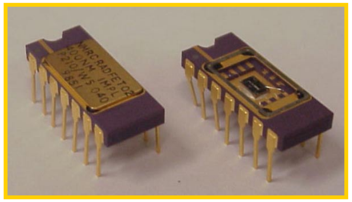
Modelling packaging effects on proton irradiation response of NMRC RadFETs

New GEANT4 simulations



A.Keating[1], A.Mohammadzadeh[1], P.Nieminen[2], B.Nickson[1], W. Hajdas[3], A.Jaksic[4]

[1] ESA/ESTEC/TOS-QCA, Postbus 299 - NL 2200 AG Noordwijk, The Netherlands.

[2] ESA/ESTEC/TOS-EMA, Postbus 299 - NL 2200 AG Noordwijk, The Netherlands.

[3] PSI, Paul Scherrer Institut, CH-5232 Villigen, Switzerland.

[4] NMRC, University College Cork, Lee Maltings, Prospect Row, Cork, Ireland.

Abstract

Previous observations indicate RadFET response :

- may depend on proton energy
- varies with the package configuration.

In this work GEANT4 has been used to :

- Analyse the influence of the RadFET package on the proton response for different energies.
- Compare simulated and experimental results, using the ratio between the primary and secondary total ionising dose contributions for different packaging configurations.

Outline

- Introduction
  - NMRC RadFET description and Geometry
  - Briefly: Physics Models
  - Simulation scheme
- Proton beams
- Simulated Response:
  - Primary TID vs. Proton energy
  - Secondary TID vs. Proton energy
  - Primary vs. Secondary TID
  - Package effect
  - Secondary particles
- Simulation/Experimental results
  - 10MeV case: considerations
- Conclusions
  - Further work: possible improvements

Introduction

Global scope:

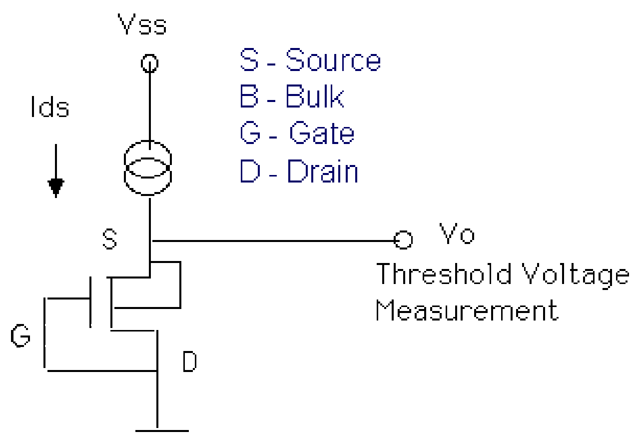
- Learn how to predict component radiation behaviour in space by performing lab experiments and simulations.

Work description:

- Proton beams simulated according to PSI beam profiles for 10, 60 and 300 MeV.
- Employ the GEANT4 to quantify TID contribution from secondary particles generated in the RadFET package and Gate Oxide.

NMRC RadFET description

- MOSFET based dosimeter with optimised gate-oxide for increased radiation sensitivity.
- Induces charge trapping in the gate oxide and at Si/SiO_2 interface → threshold voltage shift : $\Delta Vo = f\,(TD)$

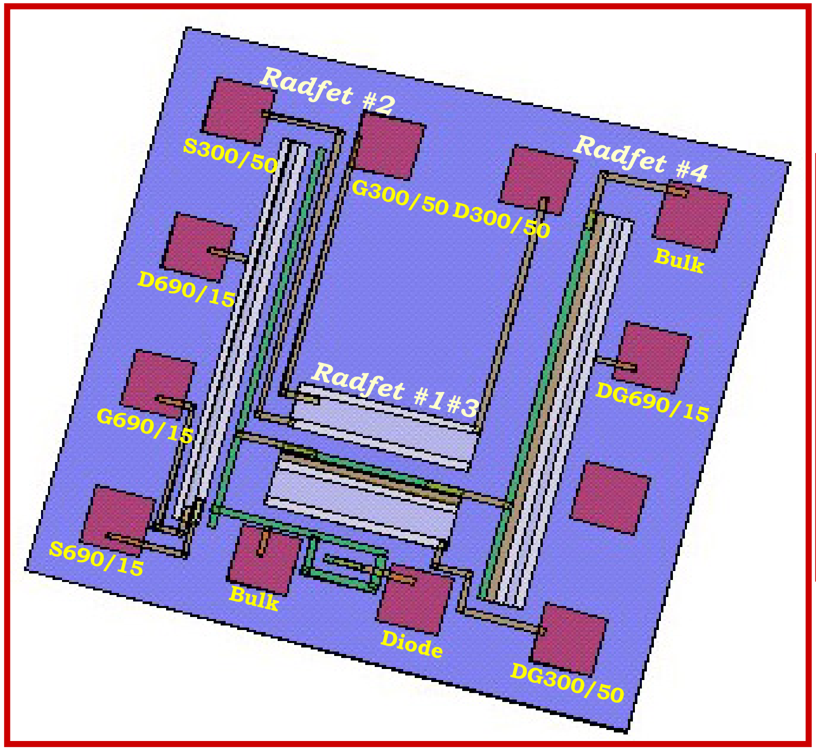


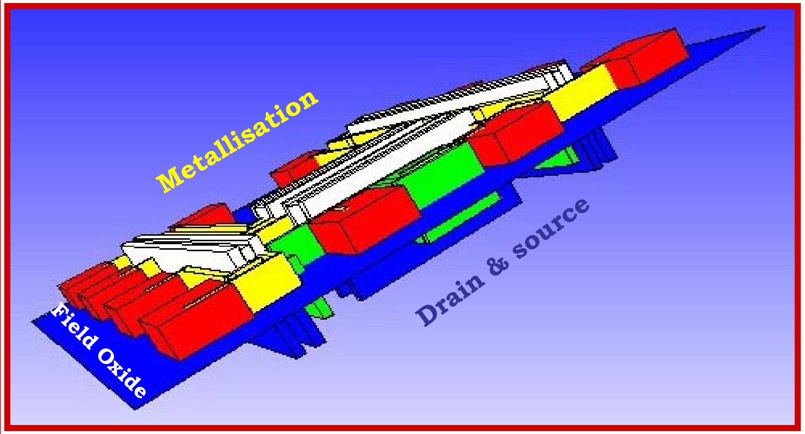
Vo is measured by:

- applying a constant current (Ids) and measuring the source-drain voltage.
- Due to the constant current, the source-drain voltage increases as the irradiation induced charge build-up in the gate oxide increases.
- Ids is typically of 10μA.
- Drain is shorted to gate and source is shorted to bulk.

