TCAD for electronic devices part 1

Microelectronics devices, sensors and MEMS

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Synopsys TCAD tutorial – part 1

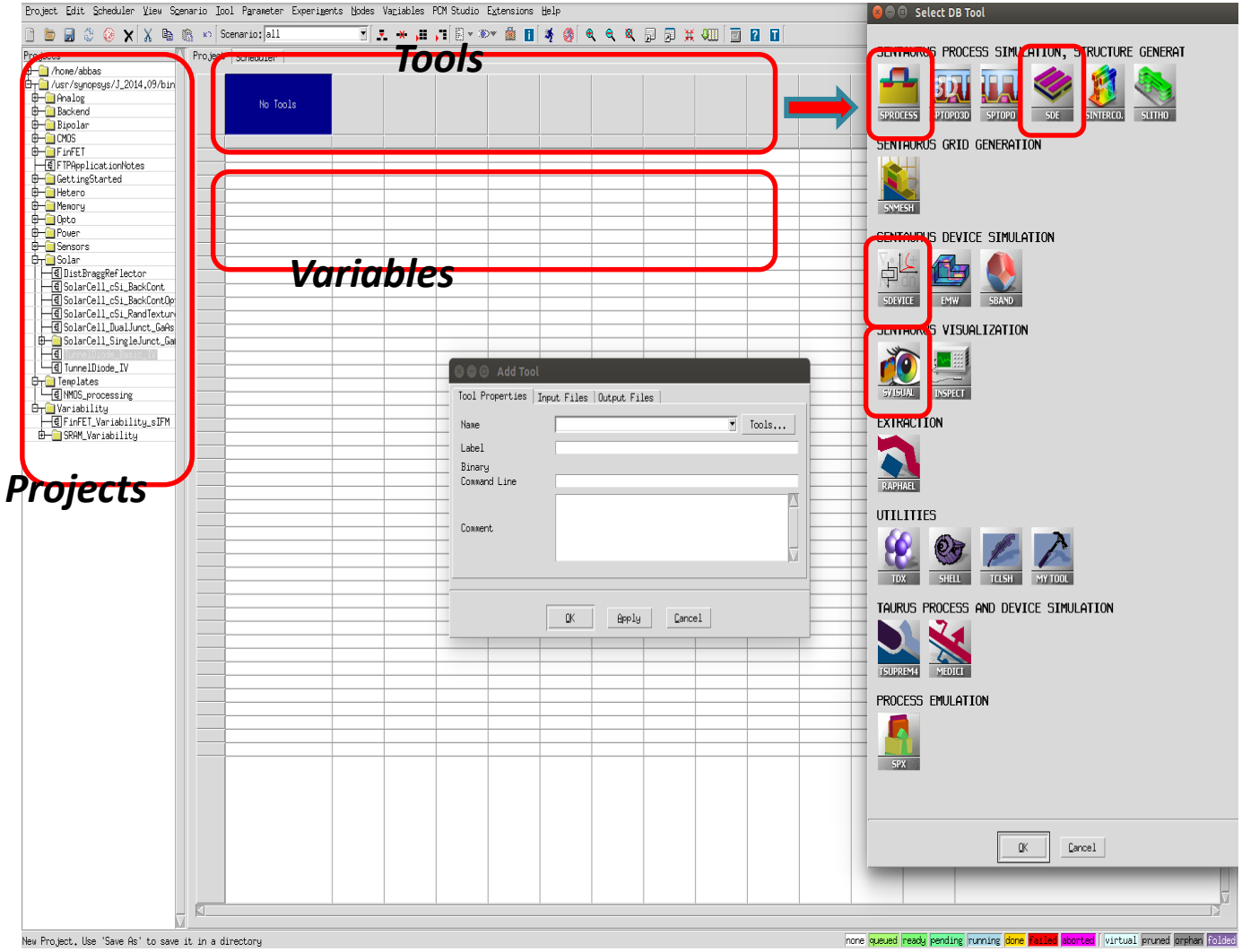
- Introduction to Synopsys simulation programs
- Numerical simulation of semiconductor resistive structures
- Getting started:
  - Start PC with **linux** OS
  - Download this guide and the script files from the course website:

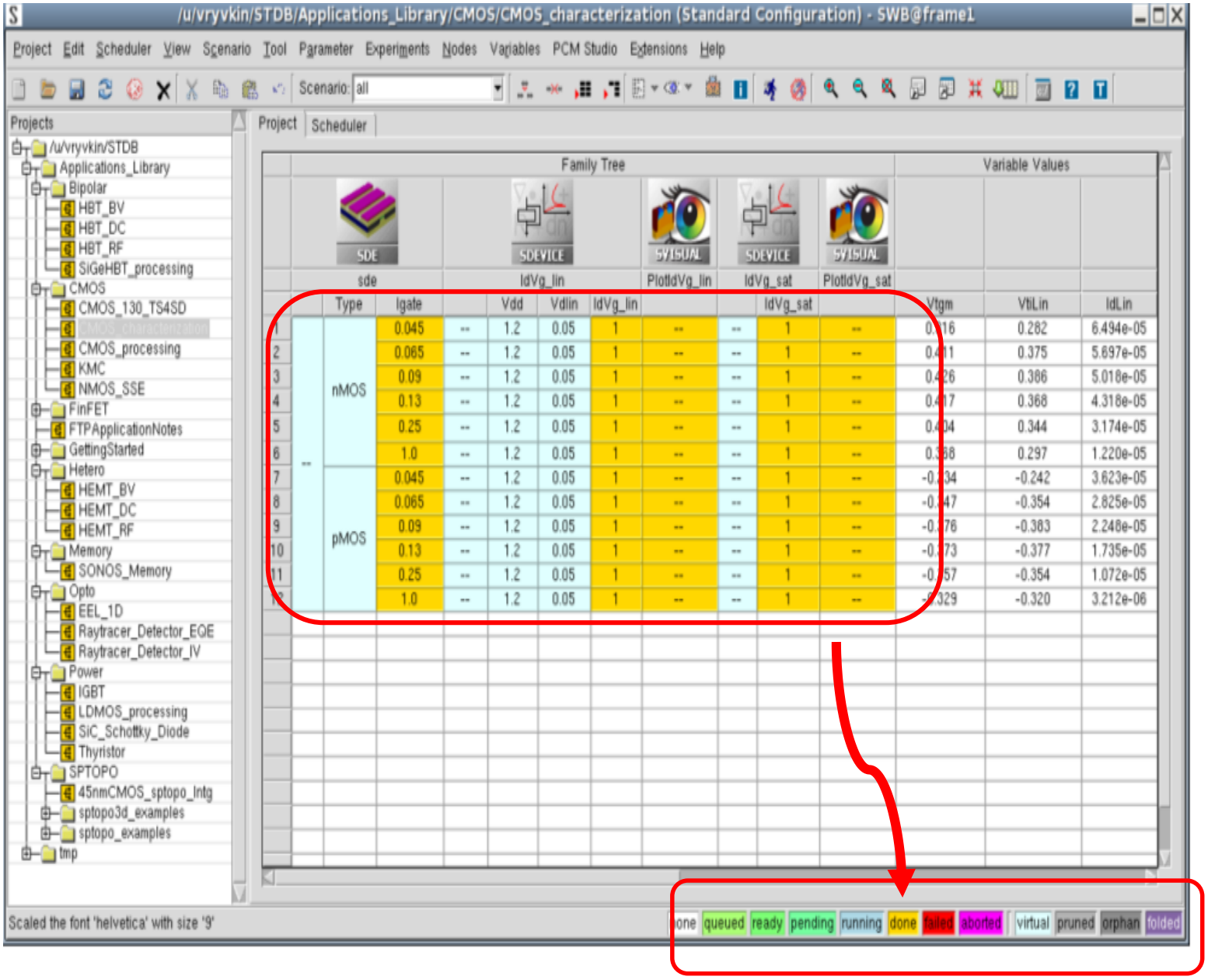
    http://webapps.unitn.it/geco/
  - Open a terminal/console

Part 1: SWB

Sentaurus Workbench (SWB)

