A Geant4 example for radiation effects on Components

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Aim

- Illustrating how to build a Geant4 application on a simple field-effect transistor;
- Introducing important features for nanodevices in space.

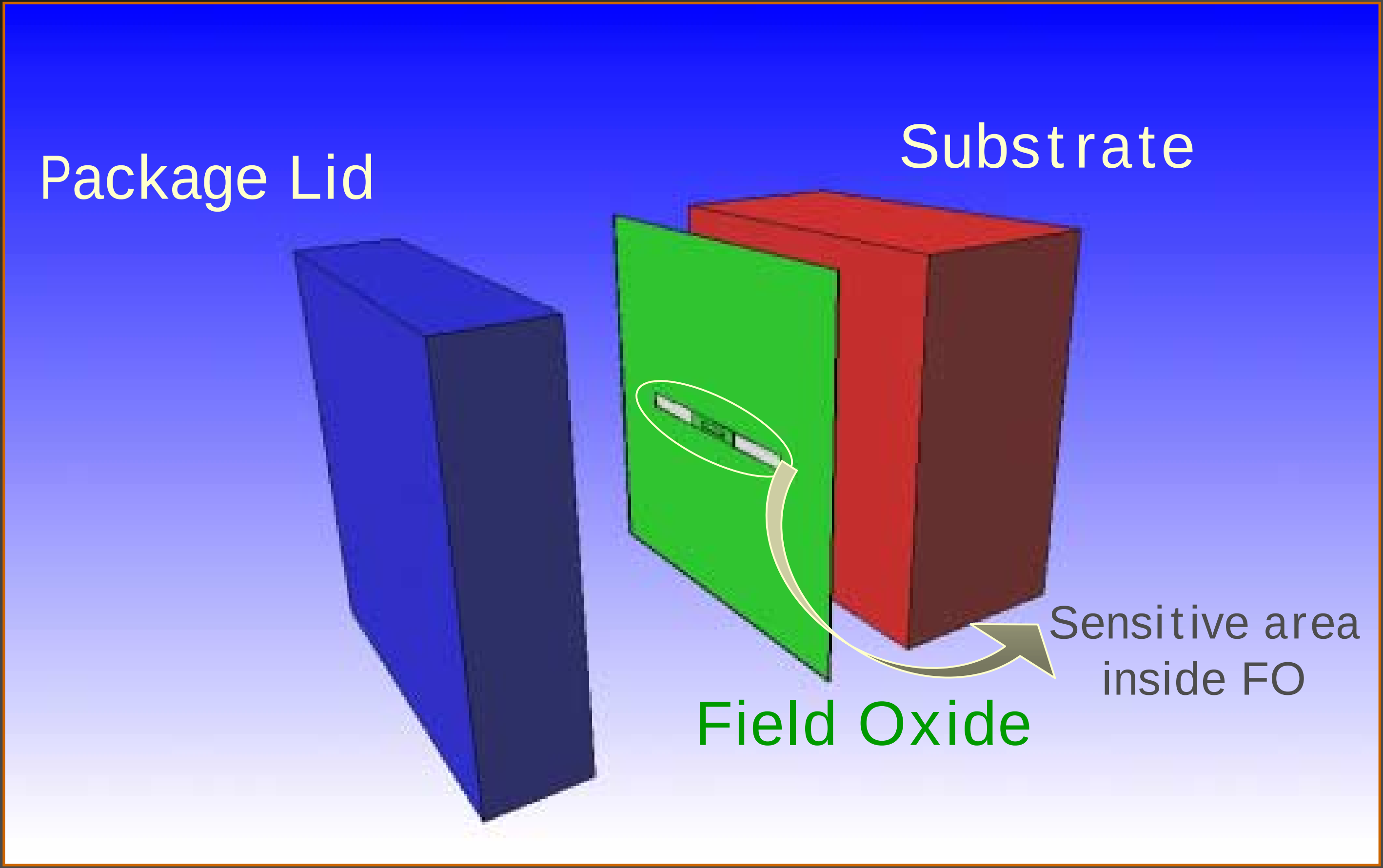
Simulation goal:

- Calculating ionising dose deposited in gate oxide
- Check packaging contribution

