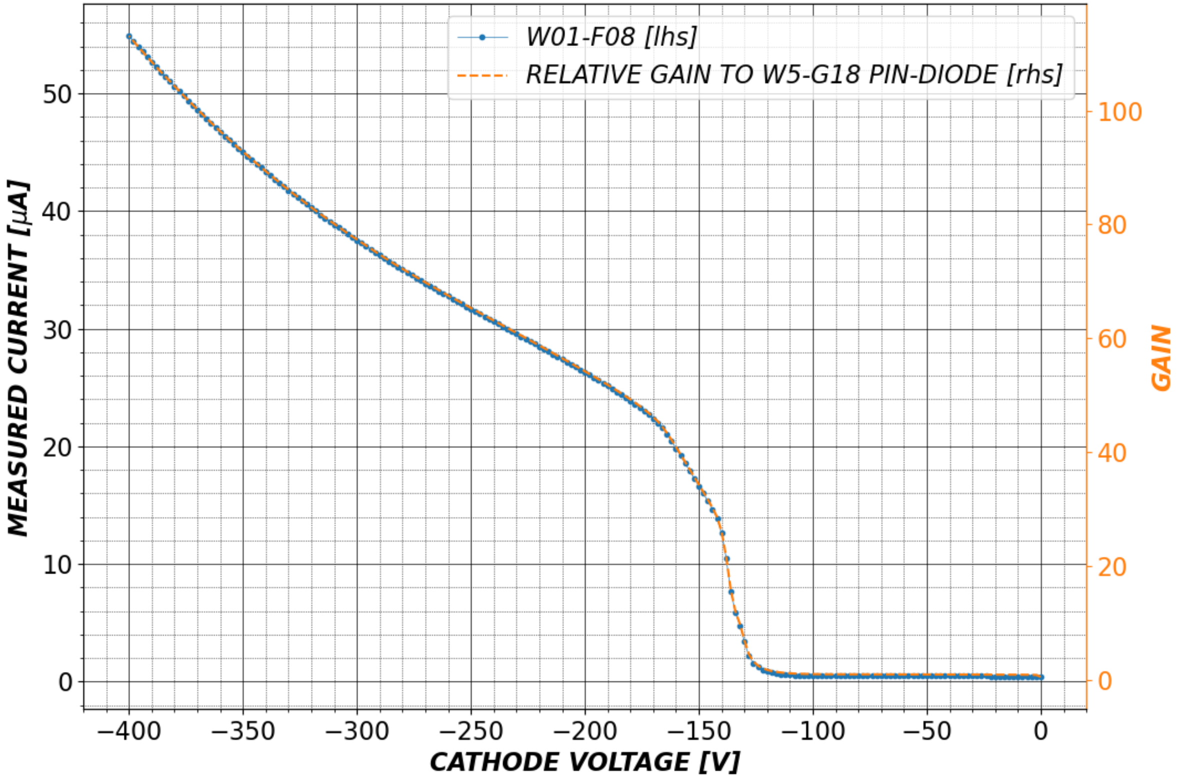
high gain diode



gain measurement

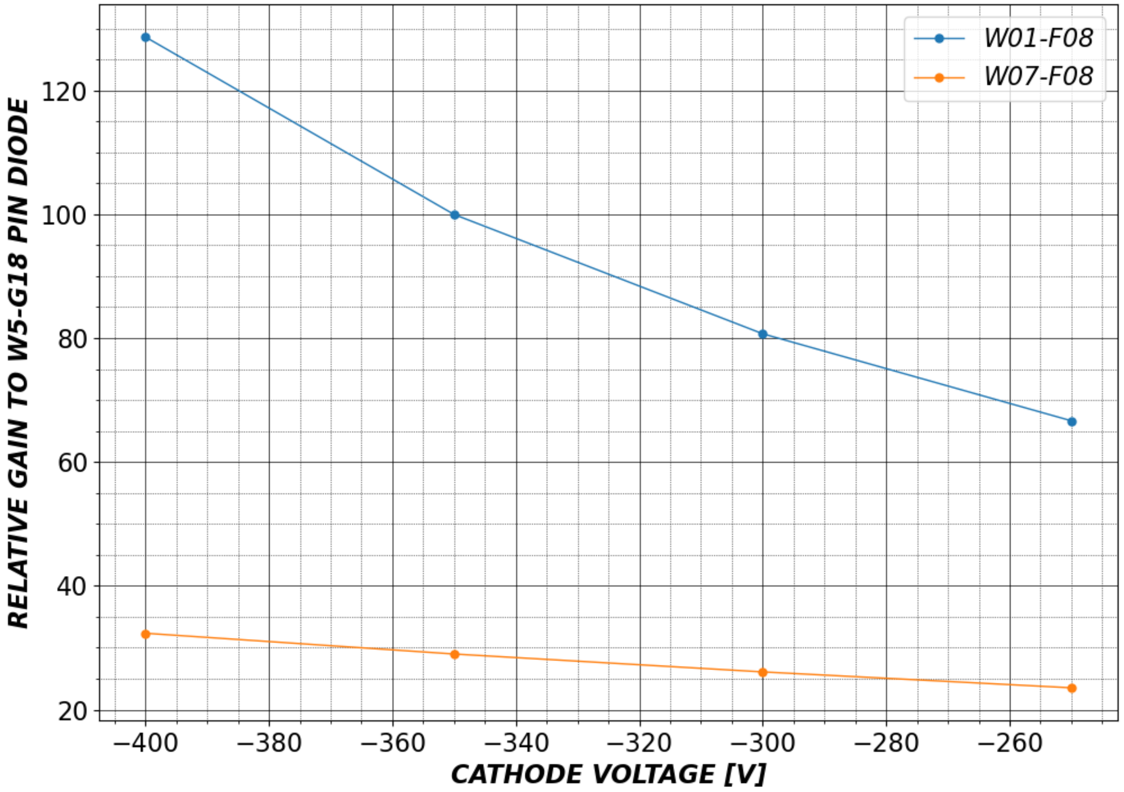
- **diode illuminated by laser**
- **measure photocurrent of APD and PIN diode**
- **Gain as ratio of photocurrents**
- **backside voltage sweep**

steep current increase at -140V

- **depletion of MR**
- **further increase of gain with backside voltage**
- **gain of ~80 @ -300 V**

