# Modelling packaging effects on proton irradiation response of NMRC RadFETs

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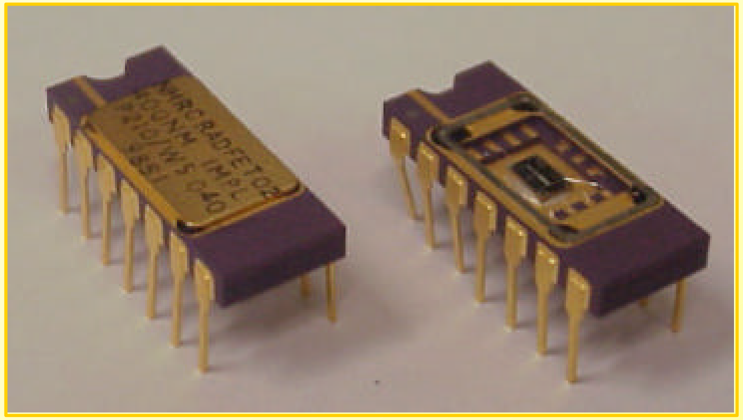


# Abstract

The gamma radiation response of NMRC RadFETs has been well established in previous calibration work at the ESA $^{60}Co$ facility. However, recent proton irradiation results of NMRC RadFETs have revealed discrepancies in terms of the RadFET proton response. Observations indicate that the RadFET response is dependent on proton energy as well as varying with the package configuration. In this work, a novel approach involving the particle transport Monte Carlo software tool (GEANT4) has been adopted to analyse the influence of the RadFET package on its proton response. The packaging effect was investigated by studying the total ionising energy deposited by primary and secondary particles (generated in the RadFET and its package) in the RadFET gate oxide. During the simulation run, each secondary particle generated was logged including information regarding its origin, species, energy, trajectory and the energy deposited in the gate oxide. The ratio between the primary and secondary total ionising dose contributions were calculated and compared to experimental proton irradiation results for different packaging configurations.

# Introduction

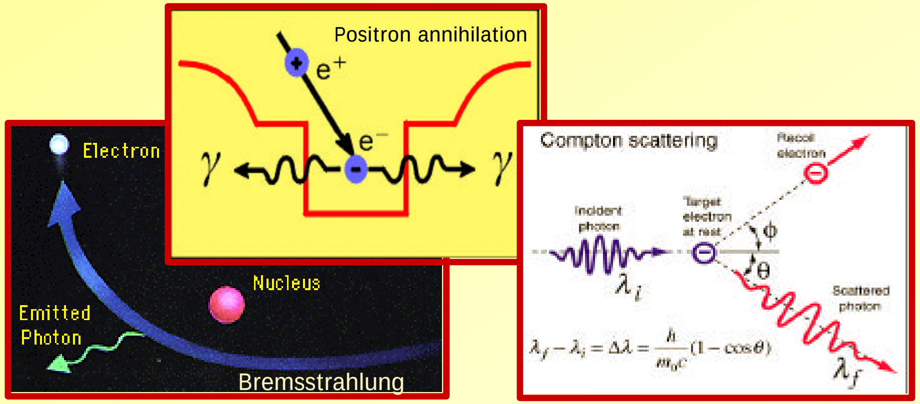
The scope of this activity is to employ the GEANT4 toolkit to perform proton irradiation simulation runs on NMRC RadFETs equivalent to proton irradiation tests performed on the devices to quantify Total Ionising Dose contribution from secondary particles generated in the RadFET package. Proton irradiation tests were performed with three different proton energies, 10, 60 and 300 MeV. For ease of comparison the same proton energies were employed in the GEANT4 simulation runs. As for the irradiation tests the GEANT4 simulations were performed for devices with and without package lid.

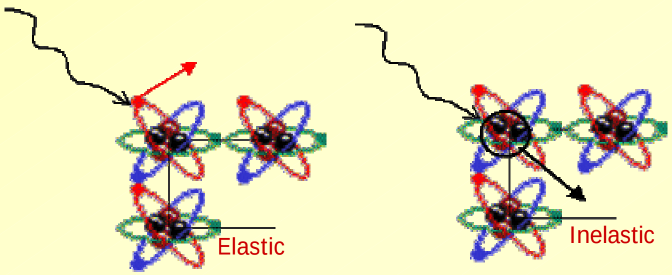
# Using Geant4.4.0 to simulate NMRC Radfets

Geant4 is a Monte Carlo simulation toolkit for particle transport and interaction through matter, across a wide energy range from a few eV to PeV. It provides a set of tools for detector simulation: Geometry, Tracking, Detector Response, Events Run, Event Description and Track Management, Visualisation and User Interface, as well as an abundant set of Physics Processes handling the complex interactions of particles with matter.

As for the proton irradiation tests the simulated proton beam was perpendicular to the RadFET front side. To simulate the NMRC RadFET response to different proton energies the following physical processes were selected.

