Calculation of effective space charge of irradiated Si detectors

Comparing simulations with measurements

Urban Senica
CERN, Route de Meyrin 385, 1217 Meyrin, Switzerland

Marcos Fernández
IFCA: Instituto de Física de Cantabria IFCA-CSIC-UC, Ed. Juan Jordá, Avda. Los Castros s/n, 39005 Santander, (Spain)

Goal Development of a **fast simulator** of **non-irradiated** and **irradiated** silicon (Si) microstrip **detectors**. Detector parameters (effective space charge, trapping time...) extracted **fitting** simulation to real data.

Why **RD50** collaboration's main activity is the development of **silicon detectors** for the **HL-LHC** upgrade. The study of **irradiated detectors** plays a crucial role in designing new devices, adapted to **increased particle fluences**. Simulations, in combination with measurements, provide valuable insight into the detectors' behaviour.

Si microstrip detectors

Usually around 300 μm thick, these **segmented devices** are used as **trackers** in particle physics experiments. When a particle crosses the detector, it generates free charge carriers (e- and h+), which are collected in the strips to produce a signal. The device operates in **reverse bias** mode to ensure a minimum quantity of free carriers in the bulk (depleted region). The **effective space charge (Neff)** in the bulk is constant in unirradiated detectors, resulting in a **linear electric field**. During operation, detectors are exposed to radiation, causing several (undesired) effects and changing the device's characteristics. Irradiated detectors can be parameterised using a **trilinear Neff**, resulting in a **parabolic electric field**.

Edge-TCT measurements

Transient Current Techniques study the transient current pulses induced by the moving charge carriers in the electric field of the detector.

In conventional TCT, a pico-second **laser pulse** is injected either form the top or bottom part of the device and generates free charge carriers. In edge-TCT, the pulse is injected from the side, enabling **depth-dependant** measurements. The shape of the measured transients is directly connected to the electric field inside the detector.