PRODUCED GAIN RANGE

high gain and low gain diode



comparision of gain of two APDs from different wafers

full depletion @ -250V

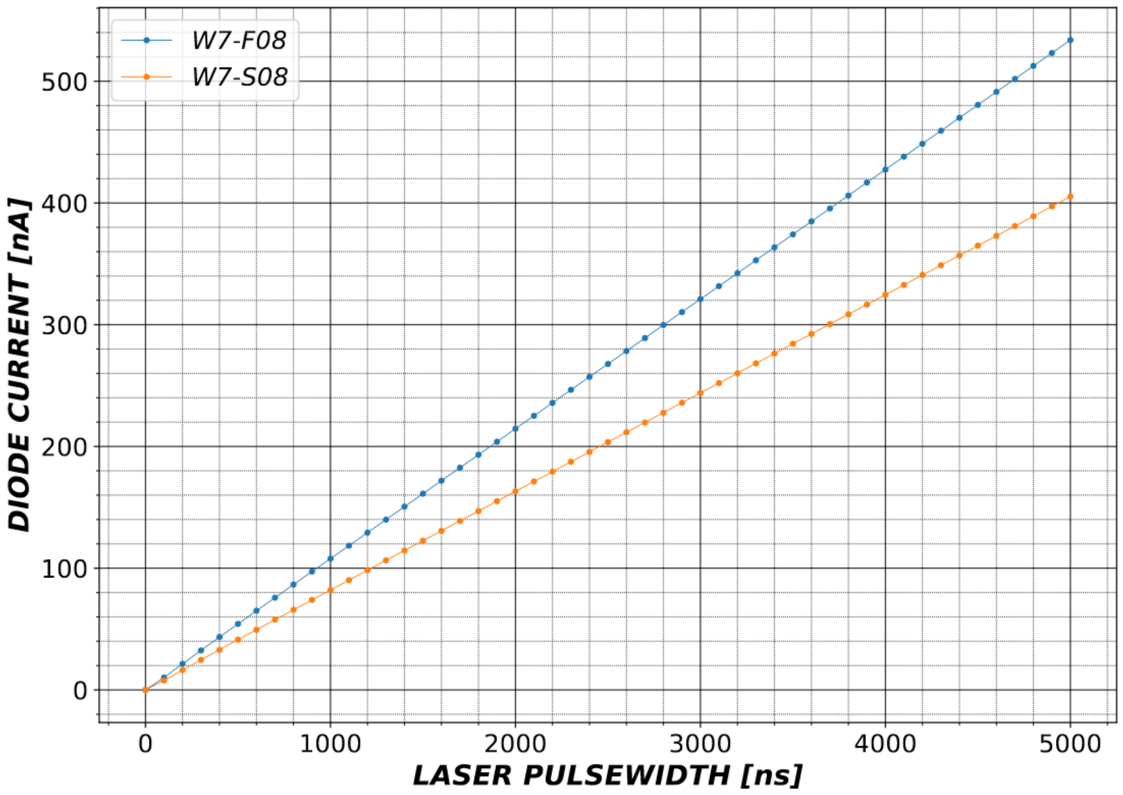
- **depletion of MR + Bulk**

high gain of 81 @-300V

low gain of 26 @-300V

GAIN VARIATION (OF TWO DEVICES)

low gain diodes



40 ns Laser Puls ~ 11000 e$^-$

laser focussed to ~ 10 µm

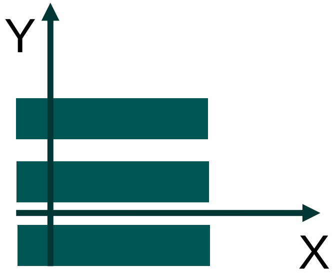
maximal Signal ~ 10^6 e$^-$

diode response largely linear

two diodes at 6.5 cm distance

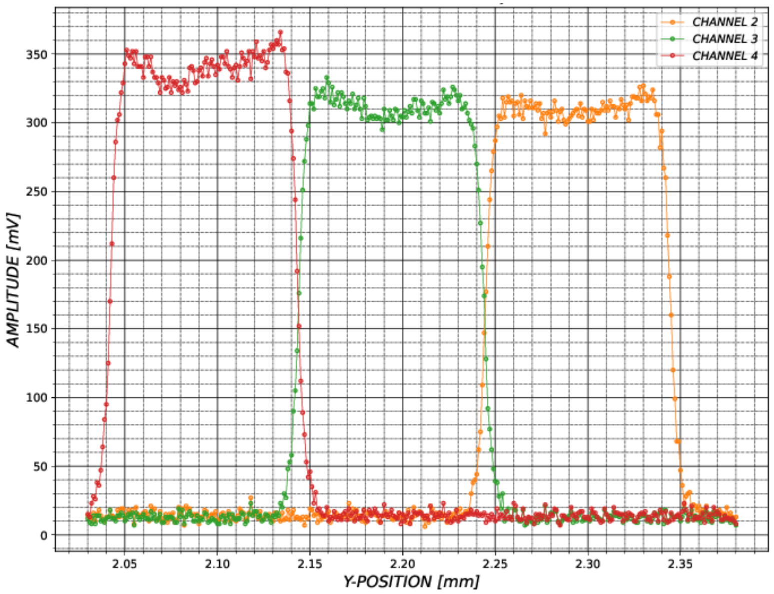
gain variation ~ 25% (on wafer scale)

