Medical Applications and Microdosimetry with GEANT4

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V Encuentro de Física Nuclear
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Outline

- Introduction
- IMRT treatment verification project (Radia)
- Optimization of a GEANT4 code for proton therapy
- Radiation Effects in Integrated Circuits
- *mini-SeD* prototype simulation
- Conclusions

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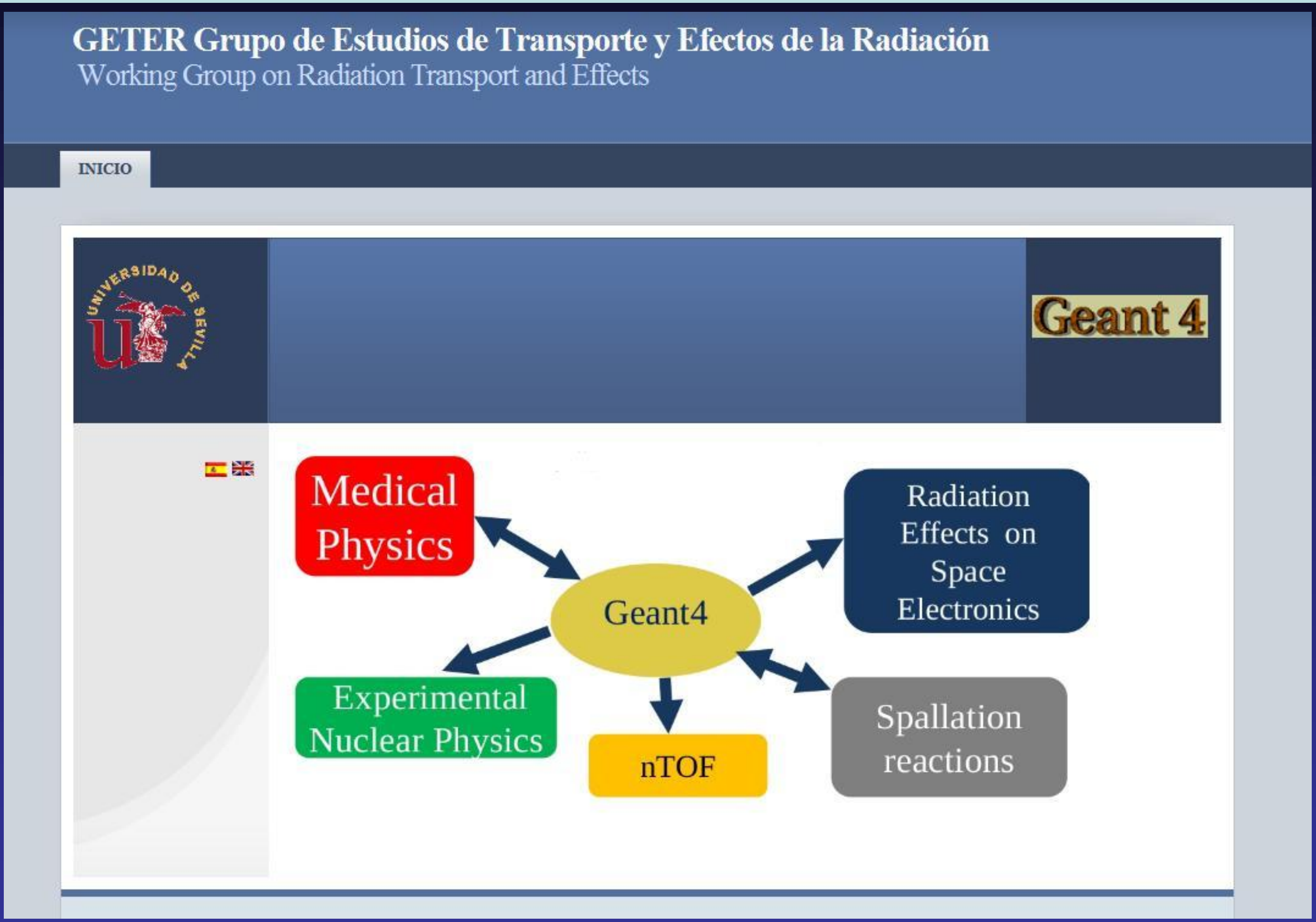
Introduction

- GEANT4 (GEometry ANd Tracking) Monte Carlo toolkit is a very powerful tool for the simulation of the passage of radiation through matter.
- It can be used in a wide range of applications, from high-energy physics to scintillation detectors.
- This talk is structured to show an overview of the GEANT4 applications developed in our group recently.

Introduction



http://atomix.us.es/institucional/geter/

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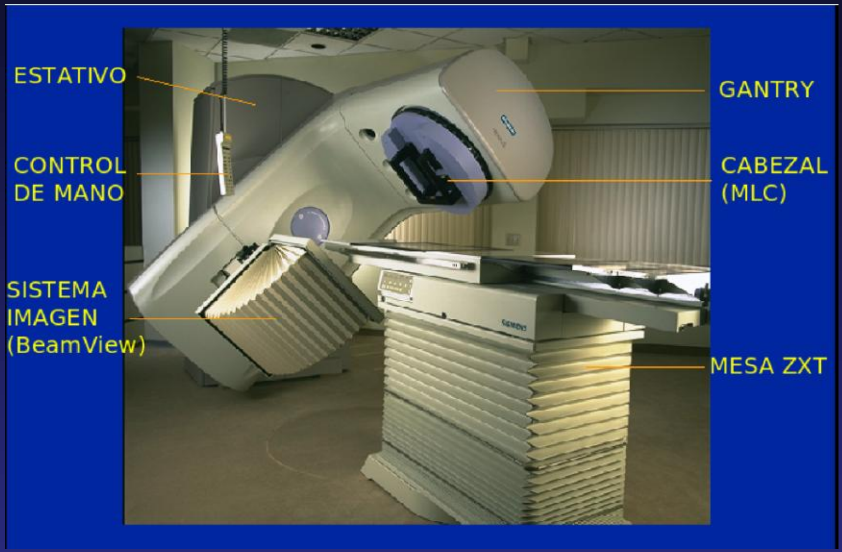
IMRT treatment verification project (Radia): Motivation

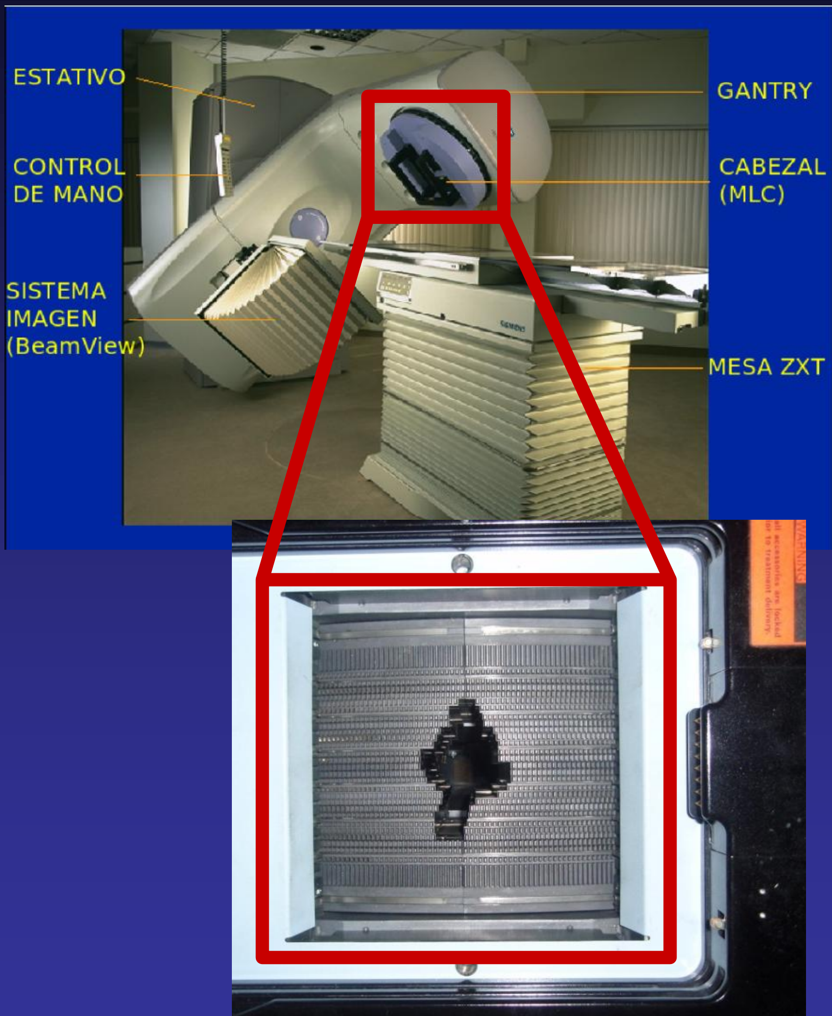
- The increasing sophistication of Intensity-Modulated Radiation Therapy (IMRT) treatments is a major challenge for Treatment Planning Systems (TPS). Therefore, verification of empirical dose distribution is highly advisable prior real dose delivery to patient.
- The goal is the validation of a novel method for measuring the dose map before treating patients with Intensity-Modulated Radiation Therapy (IMRT).
- These simulations are devoted to estimate the sensitivity of a Micron SSSSD detector in different situations.
- We use a SSSSD detector to measure the dose at different angles. This information is reconstructed to get the actual dose map.

