Design and TCAD simulation of a new generation of 3D Sensors for HL-LHC within the INFN (ATLAS-CMS) R&D program in collaboration with FBK

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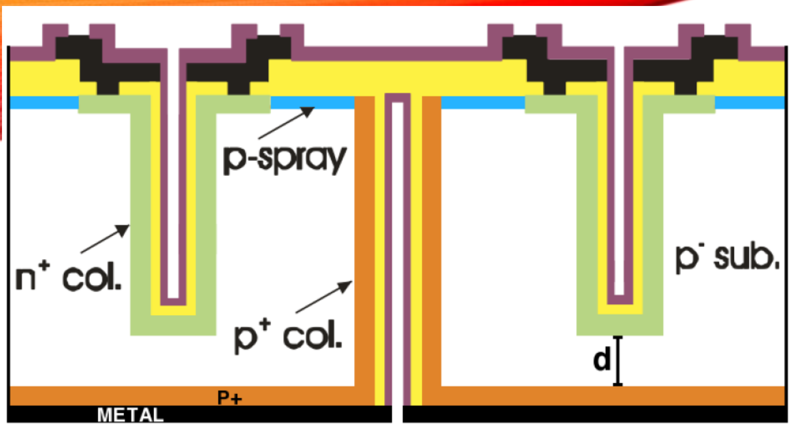
Outline

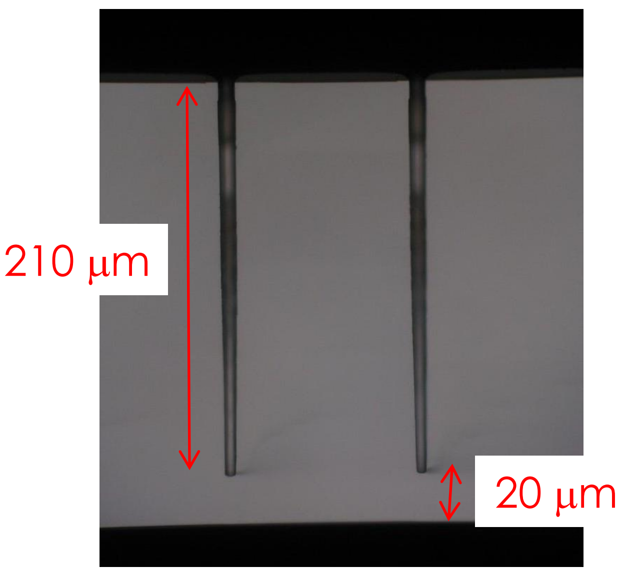
- Introduction: Modified 3D sensor technology at FBK
- New technology developed for new thin sensors generation
- Layout design
- TCAD Simulation:
  - Electrical simulation
  - Functional results for irradiated sensors
- Conclusions

Modified 3D sensor technology at FBK

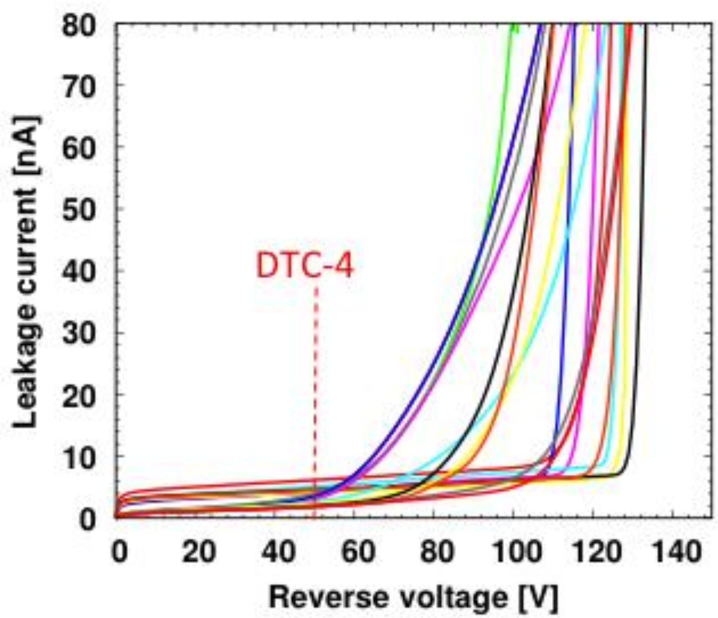


Optimization of the DRIE step to accurately control columns depth

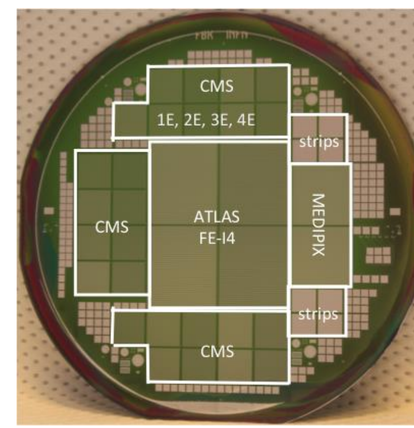
- Partially etched junction columns
- Passing-through ohmic columns for
- effective slim edges (50 μm achieved !)



M. Povoli et al., IEEE NSS 2012

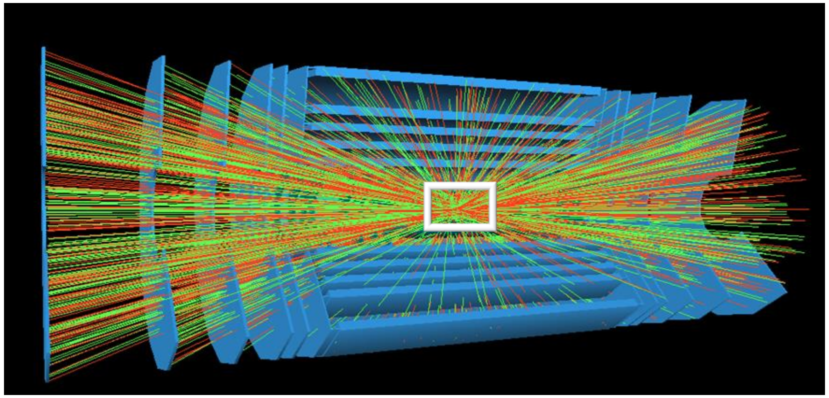


G.F. Dalla Betta et al., IEEE NSS 2013

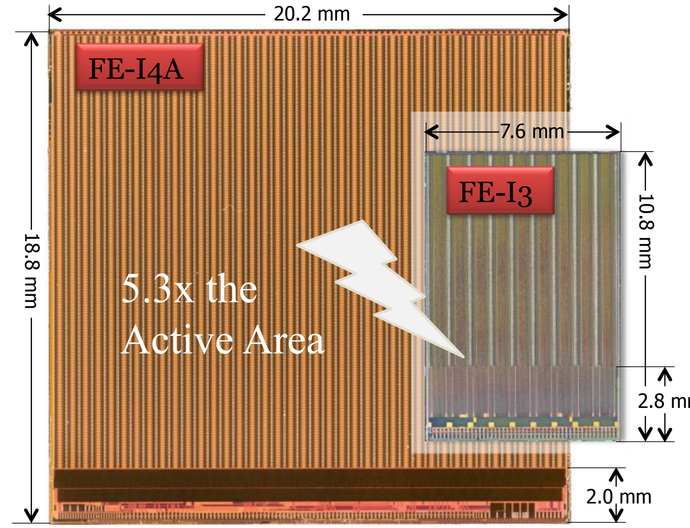


Pixel Roadmap LHC → HL-LHC

N. Wermes, TN workshop 2014 in Genova



Technology roadmap □
5x Chip Size
½ threshold
20x TID dose
20x NIEL
6x event pile-up



Increased luminosity requires:

- Higher hit-rate capability
- Increased granularity (e.g., 100x25 or 50x50 μm^2 pixel size)
- Higher radiation tolerance (up to a fluence of 2×10^{16} n_{eq} cm^{-2})
- Reduced material budget and better geometrical efficiency

Implications for 3D sensors

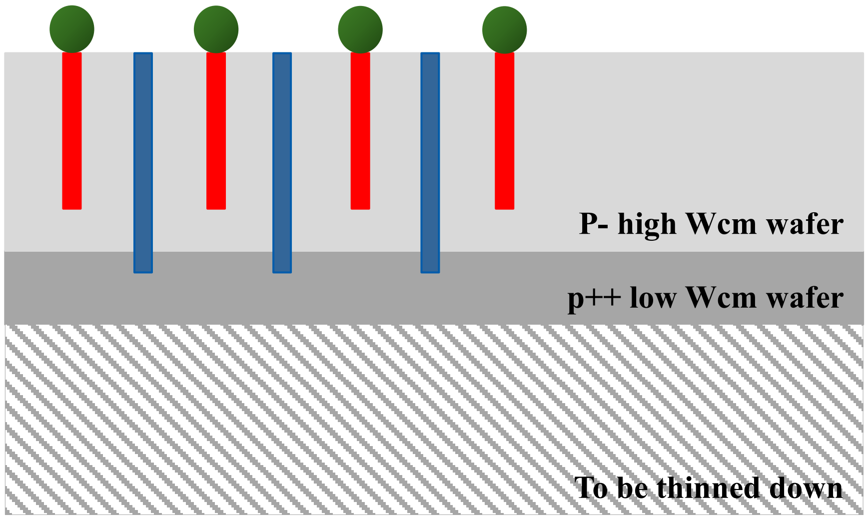
Modified technology for:

- thinner sensors
- narrower electrodes
- reduced electrode spacing
- very slim (or active) edges

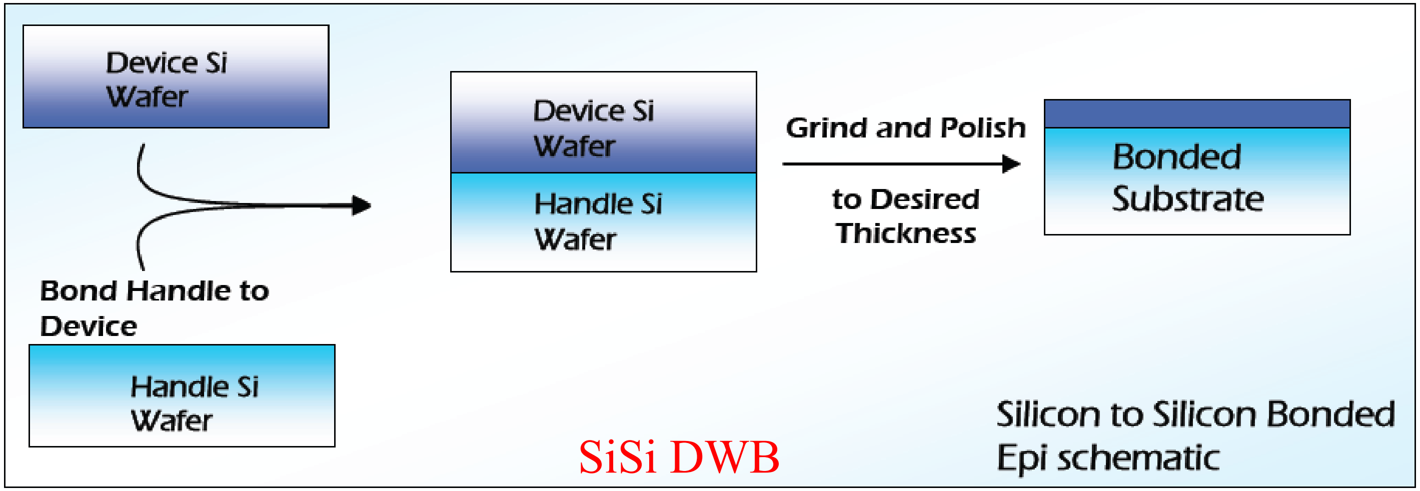
3D pixels are an option for the innermost layers

What's the next technology?

- Single-sided process
- "Thin" active layer: SiSi, SOI, epitaxial …
- Ohmic columns depth > device wafers
- Junction columns depth < device wafers
- Reduction of hole diameters to ~ 5 µm
- Holes partially filled with poly
- Compatible with active edge

