3D pixels sensors in Trento: update on activities and plans

AIDA 2020

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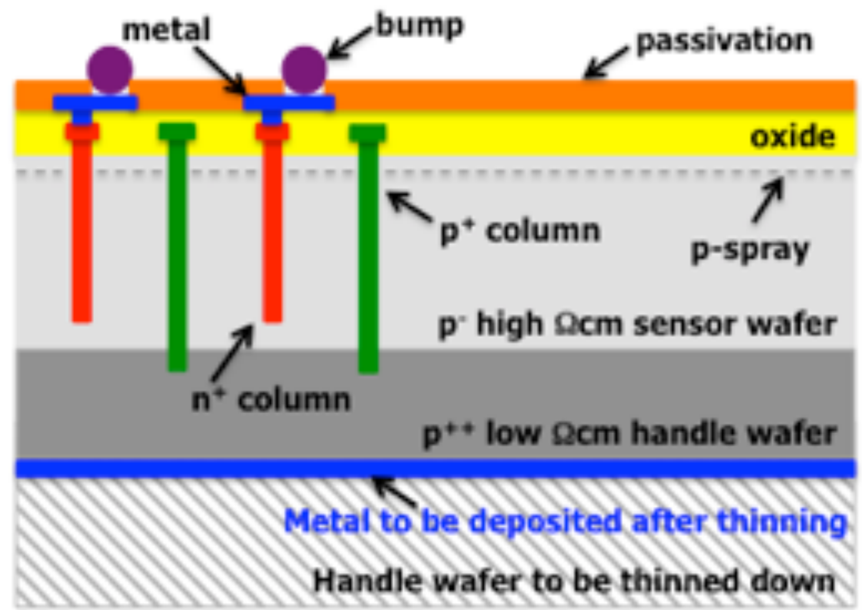
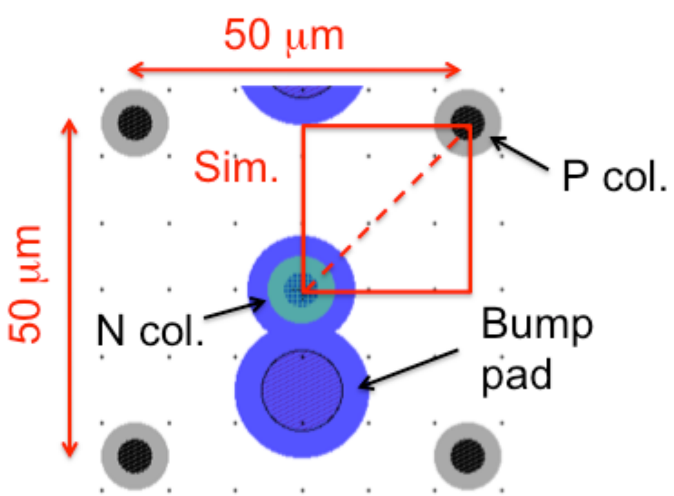
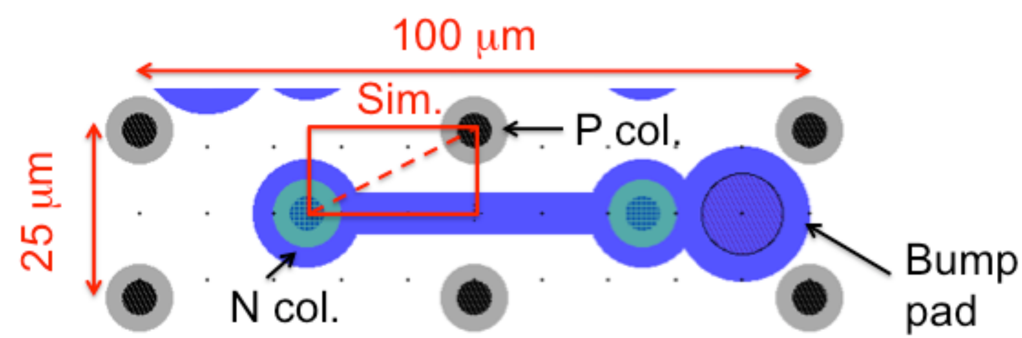
- D7.1 : Simulation of 3D pixel sensor cells [M18] Simulation of new sensor cells for thin 3D sensors with fine pitch, reduced column diameter and inter-column distance. Simulation of charge collection properties of 3D sensors with thinner substrates and determination of optimal thickness for pixel detectors working at HL-LHC. (Task 7.2)
- 2nd year summary, work in progress and next steps

New thin 3D on 6” @ FBK

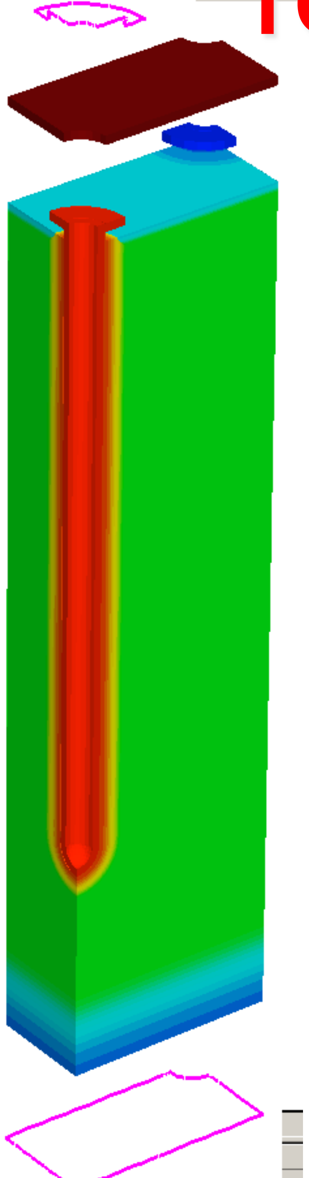
- Single-sided process (3D-SS)
- “Thin” active layer: SiSi (or SOI)
- Ohmic columns depth > active layer
- Junction columns depth < active layer
- Reduction of column diameter to 5 um
- Holes partially filled with poly
- Very slim or active edge

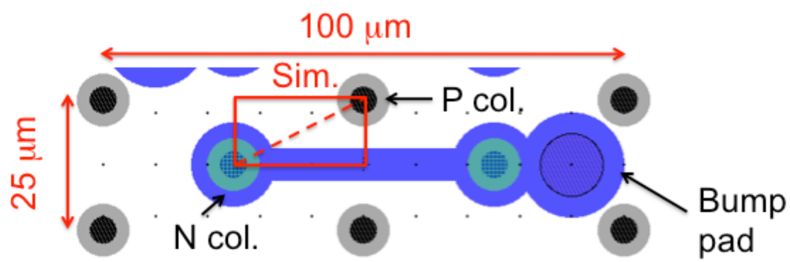




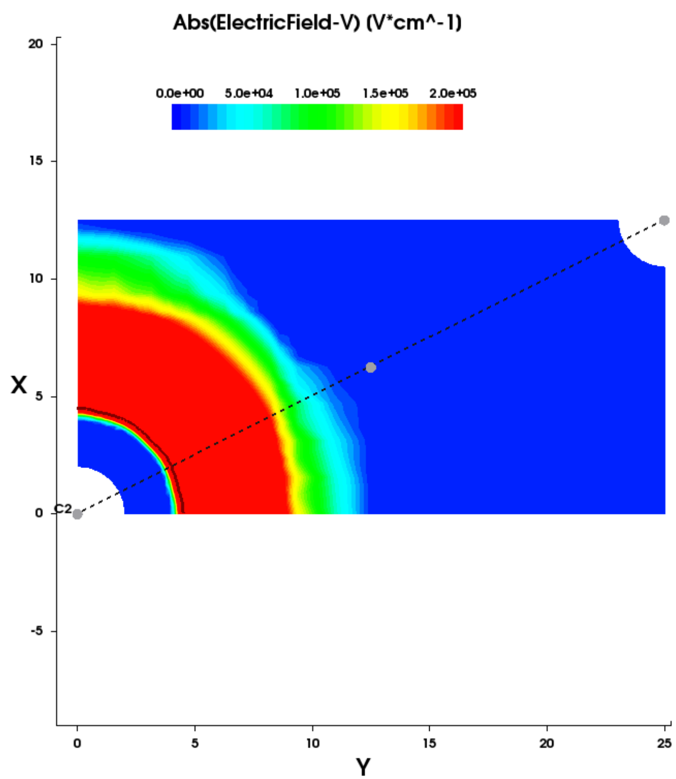


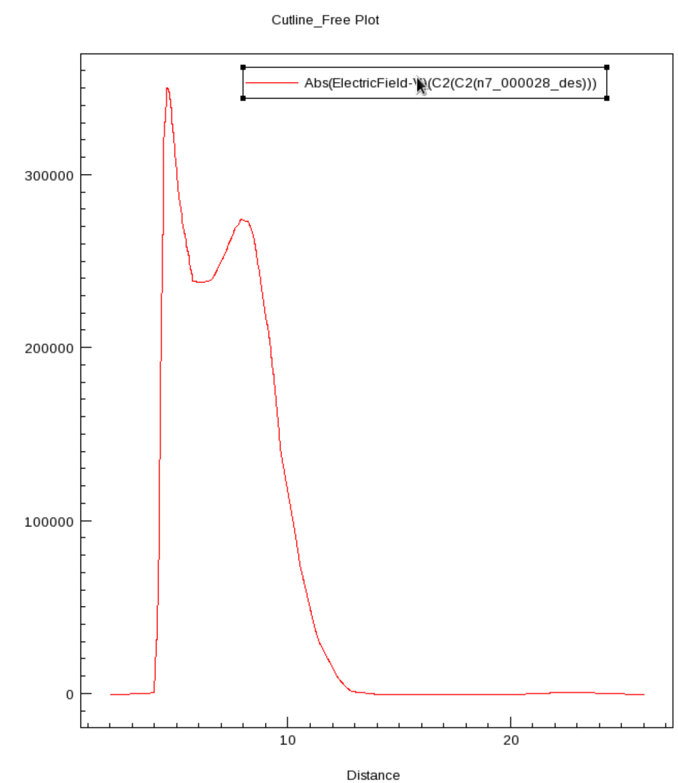
TCAD Simulations: full 3D approach





- Domain: 1/8 of pixel
- Thickness: 100um
- n^+ column depth 75um
- All technological details

