TRACS update

(TRAnsient Current Simulator)

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17-18 October 2016
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What is TRACS

- TRACS is a fast simulator of transient currents in Silicon. What does “fast” mean here?

  Reduced accuracy:

  Currents calculated using Ramo's theorem

  Radiation damage is parametrized in Neff

  No continuity equations are solved

  Tries to be **efficient,** where possible:

  Laplace and Poisson equations are solved using efficient Finite Element open-source libraries (Fenics).

  Carriers transport only by drift (no diffusion yet). Runge-Kutta-4 method from BOOST libs

- Why **another** “fast simulator”?

At the time of writing the 1st line of code of TRACS:

1) We did not know of the existance of Kdetsim
2) Waveform2 was at the beginning of its development

We still need some marketing...

Oct 2015

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silicon transient current simulator

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Electro thermal transient simulation of silicon carbide power ...
ieeexplore.ieee.org/.../abs_al... Institute of Electrical and Electronics Engineers
by BN Pushpakaran - 2013 - Cited by 1 - Related articles
Electro thermal **transient simulation** of **silicon** carbide power MOSFET ... blocking voltage of 1200V and a rated drain **current** of 1A at 100A cm^{-2} **current** density.

Simulation of Alpha Particle Impact on NP Silicon Junctions
www.inf.ufrgs.br/~... Universidade Federal de Ciências da Saúde de Porto...
Introduction. When a high energy particle hits a PN junction inversely biased, a charge may be collected by the node and a **transient current** of hundred of ...

Silicon Validated Sign-off Accuracy - redhawk features - Ansys
www.ansys.com/.../**Simulation**.../**Silicon**+Validated+Sign-off+Accu... Ansys
image of RedHawk vs. SPICE **transient current simulation** correlation View larger image. ANSYS RedHawk vs. SPICE **transient current simulation** correlation ...

[PDF] arXiv:1407.2761v2 [physics.ins-det] 2 Oct 2014
arxiv.org/pdf/1407.2761 arXiv
by C Scharf - 2014 - Cited by 2 - Related articles
Oct 3, 2014 - The method has been applied successfully for the **simulation** of ...
Keywords: **silicon** pad sensor, **transient current** technique, transfer function, ...

Oct 2016

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Transient Simulation of Silicon Devices and Circuits
dl.acm.org/citation.cfm?id=2300769 Association for Computing Machinery
by RE Bank - 2006 - Cited by 306 - Related articles
Transient Simulation of **Silicon** Devices and Circuits ..... The **current** status of semiconductor device **simulation** at NTT is described. Device **simulators** at NTT are ...