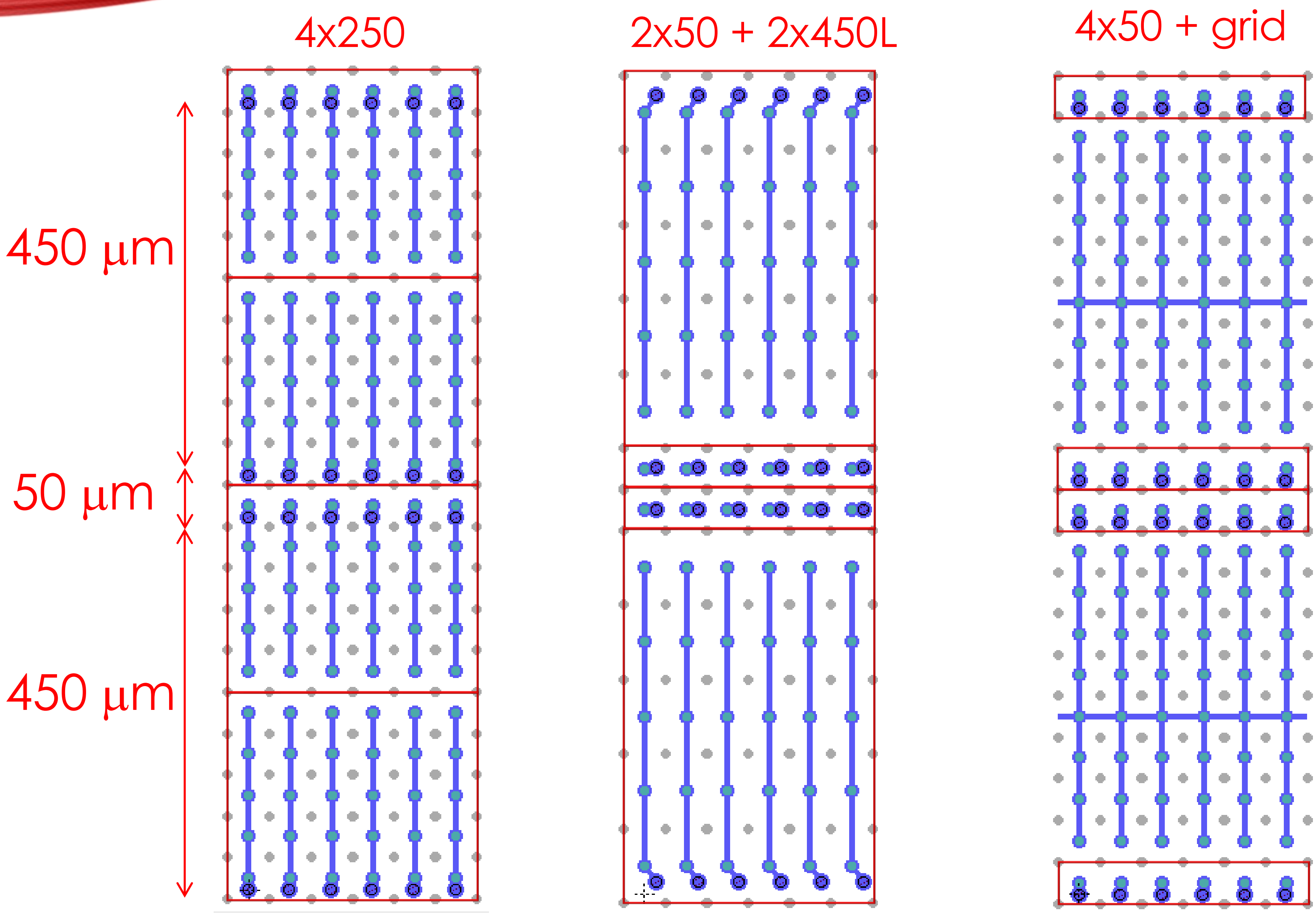


G.F. Dalla Betta et al.,
Itk Week 2014

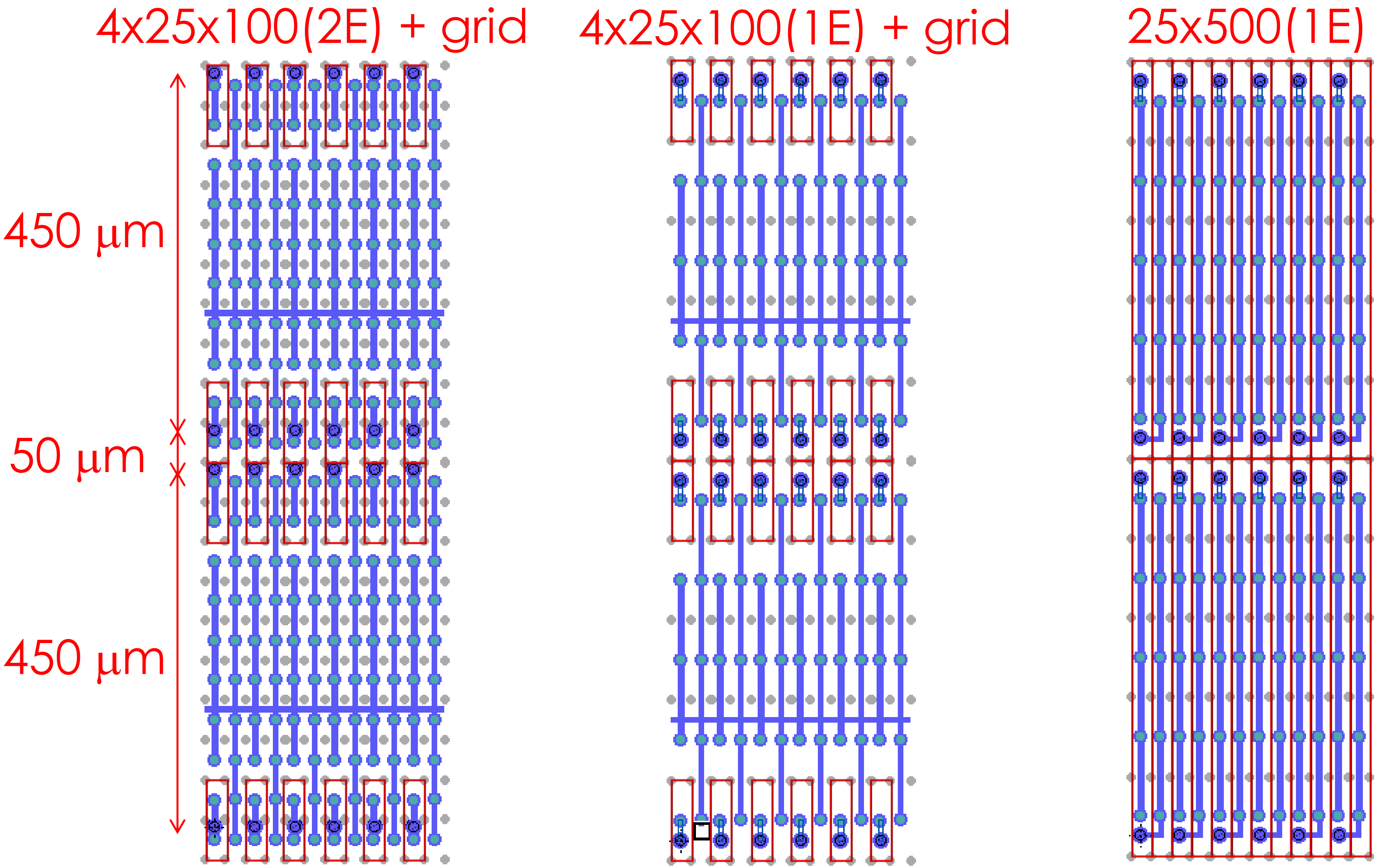


SiSi DWB

IV FEI4-compatible test pixels 50 x 50

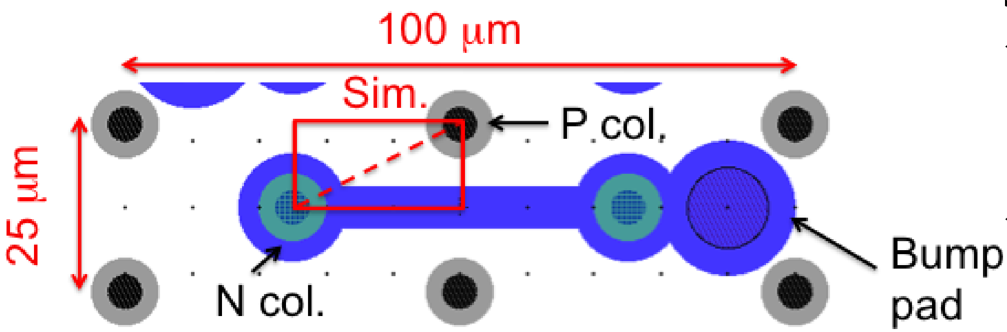


IV FEI4-compatible test pixels 25 x 100

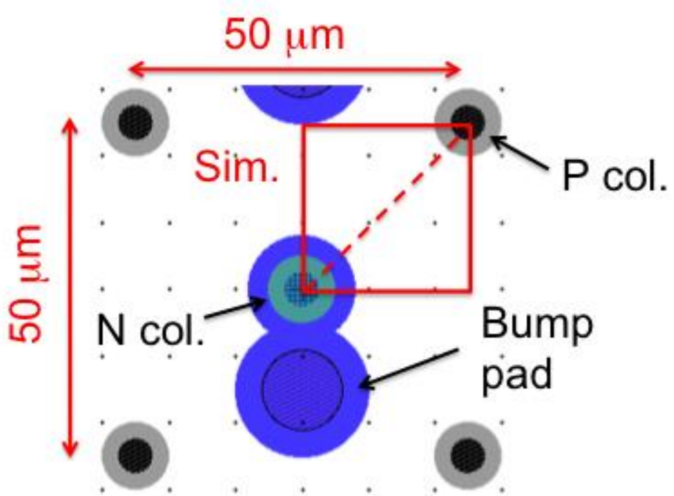


IV Simulation on new 3D devices

25 x 100



50 x 50



Structure domain:

- ✓ Elementary cell simulated: only 1/4 for 50x50 geometry and 1/8 for 25x100
- ✓ Oxide thickness: 1µm
- ✓ Polysilicon replaced with silicon
- ✓ Column diameter=5mm

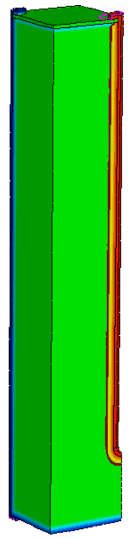
Data analysis:

- ✓ Breakdown

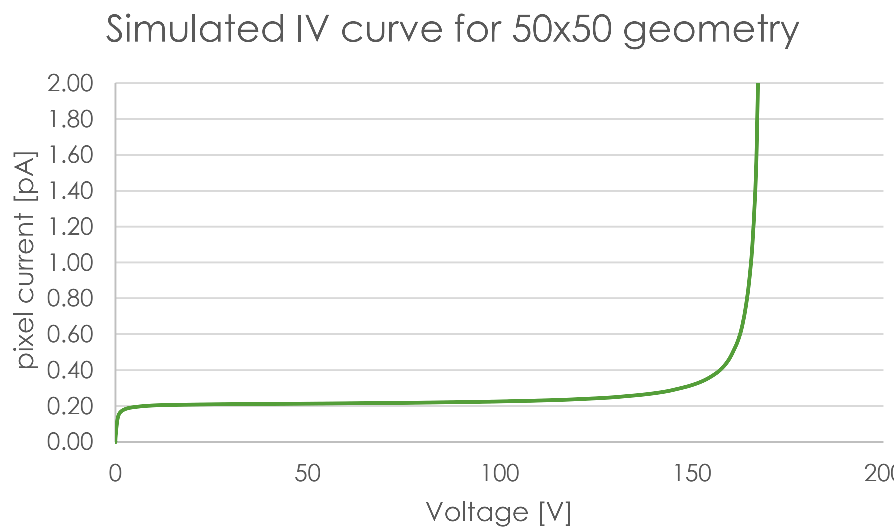
3-trap level "Perugia" model, parameters from D. Pennicard, NIMA 592 (2008) 16 [Tends to underestimate the signal efficiency at largest fuences, to be optimized]

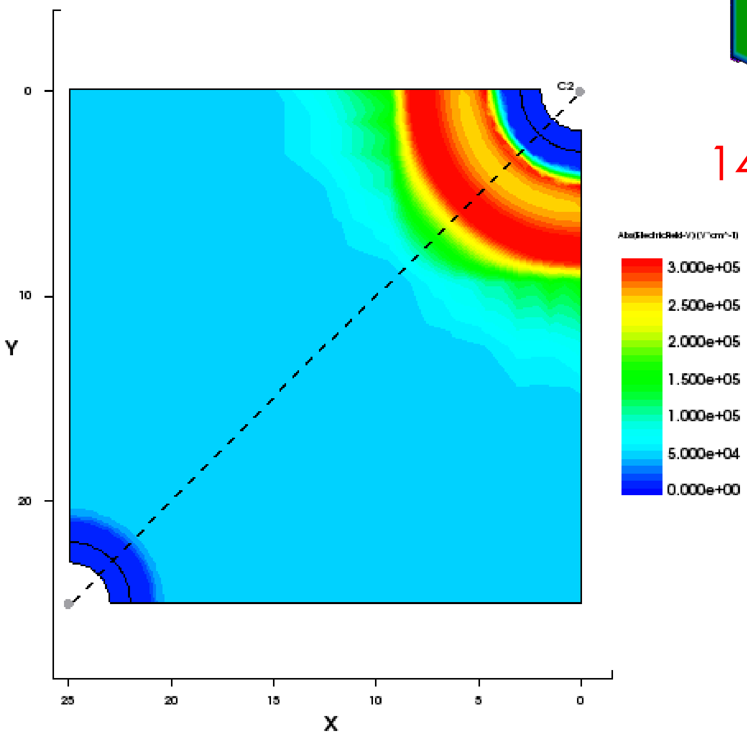
IV Simulation 50x50 geometry

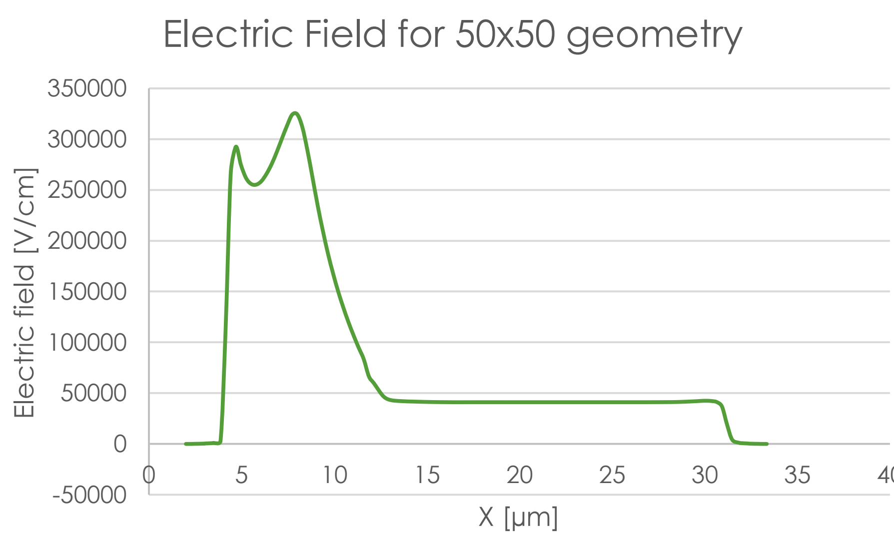
- IV simulation for 50x50
- Breakdown Higher than 150V
- Electrical cut for 2d figure on the interface