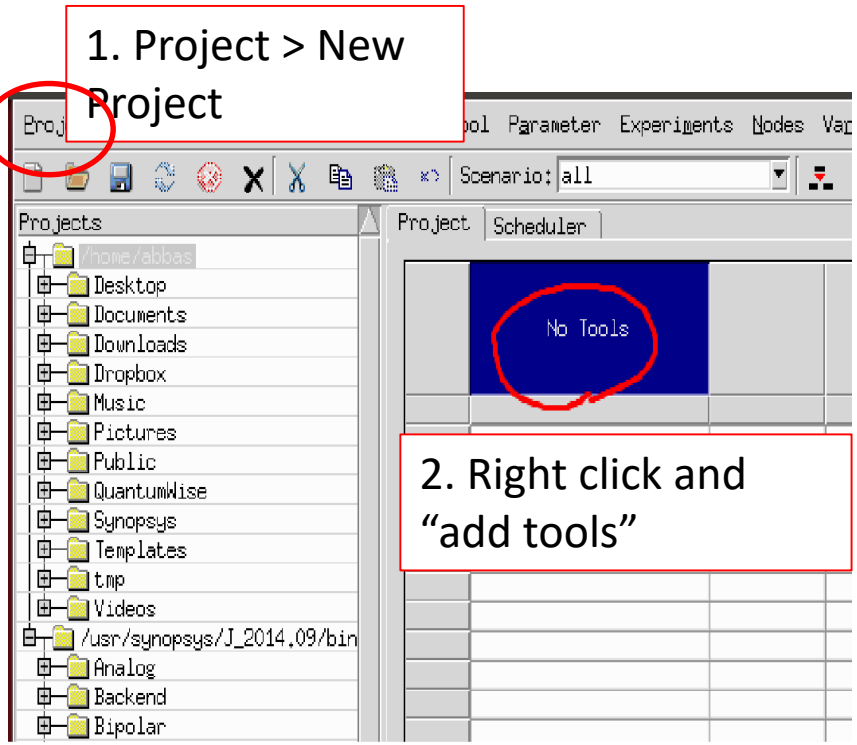
To launch SWB: type command “swb &” at the terminal