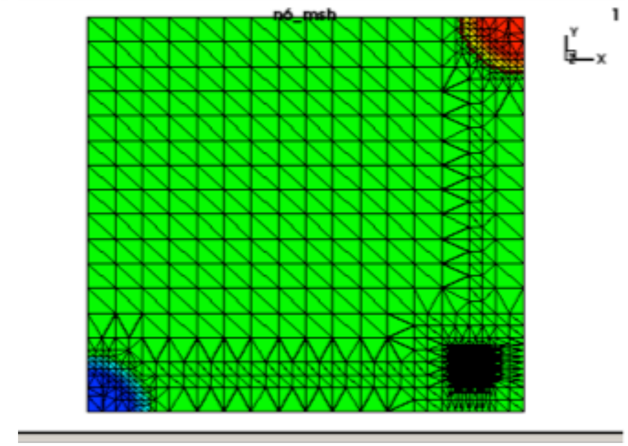


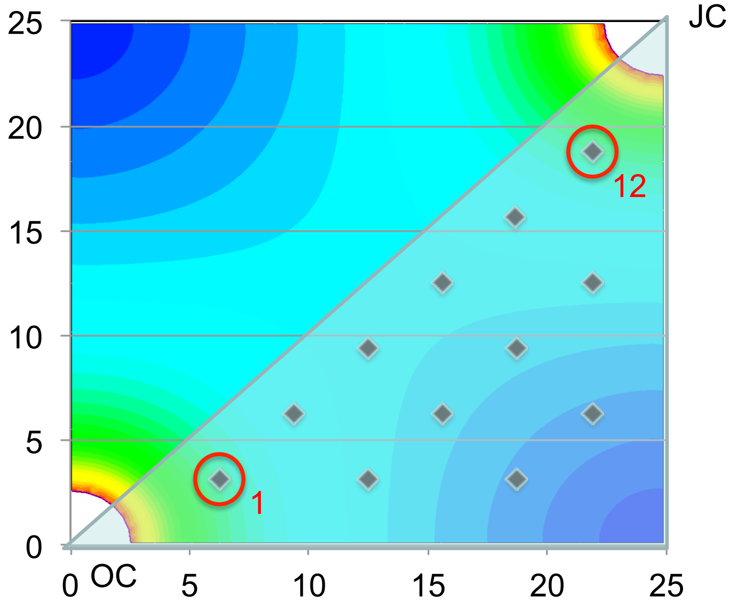


CCE simulation approach

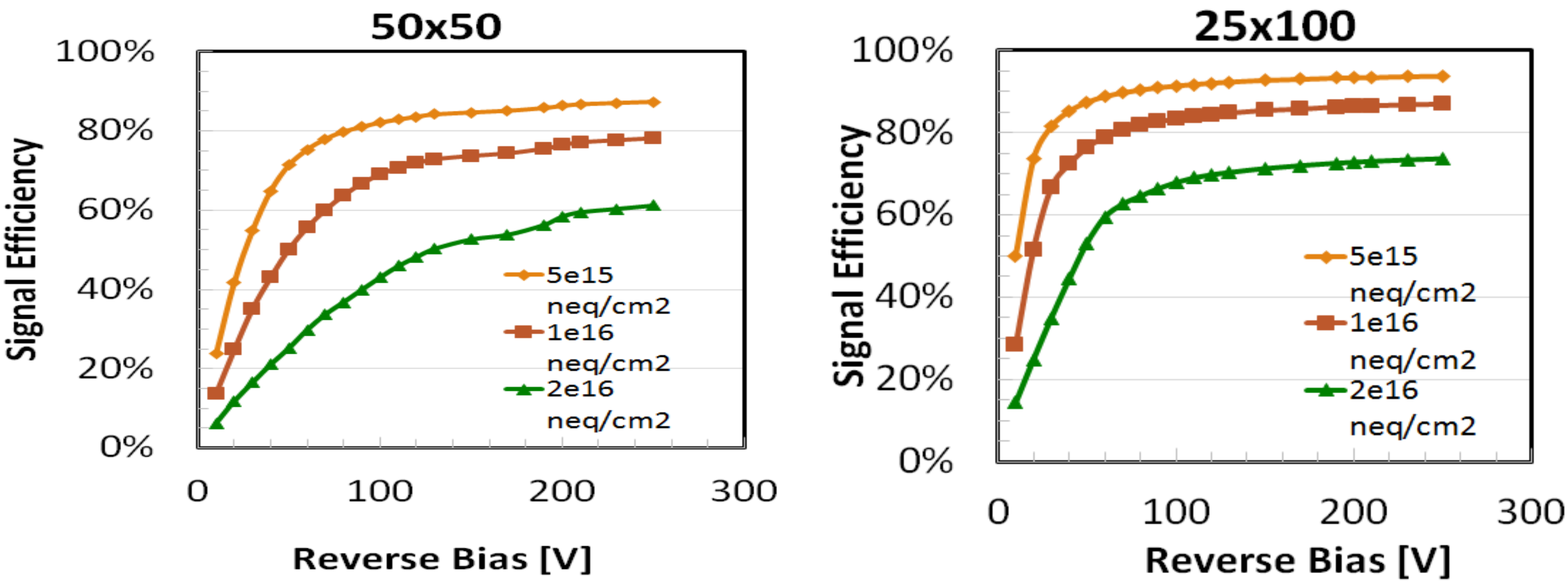
50x50

- Simplified simulation domain (~2d):
  1 μm thick slice (1/4 or 1/8 of pixel)
- MIP (heavy ion model): vertical hits at several different positions representing different electric field values
- New Perugia radiation damage model
- Avoiding boundaries: no charge sharing
- Subtract leakage current
- 20-ns integration of current signals
- Average charge over all hit positions
- Normalization to injected charge
- Repeat at different bias voltage





