16th Workshop of CERN RD50 - Radiation hard semiconductor devices for very high luminosity colliders, Barcelona, Spain, May 31 to June 2, 2010

Full 3D Simulations on The New BNL ICDA(3D-Trench-Electrode) Detectors

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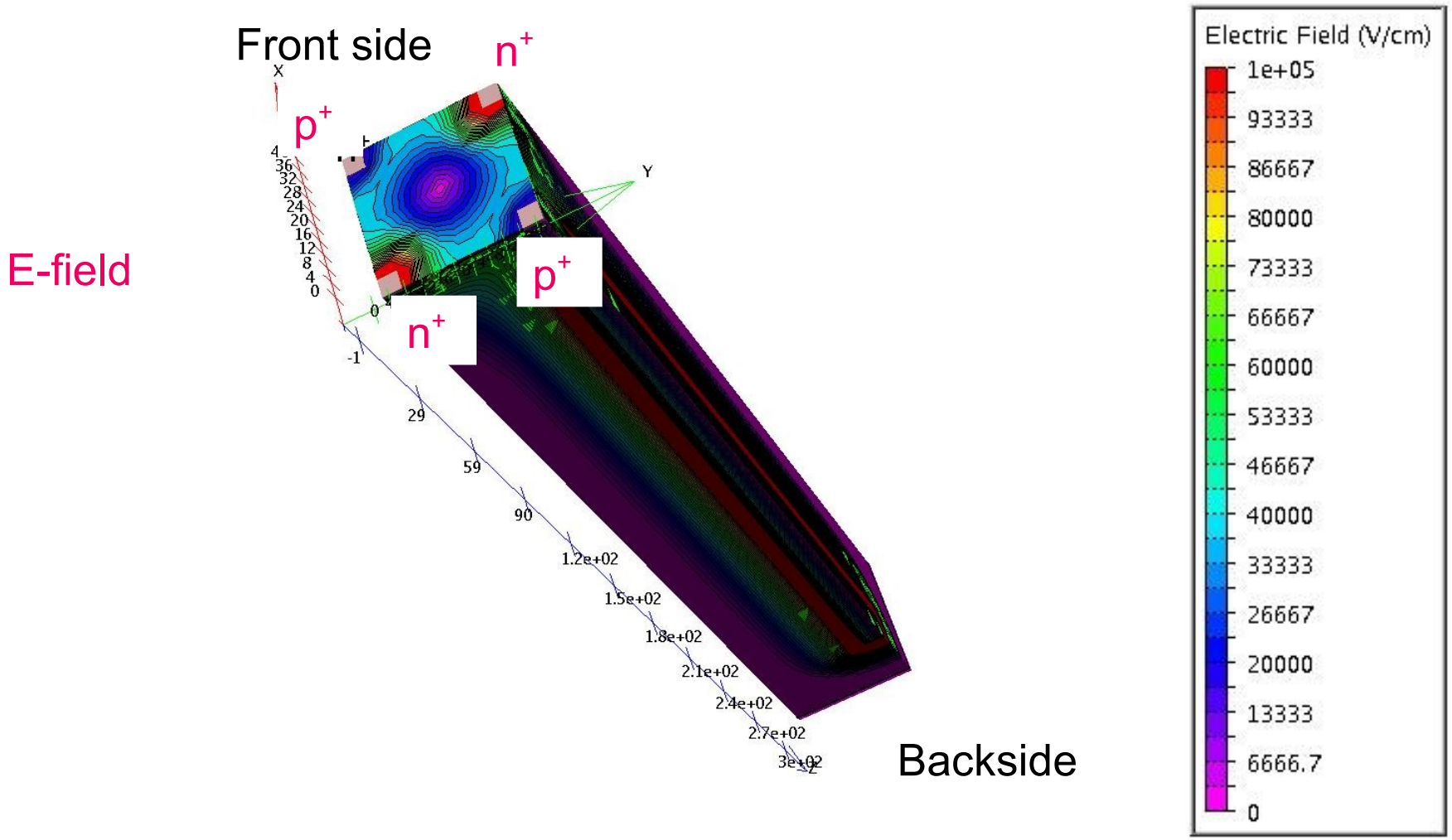
OUTLINE

- The New BNL Independent Coaxial Detector Array (ICDA)
- 3D Simulation results
- Preliminary design of the mask set
- Summary

• Complicated and high electric field profiles
in conventional 3D detectors with column electrodes

3D simulation of BNL-2C-3D, 1x10^{16} n_{eq}/cm^2, 150 V



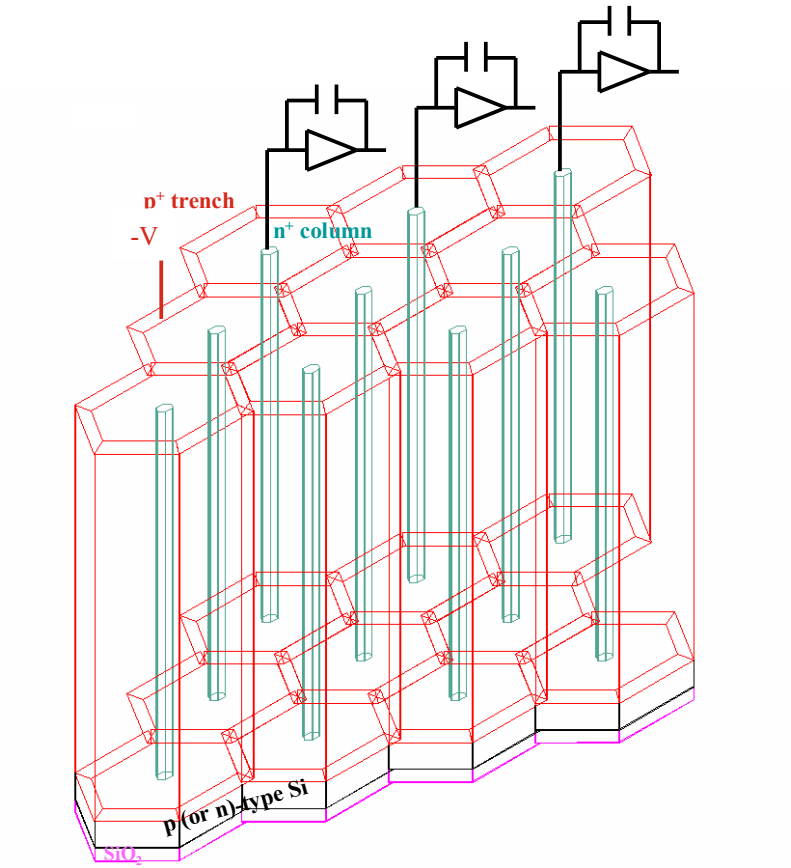
The main advantages of the new ICDA configuration

- More uniform, homogeneous electric field
- No saddle points, no low/no field region
- No extremely high field regions near breakdown condition
- Still decoupling thickness from depletion depth (rad-hard and possible to deplete very thick detectors)

- Independent Coaxial Detector Array (ICDA) ------ US patent pending (1004305-027US)

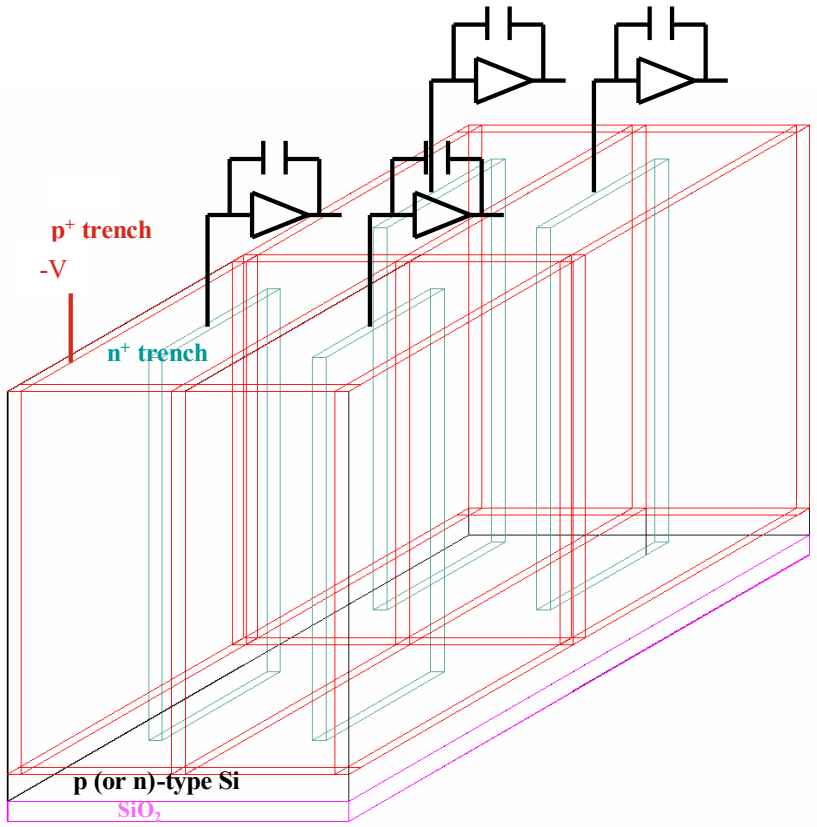
At least one electrode is a trench, each cell is an independent detector

Homogeneous electric field, no saddle point



Concentric type

Electric field with nearly no θ dependence

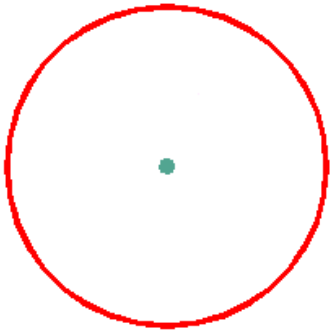


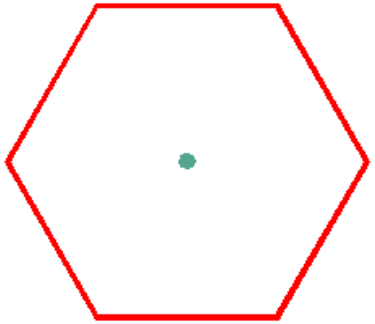
Parallel plate type

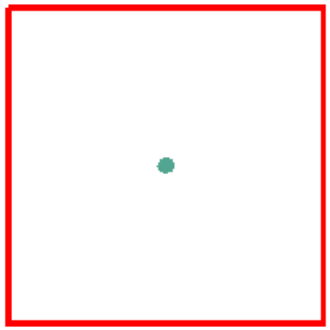
Near-linear electric field

Examples of single cells of ICDA

Concentric type:



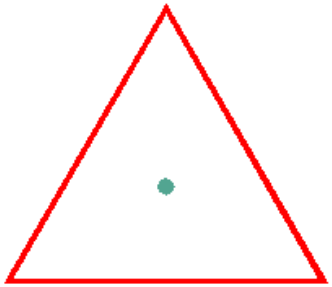


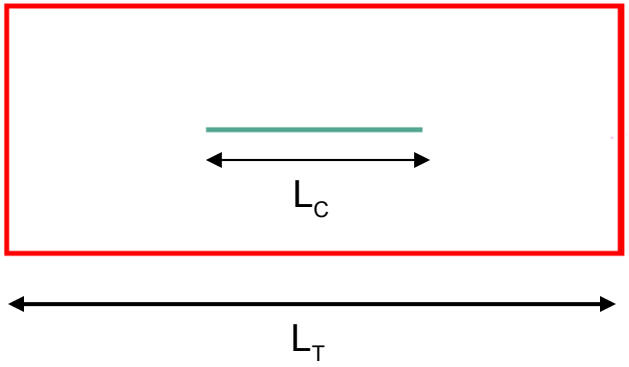


p^+ (or n^+) trench

n^+ (or p^+) column

n (or p) type bulk

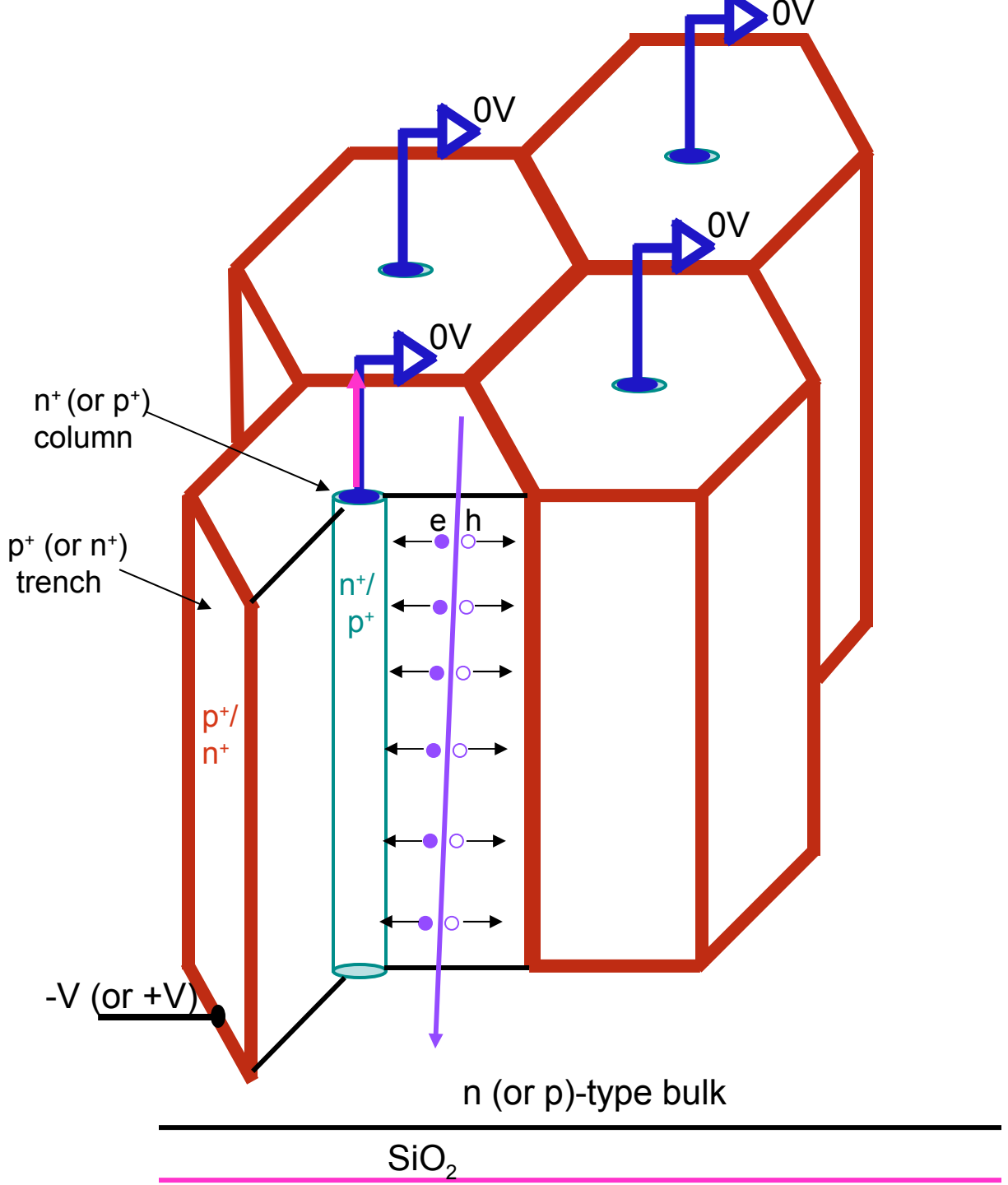




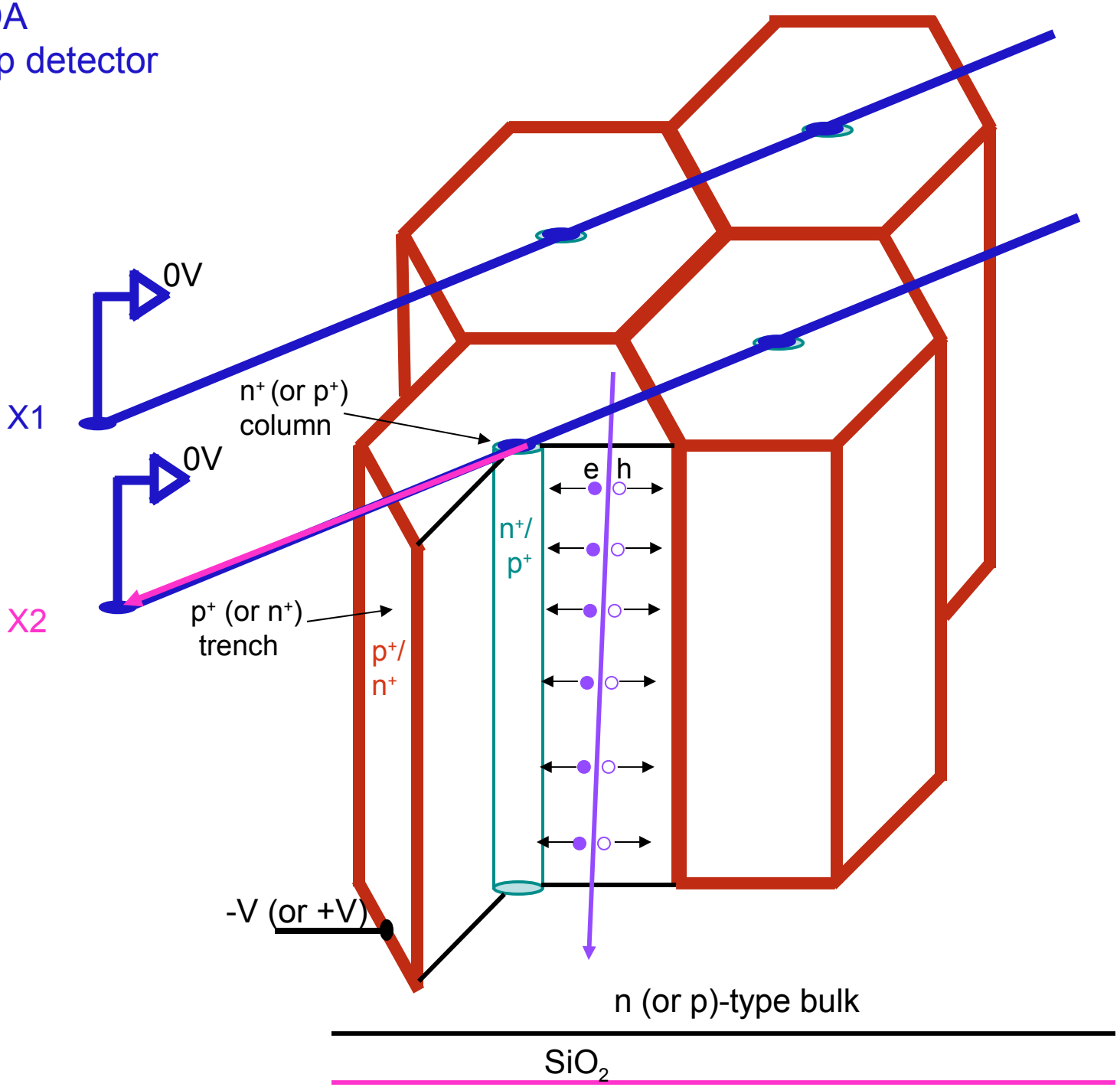
n^+ (or p^+) trench

Parallel plate type:

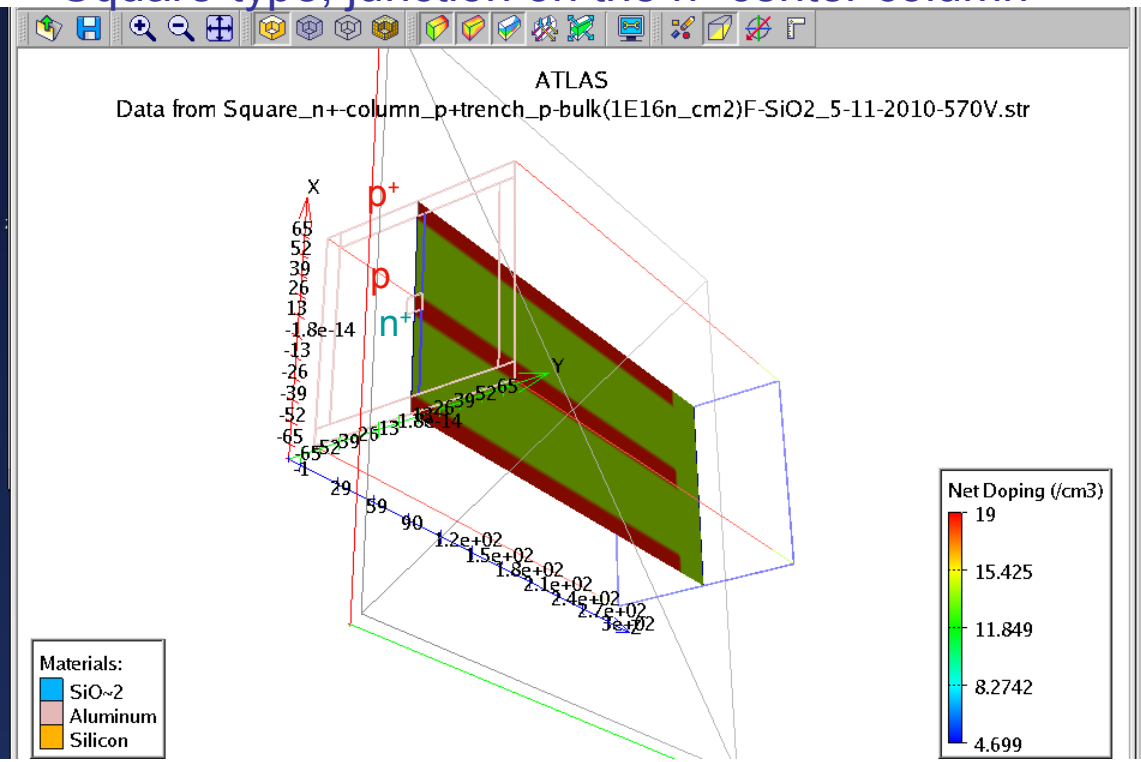
ICDA
Pixel detector

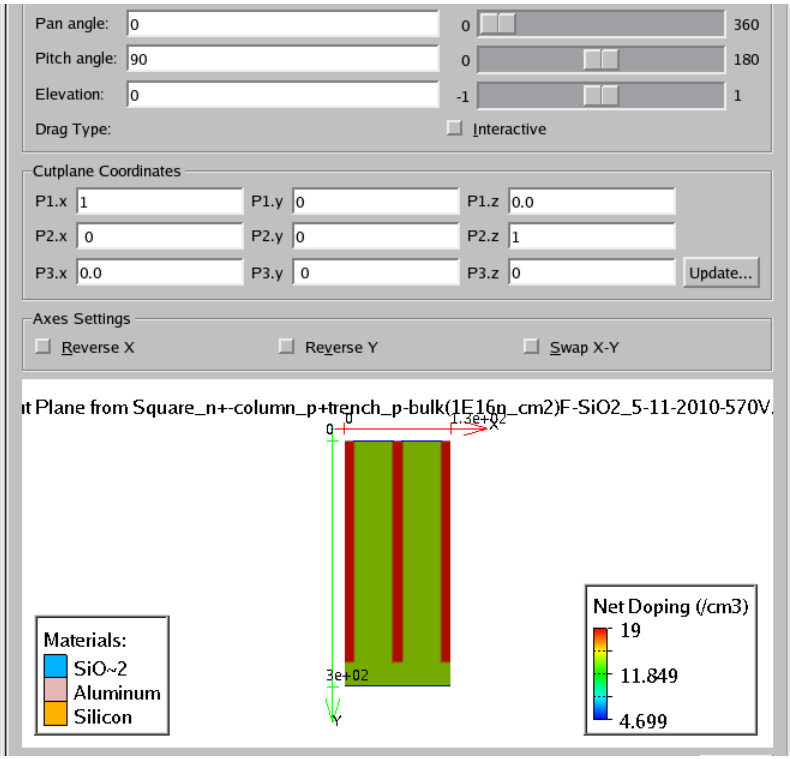


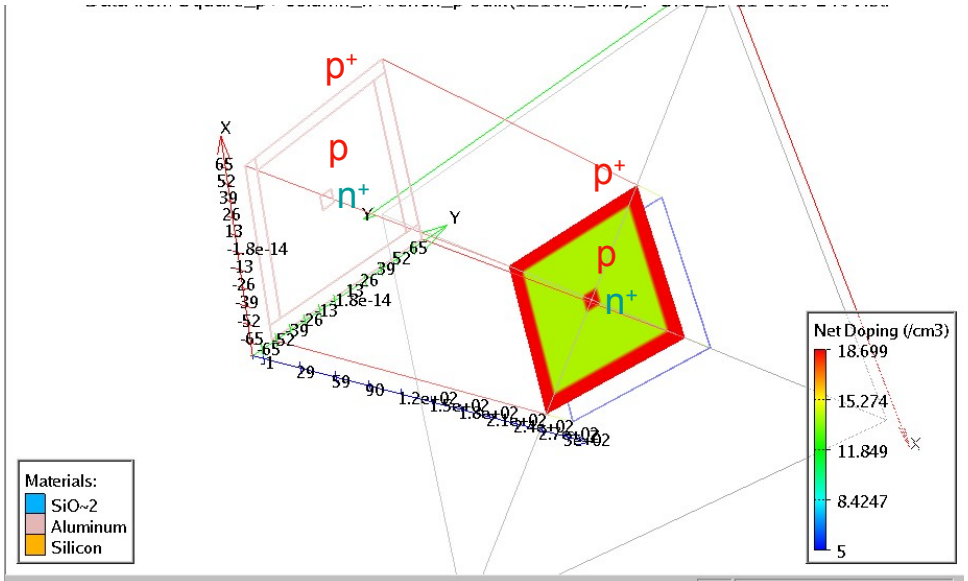
ICDA
Strip detector

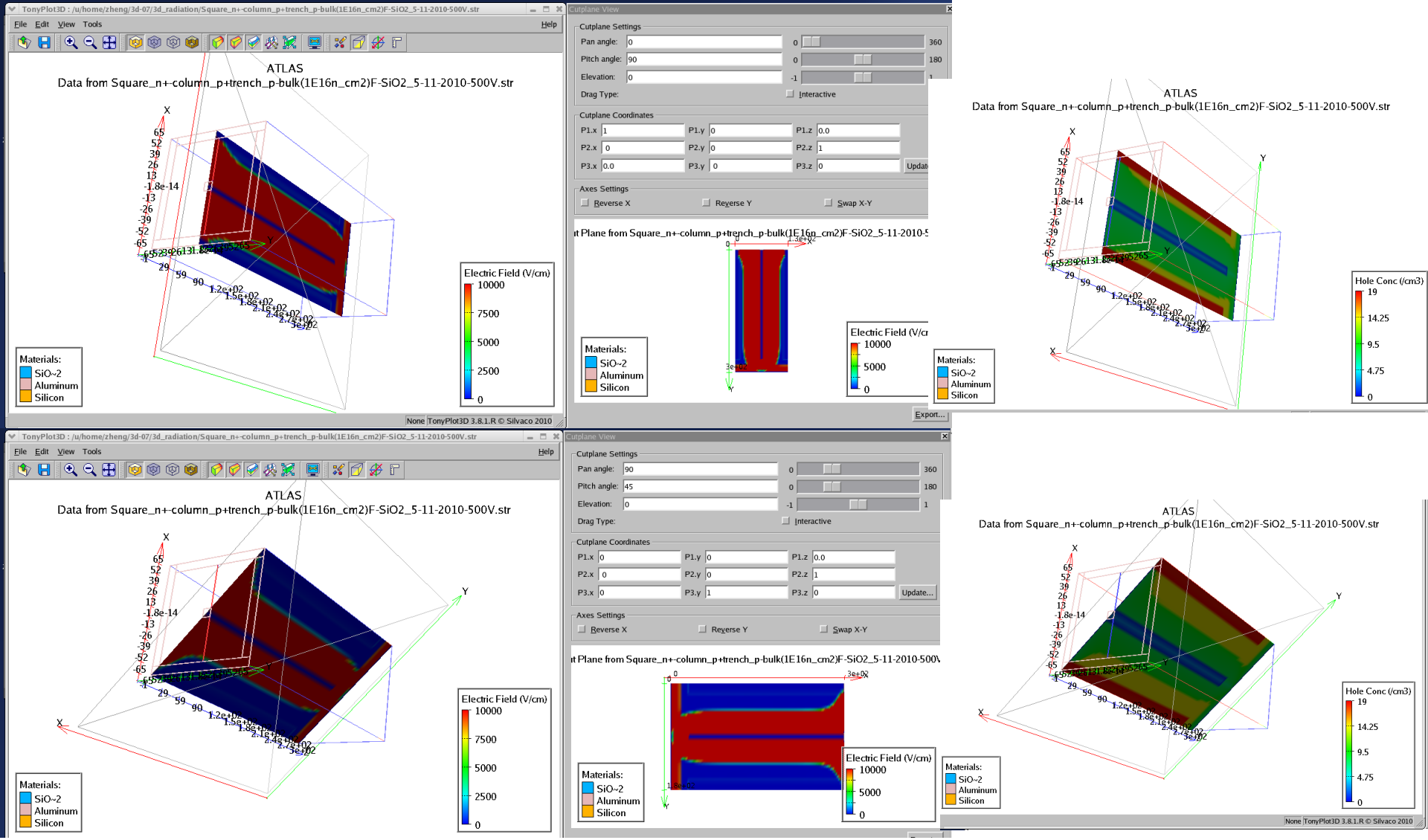


Square-type, junction on the n⁺ center column





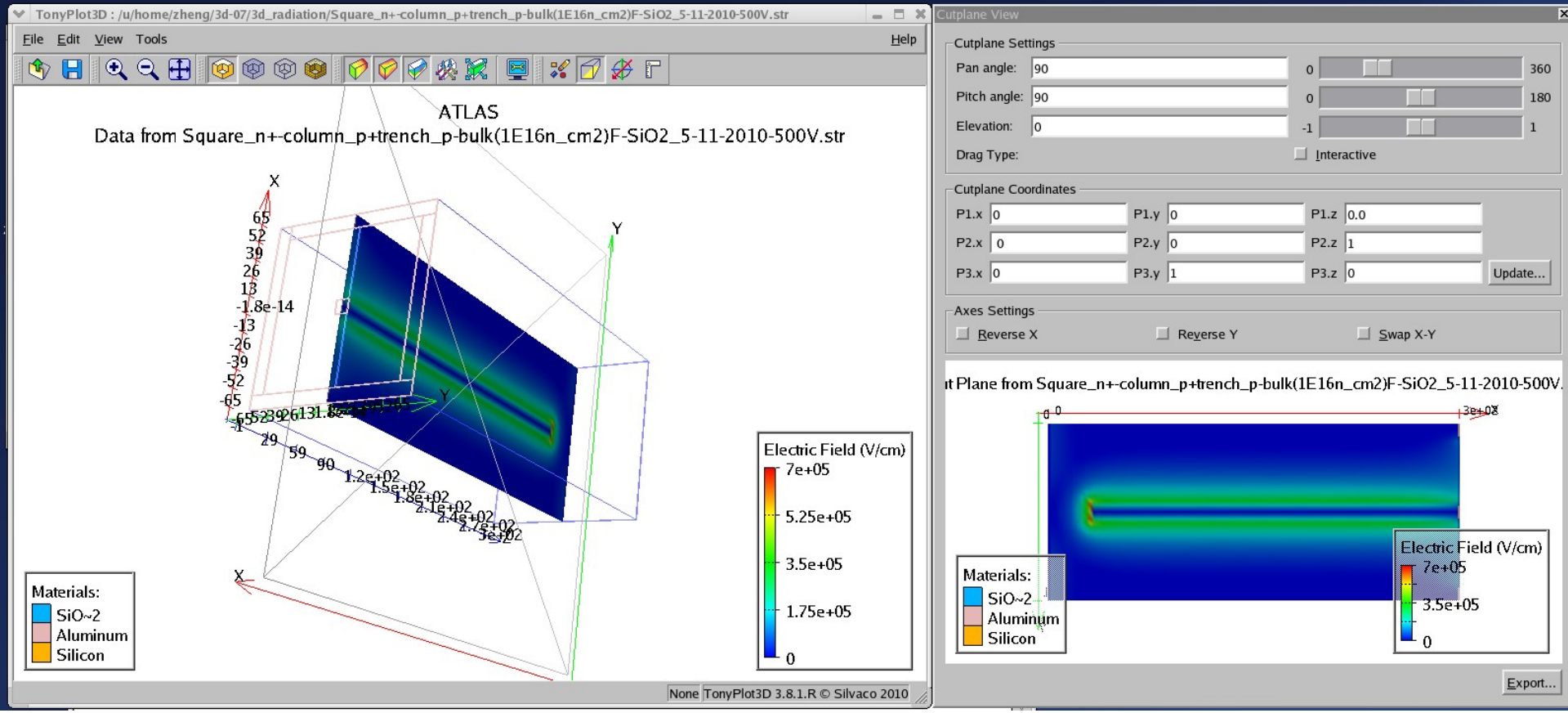




Homogeneous electric field

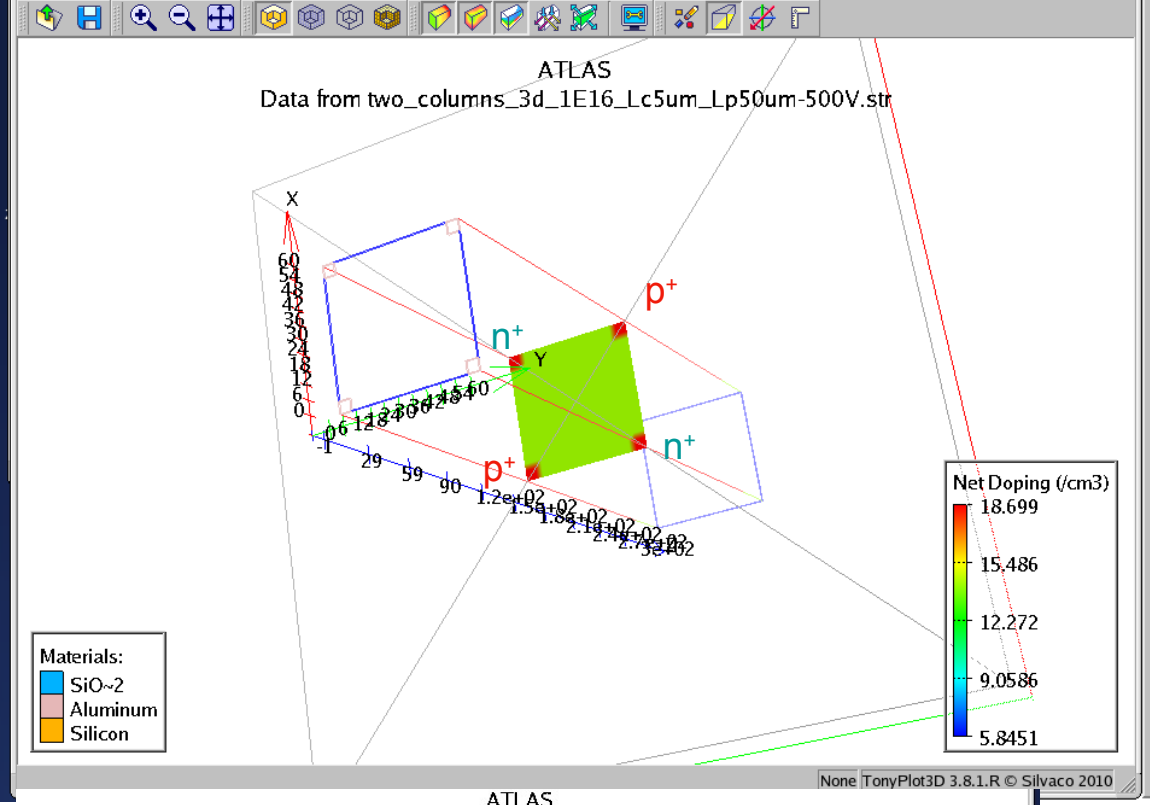
E-field even under the trench and column --- good for sensitivity under

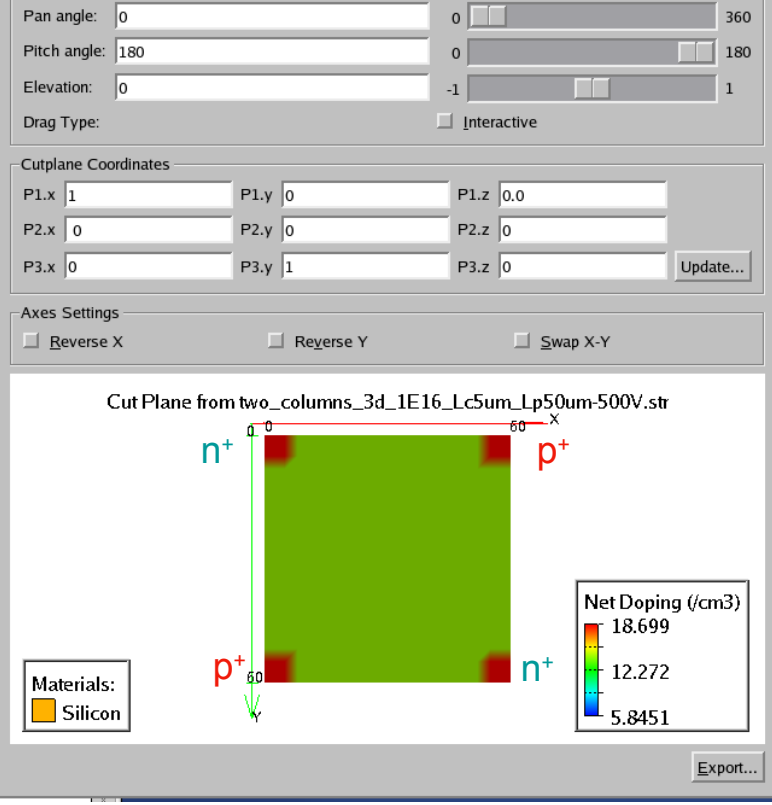
E-field and hole concentration, junction on the center column, 1×10^{16} n_{eq}/cm^2, 500 V.

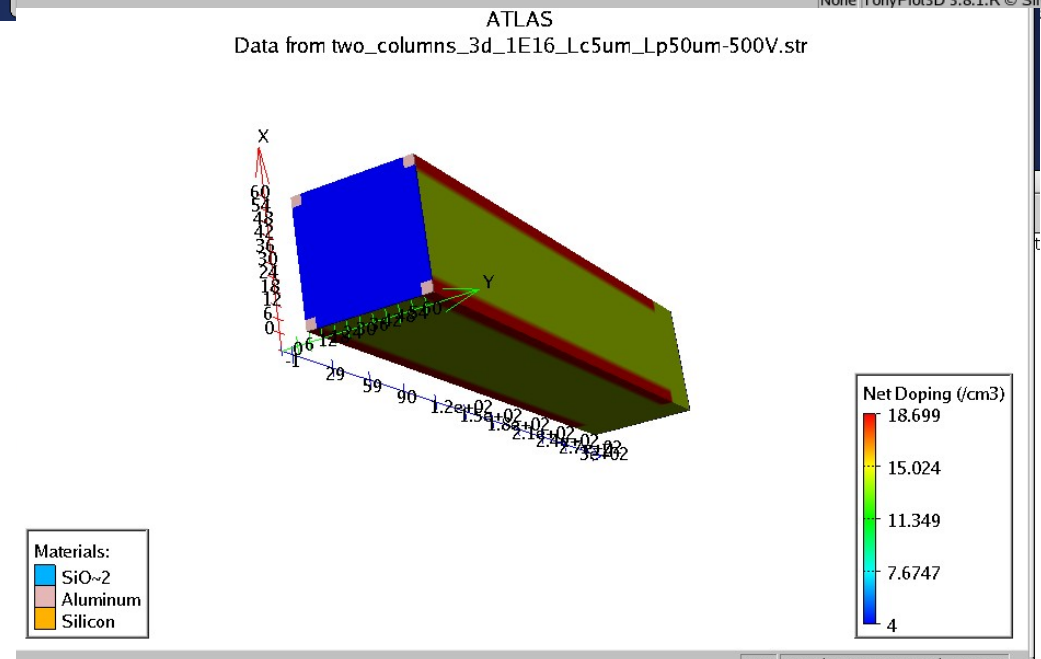


The highest E-field is under the junction column >700 kV/cm

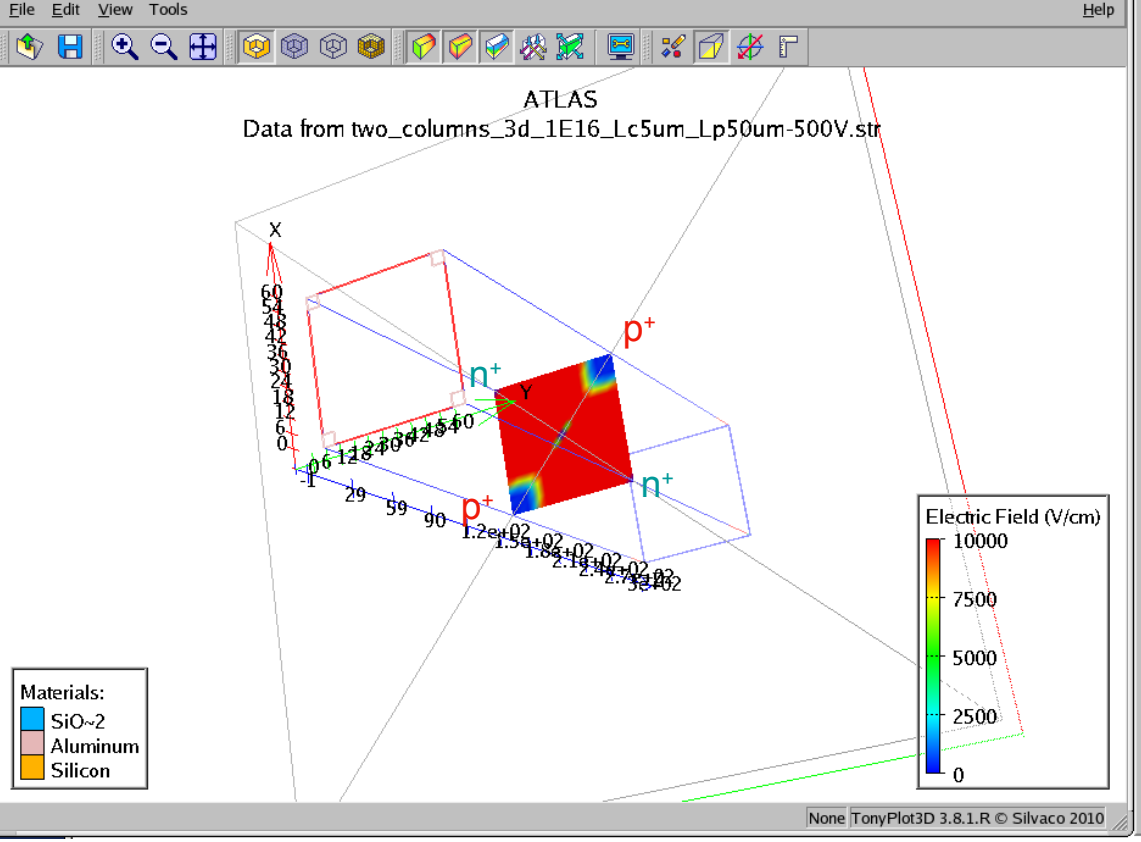
E-field, junction on the center column, $1x10^{16}$ n_{eq}/cm^2, 500 V.

