Measurements with strips and diodes LGAD p-type detectors fabricated at CNM

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RD50 project. Institutes collaborating:

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1. Thin p-type epitaxial wafers

Detector proposed by Hartmut Sadrozinski and Abe Seiden (UCSC), Ultra Fast Silicon Detectors (UFSD).[1]

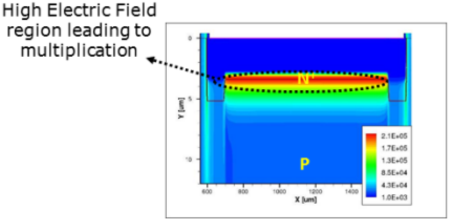
- Provide in the same detector and readout chain:
  - Ultra fast timing resolution [10's of ps]
  - Precision location information [10's of μm]
- Proposed to achieve high electric field using thin p-type epitaxial substrates grown on thick support wafers, p+ type doped, that acts as the backside ohmic contact.

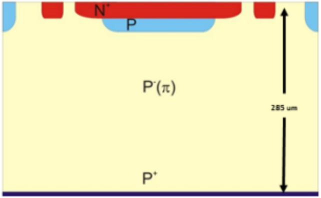
Different thicknesses are used: 10, 50, 75 μm.

[1] H. Sadrozinski, *"Exploring charge multiplication for fast timing with silicon sensors"*

2. Low gain avalanche detectors (LGAD)

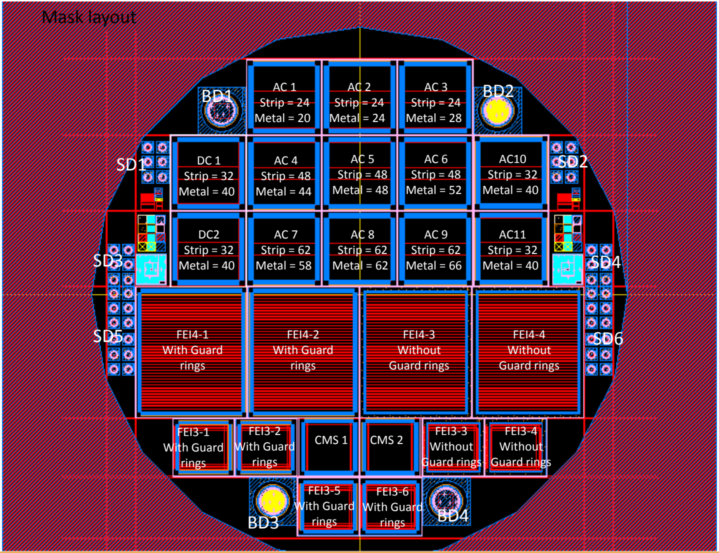
Creating an $n++/p+/p-$ junction along the center of the electrodes. Under reverse bias conditions, a high electric field region is created at this localized region, which can lead to a multiplication mechanism[2].





[2] P. Fernandez et al, "Simulation of new p-type strip detectors with trench to enhance the charge multiplication effect in the n-type electrodes", Nuclear Instruments and Methods in Physics Research A658 (2011) 98 102.

Mask layout


Mask layout
AC 1 Strip = 24 Metal = 20
AC 2 Strip = 24 Metal = 24
AC 3 Strip = 24 Metal = 28
BD1
BD2
SD1
SD2
DC 1 Strip = 32 Metal = 40
AC 4 Strip = 48 Metal = 44
AC 5 Strip = 48 Metal = 48
AC 6 Strip = 48 Metal = 52
AC10 Strip = 32 Metal = 40
SD3
SD4
DC2 Strip = 32 Metal = 40
AC 7 Strip = 62 Metal = 58
AC 8 Strip = 62 Metal = 62
AC 9 Strip = 62 Metal = 66
AC11 Strip = 32 Metal = 40
SD5
SD6
FEI4-1 With Guard rings
FEI4-2 With Guard rings
FEI4-3 Without Guard rings
FEI4-4 Without Guard rings
FEI3-1 With Guard rings
FEI3-2 With Guard rings
CMS 1
CMS 2
FEI3-3 Without Guard rings
FEI3-4 Without Guard rings
BD3
FEI3-5 With Guard rings
FEI3-6 With Guard rings
BD4

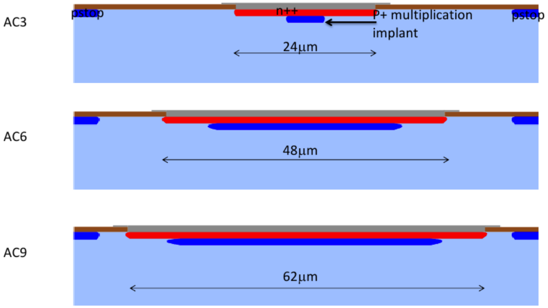
Strip detectors

Pitch $p = 80\mu m$

	Strip $[\mu m]$	Metal $[\mu m]$	P-implant $[\mu m]$	w/p	P-implant / pitch
AC1	24	20	6	0.3	7.5%
AC2	24	24	6	0.3	7.5%
AC3	24	28	6	0.3	7.5%
AC4	48	44	30	0.6	37.5%
AC5	48	48	30	0.6	37.5%
AC6	48	52	30	0.6	37.5%
AC7	62	58	44	0.775	55%
AC8	62	62	44	0.775	55%
AC9	62	66	44	0.775	55%
AC10 and AC11 and DC	32	40	14	0.4	17.5%

Strips cross section

Strip outline



Three different metal width:

- Field plate
- No field plate (metal as width as the strip)
- Metal smaller than the strip width

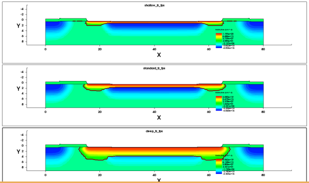
Wafers

Thickness $[\mu m]$	Resistivity $[\Omega cm]$	Resistivity substrate $[\Omega cm]$	Substrate thickness $[\mu m]$	Nominal full depletion
9.8	110.5	0.006	525	9.3V
50.4	96.7	0.006	525	267V
75.2	104.6	0.006	525	550V
285 (FZ)	12000 ± 7000			70V