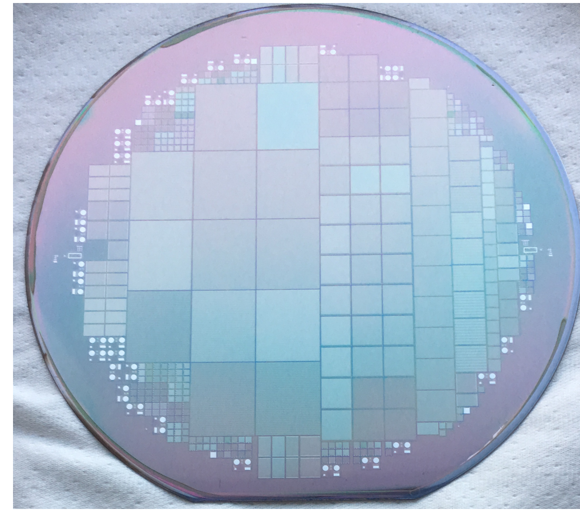
Average Signal Efficiency

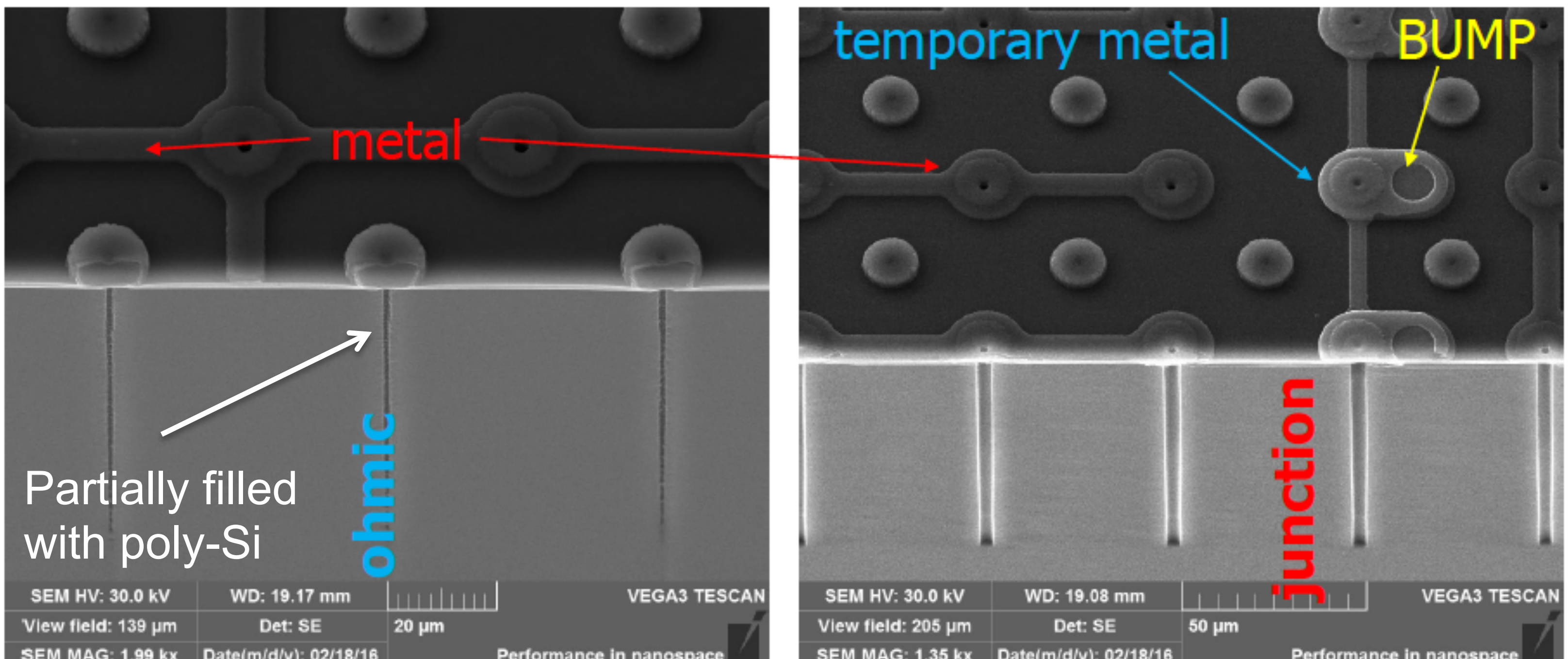


- Very high average signal efficiency
- True values will be smaller due to pixel edge effects
- Significant variations of signal efficiency with hit position, increasing with fluence

1st FBK 3D-SS batch

- Ten wafers processed (completed Feb. 2016)
- Two different active thicknesses: 100 vs 130 μm
- Several pixel layouts (small pixels with grid) FE-I4, FE-I3, PSI46, CHIPIX65, etc.
- Test structures: 3D strips and diodes

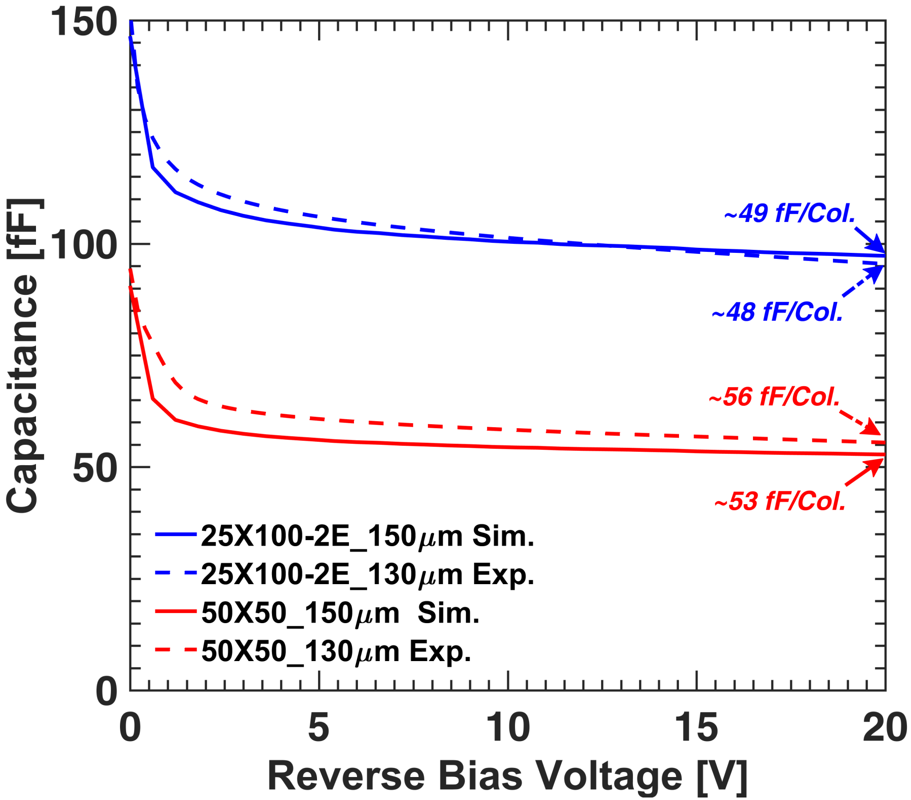


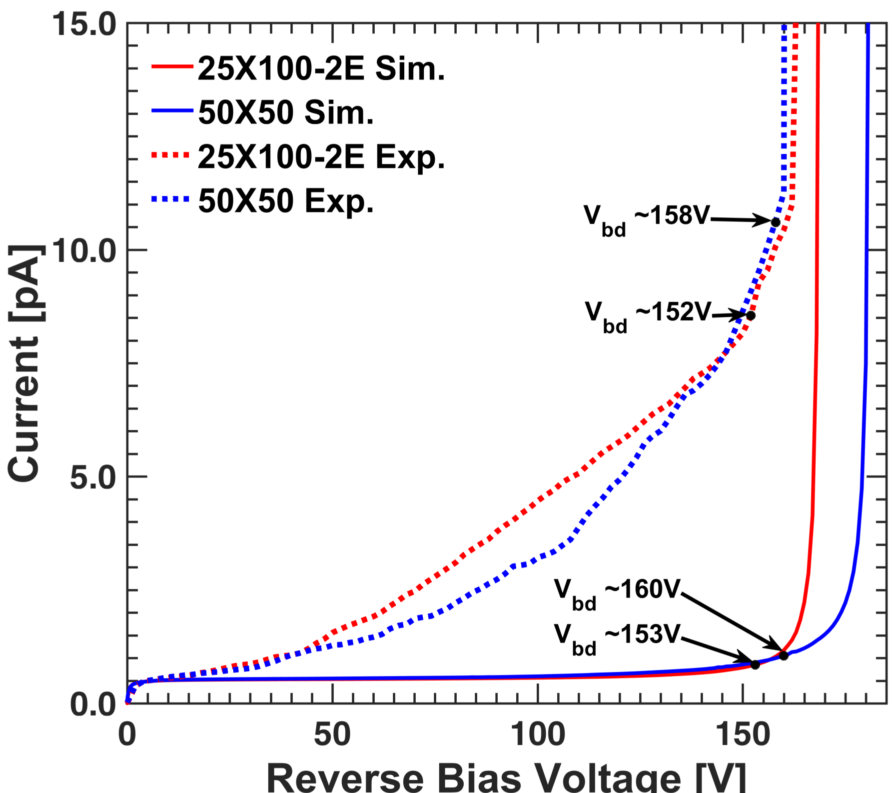


Measurements vs TCAD simulations

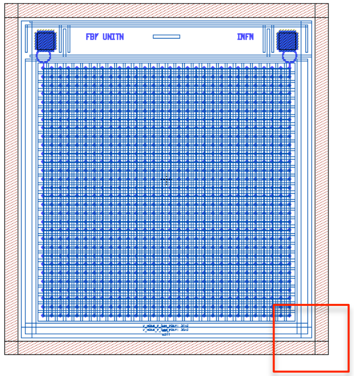
- From 3D diode measurements
- Very good agreement in C-V curves
- Good agreement in I-V curves but for the slope (that depends on interface states, so far not included in the model)