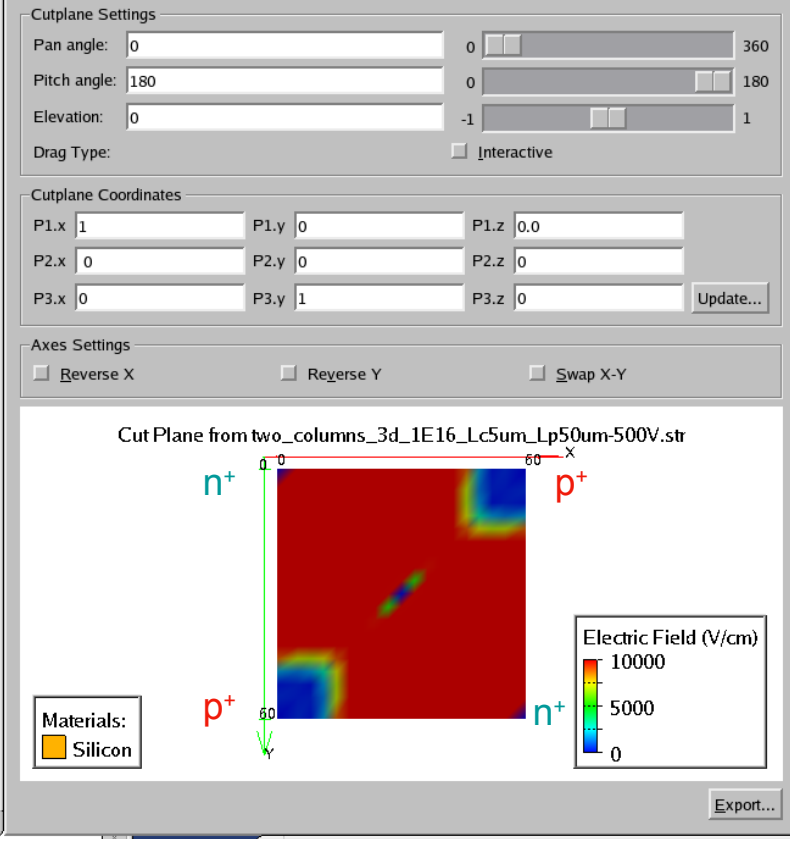




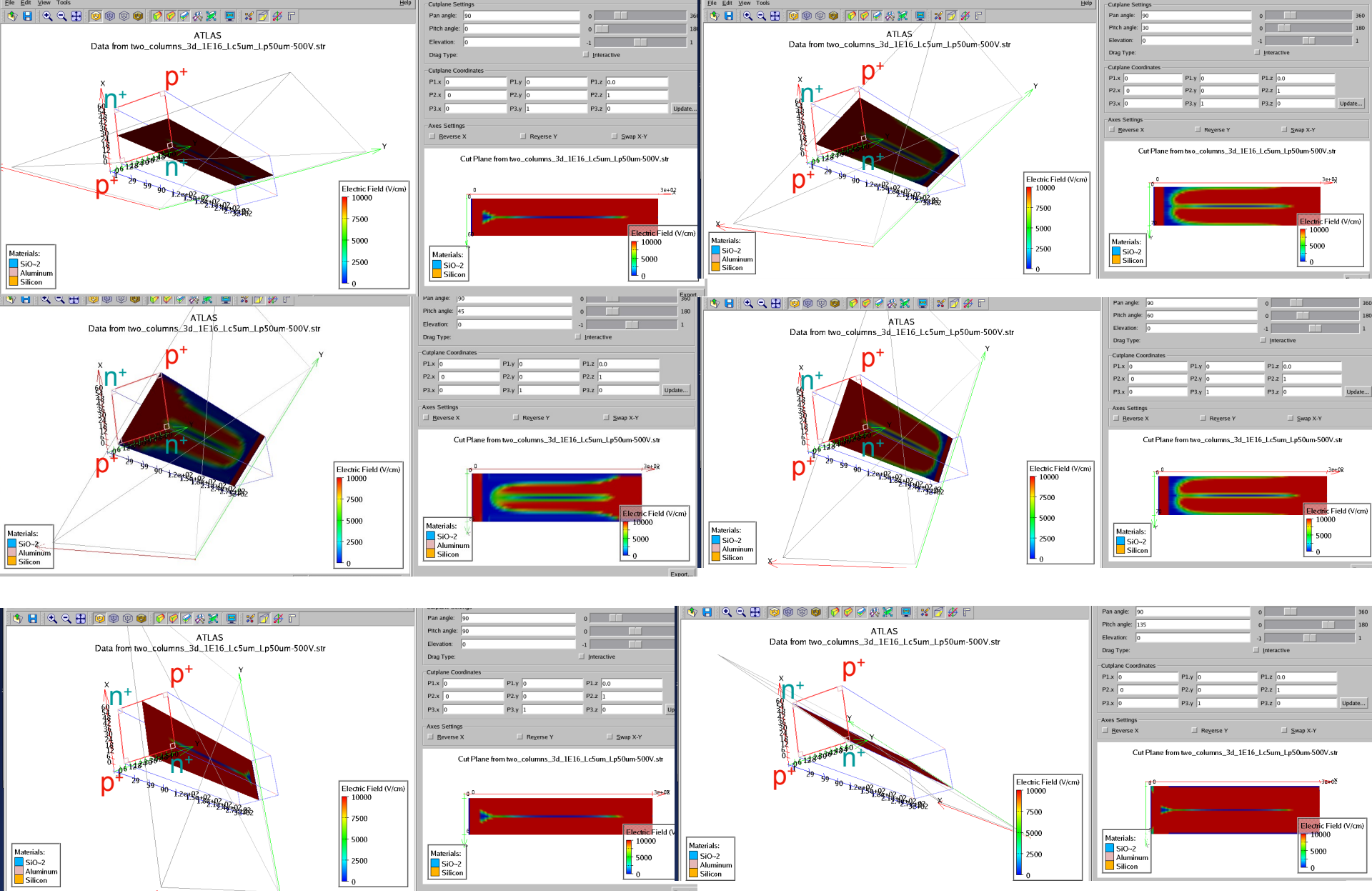


Standard (STD) BNL 2C-3D detector



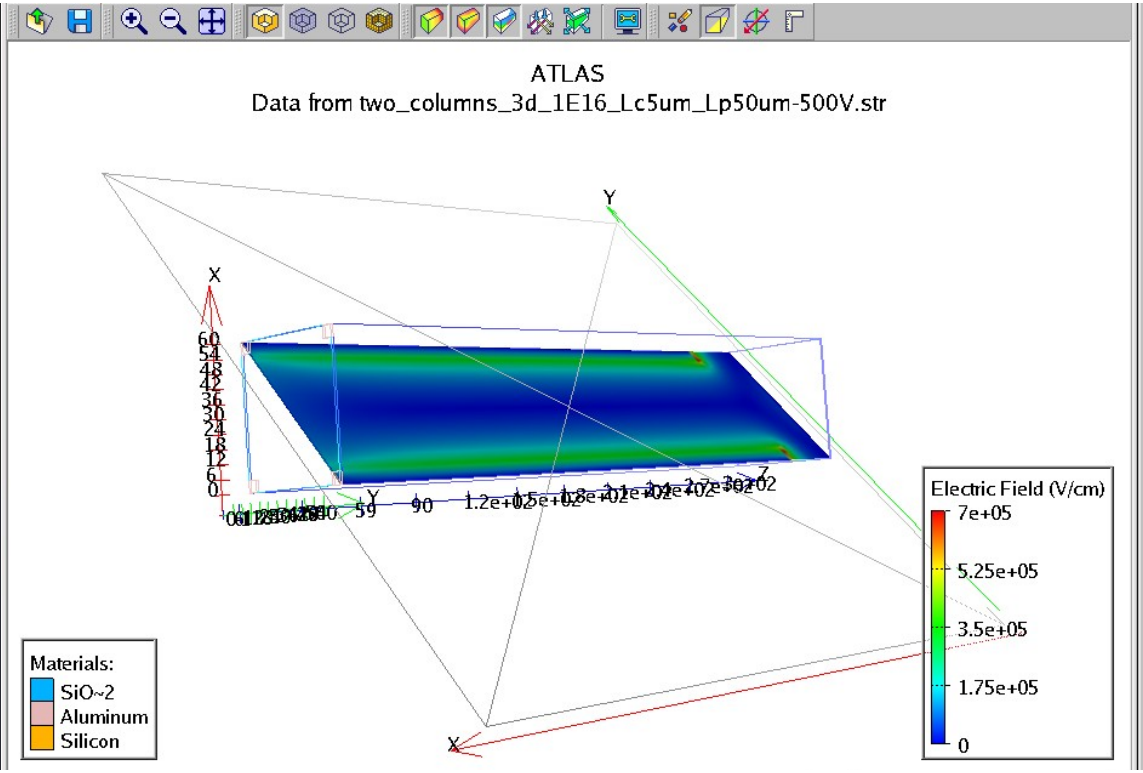


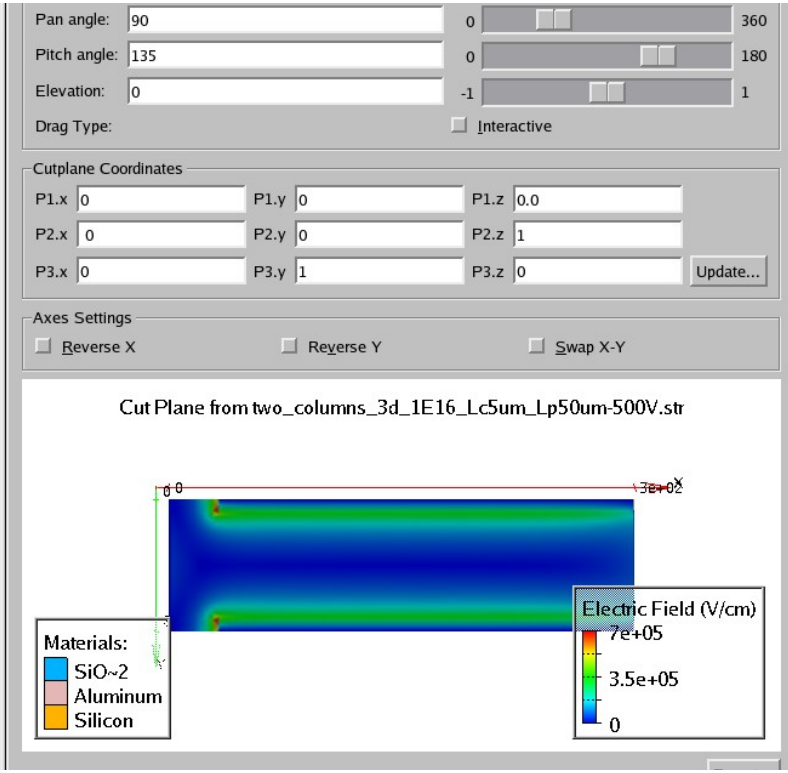
No/low field at saddle points



Very non-homogeneous electric field, no/low field at saddle points

E-field, STD BNL 2C-3D detector column, 1×10^{16} n_{eq}/cm^2, 500 V.

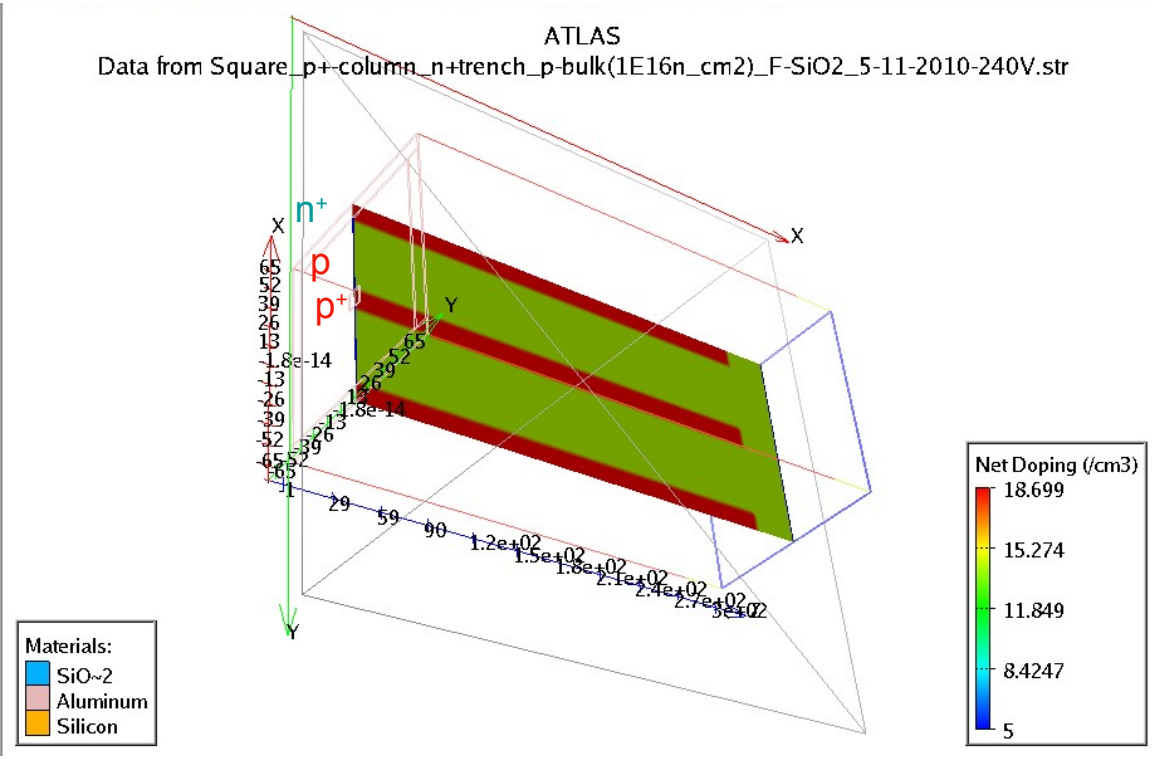


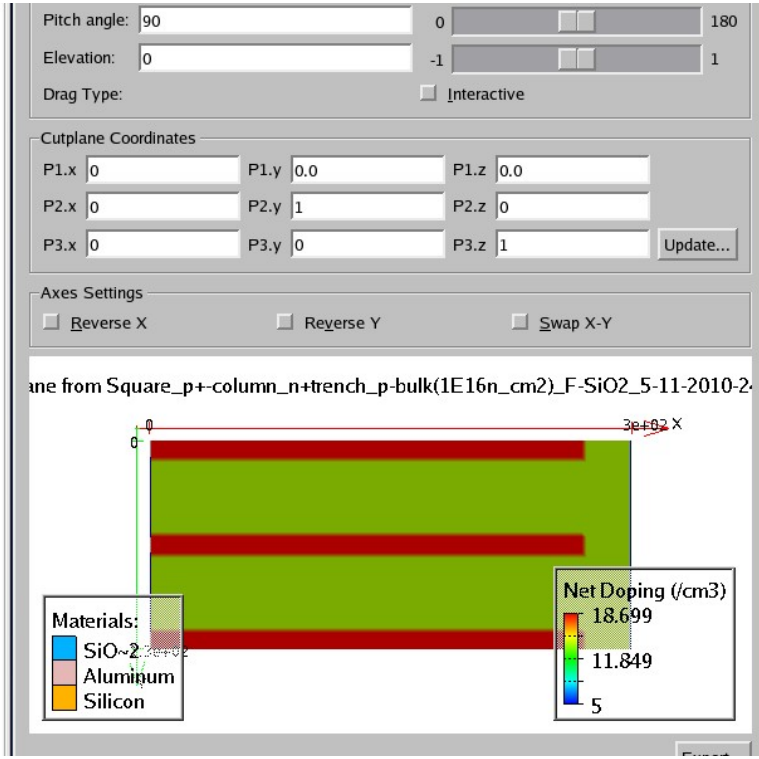


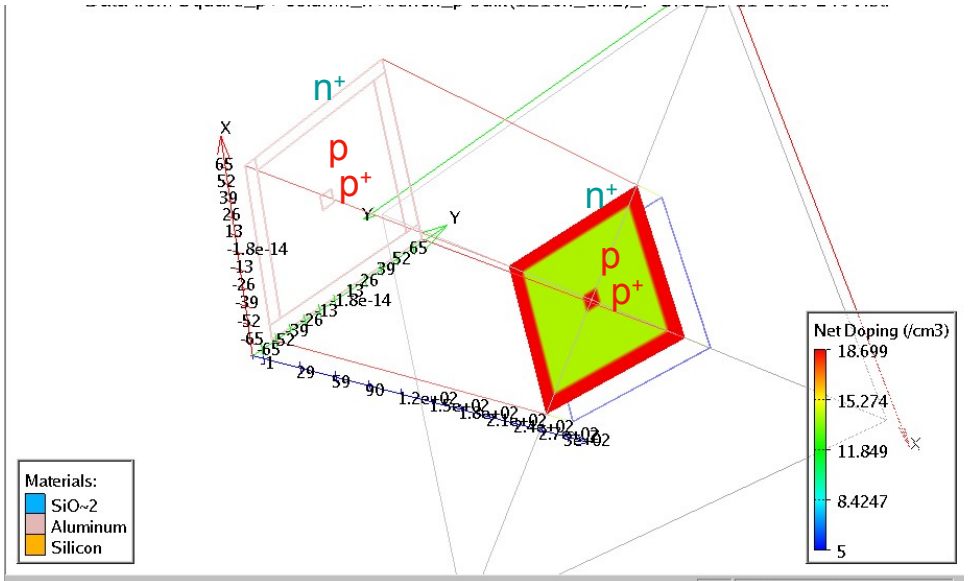
