Geant4 + TCAD:
An Application Example

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Scope

- This is an introductory presentation prepared for those who already know about Geant4...

  … but are newcomers for SEE analysis and prediction.

- We use a Geant4 application developed in our group to show some issues that a new user may find with FASTRAD, Geant4, GDML and TCAD.
  - In other words, this talk tries to present some things that one would like to hear about when starting an application development.

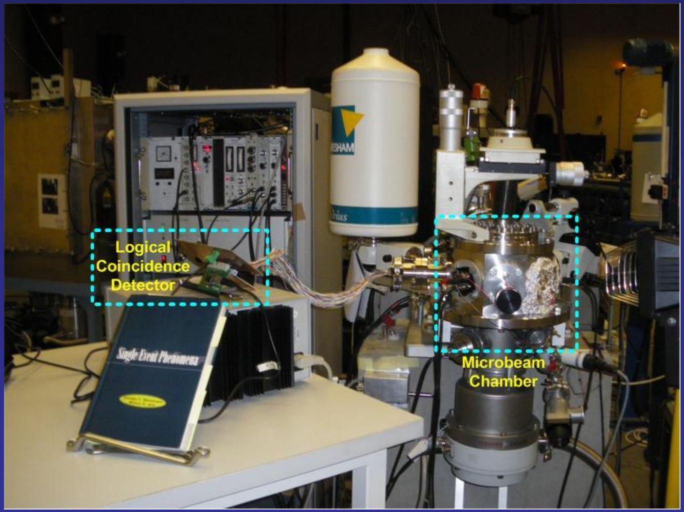
- Introduction of developments to extend Geant4 capabilities and TCAD analysis, presented in the next sessions.

Outline

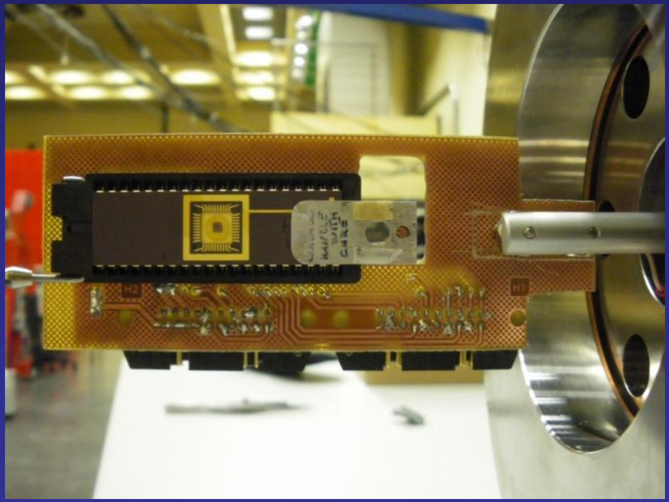
- Introduction
- Geometry modelization with FASTRAD
- Main features of our Geant4 application
- Getting Geant4 charge distribution for TCAD
- Charge distribution model in Sentaurus TCAD and ATLAS Silvaco (*de-facto* standards)
- Proposed improvements

Introduction

- We present a GEANT4 approach to simulate the incidence of charged particles on a CMOS flip-flop designed according to AMIS C5 rules.
  - Protons (18 MeV) and deuterons (9 MeV) produced at IBA-CNA cyclotron (Seville, Spain).
  - Ion beams produced at the 3-MV tandem accelerator present at the CNA facility as well.



Experiment data acquisition (*)

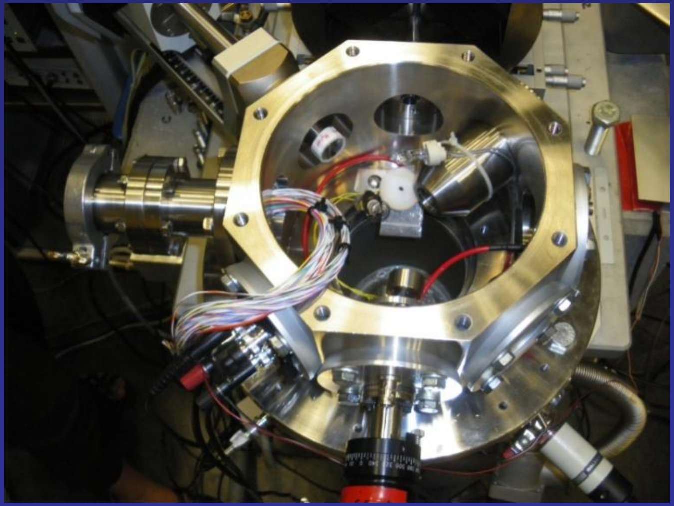


Target (*)

(*) Courtesy of F. Rogelio Palomo (Univ. Seville)