G.-F. Dalla Betta et al., Vertex 2016

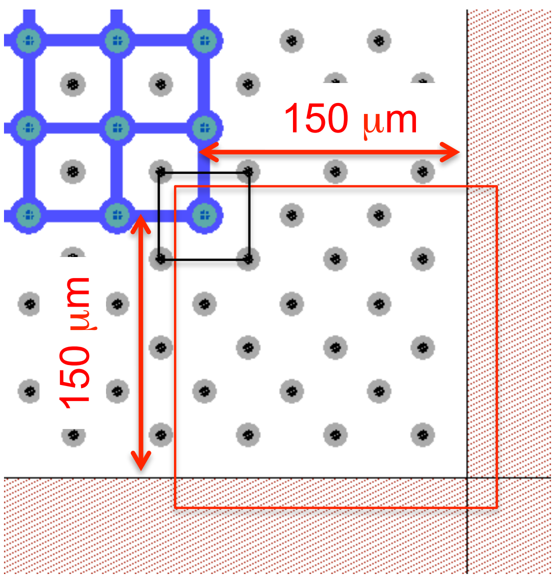


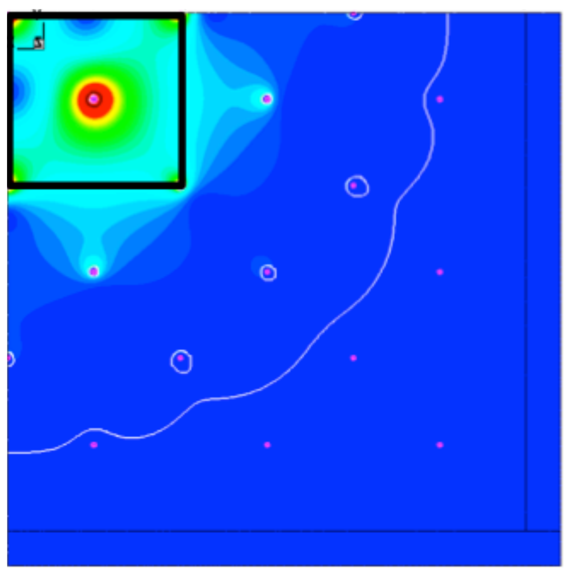


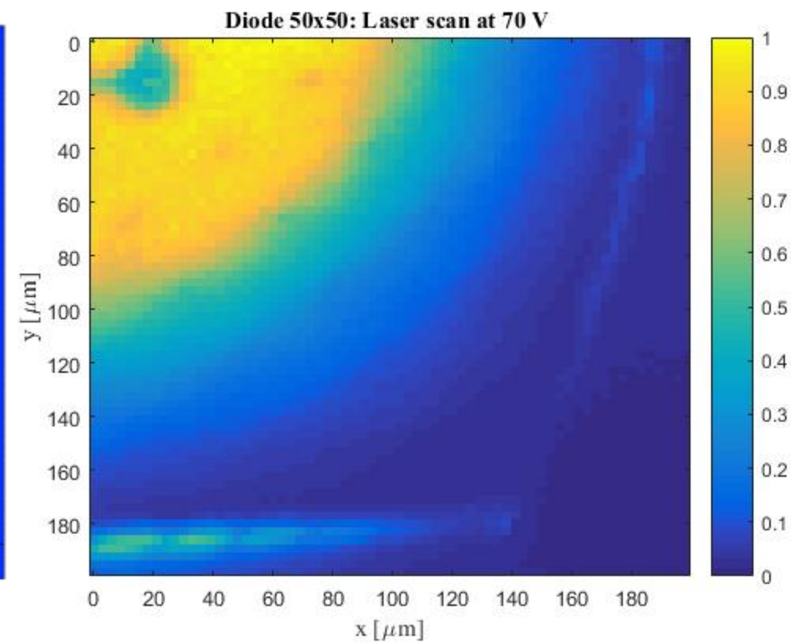
Slim edge laser test



- Slim edge based on multiple ohmic columns developed for IBL (~200 μm) M. Povoli et al., JINST 7 (2012) C01015, here made slimmer (~100 μm) with reduced inter-electrode spacing
- Safe operation of 3D diode (50 μm x 50 μm design) tested with position resolved laser system
- High signal indicates extension of the depleted volume at the corner (~80 μm at 70 V), in good agreement with simulations

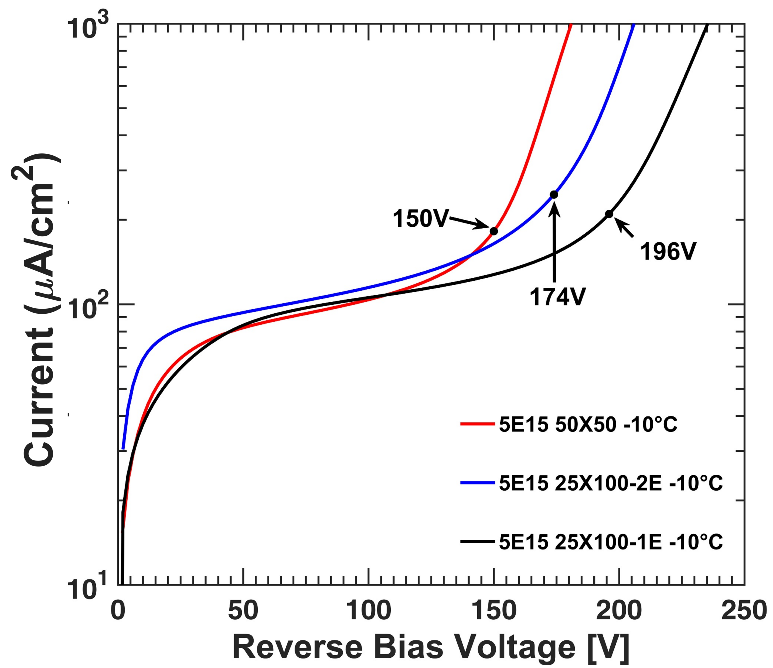


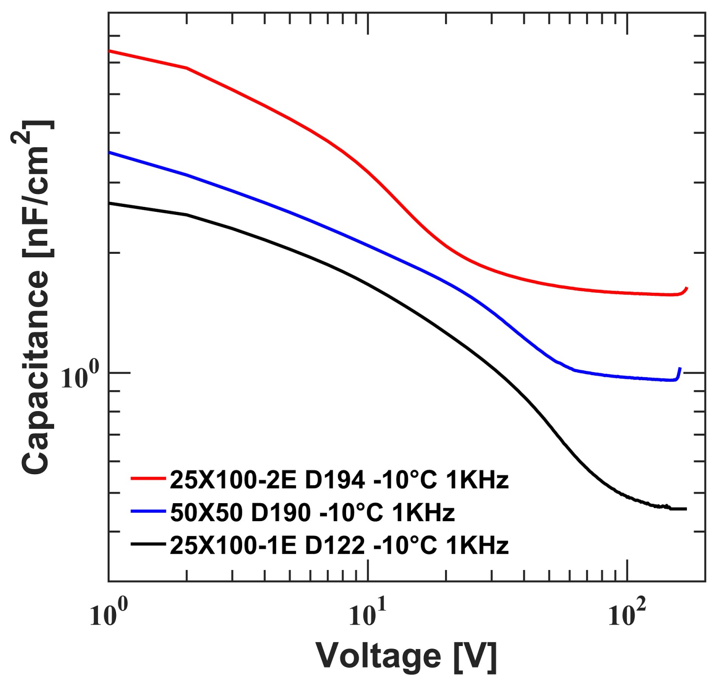




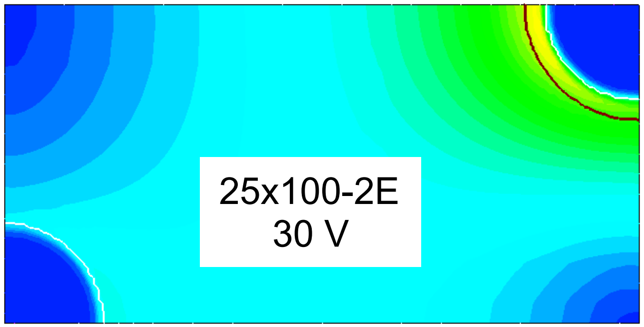
3D diode neutron irradiation

Neutron irradiation at $5x10^{15}$ n_{eq}/cm^2 (JSI Lubiana, thanks to V. Cindro)