S-Pisces - 2D Silicon Device Simulator - Silvaco
www.silvaco.com/products/vwf/atlas/spisces/spisces_br.html
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Atlas - Device Simulation Framework - Silvaco
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[PDF] Transient Analysis of Silicon Carbide Power MOSFET by Bejoy ...
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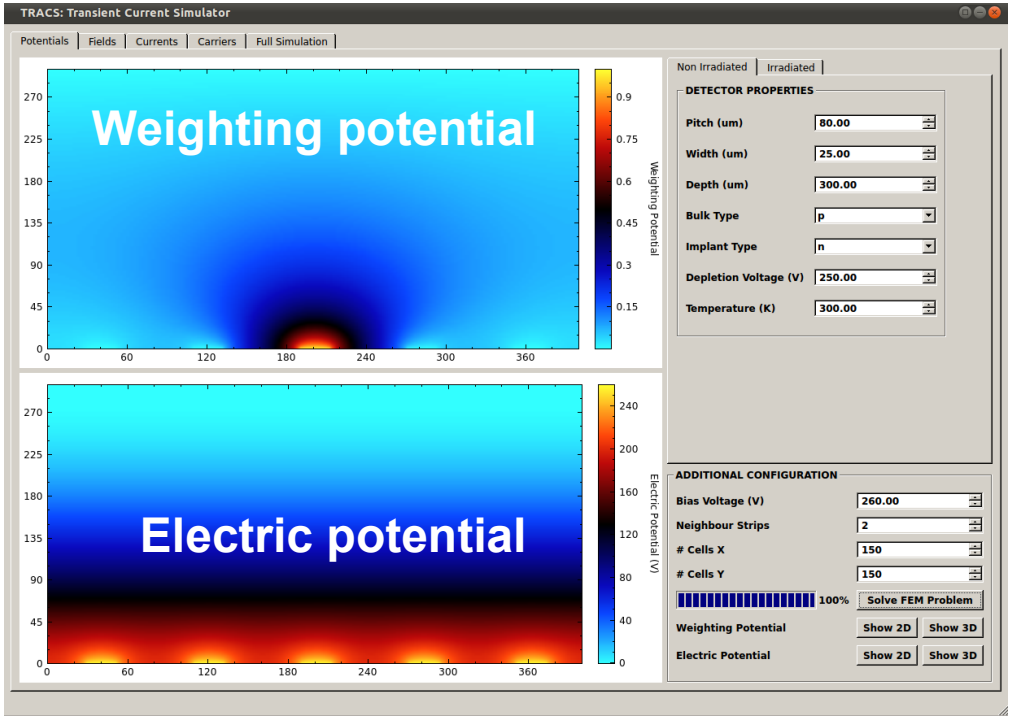
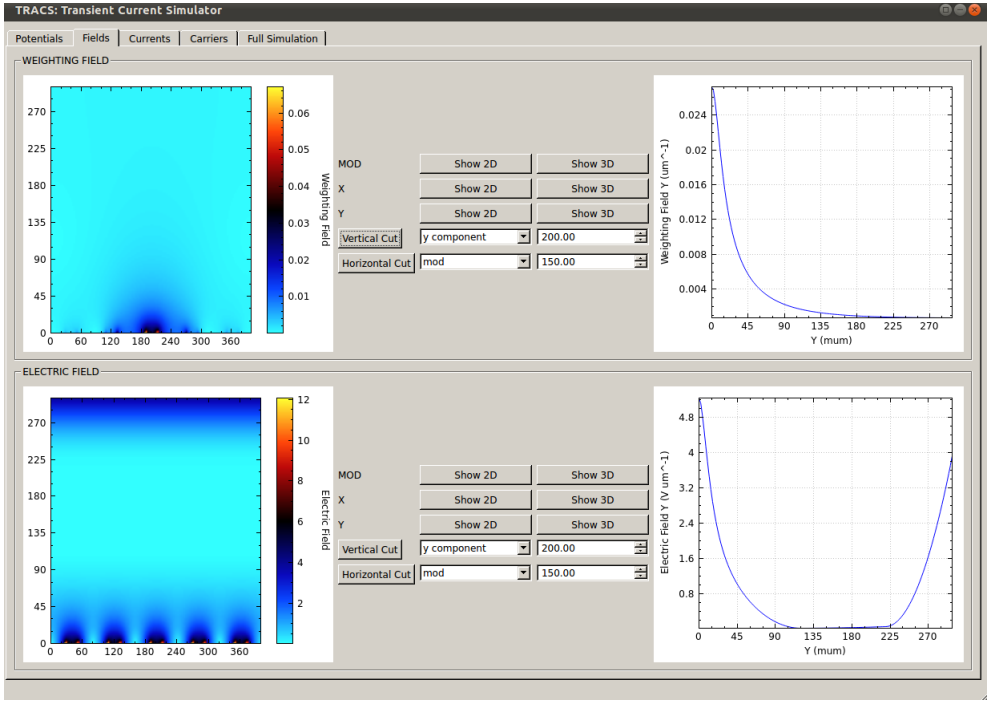
Transient Analysis of **Silicon** Carbide Power MOSFET by. Bejoy Nariampully Pushpakaran, B.Tech .... FACTORS AFFECTING THERMAL **SIMULATION** . ..... 14.3 PEAK **CURRENT** = 5A PULSE WIDTH = 50 µs TAMBIENT = 300K ..... 79.