The highest E-field is under the n^+ junction columns >700 kV/cm

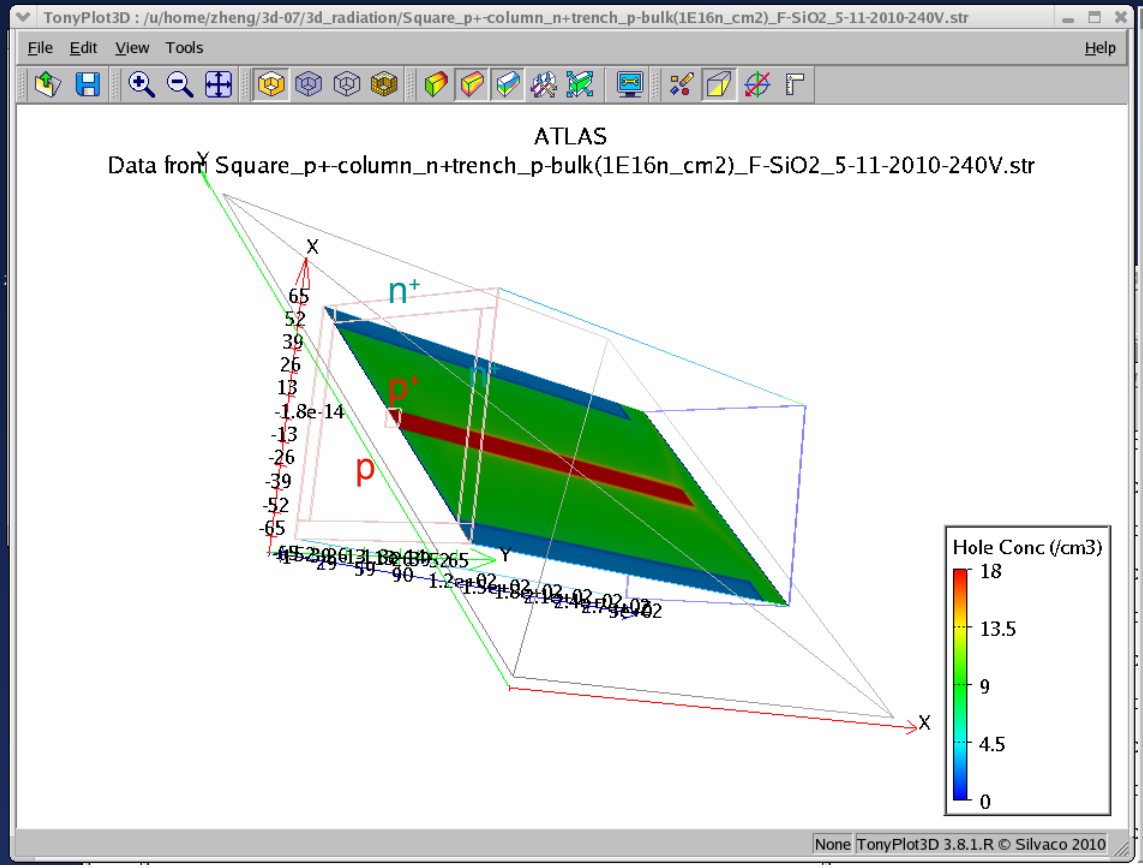
E-field, STD BNL 2C-3D detector column, $1x10^{16}$ n_{eq}/cm^2, 500 V.

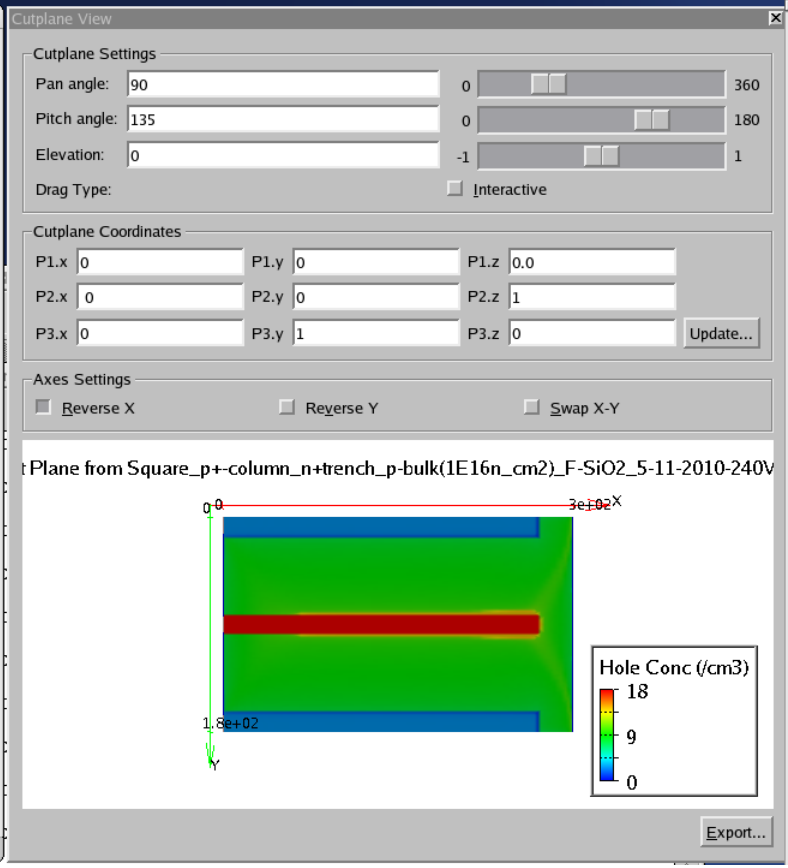
Square-type, junction on the n⁺ trench











The hole concentration for non-depleted Si is $2 \times 10^{14}/cm^3$

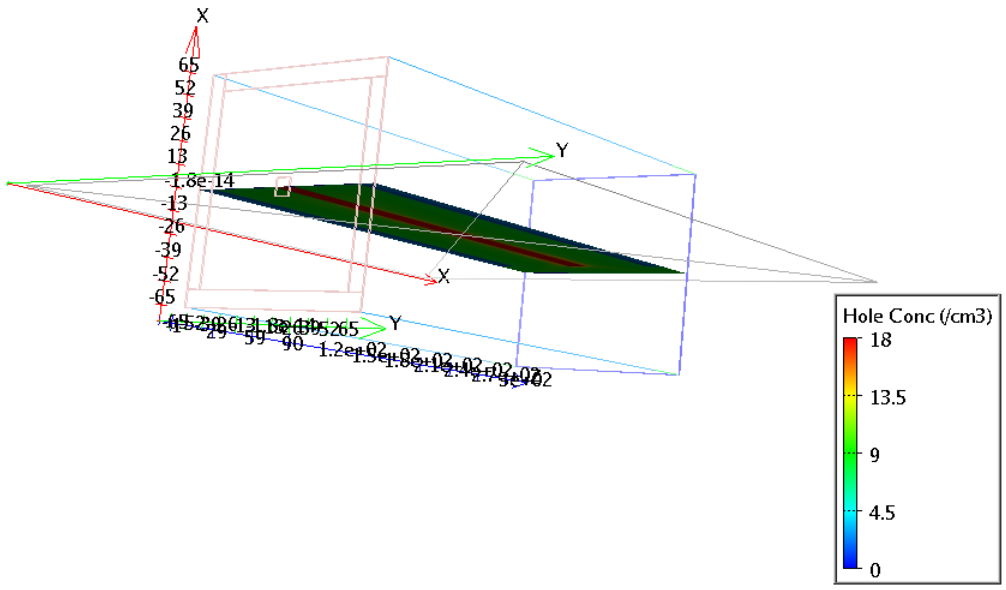
The whole cell is fully depleted at 240 V
even < the value of 400 V for 2D planar detector!

