# VTT's EDGELESS DETECTORS FOR EUDET

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# Outline

- Facilities and process resources
- 3D detector process
- Edgeless detector prototypes on 6” wafers
    - Wafer layout, fabrication process
    - Different designs: p-on-n and n-on-n
- Strip detector characteristics review
- N-on-n medipix2 pixel detector design & characteristics
    - IV-curves
    - First X-ray image
- Study of edgeless detector response
    - TCAD simulation
    - X-ray tube response
    - Radiation source responses
- Summary

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# MICRONOVA CLEANROOMS

## Main Cleanroom Characteristics

| | |
|---|---|
| Total Area | 2 600 $m^2$ |
| Cleanroom Classification (in clean bays) | ISO 4…ISO 6 (10…1000) |
| Temperature | 21 °C ± 0,5 °C |
| Relative humidity | 45 % ± 5% |

Clean bay - Service chase type
Ventilation based on filter fan units
Raised perforated floor
Subfab with technical support areas

## Labs with built-in Cleanrooms

Micropackaging lab - dicing saws, wire bonding

SubTech lab - Ion implantation, CMP, backgrinder, wafer bonder

**Process equipment is mainly for 150 mm wafer size, but some processes can be performed also on 200 mm wafers**

# Equipments

**Furnace:**
- oxidation, LTO, TEOS, Nitride, doped and undoped polysilicon
- 2 Centrotherm furnace stacks

**Lithography:**
- Contact aligners – MA150 and MA6 (bottom side alignment), MA200
- E-beam writing – Zeiss LEO 1560
- Step and Stamp Imprint Lithography – Suss MicroTec NPS 300
- i-line stepper, Canon FPA 2500i3
- Resist/development tracks, Suss ACS 200 and AIO Duna 700

**Dry etching**
- Etchers for silicon oxide, nitride, metals - LAM 4520/4420/9600
- Deep silicon etching - Aviza Omega i2L and STS ASE
- Silicon oxide ICP etching – STS AOE
- RIE – Oxford 80Plus
- Plasma strippers (PRS 800/801), microwave asher (Aura 1000), wet ozone stripping

**Ion Implantation**
- Medium current, 200 keV, P, As, B – Eaton NV8200-P

# Equipments

**Sputtering:** AlSi, Mo, TiW, Si - Provac LLS 801

**PECVD:** Silicon oxide and nitride, incl. TEOS-process

**Electroplating:**

- Ni, Cu, SnAg, SnPb and SnBi – RENA and home-built plating systems

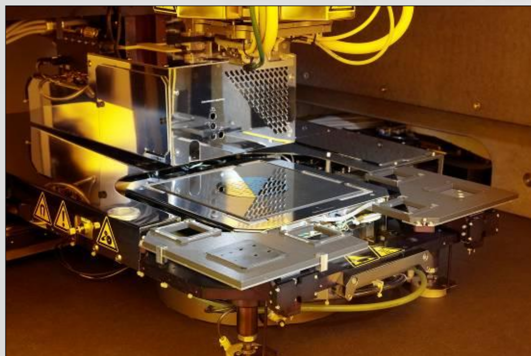
**Flip-chip bonding:** 2 Suss MicroTec FC150 bonders

**Dicing:** Disco DFD 651 and Loadpoint uAce-352

**Fusion wafer bonding:** EVG 5201S and EV 801 (non-IC materials)

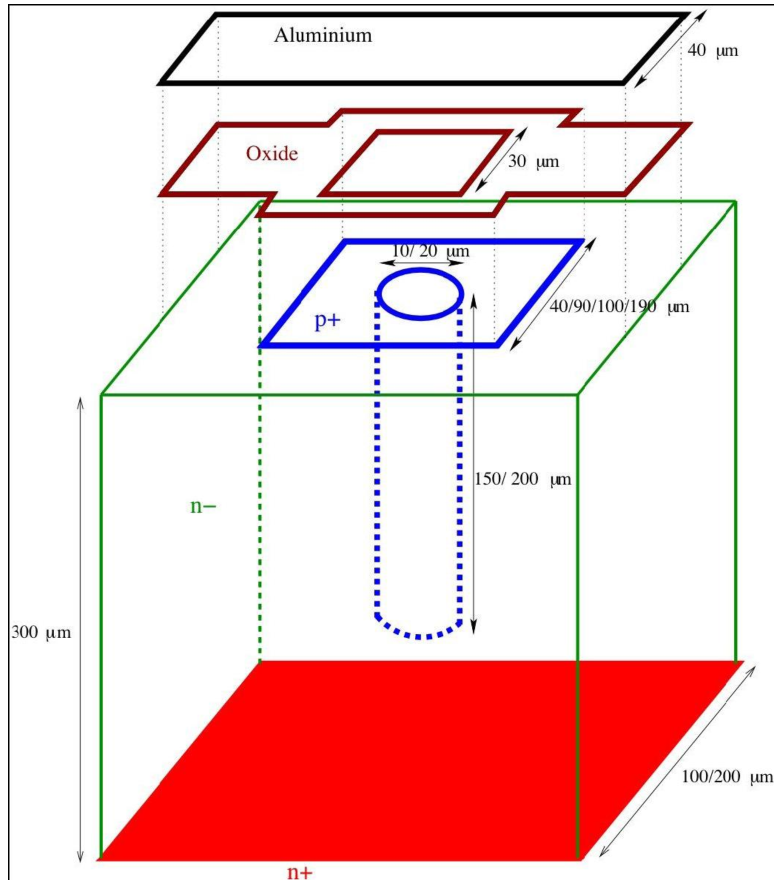
**Backgrinding (wafer thinning):** Strasbaugh 7AF

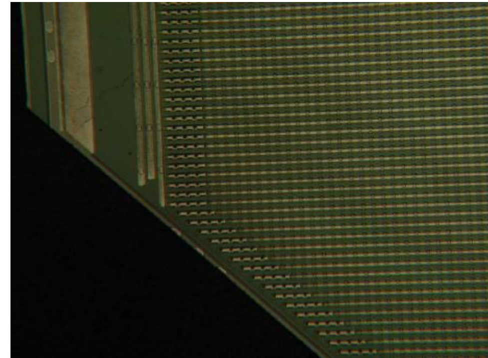
**Polishing and planarization:** Strasbaugh 6DS-SP

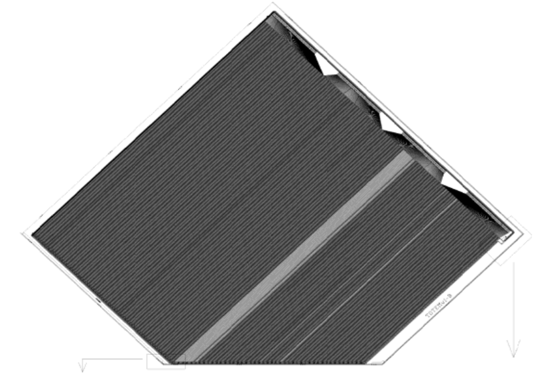


# VTT's 3D DETECTORS

## Pixel element of a strip detector

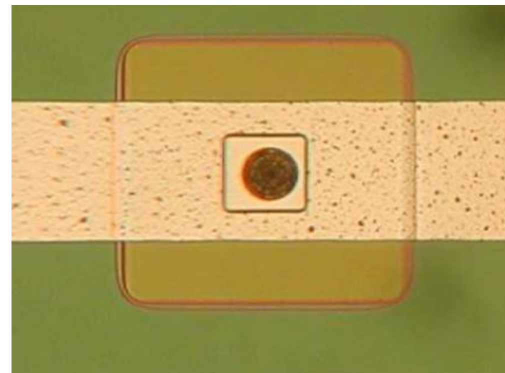


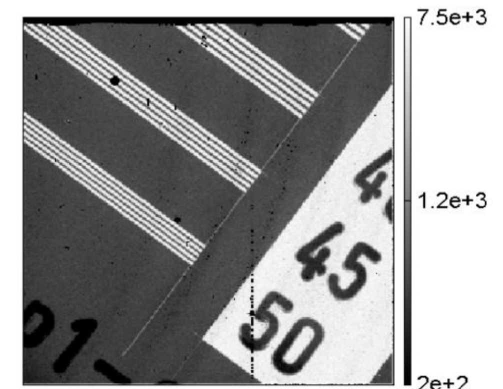





**PROPERTIES**

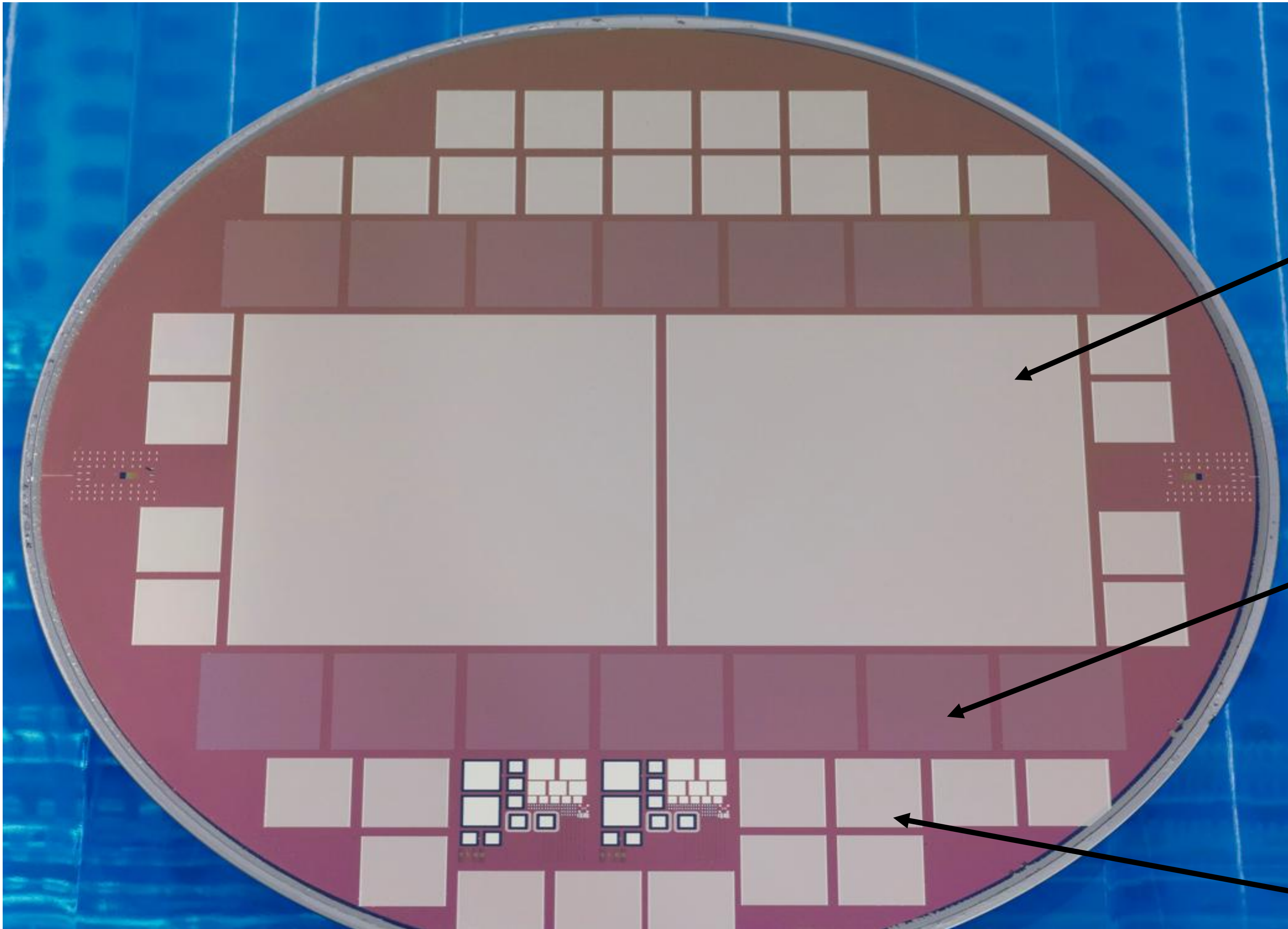
- GOOD SPATIAL RESOLUTION
- TUNABILITY OF THE VERTICAL DOPING PROFILES
- SMALL DEPLETION VOLTAGE
- LARGE AREA STRIP AND PIXEL DETECTORS DEMONSTRATED (~10 $cm^2$)
- SAME TECHNOLOGY FOR VERTICAL I/O's & EDGELESS DETECTORS