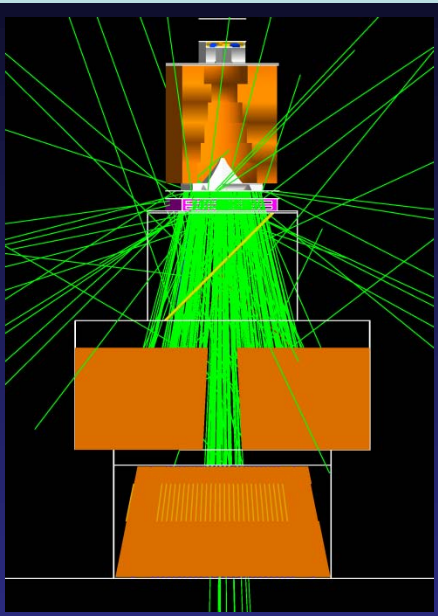
IMRT treatment verification project (Radia): Experimental setup

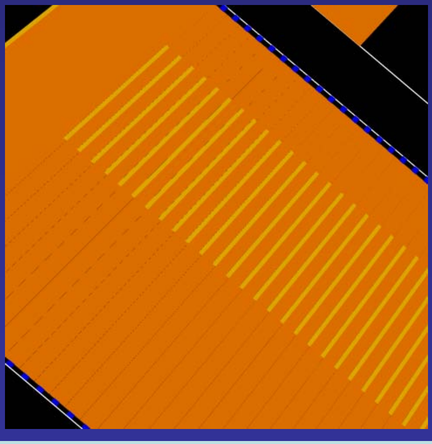


Siemens PRIMUS™ linac

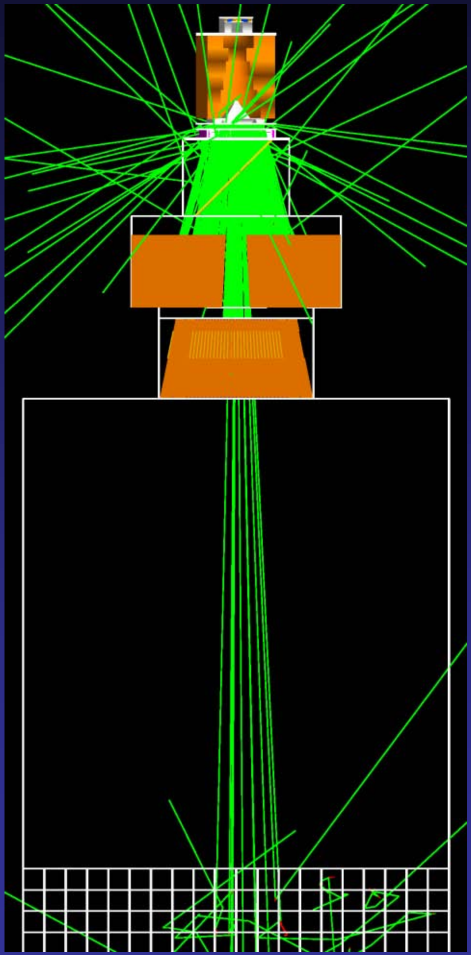
IMRT treatment verification project (Radia): GEANT4 simulation of the treatment head

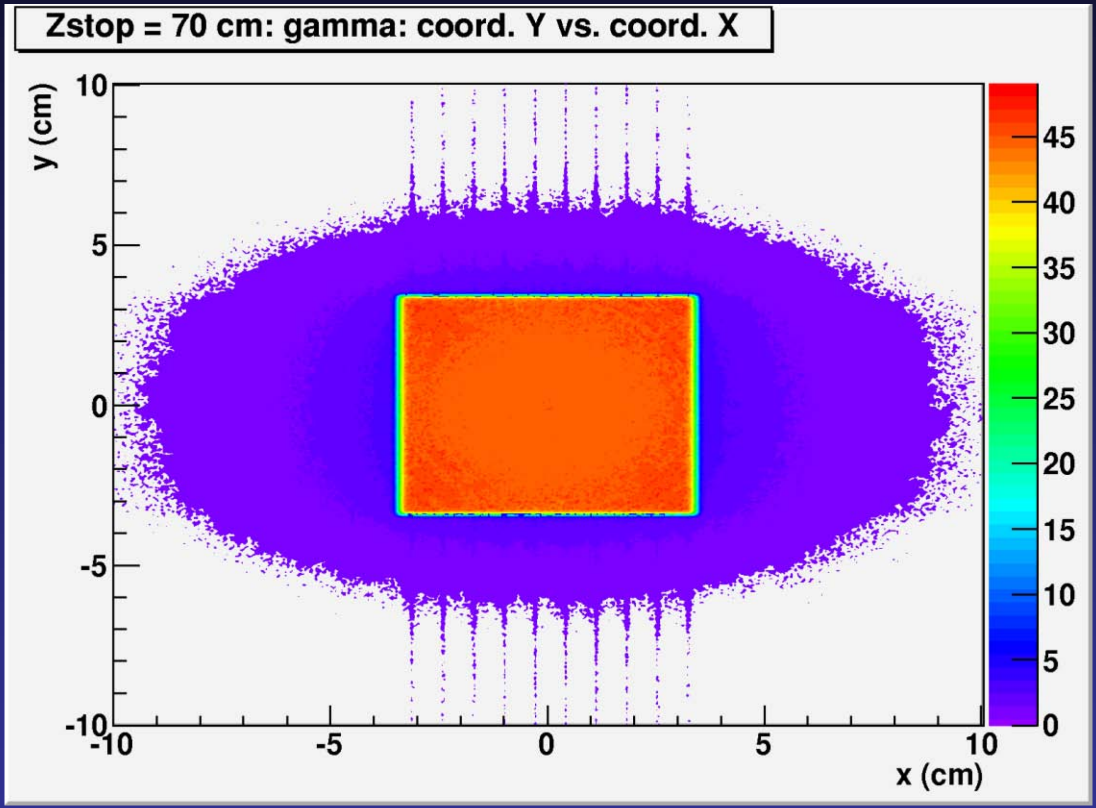






IMRT treatment verification project (Radia): GEANT4 simulation of the treatment head

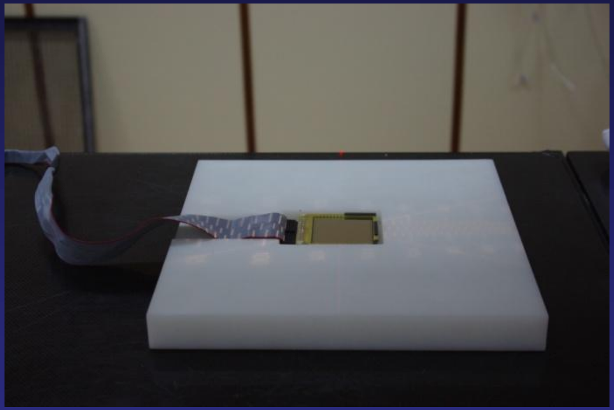




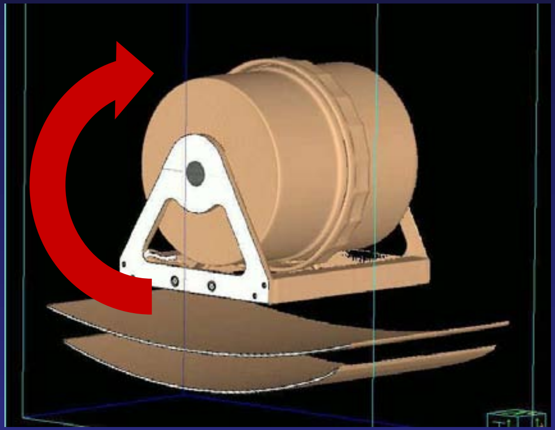
10 × 10 cm^2 radiation field
(*SSD* = 70 cm)