TonyPlot3D : /u/home/zheng/3d-07/3d_radiation/Square_p+-column_n+trench_p-bulk(1E16n_cm2)_F-SiO2_5-11-2010-240V.str

File Edit View Tools Help

ATLAS

Data from Square_p+-column_n+trench_p-bulk(1E16n_cm2)_F-SiO2_5-11-2010-240V.str



Cutplane View

Cutplane Settings

Pan angle: 90 0 360

Pitch angle: 0 0 180

Elevation: 0 -1 1

Drag Type: Interactive

Cutplane Coordinates

P1.x 0 P1.y 0 P1.z 0.0

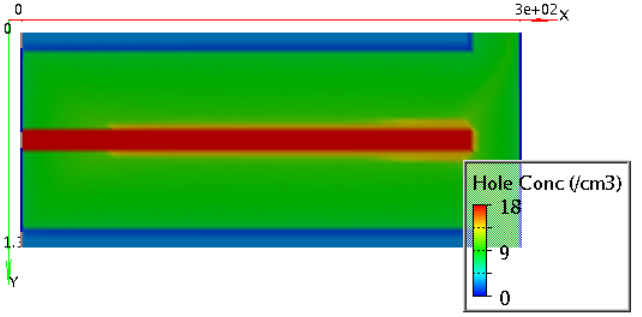
P2.x 0 P2.y 0 P2.z 1

P3.x 0 P3.y 1 P3.z 0 Update...

Axes Settings

Reverse X Reverse Y Swap X-Y

Plane from Square_p+-column_n+trench_p-bulk(1E16n_cm2)_F-SiO2_5-11-2010-240V



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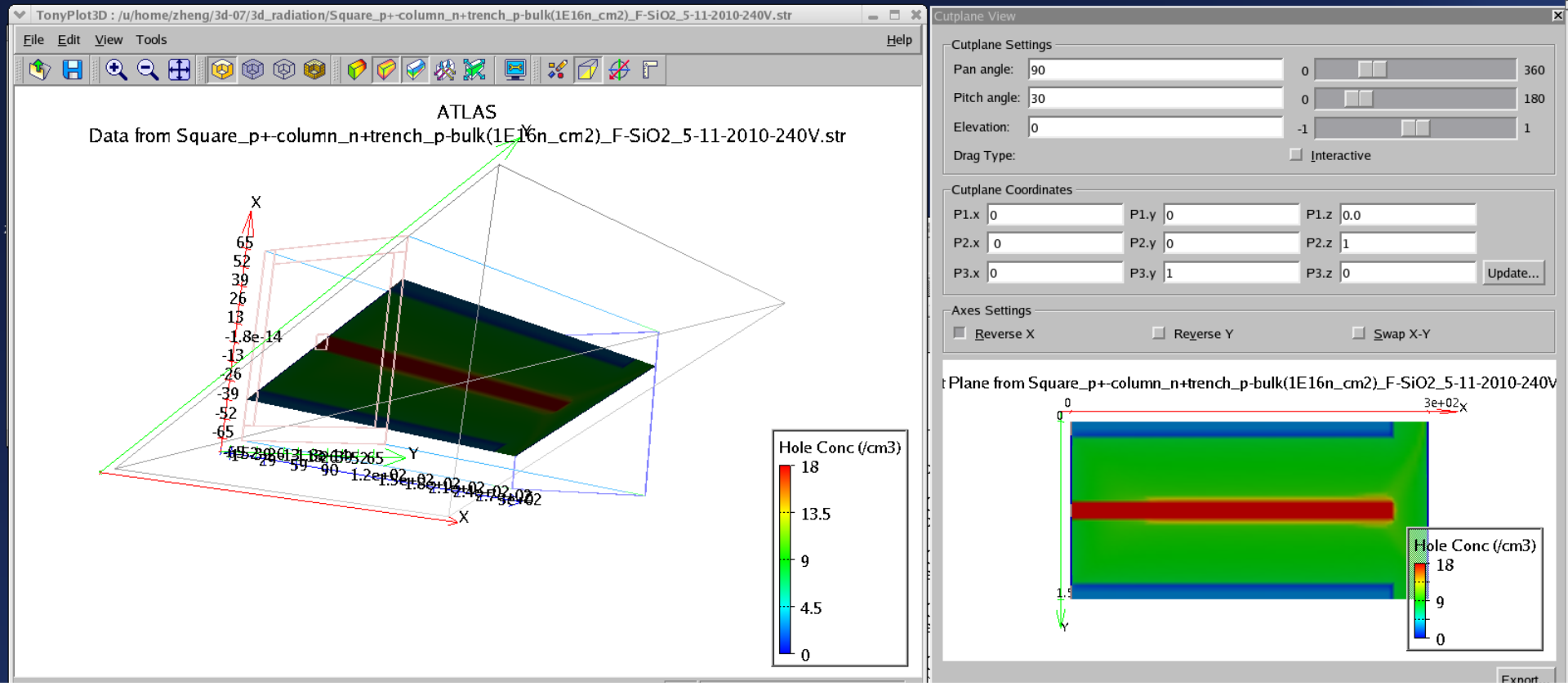
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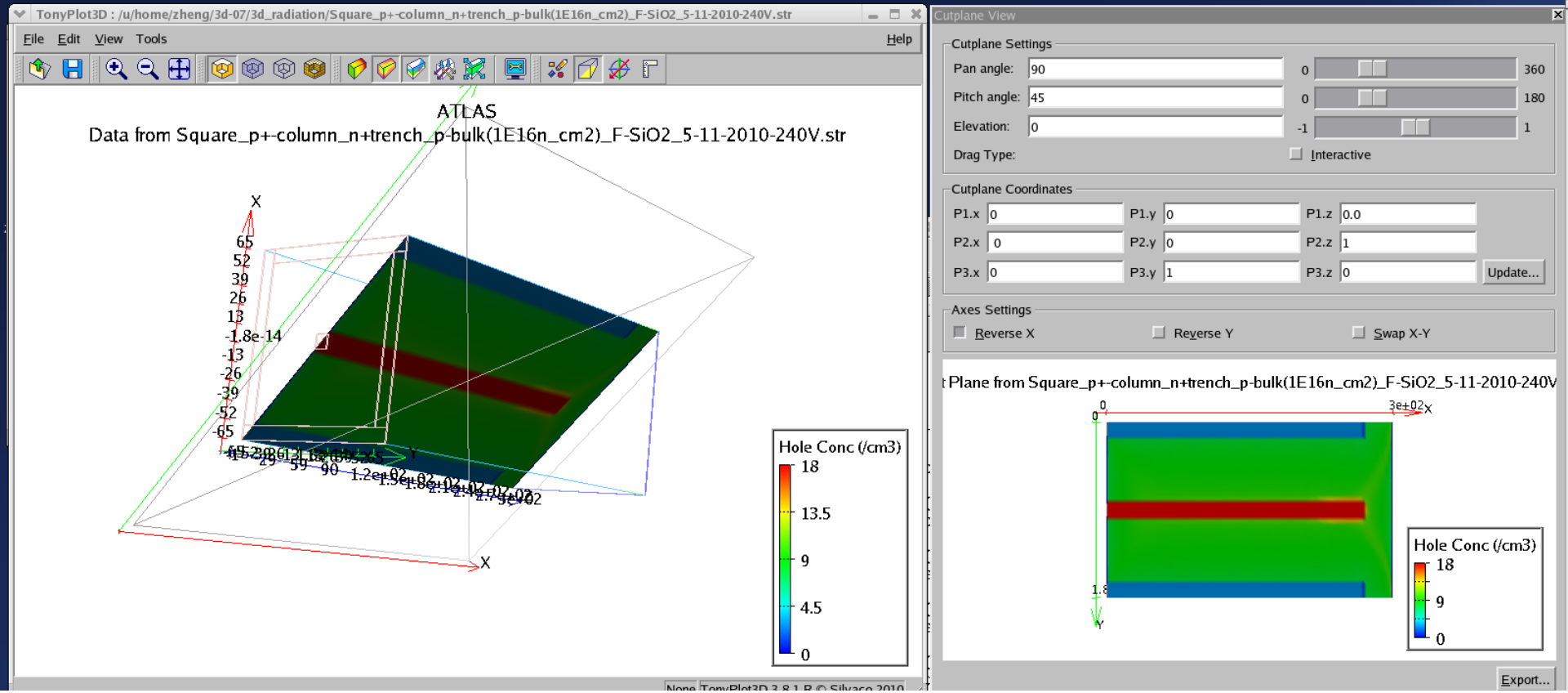
File Edit View Tools Help
ATLAS
Data from Square_p+-column_n+trench_p-bulk(1E16n_cm2)_F-SiO2_5-11-2010-240V.str
Hole Conc (/cm3)
18
13.5
9
4.5
0
Cutplane View
Cutplane Settings
Pan angle: 90
Pitch angle: 30
Elevation: 0
Drag Type:
Interactive
Cutplane Coordinates
P1.x 0 P1.y 0 P1.z 0.0
P2.x 0 P2.y 0 P2.z 1
P3.x 0 P3.y 1 P3.z 0
Update...
Axes Settings
Reverse X
Reverse Y
Swap X-Y
Plane from Square_p+-column_n+trench_p-bulk(1E16n_cm2)_F-SiO2_5-11-2010-240V
Hole Conc (/cm3)
18
9
0
Export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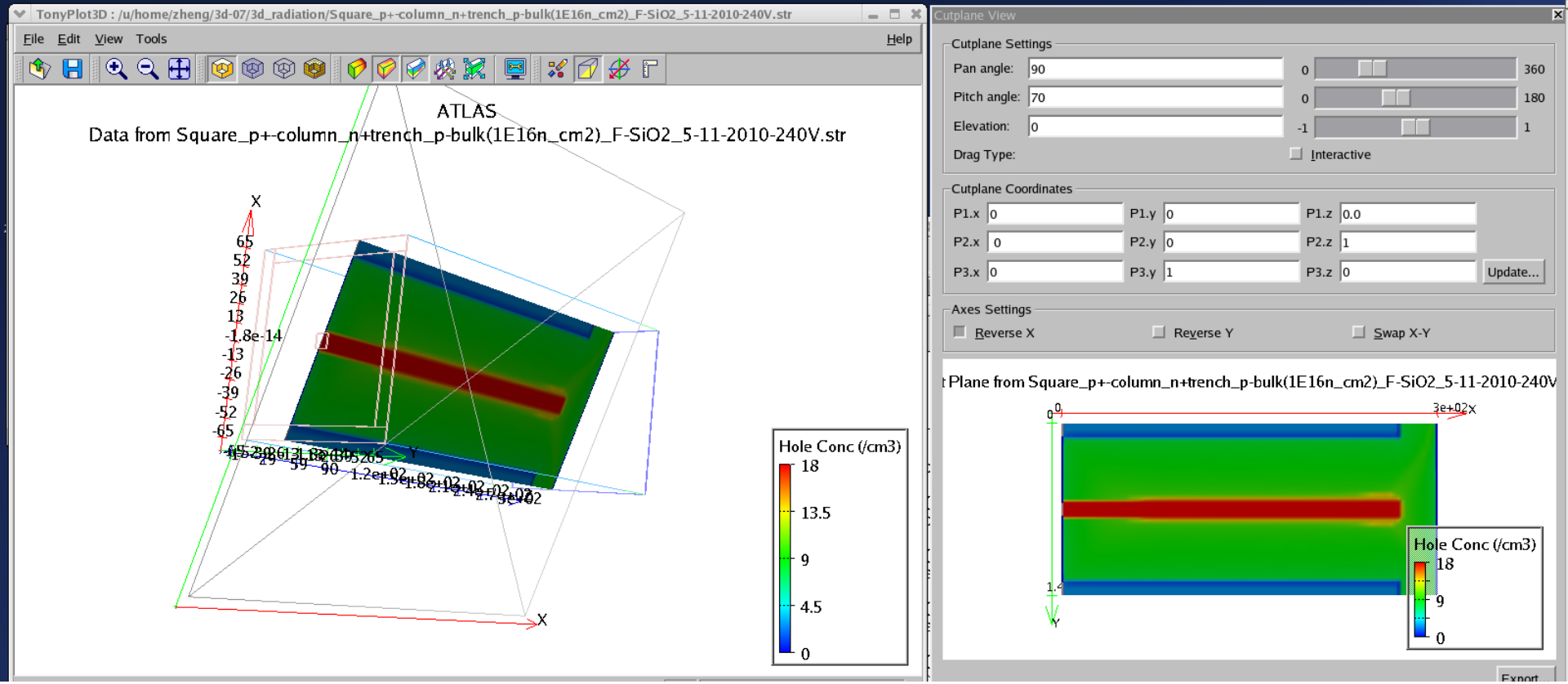
File Edit View Tools Help
ATLAS
Data from Square_p+-column_n+trench_p-bulk(1E16n_cm2)_F-SiO2_5-11-2010-240V.str
Hole Conc (/cm3)
18
13.5
9
4.5
0
Cutplane View
Cutplane Settings
Pan angle: 90
Pitch angle: 45
Elevation: 0
Drag Type:
Interactive
Cutplane Coordinates
P1.x 0 P1.y 0 P1.z 0.0
P2.x 0 P2.y 0 P2.z 1
P3.x 0 P3.y 1 P3.z 0
Update...
Axes Settings
Reverse X
Reverse Y
Swap X-Y
Plane from Square_p+-column_n+trench_p-bulk(1E16n_cm2)_F-SiO2_5-11-2010-240V
Hole Conc (/cm3)
18
9
0
Export...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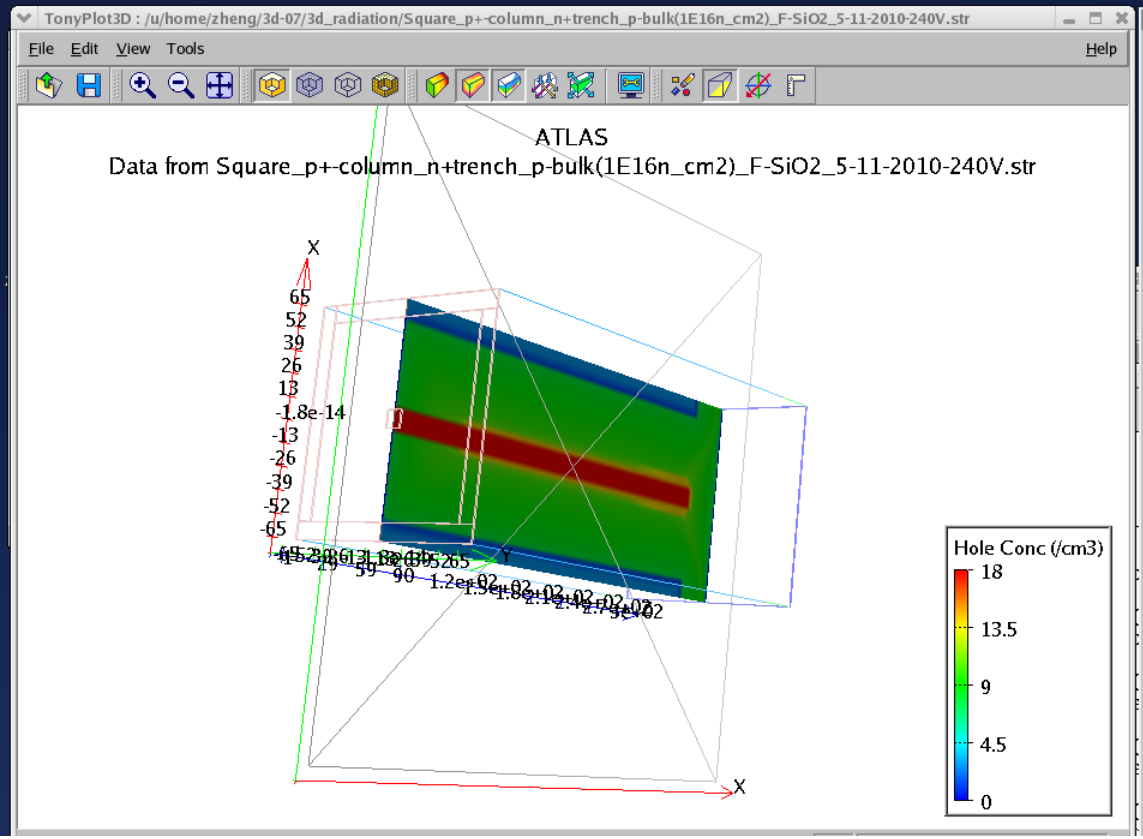
File Edit View Tools Help
ATLAS
Data from Square_p+-column_n+trench_p-bulk(1E16n_cm2)_F-SiO2_5-11-2010-240V.str
Hole Conc (/cm3)
18
13.5
9
4.5
0
Cutplane View
Cutplane Settings
Pan angle: 90
Pitch angle: 70
Elevation: 0
Drag Type:
Interactive
Cutplane Coordinates
P1.x 0 P1.y 0 P1.z 0.0
P2.x 0 P2.y 0 P2.z 1
P3.x 0 P3.y 1 P3.z 0
Update...
Axes Settings
Reverse X
Reverse Y
Swap X-Y
Plane from Square_p+-column_n+trench_p-bulk(1E16n_cm2)_F-SiO2_5-11-2010-240V
Hole Conc (/cm3)
18
9
0
Export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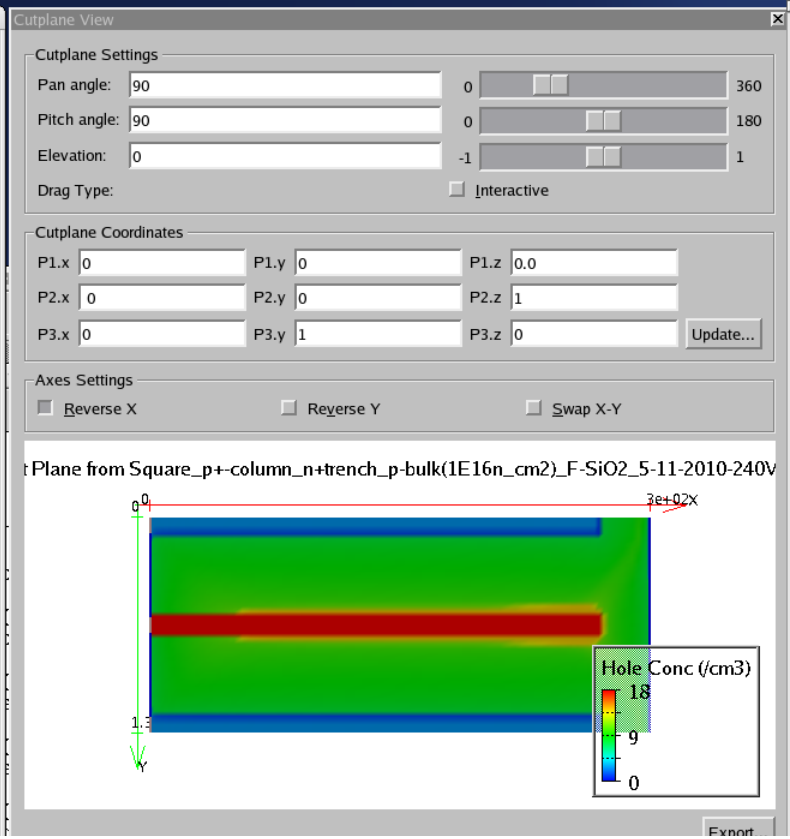
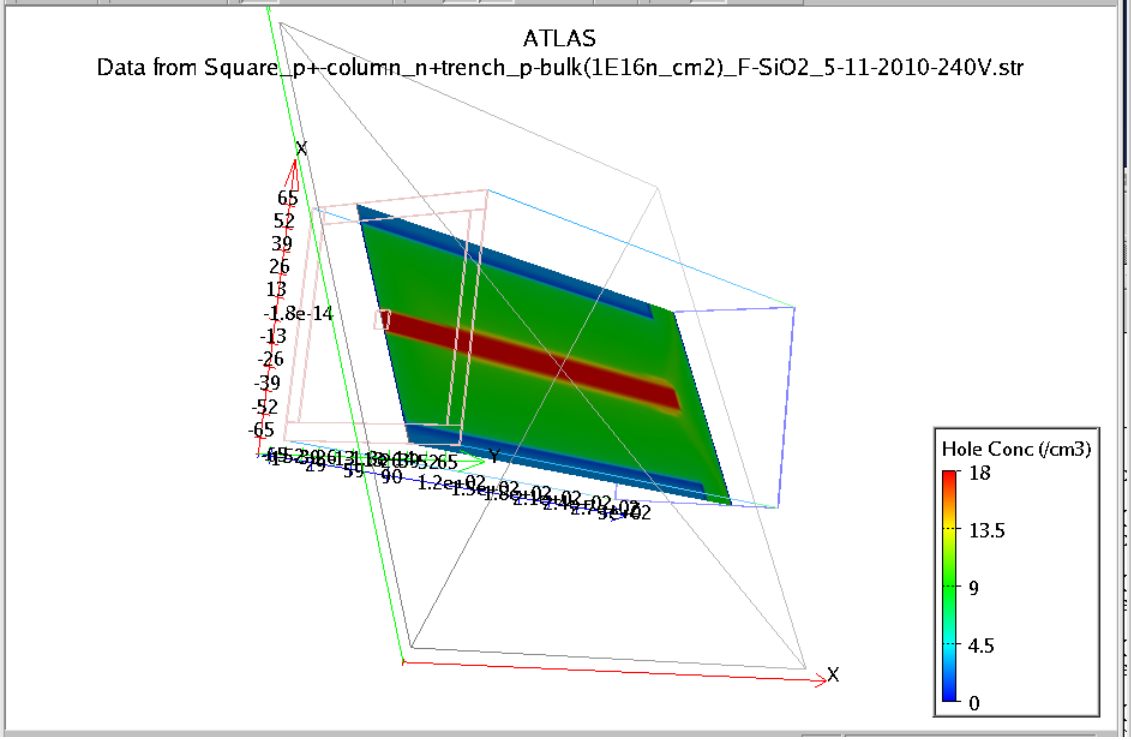
File Edit View Tools Help
ATLAS
Data from Square_p+-column_n+trench_p-bulk(1E16n_cm2)_F-SiO2_5-11-2010-240V.str
X
65
52
39
26
13
-1.8e-14
-13
-26
-39
-52
-65
Y
X
Hole Conc (/cm3)
18
13.5
9
4.5
0