The CNA facility in Seville

3 MV Tandem Van de Graaf Accelerator

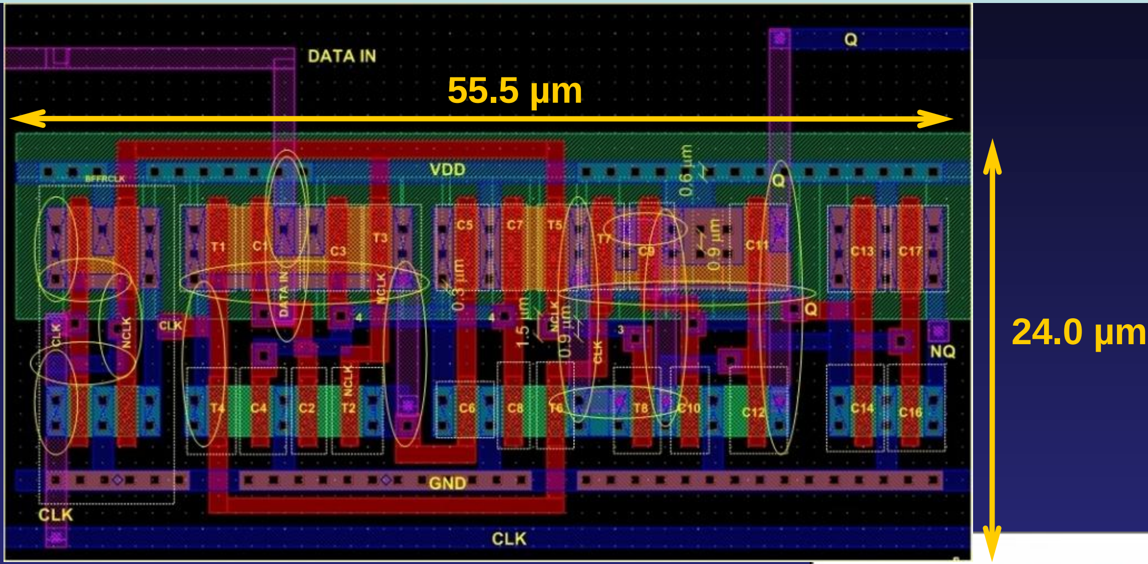


Microbeam chamber

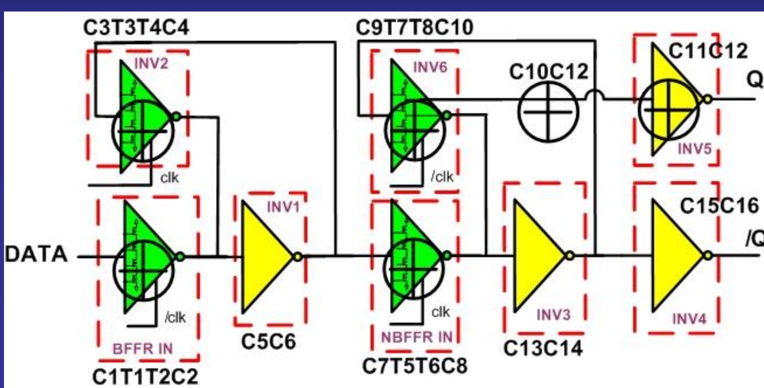
IBA-CNA cyclotron

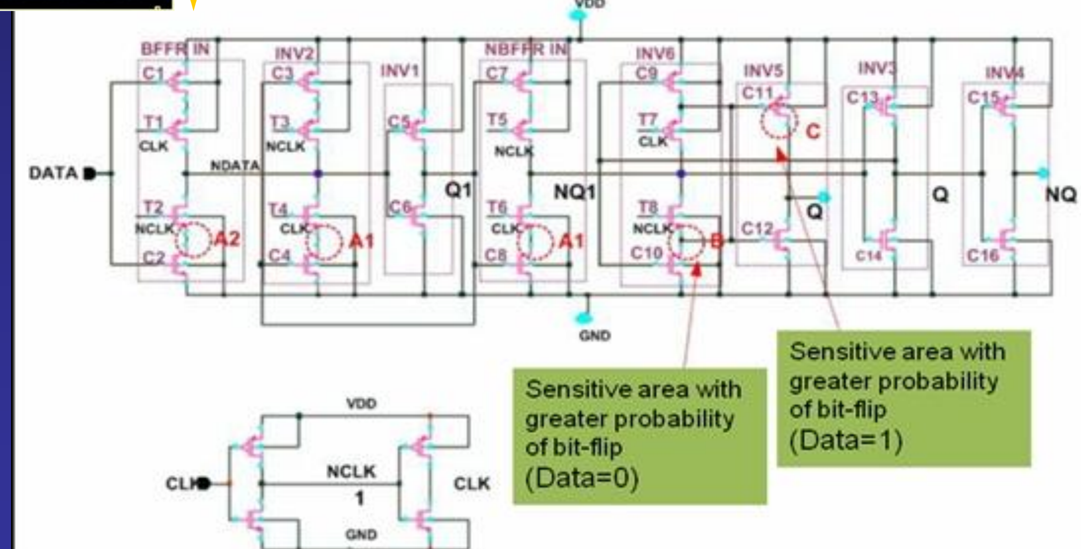
(http://www.cna.us.es)