# *Geant4 Physics Models and Data Sources:*



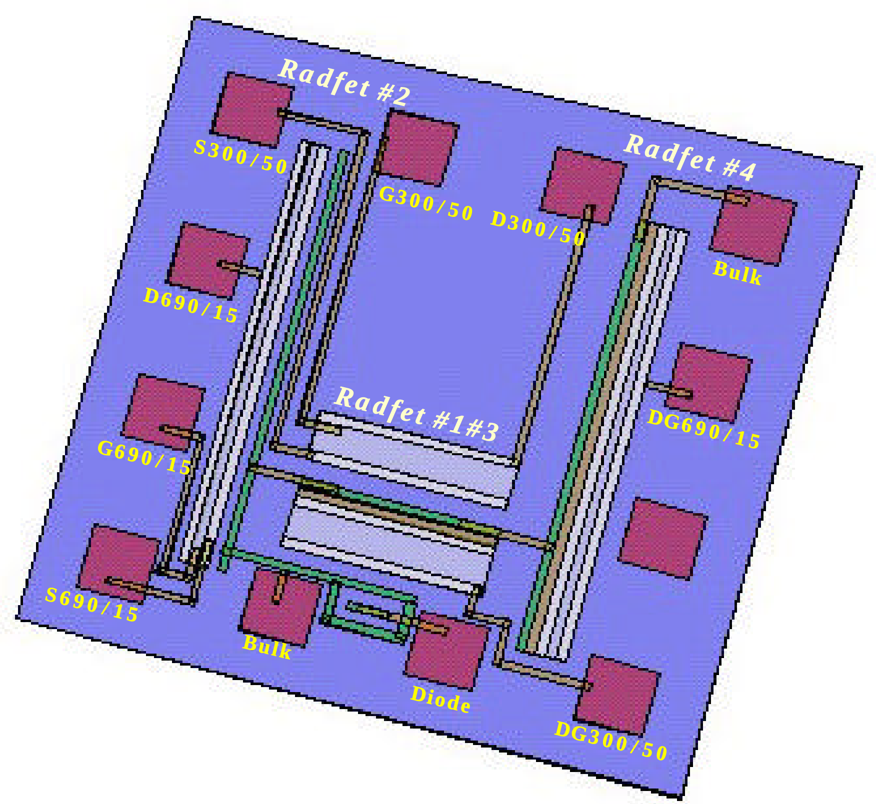

- **Standard and Low energy Electromagnetic:** Ionisation; δ-ray production; Multiple scattering; Bremsstrahlung; Annihilation; Photoelectric effect; Gamma conversion; Compton scattering; Rayleigh scattering; Pair-production; Atomic relaxation.

- **Low and High Energy Hadronic Shower:** Elastic and Inelastic interactions for different hadrons (protons, neutrons, tritons, deuterons,…) targeting particles from 10MeV up to some GeV.

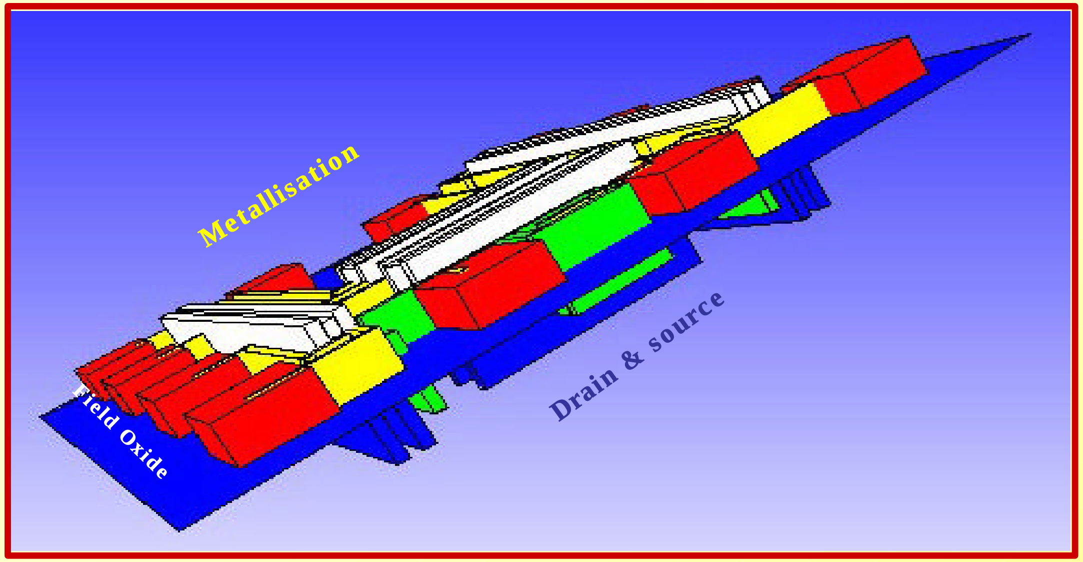
# *Physics Models limitations:*

These models do not allow secondary heavy ions tracking!

## *NMRC RadFET Geometry Definition:*




There are four RadFET in each device.