NMRC RadFET description

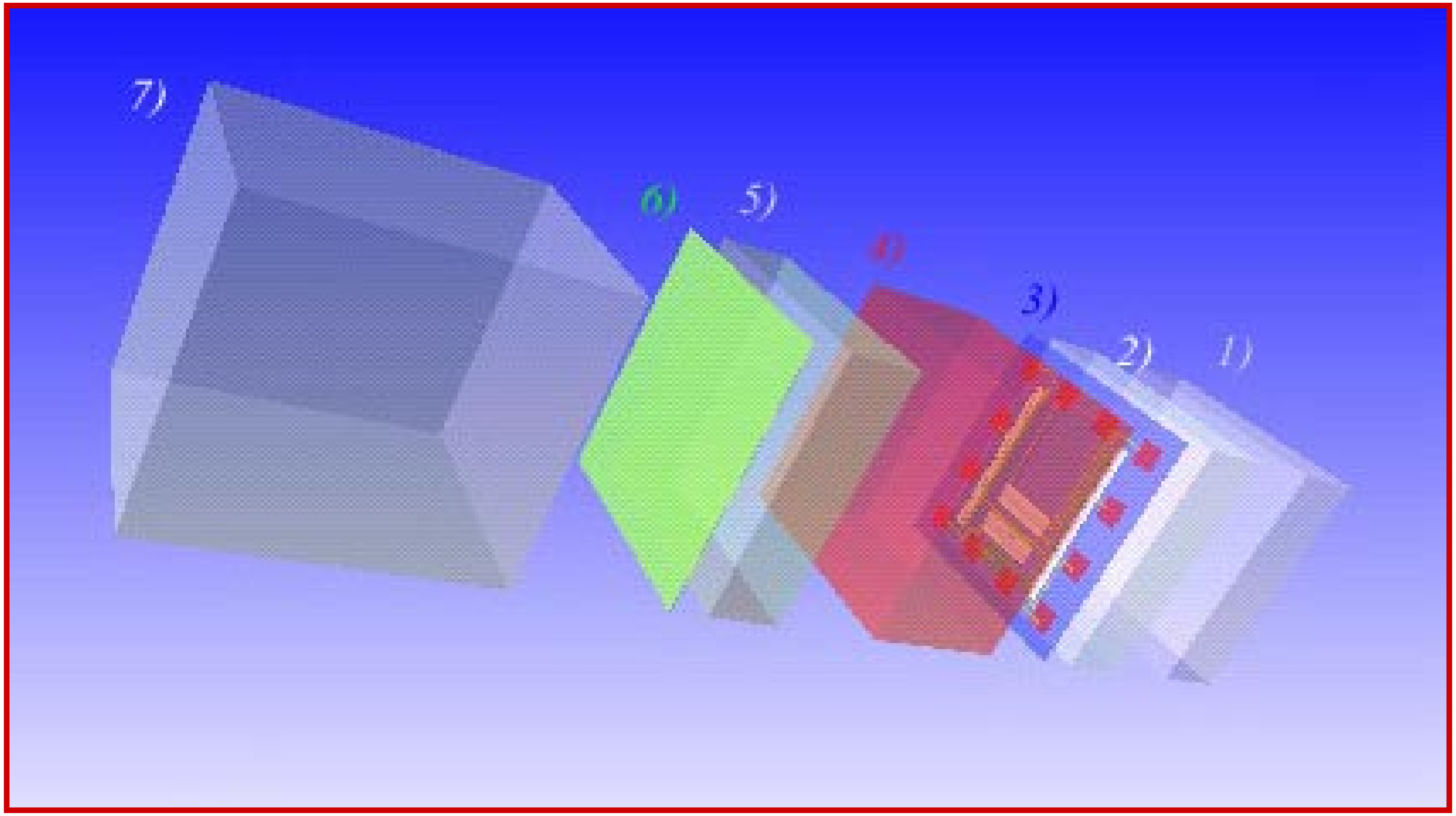
There are four RadFET on each device.





400NM implanted gate oxide devices.

Exploded view



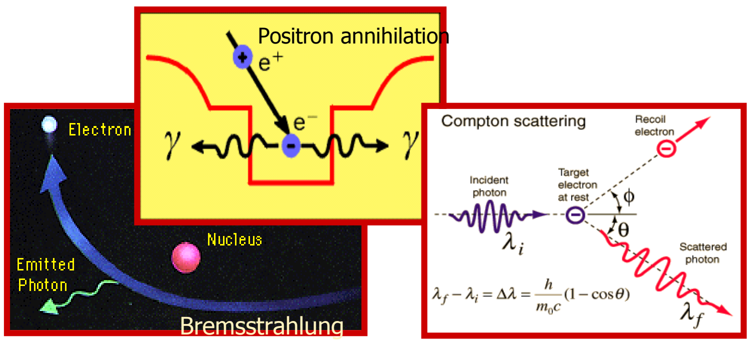
Package: lid (1), adhesive(5), the attach pad(6) and the base (7)

NMRC Device Packaging

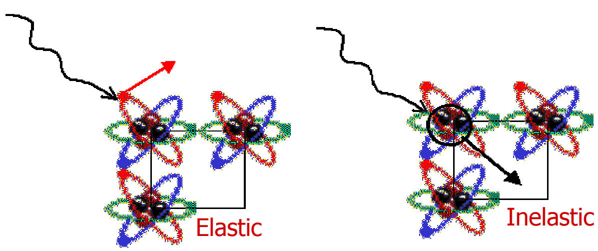
The simulated and tested devices are composed of:

1) Package lid - Th: 250 μm; Kovar (Ni, Co, Fe);
2) Package cavity - Th: 250 μm;
3) RadFET Die - Th: 1.5 μm;
4) Substrate - Th: 500 μm;
5) Die attach adhesive - Th: 250μm; (Ag, SiO2)
6) Die attach pad - Th: 3.75 μm;
7) Package base - Th: 1000μm; (Al_2O_3);

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.

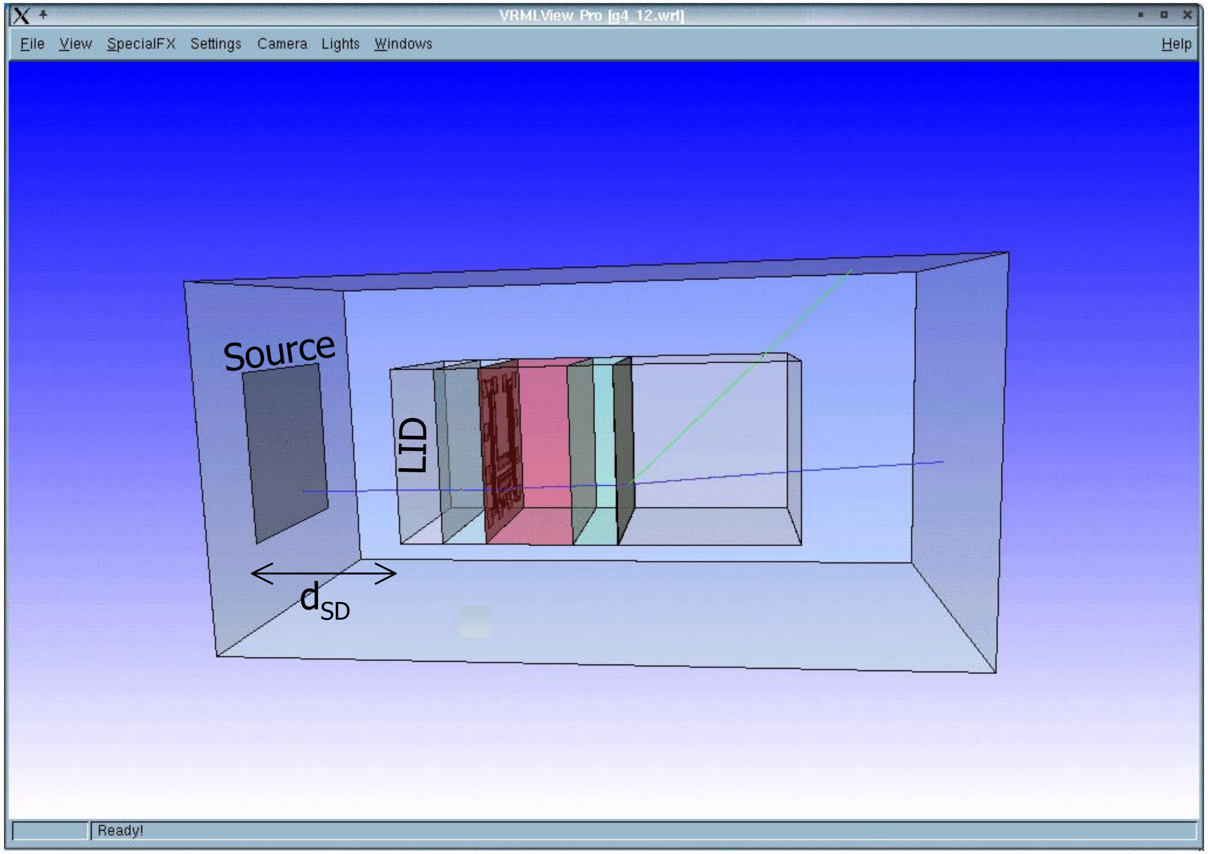


- **Low and High Energy Hadronic Shower:** Elastic and Inelastic interactions for different hadrons (protons, neutrons, tritons, deuterons,…) targeting particles from 10MeV up to some GeV.