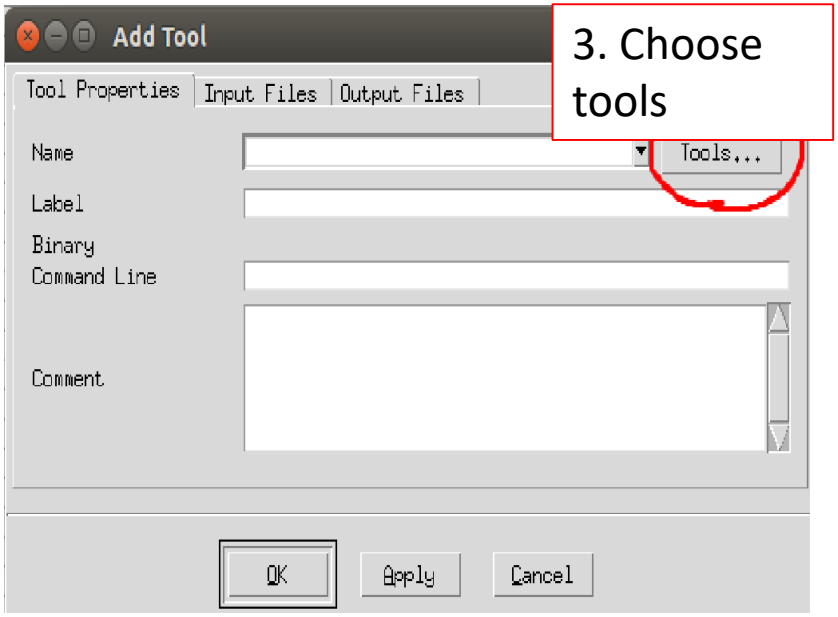


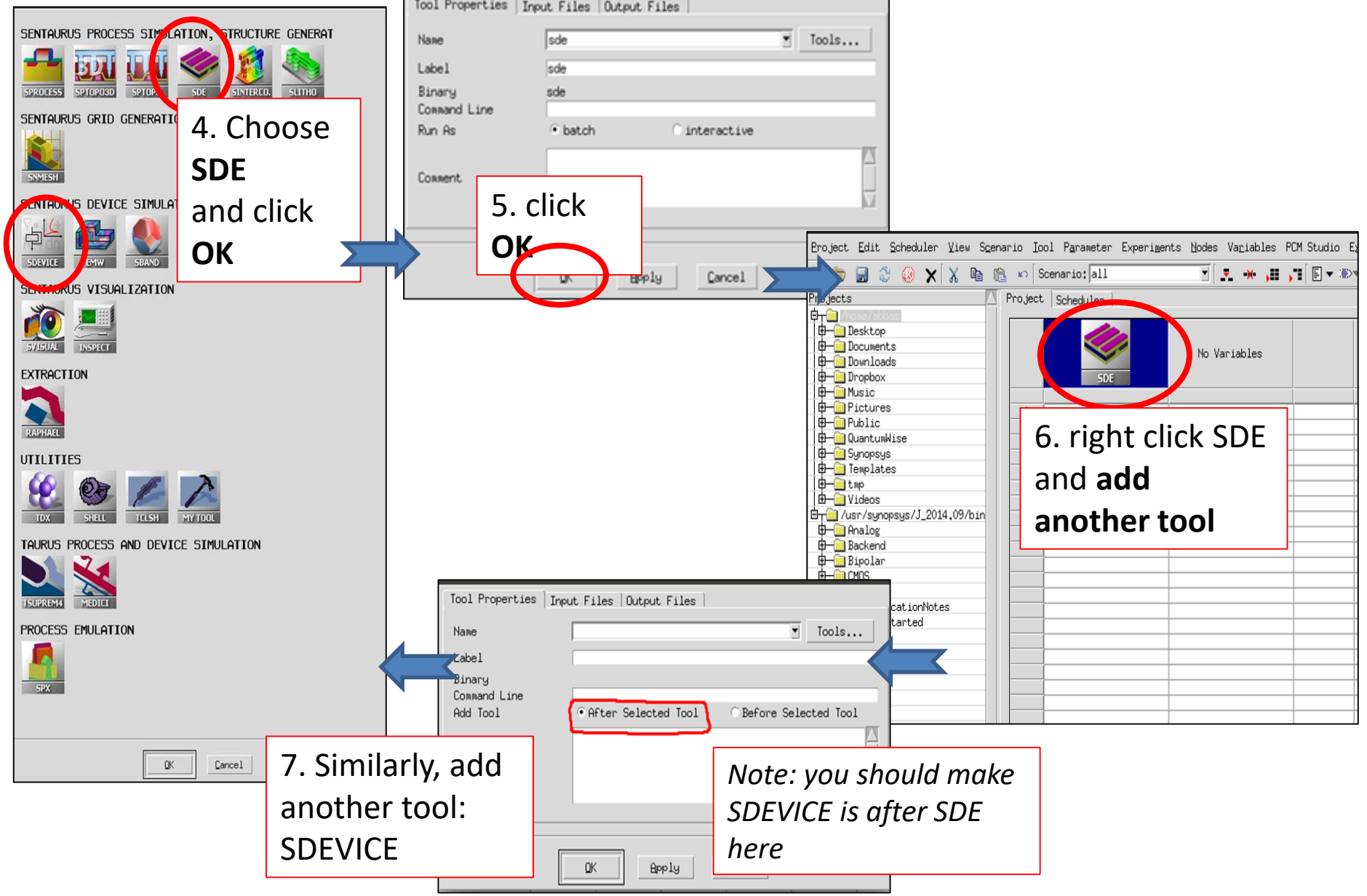


Different color indicates different status of the node

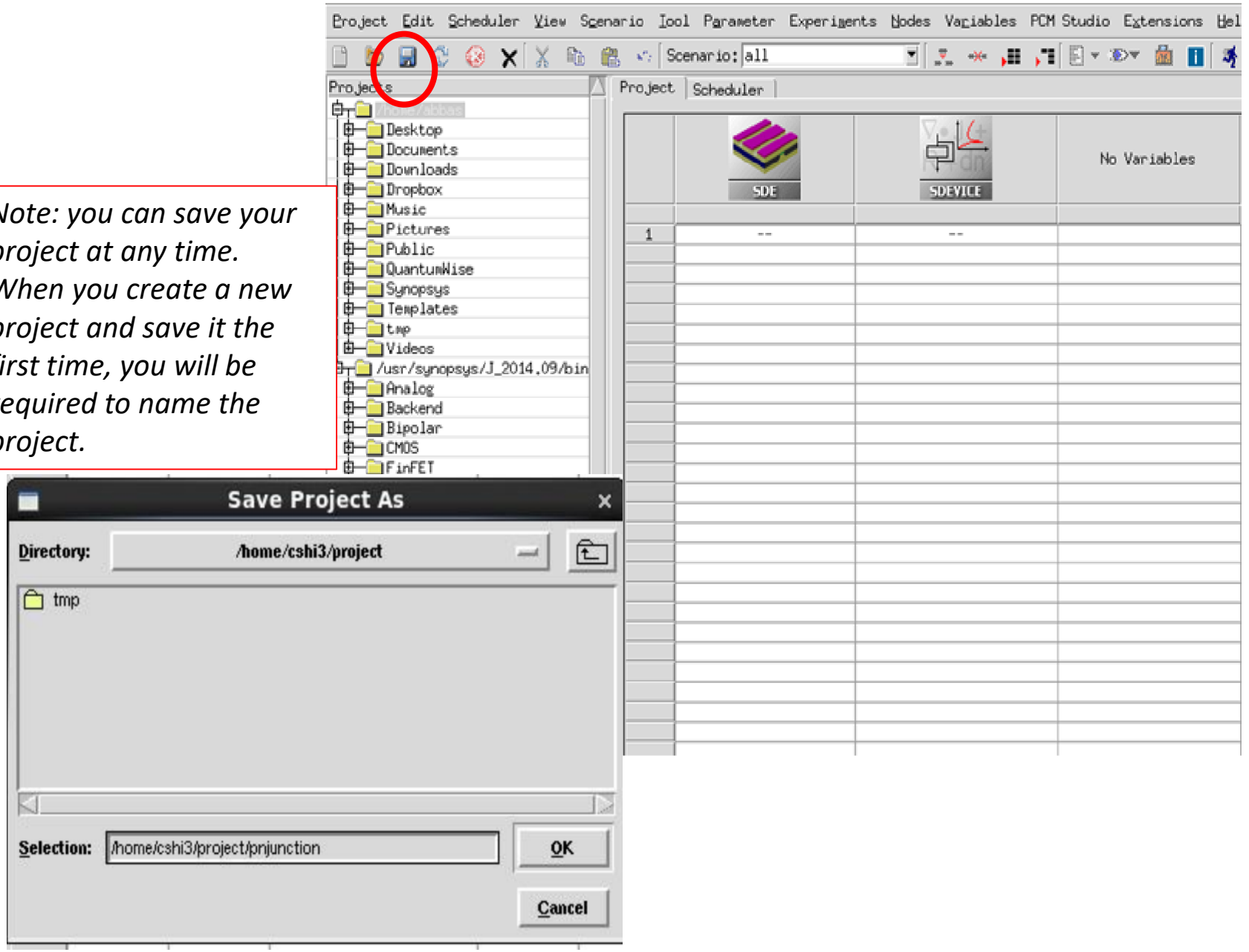
Create New Project and Add tools





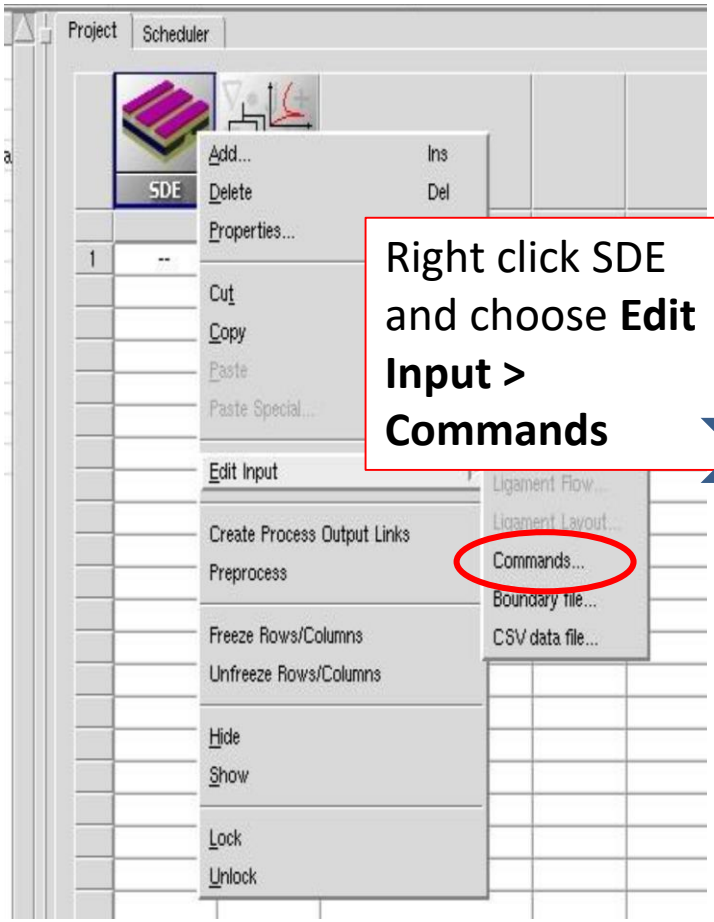

SENTAURUS PROCESS SIMULATION, STRUCTURE GENERAT
SPROCESS
SPTOPO3D
SDE
SINTERCO.
SLITHO
SENTAURUS GRID GENERATI
SNMESH
SENTAURUS DEVICE SIMULAT
SDEVICE
EMW
SBAND
SENTAURUS VISUALIZATION
SVISUAL
INSPECT
EXTRACTION
RAPHAEL
UTILITIES
TDX
SHELL
TCLSH
MY TOOL
TAURUS PROCESS AND DEVICE SIMULATION
TSUPREM4
MEDICI
PROCESS EMULATION
SPX
OK
Cancel
4. Choose SDE and click OK
Add Tool
Tool Properties
Input Files
Output Files
Name
sde
Tools...
Label
sde
Binary
sde
Command Line
Run As
batch
interactive
Comment
OK
Apply
Cancel
5. click OK
Project Edit Scheduler View Scenario Tool Parameter Experiments Nodes Variables PCM Studio
Scenario: all
Projects
Project
Scheduler
Desktop
Documents
Downloads
Dropbox
Music
Pictures
Public
QuantumWise
Synopsys
Templates
tmp
Videos
/usr/synopsys/J_2014.09/bin
Analog
Backend
Bipolar
CMOS
SDE
No Variables
6. right click SDE and add another tool
Tool Properties
Input Files
Output Files
Name
Tools...
Label
Binary
Command Line
Add Tool
After Selected Tool
Before Selected Tool
OK
Apply
7. Similarly, add another tool: SDEVICE
Note: you should make SDEVICE is after SDE here

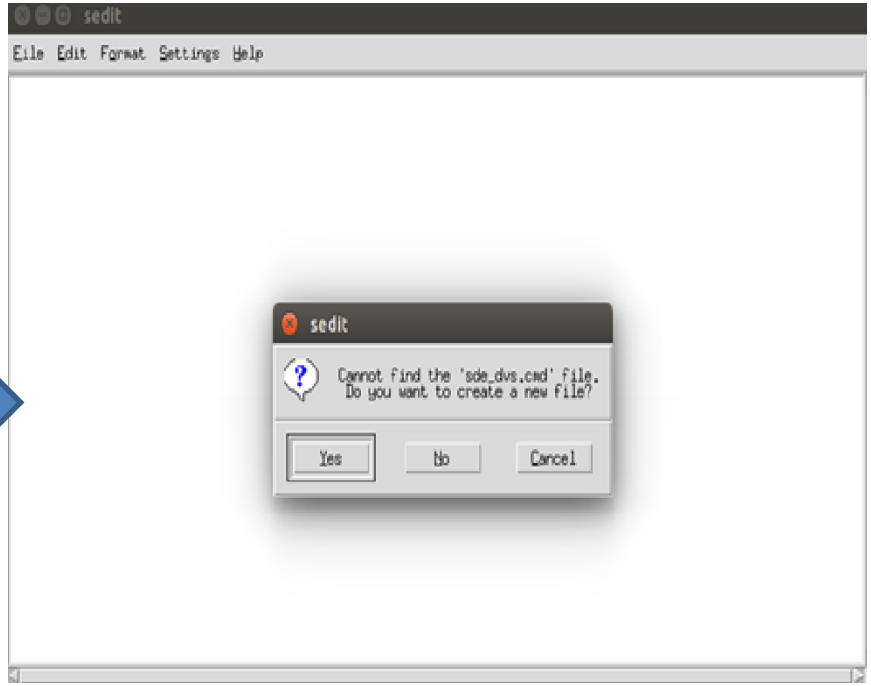
Note: you can save your project at any time. When you create a new project and save it the first time, you will be required to name the project.



Part 2: SDE

Sentaurus Device Editor (SDE): using the command interface





```
;;
;; Example 1: silicon resistance
;;

;; Define geometry
(sdegeo:create-rectangle (position 0 0 0 )  (position 100 100 0 ) "Silicon" "substrate" )

;; Defines contact names and placements
(sdegeo:define-contact-set "C1" 4  (color:rgb 1 0 0 ) "##" )
(sdegeo:set-current-contact-set "C1")
(sdegeo:set-contact-edges (list (car (find-edge-id (position 1 0 0)))) "C1")
(sdegeo:define-contact-set "C2" 4  (color:rgb 0 1 0 ) "##" )
(sdegeo:set-current-contact-set "C2")
(sdegeo:set-contact-edges (list (car (find-edge-id (position 1 100 0)))) "C2")

;; Defines the doping profiles
(sdedr:define-constant-profile "Substrate_prof_def" "BoronActiveConcentration" 1e15)
(sdedr:define-constant-profile-region "Substrate_prof_plac" "Substrate_prof_def"
"substrate")

;; Defines the mesh discretization rules
(sdedr:define-refeval-window "Global_ref_win" "Rectangle"  (position 0 0 0) (position 100
100 0))
(sdedr:define-refinement-size "Global_ref_def" 5 2 0 5 2 0 )
(sdedr:define-refinement-placement "Global_ref_plac" "Global_ref_def" "Global_ref_win" )


; saves the model file and the mesh file
(sde:save-model "p@node@")
(sde:build-mesh "snmesh" "-a -c boxmethod" "n@node@")
```