## *Geometry simplification:*

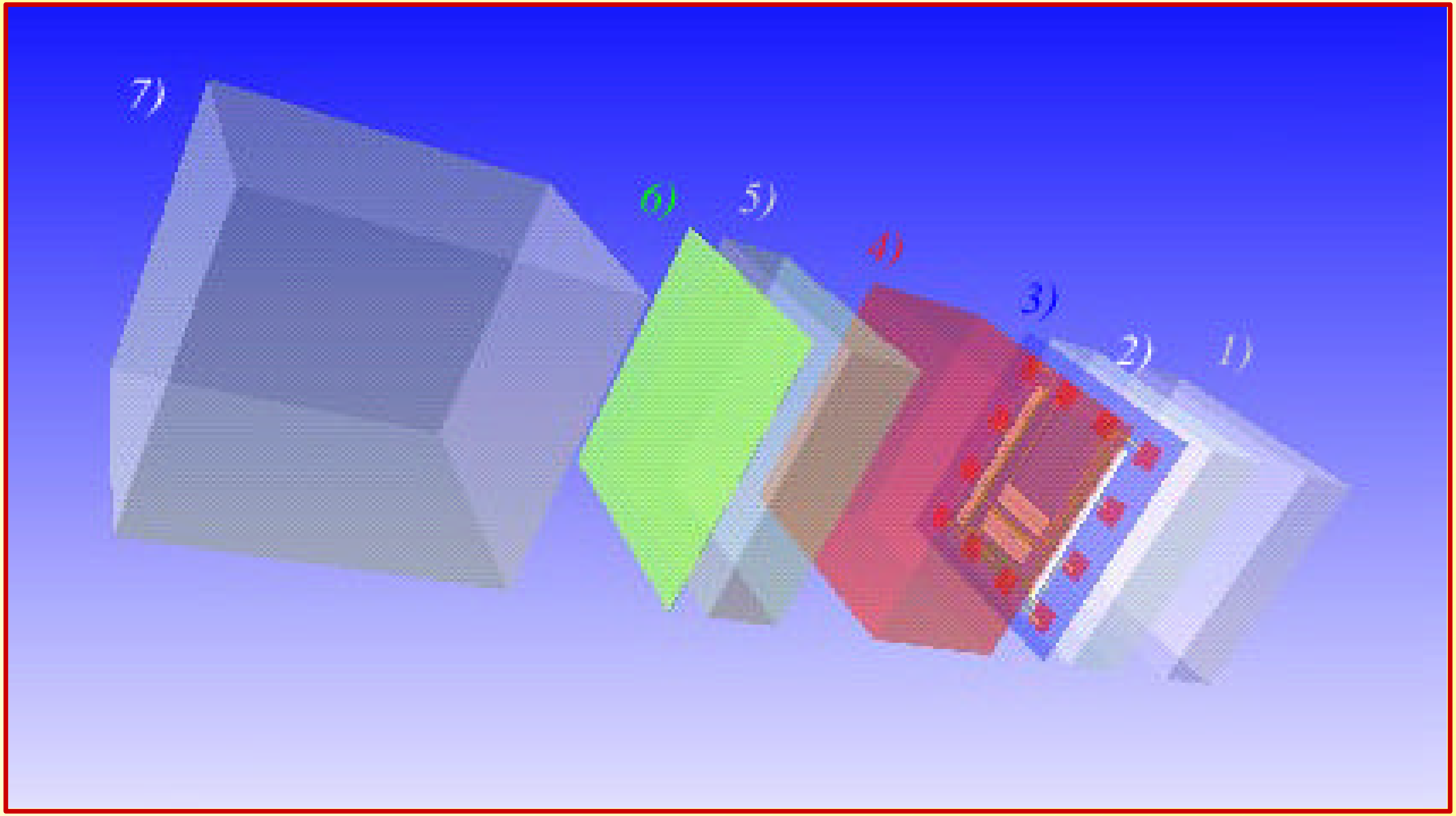
Gate oxide doping not considered.

# NMRC Device Packaging

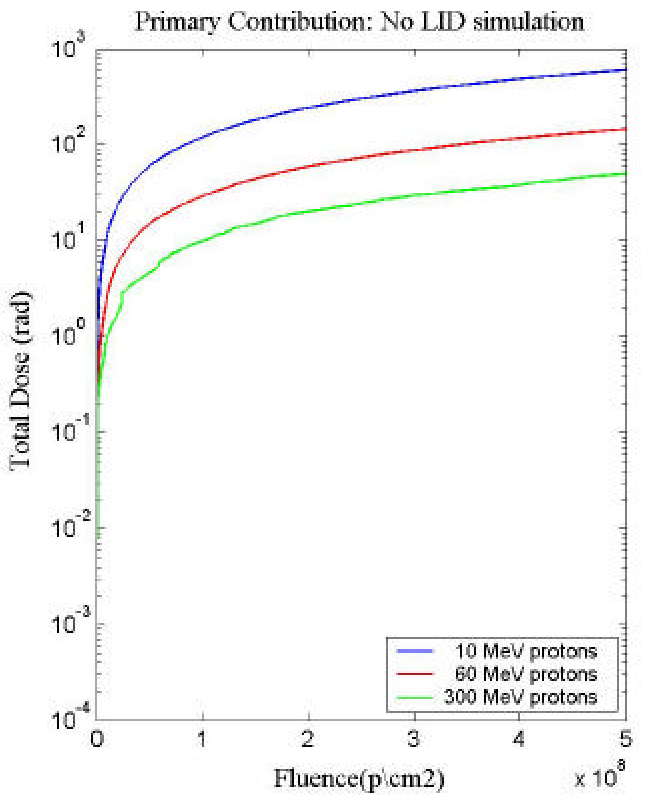
The simulated and tested devices are composed by the following layer (illustrated in the figure below) of different thickness and composition:

- Package lid - Th: 250 μm; Kovar (Ni, Co, Fe);
- Vacuum - Th: 250 μm;
- RadFET DIe - Th: 1.5 μm;
- Substrate - Th: 500 μm;
- Die attach adhesive - Th: 250μm; (Ag, SiO2)
- Die attach pad - Th: 3.75 μm;
- Package base - Th: 1000μm; ($Al_2O_3$);

An exploded view of the device illustrates the lid (1), the adhesive, the attach pad and the base (5-7) as part of the package.