Physics Models limitations:

These models do not allow secondary heavy ions tracking!

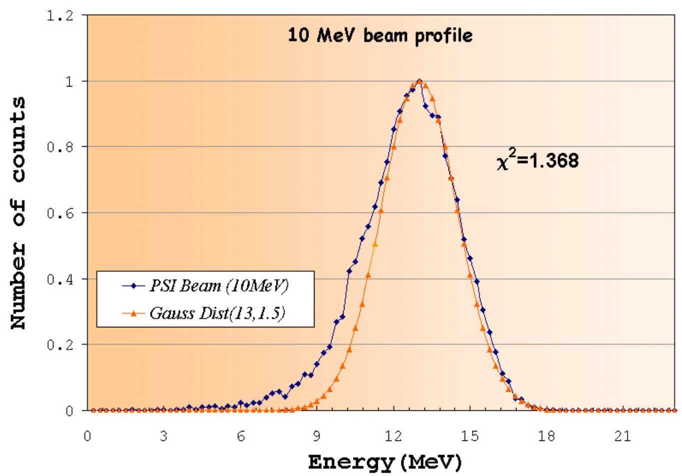
Simulation Scheme

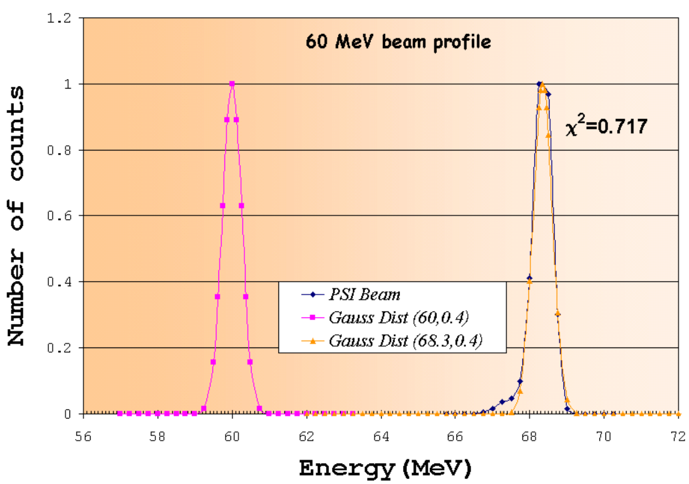


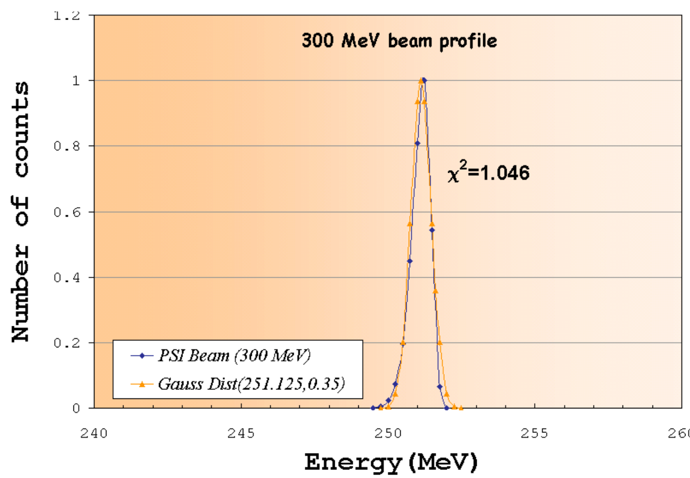
- Geant Version: 4.4.0.3
- Cut Value: 1μm
- Source: $1mm^2$
- Device: $1mm^2$
- Source/Device dis.: d_{SD}=10cm
- Air
- Detector: RadfFET1' Gate Oxide
- Package conf:
  - Lid
  - No Lid

Simulated vs. PSI Proton Beams

- PSI *10 MeV* beam – (>13MeV) gaussian beam : μ=**13MeV** and σ= **1.5MeV**
- PSI *60 MeV* beam - gaussian beam with peak at 68 MeV. - Simulated : μ= **60MeV** and σ= **0.4 MeV.**
- PSI *300 MeV* beam - gaussian distribution: μ= **251MeV** and σ= **0.26MeV**

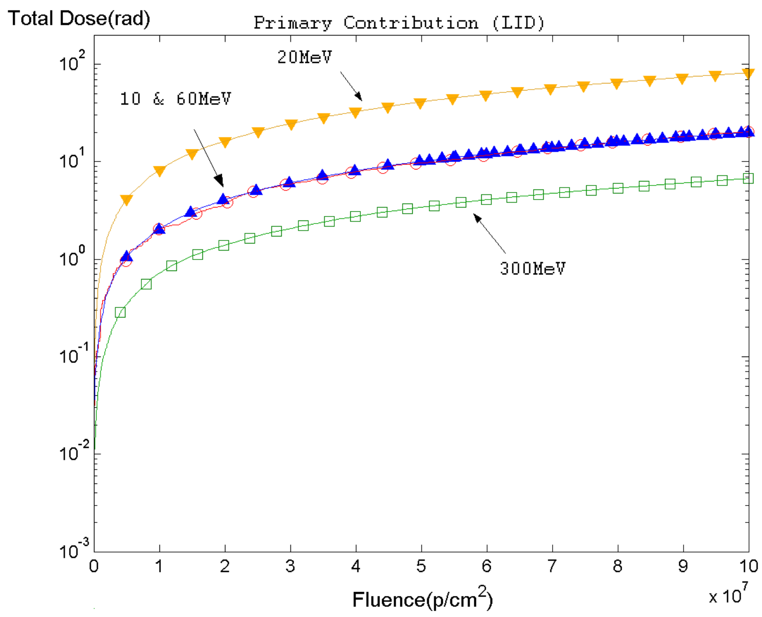


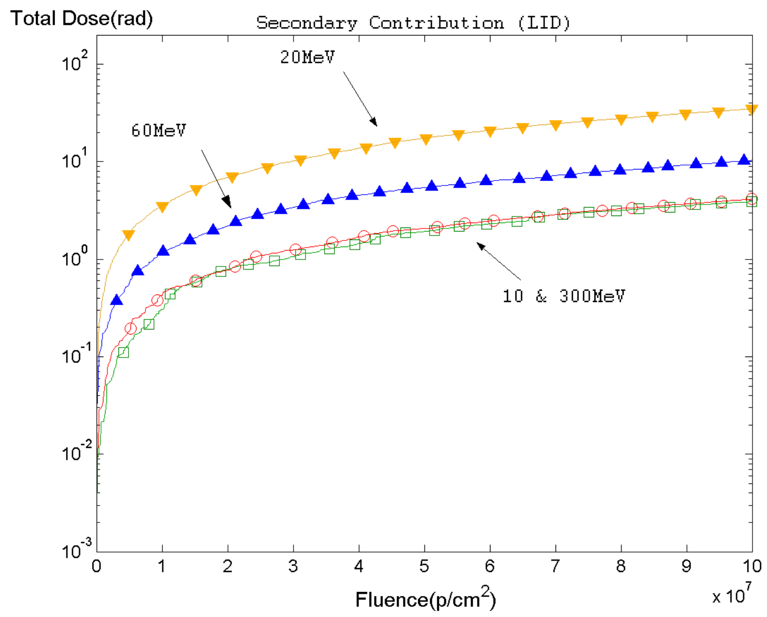




LID Simulated Response to Proton Irradiation

"LID"