Flip-Flop Schematics & Design

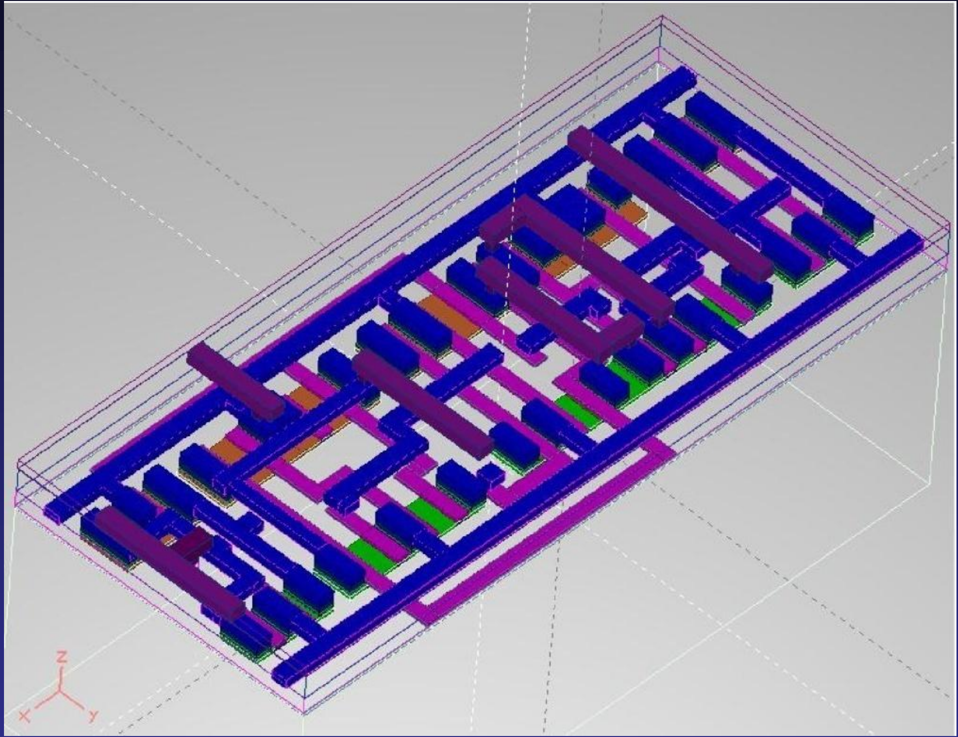


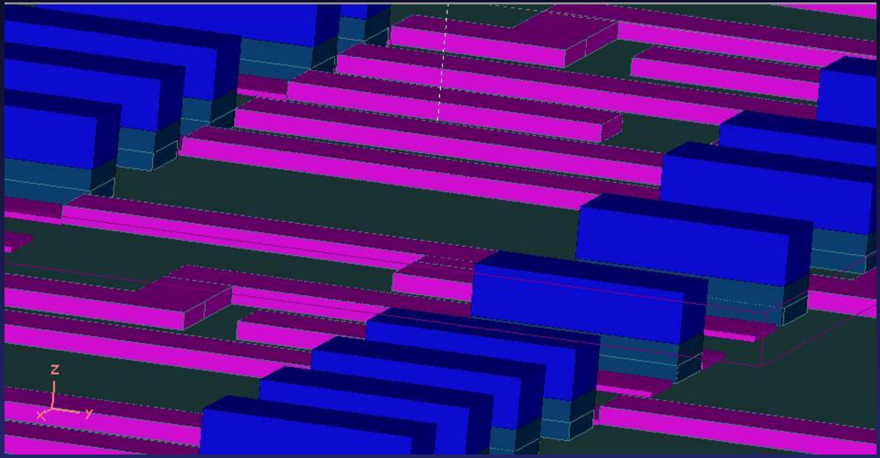
Master-slave flip-flop (AMIS C5) and clock buffer, comprised of 28 transistors in total.