# Simulated Response to Proton Irradiation



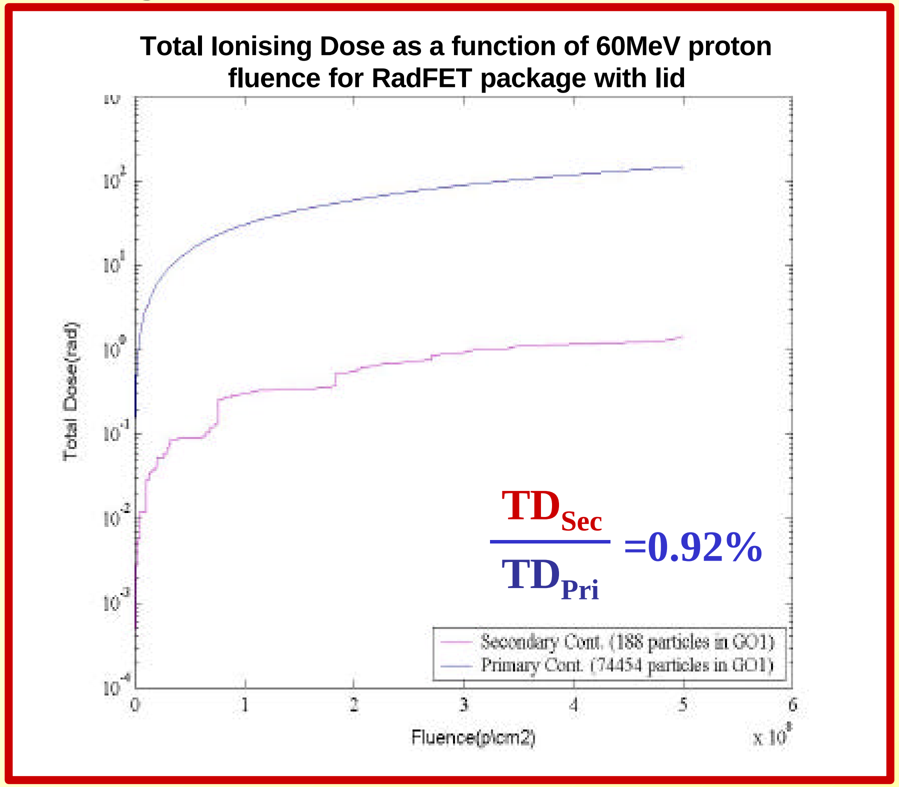

Geant4 simulation of primary particle energy deposition in the RadFET Gate Oxide.

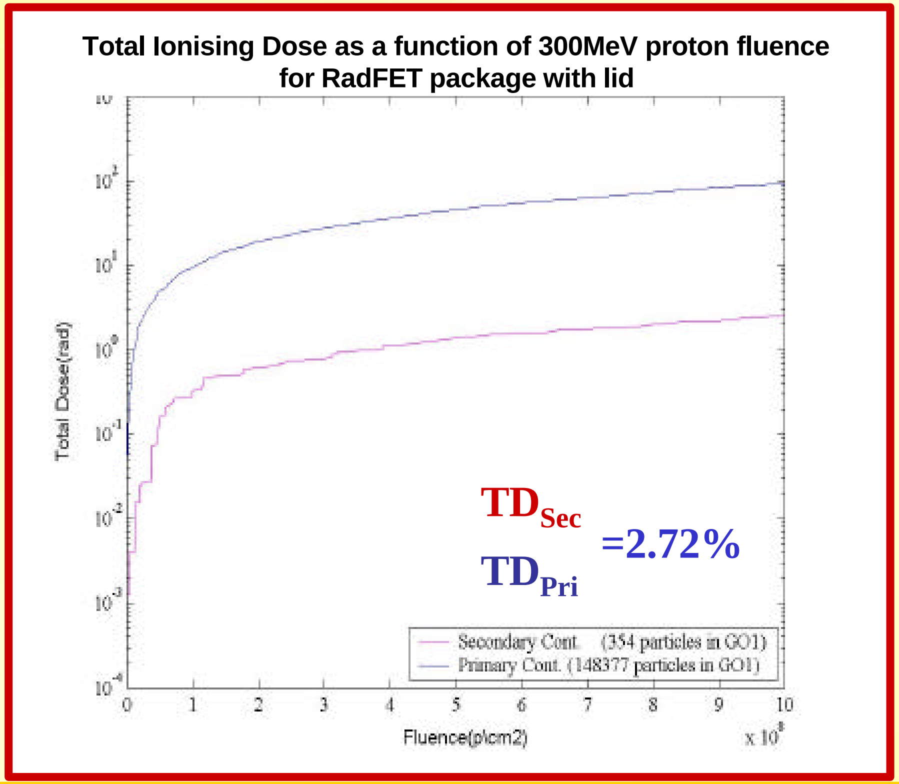
These results were used to compare the ratio between primary and secondary TID contributions.

Primary TID deposition values agreed well with results obtained from TRIM simulations.

# Primary and Secondary Contributions

Geant4 simulation shows that the ratio between the secondary and primary contributions is dependent on the proton energy.