Pixel of a 3D strip detector and X-ray image taken with a 3D detector coupled to the Medipix2

# EUDET EDGELESS DETECTORS on 6" (150 mm) WAFER



**Main edgeless strip detectors**

- 5 x 5 $cm^2$
- DC & FOXFET
- 50 µm edge distance

**Medipix 2 edgeless pixels**

- 1,4 x 1,4 $cm^2$
- 20 & 50 µm edge distance

**Baby edgeless strip detectors**

- 1 x 1 $cm^2$
- DC, PT & FOXFET
- 20, 50 & 100 µm edge distance

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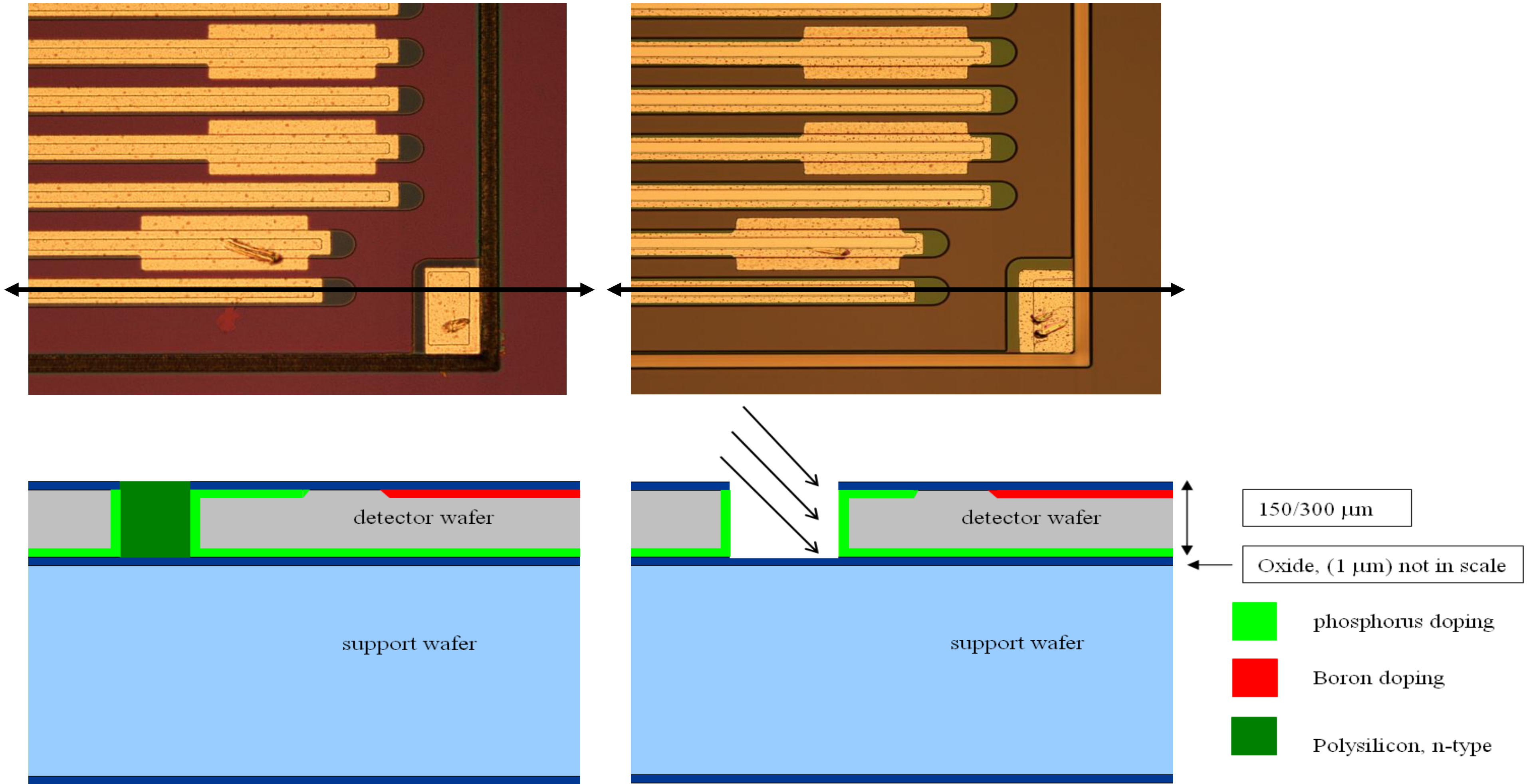
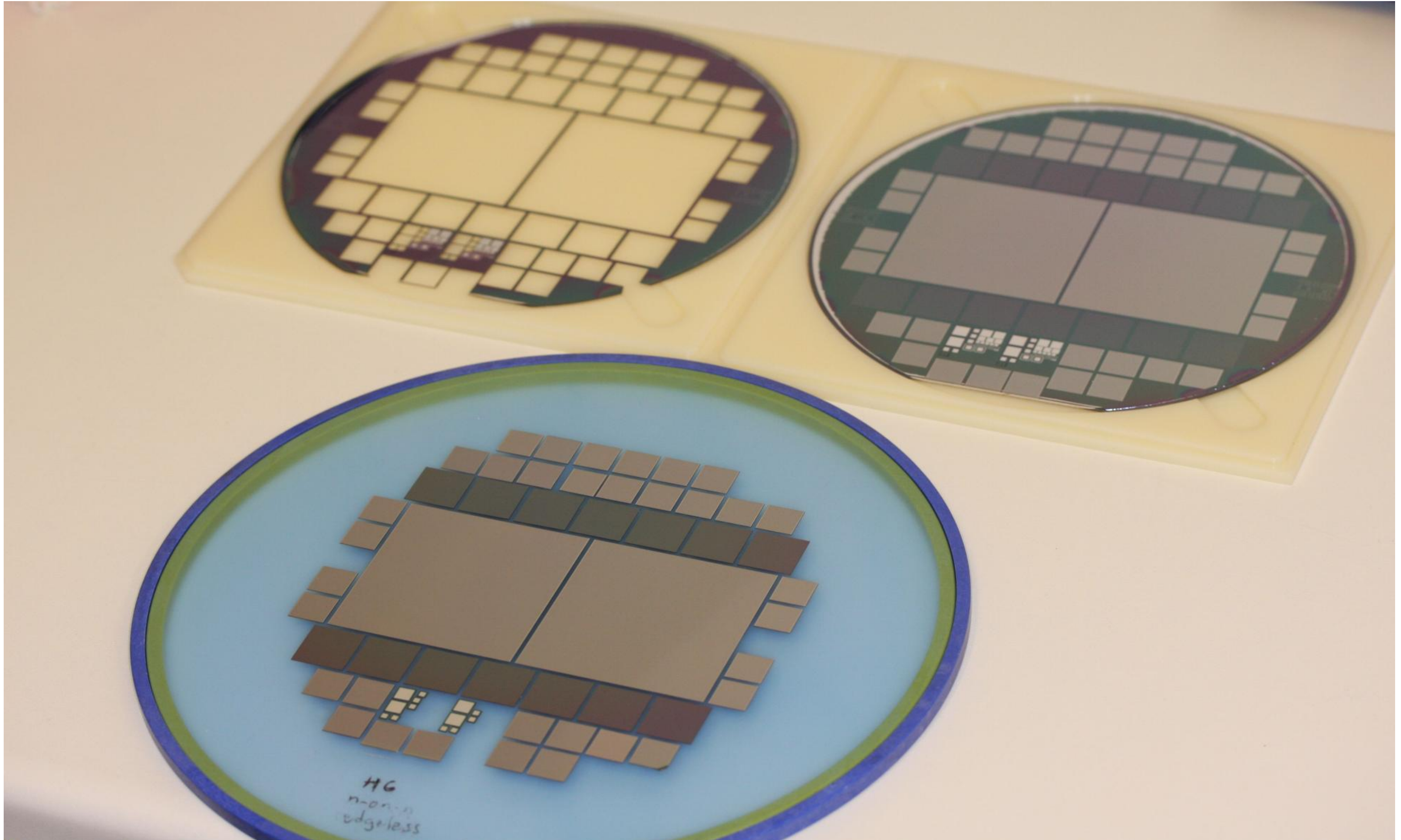
# VTT's edgeless fabrication process

Poly process, p-on-n

Edge implantation, p-on-n

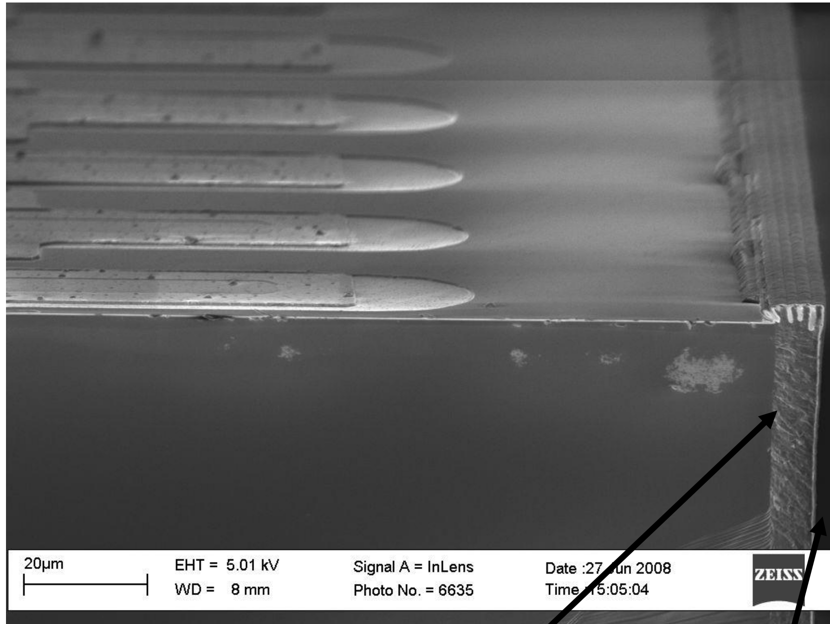


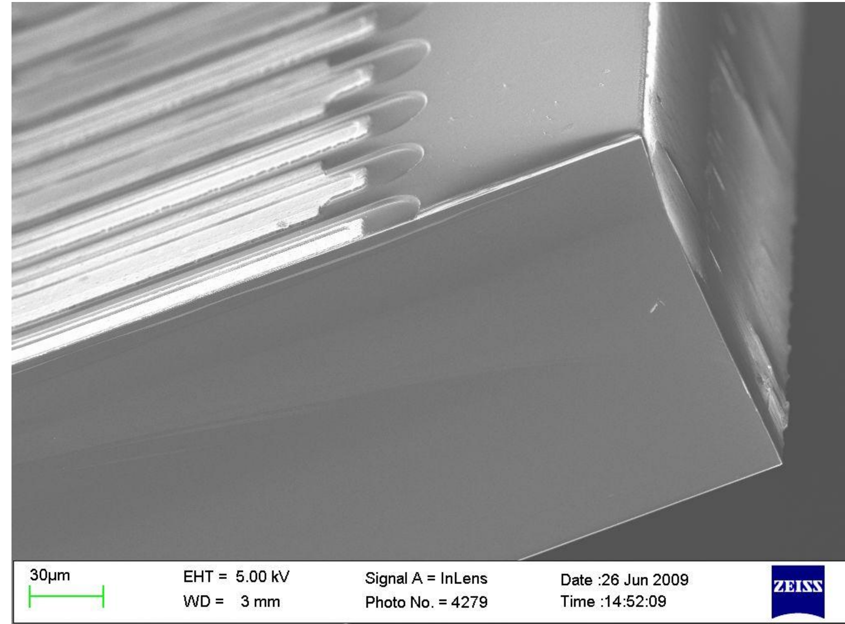
# Handle wafer removal

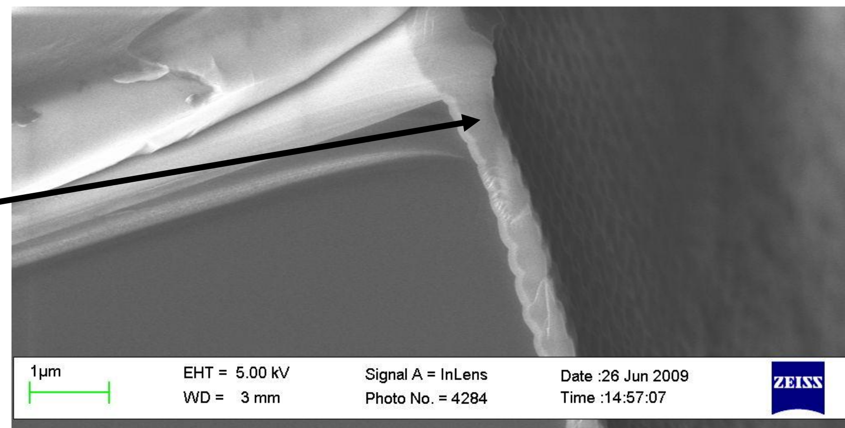


# Poly process

# Edge implantation




***6 um inactive polysilicon***

***500 nm oxide***

# 3D PROCESSING WITH POLYSILICON FILLING

- Polysilicon filling of the trenches is a slow process for the n-type active edge
  - Almost 50% of the edgeless process equipment time in furnace (diff, poly, anneal)
- Significant bowing of 6” wafers due to the polysilicon growth (~0.5 mm)
  - Difficulties in lithography, planarization and ion implantation
- Wafers brittle due to the polysilicon growth -> increased possibility of wafer cracking
- Slow planarization process required
- Detector edge cracking after the support removal
- Physical inactive edge region ~5-10 µm