Diffusion times of the dopant

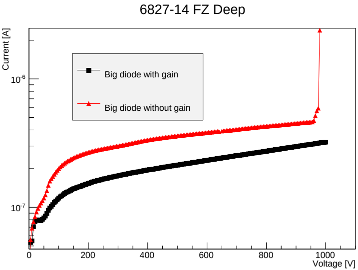
- Shallow
- Standard
- Deep

Strip cross section



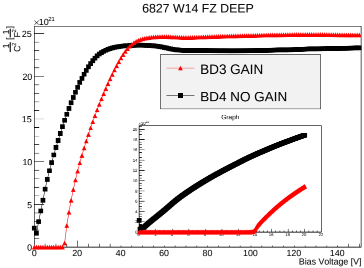
Big diodes from W14 FZ DEEP with and without gain measured at CNM Barcelona

IV



Current without gain higher than current with gain

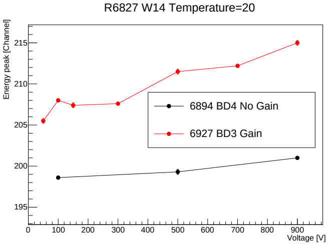
CV



Foot of gain reaching 14V

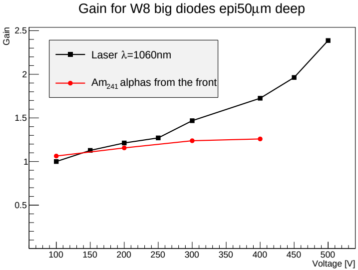
Charge measurement for big diodes

R6827 W14 FZ Deep big diode with Trialpha source



Measured with a PCB connected to an MCA CNM Barcelona

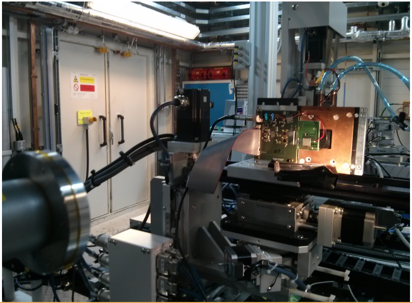
TCT from R6827W8 big diode EPI 50 Deep



Measurements taken at UCSC

Diamond Light Source

- R6827W4AC9 - Epi10 Standard Gain (High current)
- R6894W4AC9 - Epi10 Standard NO Gain
- R6827W13DC2 - FZ Standard Gain (Up to 300V)
- R6827W14AC11 - FZ Deep Gain (Up to 900V)
- R6894W14AC11 - FZ Deep NO Gain (Up to 500V)

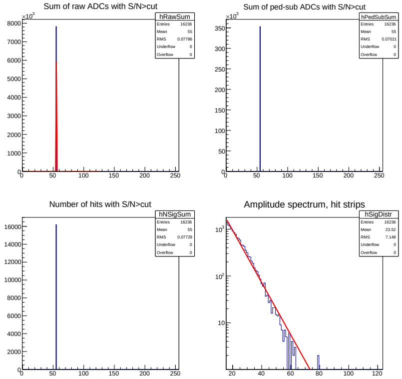


Measurements with X-Rays:

- Photons with energy 15keV
- Microfocused beam
- Data taken with Alibava

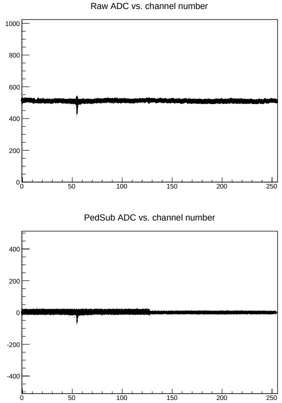
Analysis: data taken with Alibava systems

Beam analysis



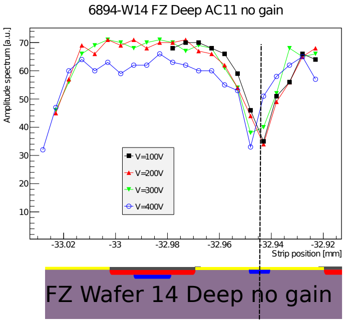
Histogram of the amplitude

Channel: strip hit



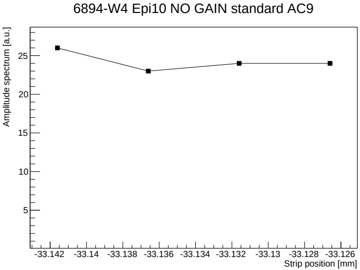
Measures detectors NO GAIN at Diamond

R6894W14AC11 FZ Deep no gain



Data from 10^5 events

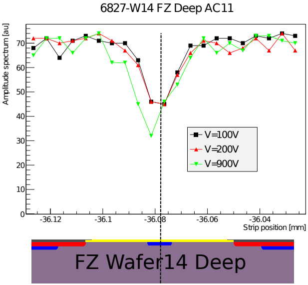
Measures at 80V Epitaxial $10\mu m$ NO GAIN