GAP BEHAVIOUR OF FIRST PROTOTYPE

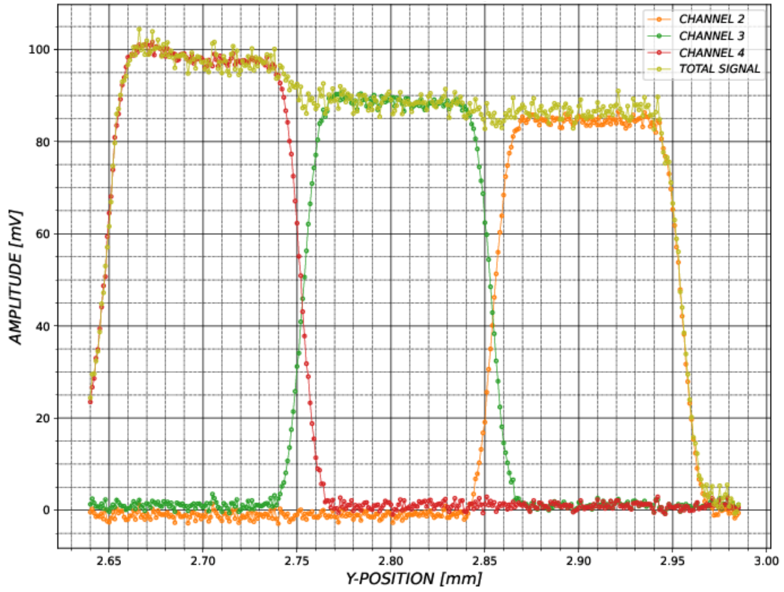


strips
3 µm gap

high gain strips



low gain strips



40 ns Laser Puls ~ 11000 e$^-$

laser focussed to ~ 10 µm

different signal height due to variation of the ROE (parasitic capacity on PCB)

„overshot“ related to field in gap region

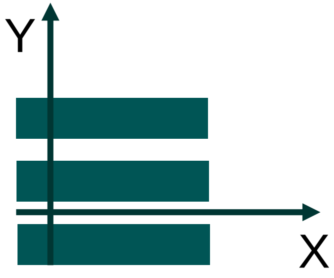
optimized settings: gain in gap-region (mostly) constant

gap isolation functional

overshot for high gain (as expected)