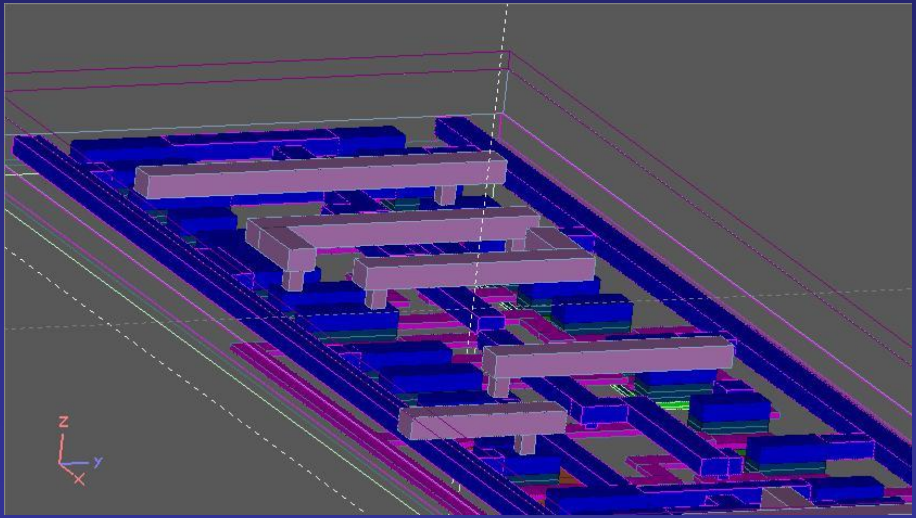




FASTRAD Model of the Flip-Flop







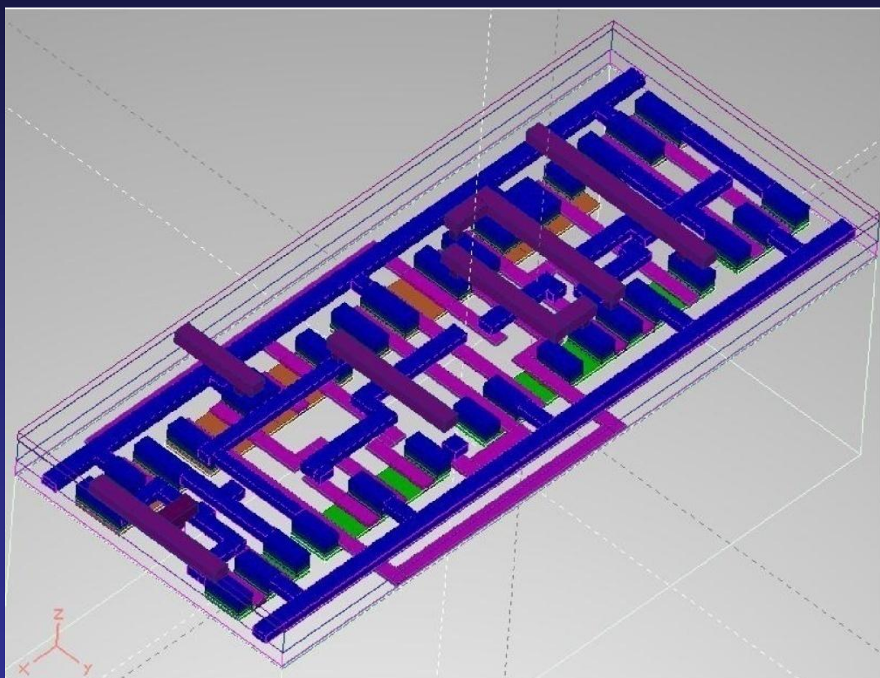
•Non-overlapping volumes nor mother-daughter hierarchy.

•Trenches must be modeled in the substrate prior placing components.

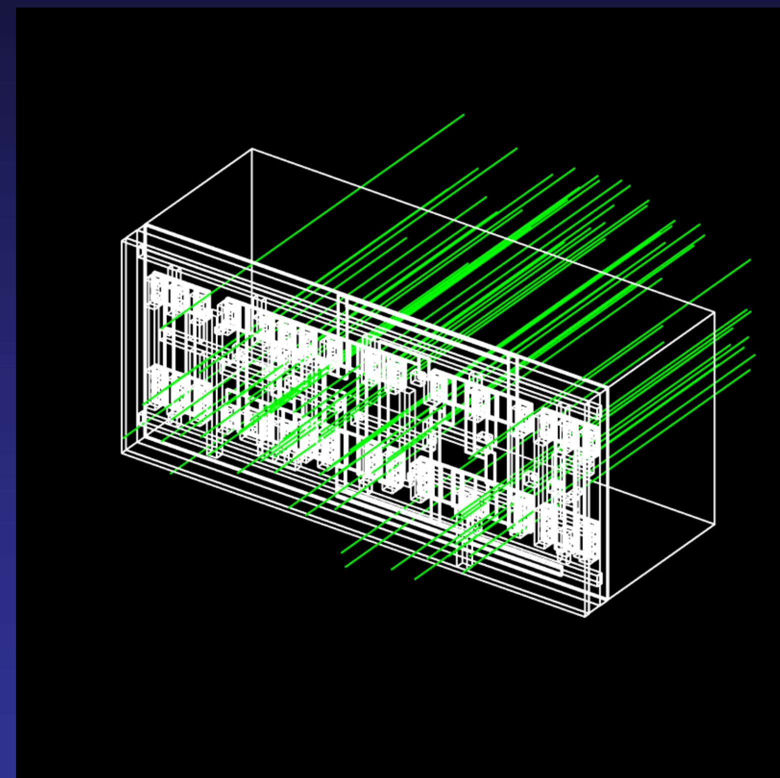
•Model scaled from microns to mm for clarity.