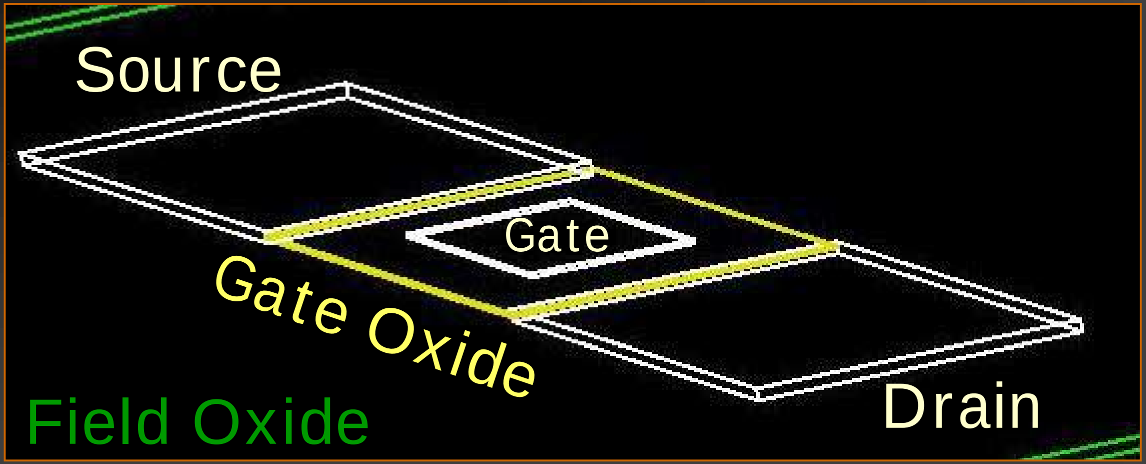
Overview

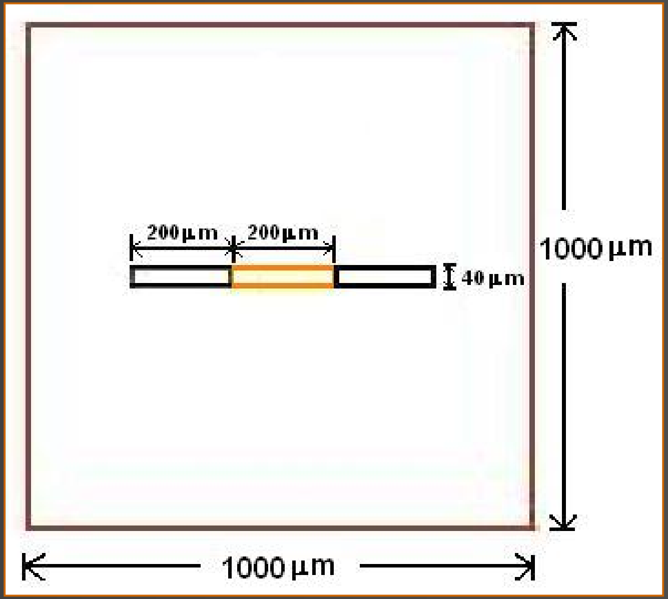
- Simple device example
  - Device description
  - Geometry and Materials
  - Physics and cuts
  - Results
  - Different cuts: comparisons
- Real device application
  - Device description
  - Results
- Conclusions

Simple Device Example



Geometry



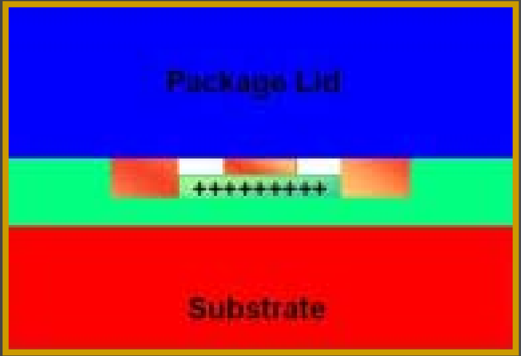


Gate Oxide > Sensitive Volume

Cross Sections

Lid = 250 µm
FO = 1.5 µm
Gate = 0.5 µm
GO = 0.4 µm
SD = 1.4 µm
Substrate = 500 µm

Materials



World

-
```
Air = new G4Material("Air", 1.290*mg/cm3, 2);
Air->AddElement(elN,0.7);
Air->AddElement(elO,0.3);
```

Package Lid

-
```
PackageLidMat=new G4Material("PackageLidMat",9.*g/cm3,2);
PackageLidMat->AddElement(elNi,0.5);
PackageLidMat->AddElement(elFe,0.5);
```

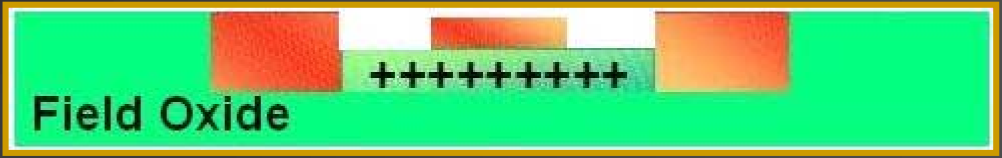
Substrate

-
```
SubstrateMat= new G4Material("SubstrateMat",2.3*g/cm3,1);
SubstrateMat->AddElement(elSi,1);
```

Materials

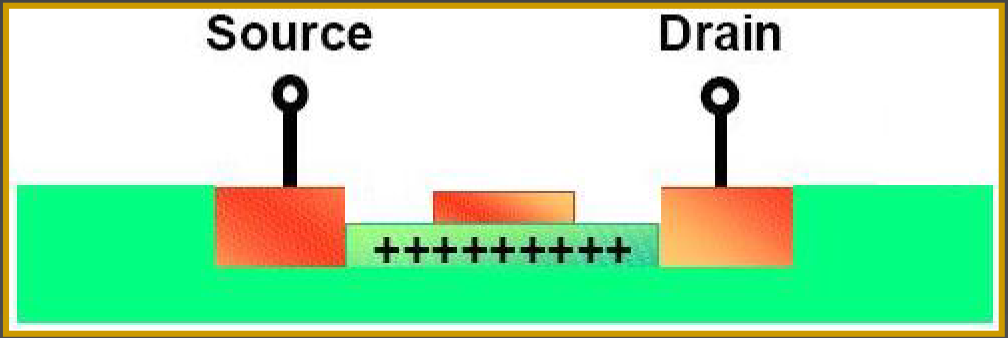
Field Oxide

-
  ```
  FieldOxideMat = new G4Material("FieldOxideMat",2.2*g/cm3,2);
  FieldOxideMat->AddElement(elSi,1);
  FieldOxideMat->AddElement(elO ,1);
  ```



Source Drain

-
  ```
  DSMat = new G4Material(name="DSMat", 2.7*g/cm3,1);
  DSMat->AddElement(elAl,1);
  ```