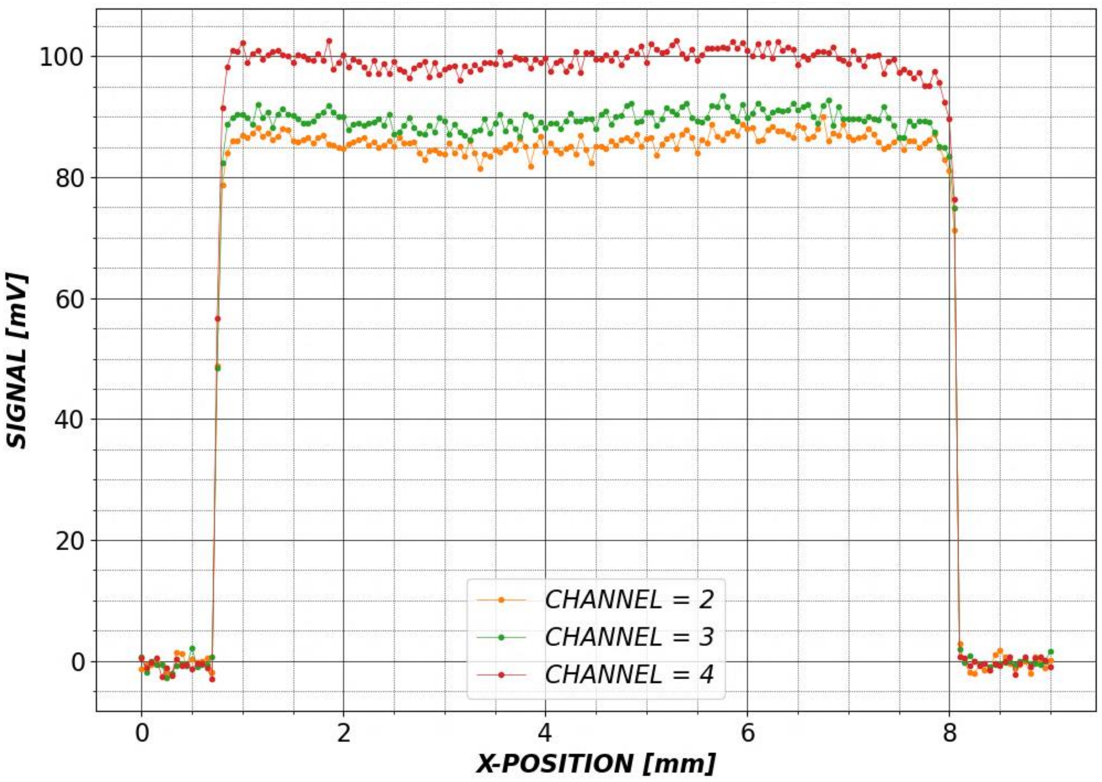
no inter pixel dead space

GAIN HOMOGENEITY



strips
3 µm gap

low gain strip



laserscan over the length of the strip.

no significant change of signal over 7 mm

good homogeneity over small scales

SUMMARY

MARTHA

- novel APD concept
- no inter pixel dead space
- suitable for large pixel arrays
- first prototyping
  - small APD arrays and strips

Measurements on First Prototype

- devices from two wafers with APD
  - gain of 26 and 78 @ -300 V