# 3D PROCESSING WITH ALTERNATIVE PROCESS

- No need for polysilicon filling, planarization and separate ICP dicing
- Fast process and no bowing of the wafer
- Detector edges sustain handling – no edge cracking
- Physical inactive edge region <1 µm
- Requires non-planar lithography -> readiness available at VTT

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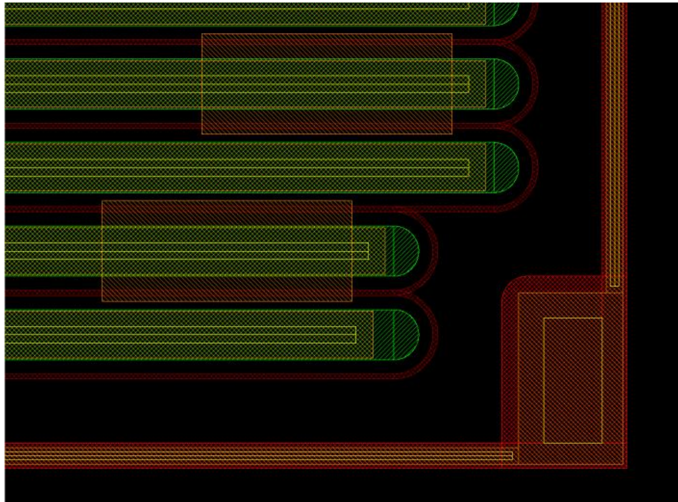
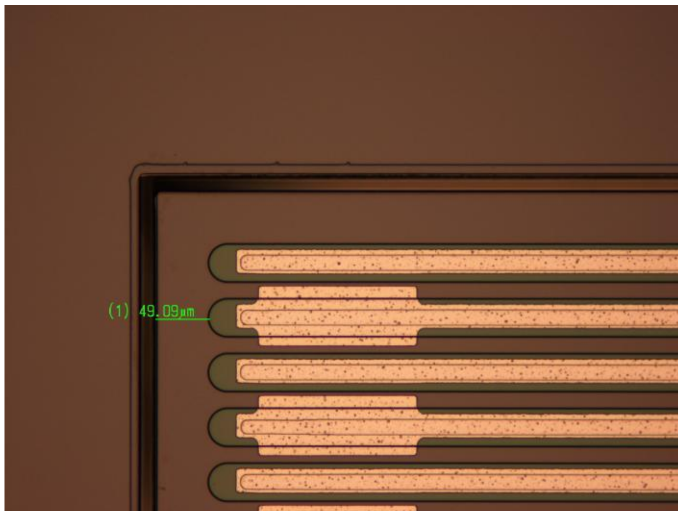
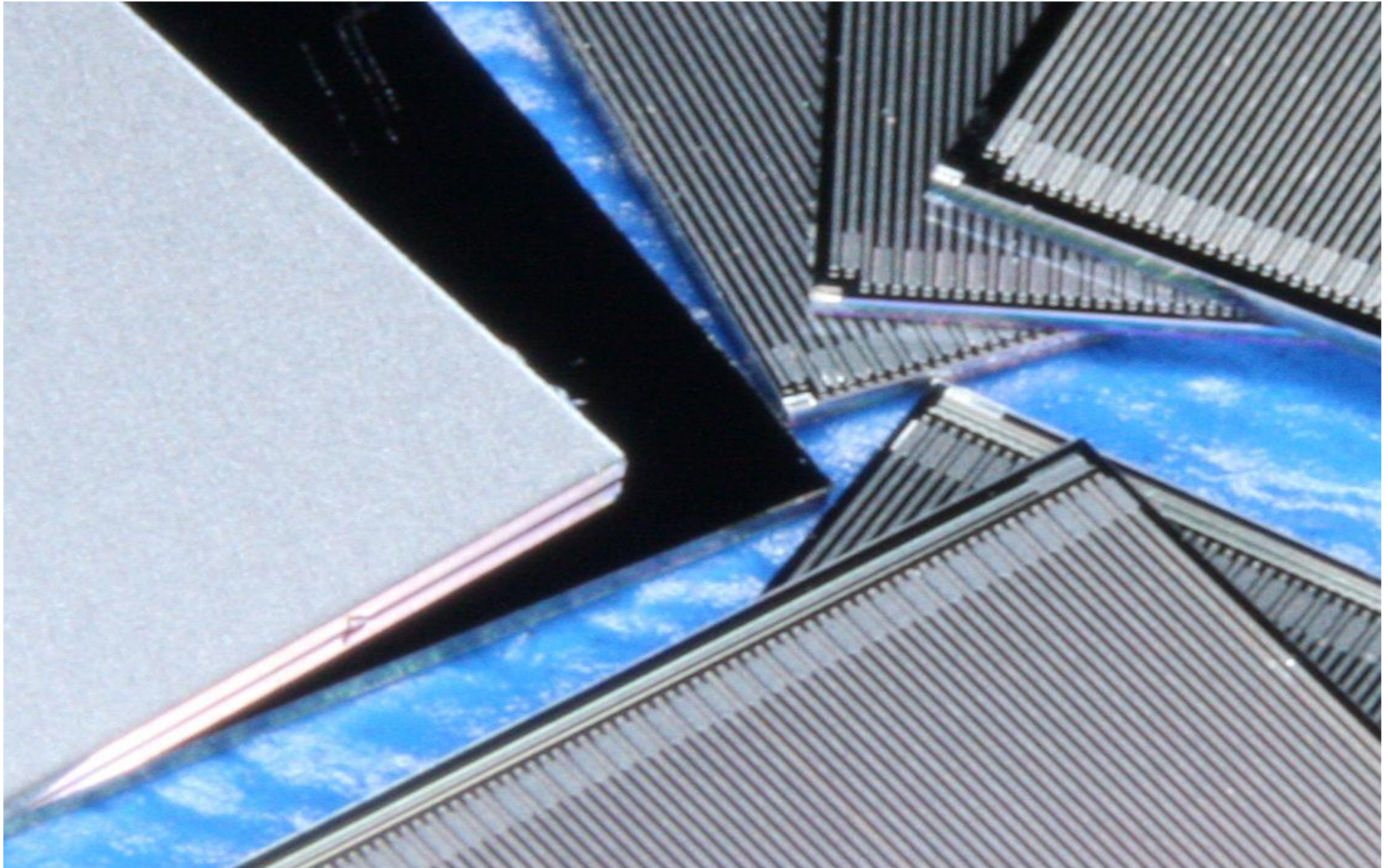
# DC-coupled strip desings & n-on-n layout



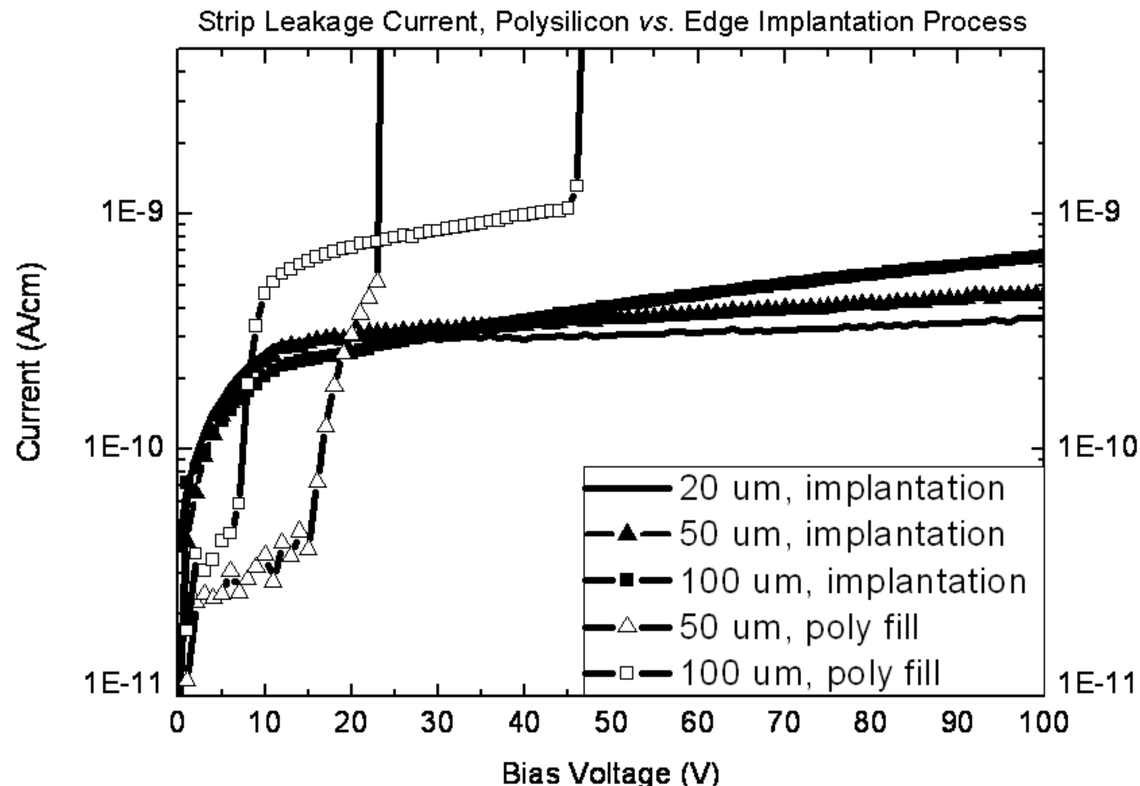


# Edgeless strip detectors



# Strip leakage current: p-on-n implantation vs. poly

- Low leakage currents for both process approaches
- Very early breakdown voltages for poly filling
- Leakage current depends on the active edge distance