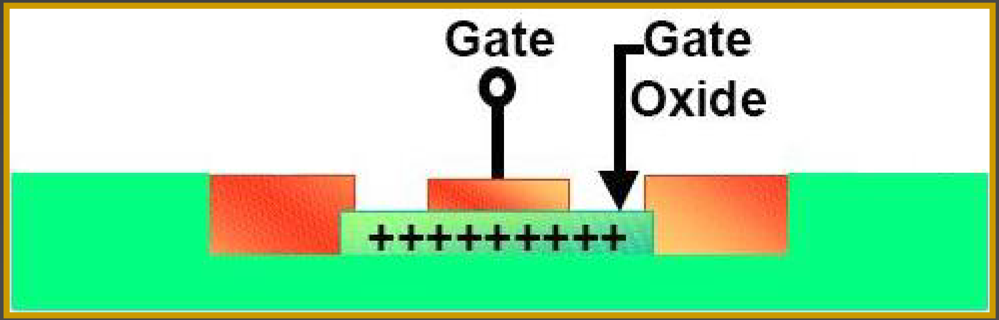
Materials

Gate Oxide

-
  ```
  GateOxideMat = new G4Material("GateOxideMat", 2.3*g/cm3,2);
  GateOxideMat->AddElement(elSi,1);
  GateOxideMat->AddElement(elO ,2);
  ```

Gate

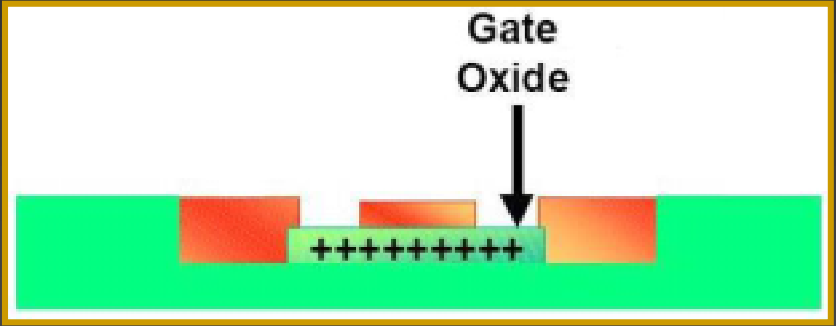
-
  ```
  GateMat = new G4Material("GateOxideMat", 2.7*g/cm3,1);
  GateMat->AddElement(elAl,1);
  ```



Sensitive volume

Set GO to sensitive detector:

```
gateoxide = new
      EEECGateOxide(SDname="/gateoxide");
SDman->AddNewDetector(gateoxide);
logicalGO->SetSensitiveDetector(gateoxide);
```



Collecting information on:

- **Position,**
- **Energy,**
- **Charge Number,**
- **Particle Name,**
- **Track ID**
- **Ionising energy deposited**
- **Layer where secondary particles are generated**

```
EEECGateOxideHit* aHit = new
EEECGateOxideHit();
aHit->SetWorldPos(worldPos);
aHit->SetLocalPos(localPos);
aHit->SetEnergy(KinE);
aHit->SetPCharge(charge);
aHit->SetPNamef(pNameflag);
aHit->SetTrackId(tracID);
if(tracID!=1)
 {aHit->SetVertexVol(SVVolflag);}
hitsCollection->insert(aHit);
// add energy deposition
aHit->AddEdep(edep);
```

Physics List

```
// General Physics
RegisterPhysics( new EEECGeneralPhysics("general") );

// Electromagnetic Physics
RegisterPhysics( new EEECEMPhysics("Low EM"));

// Hadron Physics
RegisterPhysics(  new EEECHadronPhysics("hadron"));

// Ion Physics
RegisterPhysics( new EEECIonPhysics("ion"));
```

Cuts per region

- The cuts define the range from which secondary particles will be tracked as particles or just considered as deposited energy;
- Nano-components have very thin sensitive layers;
- Source-Drain, Gate, Gate Oxide and Field Oxide have much lower cuts than Package Lid, Substrate and World volume