- gap-isolation functional
- no dead space between strips

Next Steps

test of more devices

- homogeneity over wafer scale
- further investigation of gap regions
  - gap sizes from 1-5 µm available

design of optimized readout electronics

- investigate timing capabilities of current devices
  (450 µm Bulk)

OUTLOOK

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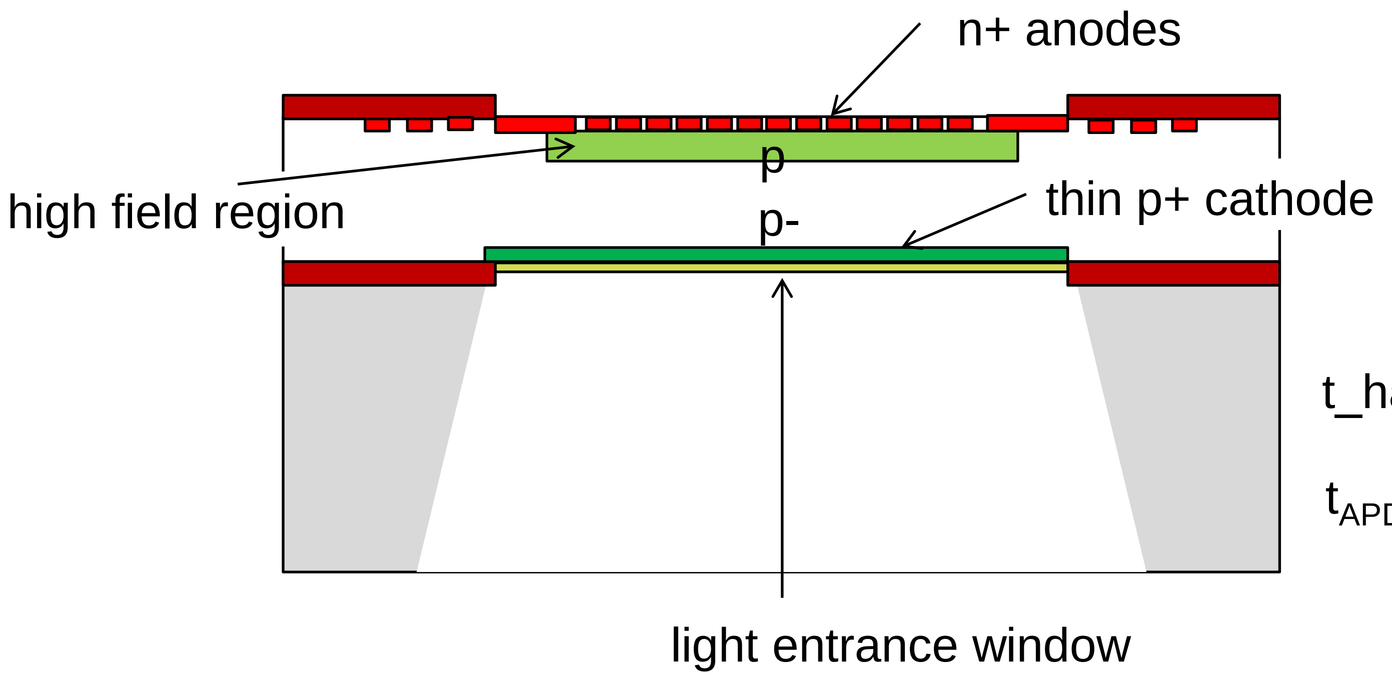
- **MARTHA sensors can also be produced on thinned wafers**
  - **improved timing capabilities**