144 V

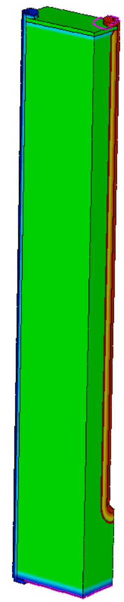




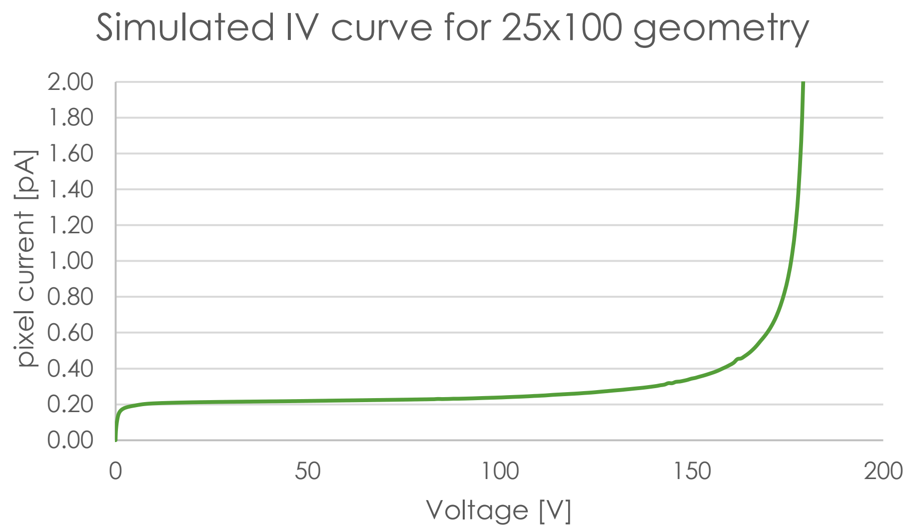


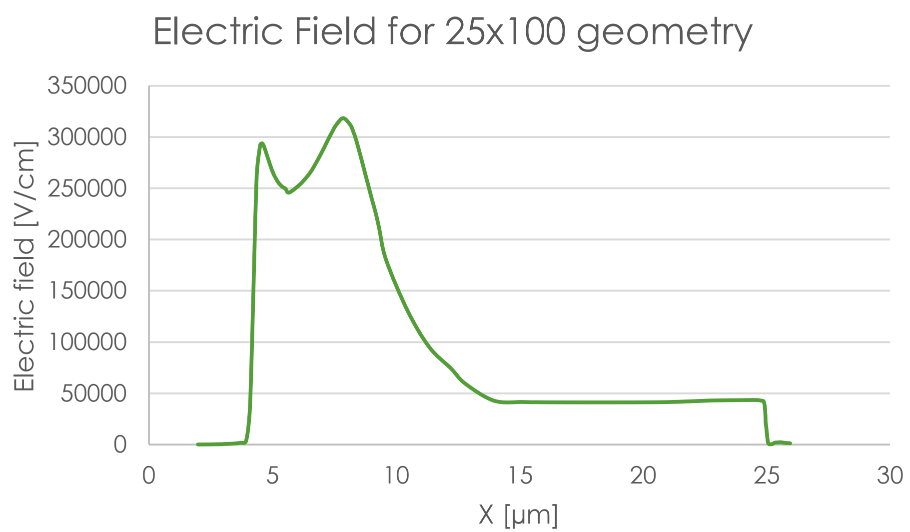
IV Simulation 25x100 geometry

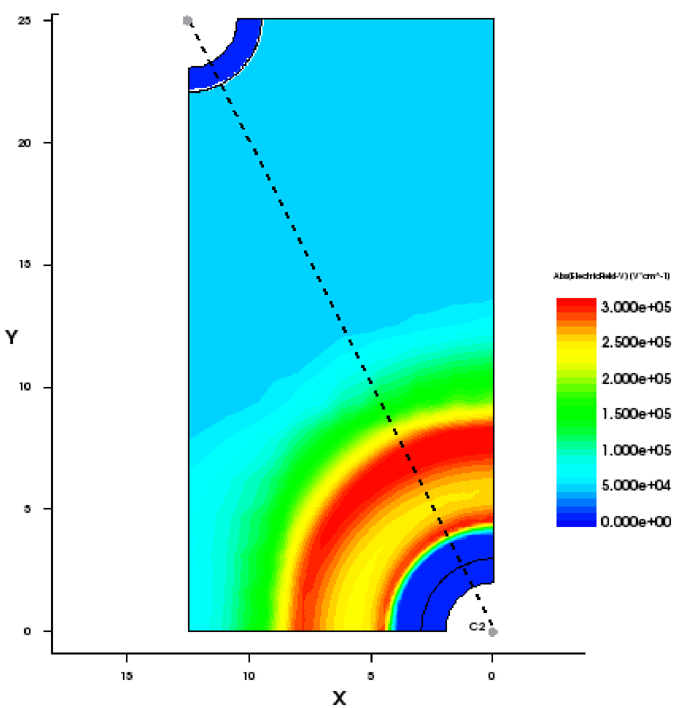
- IV simulation for 25x100
- Breakdown Higher than 150V
- Electrical cut for 2d figure on the interface