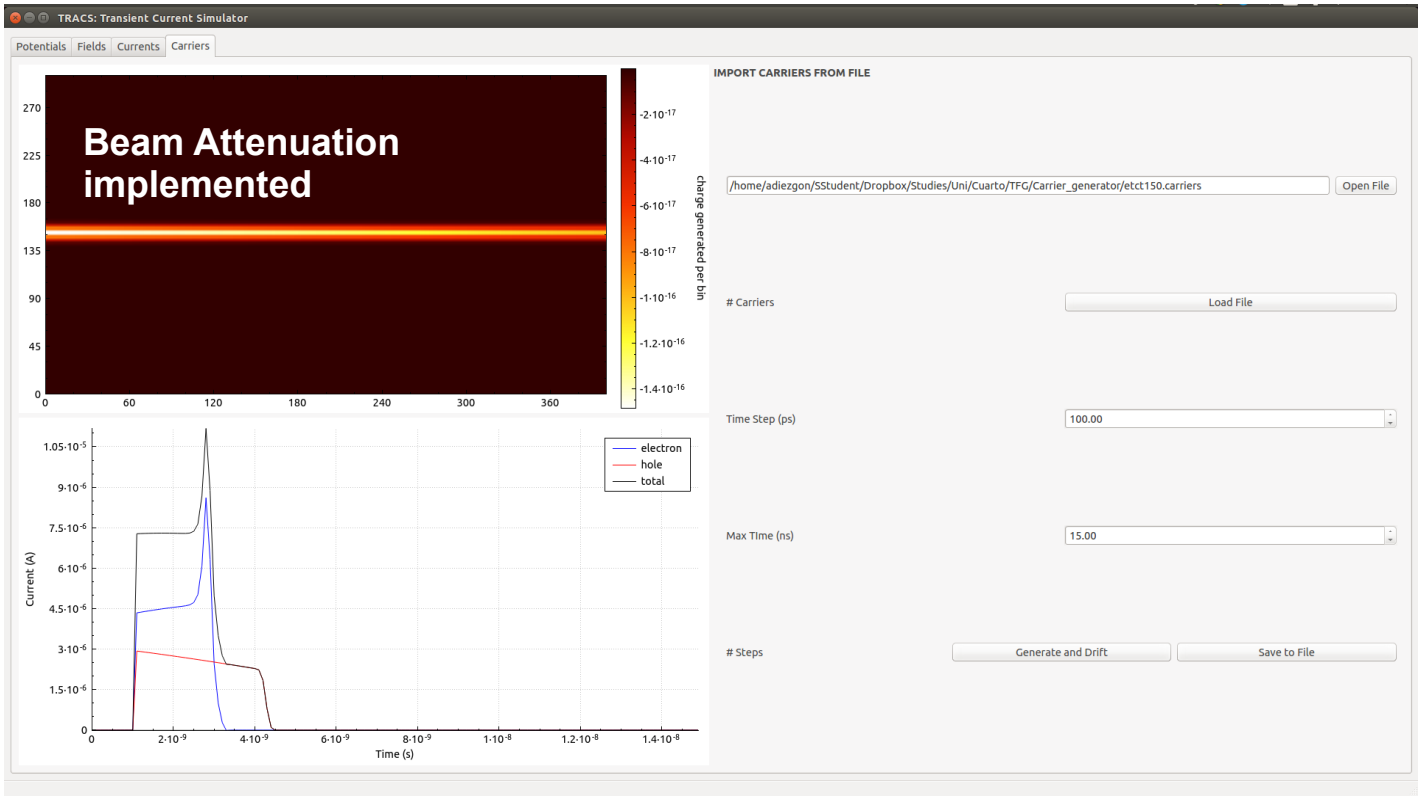
IEEE Xplore Abstract - Electro thermal transient simulation of silicon ...
ieeexplore.ieee.org/.../articleDetails.jsp?... Institute of Electrical and Electronics Engineers
This research focuses on the **transient** performance of N-Channel **Silicon** Carbide ... Each **simulation** was performed using a **current** pulse generated through an ...

Advances in Mathematical Modeling and Simulation of Electrochemical ...
https://books.google.com/books?isbn=1566772044
John William Van Zee, Electrochemical Society. Industrial Electrolysis and Electrochemical Engineering Division, Electrochemical Society. Energy Technology Division - 1998 - Cathodes
TRANSIENT CURRENT MEASUREMENTS ON THE SI-HF SYSTEM AS DIRECT ... the dissolution of **silicon** in fluoride electrolytes causes **current** oscillations ...

Silicon-on-Insulator Technology and Devices X: Proceedings of the ...







TRACS operation modes:

- GUI
- CLI
- Toolkit mode

- But the main goal of TRACS is not only to simulate but to **fit measurements. We want to use TRACS as a parameter extraction tool from measurements**

Edge-TCT/TPA measurement

Typical 300 waveforms, Δz=1 μm
Δt=50 ps, 15 ns window
Several bias voltages

TRACS

[Neff(z), τ] as starting parameters

$$\chi^2 = \sum_{z=0}^{300\,\mu m} \sum_{t=0}^{10\,ns} \left[I_{MEAS}(t, z; V_{bias}) - I_{TRACS}(t, z, N_{eff}(z), \tau; V_{bias}) \right]^2$$

Challenging computer simulation:

An edge-TCT simulation like described above is 45 min in a recent 4 cores machine

Fits are **iterative** processes. Up to 1000 iterations may be needed

We need to **speed** things up, **without** scarifying more physics accuracy

Go parallel

Past, present and future of TRACS

Up to summer of 2016, TRACS was only developed by summer students at the CERN-SSD :

2014: Pablo de Castro, first usable version including GUI and Command Line

2015: Alvaro Diez, **Radiation** damage parametrization (Neff(z), trapping).
First **interface class** for TRACS as a toolkit.