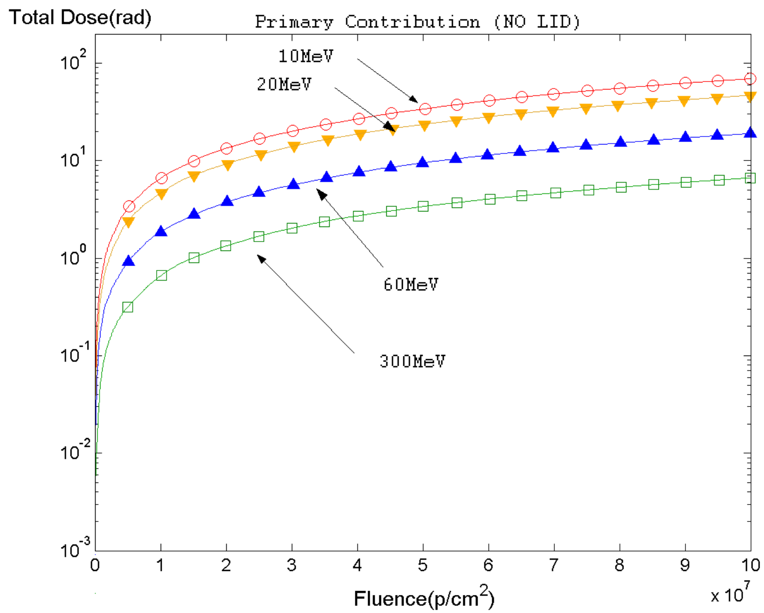


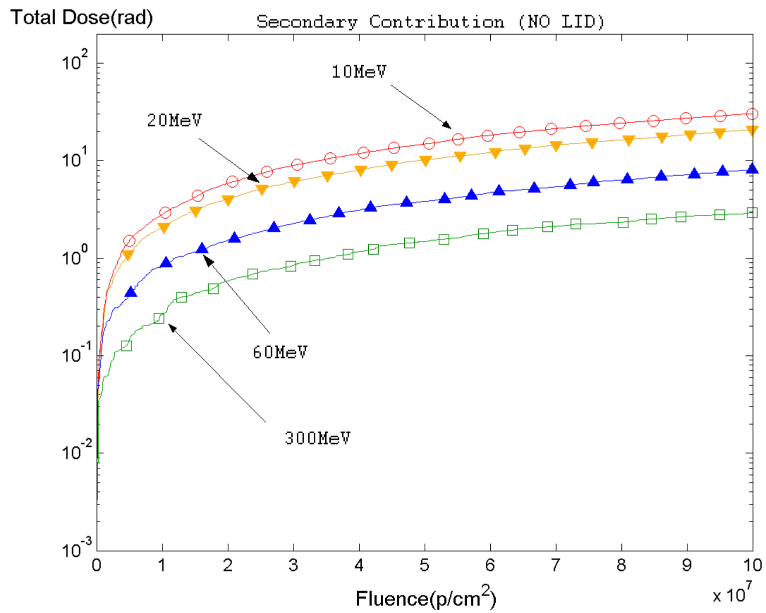


- Primary & Secondary TID ~ Function(Proton energy)
- Except for 10MeV

NO LID Simulated Response to Proton Irradiation

"NO LID"

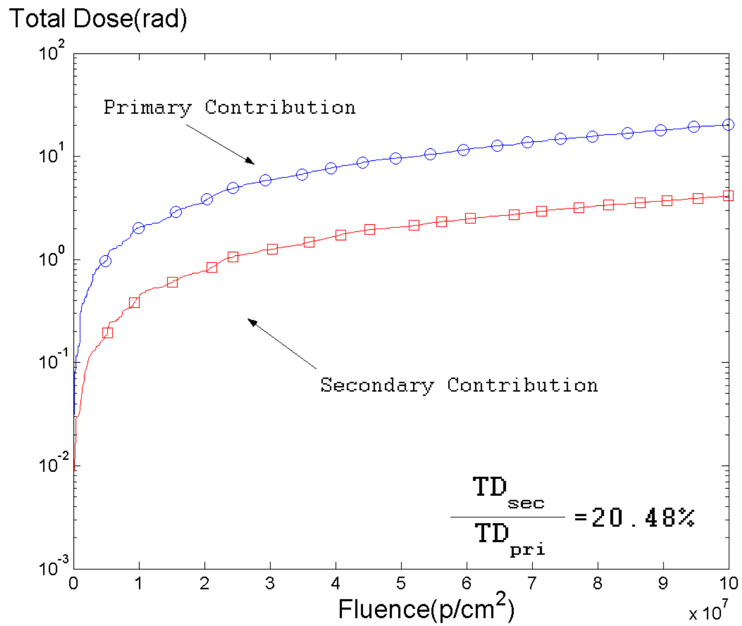




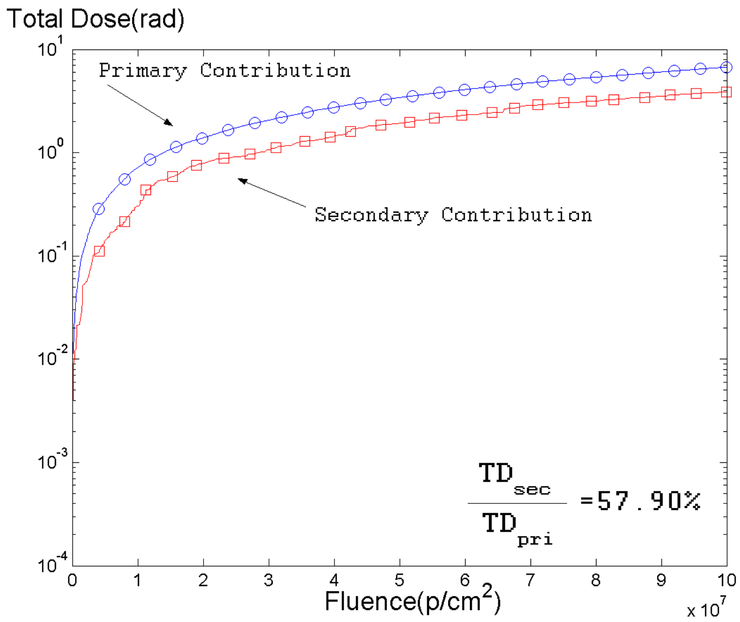
- Primary & Secondary TID ~ Function(Proton energy)

LID Configuration Primary and Secondary

10MeV: "LID"



300MeV : "LID"