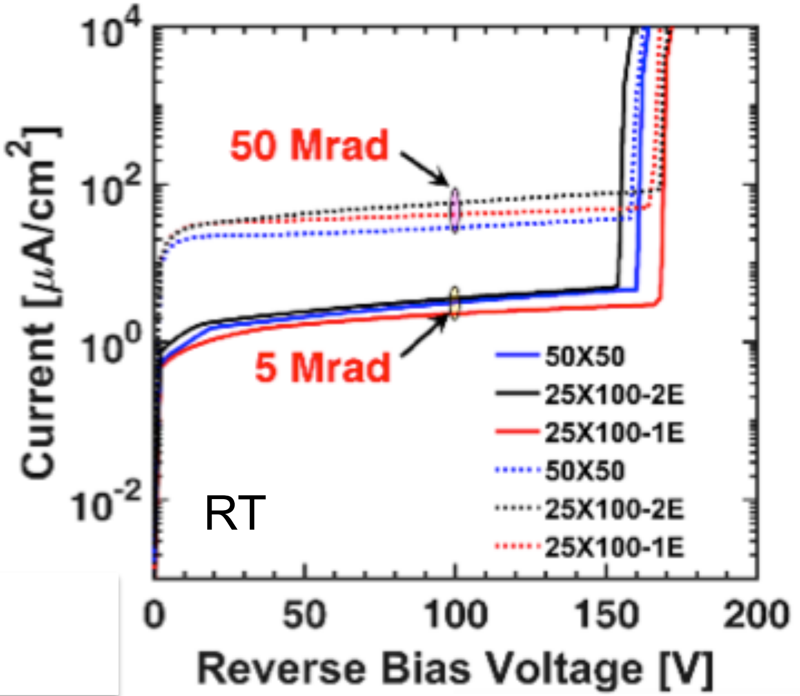


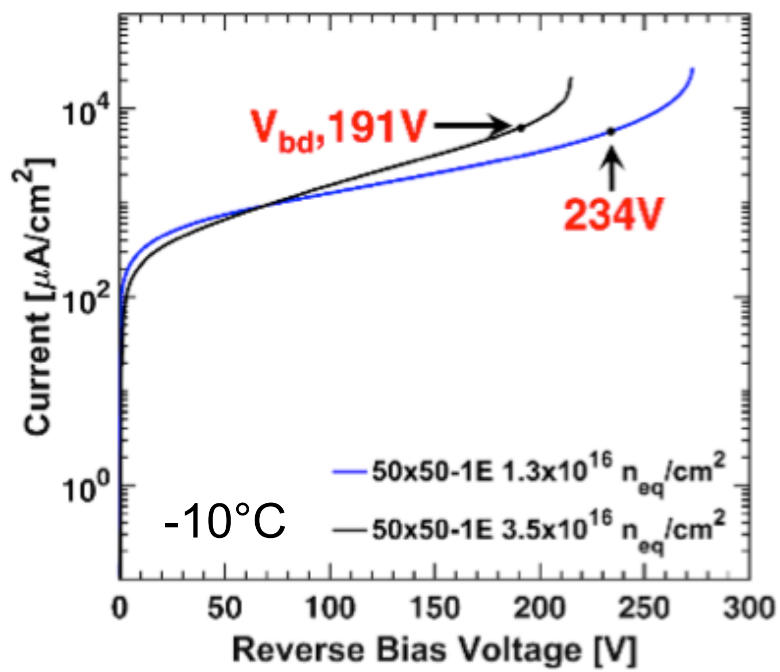
- Leakage current increases as expected:
  - Damage constant $\alpha \sim 4x10^{-17}$ A/cm
- Breakdown voltage also increases and is large enough wrt depletion voltage



3D diode: γ–ray and proton irradiation

Gamma irradiation at SANDIA, protons irradiation at LANSCE
(thanks to M. Hoeferkamp and S. Seidel)

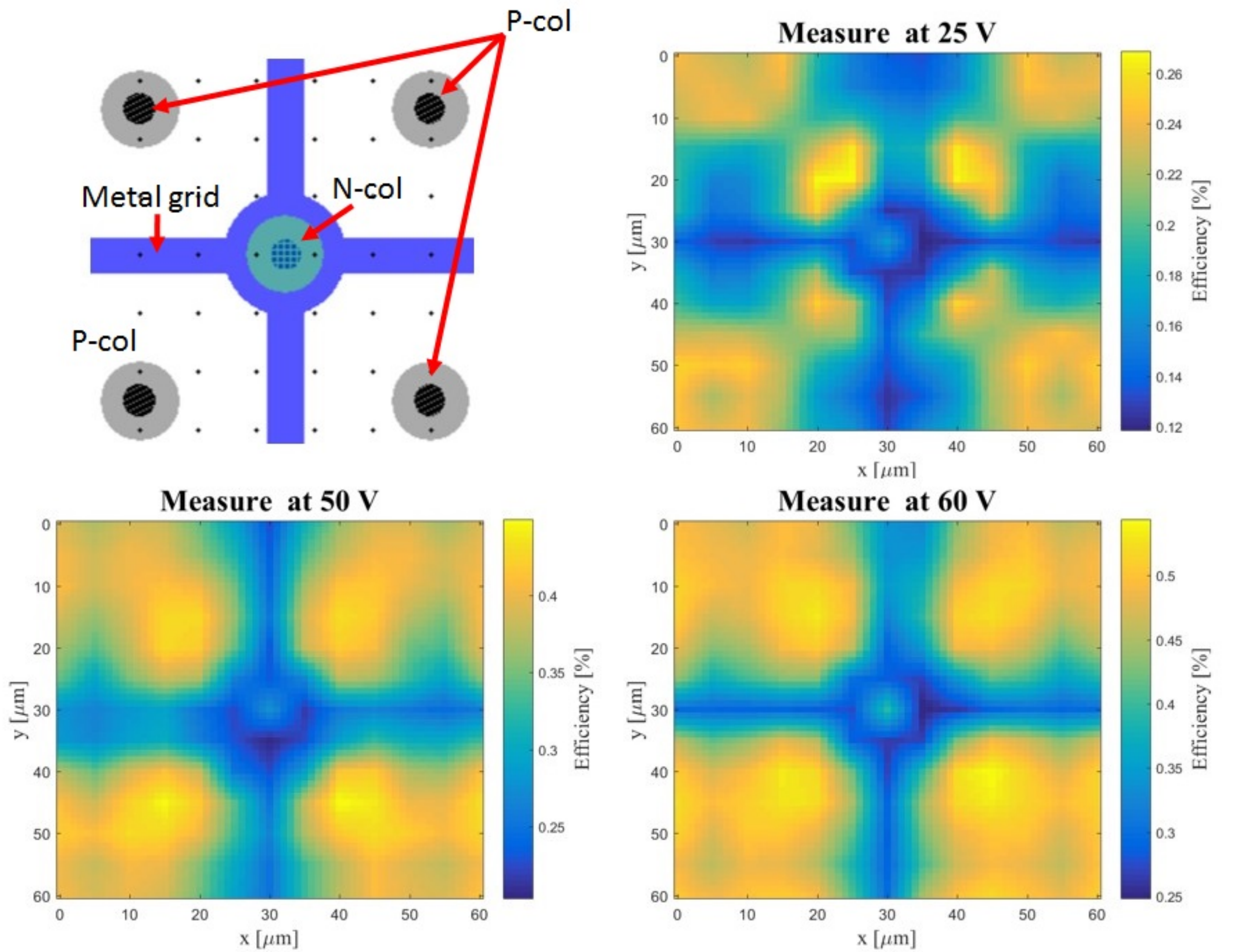




- Minor change of breakdown after gamma irradiation
- For proton irradiation, breakdown voltage increase comparable to neutron irradiation (but larger voltages observed with protons on strips at lower fluences)
  → breakdown likely occurs at junction column tips

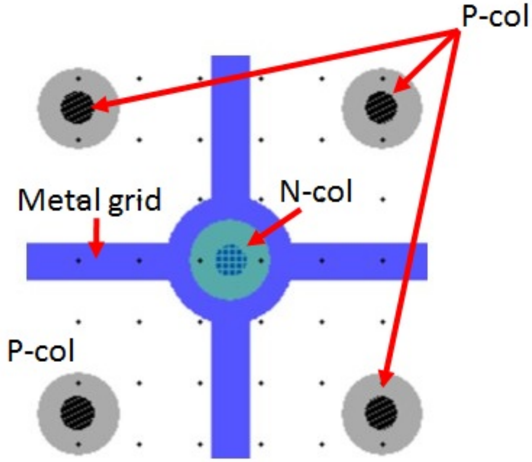
IR laser scan on irradiated 3D diode

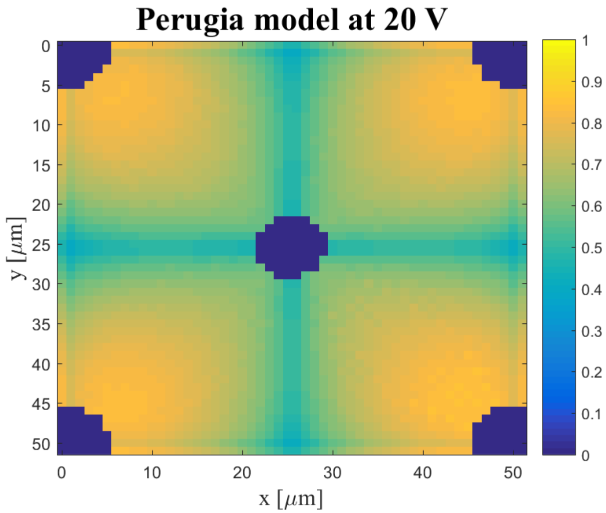
Neutron irradiated sample (5×10^{15} n_{eq}/cm^2)