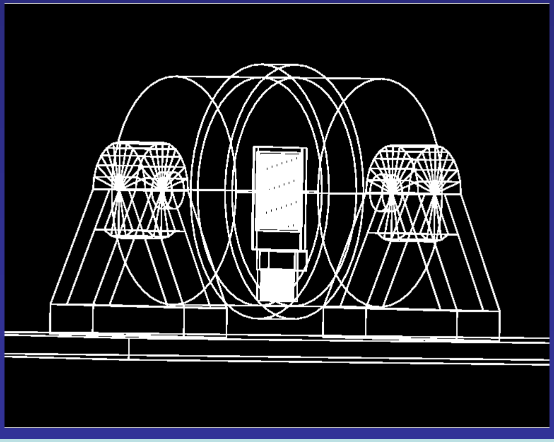
IMRT treatment verification project (Radia): Phantoms

Water-equivalent slabs



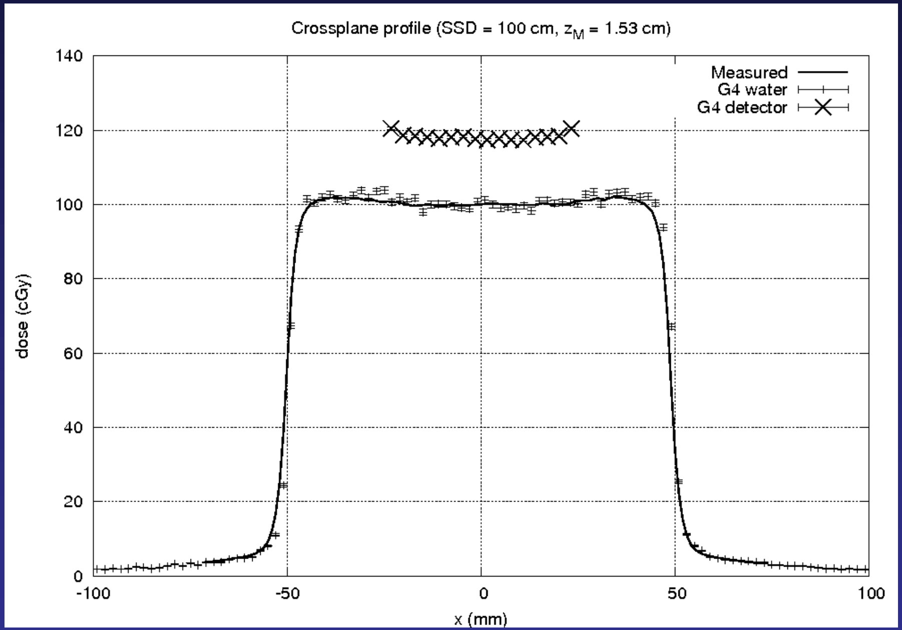
Phantom by Inabensa, Ltd. (polyethylene)



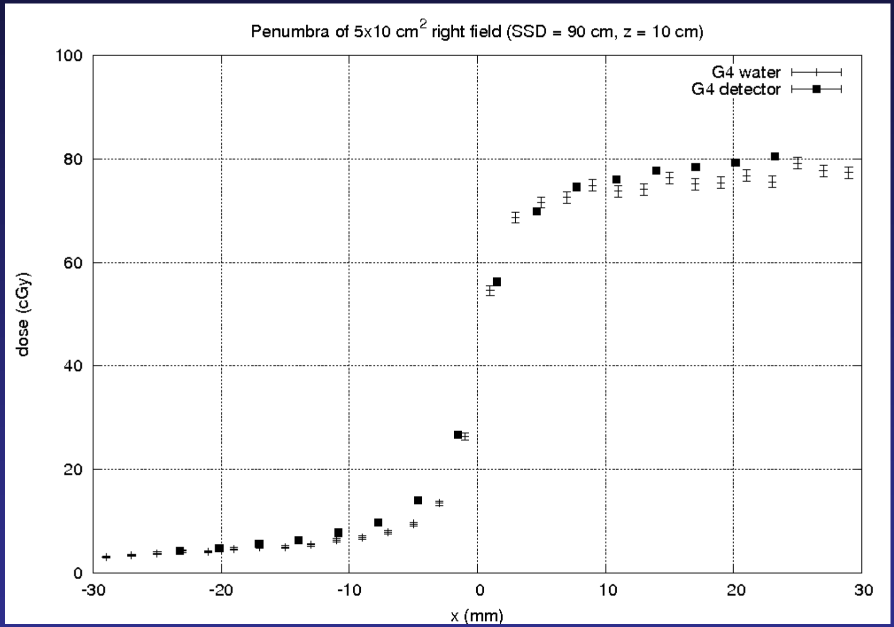


IMRT treatment verification project (Radia): Results

- **Calibration with water-equivalent slab phantom**



Crossplane profile calibration
10×10 cm^2 field
$SSD = 100$ cm, $z_M = 1.53$ cm



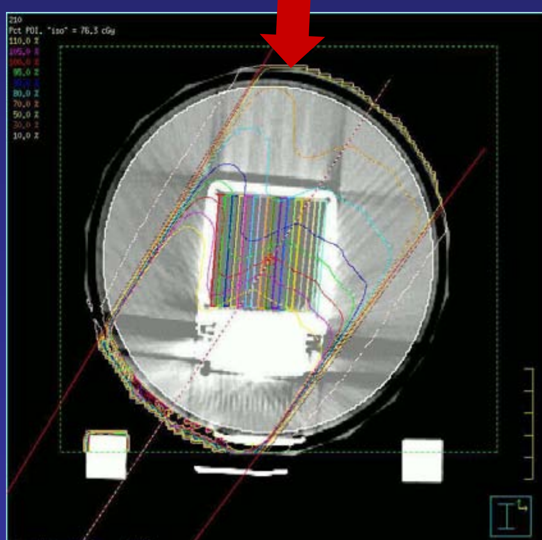
Penumbra test
5×10 cm^2 field (right)
$SSD = 90$ cm, $z_M = 1.53$ cm

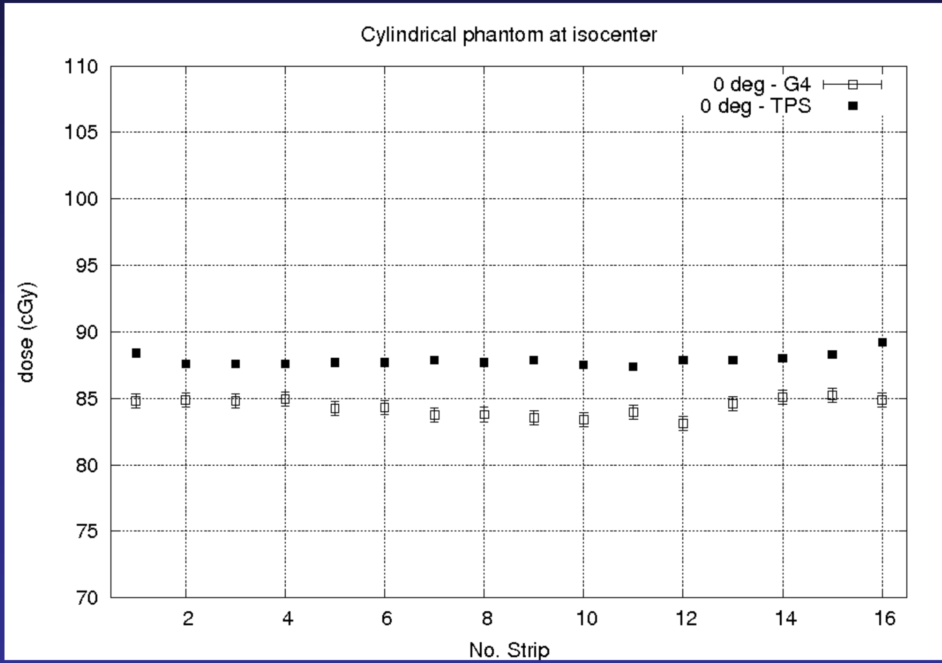
IMRT treatment verification project (Radia): Results

Geant 4

- **Comparing Geant4 simulation with Philips Pinnacle TPS**
  - **Rotation angle = 0 deg**