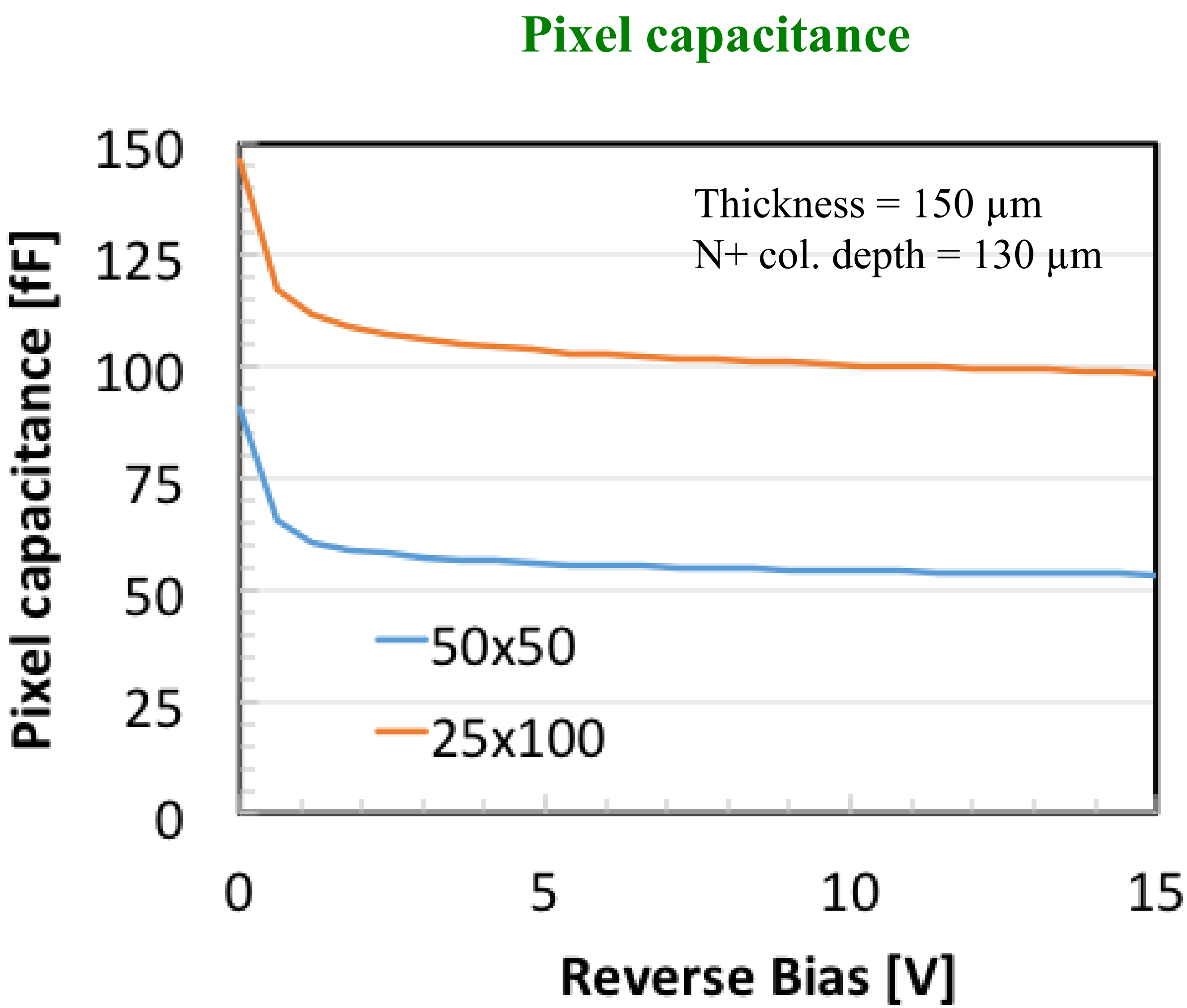
144 V





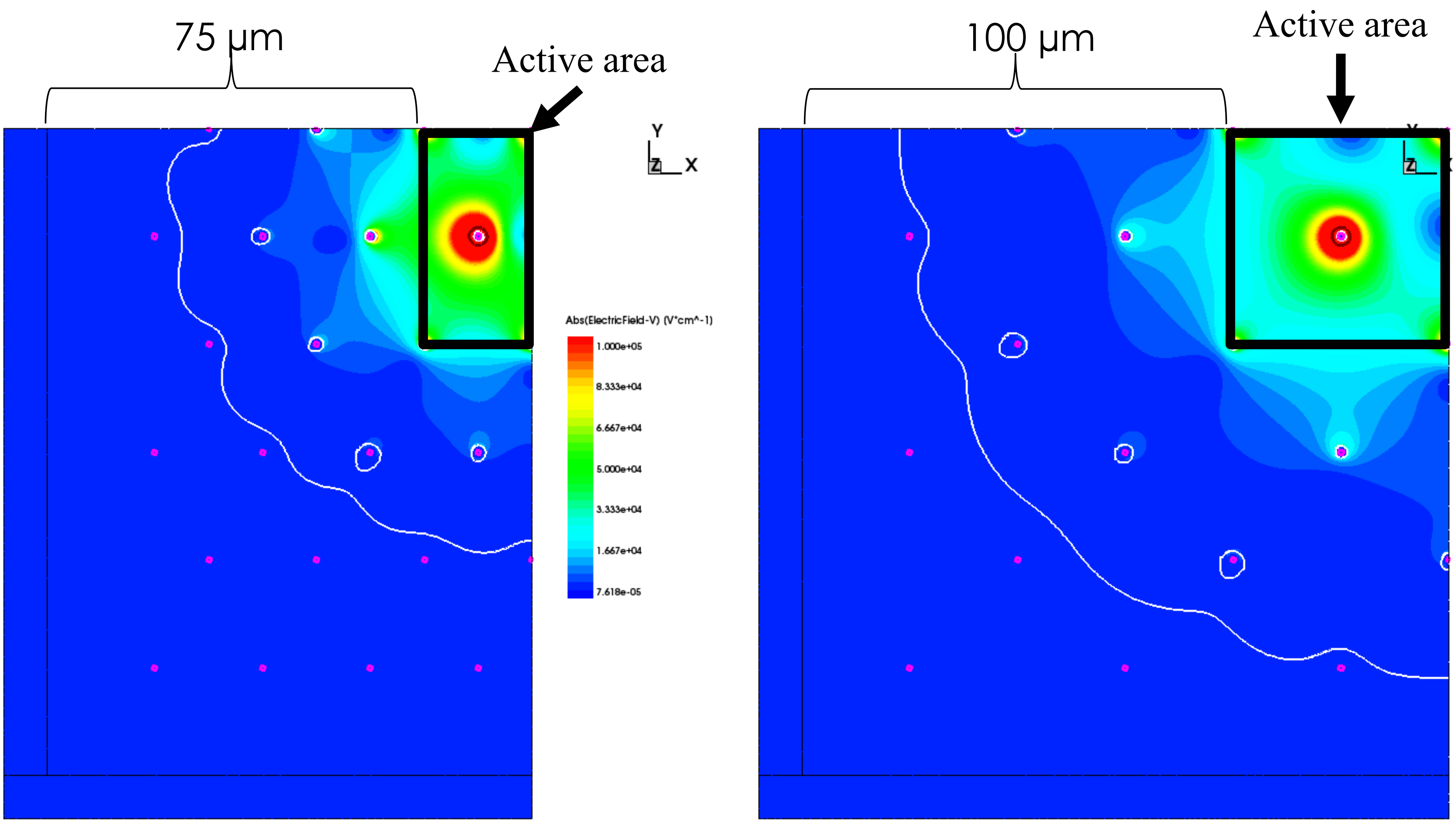


CV Simulation



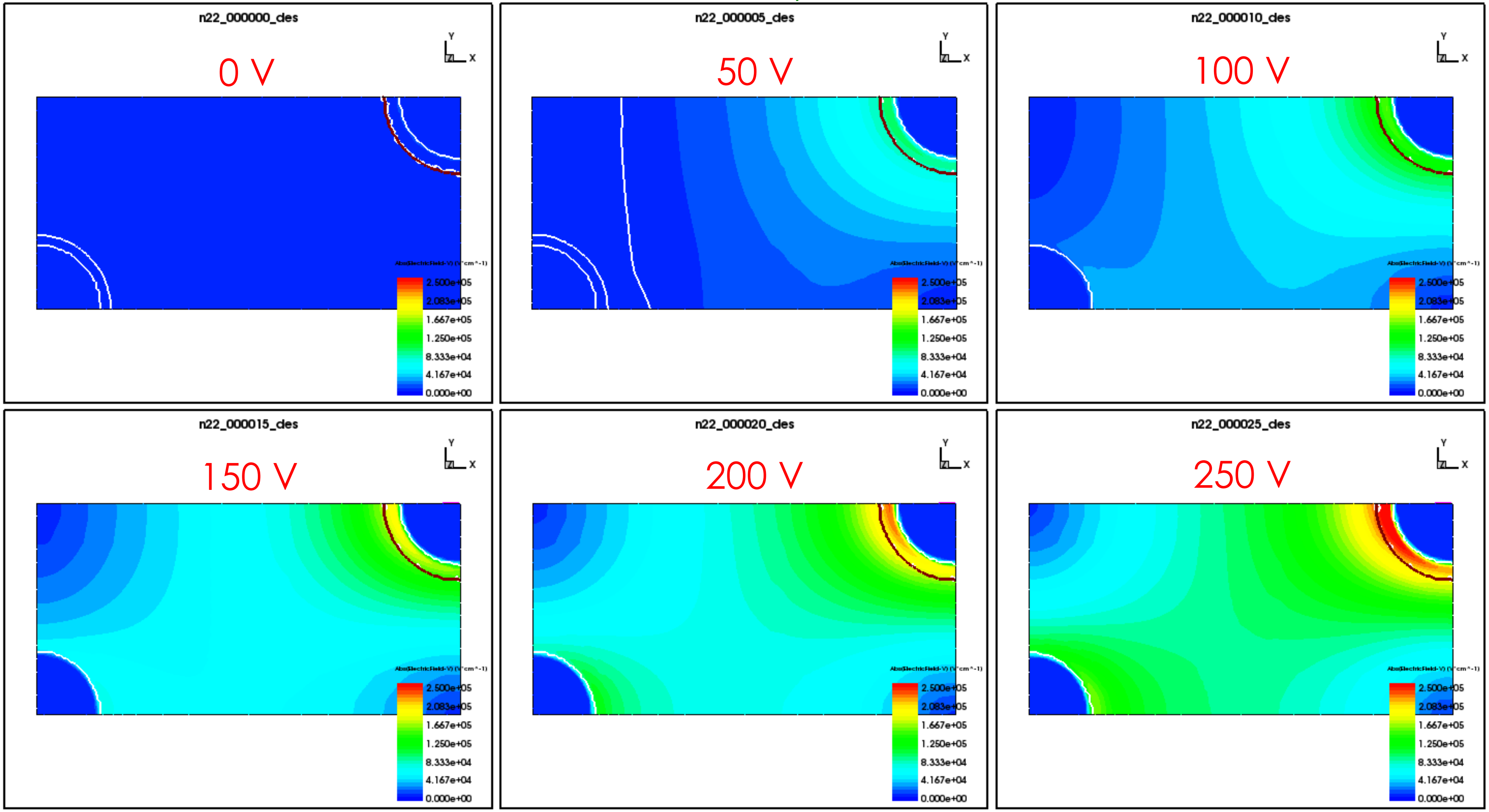
- ✓ Capacitance simulated in 3D, it includes column, tip, surface and metal contributions (it was ~200 fF in 3D pixels for IBL).
- ✓ Higher capacitance for 25x100 (2E and short distance of electrodes)