Data for 10^6 events in the Alibava system

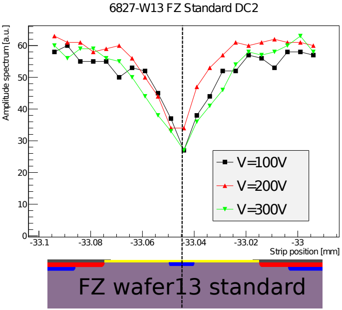
Diamond Light Source FZ

R6827W14AC11 FZ Deep gain



Data from 10^5 events

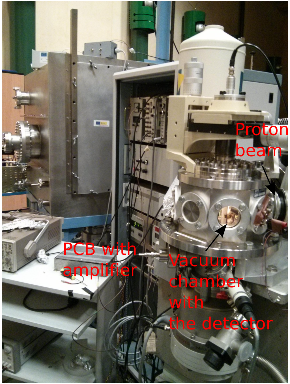
R6827W13DC1 FZ Standard gain



Data from 10^5 events

IBIC Sevilla[3]: Ion Beam Induced Charge (IBIC) microscopy

Setup from CNA Sevilla

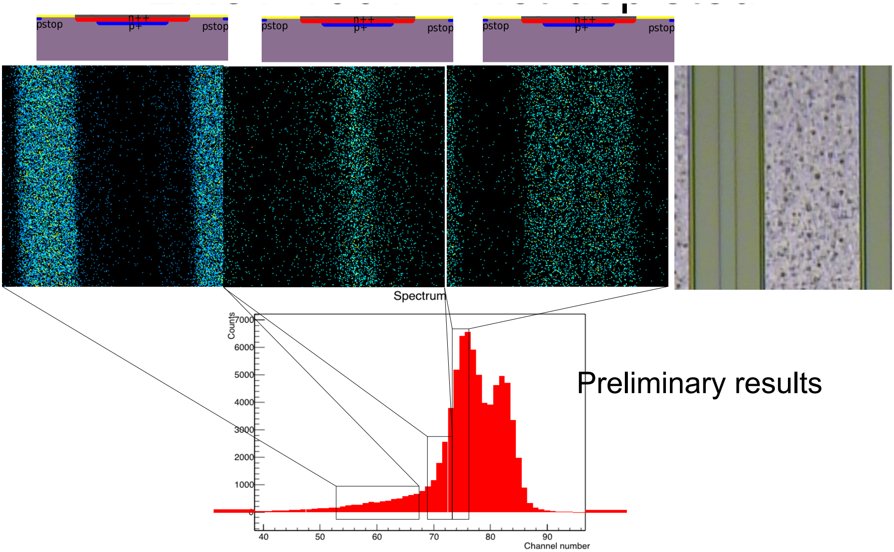


We measured 2 sensors with the Ion Beam Induced Charge microscopy Technique at CNA in Sevilla.

- Protons at 2MeV
- Beam spot around $4 \times 4 \mu m^2$
- Two sensors measured:
  Epi 50 deep
  FZ deep

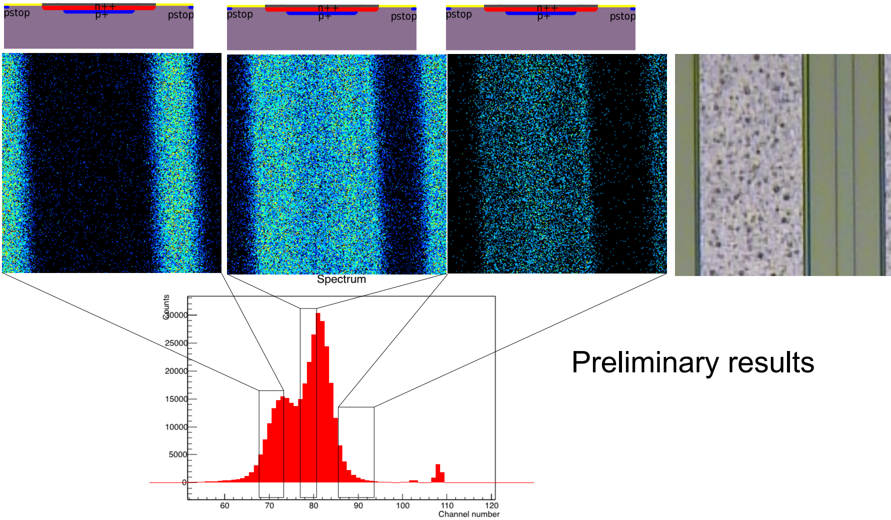
[3] With help from Dr. Javier Garcia from CNA

IBIC Sevilla: R6827W8AC4 EPI50 Deep protons 2MeV 100V



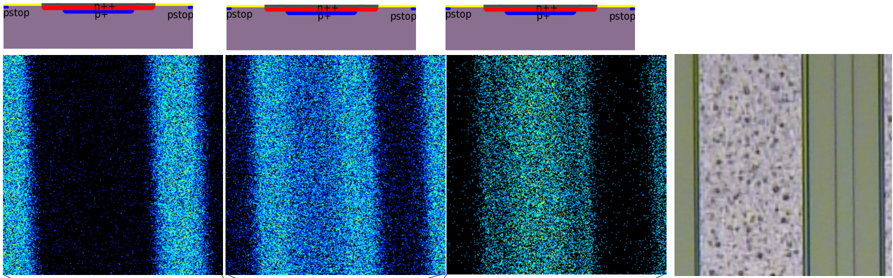
Preliminary results

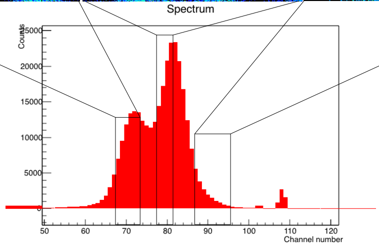
IBIC Sevilla: R6827W14AC4 FZ Deep protons 2MeV 150V



Preliminary results

IBIC Sevilla: R6827W14AC4 FZ Deep protons 2MeV 400V

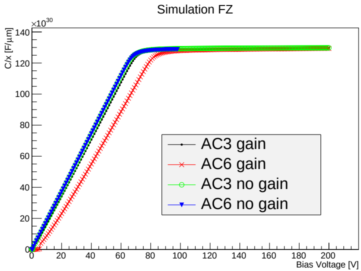


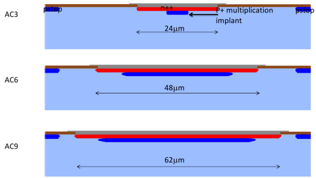


Preliminary results

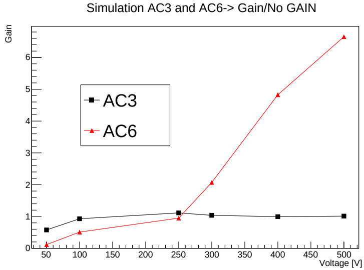
Strip simulation with Sentaurus TCAD FZ standard