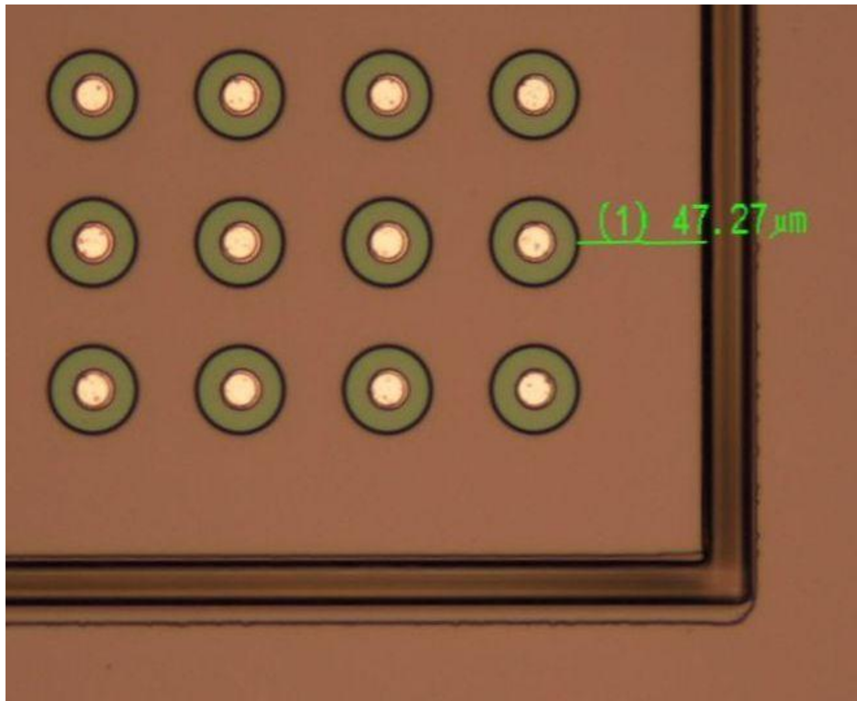


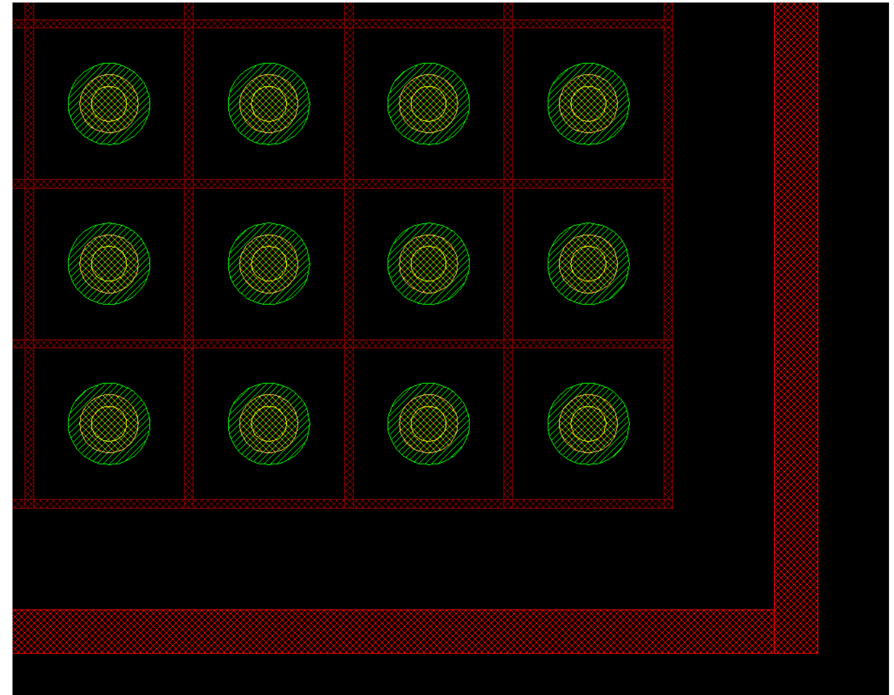
# Characteristics of 150 um thick edgeless strip detectors

| *Edge distance* | *20 µm* | | *50 µm* | | *100 µm* | |
|---|---|---|---|---|---|---|
| *polarity* | *p-on-n* | *n-on-n* | *p-on-n* | *n-on-n* | *p-on-n* | *n-on-n* |
| *Full depletion voltage* | ~25 V | ~13 V | ~35 V | ~16 V | >40 V | ~25 V |
| *IV @ 40 V ($nA/cm^2$)* | 50-59 | 118 | 58-68 | 116 | 66-70 | 117 |
| *CV @ 40 V ($pF/cm^2$)* | 580-620<br>705 (edge) | 940-960<br>855 | 652-665<br>593 (edge) | 930-950<br>800 | 650-655<br>543 (edge) | 937-955<br>805 |
| *Breakdown voltage* | ~145 V | ~75 V | ~180 V | ~90 V | >200 V | ~95 V |

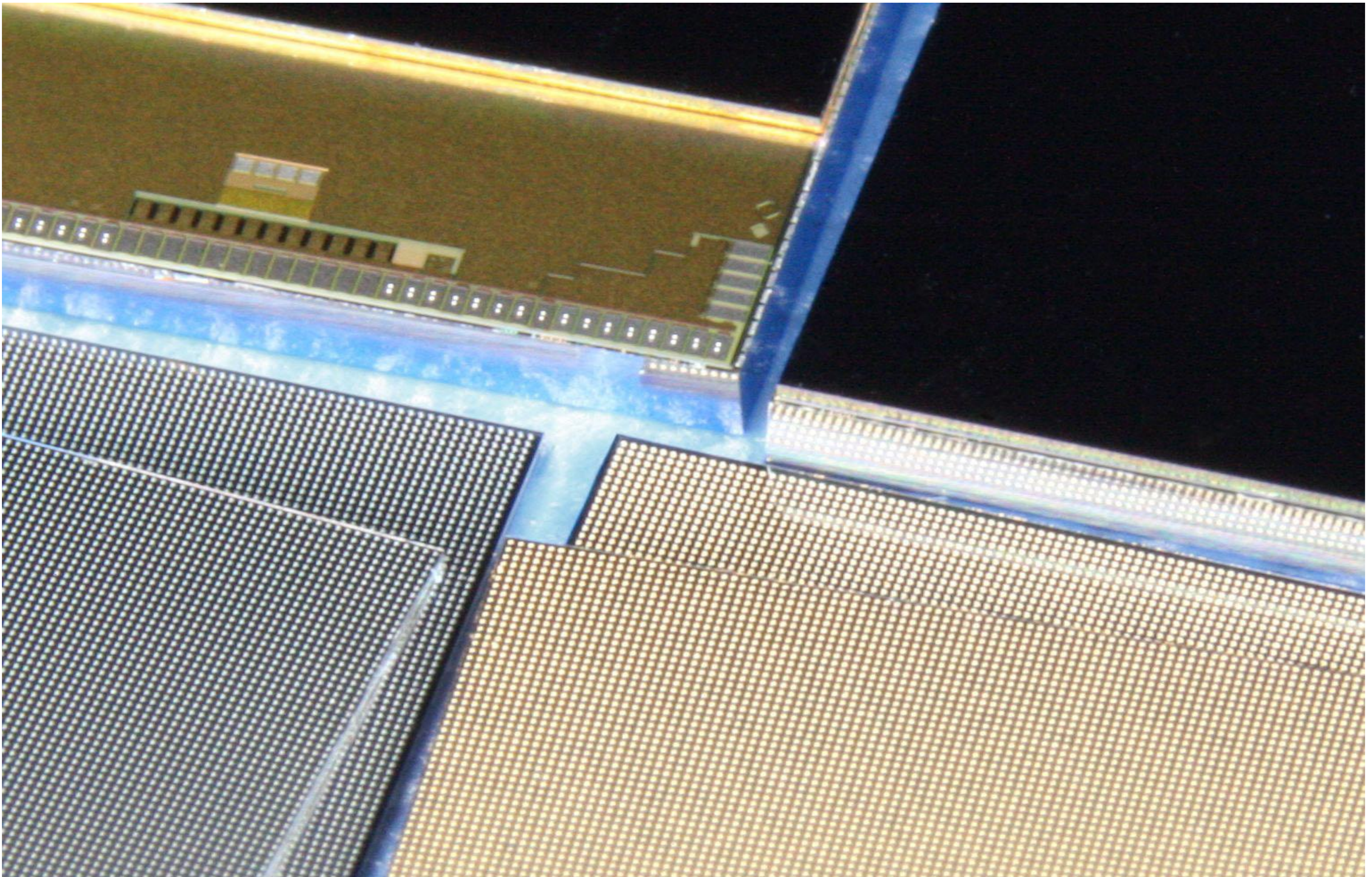
# Medipix2 pixel desing & n-on-n layout

- Pixel pitch of 55 µm
- Active edge distances 20 and 50 µm
- UBM service available from subcontractor
- Own line for electroless plating under development



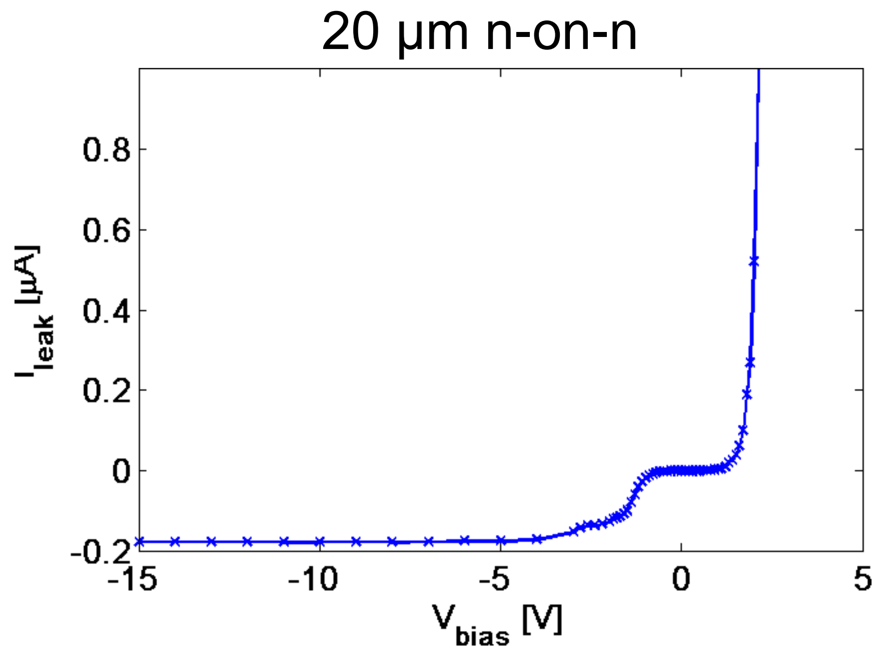
# Flip-chip bonding to Medipix2



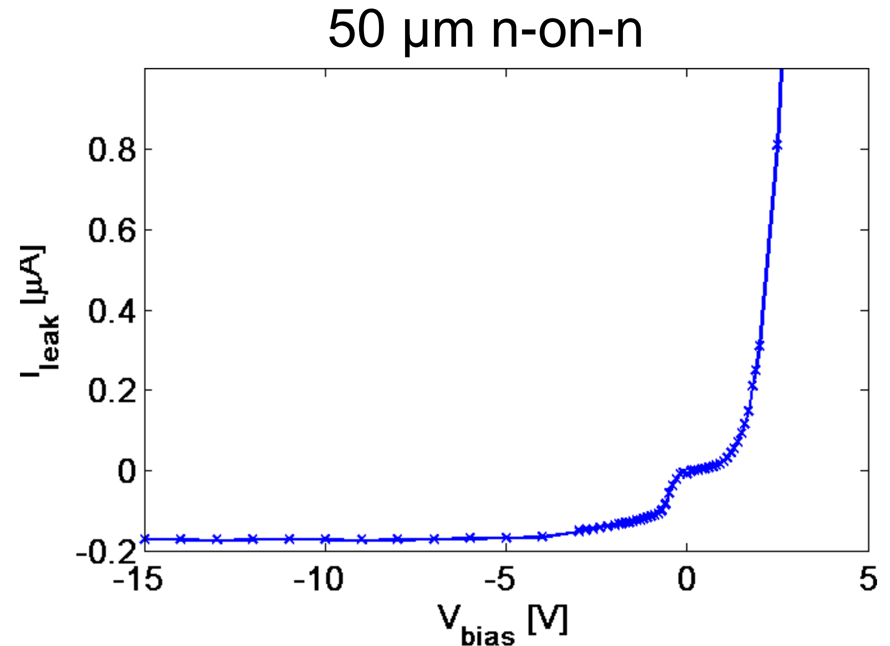
# Leakage current

- Leakage currents of 90 nA/cm$^2$ and 88 nA/cm$^2$ for 20 µm and 50 µm active edge distances
- Full depletion at 5 V
- No breakdown below 70 V