Edge Simulation



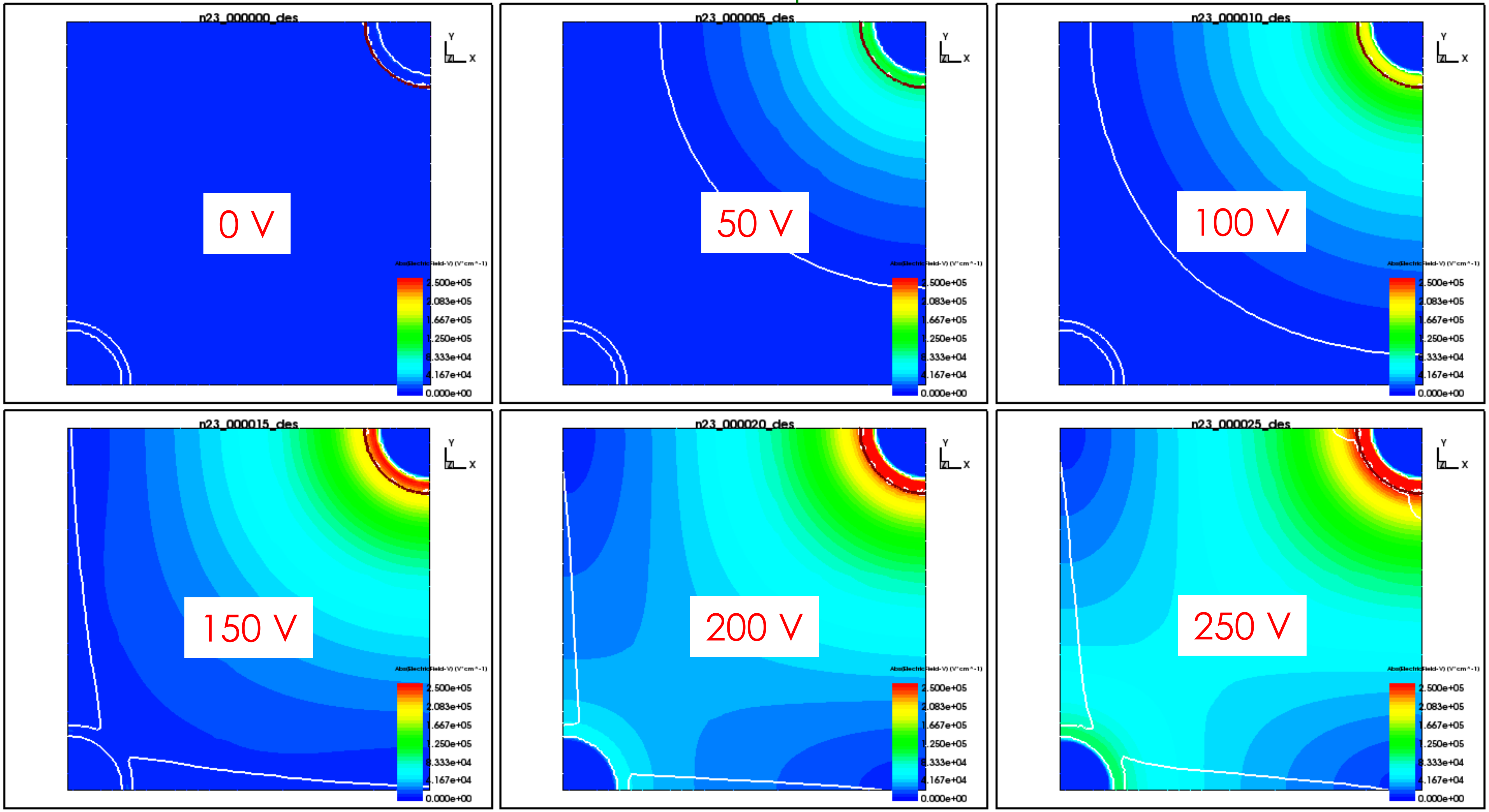
TCAD Simulation: 25x100 electric Field

$2x10^{16}\ n_{eq}/cm^2$

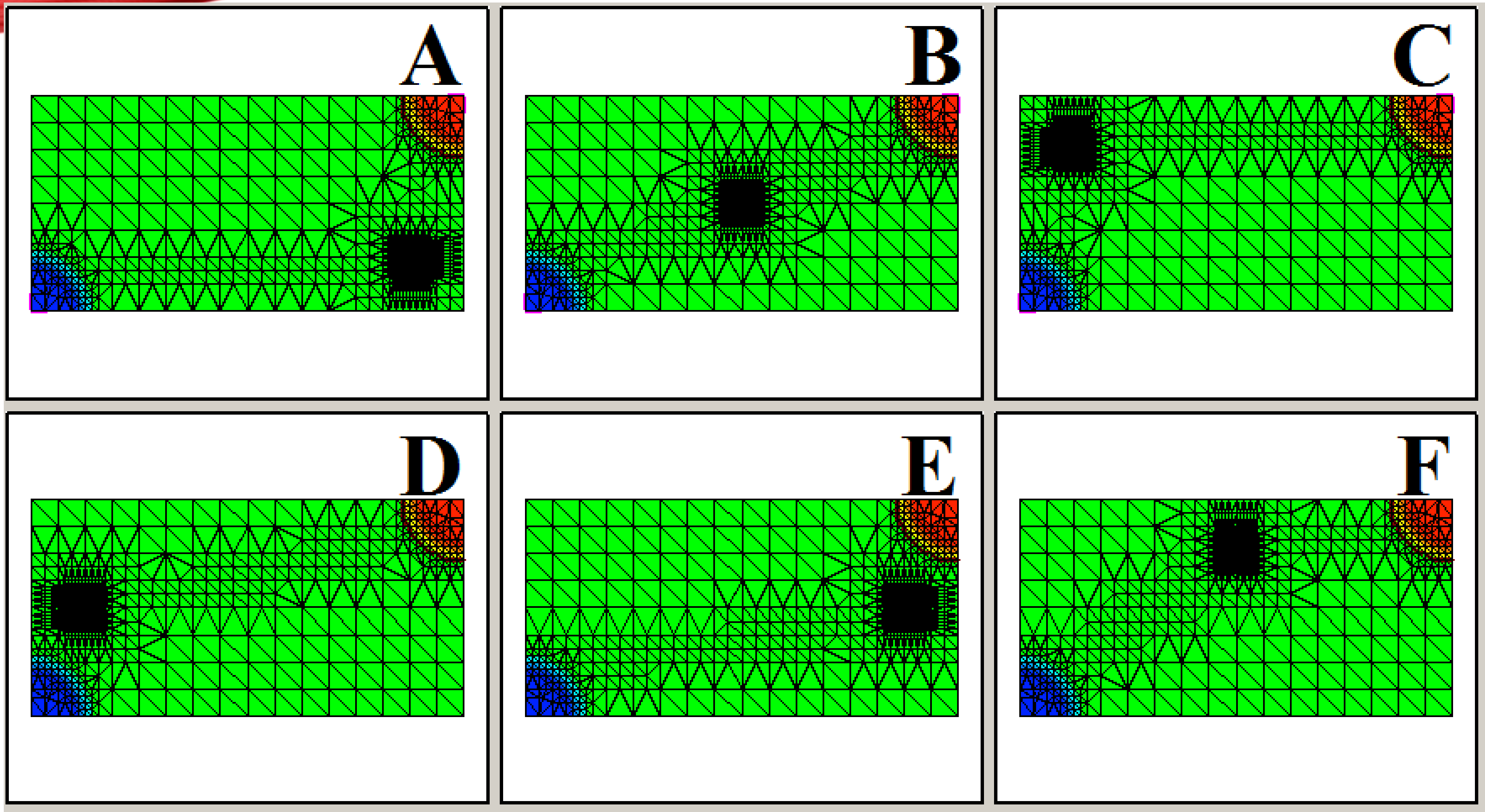


TCAD Simulation: 25x50 electric Field

$2x10^{16}\ n_{eq}/cm^2$



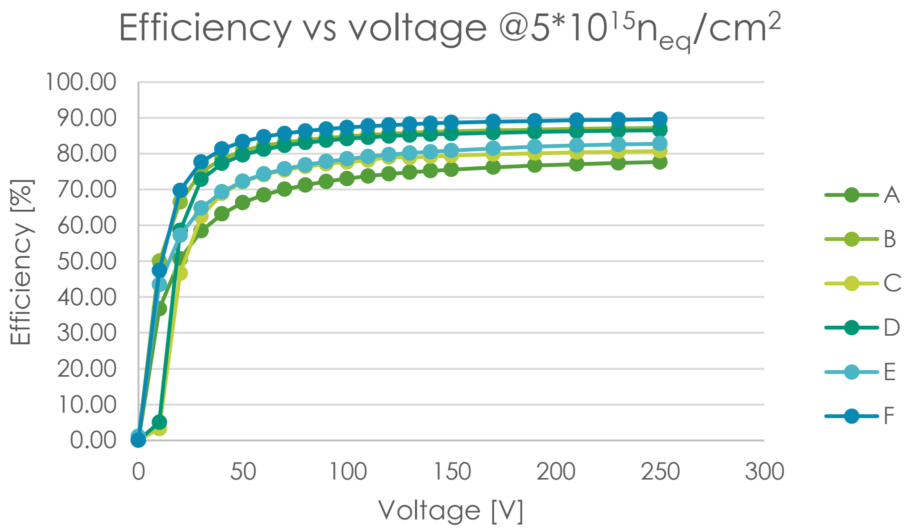
TCAD simulation: signal efficiency 25x100 (1)