Beam





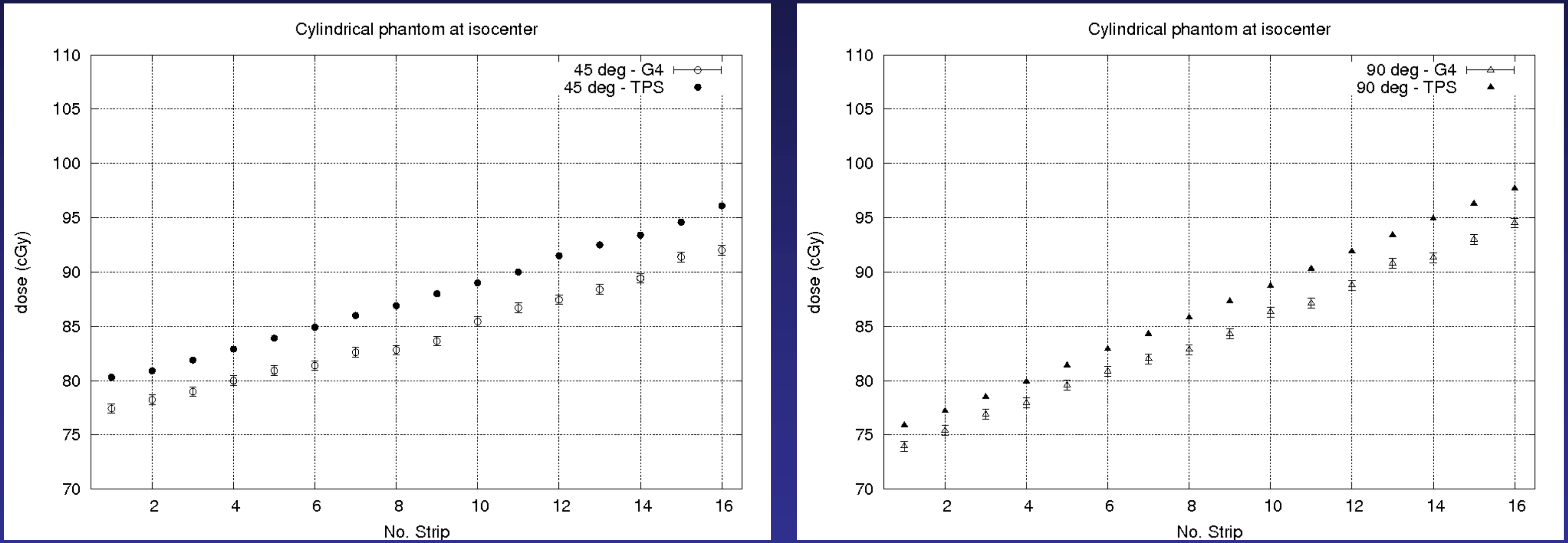
Dose in strips

10×10 cm^2 field

IMRT treatment verification project (Radia): Results

- **Comparing Geant4 simulation with Philips Pinnacle TPS**

Rotation angle = 45 deg **Rotation angle = 90 deg**



Geant4 dose calculations are 4% lower than TPS dose calculations
Calibration factors and material composition are under review

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Optimization for proton therapy applications: Motivation

Motivation

- To decrease the CPU time needed to generate a phase-space file in Monte Carlo simulations of a passive scattering proton therapy nozzle.
- Development of speed-up techniques useful for other nozzles with a similar geometry.

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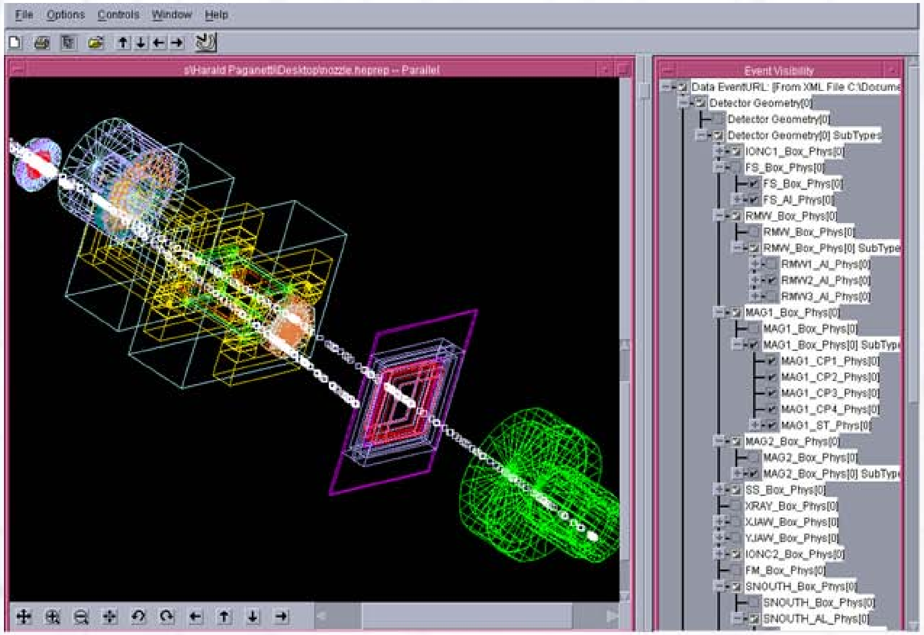
Optimization for proton therapy applications: Initial status

Geant 4

Original MC phase-space code



✓Geant4.9.0.p01

✓Only tracking of protons is considered, so that a phase-space file is created in a not too long time.

✓Secondary radiation (neutrons) is taken into account as background.

Monte Carlo treatment head model: Paganetti et al. Med. Phys. 31:2107-18 (2004)

Physics settings (Geant4 physics list): Zacharatou and Paganetti IEEE-TNS 55:1018-25 (2008)

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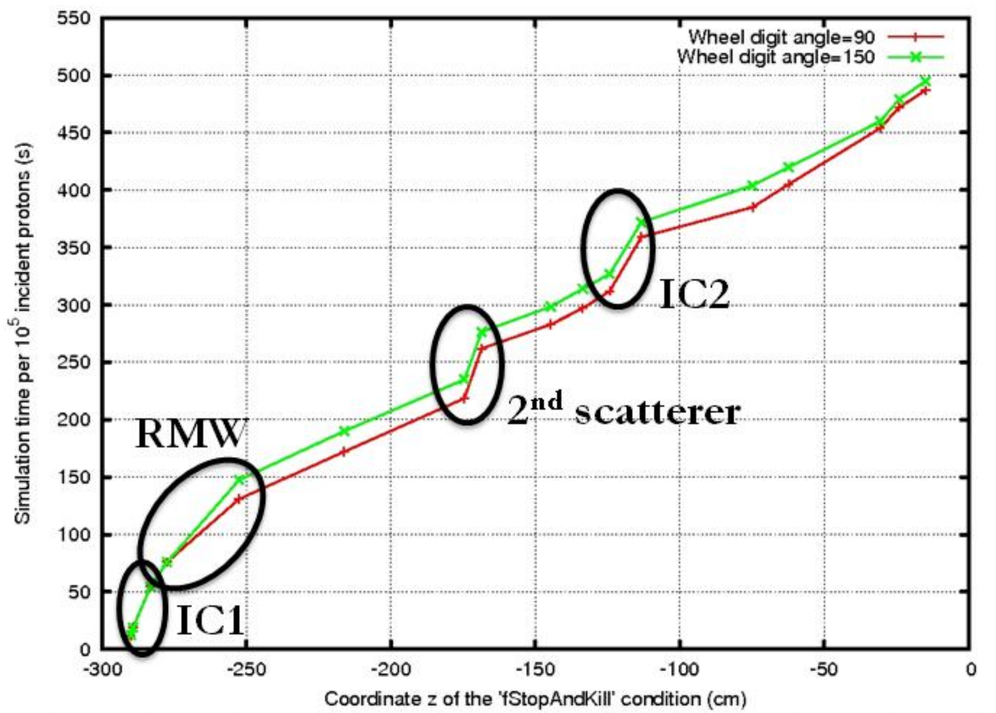
Optimization for proton therapy applications: Initial status

Time spent along the nozzle



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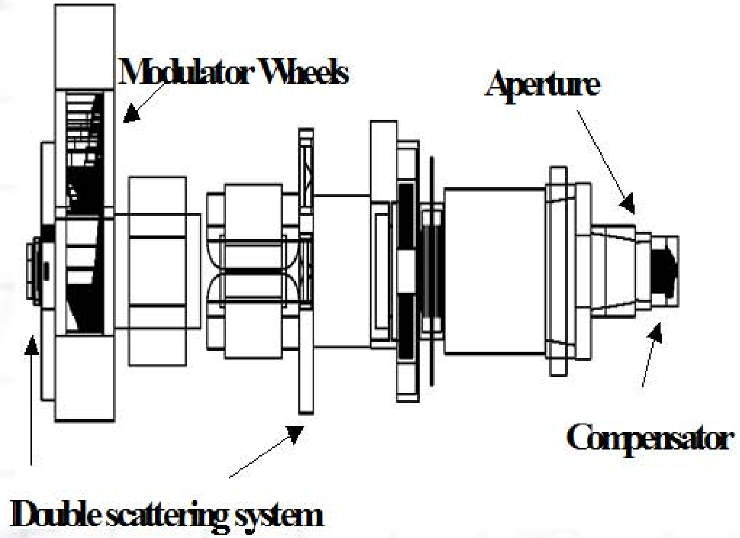
Optimization for proton therapy applications: Speed-up techniques – tracking

Tracking Optimization



- The idea is stop and finish the tracking of protons that will not reach the aperture (primary-proton killer).