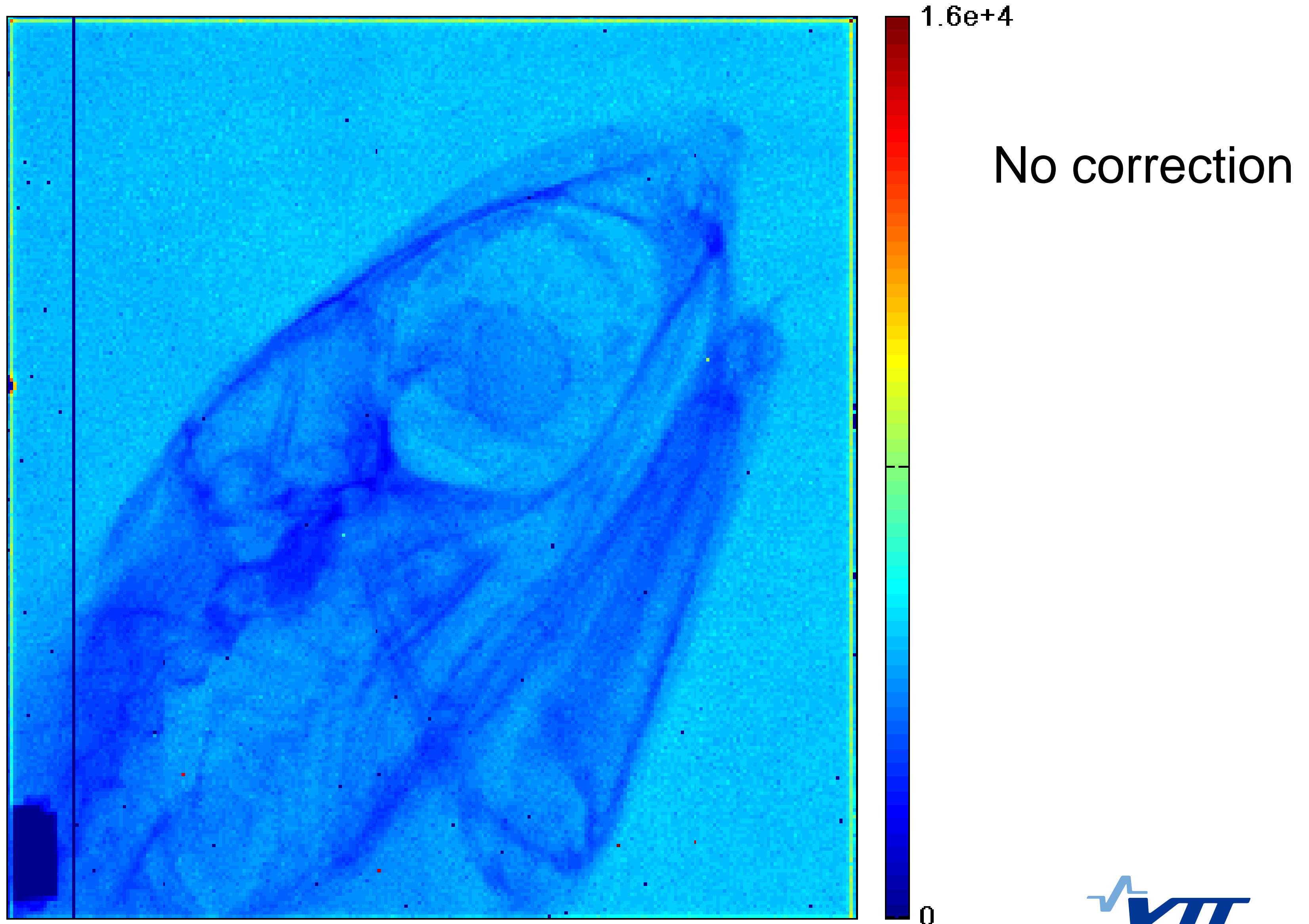
20 µm n-on-n



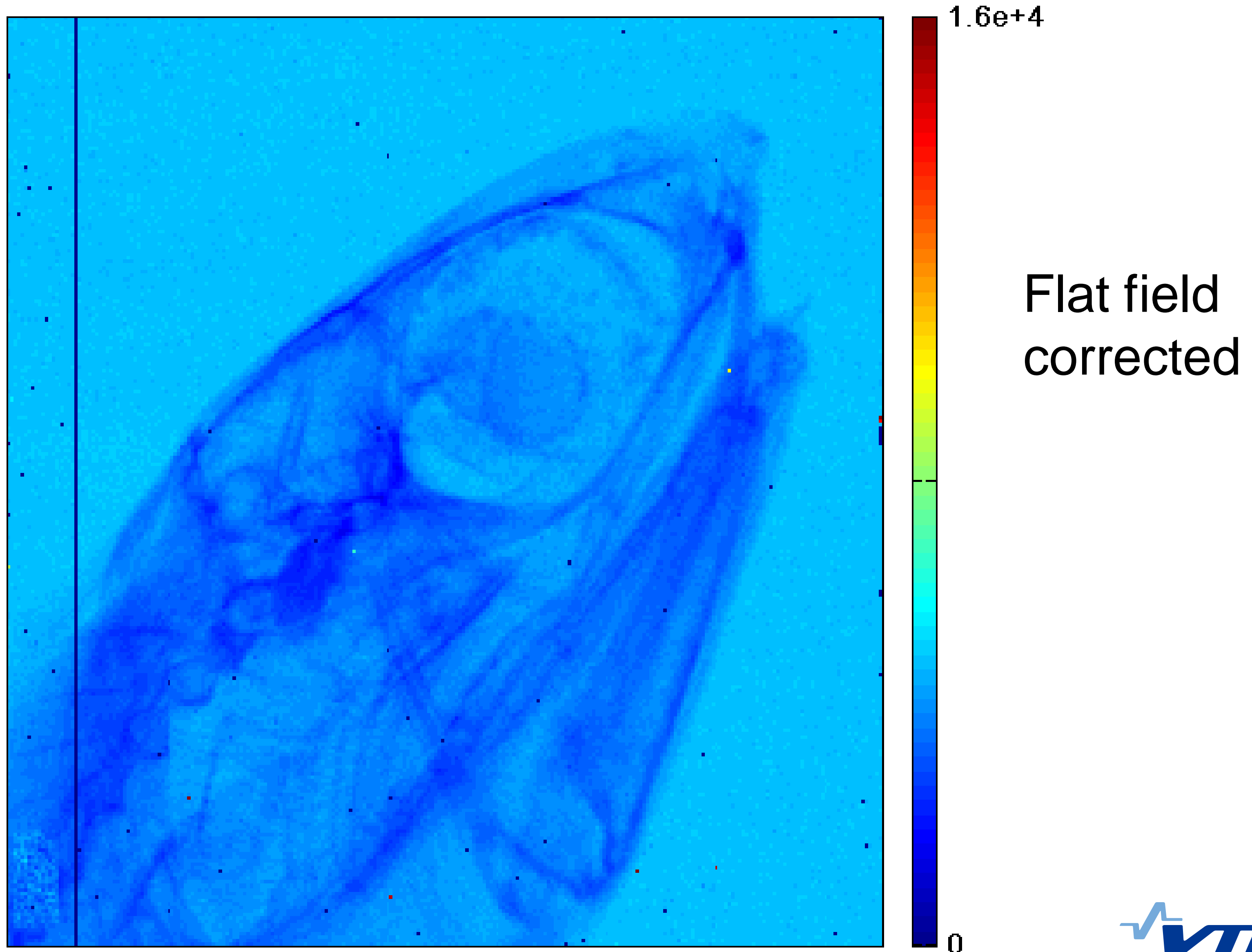

50 µm n-on-n



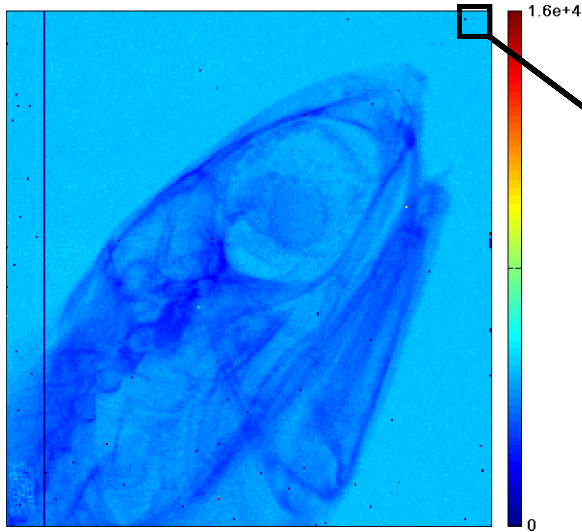
# First Medipix2 X-ray images with 50 µm detector



# First Medipix2 X-ray images with 50 μm detector




Flat field corrected




**M7 (50 um) corner image, 36 s**

Counts: 0, 1000, 2000, 3000, 4000, 5000, 6000, 7000, 8000, 9000, 10000, 11000, 12000, 13000

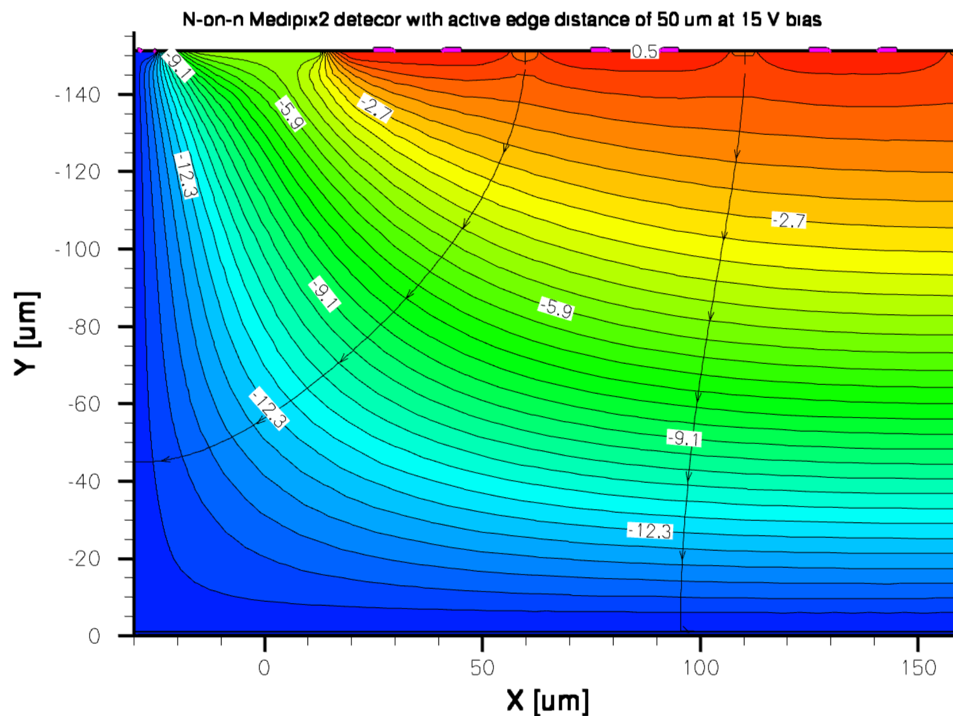
Y [um]: S1, S3, S5, S7, S9, S11, S13, S15, S17, S19, S21, S23, S25

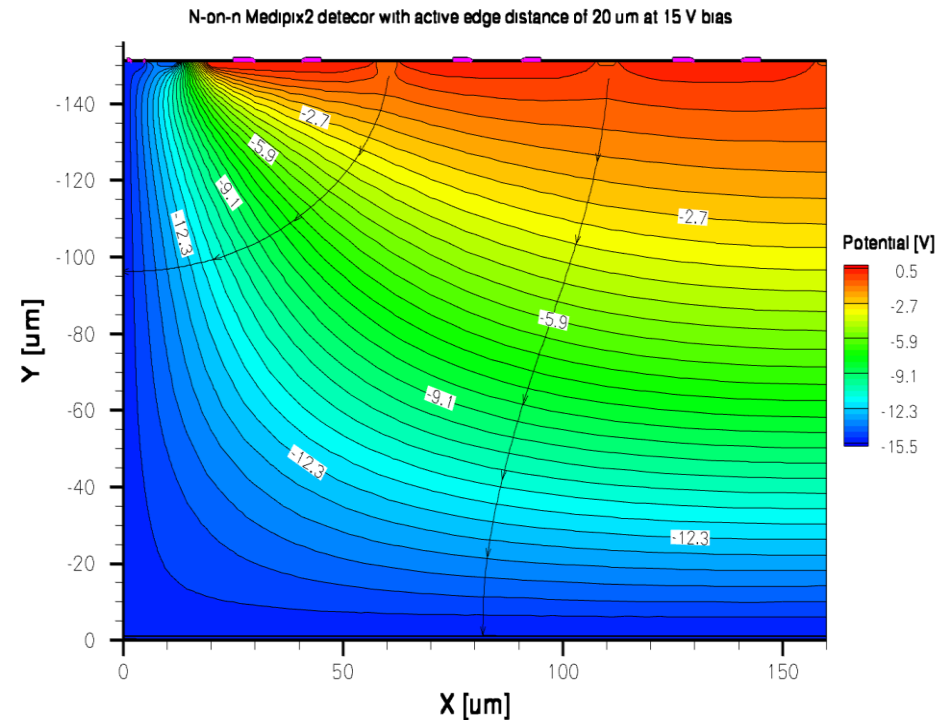
X [um}: 1, 4, 7, 10, 13, 16, 19, 22, 25

- 12000-13000
- 11000-12000
- 10000-11000
- 9000-10000
- 8000-9000
- 7000-8000
- 6000-7000
- 5000-6000
- 4000-5000
- 3000-4000
- 2000-3000
- 1000-2000
- 0-1000