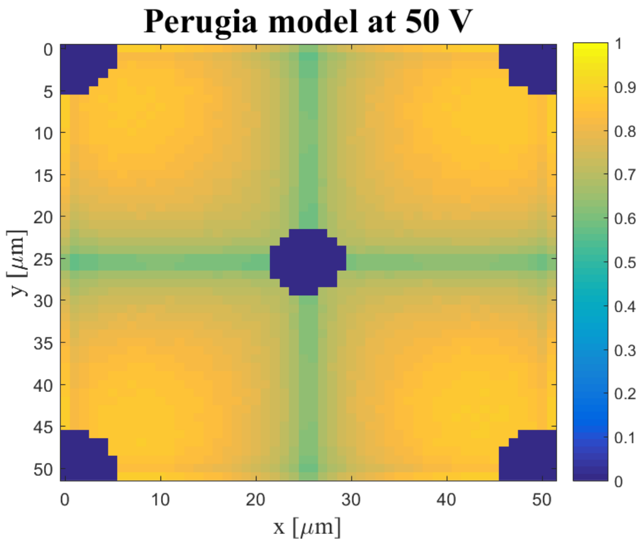


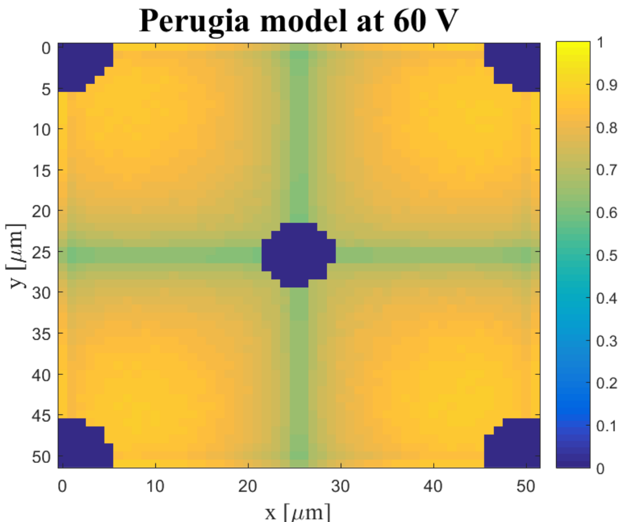
Comparison with Ramo's simulation

Neutron irradiated sample ($5x10^{15}$ n_{eq}/cm^2)





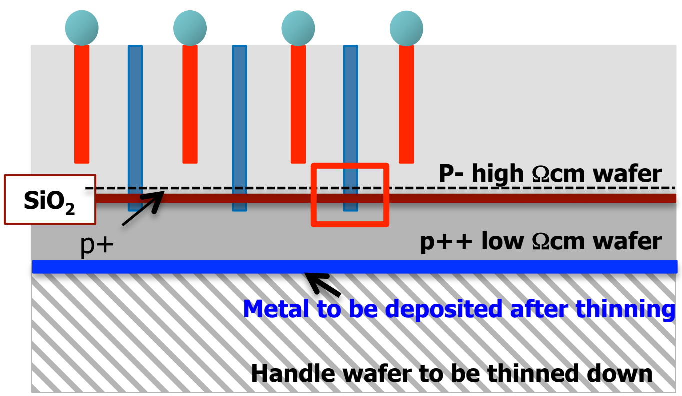




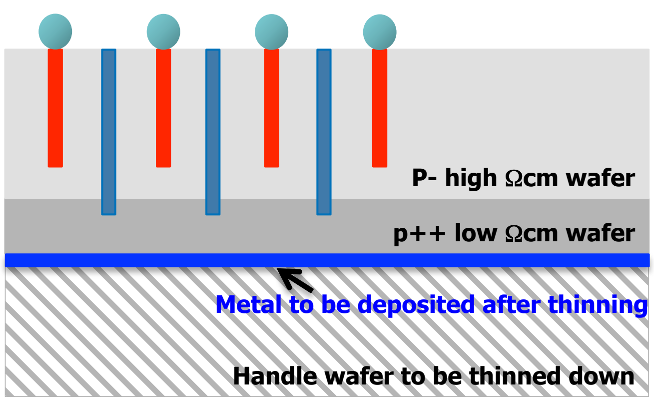
2nd FBK 3D-SS batch

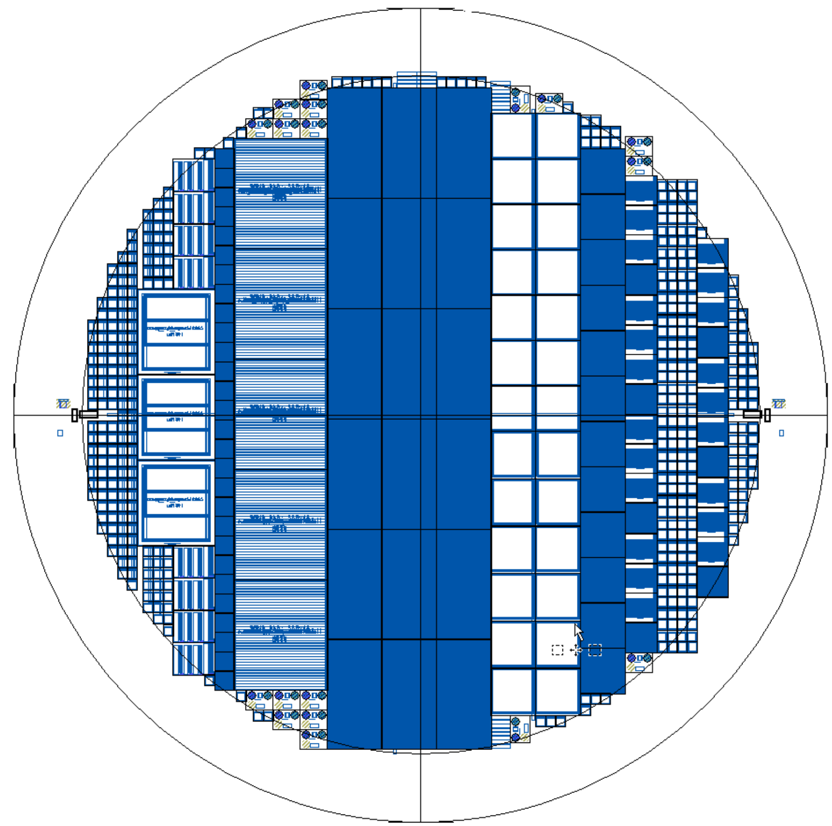
- Funded by AIDA 2020 (processing) and by INFN (substrates and masks)
- Single side process (as shown before)
- 12 wafers (6”) with 130 μm thick active layer: (8) SiSi and (4) SOI