— **Source-Drain**

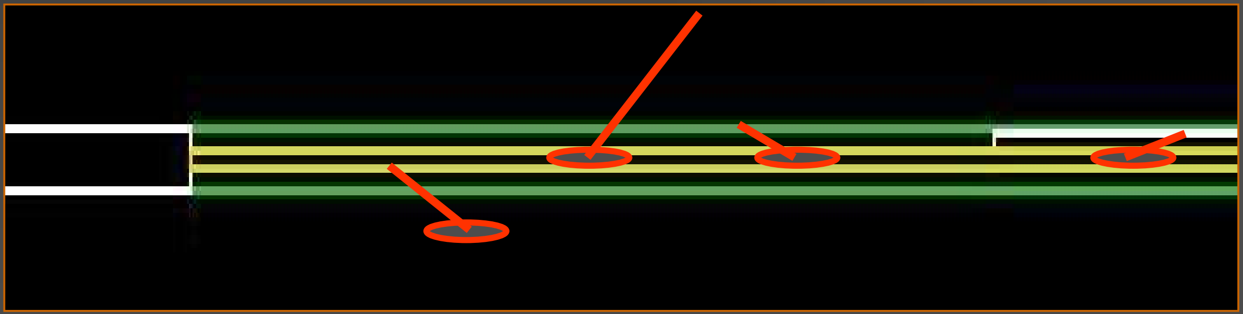
— **Gate**

— **Gate Oxide**

— **Field Oxide**

— **Secondary particle**

o **Ionising energy deposition**

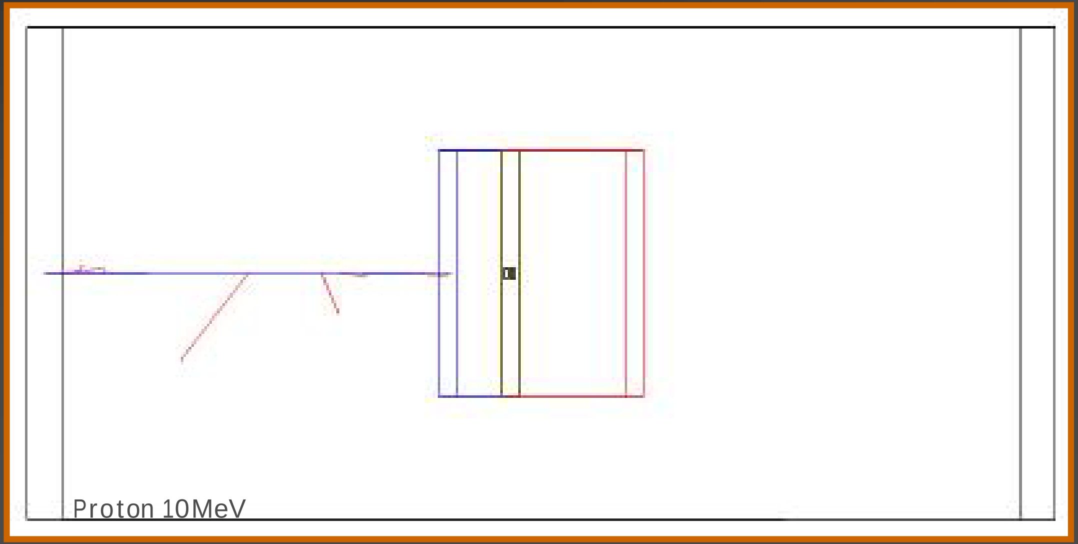


Cuts Implementation

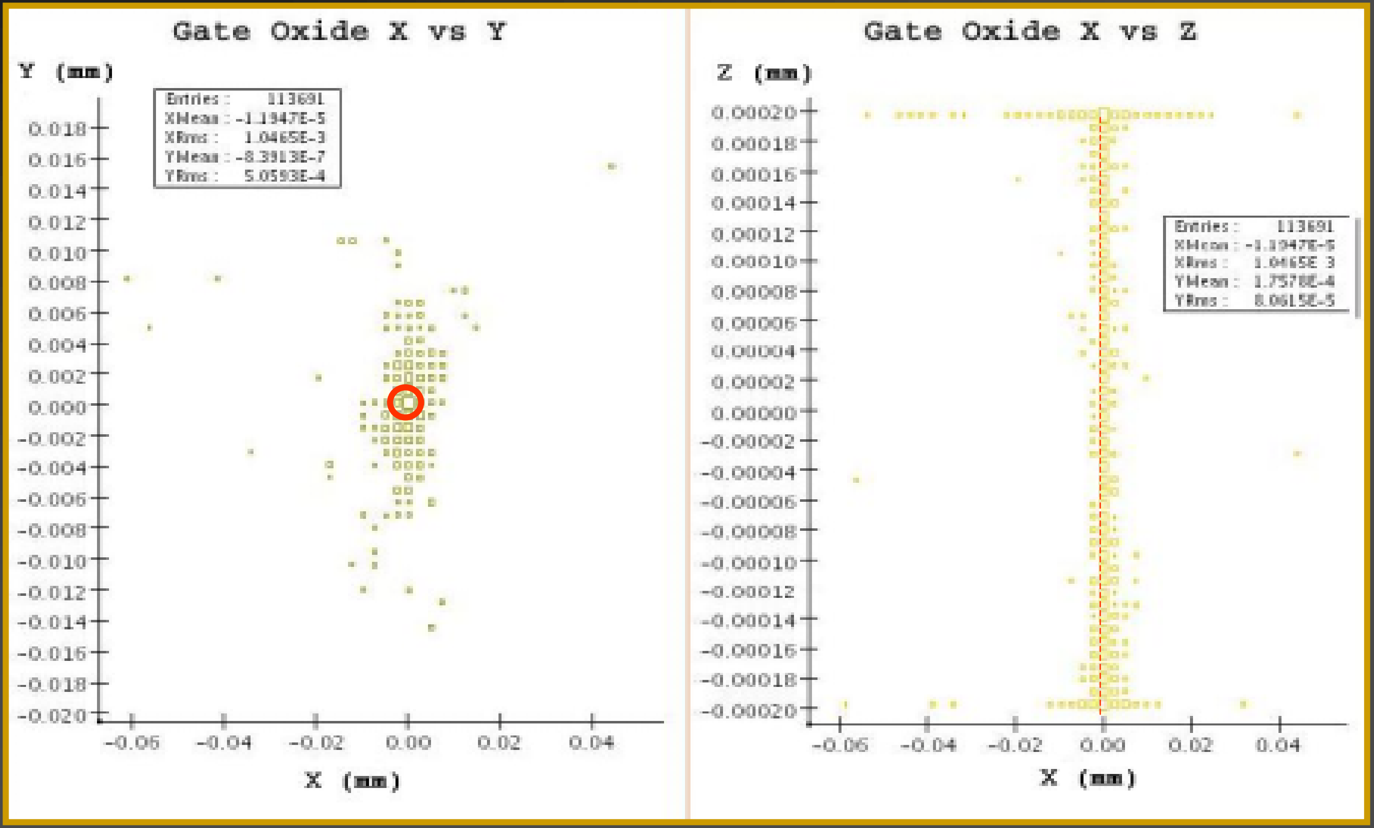
```
// Default cut value for World, Package lid and substrate
  defaultCutValue = 0.5*mm;

// Production thresholds for component regions
  G4String regName[] = {"R-GO","R-DS","R-FO“, “R-G”};
  G4double fac;
  for(G4int i=0;i<4;i++)
  {
    fac *= 0.001;
    G4Region* reg = G4RegionStore::GetInstance()-
   >GetRegion(regName[i]);
    G4ProductionCuts* cuts = new G4ProductionCuts;
    cuts->SetProductionCut(defaultCutValue*fac);
    reg->SetProductionCuts(cuts);
   }
```