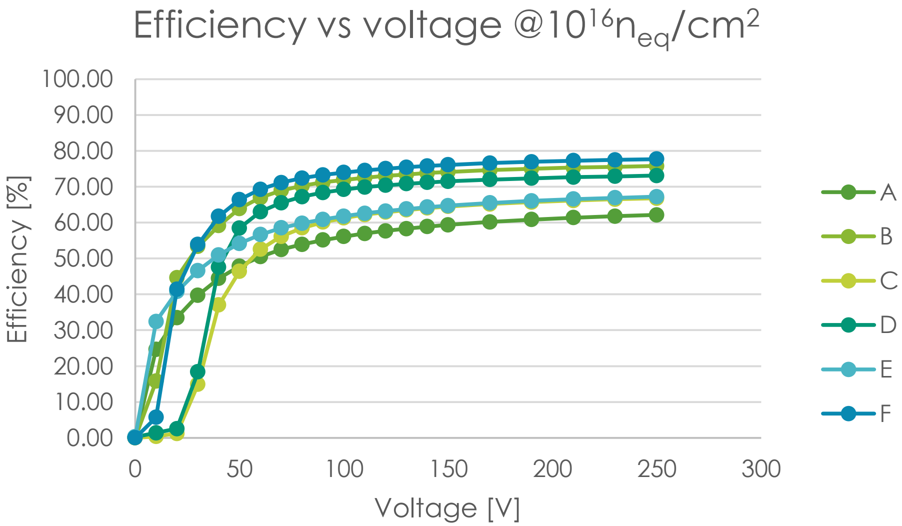


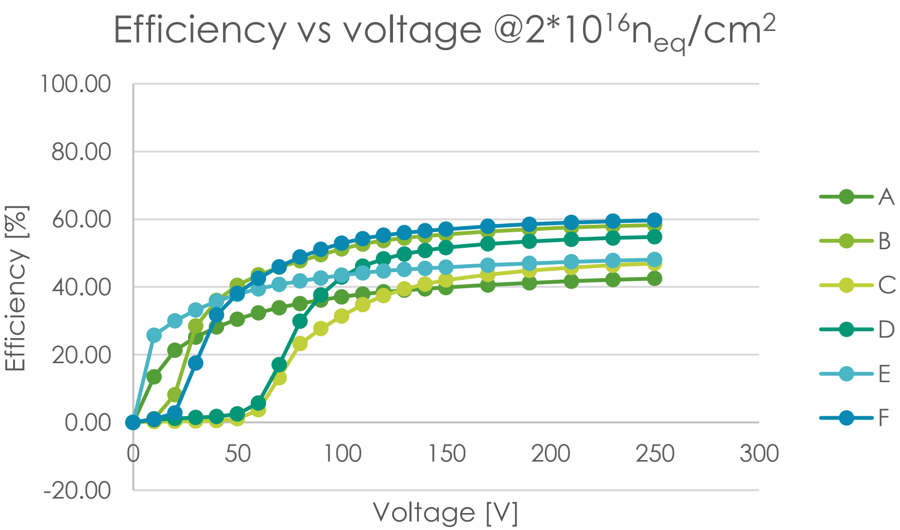
- 6 different points considered
- 3 different fluencies

TCAD simulation: signal efficiency 25x100 (2)

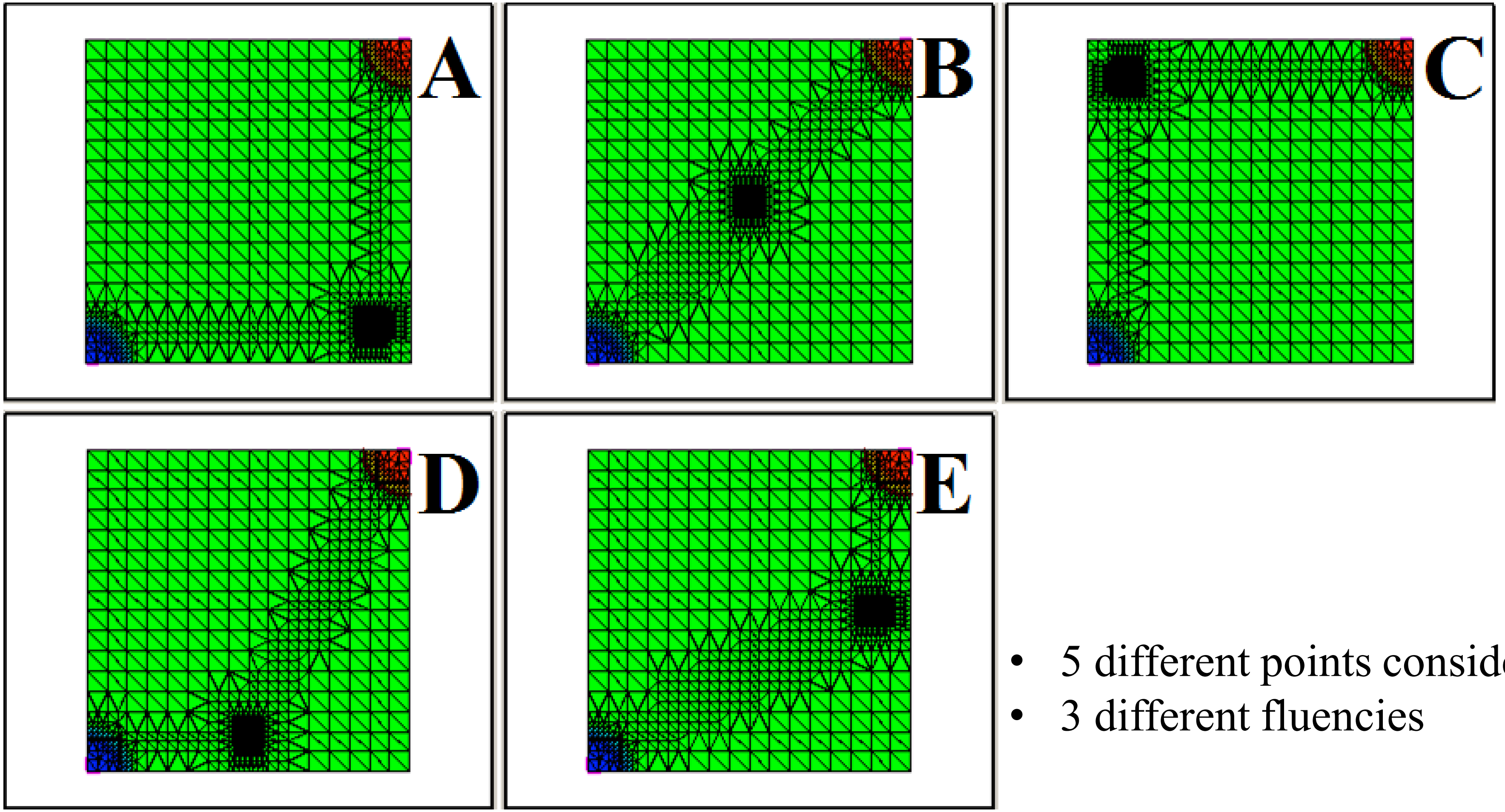
- 20-ns integration of current signals and average
- Normalization to injected charge
- 40-60% maxima efficiency for $2*10^{16}n_{eq}/cm^2$







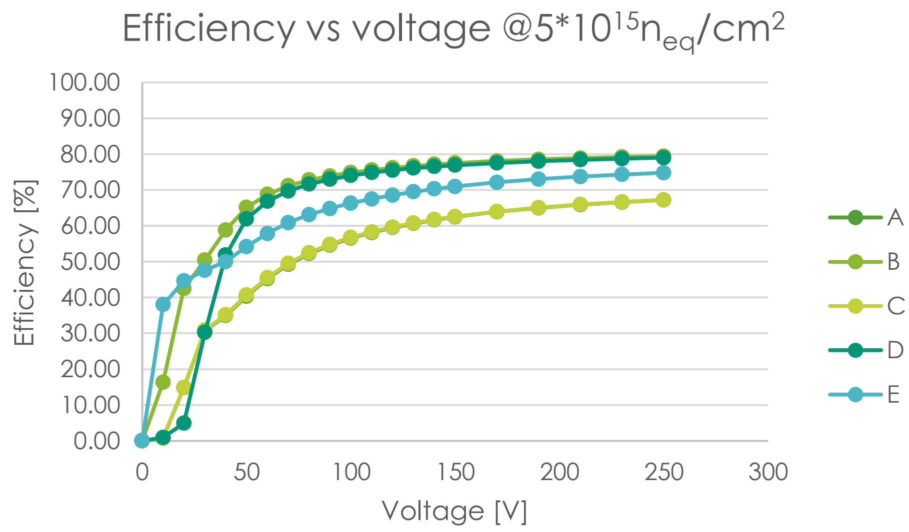
TCAD simulation: signal efficiency 50x50 (1)