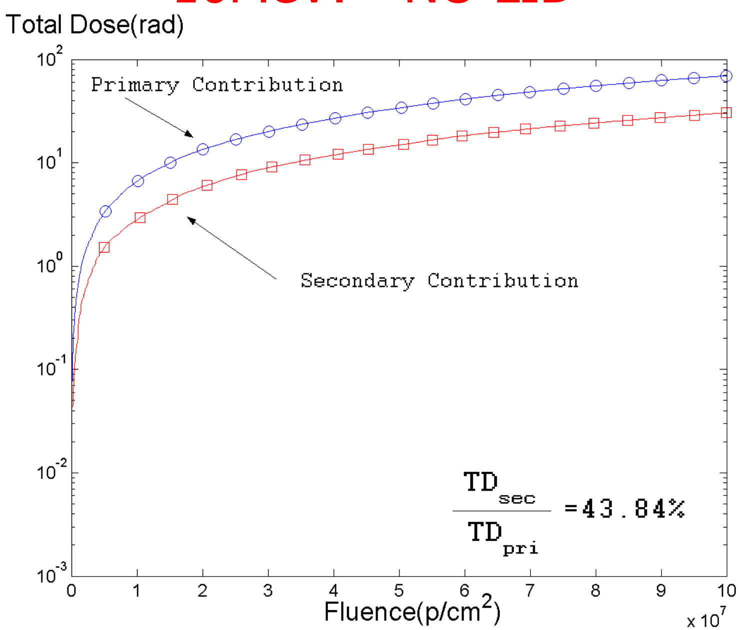


- 20% for 10 MeV
- 43% for 20MeV
- 52% for 60 MeV
- 58% for 300 MeV

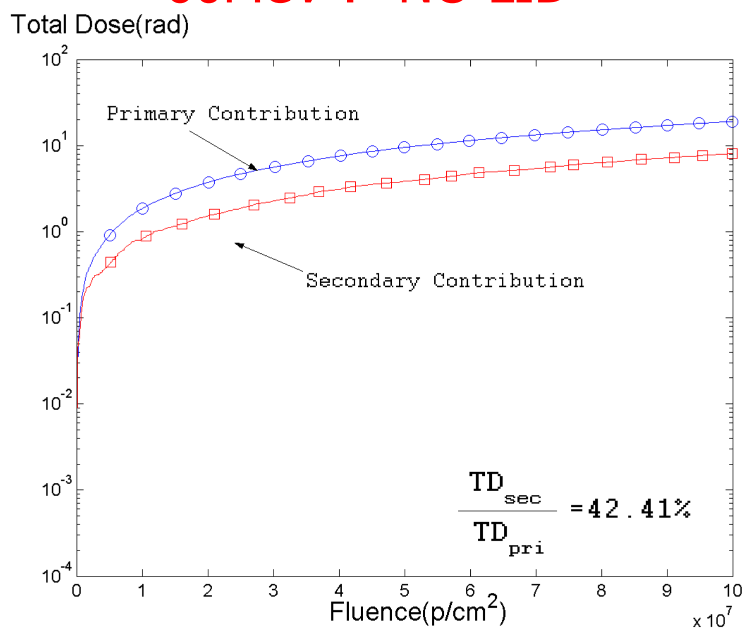
LID Sec/Pri ratios of TID contribution dependent on primary proton energy

NO LID Configuration
Primary and Secondary

10MeV: " NO LID"



60MeV : "NO LID"

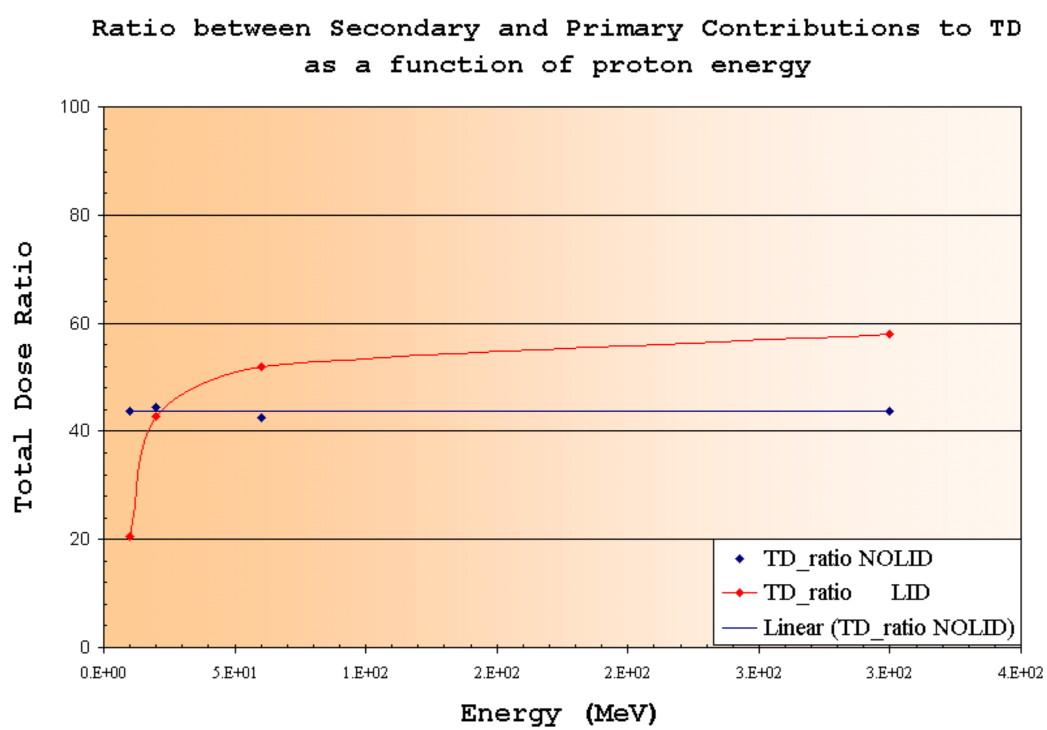


- 44% for 10 MeV
- 44% for 20 MeV
- 43% for 60 MeV
- 44% for 300 MeV

NO LID Sec/Pri ratios of TID contribution
Constant with primary proton energy

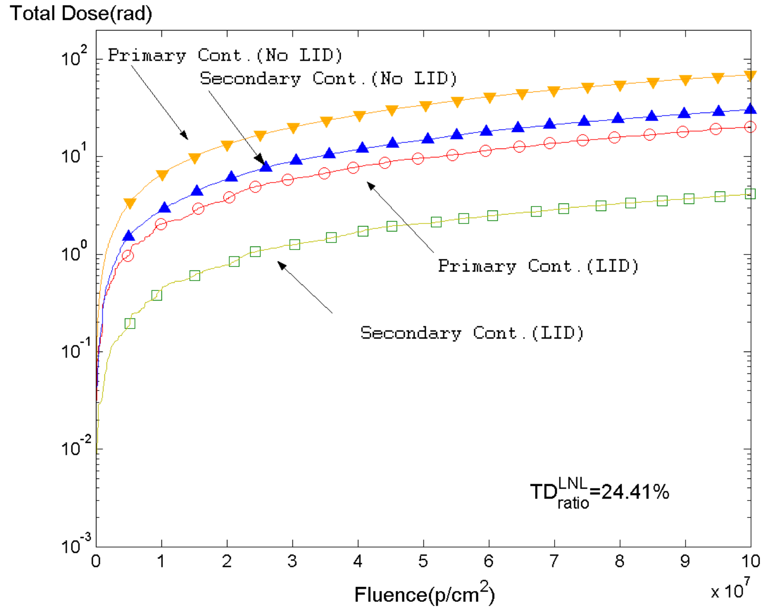
Package effect: Secondary Contribution to TID

- RadFET response to secondary particles is dependent on the packaging
- LID Configuration ratios depend on Proton Initial Energy