Conversion to a Geant4 Geometry Model

- **FASTRAD exports XML files readable by Geant4 using the GDML schema(*)**



FASTRAD model



GEANT4 model

(*) **GDML:** R. Chytracek et al., *IEE-TNS* **53**: 2892 (2006)

Geant4 Application for the Irradiation of the Flip-Flop

- **Aims:**
  - Score the energy deposition in elements of a flip-flop.
  - Geometry imported from GDML using G4GDMLParser (see persistency/gdml extended examples).
  - Regions and sensitive detectors defined with user-defined commands passing the Logical Volume (LV) name, such as:
    - `/mygeom/sdName “a LV name”`
    - `/mygeom/detailedReg “a LV name”`
- **Some needs in Detector Construction:**
  - Vectors to store the strings passed in the macro commands.
  - LV identification by name using G4LogicalVolumeStore singleton (or similar approach using GDMLAuxPairType classes).

The Geant4 Application: DetectorConstruction Class

- However, LV names given by GDML output of FASTRAD follows an automatic logic:
  - **`[name]_[a number]_Volume`**
    - (example: “Oxide_365_Volume”)
- Thus, LV identification by name becomes an issue when using copies of the same solid in FASTRAD.

- **A possible solution is:**
  - Use G4LogicalVolumeStore singleton to make a list of LV names.
  - Create a database (a table) where each LV is identified with a component of the flip-flop (according to the coordinates, solid dimensions, etc.)
  - Define geometry features (regions, SD’s) according to our needs.

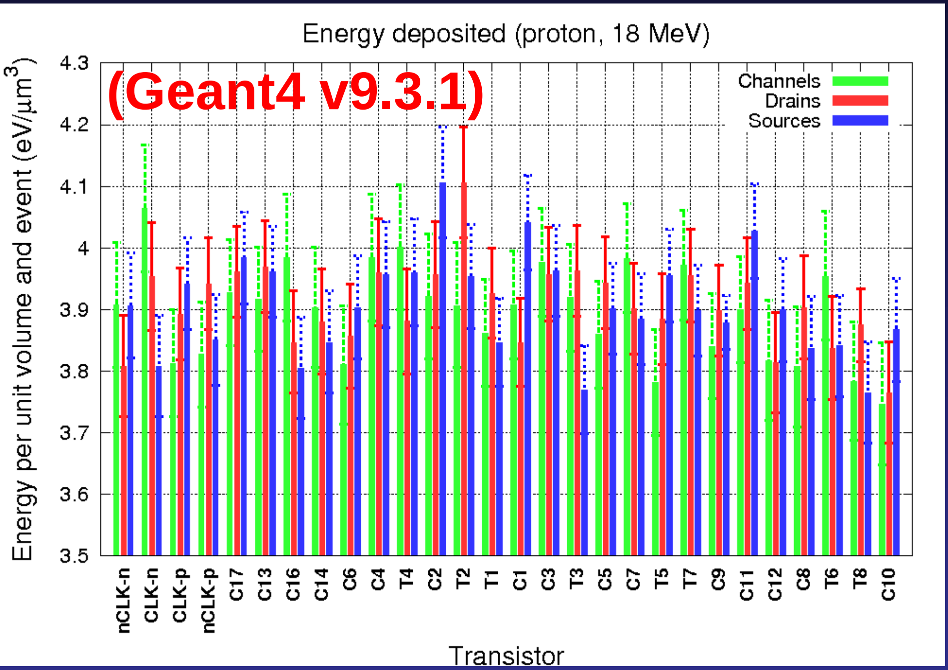
The Geant4 Application: DetectorConstruction Class