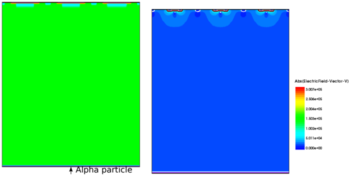
Simulation of CV curves





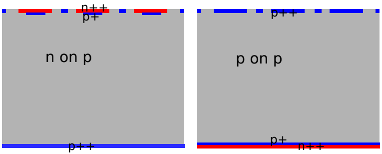
Gain simulation for 3 strips





Simulation p-on-p LGAD FZ $300\mu m$

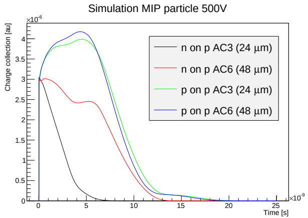
Simulation for three strips

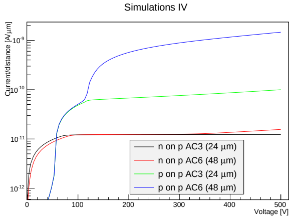


p on p - p strips with union at the backside

- High electric field in the backside - all charge is multiplied
- Not radiation hard detector - applications such linear collider

Gain simulation for 3 strips

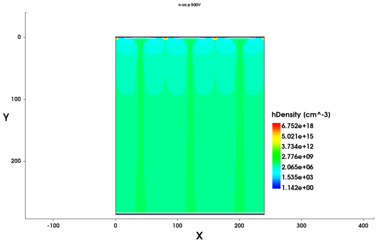




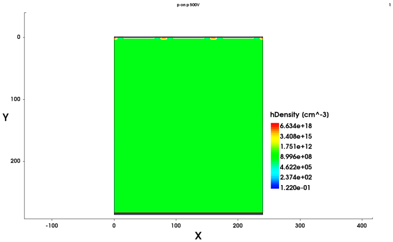
MIP crossing the middle of the detector

Holes density

n on p



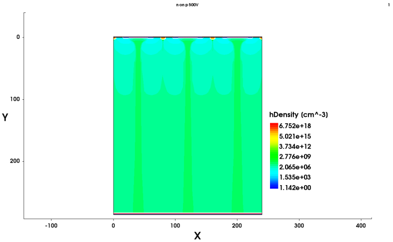
p on p



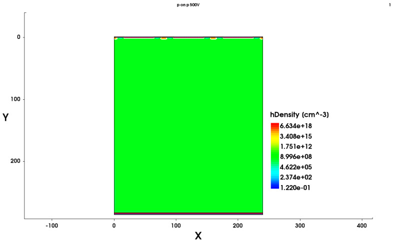
MIP crossing the middle of the detector

Holes density

n on p



p on p



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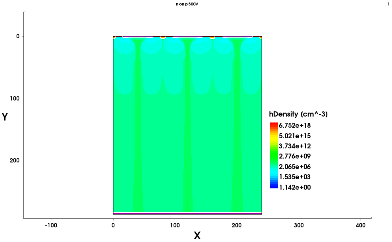

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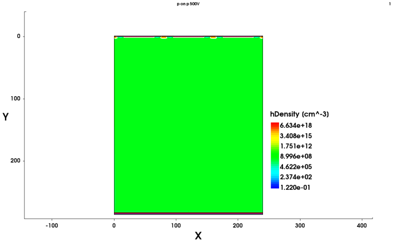

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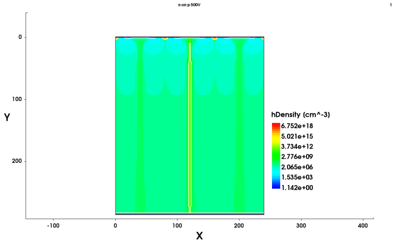

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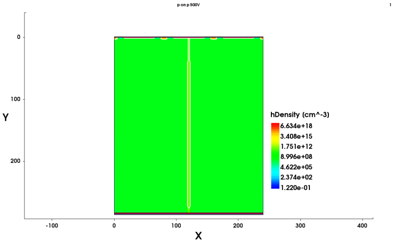

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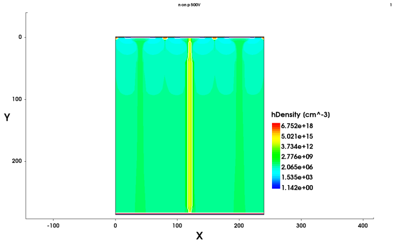

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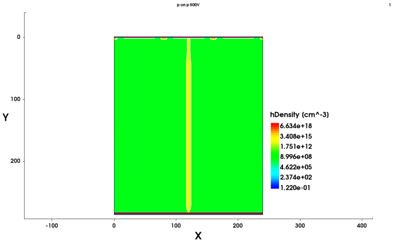

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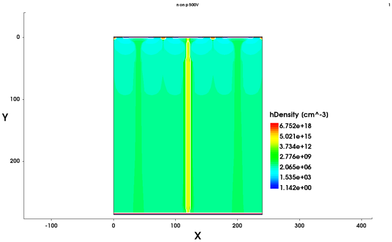

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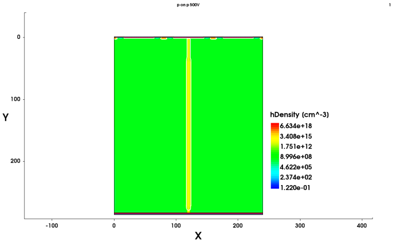

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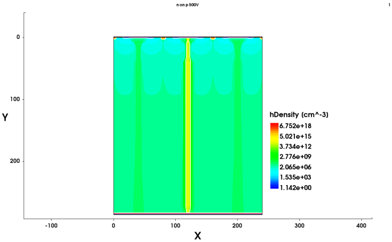

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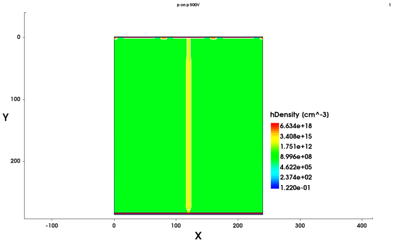

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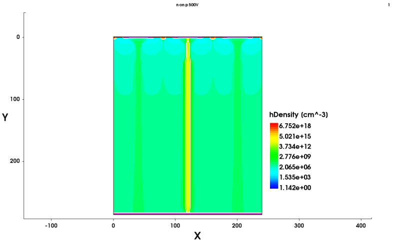