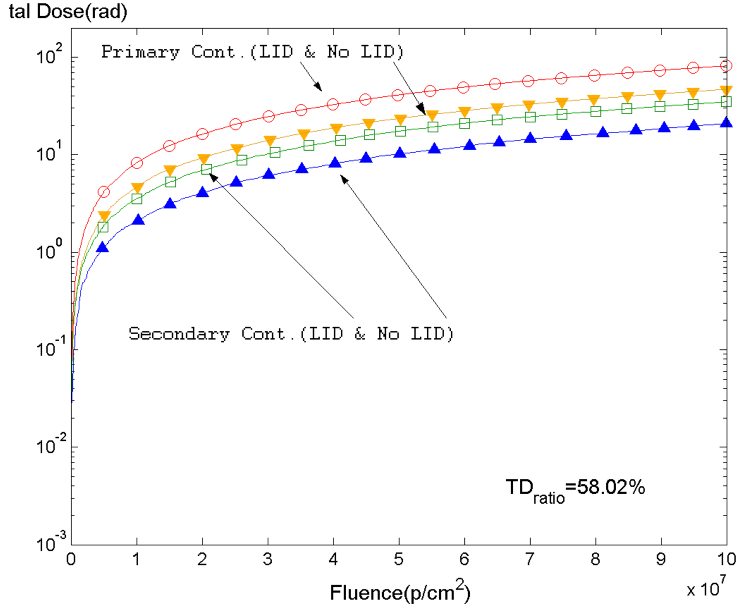


Package effect: Secondary Contribution to TID

10MeV



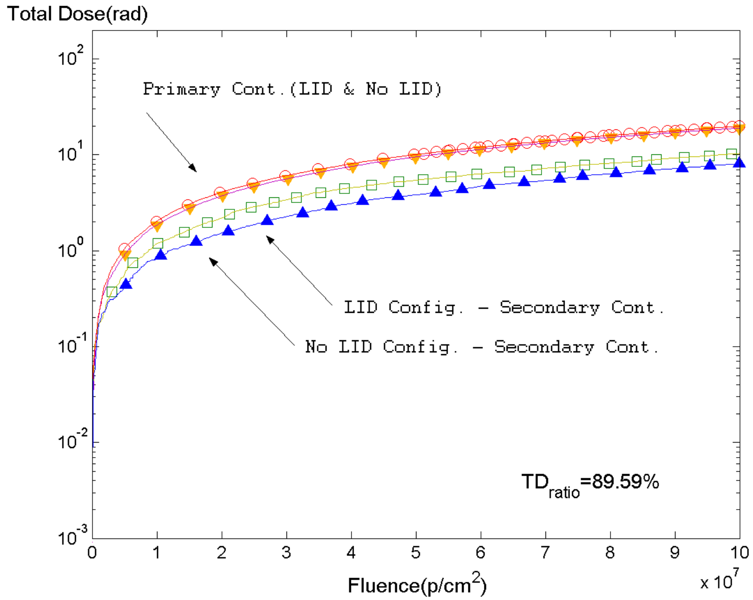
20MeV



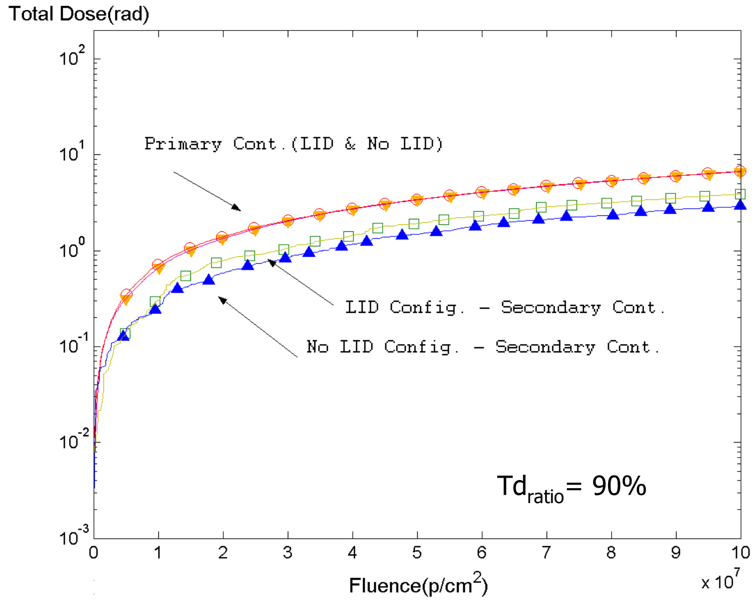
- "No Lid" configuration TID contributions is higher than "LID"
- "No Lid" configuration TID contributions is lower than "LID"

Package effect: Secondary Contribution to TID

60MeV

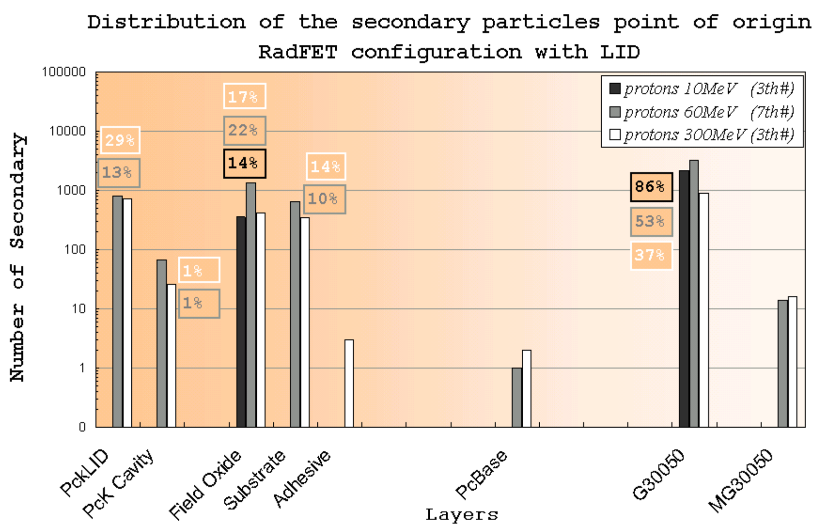


300MeV



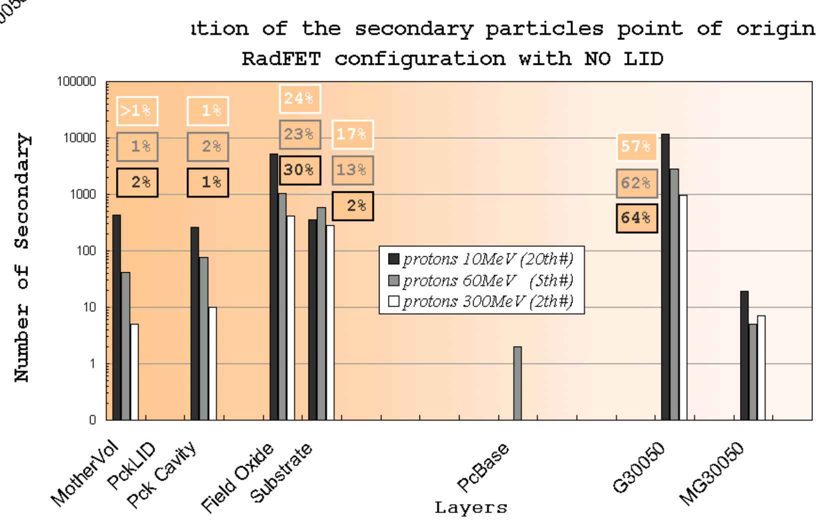
- Secondary contribution - lower for the “No Lid” configuration 20, 60 and 300 MeV

Secondary Particles



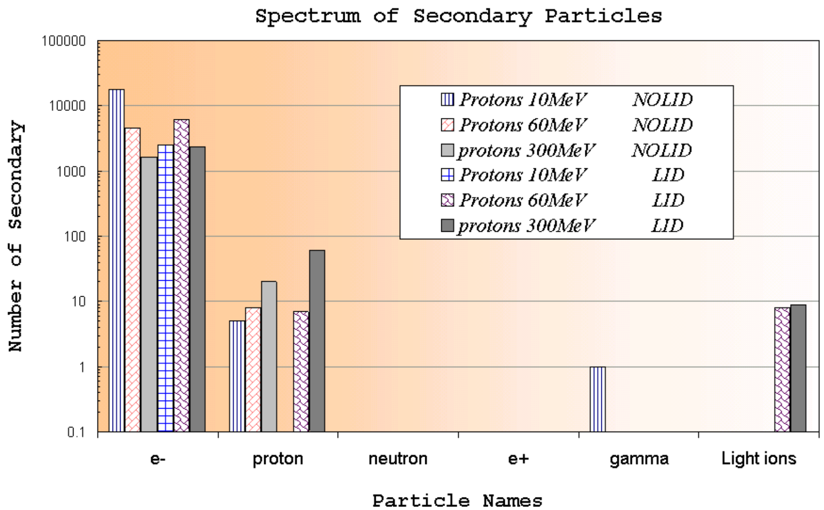
Significant contributors

- Layers very close to the gate oxide, substrate and in the package lid
- Air layer (Package cavity) (60 and 300MeV)