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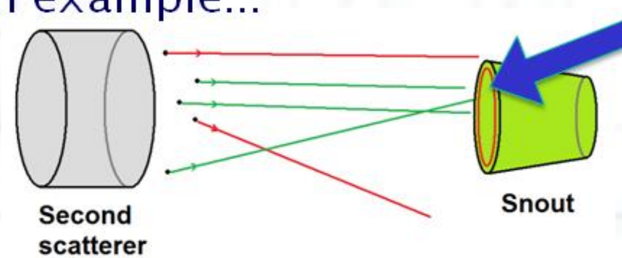
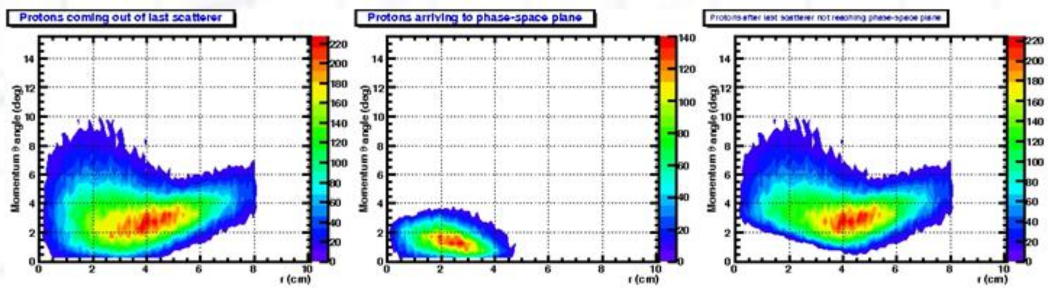
Tracking Optimization

An example...



A tolerance margin is needed.
Open field is considered for study.

- We can 'predict' protons that will not (very likely) come out of the nozzle by analyzing the proton fluence after a given module within the nozzle.



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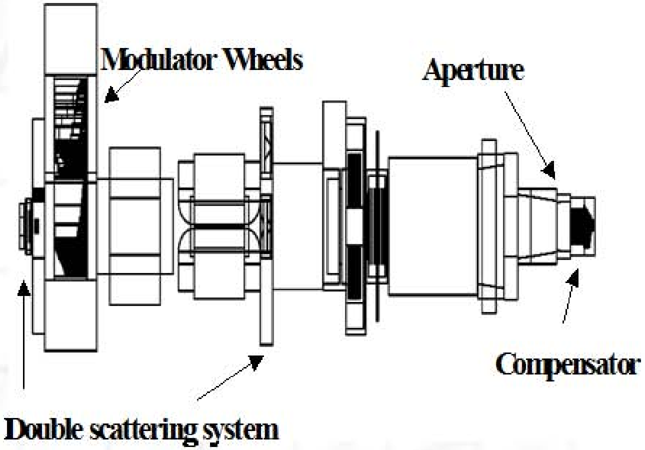
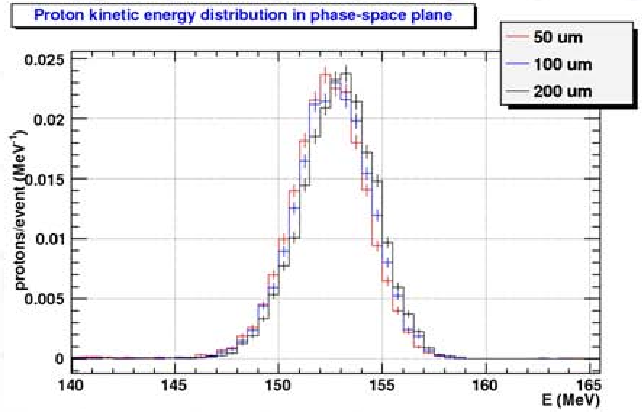
Optimization for proton therapy applications: Speed-up techniques – production cuts

Geant 4

Production Cuts per Region





- Production cuts set to 0.2 mm in hollow regions (snout, magnets, jaws).
  (saving 5% on time).
- Lower value (0.05 mm) for scattering and modulation systems.

A too high **global** cut value may vary the energy distribution at the nozzle exit!

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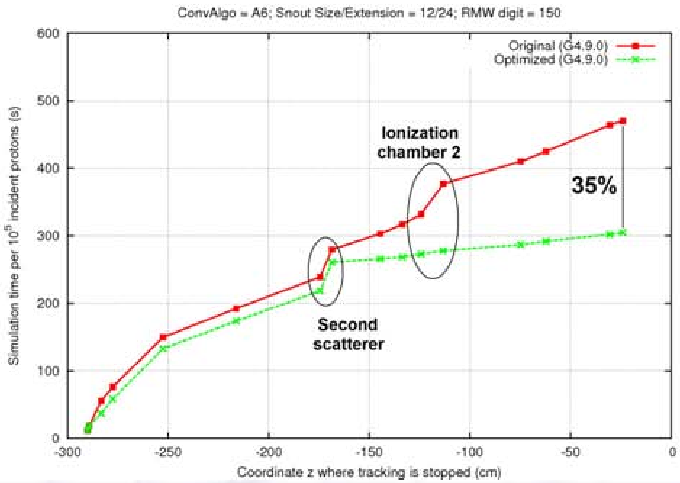
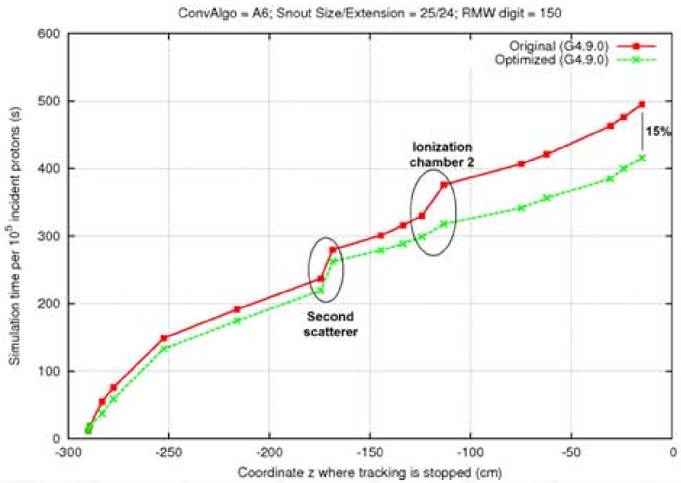
Optimization for proton therapy applications: Main results

New time profiles



12-cm-diameter snout (half extended)



25-cm-diameter snout (half extended)

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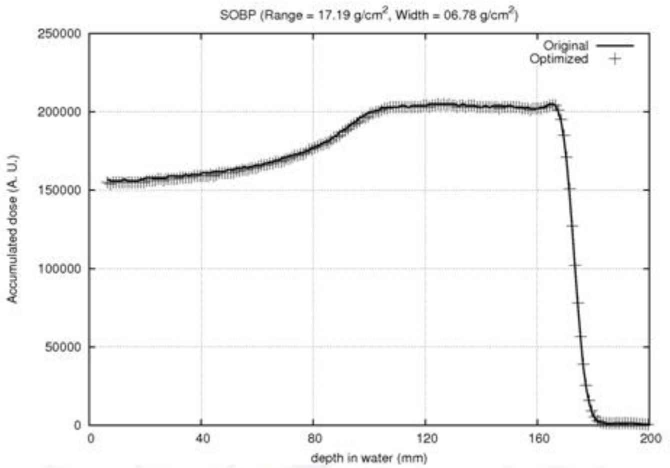
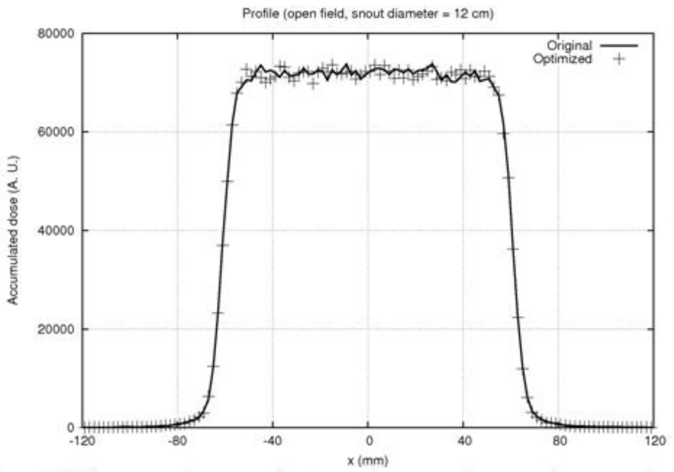
Optimization for proton therapy applications: Main results – verification