Data Analysis

- For 100x10^3 incident protons of 100 MeV
- Source point
- Mono-directional beam
- Perpendicular to the component surface



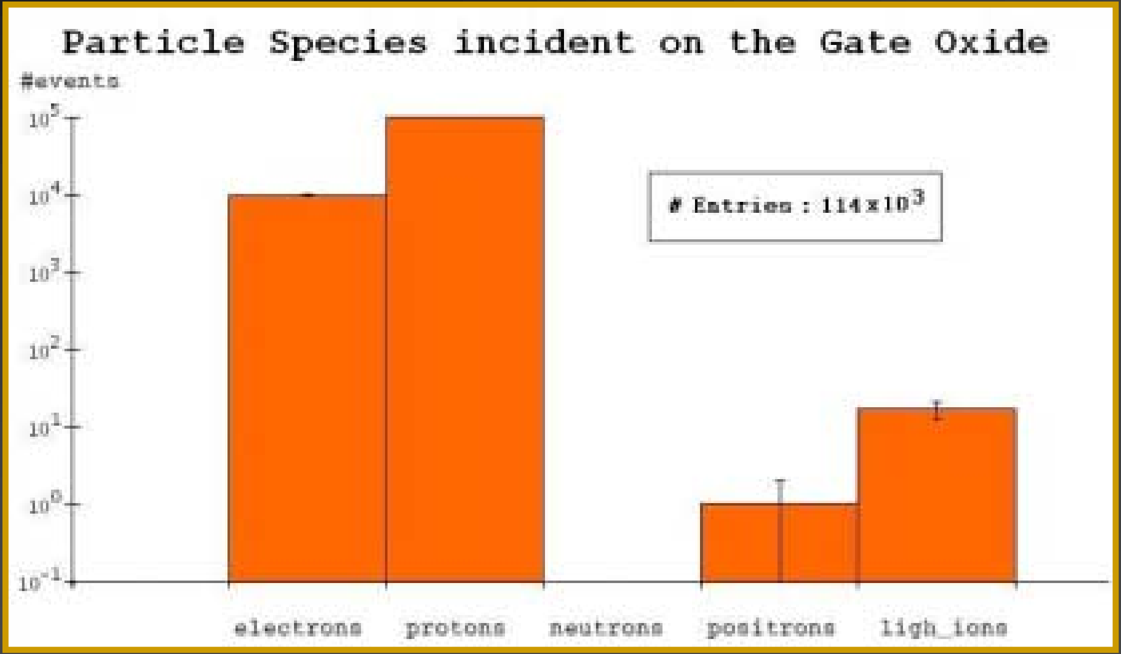
Hits Position in Gate Oxide

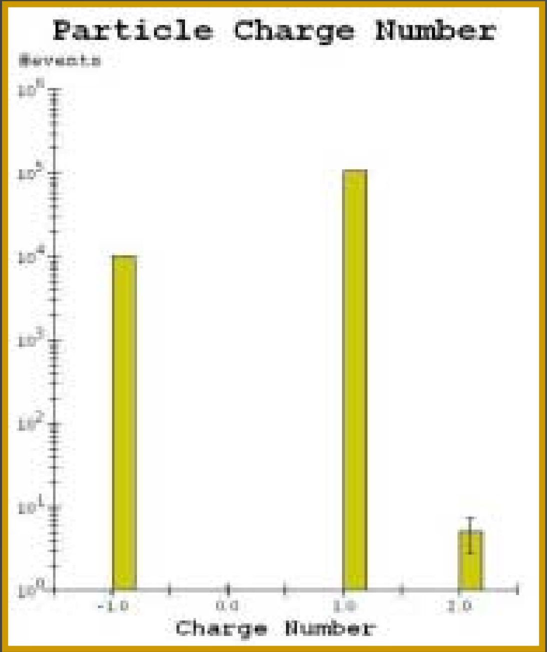


— Source Beam

Hit —> Impact Point

Kind of Particles Hitting the Gate Oxide





- Protons : around 94 x10^3 primary protons + secondary protons
- Electrons : ~ 10 x10^3
- Positron : one!
- Light ions : ~ 10