# Study of edgeless detector response

- N-on-n detector at -15 V bias
- Area ratios (vs. charge collection ratio):
  - 50 um: edge/third ~0.76 and second/third ~1.47
  - 20 um: edge/third ~0.28 and second/third ~1.13
- Even ratios between pixels at ~60 um active edge distance



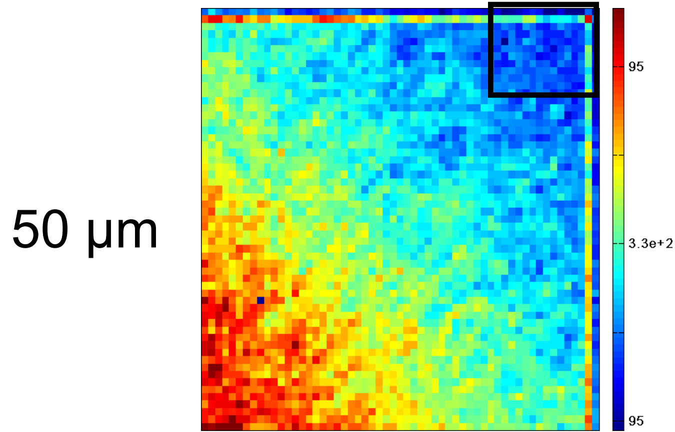



# Study of edgeless detector response

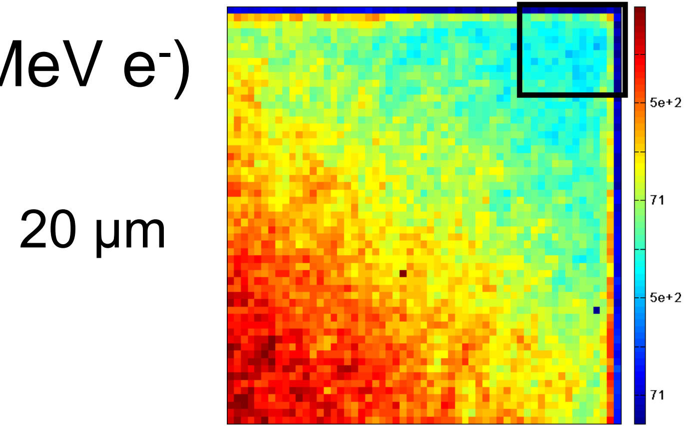
- X-ray tube:
  - 30 keV, 10 mA current and 2 mm Al filtering
  - Aquisition time 606 s
- Fe55:
  - ~6 keV X-rays, less than 100 μm range in Si (1/e ~30 μm)
  - Aquisition time 300 s
- Cd109:
  - ~22 keV X-rays (1/e ~1.3 mm)
  - Aquisition time 300 s
- Sr90:
  - ~560 keV electrons, 200 μm range in Si
  - Aquisition time 120 s

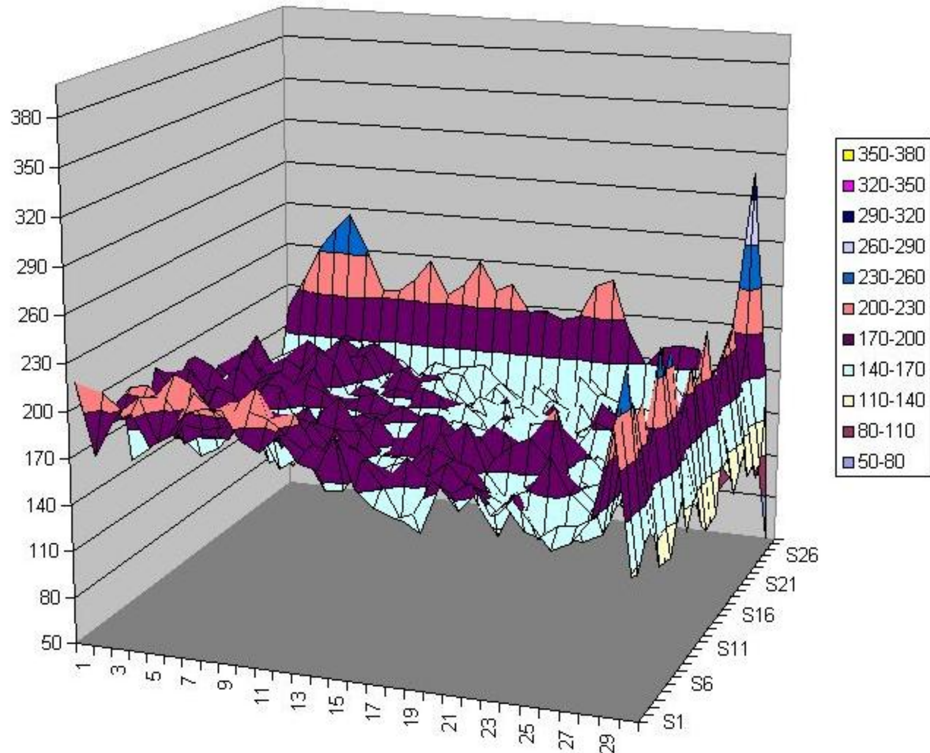
# Sr90 (0.5 MeV $e^-$)