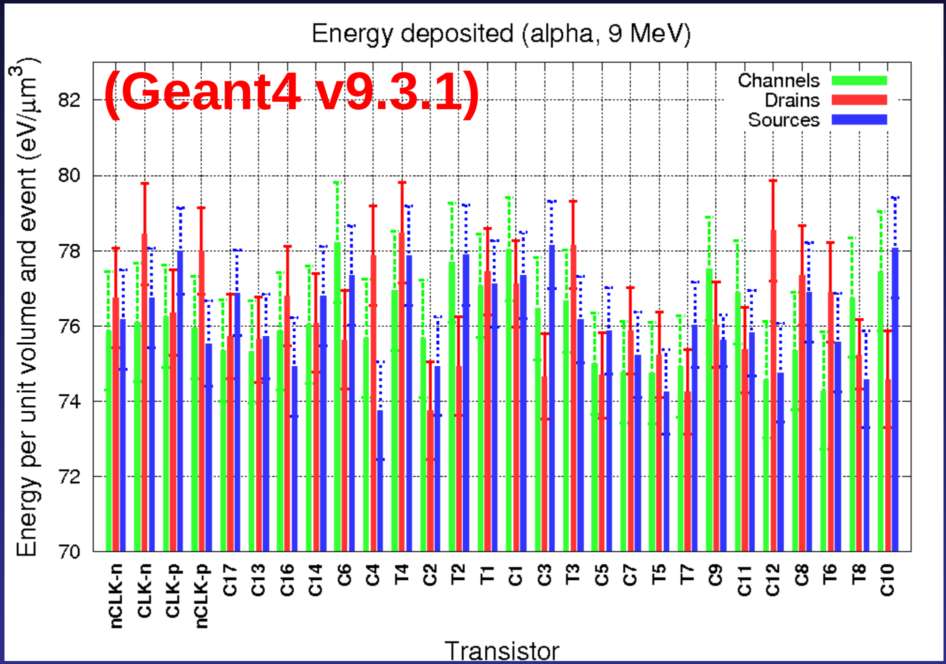
Example: Scoring energy deposition in the channel, drain and source of each transistor.

- User-defined commands:
  - `/mygeom/sdName Channel`
  - `/mygeom/sdName Drain`
  - `/mygeom/sdName Source`
- In the `Construct()` method, register an energy deposition scorer to each LV which name contains one of the strings passed in the commands.
- For each string, the SD's are registered in the same order as they appear in the list of LVs made from G4LogicalVolumeStore.
- From G4SDManager singleton we can retrieve the list of SD's registered, which must follow the same order as in G4LogicalVolumeStore. Same applies for the hit maps (or hit collections) dumped into an output file.

The Geant4 Application: Results. Energy Deposition.

Irradiation of the flip-flop with heavy-charged particles



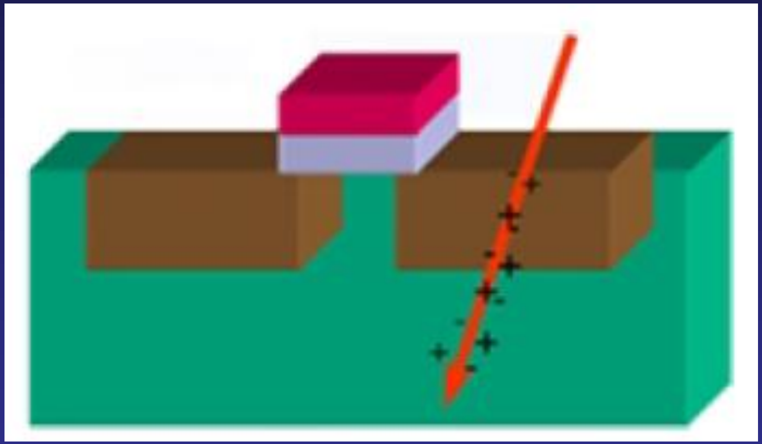


- Uniform irradiation condition has been considered.
- This detail level helps to study which structures are more vulnerable against the incidence of charged particles.

M.A. Cortés-Giraldo et al., *Progress in Nucl. Sci. Technol.* **2**: 509-515 (2011)

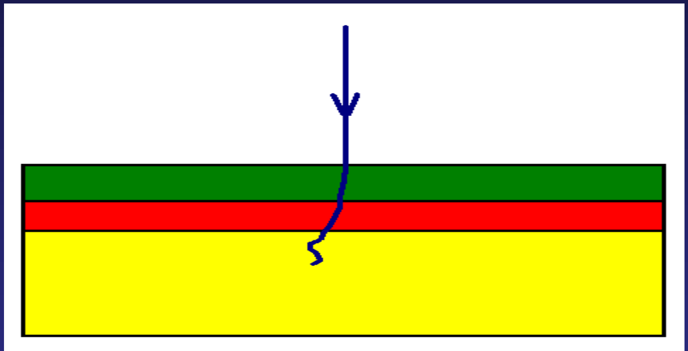
Geant4 Charge Distribution for TCAD

- The flip-flop application calculates the energy deposition averaged over the entire volume.
- This approach is enough if we are interested in accumulative damages.
- But, for SEE studies this is not enough because of high gradients in energy deposition.
- An application for track structure analysis is created to calculate a model of energy deposition in depth.