t_handle_wafer ≈ 400µm

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

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THANKS FOR YOUR ATTENTION

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BACKUP SLIDES

PIXEL CAPACITY

expected pixel capacity

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

HLL THIN ENTRANCE WINDOW

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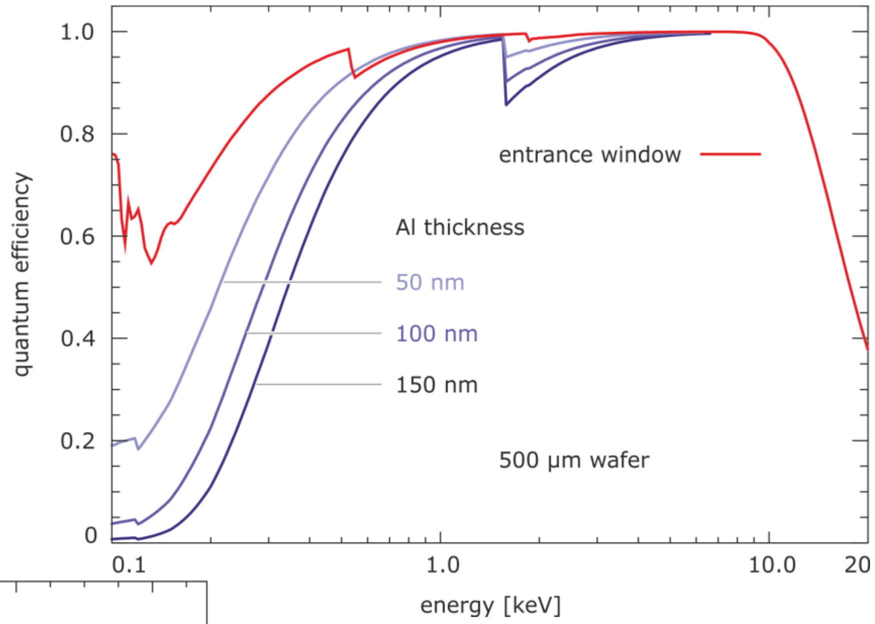
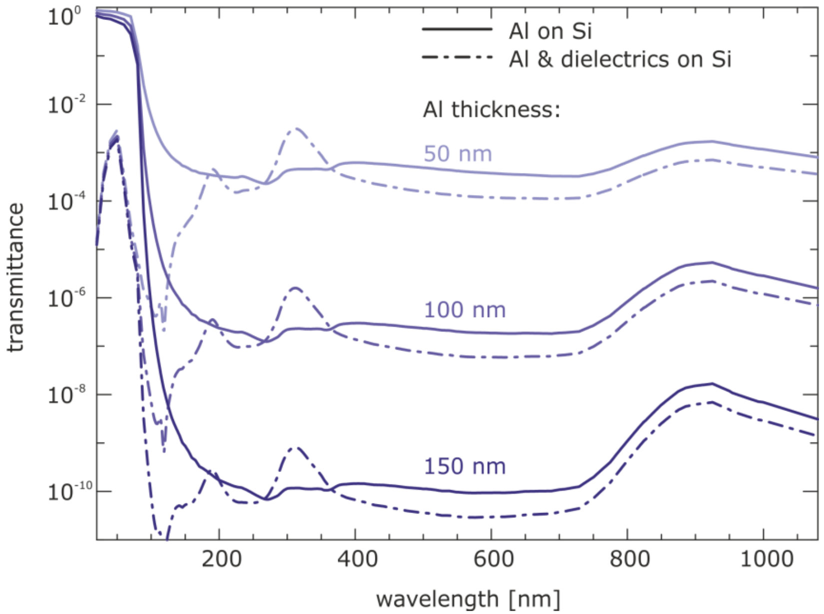
fully depleted
sensitive over the complete bulk
thickness 50 .. 450 .. 1000 µm
thin, non-structured entrance window
QE > 90% for 0.3 keV < E < 15 keV
radhart @ soft X-rays (self shielding)