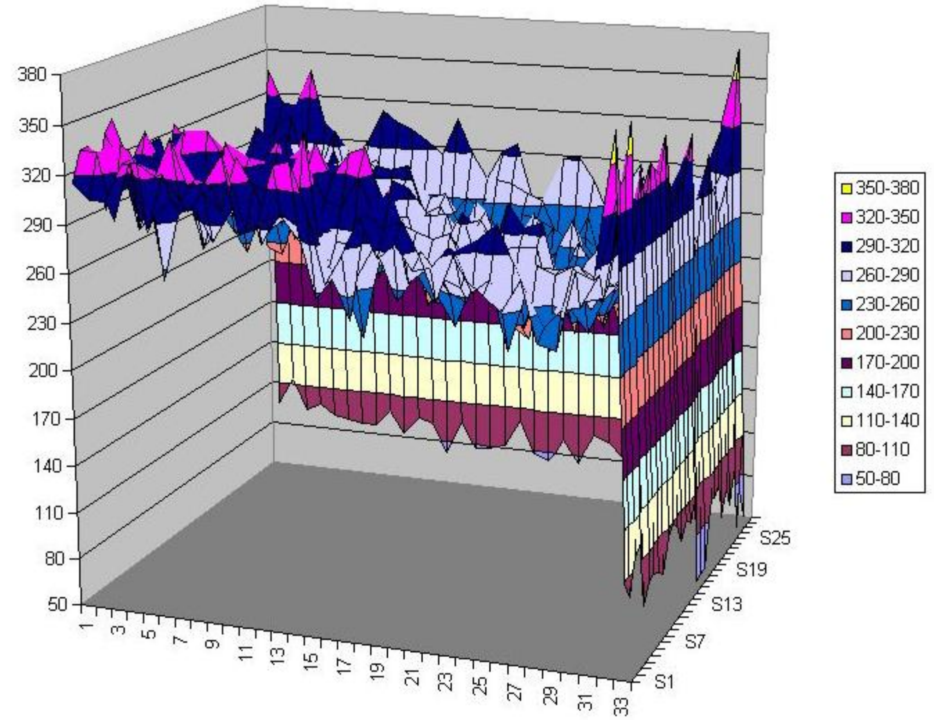
50 µm

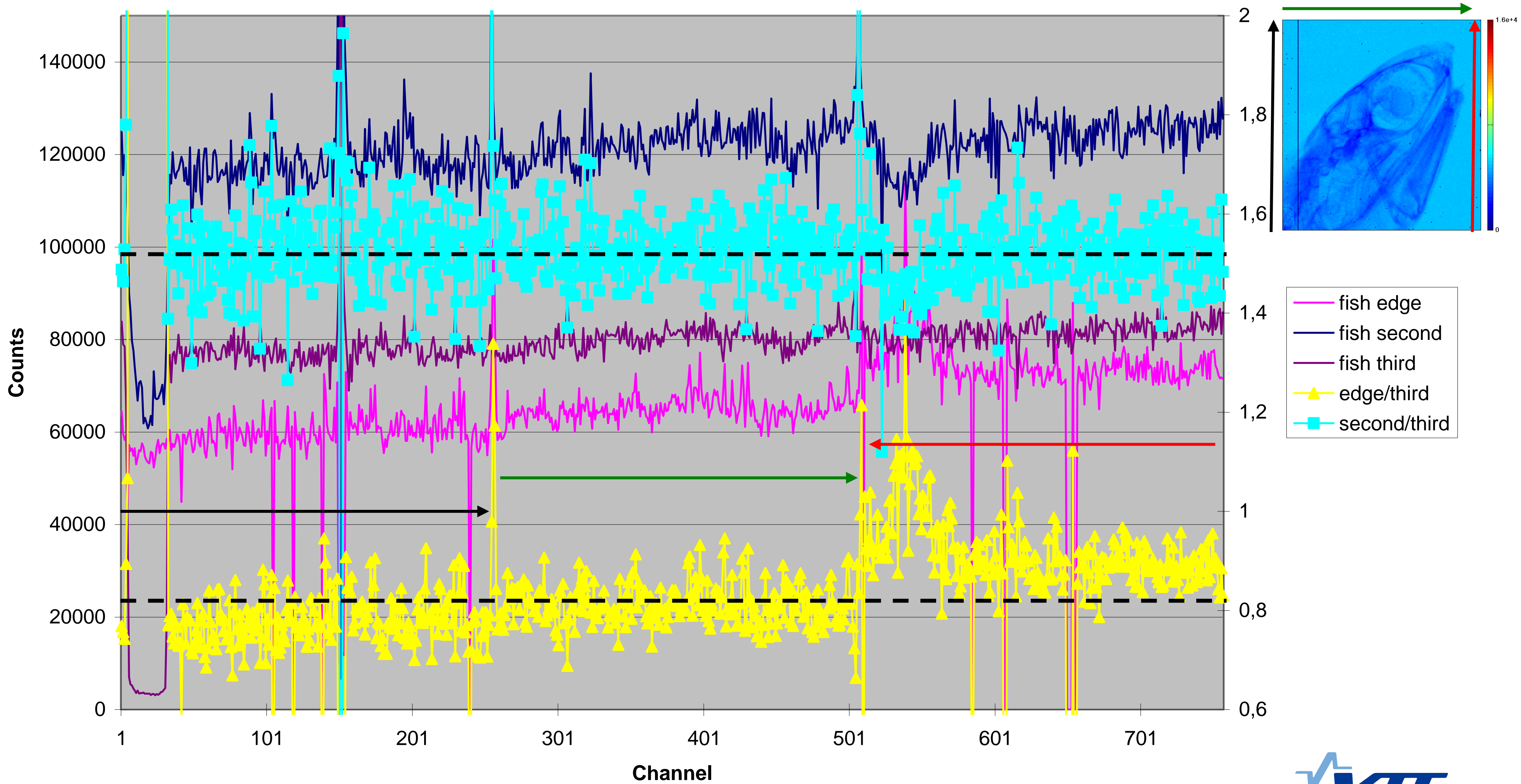



20 µm

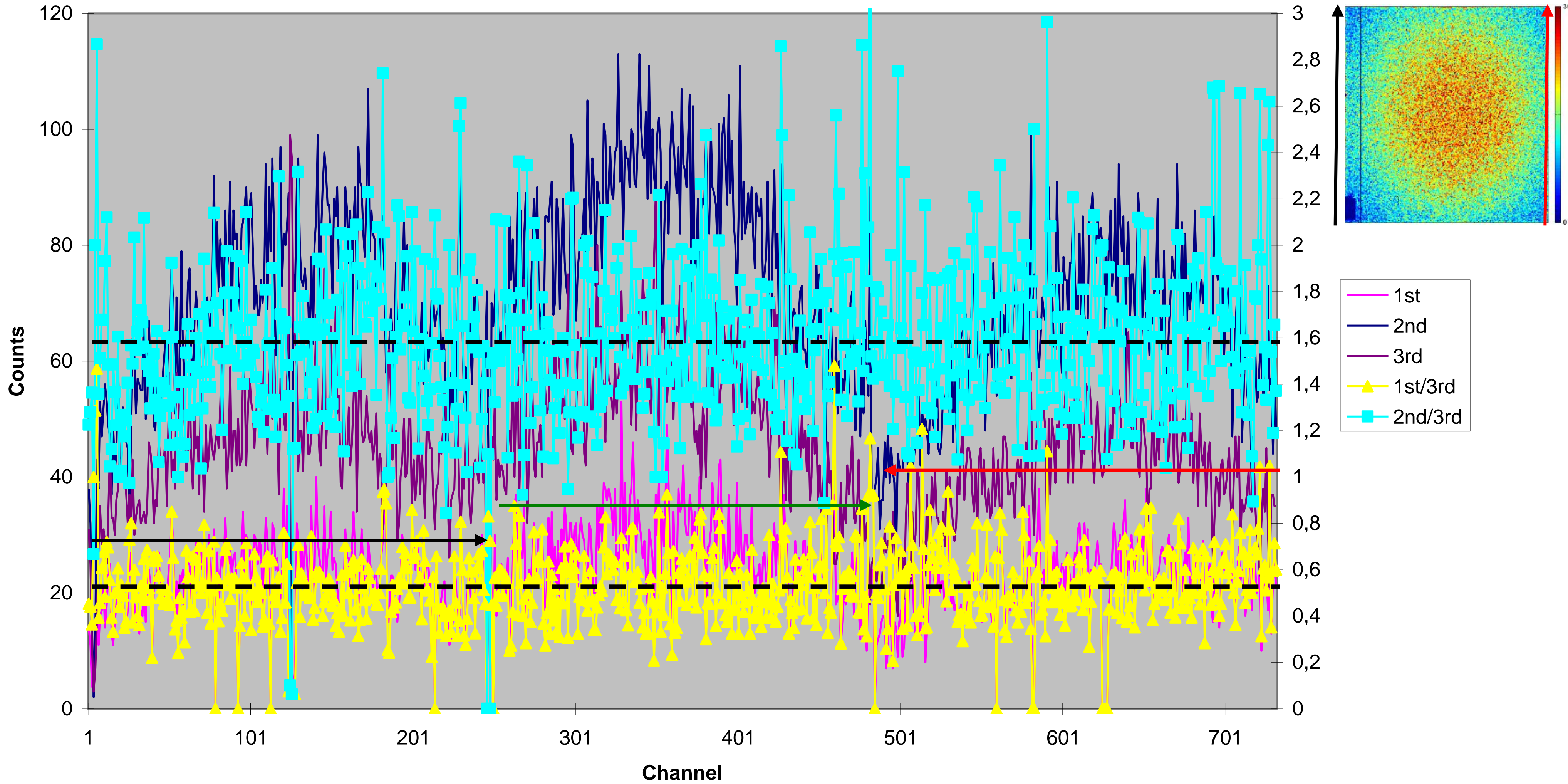


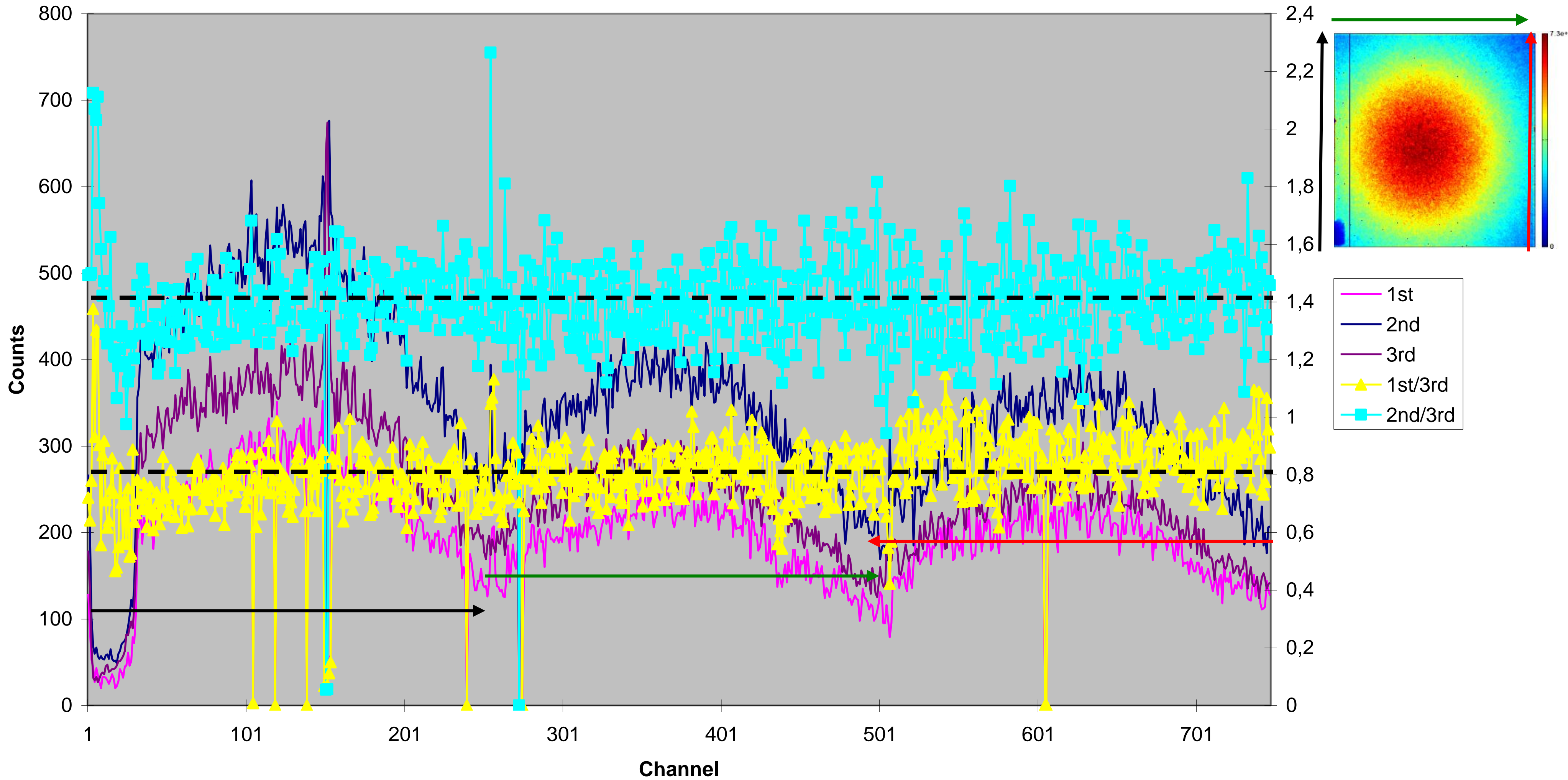



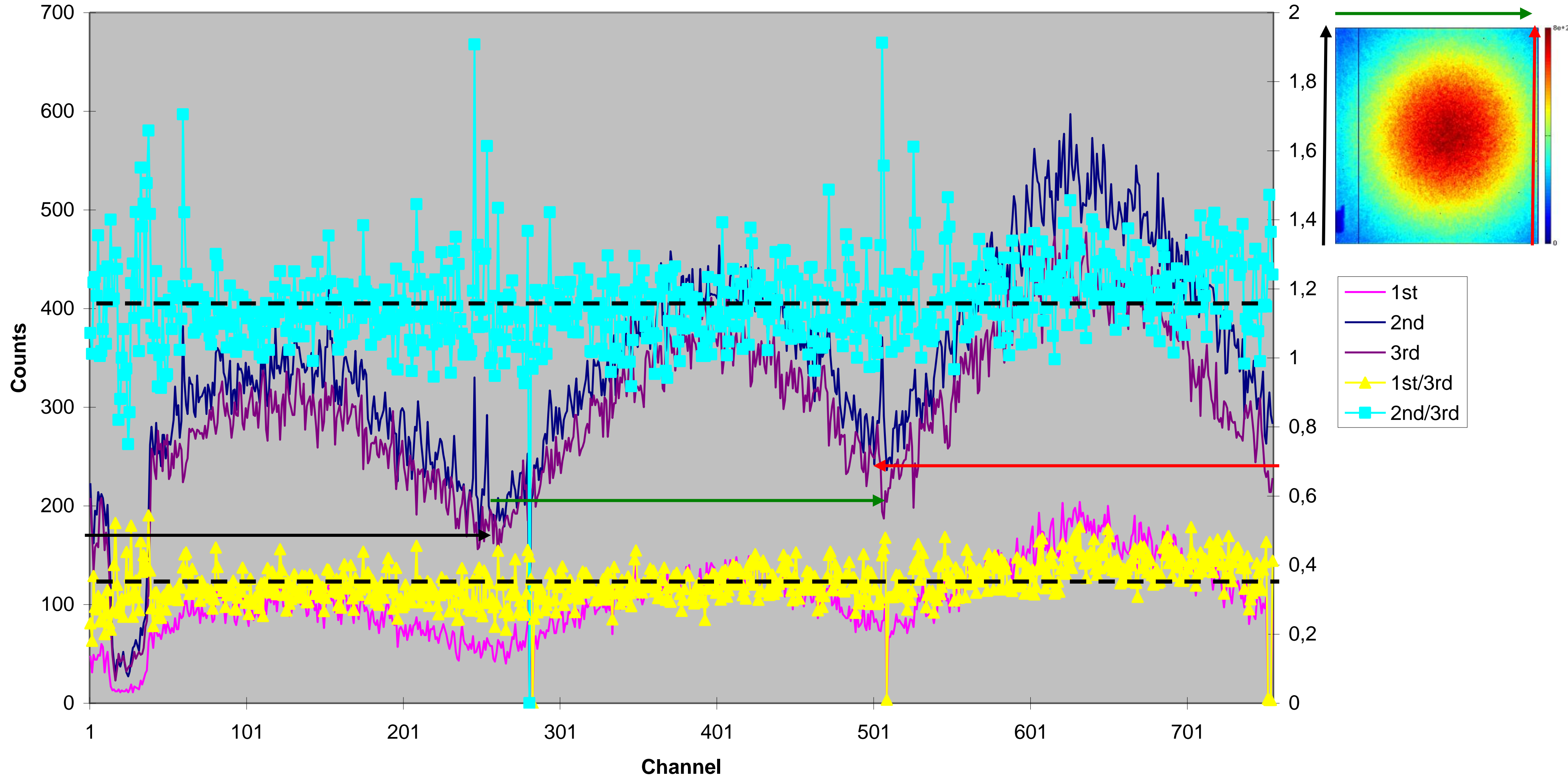


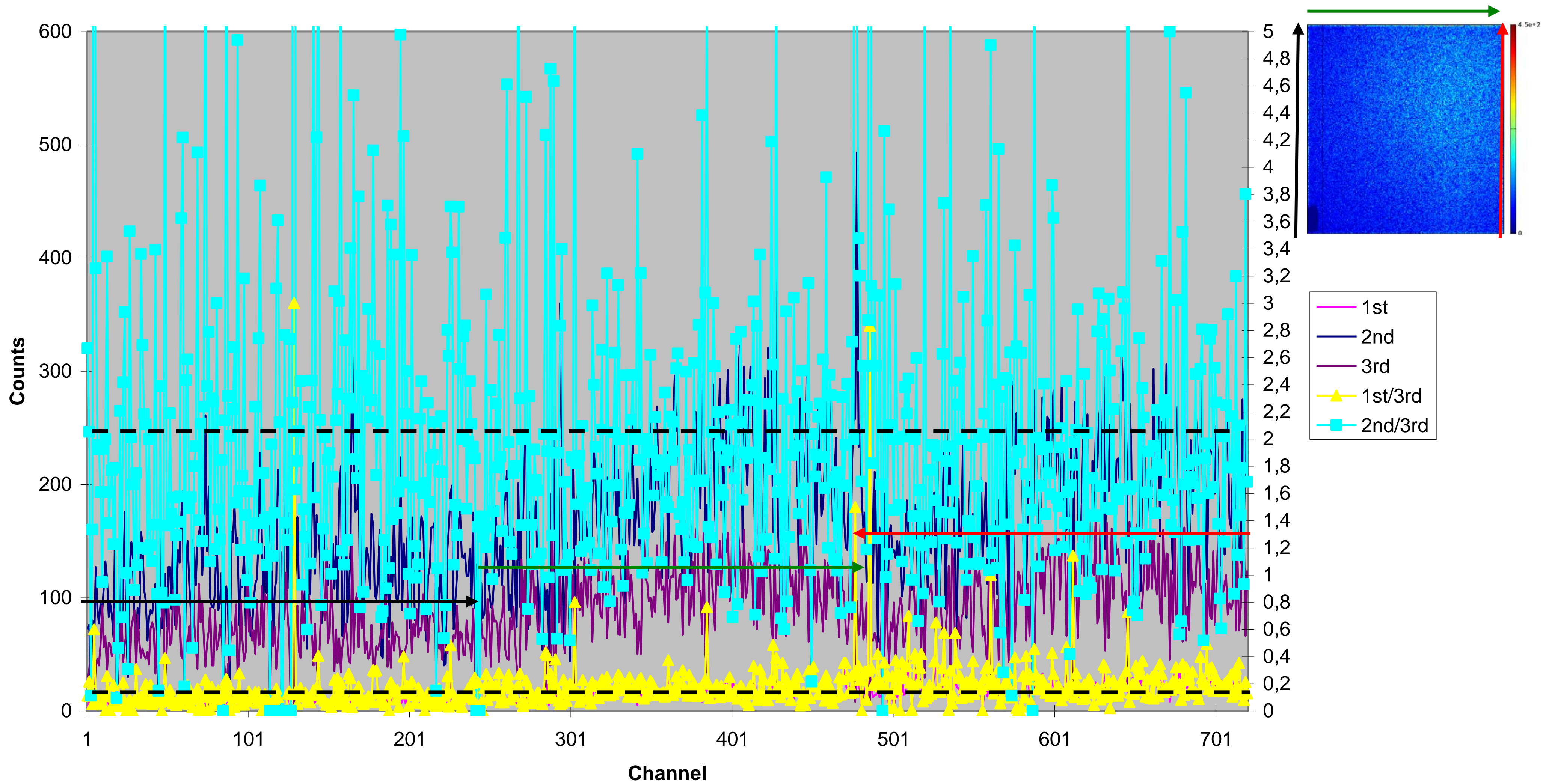
M7 (50 um), 30 keV, ff-image, 606 s
Counts
Channel
0
20000
40000
60000
80000
100000
120000
140000
1
101
201
301
401
501
601
701
0,6
0,8
1
1,2
1,4
1,6
1,8
2
fish edge
fish second
fish third
edge/third
second/third

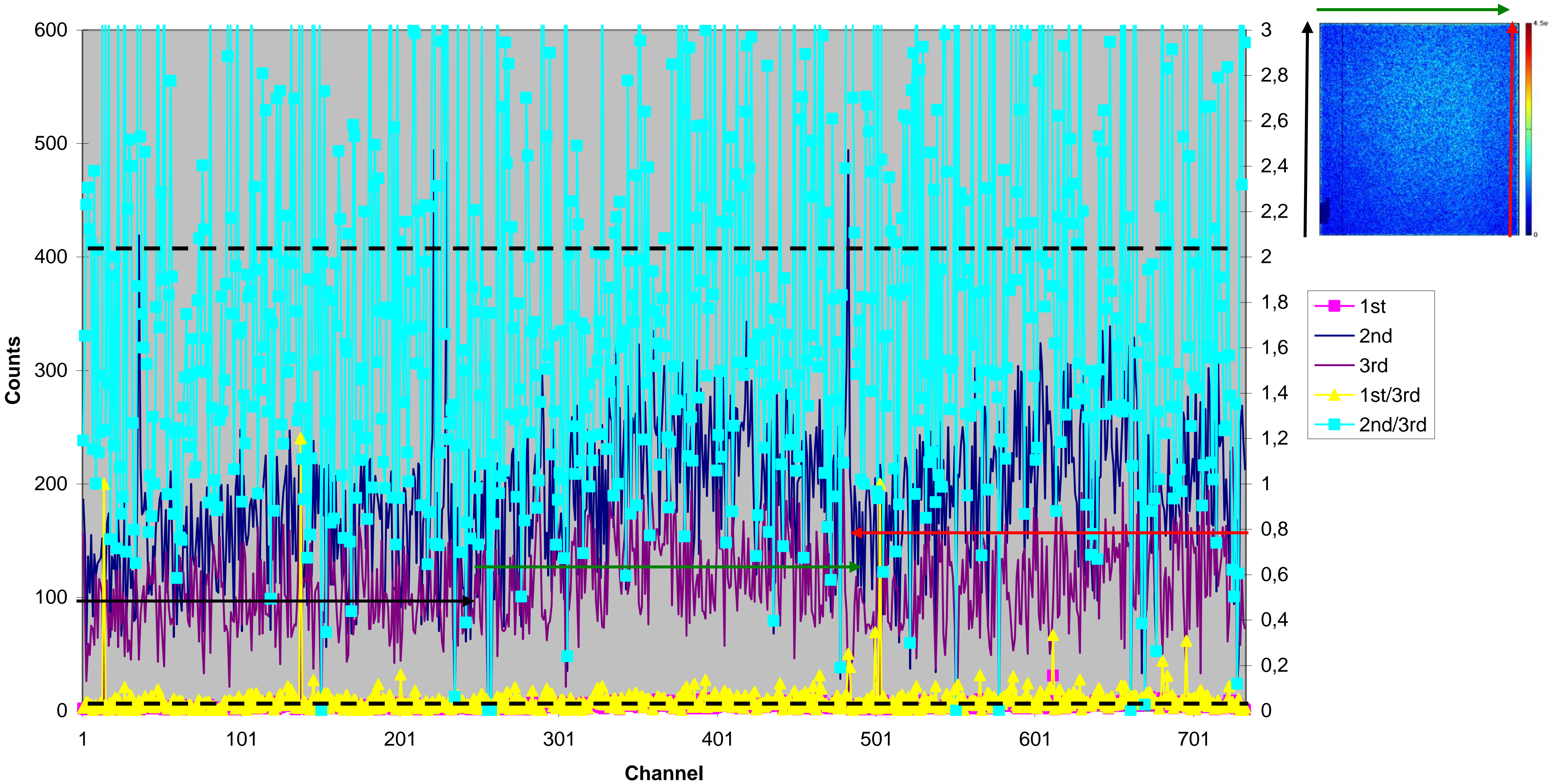


M7 (50 um) Cd109 (22 keV)
Counts
Channel
120
100
80
60
40
20
0
1
101
201
301
401
501
601
701
3
2,8
2,6
2,4
2,2
2
1,8
1,6
1,4
1,2
1
0,8
0,6
0,4
0,2
0
1st
2nd
3rd
1st/3rd
2nd/3rd


M7 (50 um) sr90 (e-)
Counts
Channel
800
700
600
500
400
300
200
100
0
1
101
201
301
401
501
601
701
2,4
2,2
2
1,8
1,6
1,4
1,2
1
0,8
0,6
0,4
0,2
0
1st
2nd
3rd
1st/3rd
2nd/3rd


L6 (20 um) Sr90 (e-)
Counts
Channel
700
600
500
400
300
200
100
0
1
101
201
301
401
501
601
701
2
1,8
1,6
1,4
1,2
1
0,8
0,6
0,4
0,2
0
1st
2nd
3rd
1st/3rd
2nd/3rd


M7 (50 um) Fe55 (1/e ~30 um)
Counts
Channel
1st
2nd
3rd
1st/3rd
2nd/3rd


L6 (20 um) Fe55 (1/e ~30 um)
Counts
Channel
600
500
400
300
200
100
0
1
101
201
301
401
501
601
701
3
2,8
2,6
2,4
2,2
2
1,8
1,6
1,4
1,2
1
0,8
0,6
0,4
0,2
0
1st
2nd
3rd
1st/3rd
2nd/3rd

# Detector Response summary

- Flat field image responses very close to the simulated area ratios
- Radiation source responses support the simulated model
- Uniform response could be obtained with 60 um edge distance for 150 um thick detector, *i.e.* edge distance/thickness ratio ~40%

| | Edge distance | 1st/3rd | 2nd/3rd |
|---|---|---|---|
| **Simulation** | 20 um | 0,28 | 1,13 |
| | ***50 um*** | ***0,76*** | ***1,47*** |
| **ff-image** | ***50 um*** | ***0,82*** **±0,08** | ***1,52*** **±0,06** |
| **Cd109** | ***50 um*** | ***0,53*** **±0,13** | ***1,60*** **±0,27** |
| **Sr90** | 20 um | 0,35±0,04 | 1,16±0,06 |
| | ***50 um*** | ***0,80*** **±0,09** | ***1,39*** **±0,11** |
| **Fe55** | 20 um | 0,04±0,03 | 2,06±1,18 |