SOBP/Profile verification





12-cm-diameter snout

Range = 17.19 cm

Modulation Width = 6.78 cm

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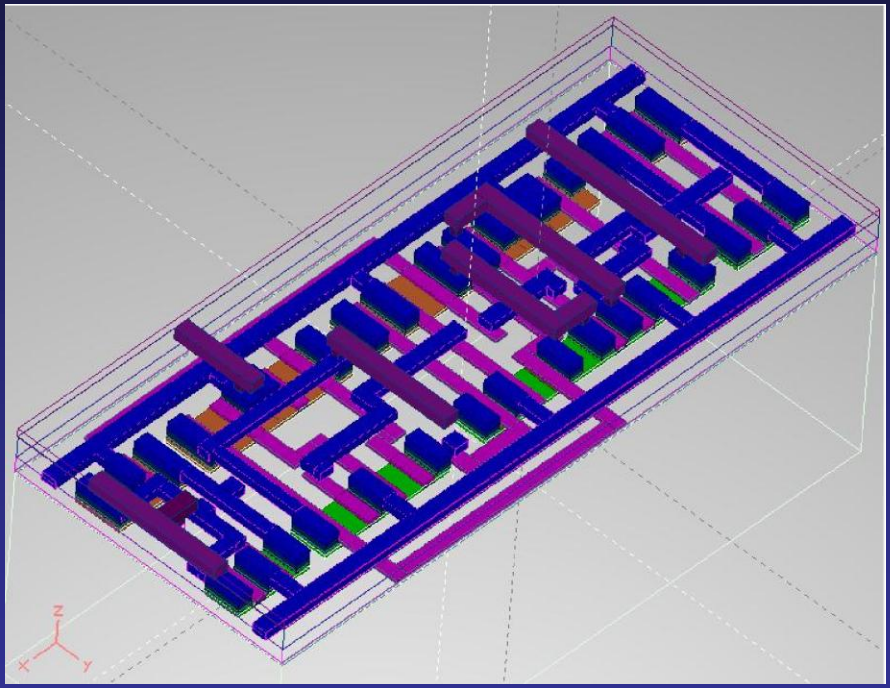
Radiation Effects in Integrated Circuits: Motivation

Geant 4

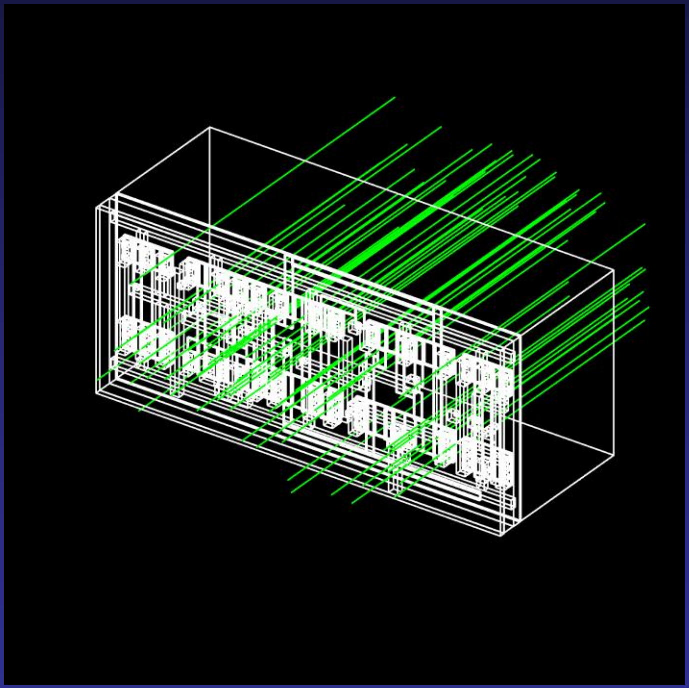
- Ionization tracks on CMOS circuits produce so called Single Event Effects (SEE). Microelectronic devices are sensitive to crossing ionizing particles due to the nanometric scale of their components.
- Measuring the absorbed energy per event in the micro-structures of an integrated circuit is difficult. Therefore, Monte Carlo simulations are useful.
- The goal of this work is to assess the deposited energy in every element of a CMOS AMISC5 flip-flop.

Radiation Effects in Integrated Circuits: Flip-flop geometry

- Geometry imported from FASTRAD (CAD application) via GDML.



FASTRAD model

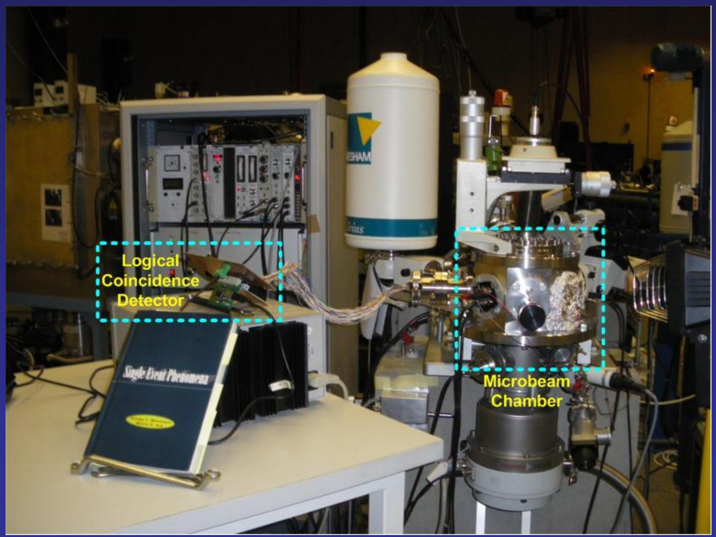


GEANT4 model

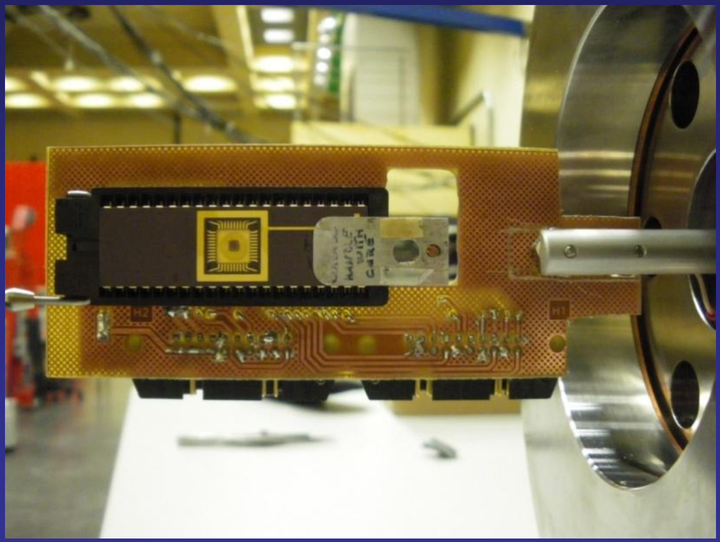
Radiation Effects in Integrated Circuits: Experimental setup

Geant 4

- Proton (18 MeV) and deuteron (9 MeV) beams produced at IBA-CNA cyclotron.
- Ion beams produced at 3-MV tandem accelerator at CNA (alpha, carbon, oxygen and silicon).