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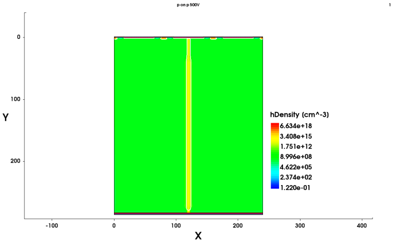

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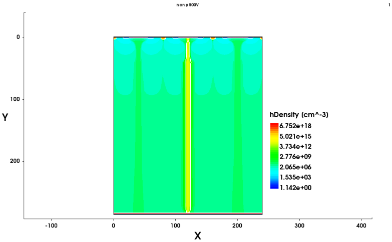

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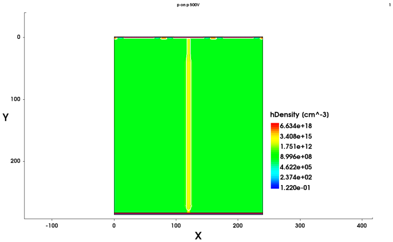

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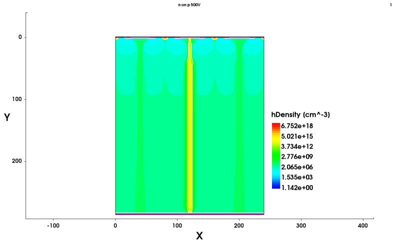

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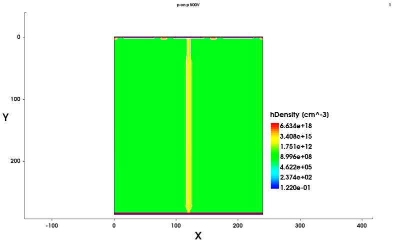

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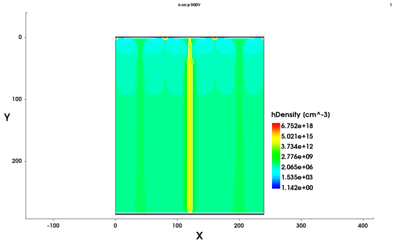

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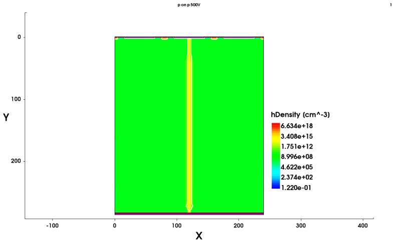

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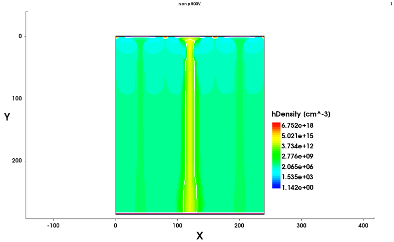

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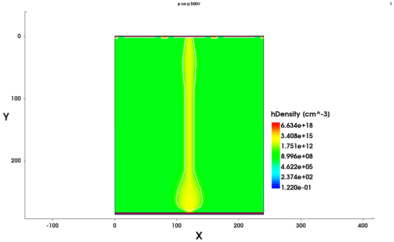

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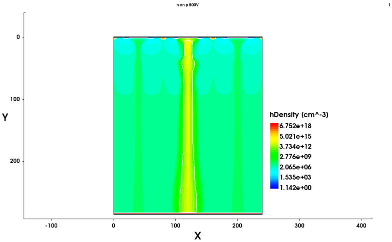

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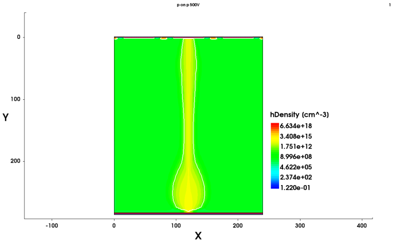

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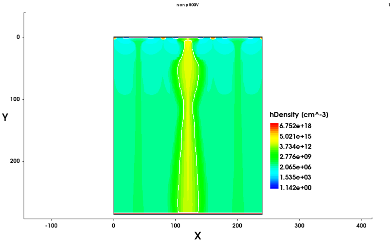
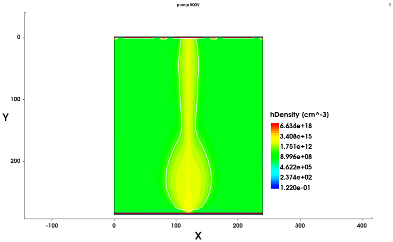


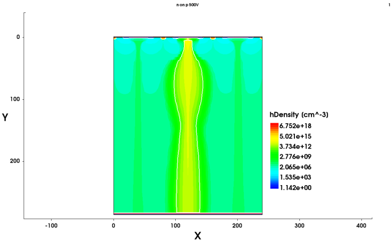
p on p



MIP crossing the middle of the detector

Holes density

n on p



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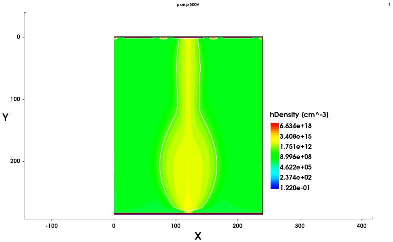
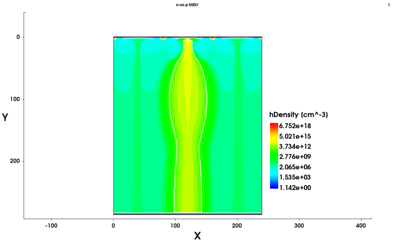


MIP crossing the middle of the detector

Holes density

n on p



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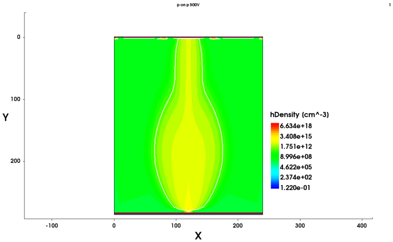
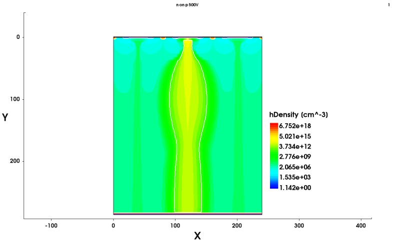