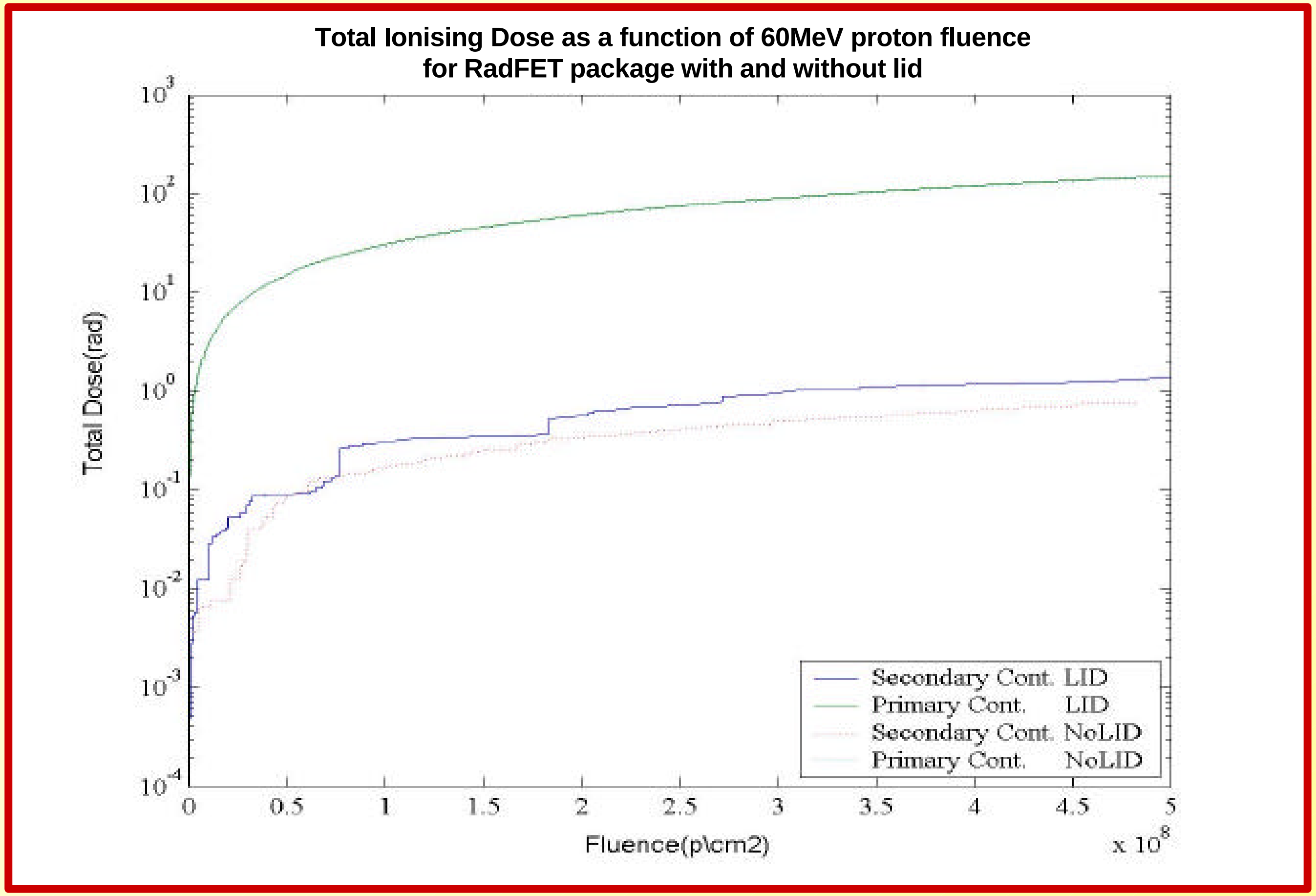



For 300MeV protons, the ratio between secondary and primary particle TID contributions is approximately 3%, for 60MeV protons the value is approximately 1%.

# Package effect: Secondary Contribution to Total Dose

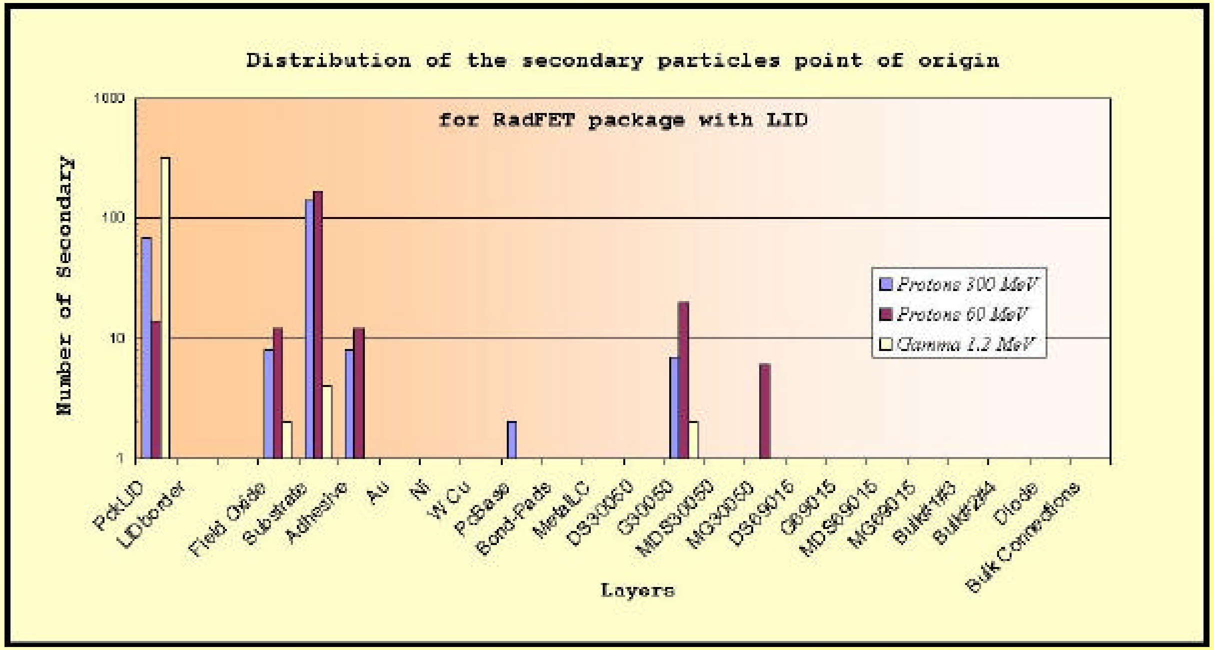
The RadFET response is dependent on the packaging. The secondary contribution is lower for the No Lid configuration.