2016: Urban Senica, Parallelization of TRACS using C++11 **multithreading** support

Since september 2016; there is a new **CERN-IT fellow** (Julio Calvo) working full time in TRACS. Goals are:

1) Ease TRACS **standalone** installation. **Done**! Just copy/paste commands in linux shell.
https://github.com/JulesDoc/Tracs/

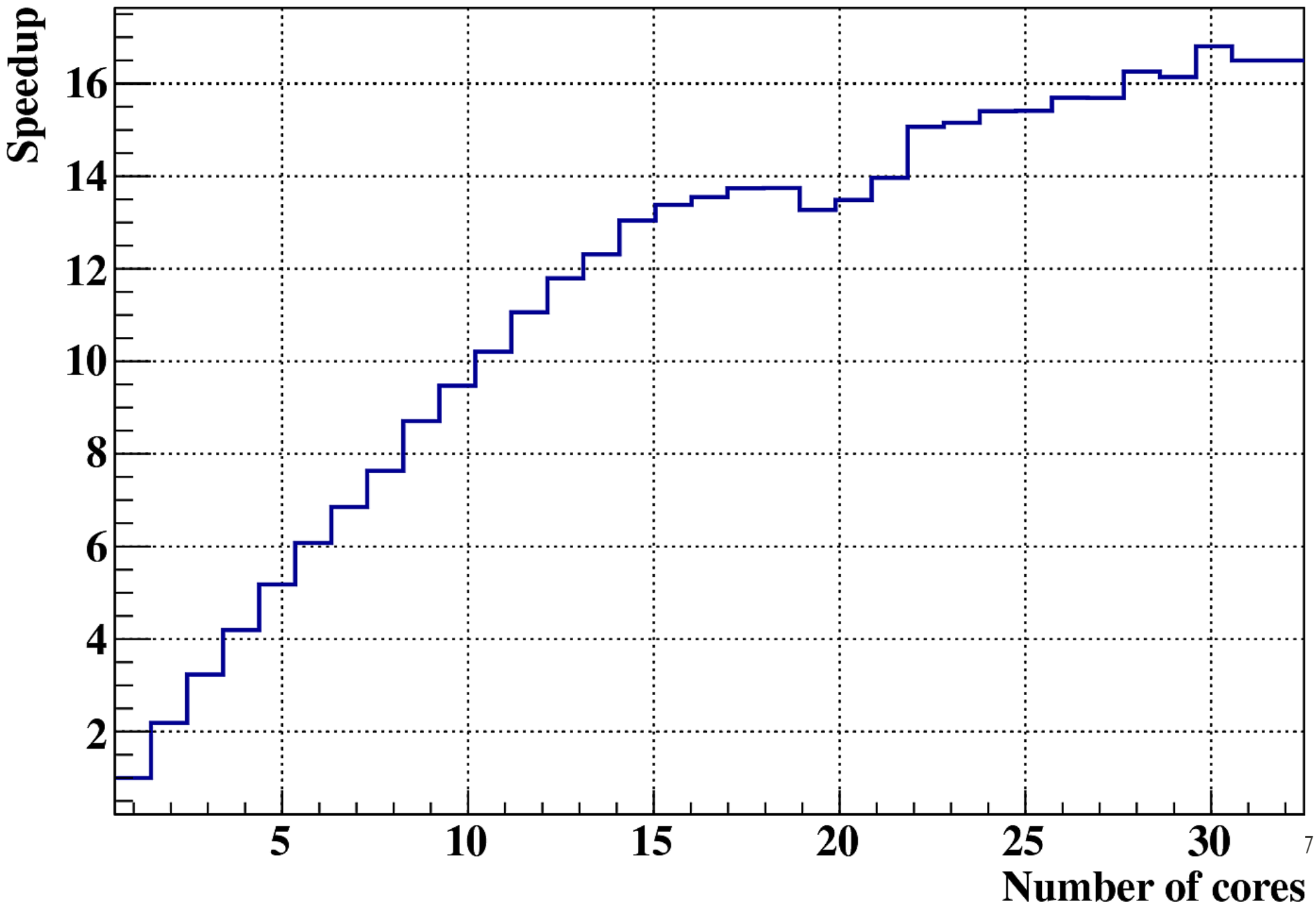
2) Improve **parallelization** scheme. **Done**!
Now TRACS can run in machines with **N cores**.

3) TRACS **toolkit**. User must be able to call TRACS from its own code.
First client is now the fitting program.

4) TRACS **service** to RD50. We just created tracs32, a CERN-Virtual Machine with 32 cores for parameter estimation

5) Further **improvements**. Diffusion, p-stops, information exchange with TCAD → 2017

Tracs32 performance



Summary and perspectives

TRACS simulation has gained momentum thanks to new manpower

Parallelization implemented in the code. TRACS tested in machines with up to 32 cores

Work is ongoing. We want to have fitting machinery in-place and tested for RD50 workshop.

1 year of development ahead of us.