MIP crossing the middle of the detector

Holes density

n on p



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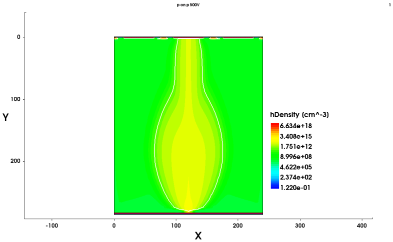
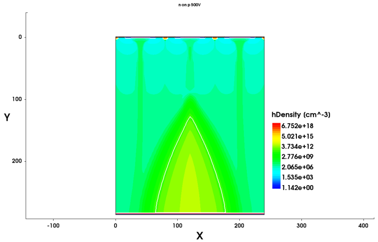


MIP crossing the middle of the detector

Holes density

n on p



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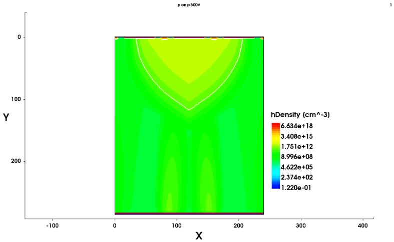
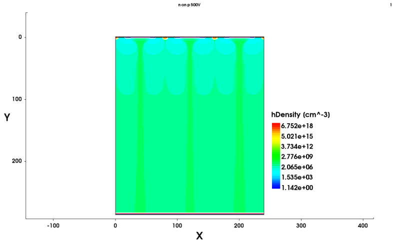


MIP crossing the middle of the detector

Holes density

n on p



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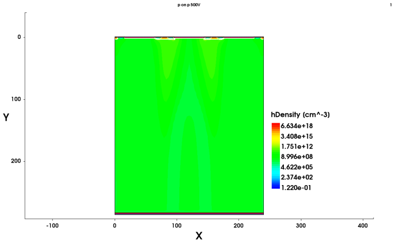
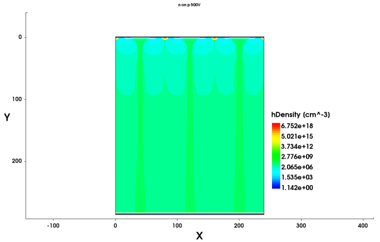


MIP crossing the middle of the detector

Holes density

n on p



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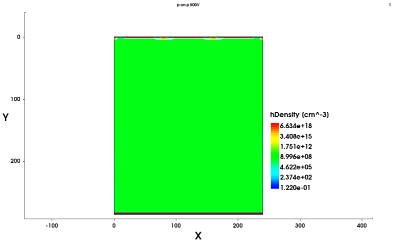


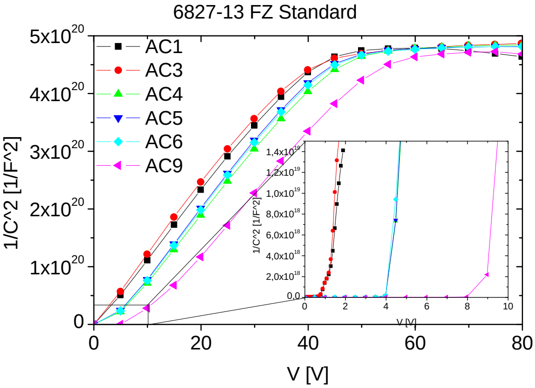
Conclusions

Conclusions

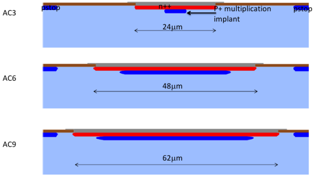
- Some diodes measured at UCSC presented gain of 2 (epitaxial $50\mu m$ deep wafer).
- Strips measured at Diamond with X-Rays did not present any gain.
- The study of the measurements taken at Sevilla with the IBIC technique are currently underway.
- Simulations for strips with different widths show that the gain increases with the width.
- Simulation for p-on-p strips with multiplication in the back plane are presented.

Thanks for your attention

CV curves strip detectors for FZ wafer



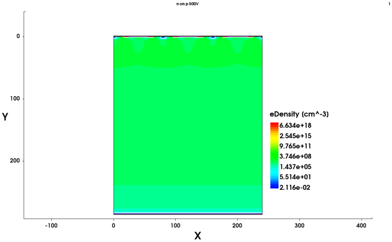
Strips layout



Backup -MIP crossing the middle of the detector

Electron density

n on p



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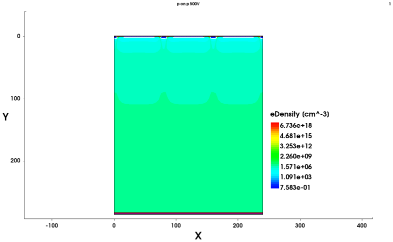
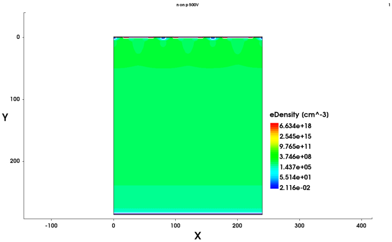


Backup -MIP crossing the middle of the detector

Electron density

n on p



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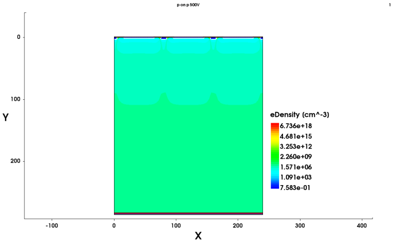
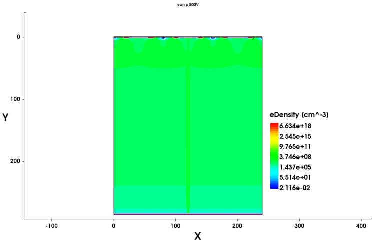