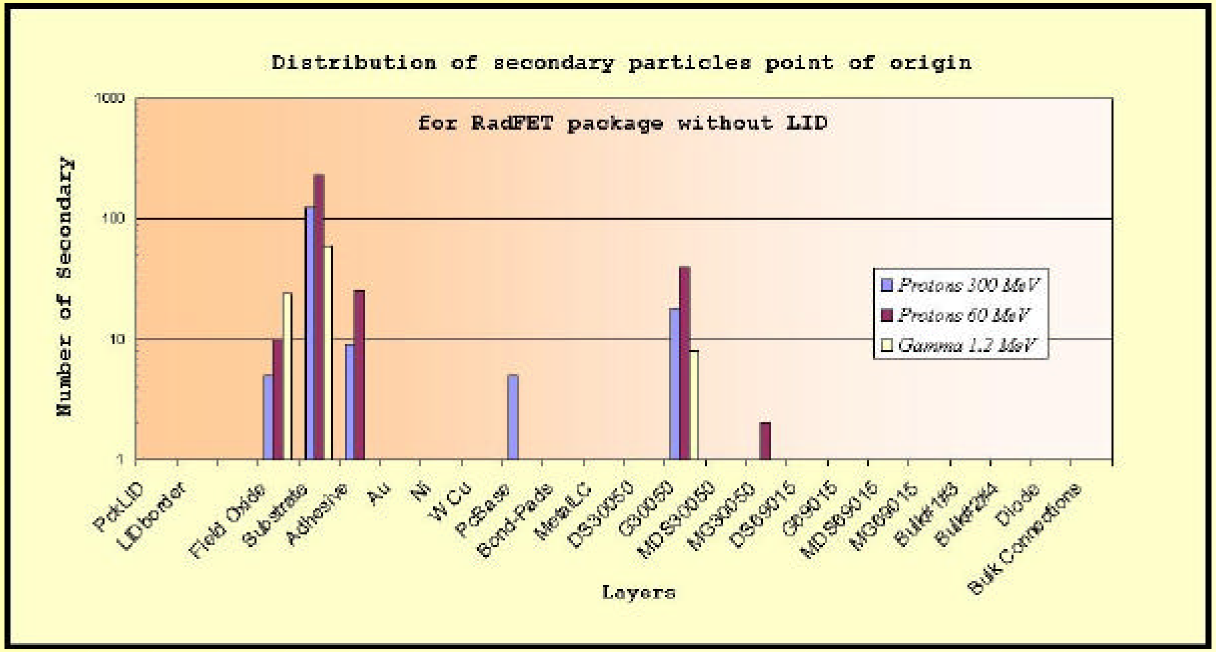


# Investigating Secondary Particles and Package Effect

In order to study the packaging influence on the secondary total dose contribution, all secondary particles were tracked from their point of origin. Two configurations, “LID” and “No LID”, were simulated.

The results reveal that a significant number of secondary particles are generated in the RadFET substrate and the package lid.