Create a square silicon region

Define the contacts

Define the doping

Define the mesh

Save the file and build the mesh

Part 3: SDEVICE

```
Math      {
      Extrapolate
      Derivatives
      Iterations=30
}

Electrode {
      { Name="C1" Voltage=0}
      { Name="C2" Voltage=0}
}

File      {
      grid    = "@tdr@"
      current = "@plot@"
      plot    = "@tdrdat@"
}

Physics{
            Temperature = 300
}
```

MATH SECTION
About calculation issue

ELECTRODE SECTION

FILE SECTION
The input file(from SDE)
Sometimes you may need parameter files.
Output file
XXX.tdr------ Device figure
XXX.plt------ Plot file
XXX.log, XXX.out----log files

PHYSICS SECTION
What models will be used

Right Click the SDEVICE tool, Edit Input > Command
Paste the command files.

```
Plot      {
      eDensity hDensity
      TotalCurrent/Vector
      eCurrent/Vector hCurrent/Vector
      ElectricField/Vector Potential
      Doping
}


Solve {
      Poisson
      Coupled{ Poisson Electron Hole }
      Quasistationary(
            InitialStep=0.1  MinStep=1e-6
            MaxStep=0.1
            Goal{ Name="C1" Voltage=1 }
      ) { Coupled { Poisson Electron Hole} }
}
```

Plot Section
What parameter will be showed in the XXX.tdr output file

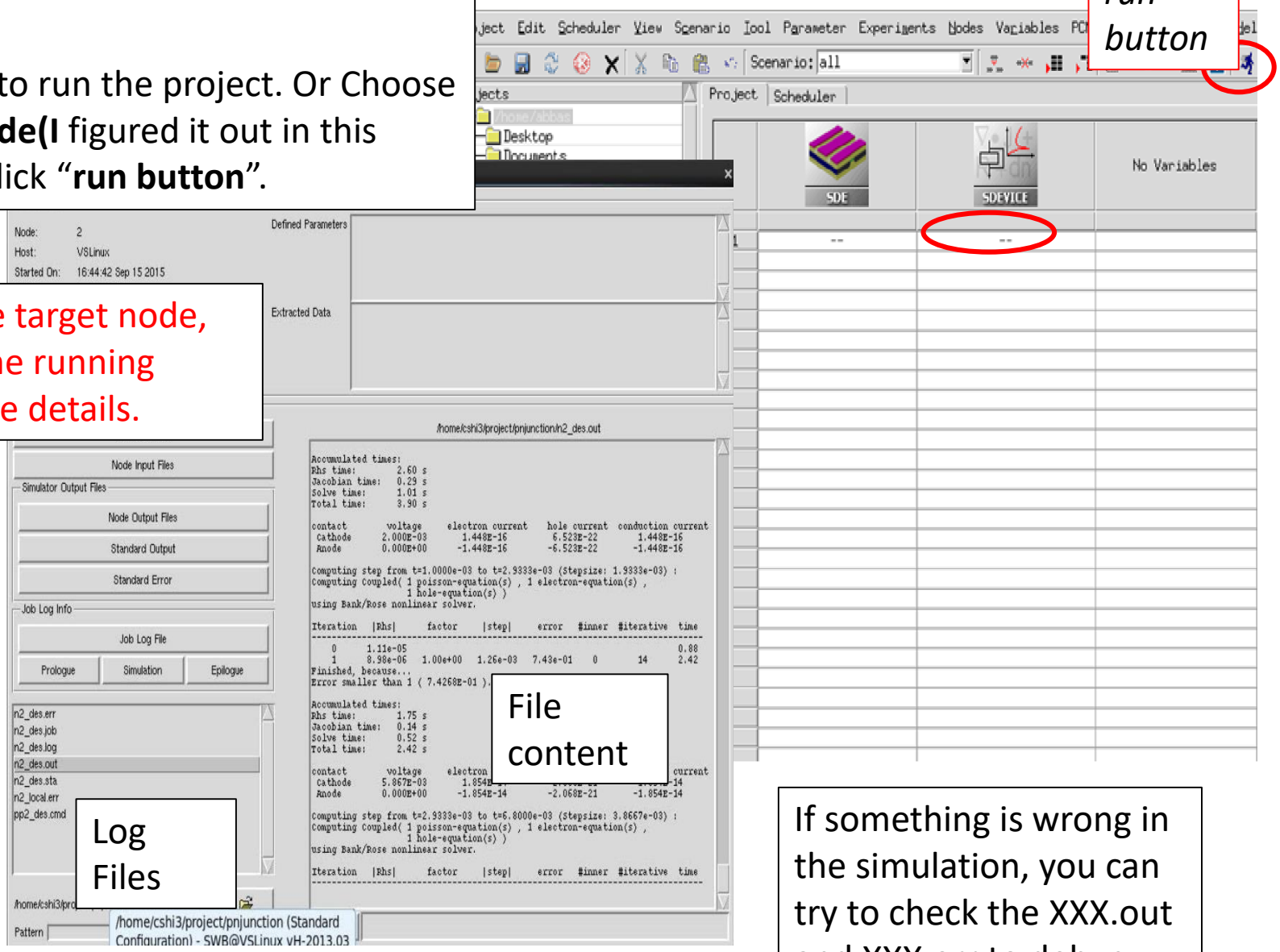
Solve Section
How to simulate the device

When you finish it, save the command file and close it.

Use “**Ctrl+R**” to run the project. Or Choose the **target node(I** figured it out in this figure), and click “**run button**”.

run button

Double click the target node, you can track the running status with more details.



If something is wrong in the simulation, you can try to check the XXX.out and XXX.err to debug.

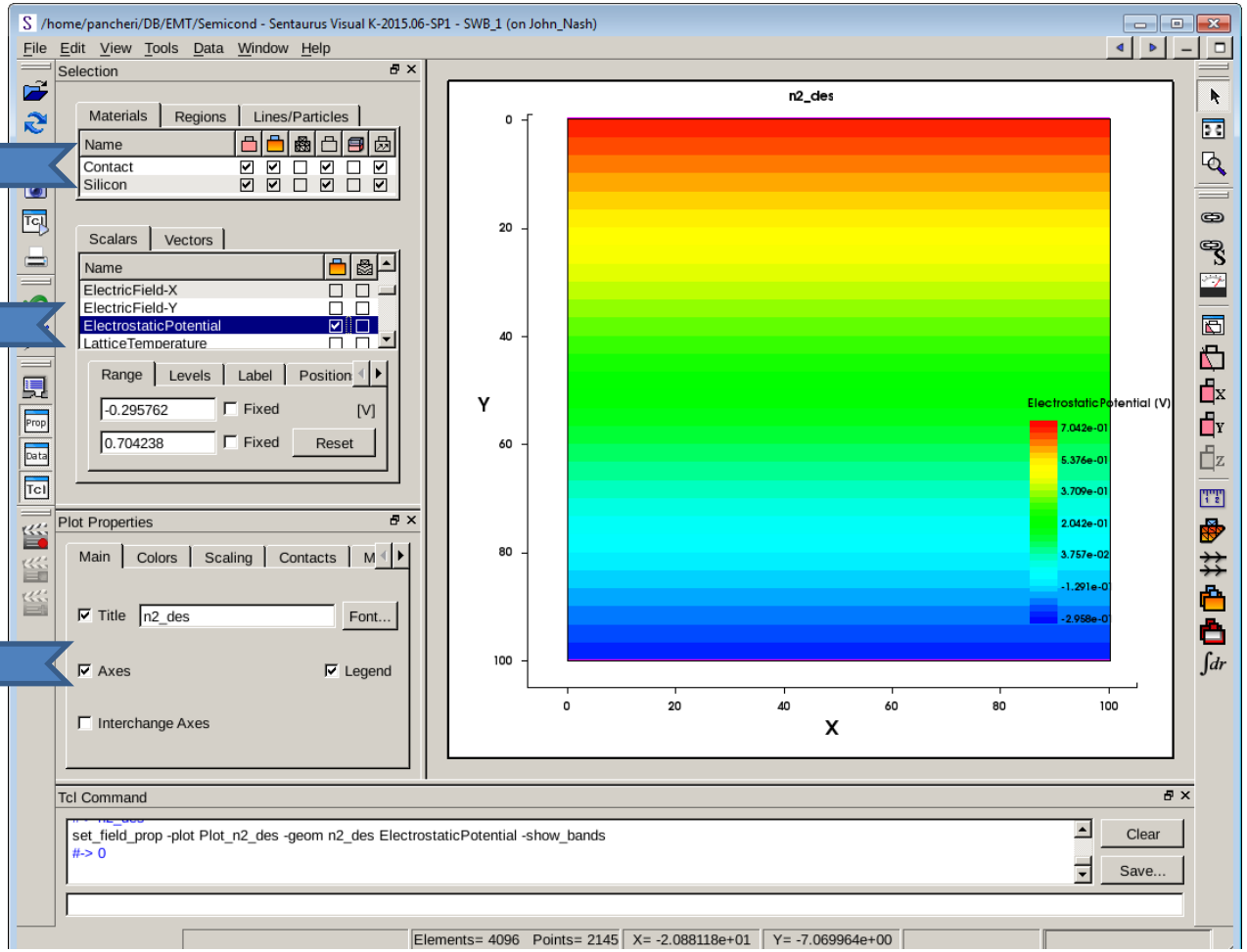
Part 4: SVISUAL

XXX.tdr output file:
Show the device figure.