| | ***50 um*** | ***0,18*** **±0,09** | ***2,12*** **±0,91** |

# Summary

- First n-on-n edgeless pixel detector prototypes have been fabricated, packaged to the Medipix2 ROC and characterized with X-ray tube and radiation sources.
  - Leakage currents of 90 nA/cm$^2$ and 88 nA/cm$^2$ for 20 µm and 50 µm active edge distances
  - Full depletion at 5 V
  - No breakdown below 70 V
  - Response of the edge pixels depends dramatically on the active edge distance
  - Detector geometry can be optimized to give uniform pixel response
- VTT has capability to produce and deliver edgeless and full 3D edgeless pixel detectors in 2-4 months.
  - Three edgeless prototype processes done (1 poly & 2 edge implantation)
  - Good understanding of the edgeless 3D process and non-planar lithography
  - Improved process started: includes AC-coupled FOXFET and PT detectors
- Further work in edgeless detectors: fabrication for different ROC designs, radiation hardness tests and beam tests.

VTT

# VTT creates business from technology

# VTT's process capabilities for advanced detectors

- Operator time 48-54% of the equipment time -> parallel batch processing
- Delivery time includes possible UBM process and handle wafer removal
- Add 1 month to the delivery time for the prototype process

| | DC PIXEL (realized) | EDGELESS POLY (realized) | EDGELESS IMPLANTATION (realized) | NEW EDGELESS IMPLANTATION (estimate) | FULL 3D EDGELESS POLY (estimate) |
|---|---|---|---|---|---|
| **PROCESS TIME (h)** | **118** (2-3 WEEKS) | **511** (10-11 WEEKS) | **305** (6-7 WEEKS) | **246** (5 WEEKS) | **356** (7-8 WEEKS) |
| **PROCESS STEPS** | 72 | 118 | 119 | 109 | 152 |
| **BOTTLE NECKS (% OF THE PROCESS TIME)** | LITHOGRAPHY 25%<br>FURNACE 24% | FURNACE 46%<br>DRY ETCH 13%<br>PLANARIZATION 12 % | LITHOGRAPHY 23%<br>FURNACE 20% | LITHOGRAPHY 22%<br>FURNACE 20% | FURNACE 27%<br>DRY ETCH 20% |
| **DELIVERY TIME** | ***1 MONTH*** | ***3-4 MONTHS*** | ***2-3 MONTHS*** | ***2 MONTHS*** | ***3 MONTHS*** |