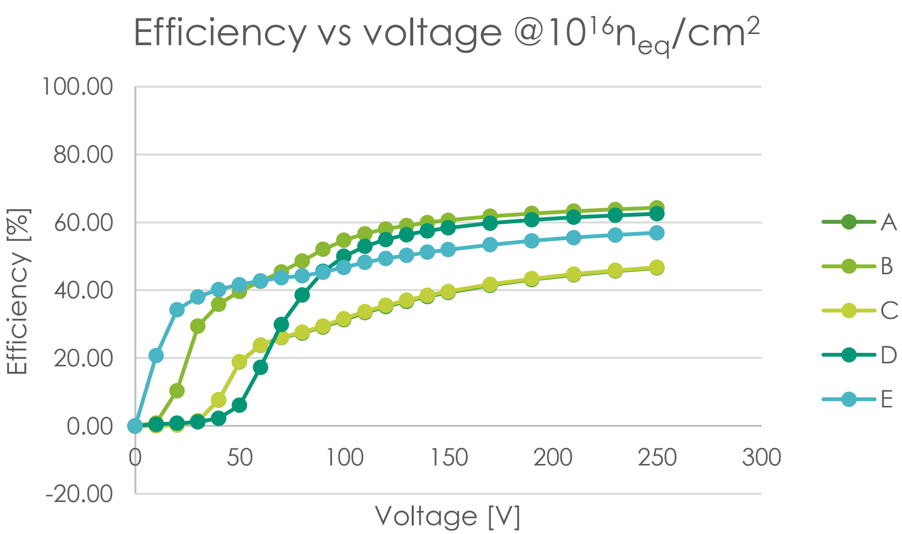


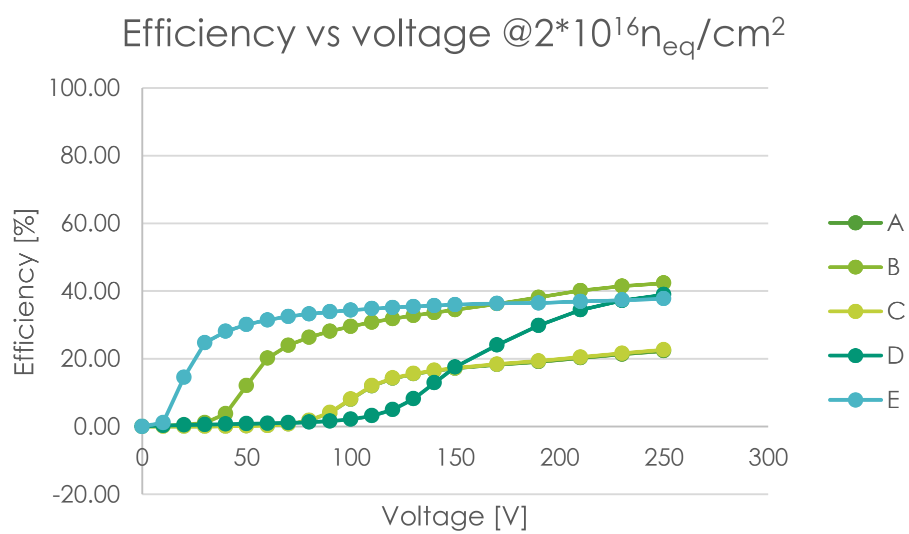
- 5 different points considered
- 3 different fluencies

TCAD simulation: signal efficiency 50x50 (2)

- 20-ns integration of current signals and average
- Normalization to injected charge
- 20-40% maxima efficiency for $2*10^{16}n_{eq}/cm^2$







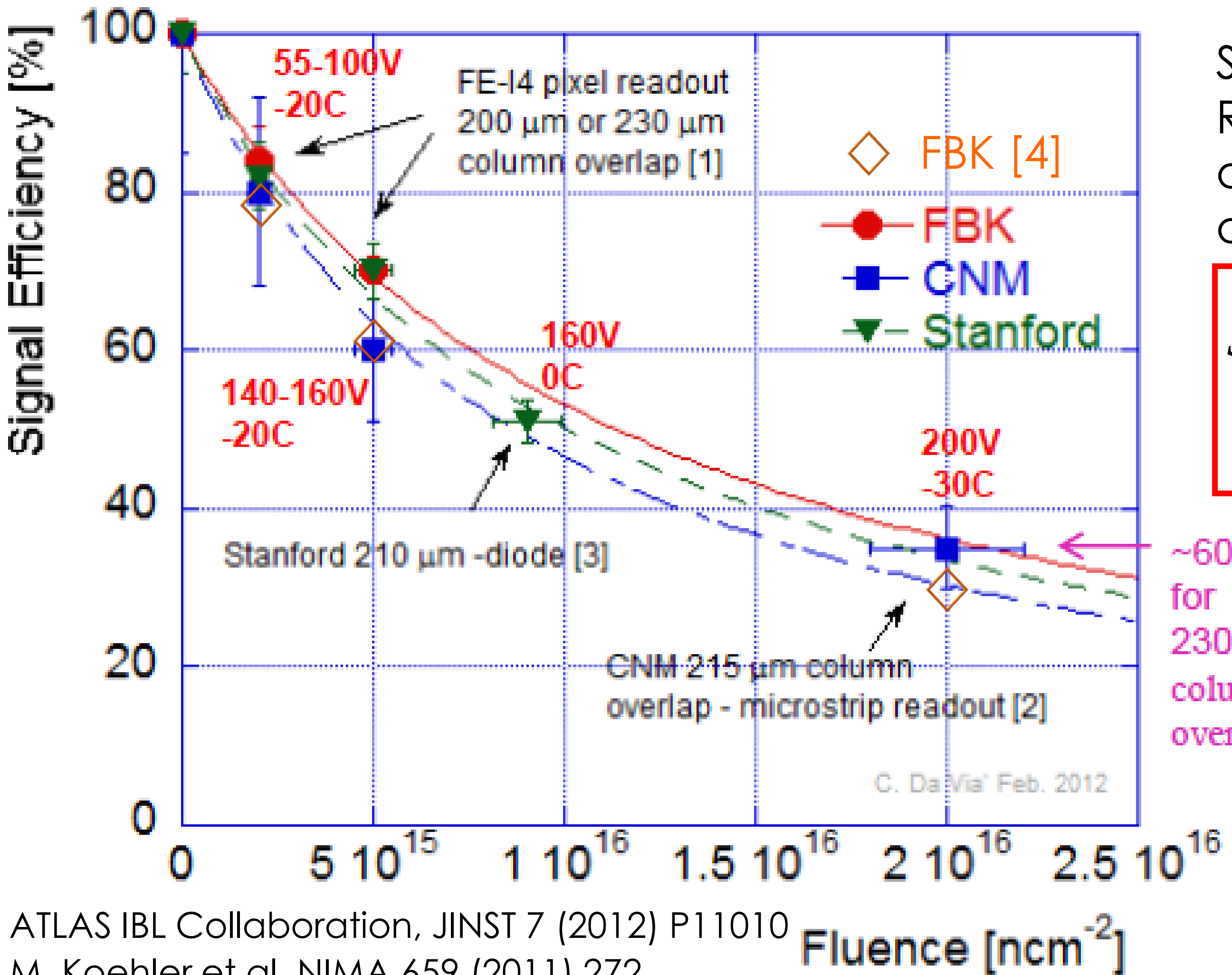
Conclusions

- Sensors with very high density of pixels have been presented with the solution proposed by UNITN/FBK
- The layout is almost ready to be processed in FBK
- We have studied the expected electrical and charge collection after irradiation
- The study will continue with more simulations (in particular after irradiation) with more precise TCAD models (Dr. Robert Klanner and Francesco Moscatelli presentations)


THANK YOU!

- backup

PERFORMANCE COMPARISON



Signal Efficiency = Ratio of max. signal after irradiation and before irradiation

$$SE = \frac{1}{1 + 0.6L\frac{K_\tau}{v_D}\Phi}$$

C. Da Via, S. Watts, NIMA 603 (2009) 319

[1] ATLAS IBL Collaboration, JINST 7 (2012) P11010
[2] M. Koehler et al. NIMA 659 (2011) 272
[3] C. Da Via, et al., NIMA 604 (2009) 505
[4] G.-F. Dalla Betta, et al., HSTD9 (2013)

Original Compilation by C. Da Via