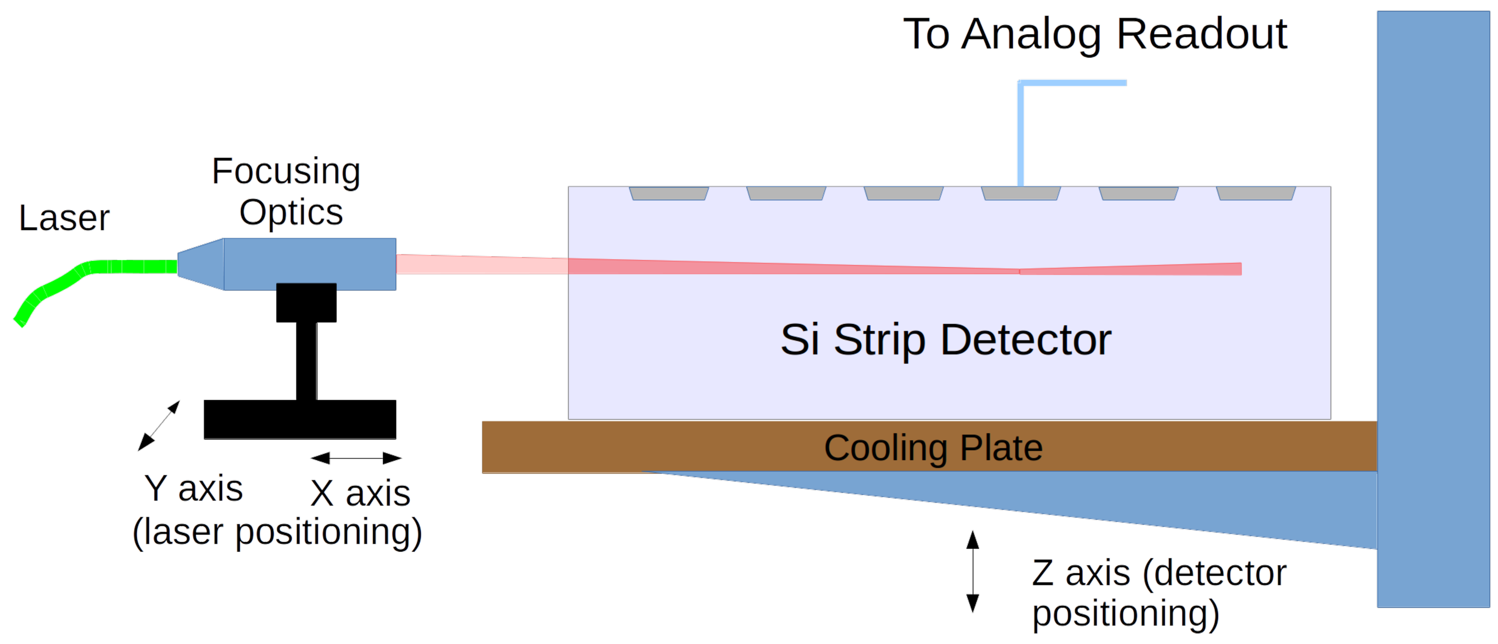


Fig.1: Sketch of an edge-TCT setup. A microstrip detector is mounted on a vertical motorized platform. One of the strips is connected to the readout electronics. A laser is focused from the side. By moving the detector in the z direction, different parameters of the sensor (electric field, drift velocity, charge collection efficiency) can be sampled as a function of depth.

TRACS

An open-source TRAnsient Current Simulator developed at CERN, implementing **Ramo's theorem** using finite element methods (**FEM**) to calculate **induced transient currents**. TRACS accepts arbitrary charge carrier distributions as input. It can simulate **microstrips** and simple **diodes**. For irradiated detectors the user needs to specify a Neff(z) profile and an effective trapping constant.

GUI (graphical user interface) and **CLI** (command line) versions available (https://github.com/IFCA-HEP/TRACS).

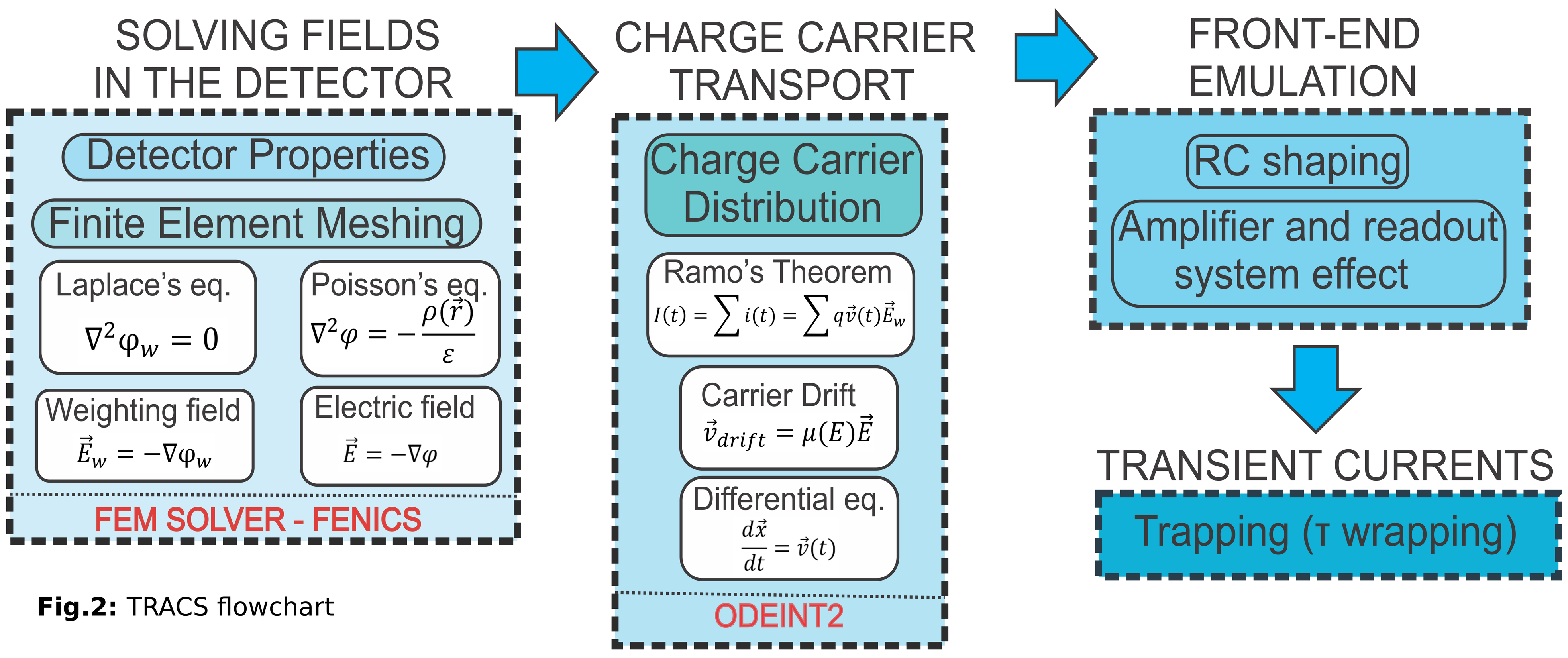


Fig.2: TRACS flowchart

Parallelization of TRACS

To **speed up** the simulation, I implemented **multithreading**, which is especially effective on multi-core machines. The "z" input coordinates of a (z, y, V) scan are split into N parts and the simulation runs independently in each of the N threads. A simple comparison of execution times is in Fig. 3.