User comments and suggestions are welcome

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SOLVING FIELDS IN THE DETECTOR → CHARGE CARRIER TRANSPORT → FRONT-END EMULATION

SOLVING FIELDS IN THE DETECTOR

- Detector properties and operative characteristics
- Finite Element Meshing
- Laplace's Equation $\nabla^2 \Phi_W = 0$
- Poisson's Equation $\nabla^2 \Phi = -\rho(\vec{r})/\epsilon$
- N_{eff} from V_{dep} or user input
- Set BCs
- Set BCs
- Solve Φ_W
- Solve Φ
- Weighting Field $\vec{E}_w = -\nabla \Phi_W$
- Electric Field $\vec{E} = -\nabla \Phi$
- Solve $\vec{E}_W$
- Solve $\vec{E}$

FEM SOLVER - *FENICS*

CHARGE CARRIER TRANSPORT

- An arbitrary charge carrier distribution (e.g. laser simulator or GEANT4)
- Ramo's Theorem $I(t) = \sum i(t) = \sum q \vec{v}(t) \vec{E}_W$
- Drift of Carriers $\vec{v}_{drift} = \mu(E) \vec{E}$
- Differential Equation $\frac{d\vec{x}}{dt} = \vec{v}(t)$

RK4 SOLVER - *ODEINT2*

FRONT-END EMULATION

- RC shaping
- Amplifier and Readout System Effect

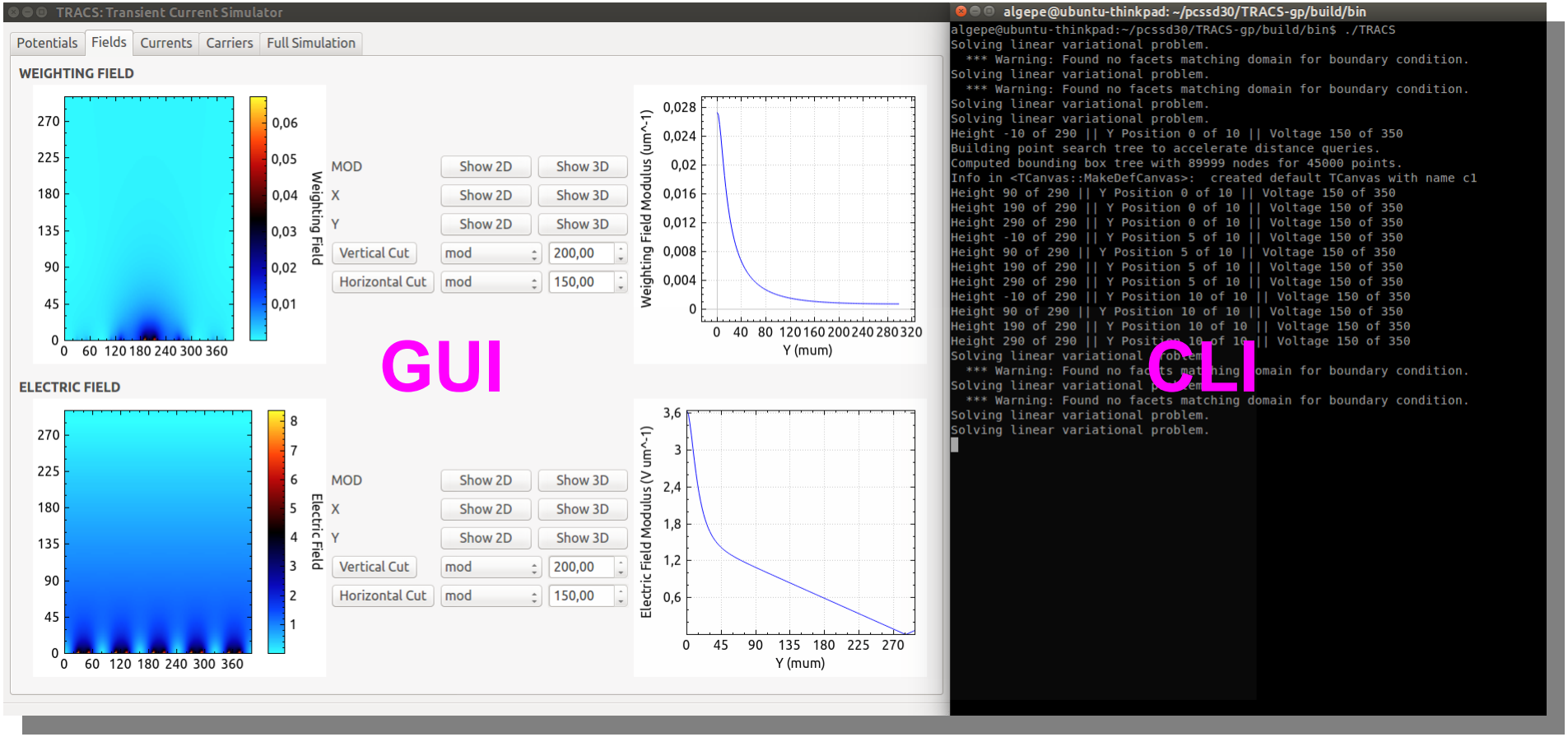
TRANSIENT CURRENTS

- Trapping (τ wrapping)

Not implemented:

Diffusion
thermal gen./recomb.
Trapping by MC method
Charge Gain

TRACS three-folded operation mode



+ toolkit mode

Now TRACS methods are made into a library that can be externally called from user code.