backside irradiation
100 % fill factor
optional light (& UV) filter

integrated first amplifier
low noise
fast readout
emi robust



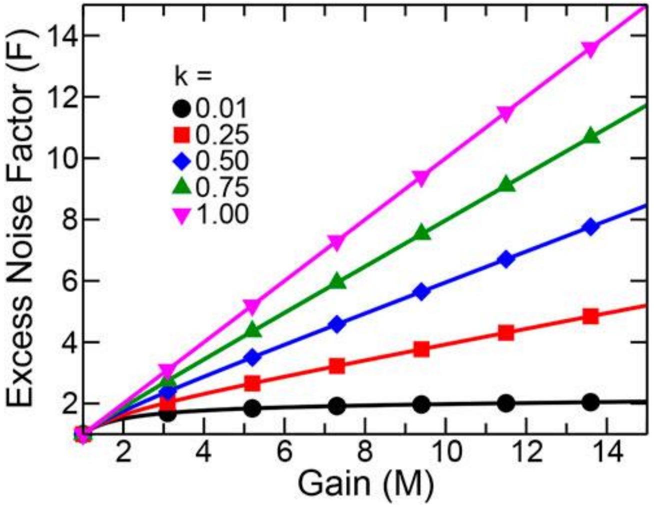


OPTIMIZATION FOR SOFT X-RAY DETECTION (LOW EXCESS NOISE)