Choose different region or contacts or material to show

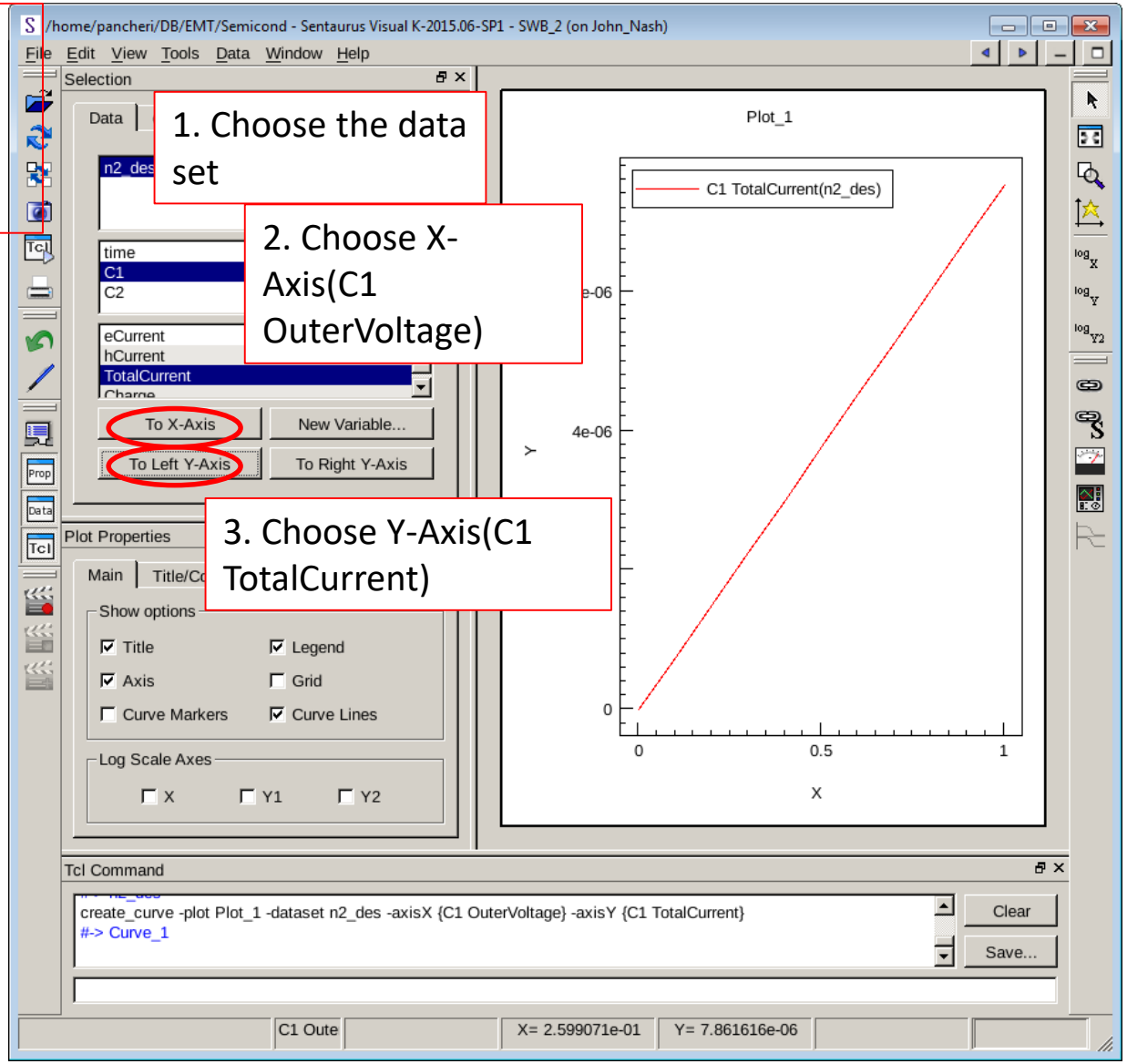
Choose what parameter you'd like to see(you have to define them in Physic Section in SDEVICE code as we mentioned above)

The Plot Properties



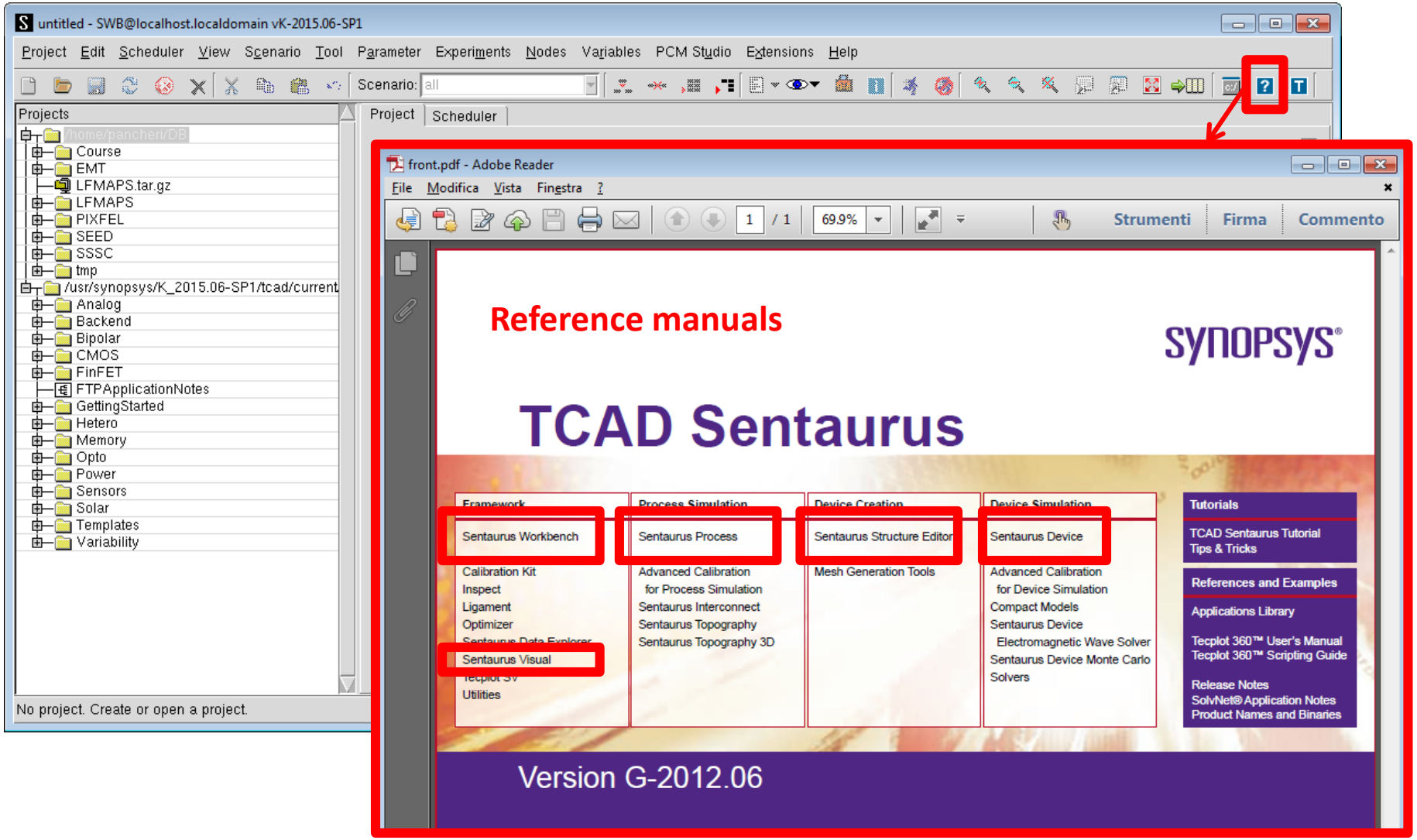
XXX.plt output file: Show the plot curve.