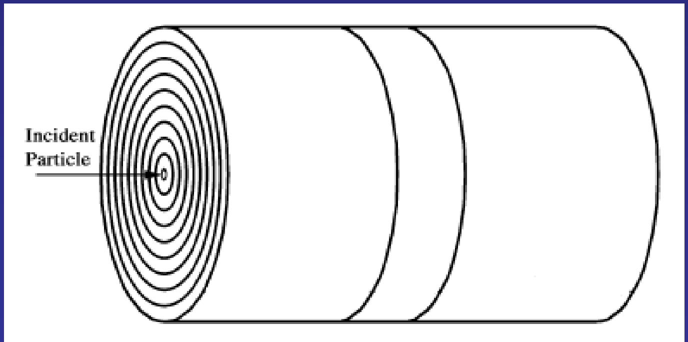


"Track Analysis" Application

- Developed to analyze charged-particle **track structure.**
- Two approaches:
  - **LET calculation:** Particle incidence on a layered geometry (SRIM geometry)



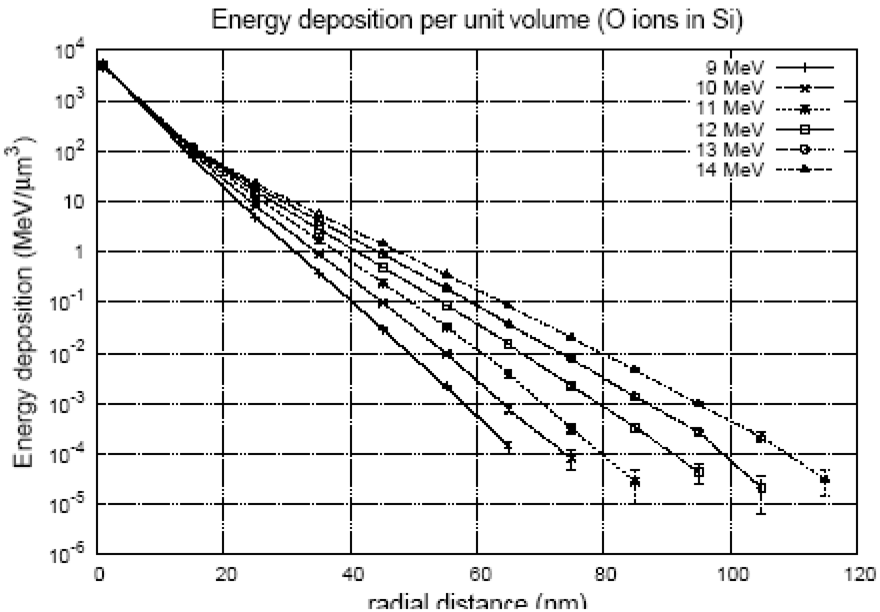
  - **Radial dose distribution:** Particle incidence on a "bullseye" geometry (*)



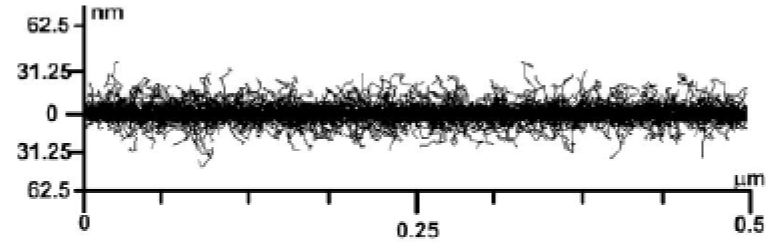
(*) Geometry similar to A.S. Kobayashi et al., *IEE-TNS* **51**: 3312 (2004)