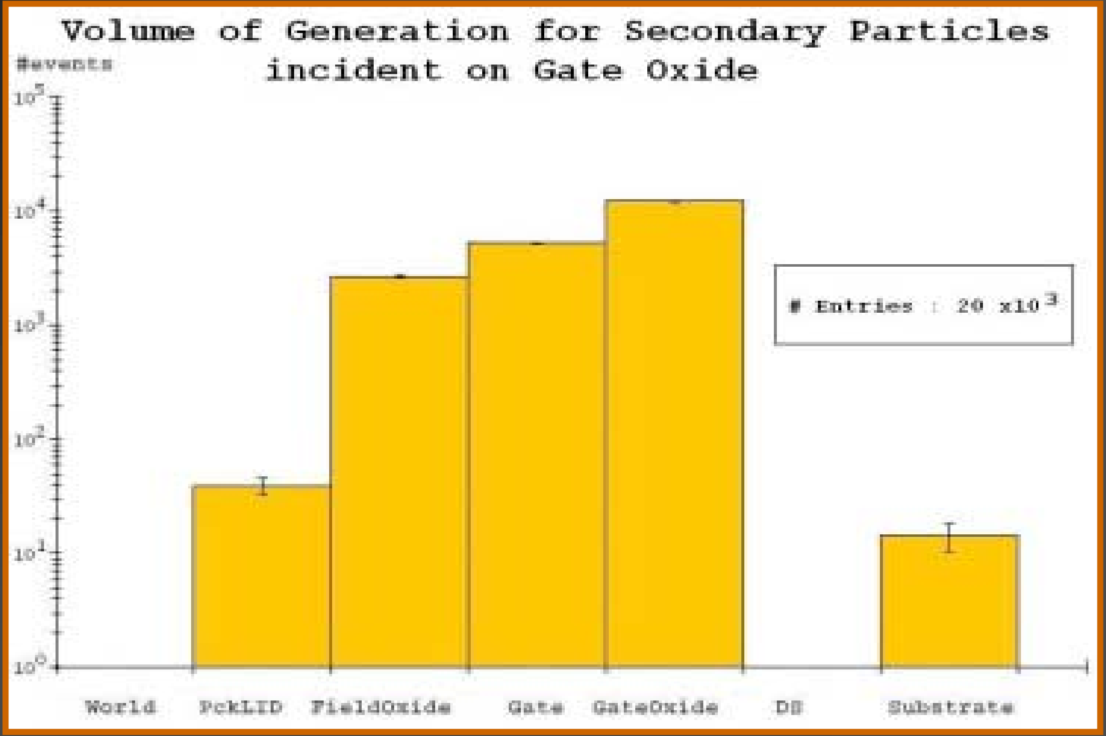
Packaging importance

Major contributors :

- Gate Oxide
- Gate
- Field Oxide

Backscattering :

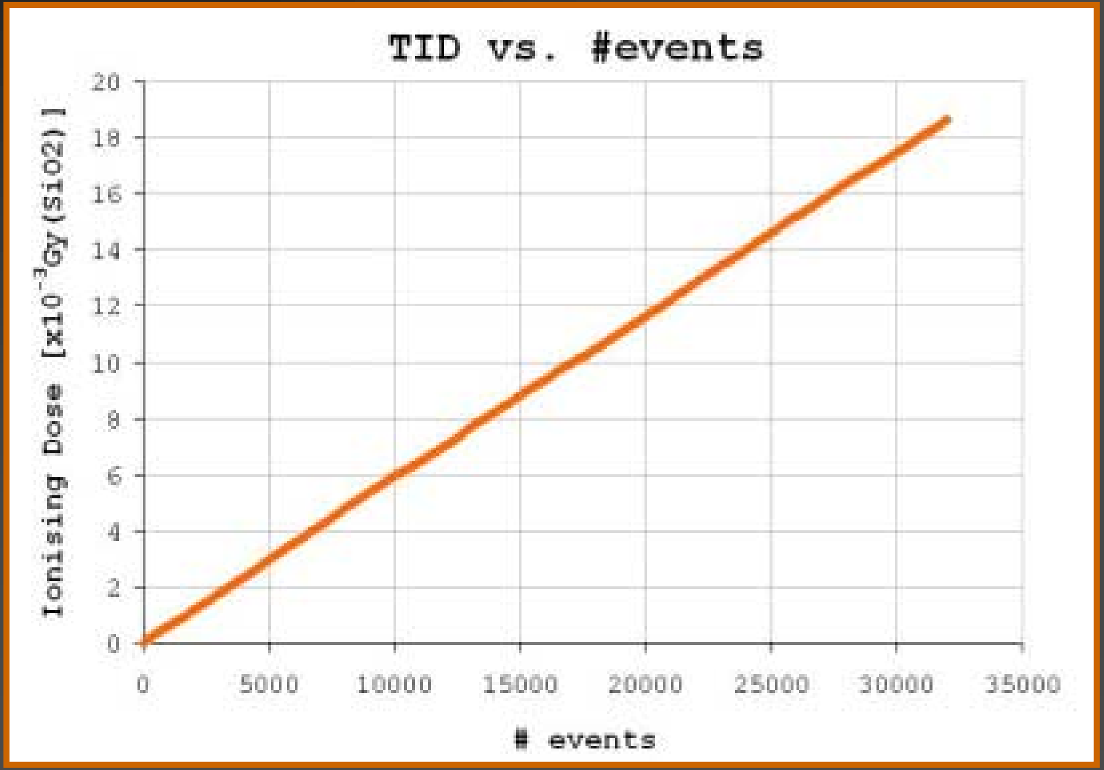
- Substrate



The lack of contribution from the source and drain is merely due to the beam direction!