Notes:
You can only choose one X-Axis value.
But you can choose many Y-Axis to plot several curves in the same graph



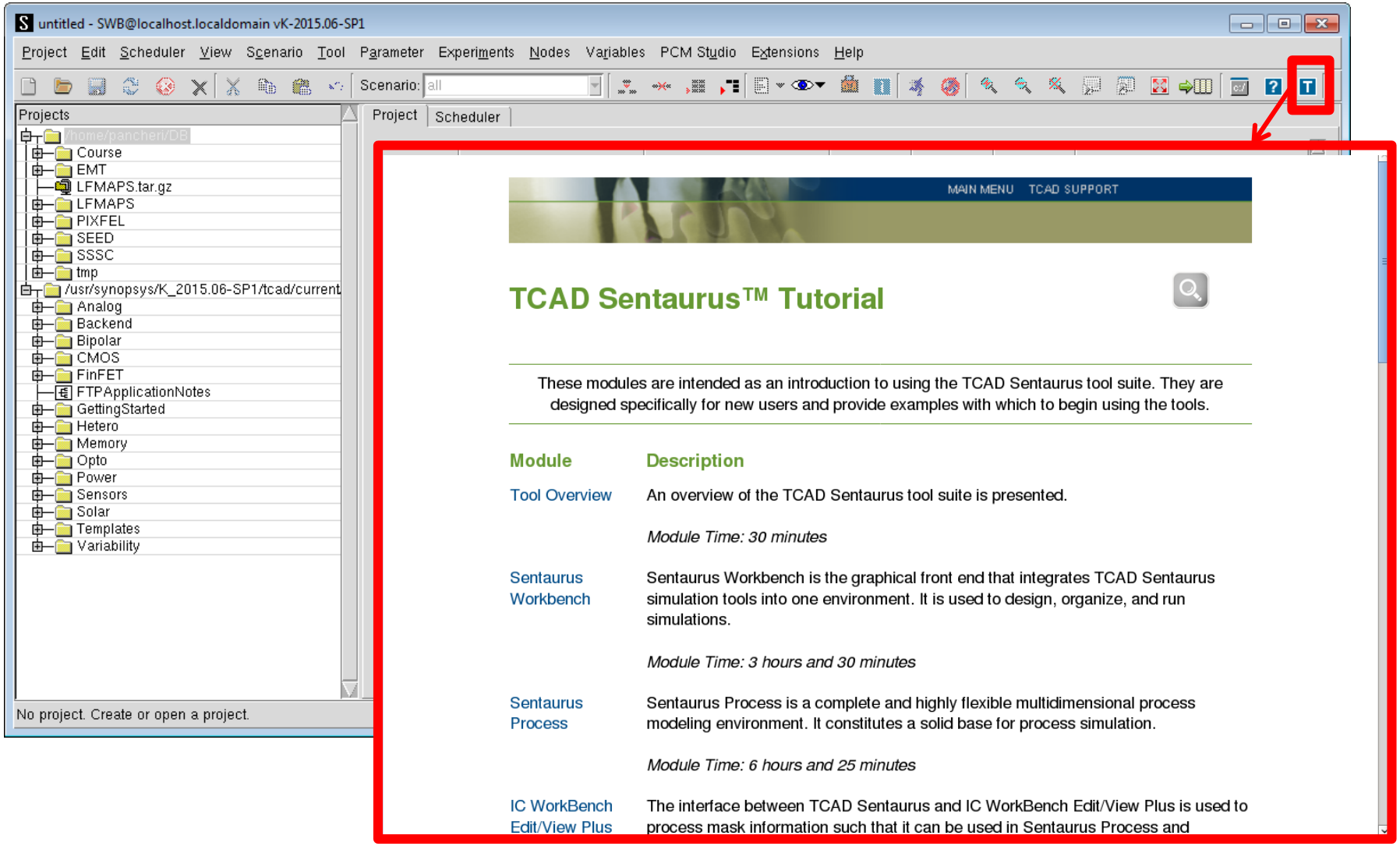
Where to get help

In sentaurus workbench: open reference manuals



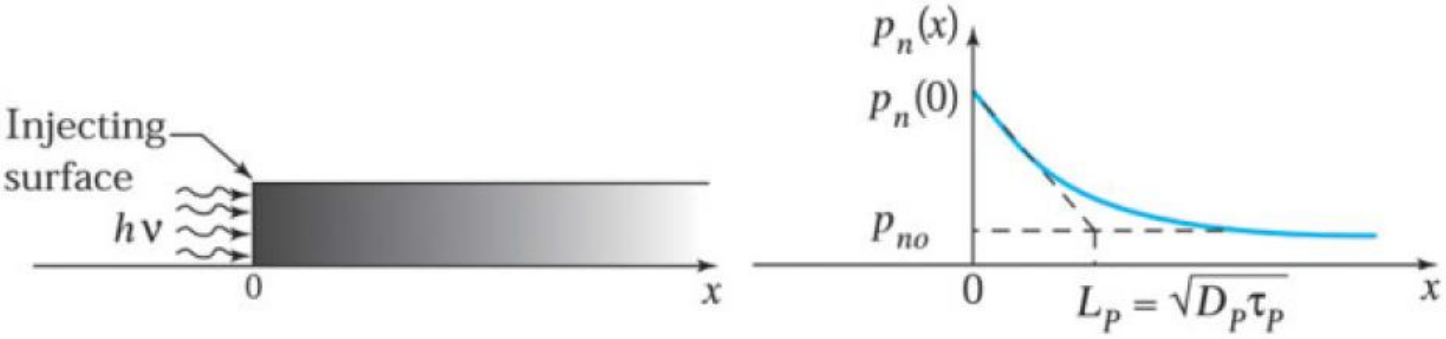
Where to get help

In sentaurus workbench: open tutorial



Example 4.

Minority carrier injection on one side



Using optical generation to inject the carriers.

In the example: p-type silicon doped with $N_A = 10^{14}$ acc./cm^3
Monitoring electron concentration decay

$D_n = 35$ cm^2/s $\tau_n = 10$ μs
$L_n = \text{sqrt}(35 \times 10 \times 10^{-6}) = 187$ μm ➔ Silicon length = 1mm

Example 4. Geometry

Device is divided in 2 regions:
- left: from 0 to 10 um: where optical generation takes place
- right: from 10um to 1mm, no optical generation

```
;; Define geometry

(sdegeo:create-rectangle (position 0 0 0 )  (position 10 1 0 )
"Silicon" "left" )
(sdegeo:create-rectangle (position 10 0 0 ) (position 1000 1 0 )
"Silicon" "right" )
(sdegeo:insert-vertex (position 2 0 0 ))
(sdegeo:insert-vertex (position 998 0 0 ))

;; Define the doping profiles

(sedr:define-constant-profile "Substrate_prof_def"
"BoronActiveConcentration" 1e14)
(sedr:define-constant-profile-region "leftSubstrate_prof_plac"
"Substrate_prof_def" "left")
(sedr:define-constant-profile-region "rightSubstrate_prof_plac"
"Substrate_prof_def" "right")
```

The two regions have the same doping

Example 4. Command file

```
Physics{
        Temperature = 300
        Recombination(SRH( DopingDep ))
}

Physics (Region = "left") {
       Optics (
           OpticalGeneration (SetConstant (Value = 1e18))
       )
}

Plot    {
        eDensity hDensity
        TotalCurrent/Vector eCurrent/Vector hCurrent/Vector
        ElectricField/Vector Potential
        eLifetime hLifetime SRH
        Doping
}

Solve {
        Poisson
        Coupled{ Poisson Electron Hole }
}
```