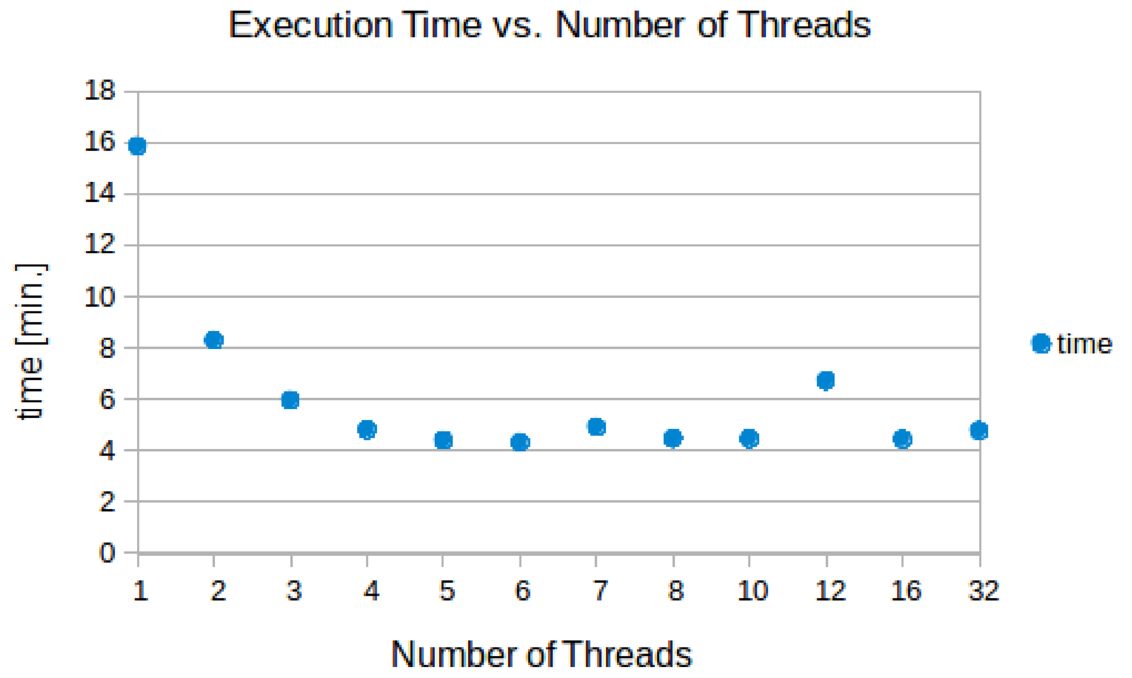


Fig.3: execution time with different numbers of threads. Calculating 32 points in z coordinate. Computed on a machine with Intel® Core™ i7-3770 Processor @ 3.40GHz with 4 cores and 8GB RAM.

Parameter extraction

The next step is a comparison of measured and simulated transient currents. The goal is to compute a **χ^2 minimization** using MINUIT minimizer software and extract the effective space charge. A simulation with 300 steps and 4 threads takes 45 minutes. If we assume we need to run ~300 minimizations, that amounts roughly to 225 hours (9.4 days). This may seem a long time, however with access to computing farms with many CPU cores the time can be decreased vastly thanks to parallelization.