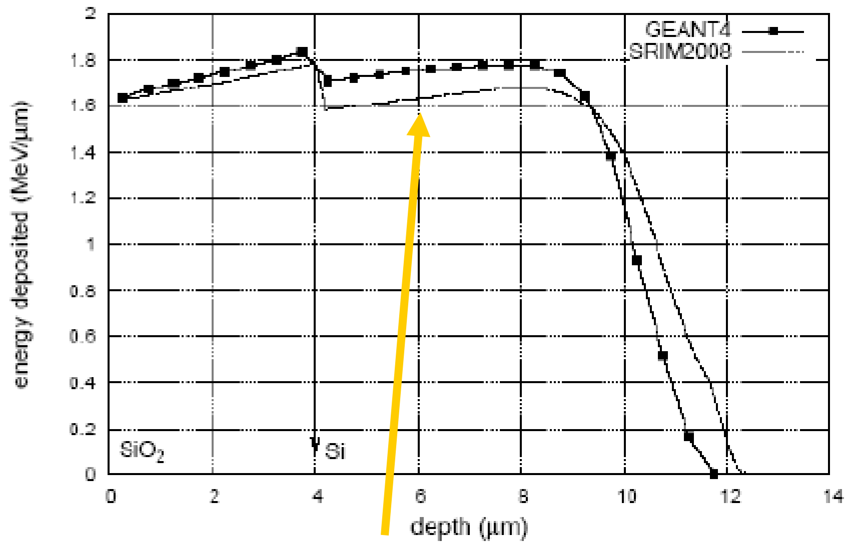
Track Analysis: Results

(Geant4 v9.3.1)



$$LET(d)_{\text{electronic}} = 2\pi \int_0^R r\,\mathrm{d}r\,D(r,d)$$





Within Geant4 EM model accuracy (~ 10%)

M.A. Cortés-Giraldo et al., *Progress in Nucl. Sci. Technol.* **2**: 509-515 (2011)

Developments in Geant4 at very low energies for Microdosimetry

- Geant4 Standard and Livermore EM packages are reliable for electrons down to ~ 0.1-1.0 keV.

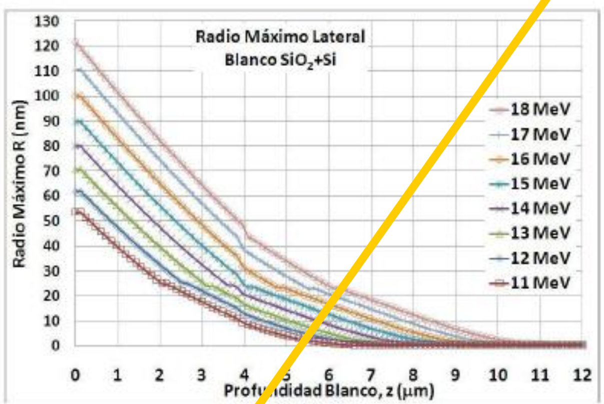
- Extensions with more accurate models at energies below 100 eV for microdosimetry:

  – **The Geant4-DNA Project** (next talk by S. Incerti).
    - Microdosimetry in water, especially developed for radiobiology

  – **The MuElec extension** (following talk by M. Raine).
    - Microdosimetry in silicon

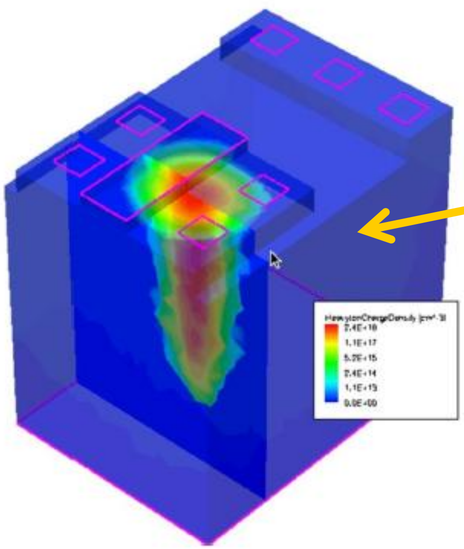
Charge Distribution Model in Sentaurus TCAD

Three arrays define the charge distribution model



Considering the whole calculus for the layered target (4 μm SiO2 +Si) we got the ionization profile inside the transistor target.

That results are codified as {z, LET(z), w(z)} in Sentaurus, because the ionization track profile is the data input for transient analysis (in this case, full spectra of oxygen ions from CNA, 11 to 18 MeV with a 1 MeV step.



Only axial symmetry is foreseen

(*) **Courtesy of F. Rogelio Palomo (Univ. Seville)**

New Tools for SEE Analysis and Prediction

- Have a look to this afternoon's presentations:
  - **MRED** (ISDE/Vanderbilt University)
  - **NanoTCAD** (CFD Research Corp.)
  - **RunSEU** (Cogenda Pte Ltd.)
  - **MINIMOS-NT** (Kallisto Consultancy Ltd.)
  - **CODES** (LIP/ESA)

Conclusions

- Use of Geant4 to calculate energy deposition in the components of a *flip-flop* microelectronic device.
  - Such outcomes are very hard to measure.
- The Geant4 usual physics list include EM models which accuracy is not that high for low energy track structure and δ-ray transport.
  - See Geant4 extensions in next talks.
- Also, commercial TCAD software present limited options to simulate charge distributions for SEE predictions.
  - Lot of work ongoing by several research groups.

Acknowledgements

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