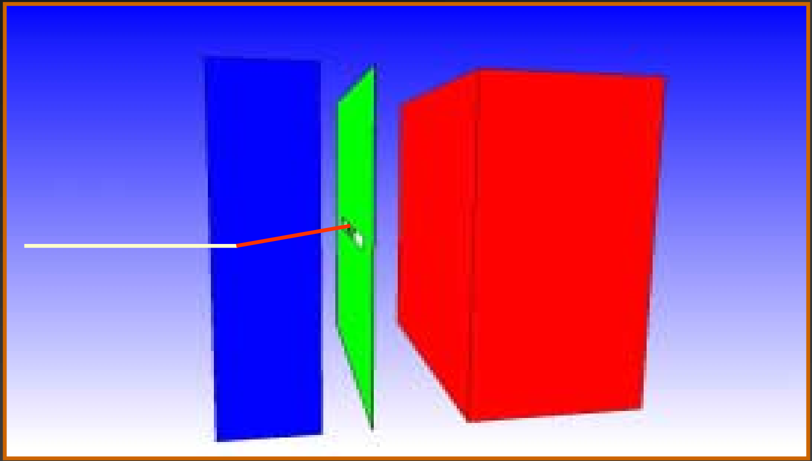
Ionising Dose in Gate Oxide

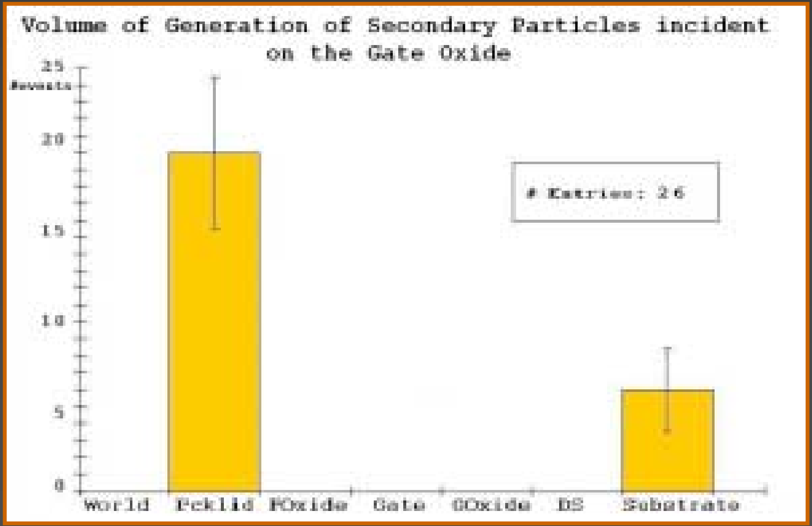
Total Ionising Dose deposited by all particles incident on the Gate Oxide



Note:
#events ∝ Fluence

Check Cuts per region

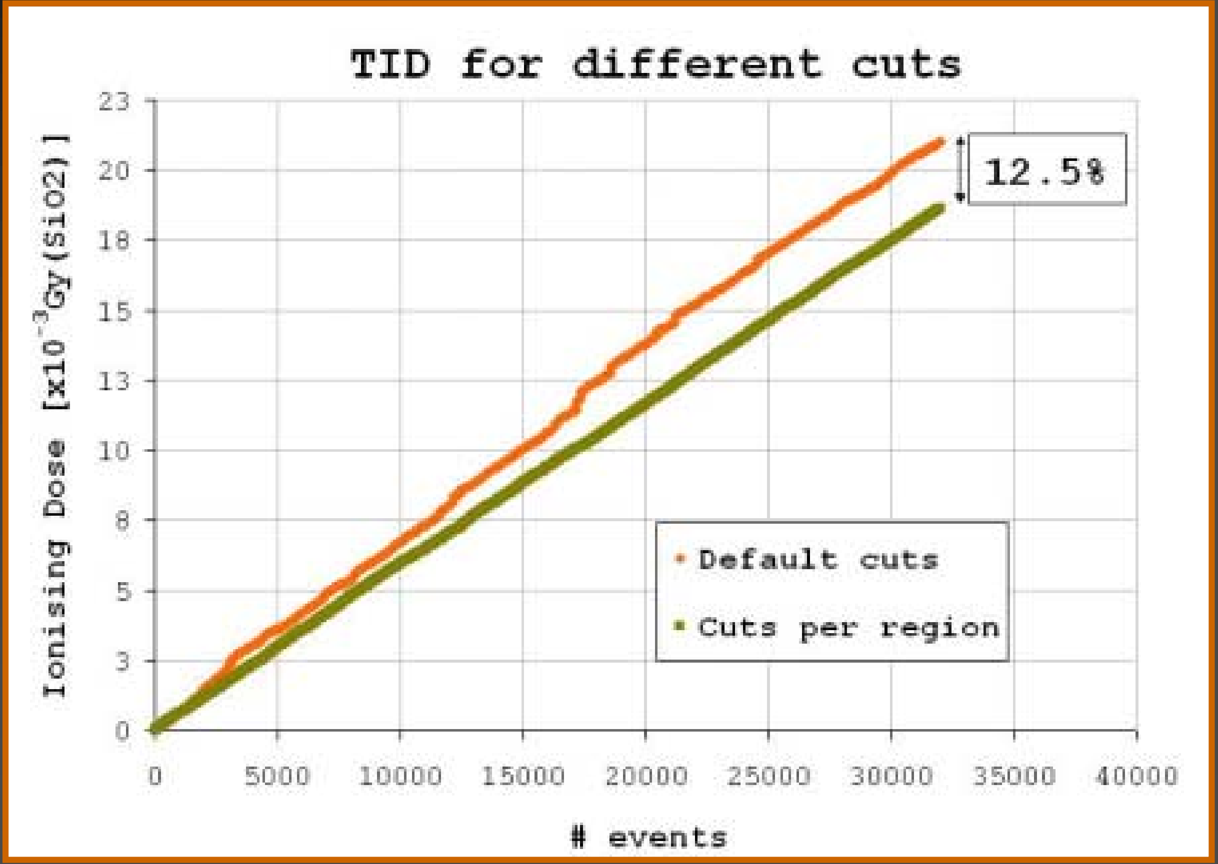




In case cuts = 0.5 mm (default):