- substrate/lid secondaries - absorbed or stopped before the gate oxide. (10 MeV)

Secondary Particles



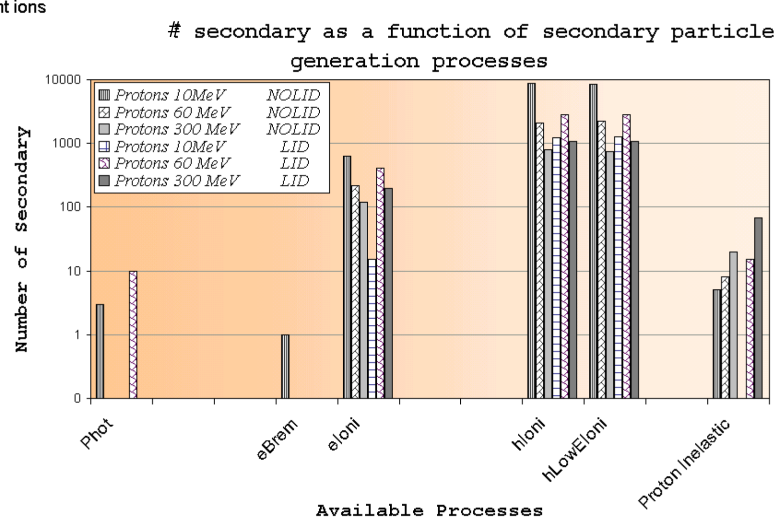
Major contributors :

- Electrons
- Protons (not for "LID" 10 MeV)

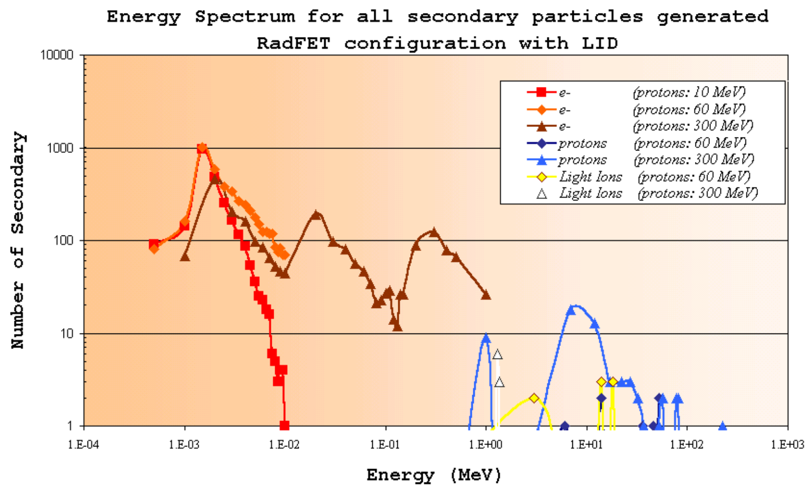
For 60 & 300 MeV "LID"

- Light ions

- electrons - by ionisation & photoelectric effect.
- protons & light ions - by means of inelastic interactions.



Secondary Particles



Most energetic "LID" :

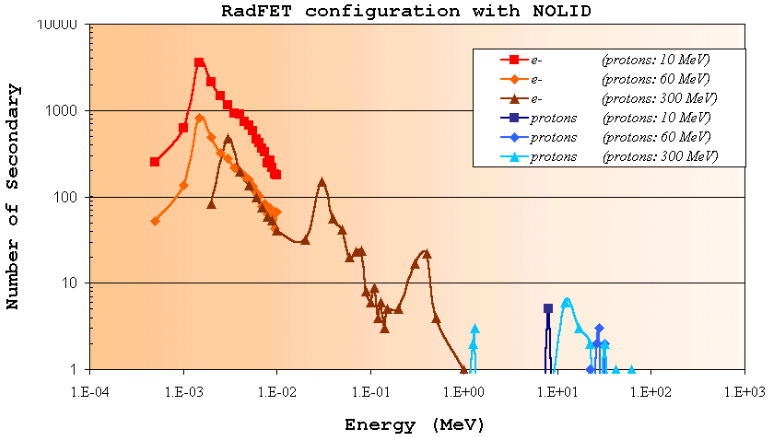
- Protons
- Light ions

(60 and 300 MeV)

Most energetic "NOLID" :

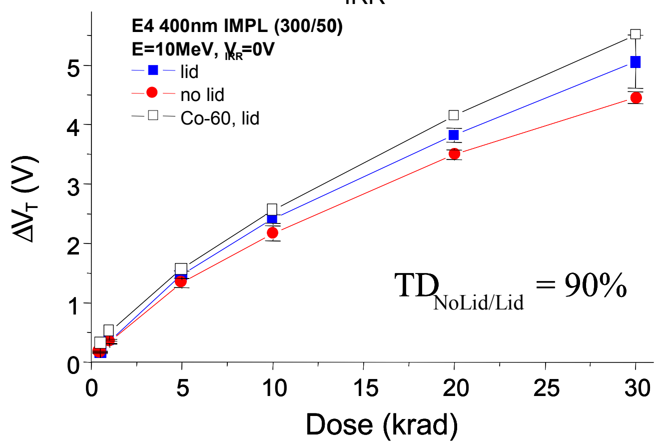
- Protons

(10, 60 and 300 MeV)

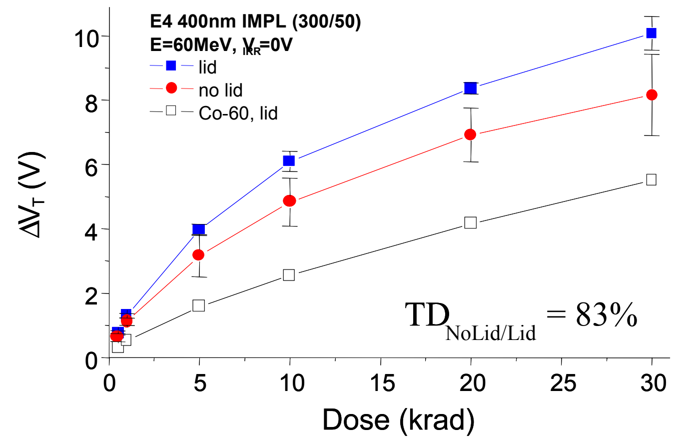


Experimental Results

10 MeV Proton $V_{IRR}=0$



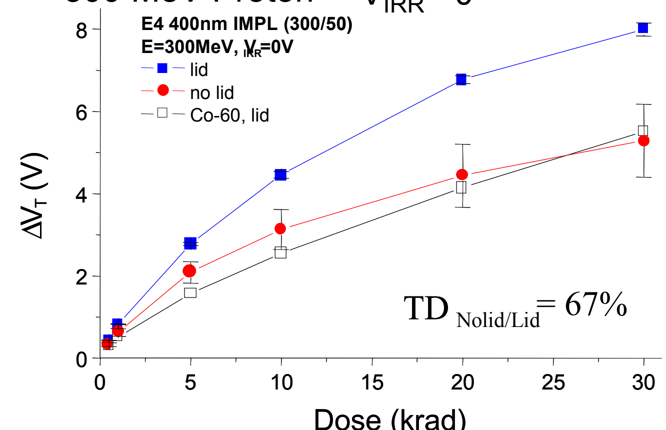
60 MeV Proton $V_{IRR}=0$



Experimental ratio bt NOLID & LID :