Cutplane View
Cutplane Settings
Pan angle: 90 0 360
Pitch angle: 90 0 180
Elevation: 0 -1 1
Drag Type: Interactive
Cutplane Coordinates
P1.x 0 P1.y 0 P1.z 0.0
P2.x 0 P2.y 0 P2.z 1
P3.x 0 P3.y 1 P3.z 0
Update...
Axes Settings
Reverse X Reverse Y Swap X-Y
Plane from Square_p+-column_n+trench_p-bulk(1E16n_cm2)_F-SiO2_5-11-2010-240V
0
3e+02X
Y
Hole Conc (/cm3)
18
9
0
Export

TonyPlot3D : /u/home/zheng/3d-07/3d_radiation/Square_p+-column_n+trench_p-bulk(1E16n_cm2)_F-SiO2_5-11-2010-240V.str

File Edit View Tools Help



Cutplane View

Cutplane Settings

Pan angle: 90 0 360

Pitch angle: 115 0 180

Elevation: 0 -1 1

Drag Type: Interactive

Cutplane Coordinates

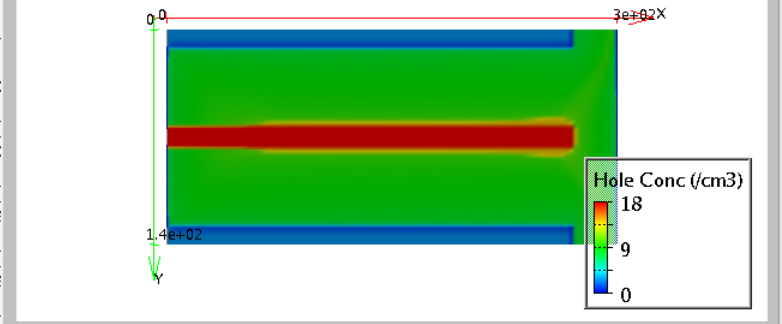
P1.x 0 P1.y 0 P1.z 0.0

P2.x 0 P2.y 0 P2.z 1

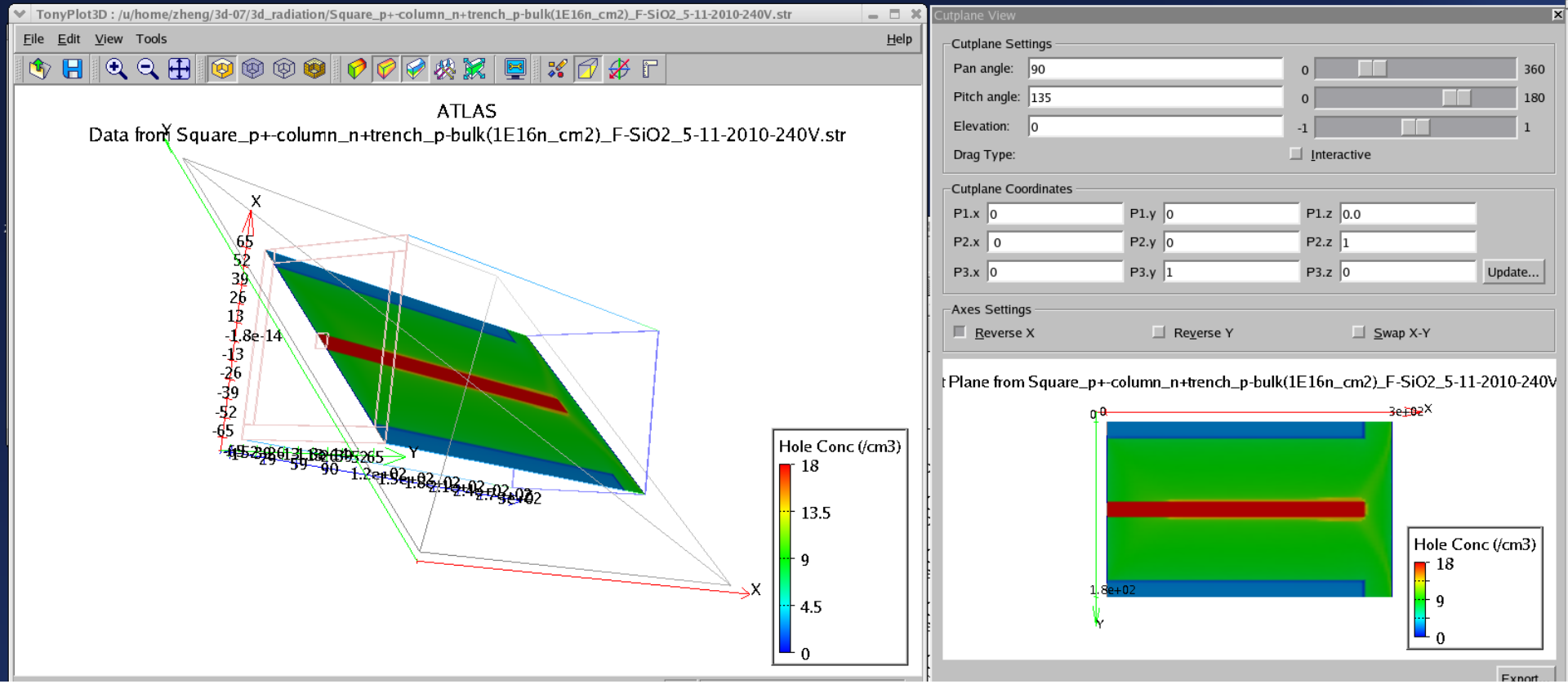
P3.x 0 P3.y 1 P3.z 0 Update...