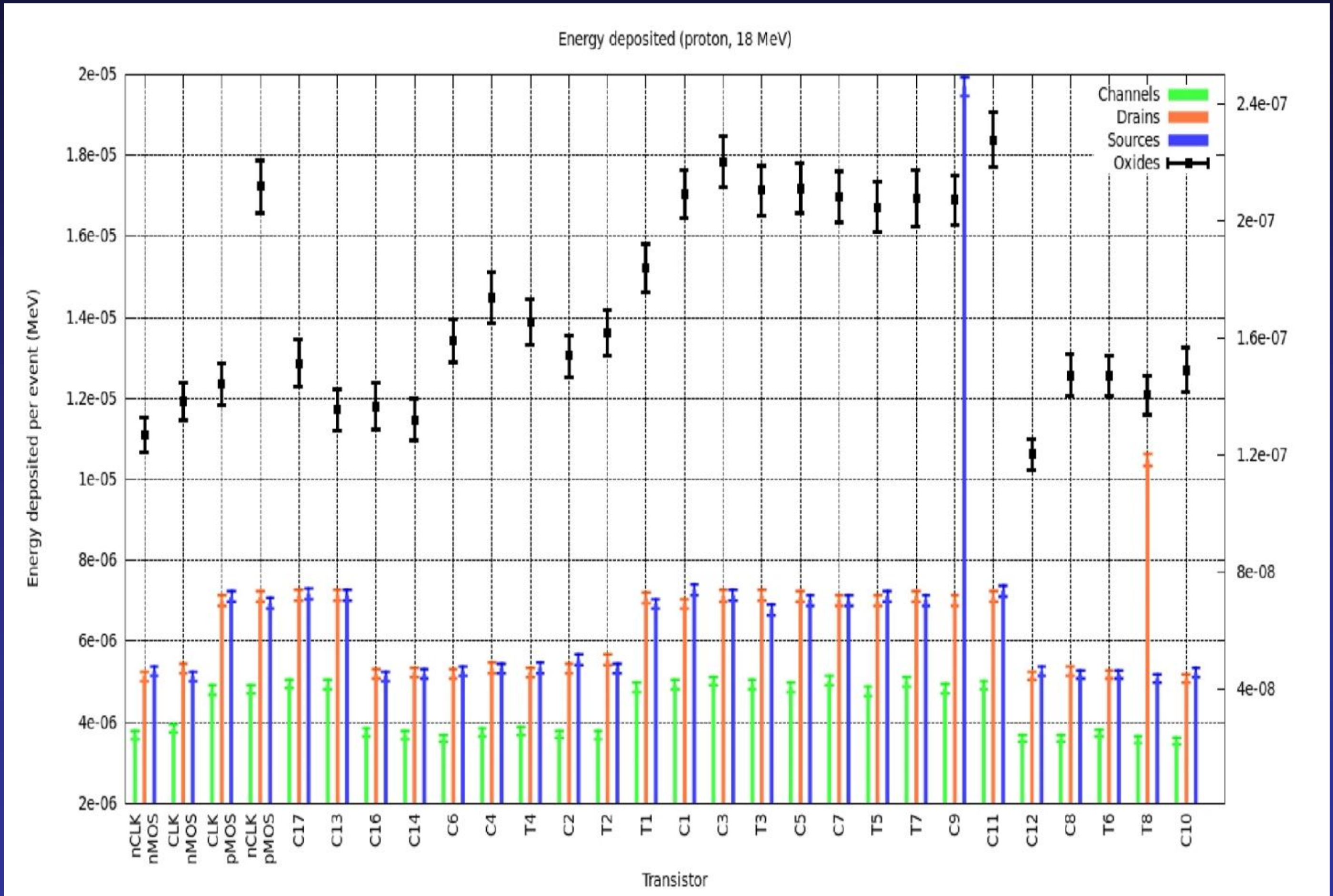


Experimental data acquisition
(by courtesy of F. R. Palomo, Univ. Sevilla)



Target
(by courtesy of F. R. Palomo, Univ. Sevilla)

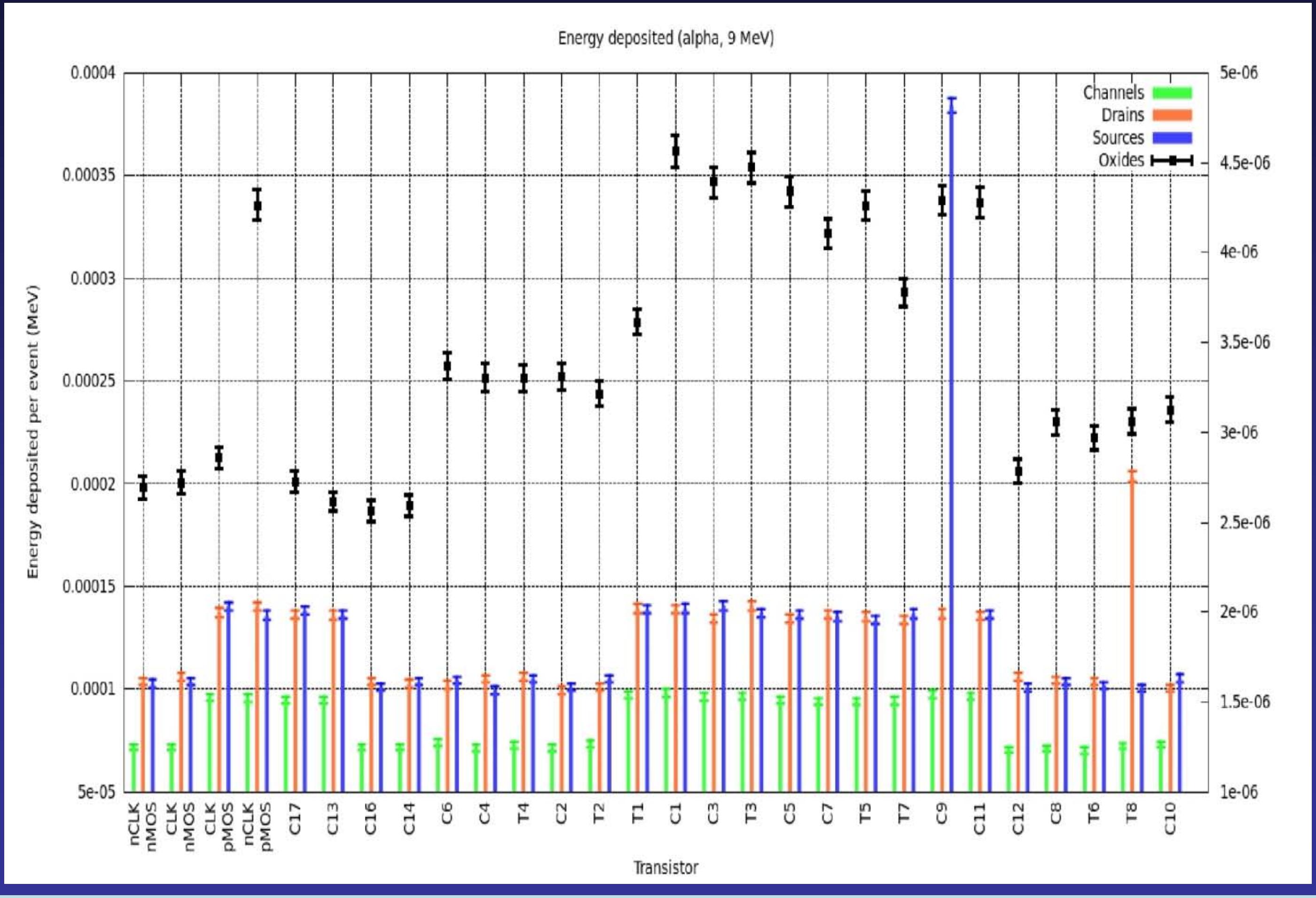
Energy deposited (proton @ 18 MeV)