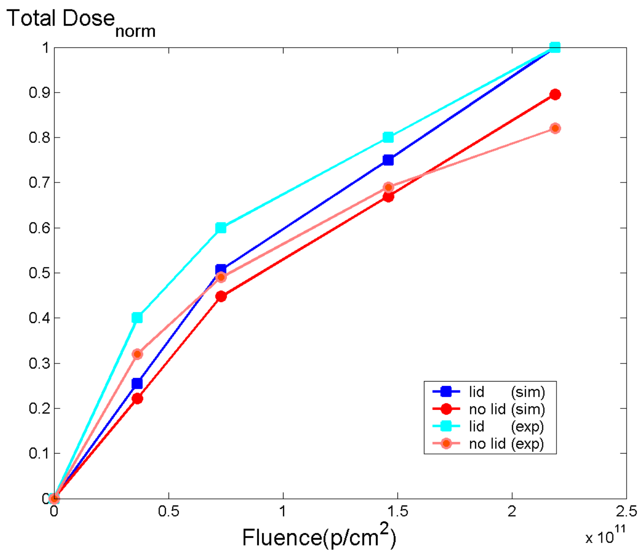
- 90% for 10MeV
- 83% for 60MeV
- 67% for 300MeV

300 MeV Proton $V_{IRR}=0$

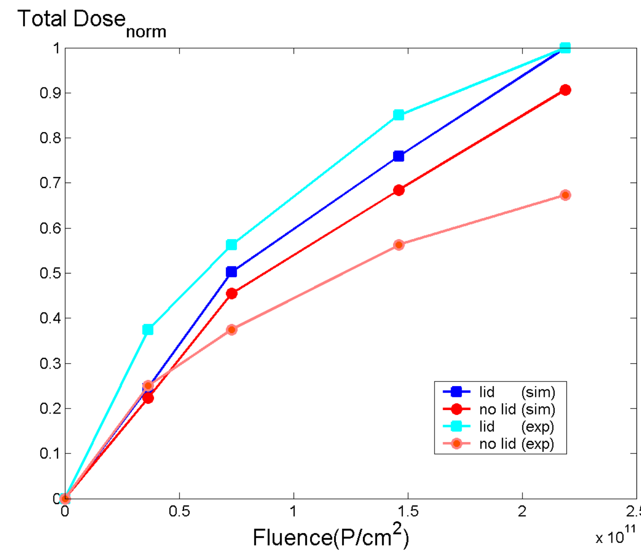


Comparing Experimental & Simulation Results

60MeV



300MeV



Simulation difference bt LID & NOLID

- 11%

Experimental:

- 18%

Simulation difference bt LID & NOLID

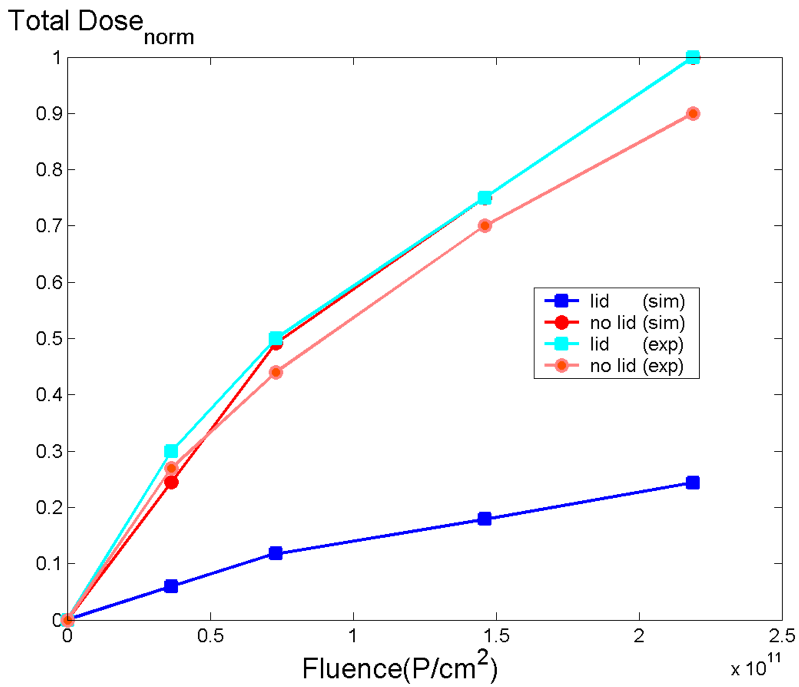
- 10 %

Experimental:

- 30%

Comparing Experimental & Simulation Results

10MeV



Simulation:

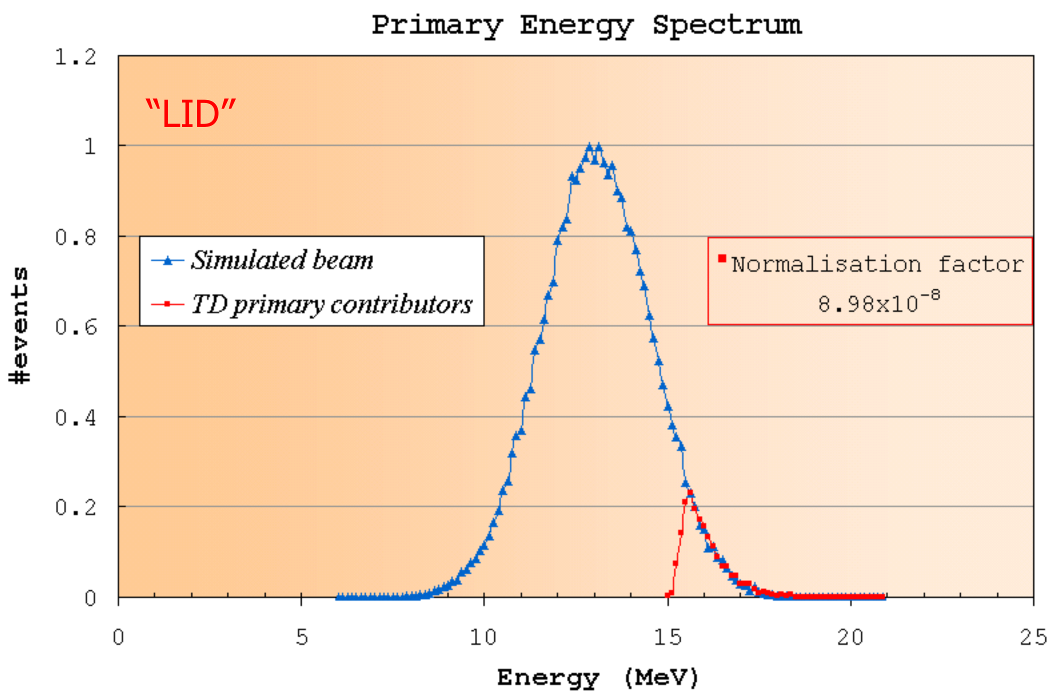
- 24%

Experimental:

- 10%

Simulation: NOLID > LID !

10 MeV Case



- Only protons > 15MeV - cross the source/device air, LID
- And deposit energy in the gate oxide!

Conclusions

GEANT4 toolkit – simulate effects of secondary particles on RadFET TID response

- Gate Oxide, Field Oxide, Lid and Substrate - main contributors to TID deposited in the RadFET gate oxide.
- Electrons & Protons – major secondary particles contributors. However, light ions (deuterons & tritons) also contribute.
- Secondary heavy ions – not considered by the models employed. But the TID contribution is believed to be marginal!
- The dominant cause of the discrepancies observed in the proton irradiation results obtained experimentally appear to be due to contribution of secondary particles generated in the Gate Oxide.

Further work

- Check for dose dependence – simulating different source-device distances (air);
- More realistic energy deposition calculations may be performed if oxide doping is included in the simulations;
- Radiation effects on components may benefit with the implementation of GEANT4 *Charge Recombination Models*