Backup -MIP crossing the middle of the detector

Electron density

n on p



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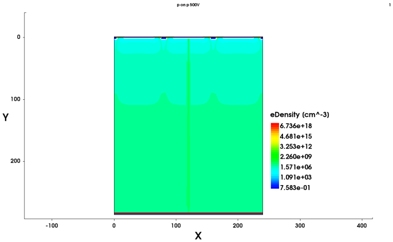
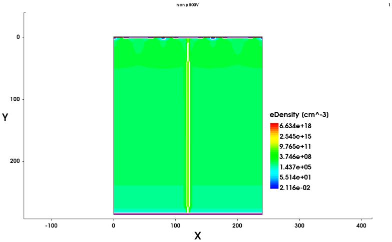


Backup -MIP crossing the middle of the detector

Electron density

n on p



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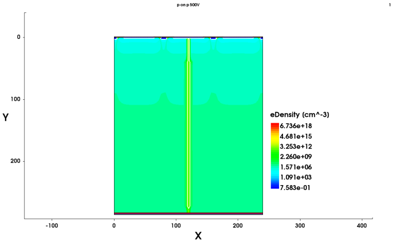
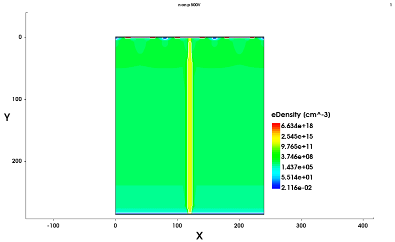


Backup -MIP crossing the middle of the detector

Electron density

n on p



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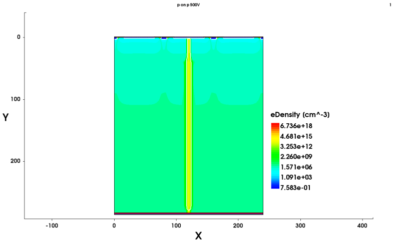

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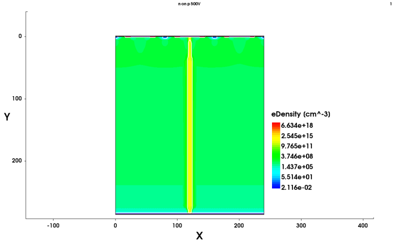
Electron density

n on p



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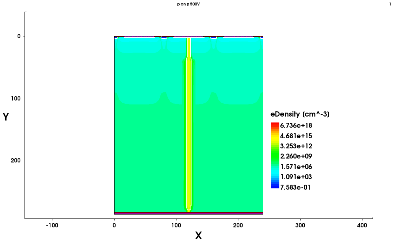
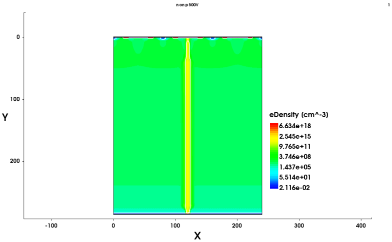


Backup -MIP crossing the middle of the detector

Electron density

n on p



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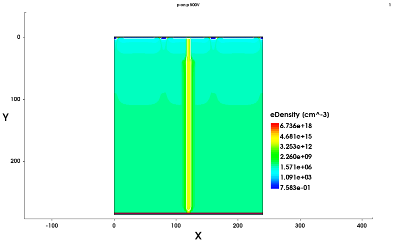

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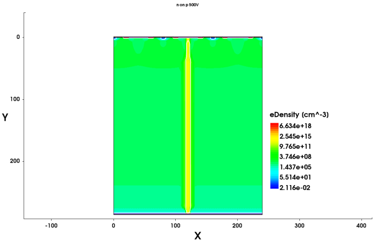
Electron density

n on p



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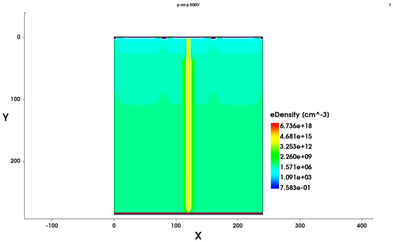

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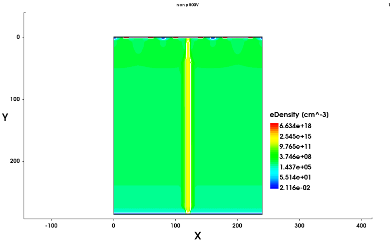
Electron density

n on p



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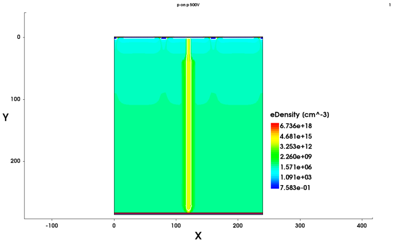

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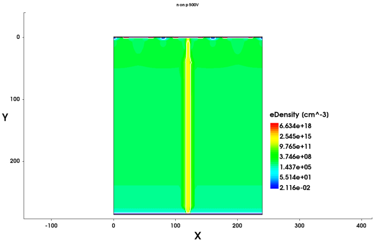
Electron density

n on p



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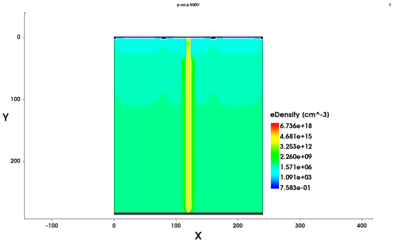

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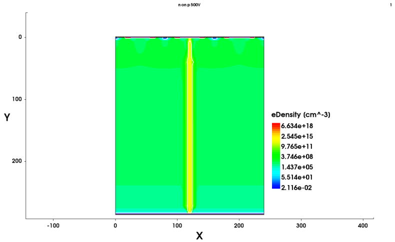
Electron density

n on p



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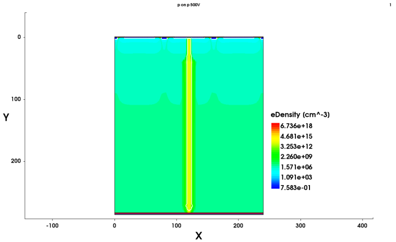