Axes Settings

Reverse X Reverse Y Swap X-Y



Export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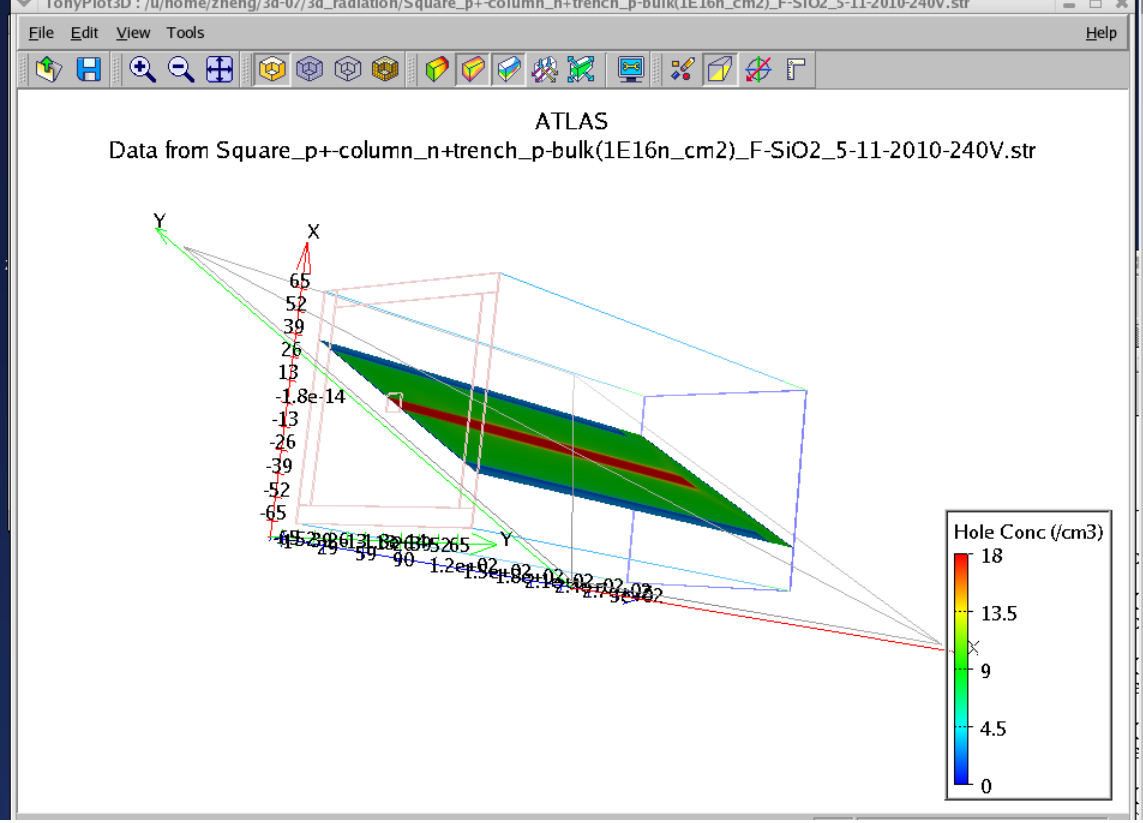
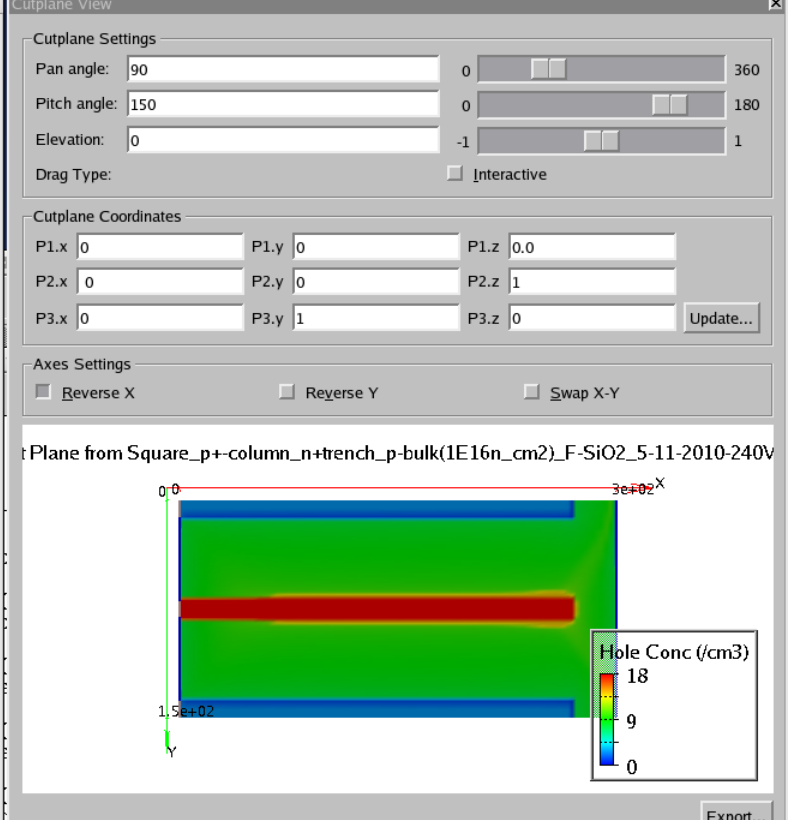
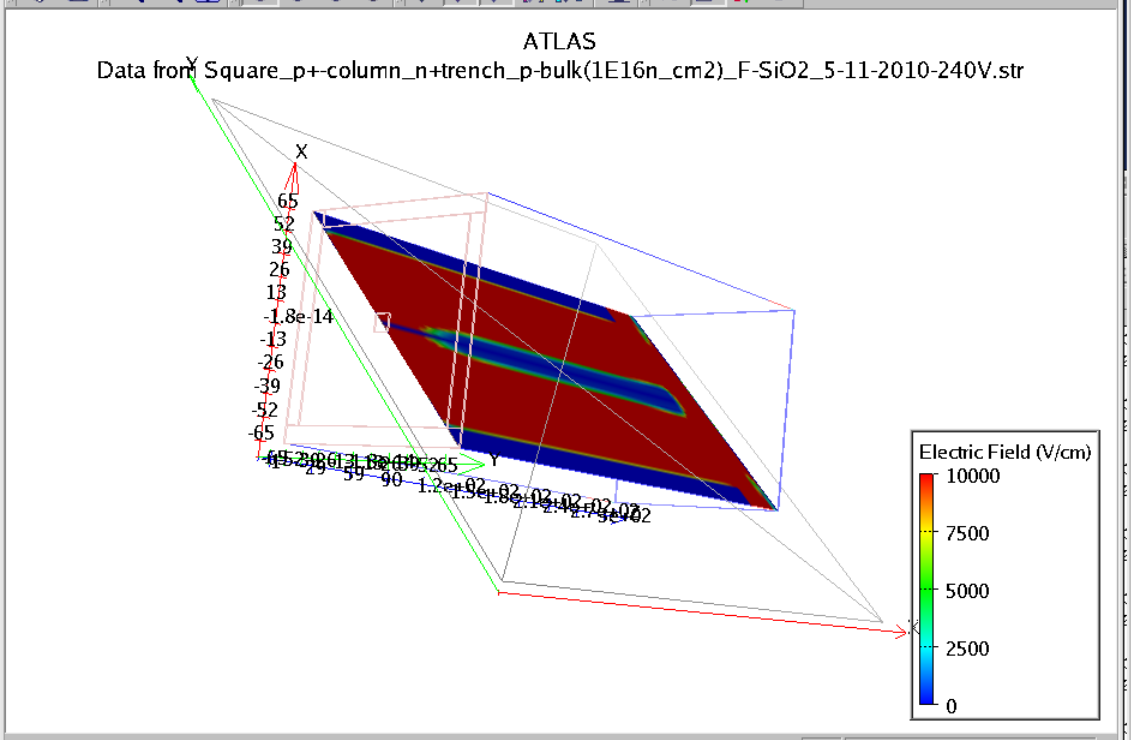
File Edit View Tools Help
ATLAS
Data from Square_p+-column_n+trench_p-bulk(1E16n_cm2)_F-SiO2_5-11-2010-240V.str
Hole Conc (/cm3)
18
13.5
9
4.5
0
Cutplane View
Cutplane Settings
Pan angle: 90
Pitch angle: 135
Elevation: 0
Drag Type:
Interactive
Cutplane Coordinates
P1.x 0 P1.y 0 P1.z 0.0
P2.x 0 P2.y 0 P2.z 1
P3.x 0 P3.y 1 P3.z 0
Update...
Axes Settings
Reverse X
Reverse Y
Swap X-Y
Plane from Square_p+-column_n+trench_p-bulk(1E16n_cm2)_F-SiO2_5-11-2010-240V
Hole Conc (/cm3)
18
9
0
Export


TonyPlot3D : /u/home/zheng/3d-07/3d_radiation/Square_p+-column_n+trench_p-bulk(1E16n_cm2)_F-SiO2_5-11-2010-240V.str
File Edit View Tools Help
ATLAS
Data from Square_p+-column_n+trench_p-bulk(1E16n_cm2)_F-SiO2_5-11-2010-240V.str
X
Y
65
52
39
26
13
-1.8e-14
-13
-26
-39
-52
-65
Hole Conc (/cm3)
18
13.5
9
4.5
0


Cutplane View
Cutplane Settings
Pan angle: 90
Pitch angle: 150
Elevation: 0
Drag Type:
Interactive
Cutplane Coordinates
P1.x 0
P1.y 0
P1.z 0.0
P2.x 0
P2.y 0
P2.z 1
P3.x 0
P3.y 1
P3.z 0
Update...
Axes Settings
Reverse X
Reverse Y
Swap X-Y
Plane from Square_p+-column_n+trench_p-bulk(1E16n_cm2)_F-SiO2_5-11-2010-240V
Hole Conc (/cm3)
18
9
0
Export

TonyPlot3D : /u/home/zheng/3d-07/3d_radiation/Square_p+-column_n+trench_p-bulk(1E16n_cm2)_F-SiO2_5-11-2010-240V.str

File Edit View Tools Help



Cutplane View

Cutplane Settings

Pan angle: 90 (0 – 360)

Pitch angle: 135 (0 – 180)

Elevation: 0 (-1 – 1)

Drag Type: Interactive

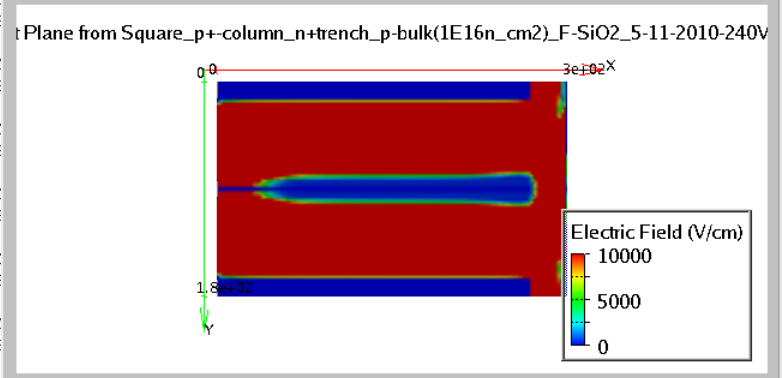
Cutplane Coordinates

P1.x	0	P1.y	0	P1.z	0.0
P2.x	0	P2.y	0	P2.z	1
P3.x	0	P3.y	1	P3.z	0

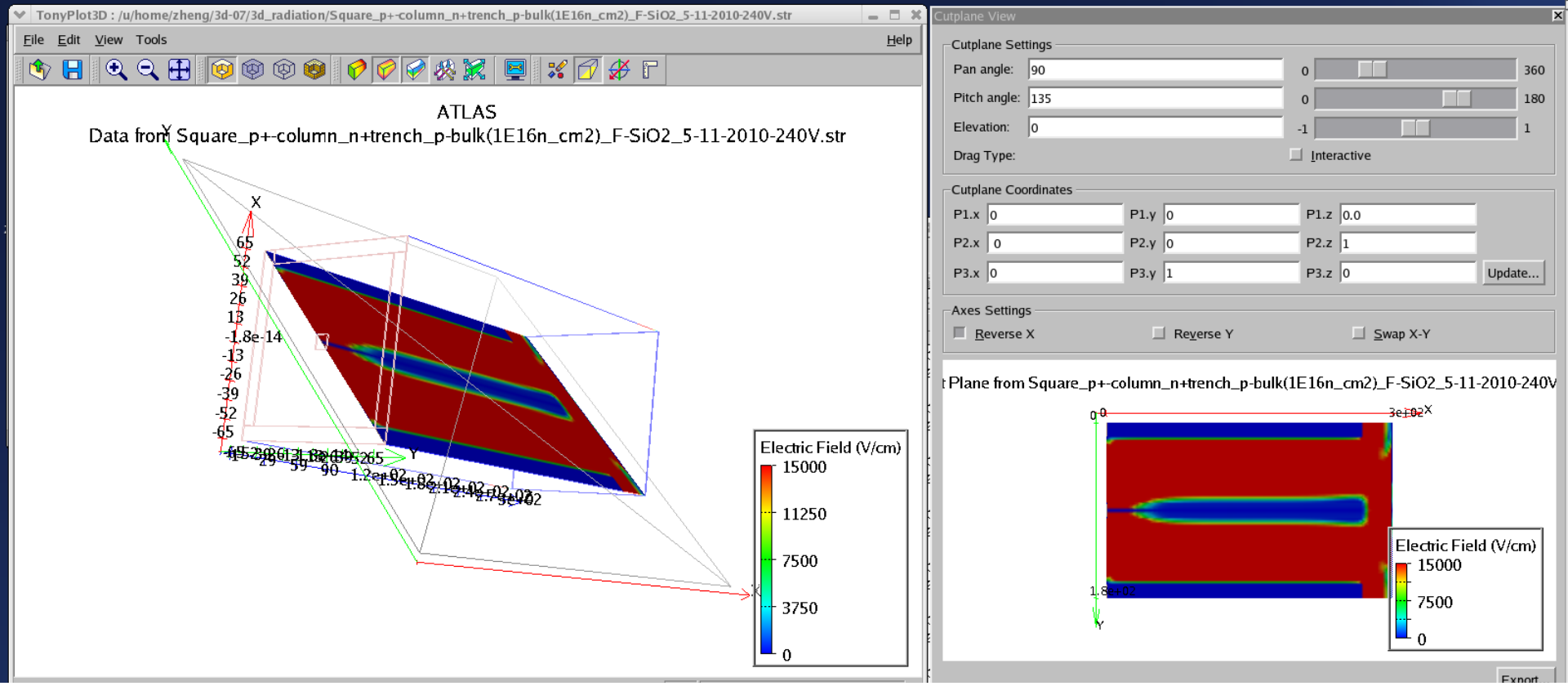
Update...

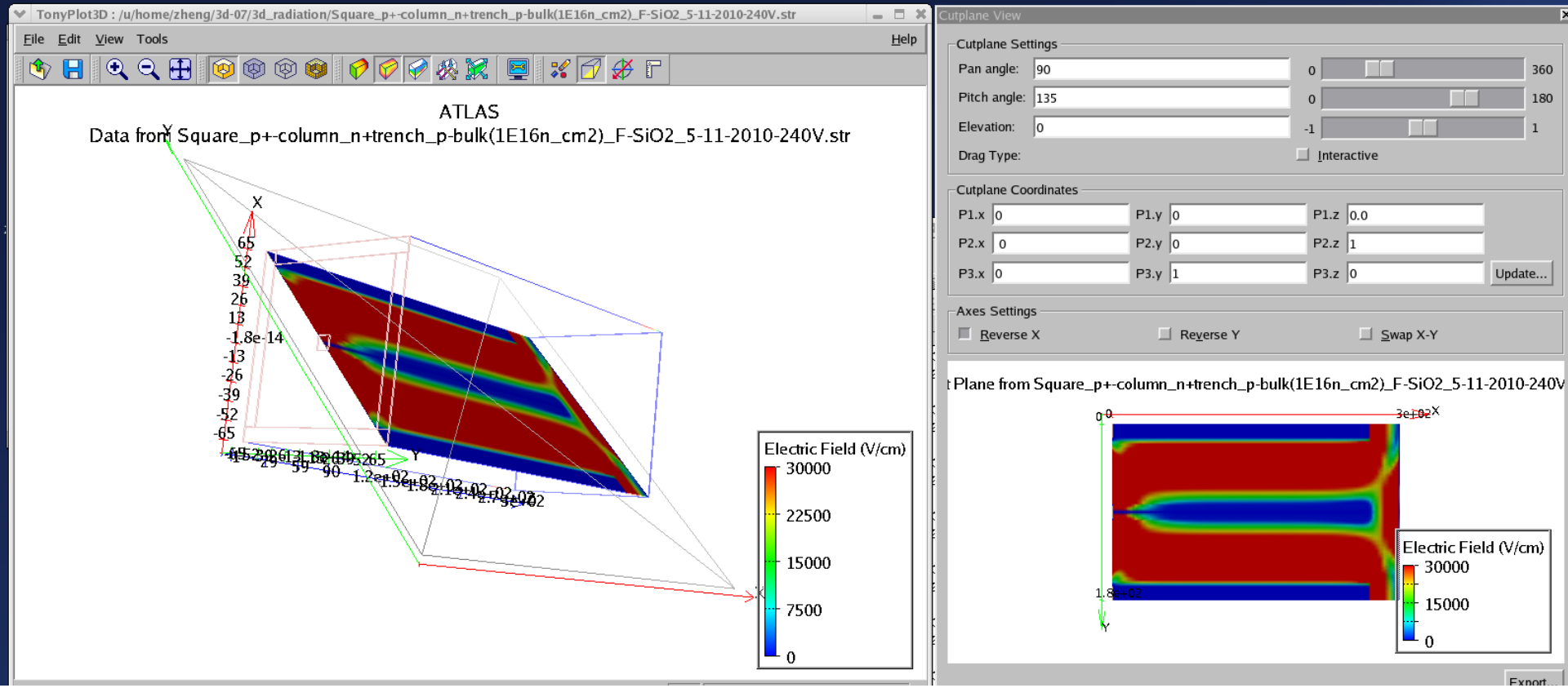
Axes Settings

Reverse X Reverse Y Swap X-Y



Export


TonyPlot3D : /u/home/zheng/3d-07/3d_radiation/Square_p+-column_n+trench_p-bulk(1E16n_cm2)_F-SiO2_5-11-2010-240V.str
File Edit View Tools Help
ATLAS
Data from Square_p+-column_n+trench_p-bulk(1E16n_cm2)_F-SiO2_5-11-2010-240V.str
Electric Field (V/cm)
15000
11250
7500
3750
0
Cutplane View
Cutplane Settings
Pan angle: 90
Pitch angle: 135
Elevation: 0
Drag Type:
Interactive
Cutplane Coordinates
P1.x 0 P1.y 0 P1.z 0.0
P2.x 0 P2.y 0 P2.z 1
P3.x 0 P3.y 1 P3.z 0
Update...
Axes Settings
Reverse X
Reverse Y
Swap X-Y
Plane from Square_p+-column_n+trench_p-bulk(1E16n_cm2)_F-SiO2_5-11-2010-240V
Electric Field (V/cm)
15000
7500
0
Export

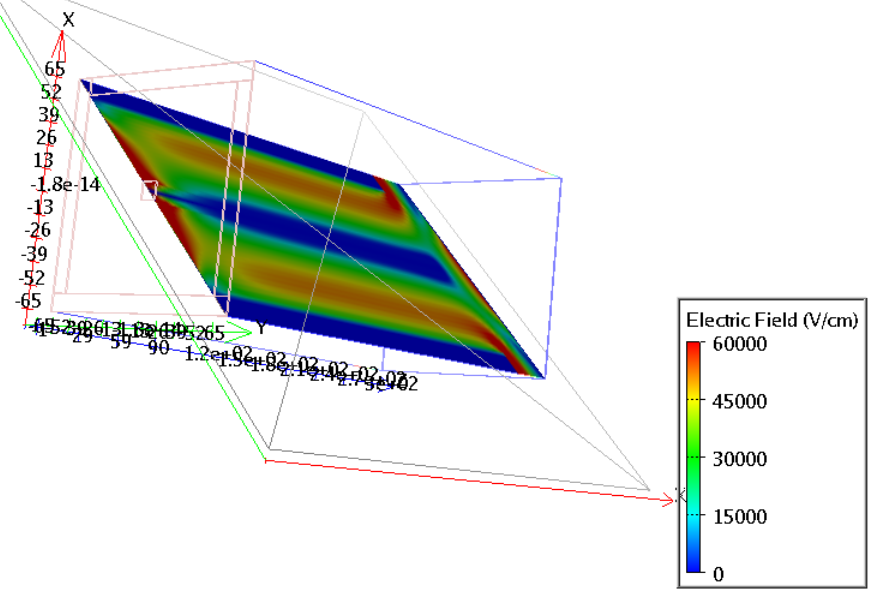

TonyPlot3D : /u/home/zheng/3d-07/3d_radiation/Square_p+-column_n+trench_p-bulk(1E16n_cm2)_F-SiO2_5-11-2010-240V.str
File Edit View Tools Help
ATLAS
Data from Square_p+-column_n+trench_p-bulk(1E16n_cm2)_F-SiO2_5-11-2010-240V.str
Electric Field (V/cm)
30000
22500
15000
7500
0
Cutplane View
Cutplane Settings
Pan angle: 90
Pitch angle: 135
Elevation: 0
Drag Type:
Interactive
Cutplane Coordinates
P1.x 0 P1.y 0 P1.z 0.0
P2.x 0 P2.y 0 P2.z 1
P3.x 0 P3.y 1 P3.z 0
Update...
Axes Settings
Reverse X
Reverse Y
Swap X-Y
Plane from Square_p+-column_n+trench_p-bulk(1E16n_cm2)_F-SiO2_5-11-2010-240V
Electric Field (V/cm)
30000
15000
0
Export...