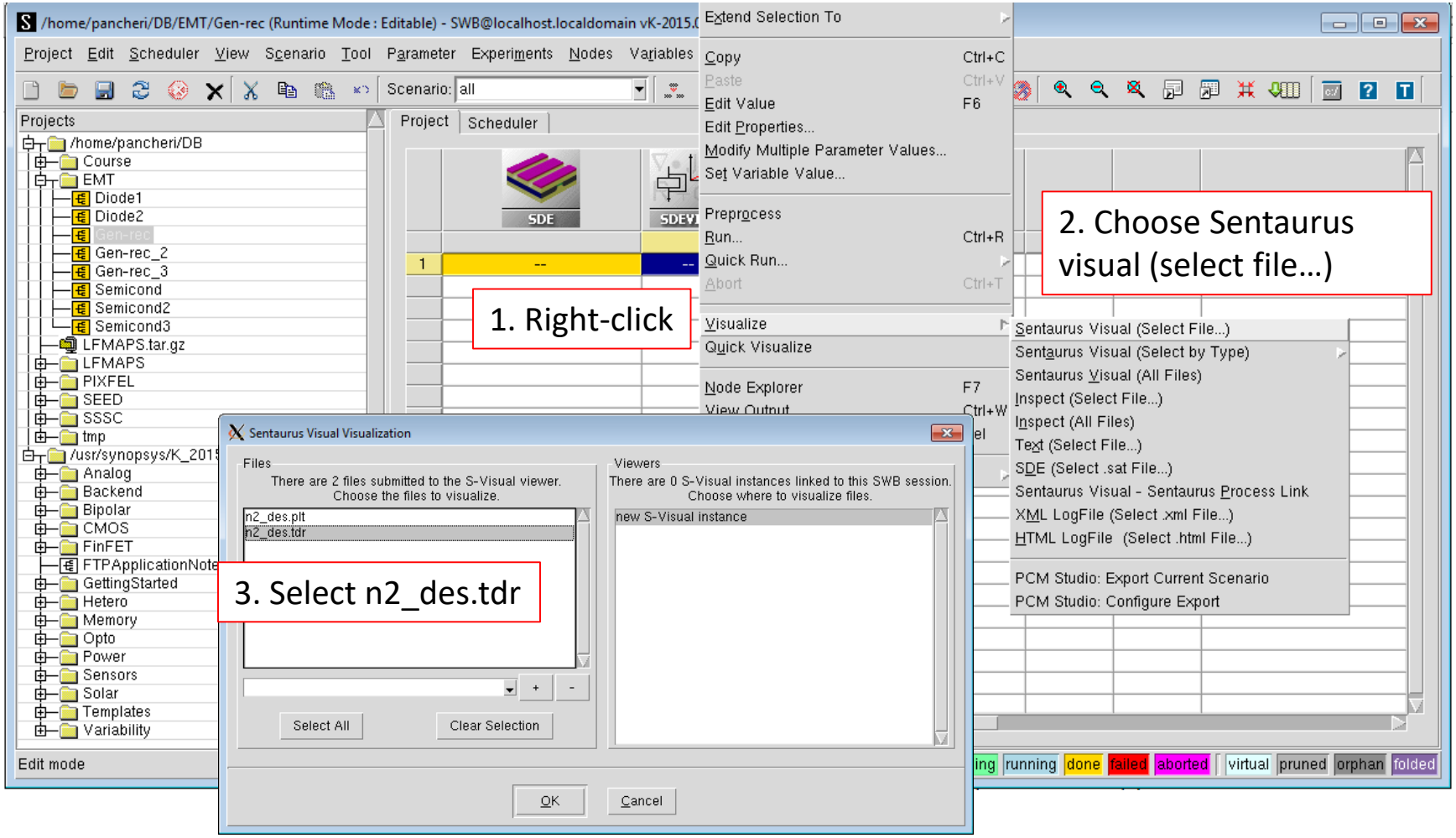
Includes SRH model (standard lifetimes expressed by Scharfetter equation)

Optical generation activated in the left region

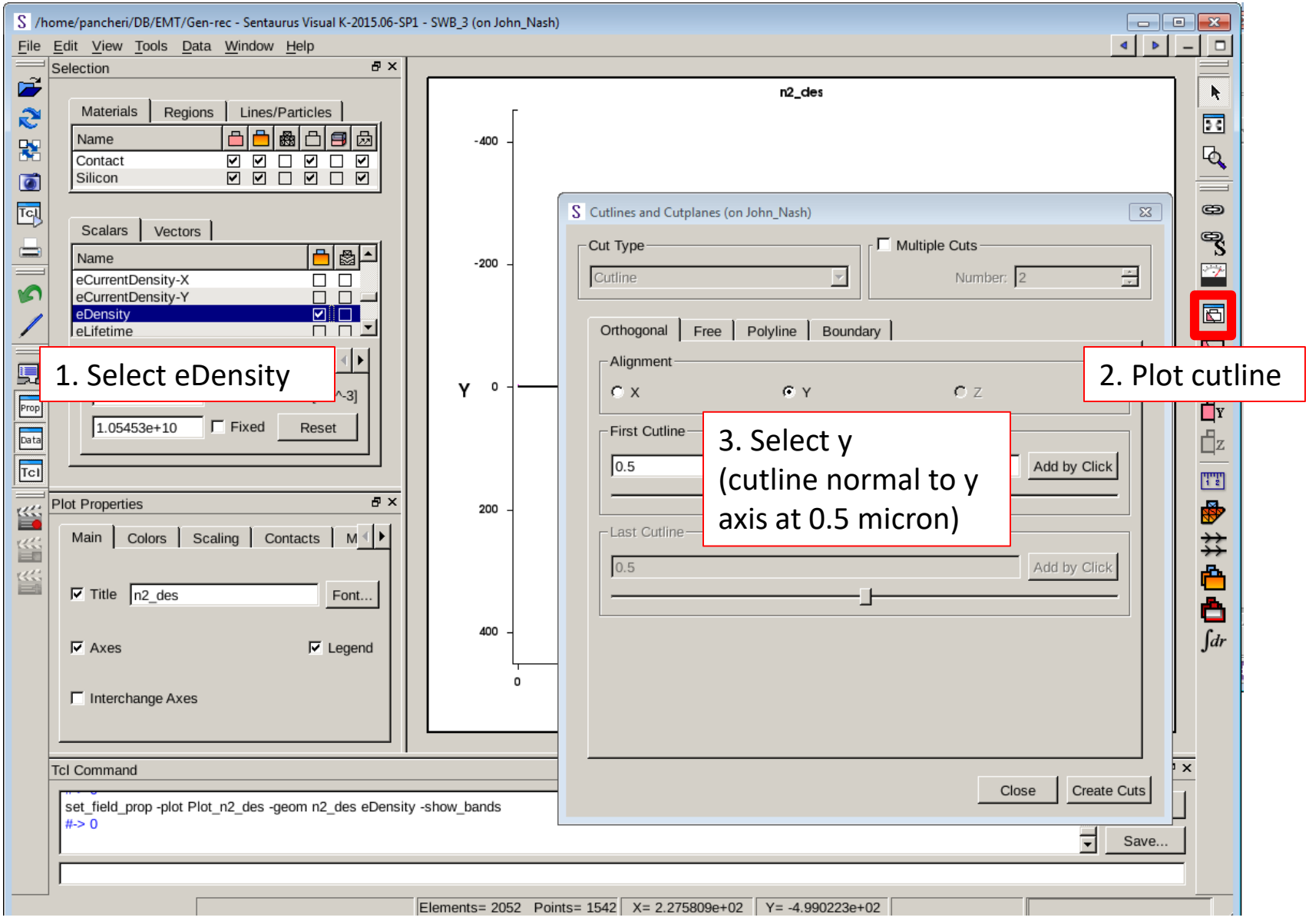
Plots also lifetime and SRH recombination