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Electron density

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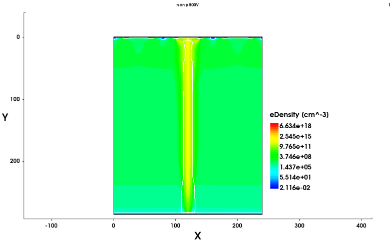

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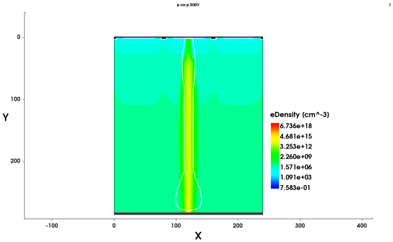

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Electron density

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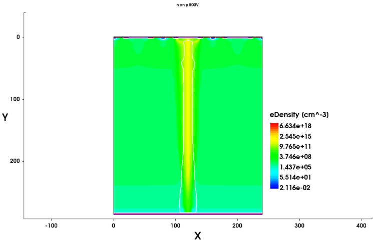

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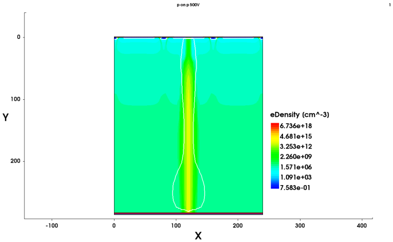

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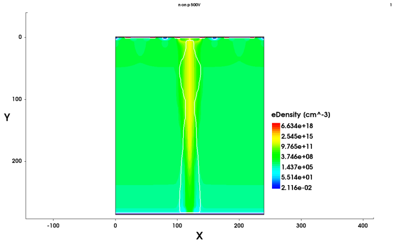
Electron density

n on p



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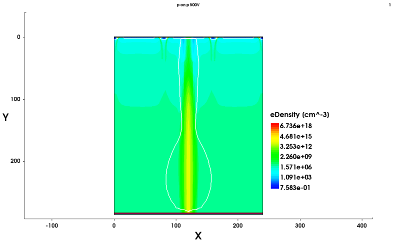

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Electron density

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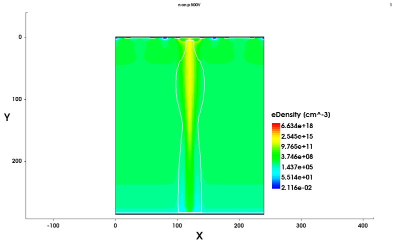

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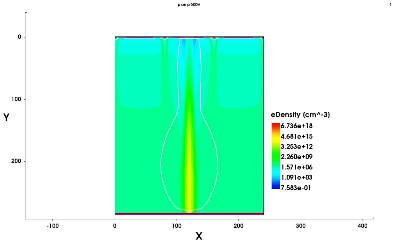

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Electron density

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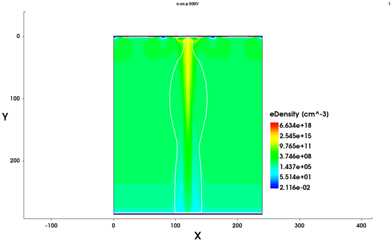

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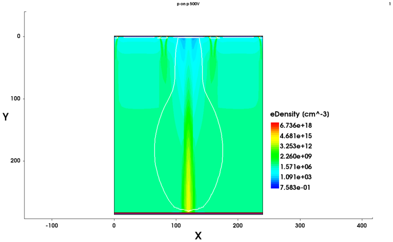

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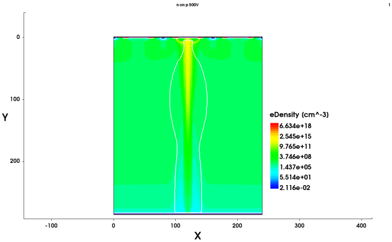
Electron density

n on p



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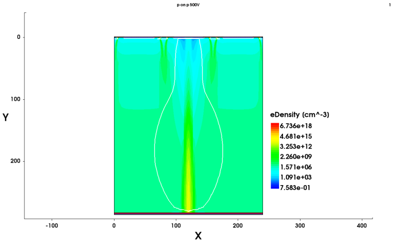
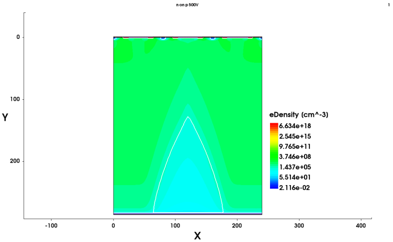


Backup -MIP crossing the middle of the detector

Electron density

n on p



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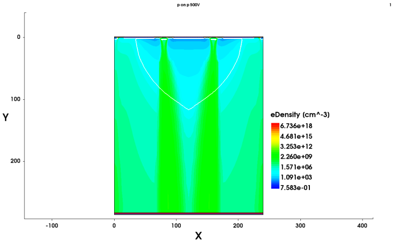

Backup -MIP crossing the middle of the detector

Electron density

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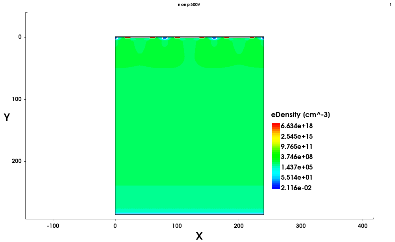

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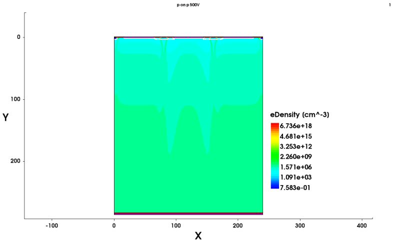

Backup -MIP crossing the middle of the detector

Electron density

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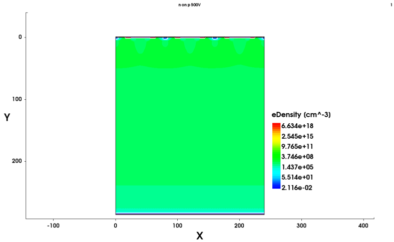

p on p