SOI

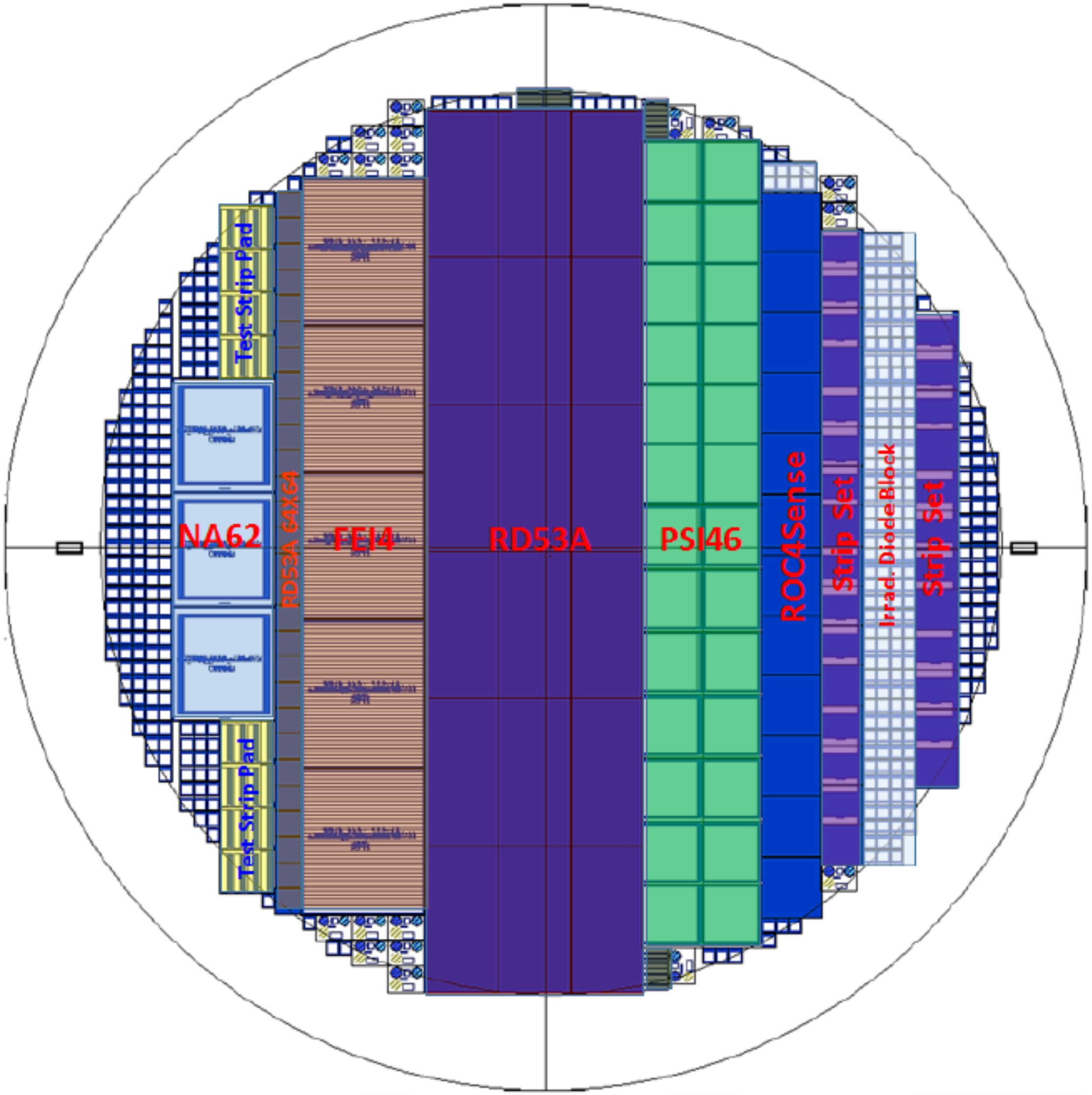


SiSi





2nd batch Wafer Layout



DMS Sultan, UniTN

- FE-I4
  - 50 x 250 (2E) std
  - 50 x 100 (1E+9E)
  - 50 x 50 (5E)
- PSI46dig (also with BOC option)
  - 100 x 150 (2E and 3E) std
  - 50 x 50 (1E)
  - 25 x 100 (1E and 2E)
- R4S
  - 50 x 50 (1E)
  - 25 x 100 (1E and 2E)
- RD53A (also with BOC option)
  - 50 x 50 (1E)
  - 25 x 100 (1E and 2E)
- CHIPIX65
  - 50 x 50 (1E and 2E)
  - 25 x 100 (1E and 2E)
- NA62
  - For timing studies

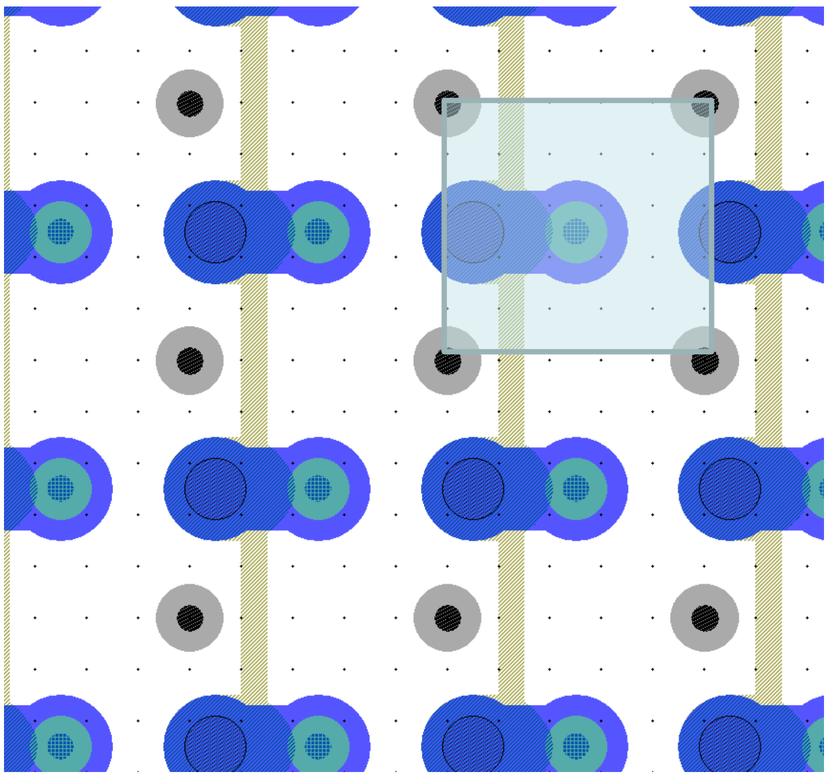
+ Test structures (strip, diodes, etc)

List of Pixel Sensors

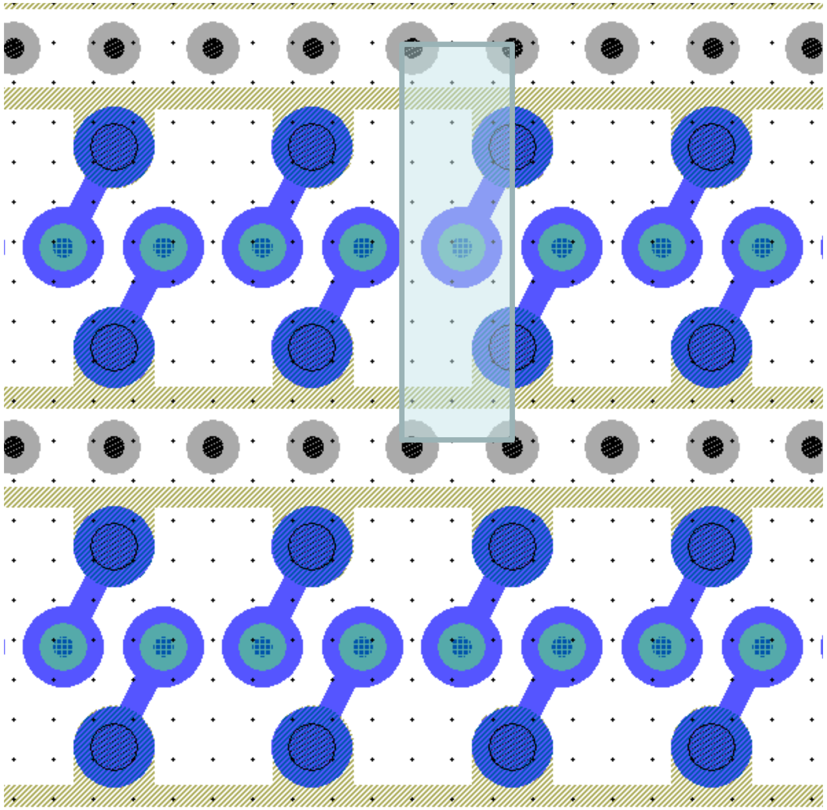
	Sensor Type	Multiplicity	Comment
Pixel Sensor	FEI4 50X250 2E	x2	IBL Generation complaint, Pixel Capacitance
	FEI4 50X250 5E	x2	Pixel Capacitance ~250fF
	FEI4 50X250 1E9E	x1	Pixel Capacitance ~50fF and ~450fF
	PSI46 2E	x4	Pixel Capacitance ~100fF
	PSI46 2E BO	x4	Pixel Capacitance ~100fF
	PSI46 3E	x3	Pixel Capacitance ~150fF
	PSI46 3E BO	x3	Pixel Capacitance ~150fF
	PSI46 50X50 1E with Grid	x2	Pixel Capacitance ~50fF
	PSI46 50X50 1E with Grid BO	x2	Pixel Capacitance ~50fF
	PSI46 25X100 1E with Grid	x1	Pixel Capacitance ~50fF
	PSI46 25X100 1E with Grid BO	x1	Pixel Capacitance ~50fF
	PSI46 25X100 2E with Grid	x3	Pixel Capacitance ~100fF
	PSI46 25X100 2E with Grid BO	x3	Pixel Capacitance ~100fF
	R4S 25X100 1E	x3	ROC4Sense, Pixel Capacitance ~50fF
	R4S 25X100 2E	x4	ROC4Sense, Pixel Capacitance ~100fF
	R4S 50X50	x5	ROC4Sense, Pixel Capacitance ~50fF
	RD53A 50X50	x8	ROC4Sense, Pixel Capacitance ~50fF
	RD53A 25X100 1E	x3	Pixel Capcitance ~50fF
	RD53A 25X100 2E BO	x2	P-Poly Cap 3µm, Pixel Capacitance ~100fF
	RD53A 25X100 2E	x5	Thinner P-Poly Field has designed due to space limit, Pixel Capacitance ~100fF
	RD53A 64X64 50X50-2E	x6	Pixel Capacitance ~100fF
	RD53A 64X64 50X50	x8	Pixel Capacitance ~50fF
	RD53A 64X64 25X100-1E	x6	Pixel Capacitance ~50fF
	RD53A 64X64 25X100-2E	x8	Pixel Capacitance ~100fF
	NA62 50um Hexagon	x2	Inter-electrode distance remains 50µm in hexagonal pixel structure
Strip Sensor	Strip 80X80	x7	Per Strip Capacitance ~3.2pF
	Strip 50X50	x7	Per Strip Capacitance ~5pF
	Strip 25X100 1E	x7	Per Strip Capacitance ~5pF
	Strip 25X100 2E	x7	Per Strip Capacitance ~10pF

RD53A Pixel Sensors

RD53A (50X50)