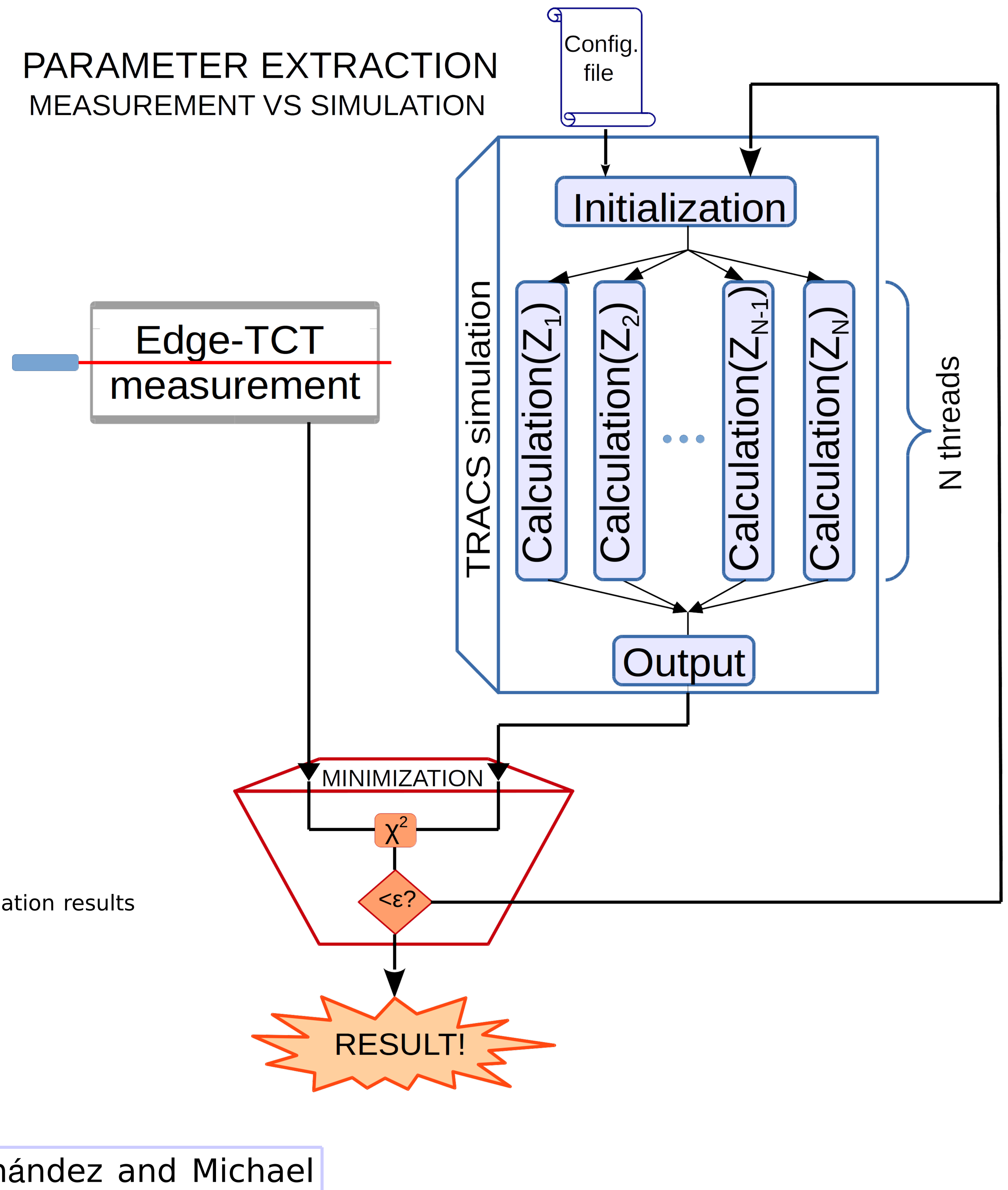
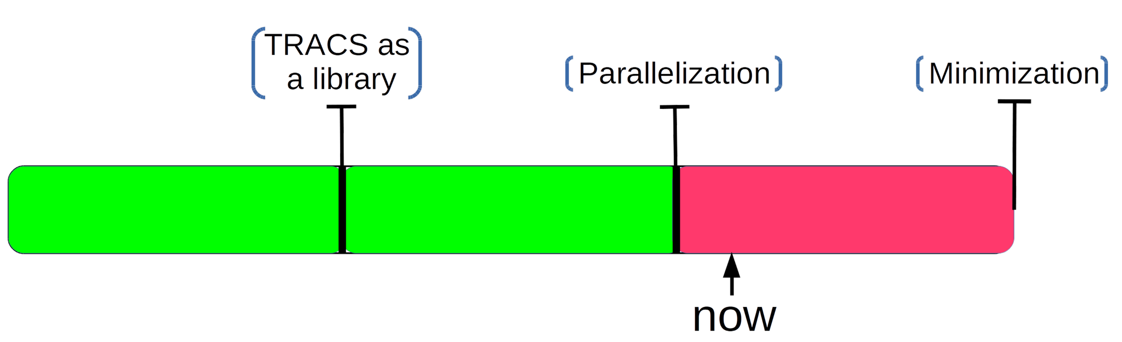


Fig.4: parameter extraction flowchart. Simulation results are fitted to measurements.

Progress



Acknowledgements

I thank my supervisors Marcos Fernández and Michael Moll and the rest of the Solid State Detectors team.