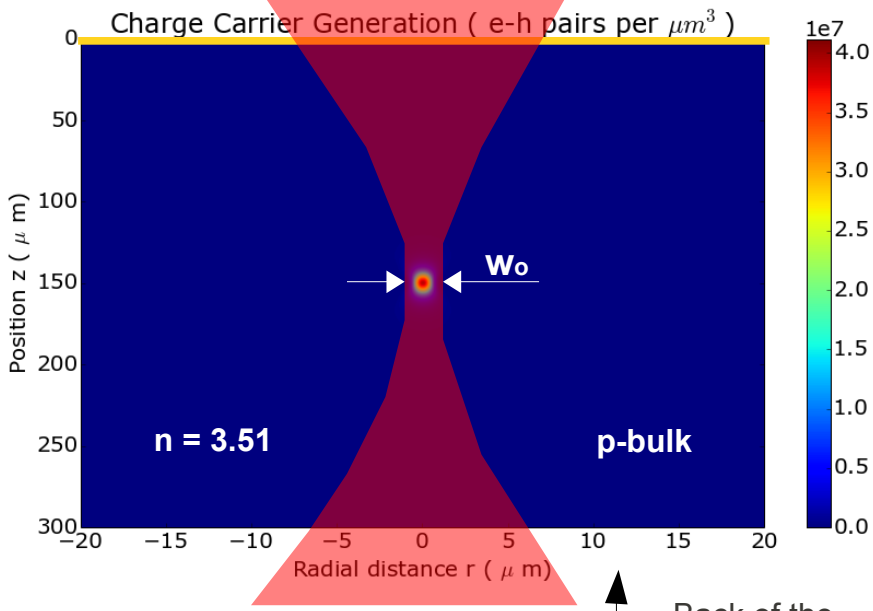
First user: fitting program

TRACS simulation example: Two Photon Absorption TPA-TCT

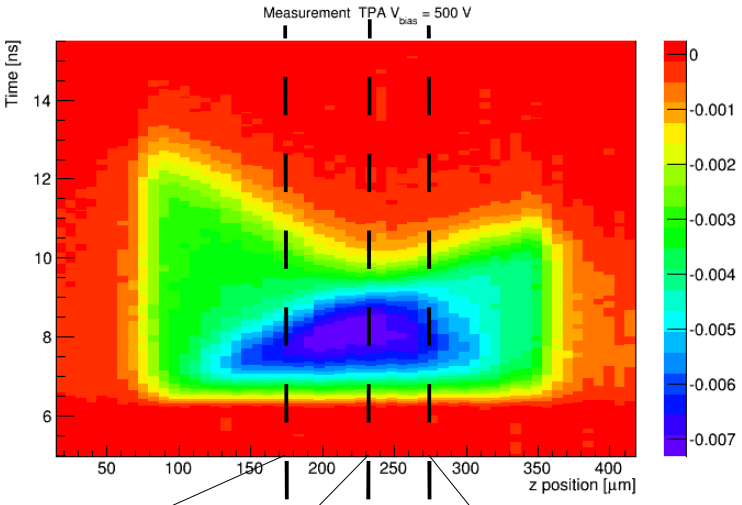
Front of the detector

1300 nm laser

TPA info: See here



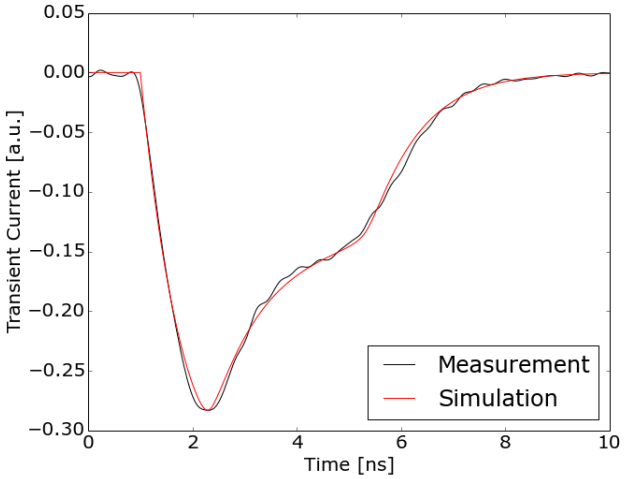
Back of the detector

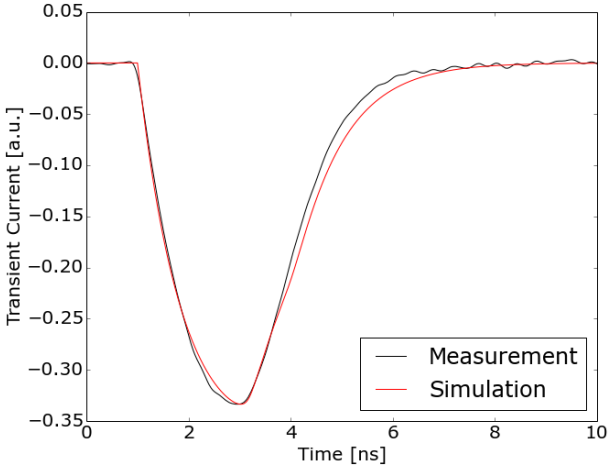


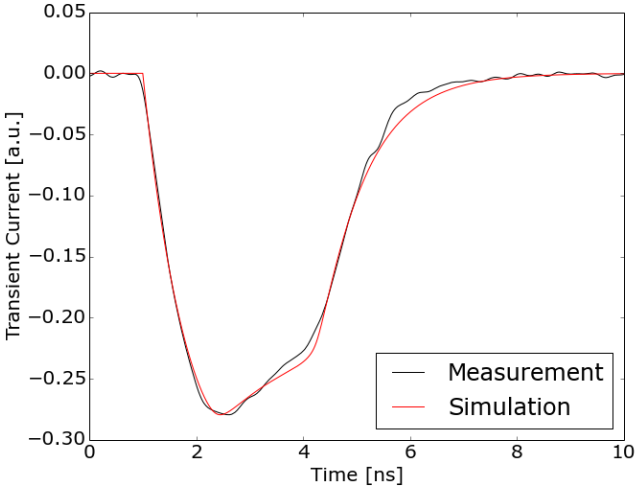
focus depth → 97 µm

focus depth → 160 µm

focus depth → 237 µm