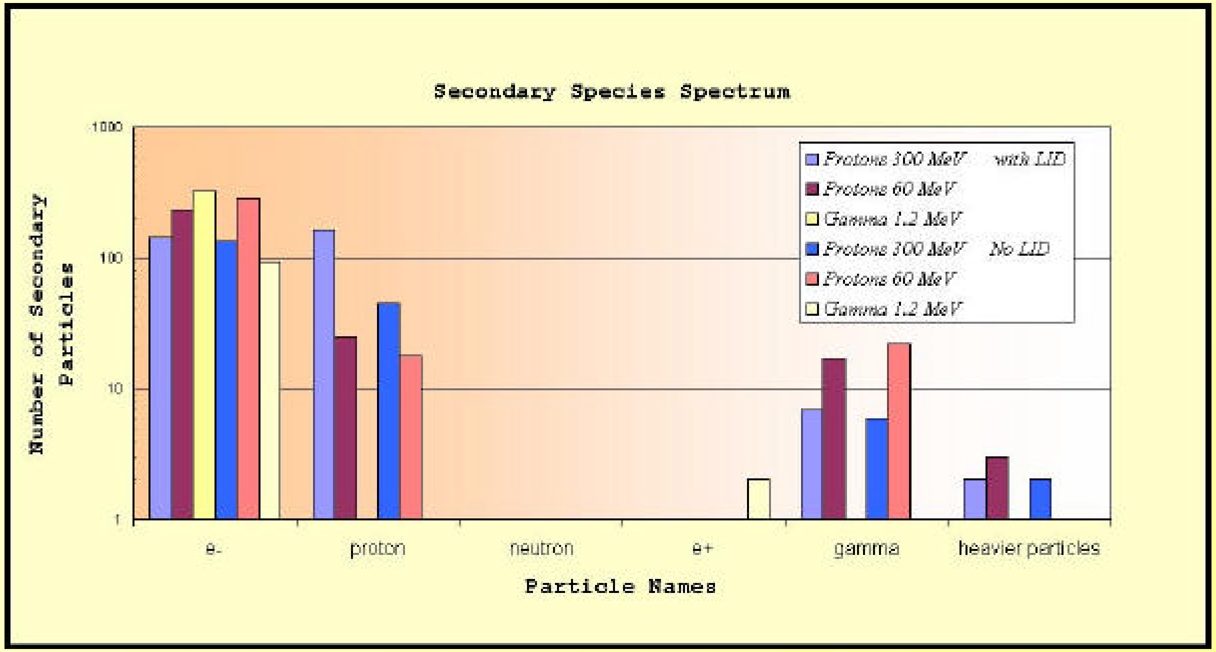


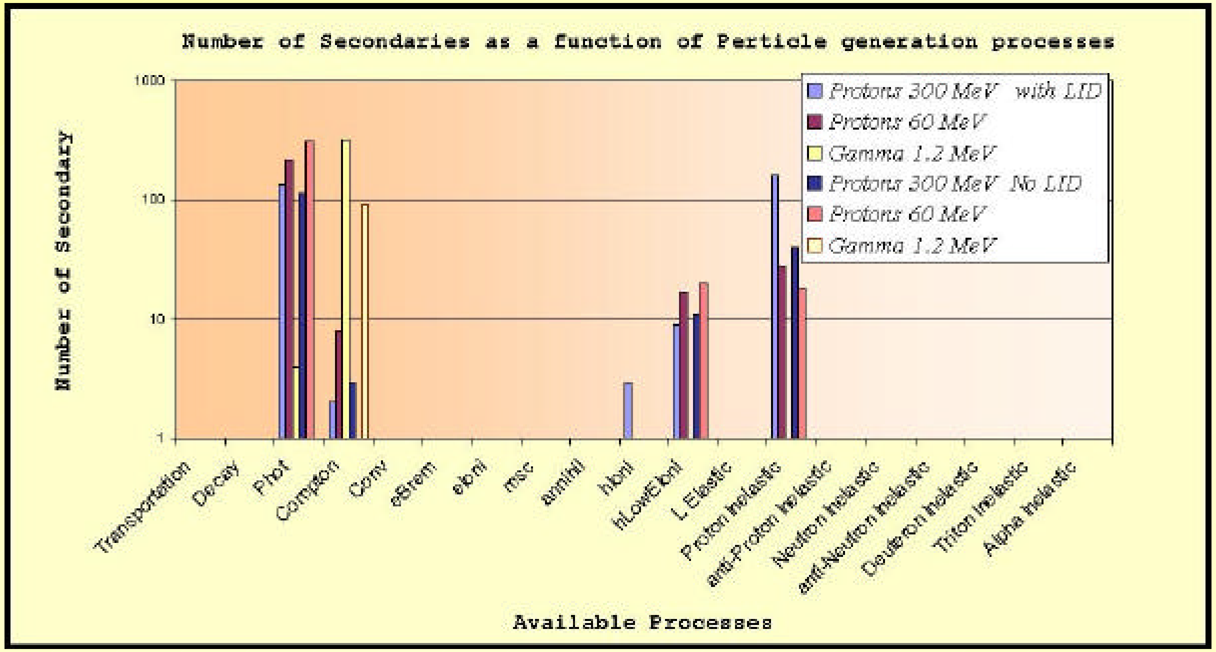



The simulation with no lid illustrates that the majority of the secondaries are generated in the substrate.

Gamma irradiation creates electrons mostly by the Compton effect.

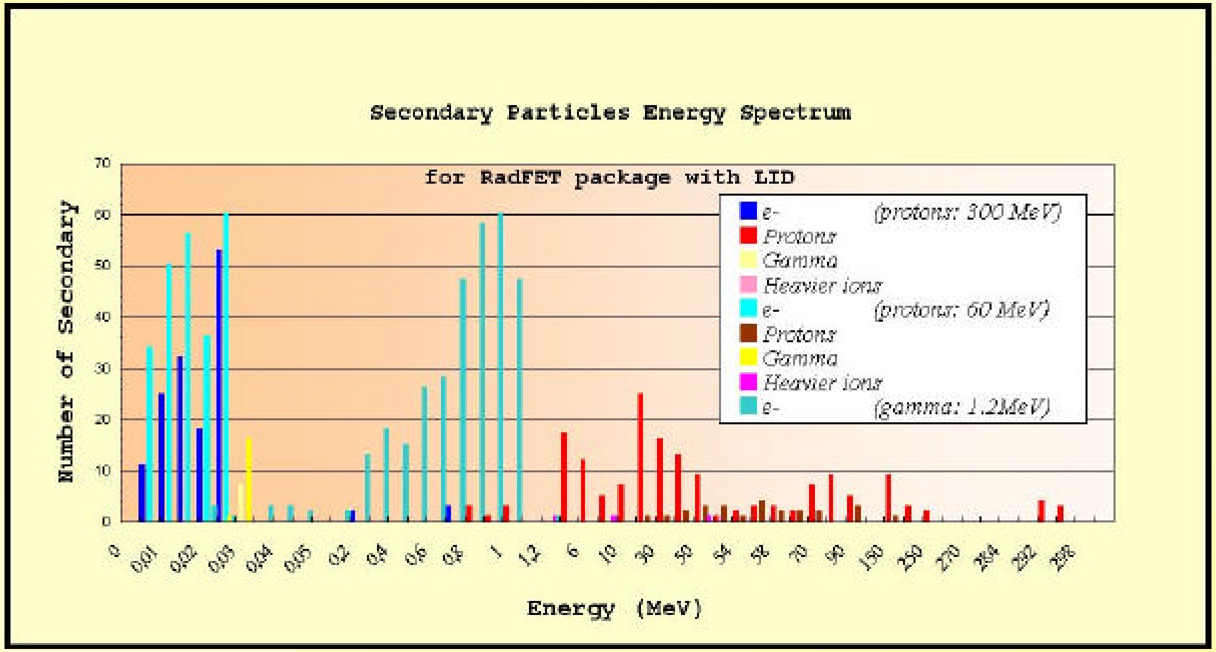
The spectrum of particles is similar for both simulation (LID&No LID).






Proton irradiation generates electrons by ionisation as well as by the photoelectric effect but it can also create protons and heavier ions by means of inelastic interactions.

The energy spectrum of the secondary particles before depositing energy in the gate oxide is similar for simulations with or without the package lid.