Steady-state simulation

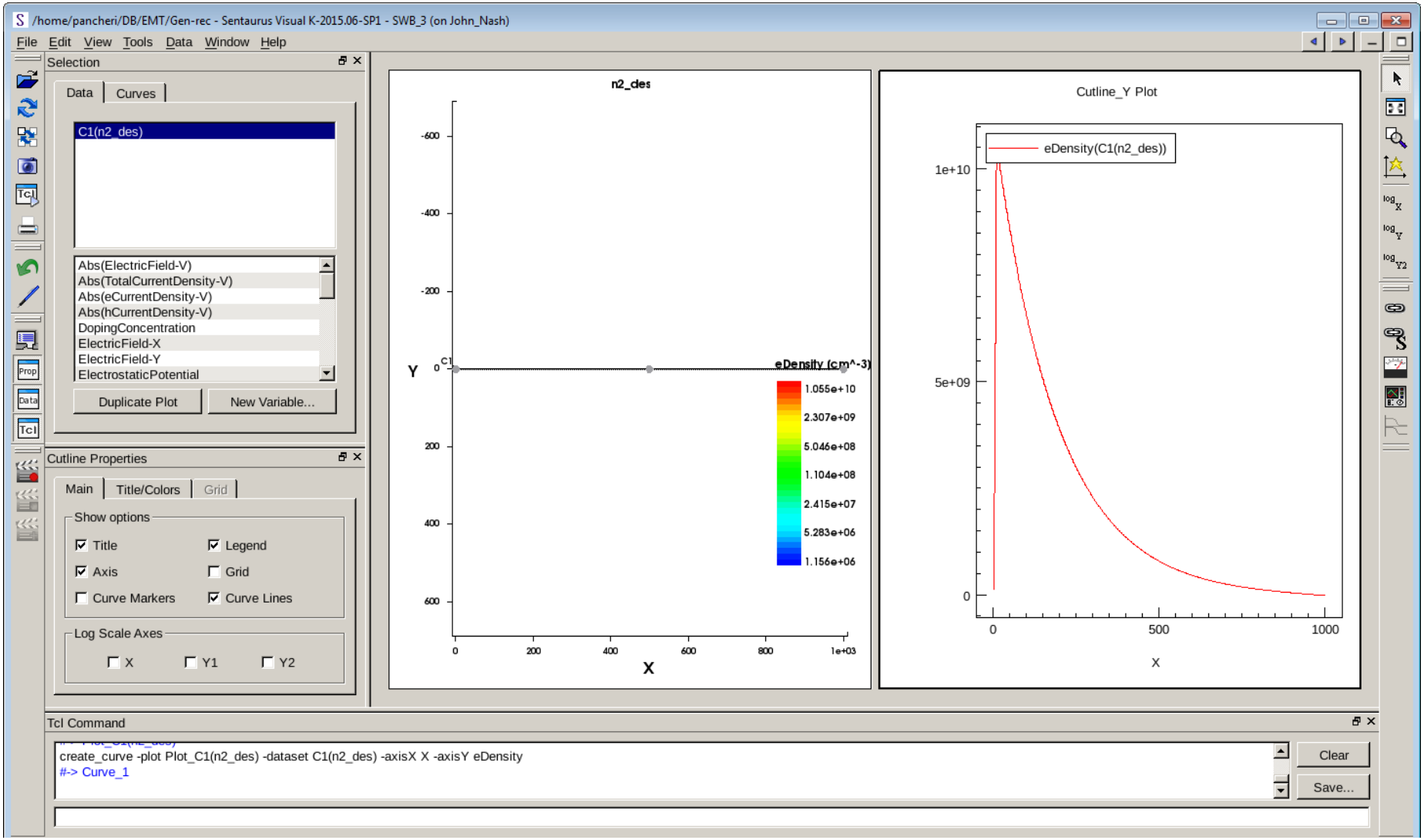
Plotting results



Plotting results: svisual

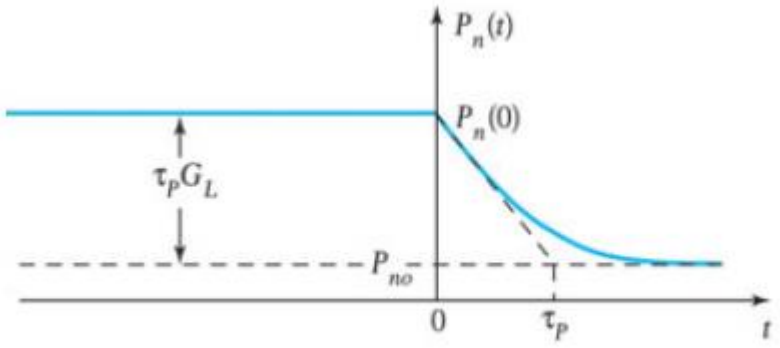


Plotting results: electron concentration



Example 5.

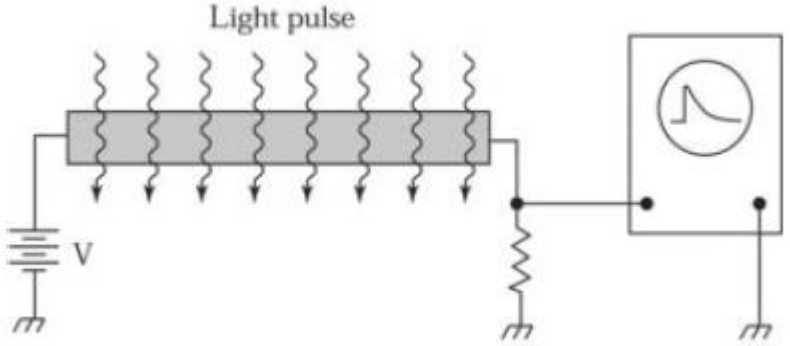
Photoconductivity decay



In the example: p-type silicon doped with $N_A = 10^{14}$ acc./cm^3

Monitoring electron concentration time decay, applying a light pulse

τ_n = 10 μs ➔ Simulation time 100 μs



Example 5. Geometry

Device is divided in 2 regions:
- left: from 0 to 10 um: where optical generation takes place
- right: from 10um to 1mm, no optical generation

```
;; Define geometry

(sdegeo:create-rectangle (position 0 0 0 )  (position 10 1 0 )
"Silicon" "left" )
(sdegeo:create-rectangle (position 10 0 0 ) (position 1000 1 0 )
"Silicon" "right" )
(sdegeo:insert-vertex (position 2 0 0 ))
(sdegeo:insert-vertex (position 998 0 0 ))

;; Define the doping profiles

(sedr:define-constant-profile "Substrate_prof_def"
"BoronActiveConcentration" 1e14)
(sedr:define-constant-profile-region "leftSubstrate_prof_plac"
"Substrate_prof_def" "left")
(sedr:define-constant-profile-region "rightSubstrate_prof_plac"
"Substrate_prof_def" "right")
```

The two regions have the same doping

Example 5. Command file 1

```
Solve {
         Poisson
         Coupled{ Poisson Electron Hole }

        Quasistationary(
                 InitialStep=0.1   MinStep=1e-6 MaxStep=0.1
                          Goal{ Name="C1" Voltage=0.1 }
         ) { Coupled { Poisson Electron Hole} }
        Save(FilePrefix="bias01V")
}
```

Steady state simulation

Saves a state file at the end of the simulation

Example 5. Command file 2

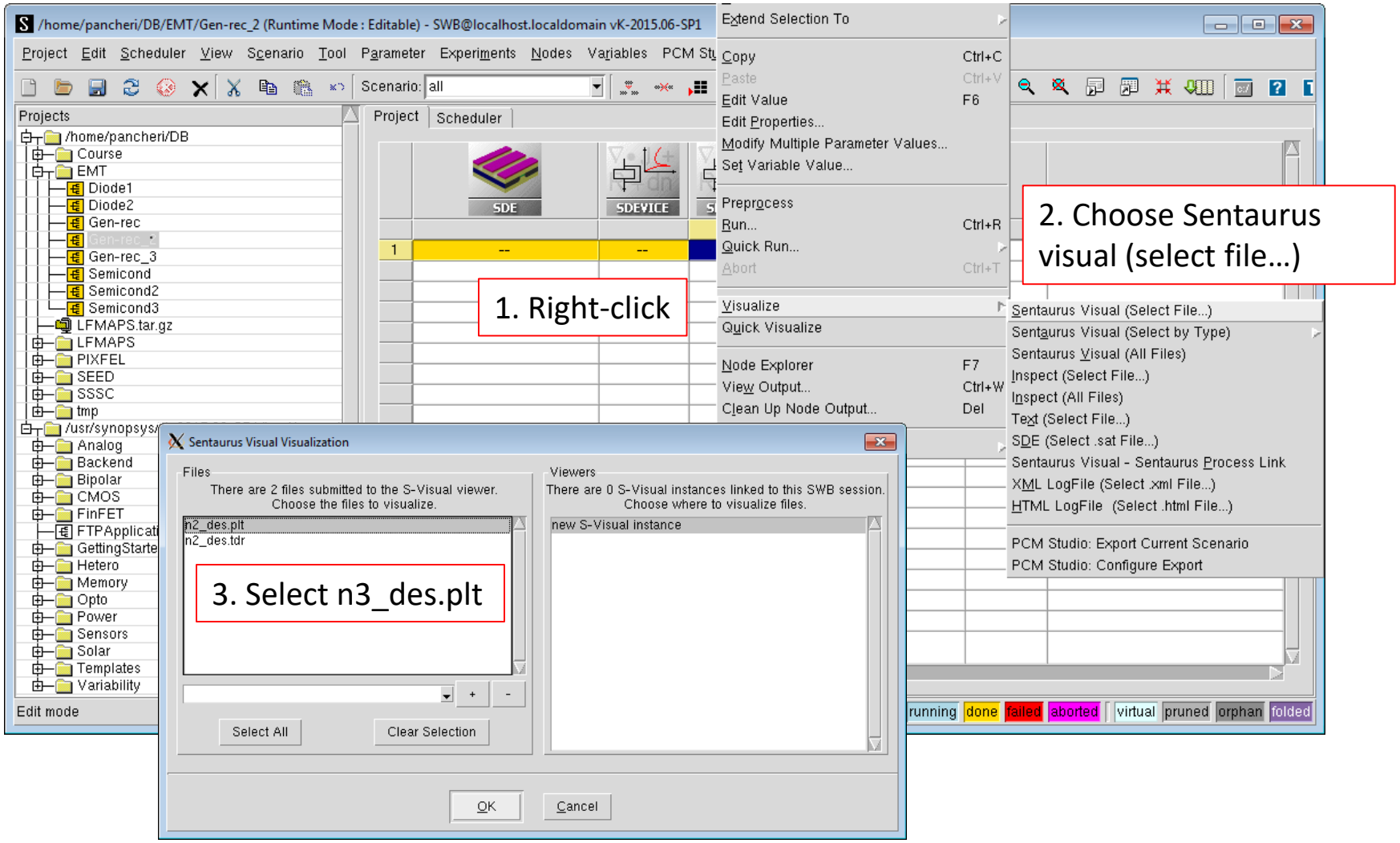
```
Physics{
        Temperature = 300
        Recombination(SRH( DopingDep ))

        Optics (
            OpticalGeneration (
                SetConstant (Value = 1e18)
                TimeDependence (
                    WaveTime = (10e-6, 50e-6)
                    WaveTSigma = 1e-9
                )
            )
        )
}
Solve {
        Load(FilePrefix="bias01V")
        Transient(
             InitialTime=0.0
             FinalTime=100e-6
             InitialStep=0.2e-6
             MaxStep=0.2e-6
             MinStep=1e-9
             Increment=1.5
             Plot { Range = (0 100e-6) Intervals =10}
         ) { Coupled { Poisson Electron Hole} }
}
```

Optical generation defines optical pulse

Transient solution, starting from the Saved state file

Plots 10 intermediate state files

Plotting results



Plotting results: svisual