Trilinear Neff model taken from:

M. Swartz et al., **Simulation of Heavily Irradiated Silicon Pixel Detectors**, SNIC Symposium, California, 3- 6 April 2006

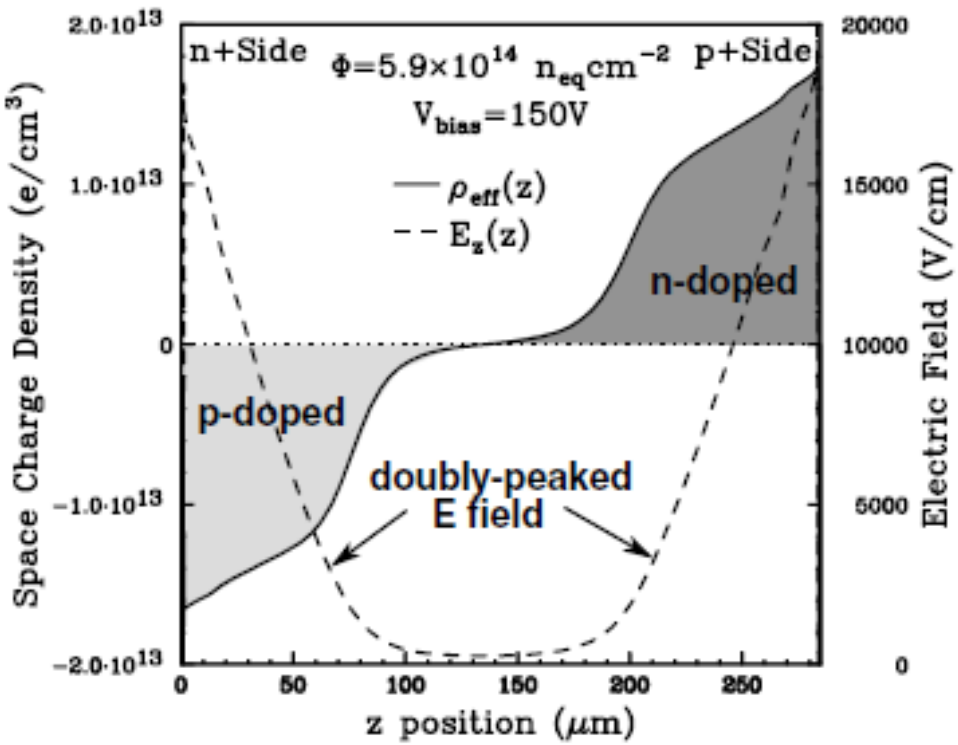


Figure 2: The space charge density (solid line) and electric field (dashed line) at $T = -10°C$ as functions of depth in a two-trap double junction model tuned to reproduce the $\Phi = 5.9 \times 10^{14} n_{eq} cm^{-2}$ charge collection data at 150V bias.