Radiation Effects in Integrated Circuits: Results

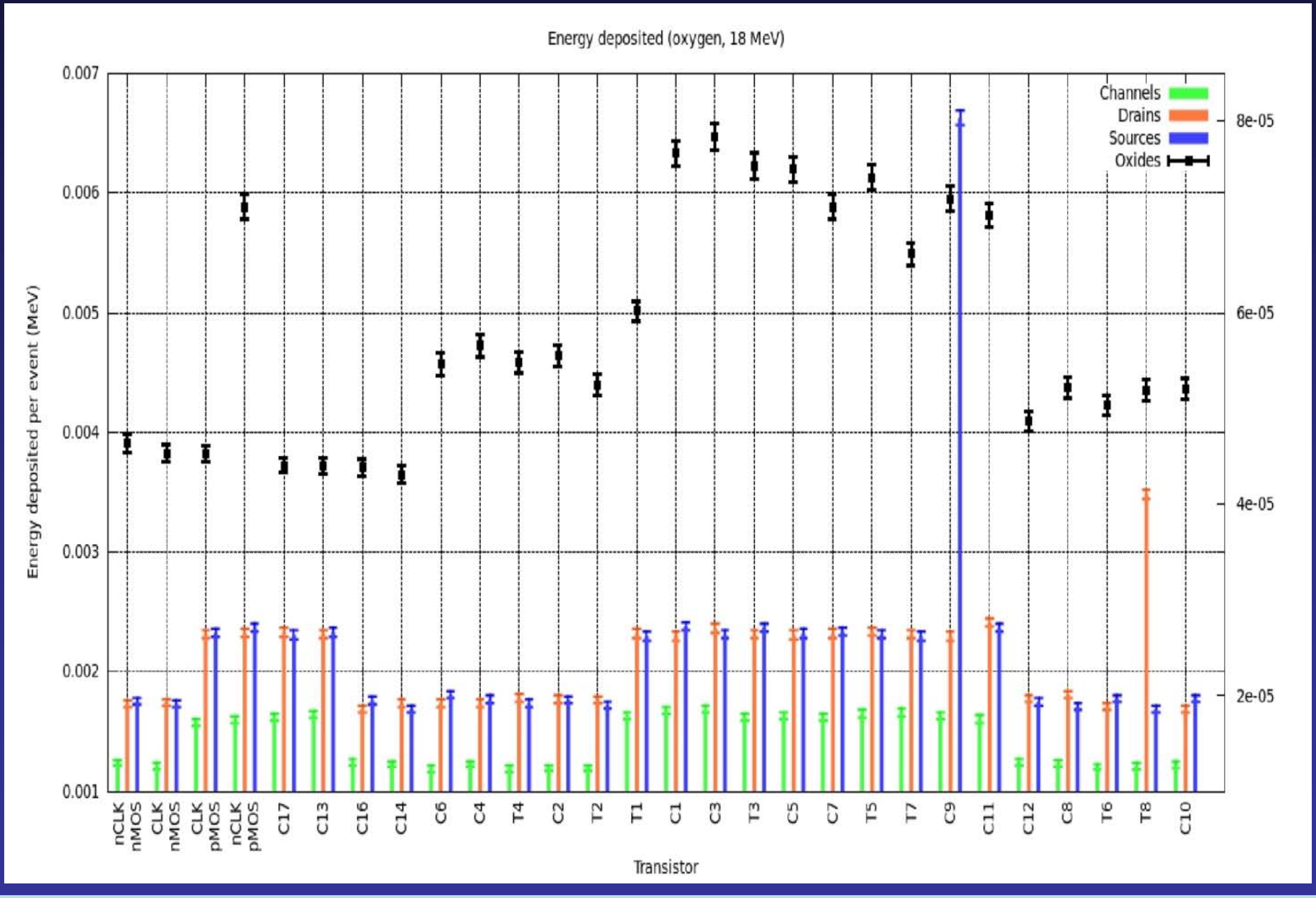
Geant 4

Energy deposited (alpha @ 9 MeV)



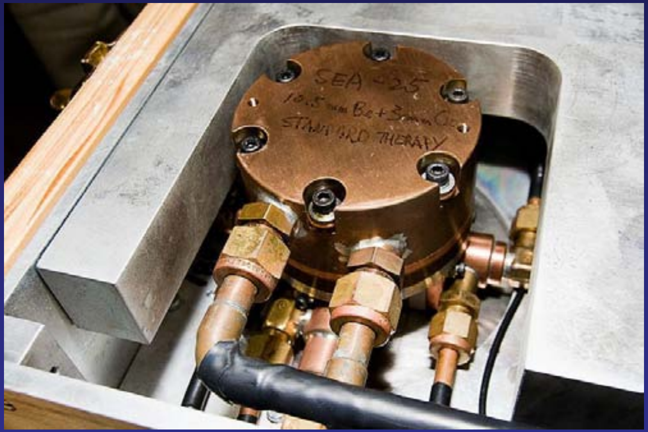
Radiation Effects in Integrated Circuits: Results

Energy deposited (oxygen @ 18 MeV)



Radiation Effects in Integrated Circuits: Work in progress

- This GEANT4 application is currently in use to simulate a new neutron source facility planned at CNA. Concretely, a ^{9}Be target will be placed at IBA-CNA cyclotron exit.



- This new facility will support fast neutron irradiation of microelectronic devices.

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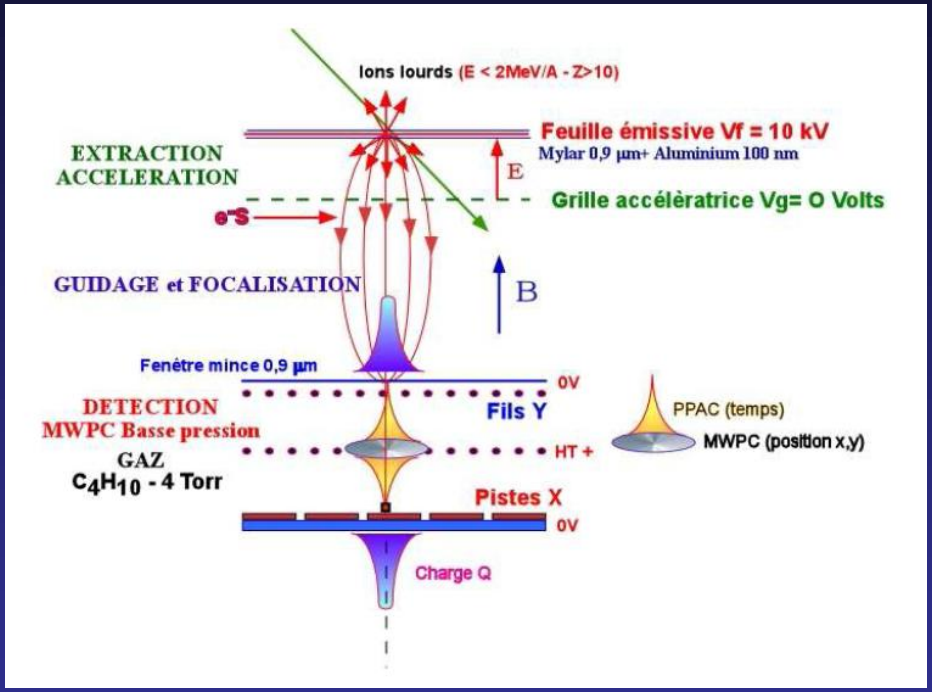
Mini-SeD prototype simulation Overview

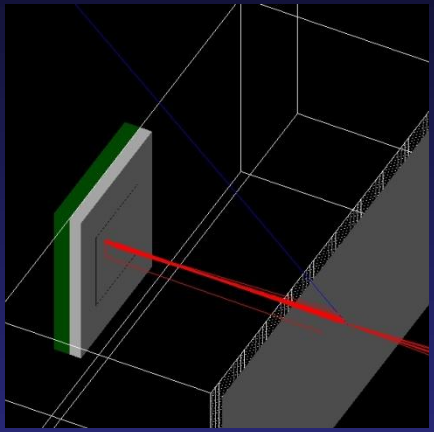
Geant 4

Experimental scheme

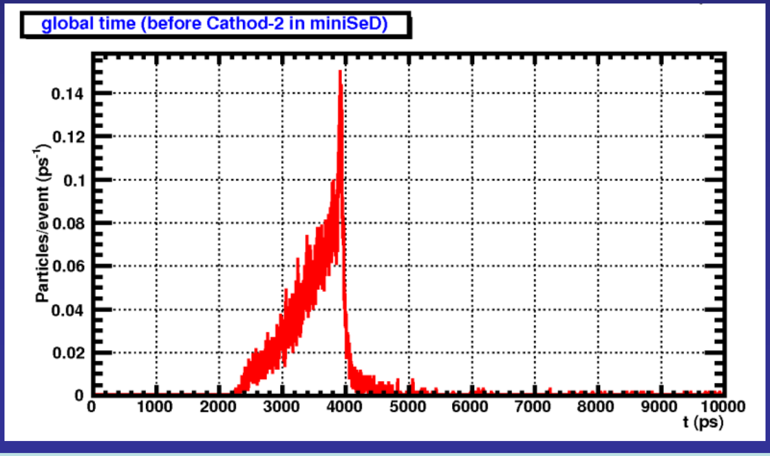


Scheme by courtesy of M.A.G. Alvarez and B. Fernández (University of Sevilla)

Geometry



time distribution for e-



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Conclusions

- We have used GEANT4 in different research fields. Monte Carlo simulations have become a very powerful tool in our group.
- In medical field, our goal is to use Monte Carlo simulations as a tool to verify radiotherapy treatments which may be challenging for TPS algorithms. Time spent by CPU is a key issue.
- In the study of the radiation effects in integrated circuits, we use GEANT4 as a tool to evaluate the energy deposited in each element of the circuit, and to give support to the experimental results (predictable malfunctions, pulses...)
- This 'virtual lab' helps us to optimize a testing detection setup.

And that’s all...

THANKS FOR YOUR ATTENTION