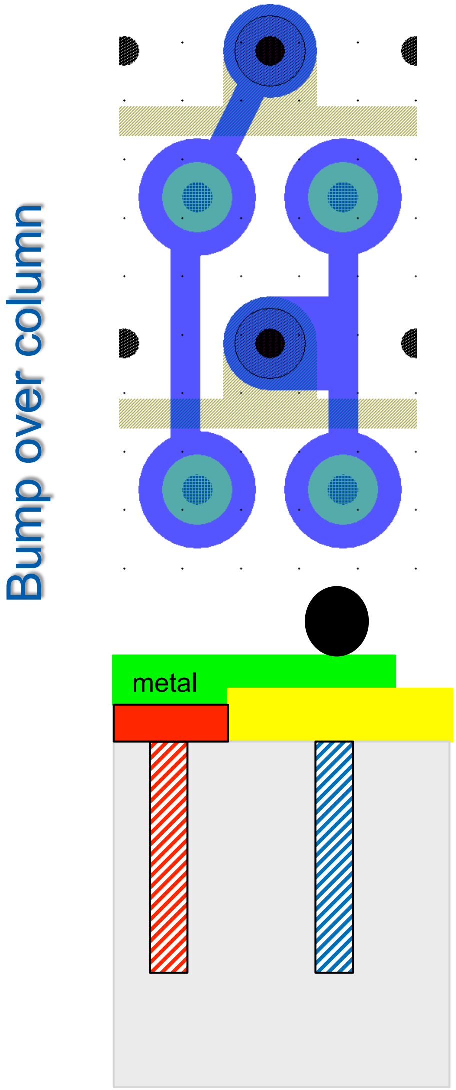


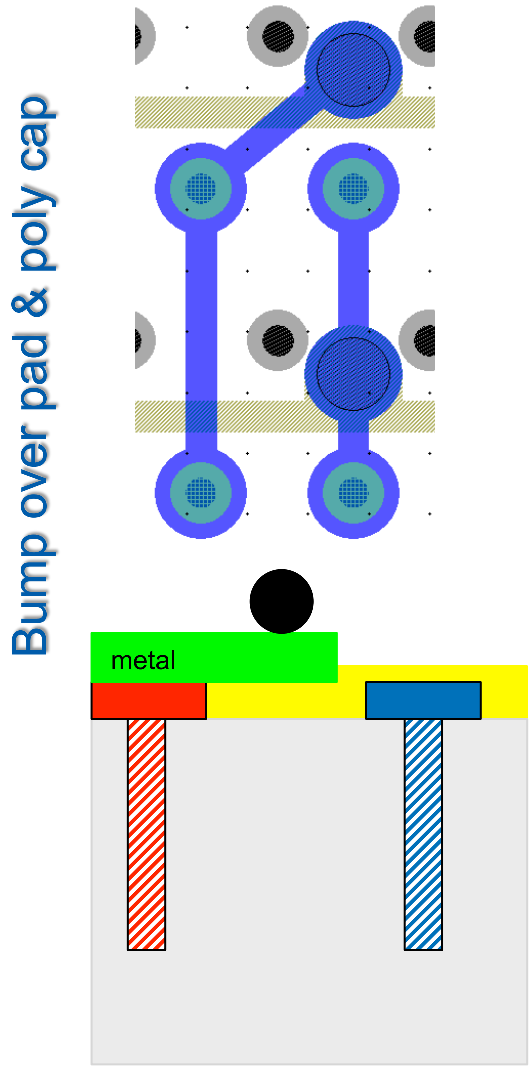
RD53A (25X100-1E)

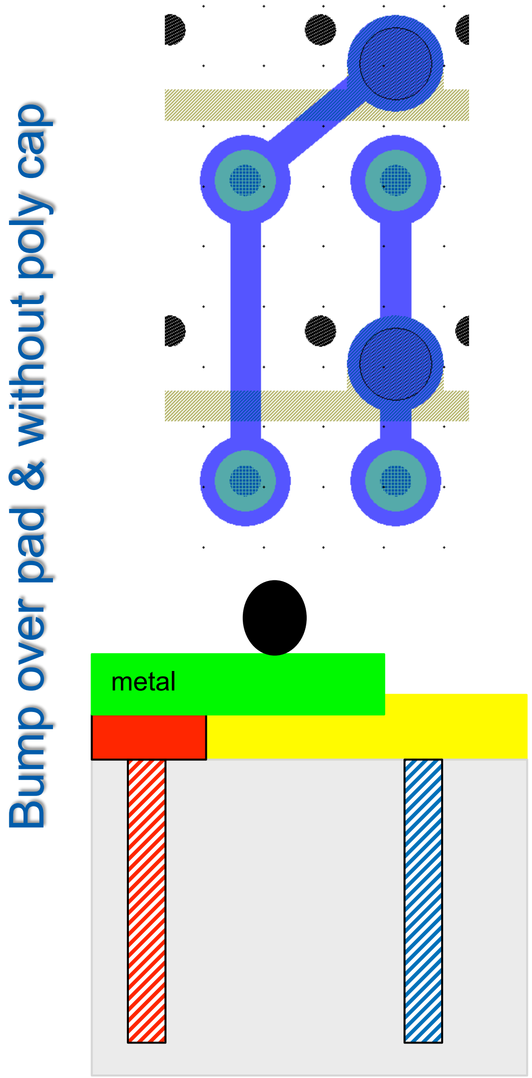


Also available as 64x64 pixel arrays (CHIPIX65 and FE65-p2)

RD53A Pixel Sensors (25x100-2E)

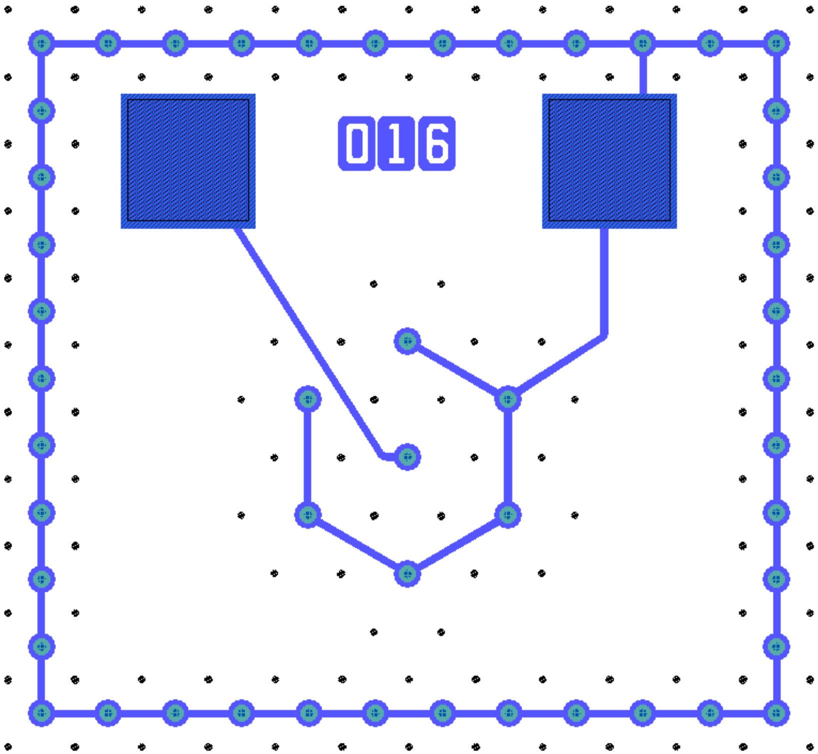




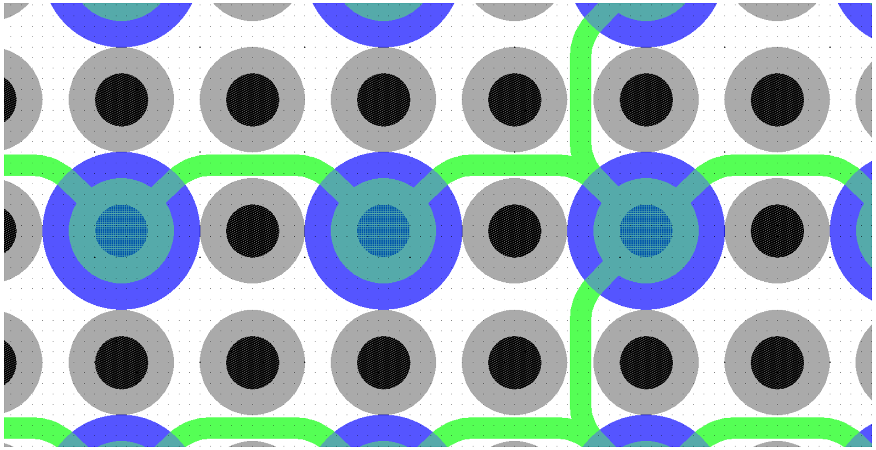


Alternative layout options

Exploring several new layouts with 3D diode test structures



Hexagonal cells cluster



Very small pitch (25x25 μm^2) diode with poly-Si column connections

Conclusion and outlook

- Milestone and related deliverable D7.1 accomplished at M18
- Characterization of irradiated samples from 1st FBK batch in progress:
  - diodes in Trento and Albuquerque
  - strips in Freiburg
  - arranged for pixel module irradiation at CERN and KIT
- More simulations being performed, also involving different bulk damage models
- Introducing surface damage model for breakdown investigation in irradiated samples
- Layout of 2nd FBK batch (funded by AIDA 2020) completed, fabrication under way (due by ~July 2017)

BACK-UP SLIDES

Simulated breakdown voltage

Electric field, 50x50, 160V