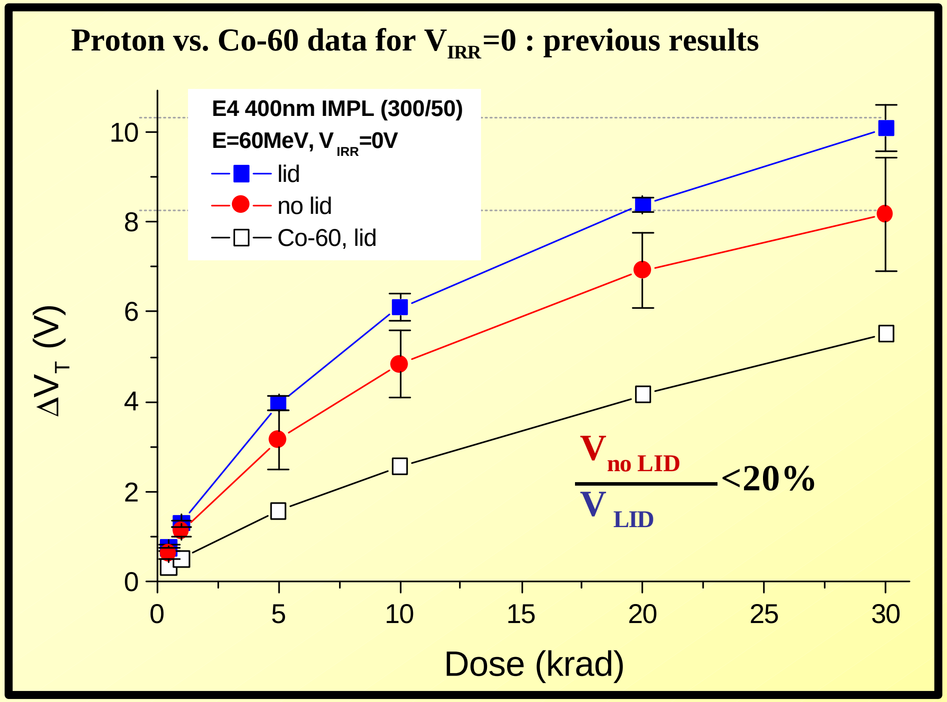



The most energetic secondary particles consist of protons and heavier ions generated by proton irradiation.

Electrons produced by gammas have higher energy than the ones generated by protons.

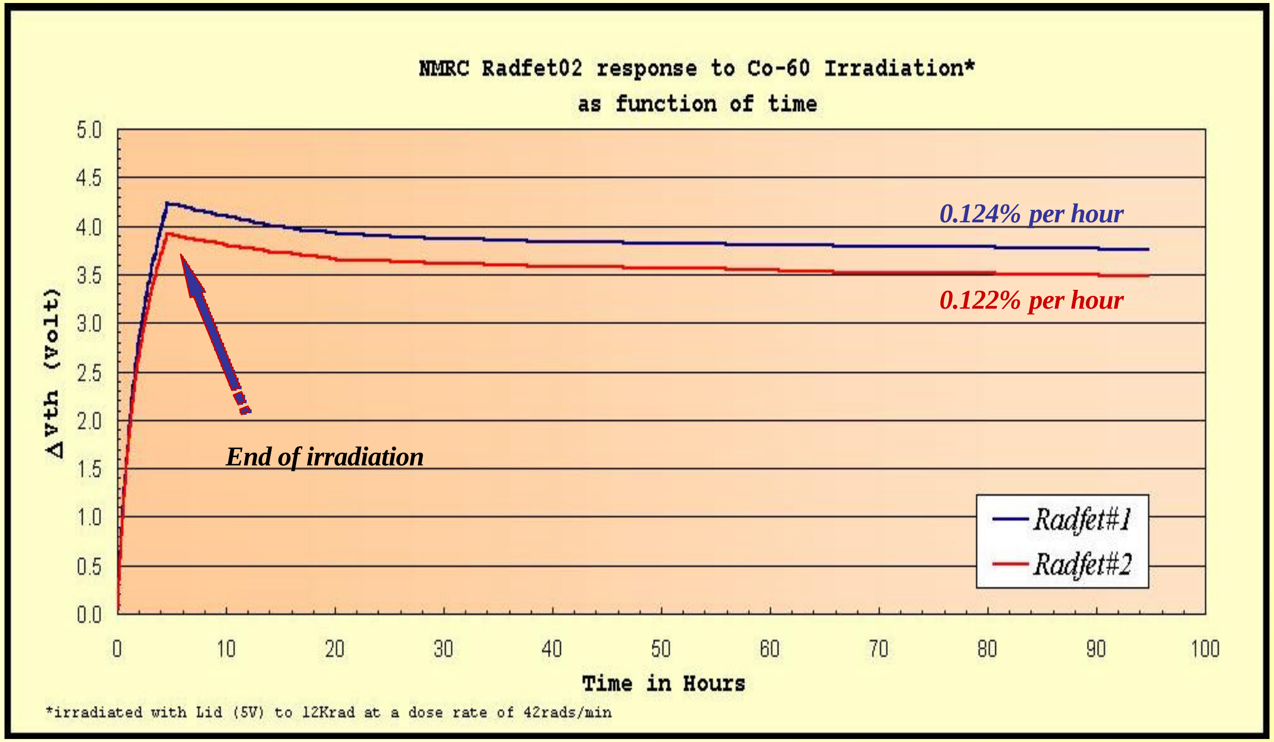
# Comparison with Experimental Results

Experimental results performed by NMRC illustrate discrepancies between proton (Lid & No Lid) and gamma irradiation results. As an example, the 60 MeV proton irradiation results indicate a factor ~2 difference compared to the gamma calibration results and a ~20% difference in response between devices with and without lid.



The GEANT4 results illustrate that these large discrepancies may not be explained by secondary particle TID contribution alone (also considering the simulation limitations). Other effects such as dose rate/annealing effects and device to device response non-uniformity may be important contributors to the observed proton/gamma irradiation response discrepancy.

Co-60 irradiations of 400nm implanted devices were preformed for both RadFET#1 and #2.




The devices were irradiated during 4.6 hours at a dose rate of 42rad/min and room temperature of 20°C (+/-0.5°C).

Preliminary results of annealing, show that the devices response decreases by 11% in 4 days. Most of the annealing occurs in the first 15 hours.

# Further Work

The GEANT4 simulation method can be improved according to the following points:

- Pre-Compound GEANT4 physics model can be implemented to track heavy ions;
- More realistic energy deposition calculations may be performed if oxide doping is included in the simulations;
- A more realistic proton beam can be simulated according to the PSI beam profile.