~5ZN model

Fit of the CCE curve

Trapping model:

$$-dN = \frac{1}{\tau\,(E(x(t)))}\,N\,dt$$

Different possible parameterisations of τ:

$\tau = \tau_0$

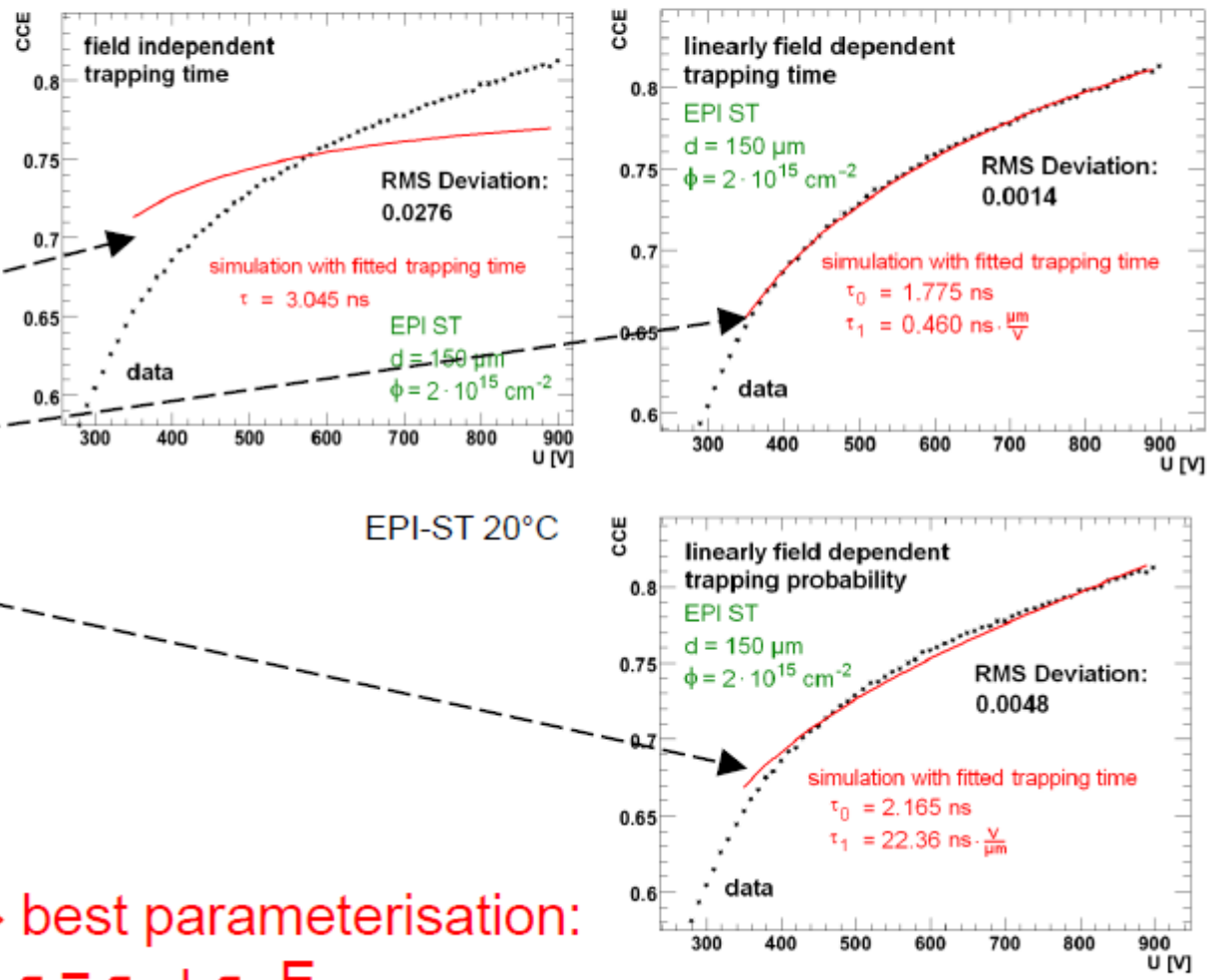
$\tau = \tau_0 + \tau_1 E$

$1/\tau = 1/\tau_0 + 1/\tau_1 E$

$1/\tau = 1/\tau_0 + 1/\tau_1 v_{dr}(E)$

- fit simulated CCE curve to the measured CCE values
- free parameters: τ_0 , τ_1

CCE versus rev. bias voltage



⇒ best parameterisation:
$\tau = \tau_0 + \tau_1 E$