TonyPlot3D : /u/home/zheng/3d-07/3d_radiation/Square_p+-column_n+trench_p-bulk(1E16n_cm2)_F-SiO2_5-11-2010-240V.str

File Edit View Tools Help

ATLAS

Data from Square_p+-column_n+trench_p-bulk(1E16n_cm2)_F-SiO2_5-11-2010-240V.str



None TonyPlot3D 3.8.1.R © Silvaco 2010

Cutplane View

Cutplane Settings

Pan angle: 90 0 360

Pitch angle: 135 0 180

Elevation: 0 -1 1

Drag Type: Interactive

Cutplane Coordinates

P1.x 0 P1.y 0 P1.z 0.0

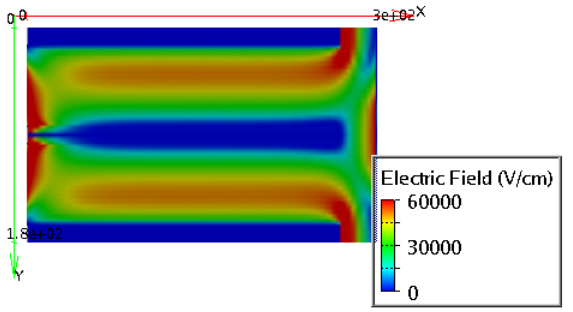
P2.x 0 P2.y 0 P2.z 1

P3.x 0 P3.y 1 P3.z 0 Update...

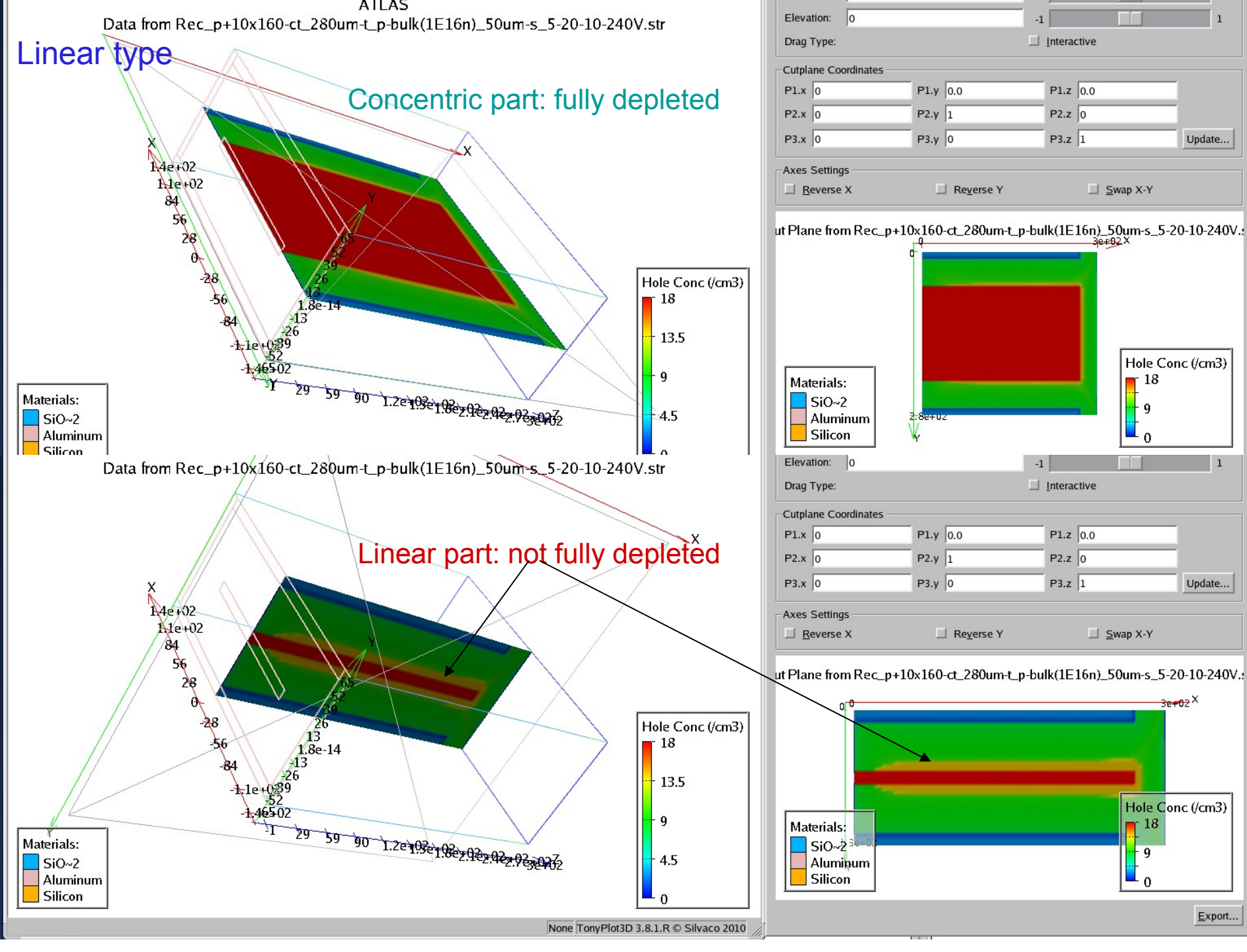
Axes Settings

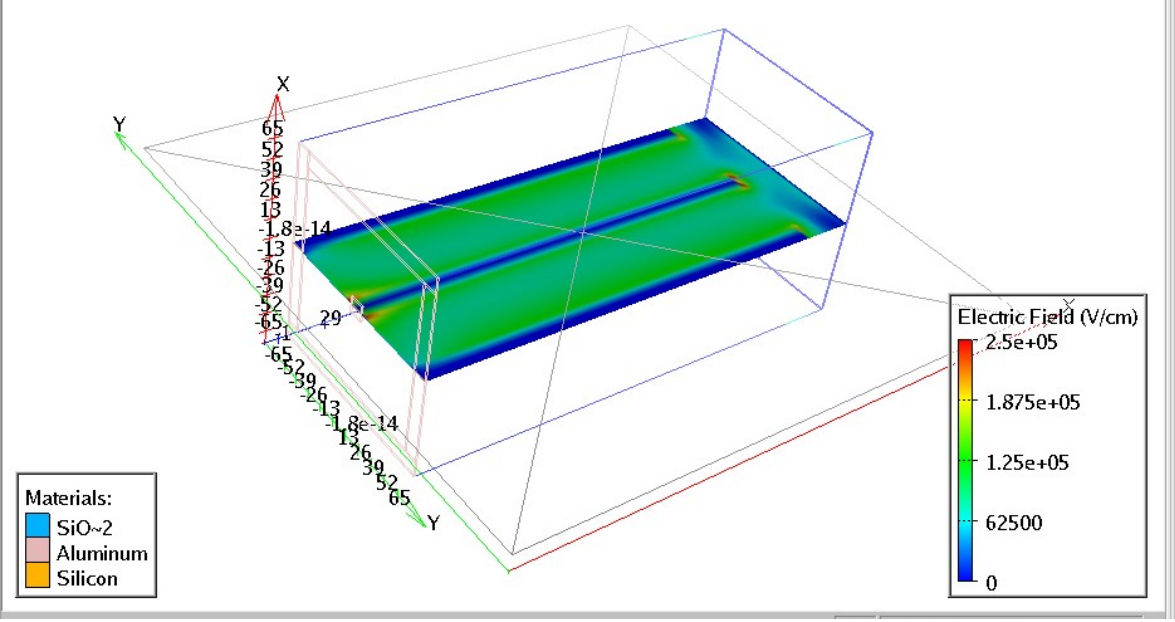
Reverse X Reverse Y Swap X-Y

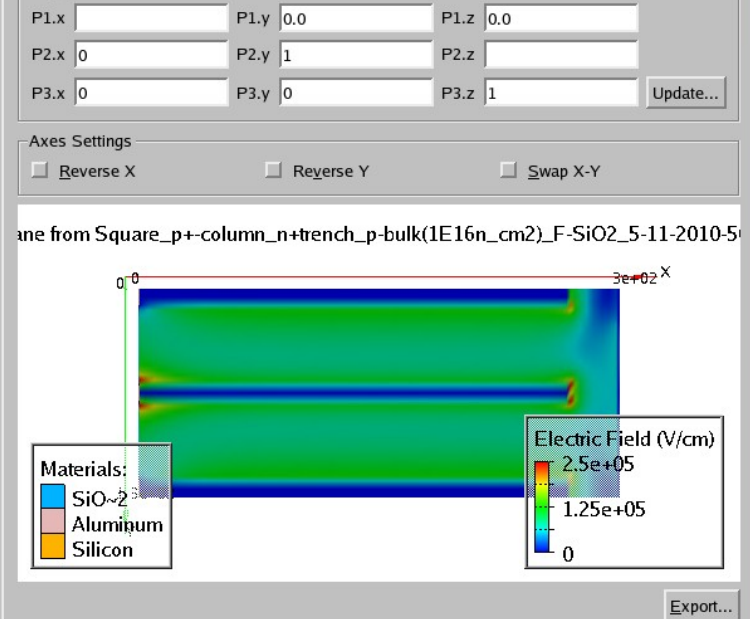
t Plane from Square_p+-column_n+trench_p-bulk(1E16n_cm2)_F-SiO2_5-11-2010-240V



Export...


ATLAS
Data from Rec_p+10x160-ct_280um-t_p-bulk(1E16n)_50um-s_5-20-10-240V.str
Linear type
Concentric part: fully depleted
Hole Conc (/cm3)
18
13.5
9
4.5
0
Materials:
SiO~2
Aluminum
Silicon
Data from Rec_p+10x160-ct_280um-t_p-bulk(1E16n)_50um-s_5-20-10-240V.str
Linear part: not fully depleted
Hole Conc (/cm3)
18
13.5
9
4.5
0
Materials:
SiO~2
Aluminum
Silicon
None TonyPlot3D 3.8.1.R © Silvaco 2010
Elevation: 0
Drag Type:
Interactive
Cutplane Coordinates
P1.x 0
P1.y 0.0
P1.z 0.0
P2.x 0
P2.y 1
P2.z 0
P3.x 0
P3.y 0
P3.z 1
Update...
Axes Settings
Reverse X
Reverse Y
Swap X-Y
ut Plane from Rec_p+10x160-ct_280um-t_p-bulk(1E16n)_50um-s_5-20-10-240V.s
Hole Conc (/cm3)
18
9
0
Materials:
SiO~2
Aluminum
Silicon
Elevation: 0
Drag Type:
Interactive
Cutplane Coordinates
P1.x 0
P1.y 0.0
P1.z 0.0
P2.x 0
P2.y 1
P2.z 0
P3.x 0
P3.y 0
P3.z 1
Update...
Axes Settings
Reverse X
Reverse Y
Swap X-Y
ut Plane from Rec_p+10x160-ct_280um-t_p-bulk(1E16n)_50um-s_5-20-10-240V.s
Hole Conc (/cm3)
18
9
0
Materials:
SiO~2
Aluminum
Silicon
Export...

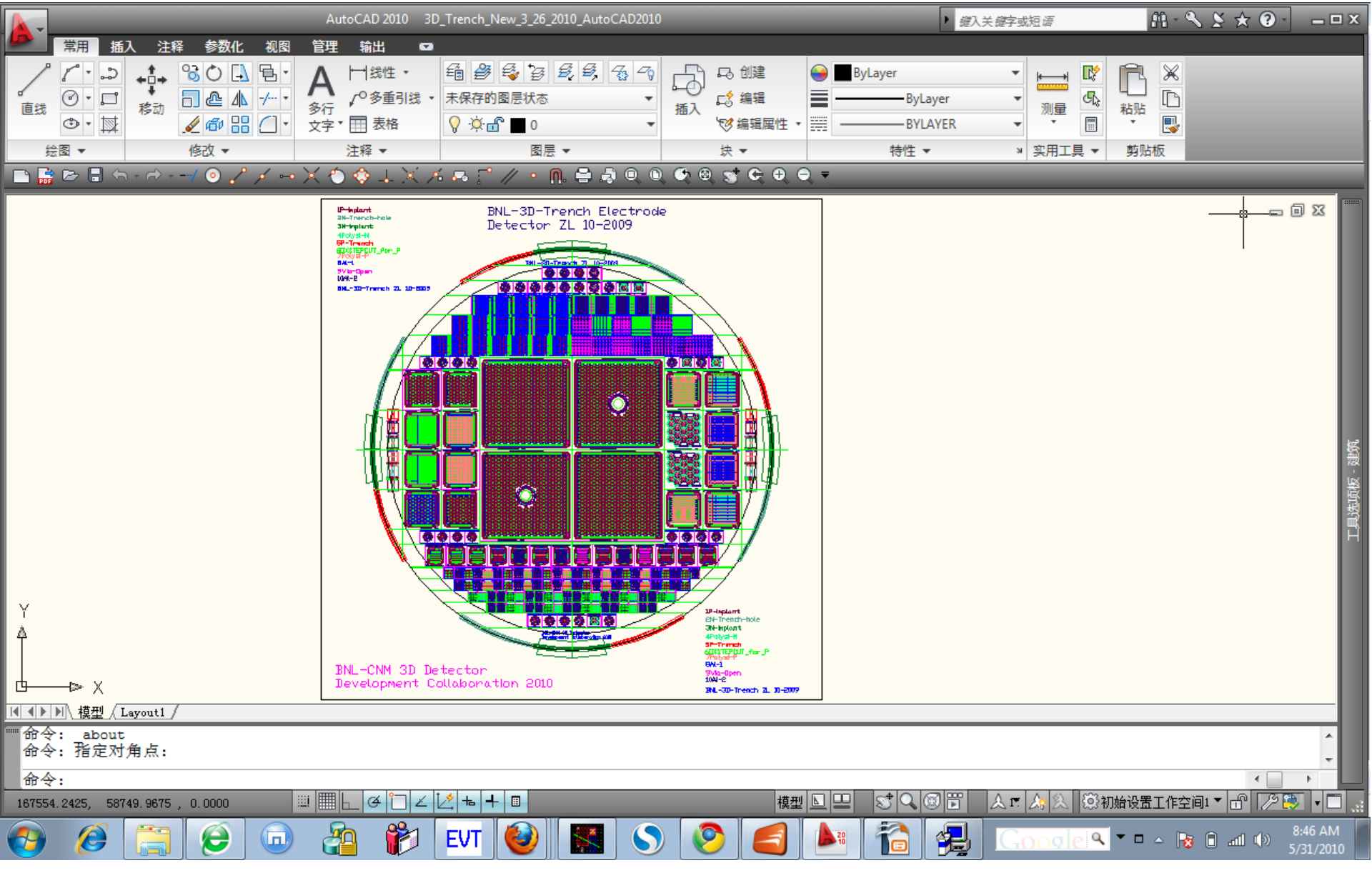




The highest E-field is under the junction trench, and near and under the column
at about 250 kV/cm at a bias 260V over-full depletion
Over-bias mainly goes to the column region where the low field
Was originally ---- resulting in a near uniform E-field in the bulk

The highest E-field is under the junction column
>700 kV/cm (500V) for STD 3D and 3D-Trench with central-column junction

Mask design almost finished
1st prototype will be processed at CNM



• Summary

- New Independent Coaxial Detector Array (ICDA) with novel, asymmetric trench electrodes has more homogeneous E-field
- The best configuration is the concentric type with the junction on the outer ring trench (ICDA-ORJ) --- electric field manipulation
- The electric field distribution in a ICDA-ORJ detector is even more uniform, and full depletion voltage is even lower than those in 2D planar detectors
- At full depletion the central column is well isolated and the volume under the trench/column are fully depleted as well, providing sensitivity in the volume
- Small area in collection electrode and intrinsic pixel isolations in ICDA-ORJ detectors provide other advantages in detector applications