Excess noise factor

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

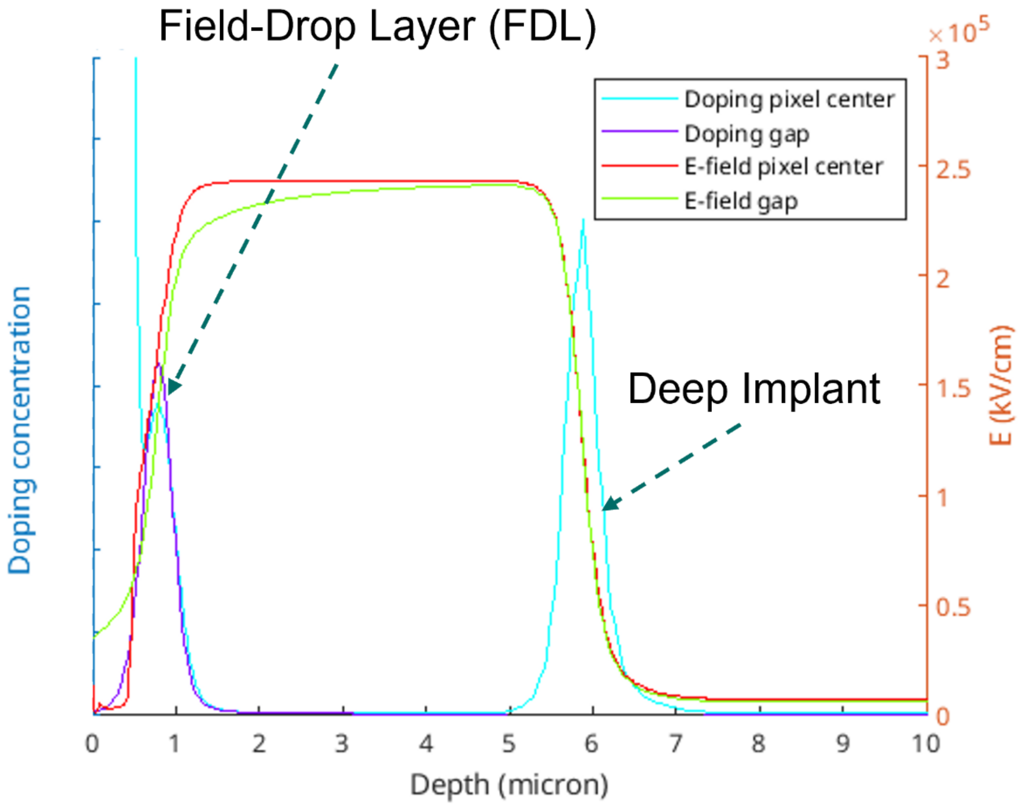
$k = \frac{\alpha_h}{\alpha_e} < 1$



A. Pilotto et. al. (2022)

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

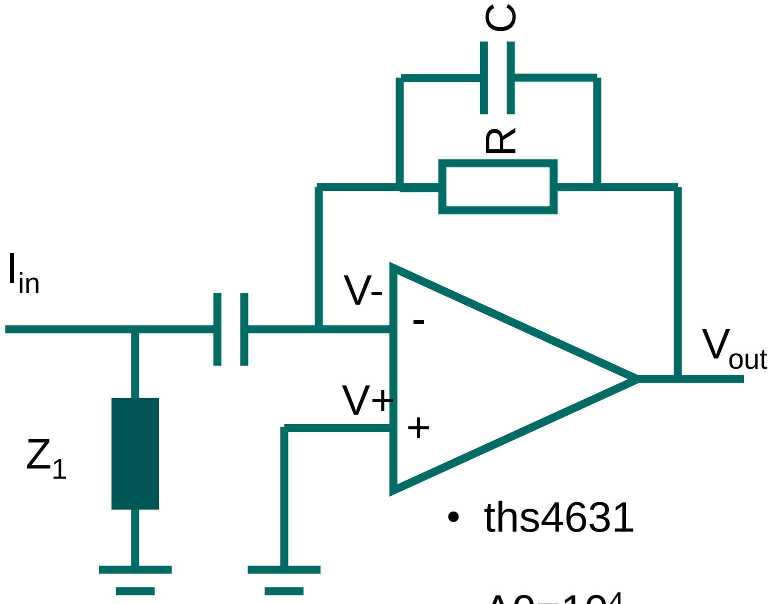
deep implant (6 µm)
extend ML



(CAPACITIVELY COUPLED) TRANSIMPEDANCE AMPLIFIER

readout electronics not optimized for APD

I2V gain given by feedback R, C and Opamp parameters



- ths4631
- $A0=10^4$
- GBP=200MHz

$R \sim 10^6$

$C \sim 10^{-12}$ **capacity dominated by parasitics**

susceptible to layout and board variations