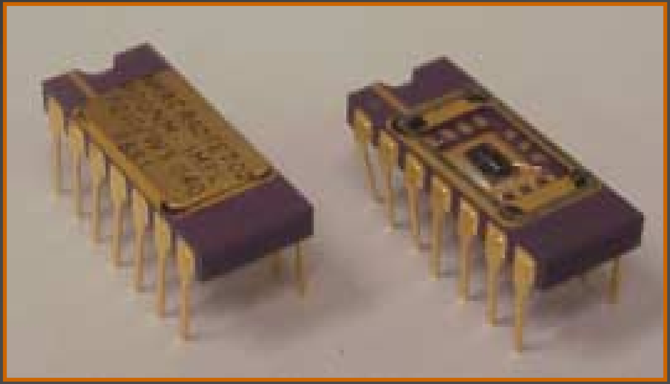
- Just secondaries with long penetration depth are considered;
- Short range secondaries will only contribute to ionising energy deposition in the layer of creation;
- Fewer secondaries reach the Gate Oxide

Total Ionising Dose for different cuts



Real Device Application

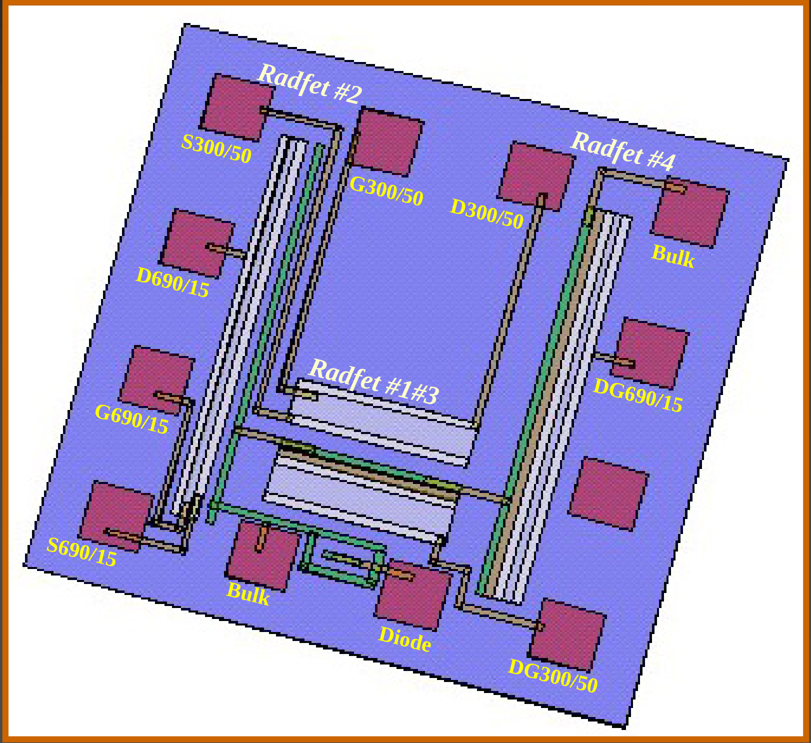
Space Users Forum 2003, Estec

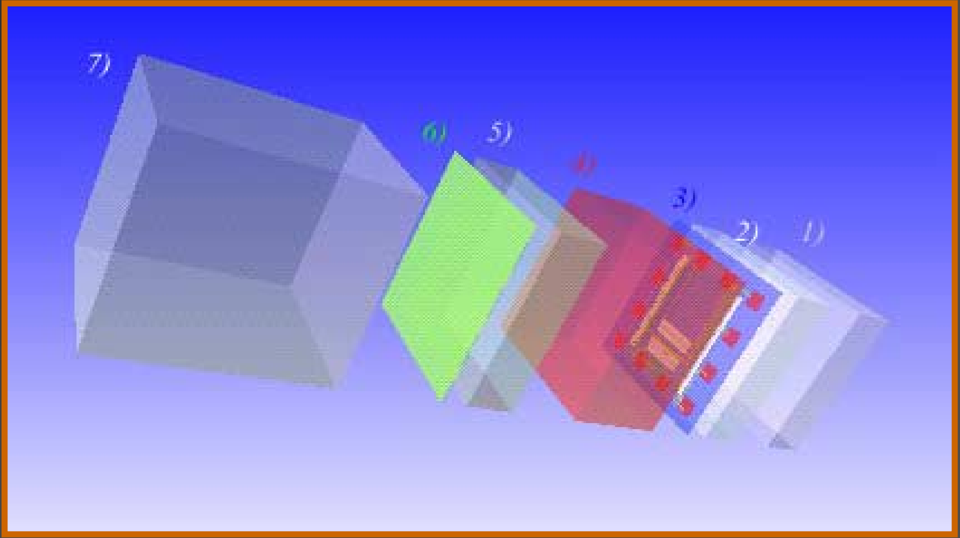


http://www.estec.esa.nl/wmwww/WMA/EMA_Events/g4spaceusers2003/presentations/GEANT4_AKeating_22012003.pdf

Device Description

- The NMRC RadFET dies consist of four RadFET Sensitive Detector: RadfFET1’ Gate Oxide



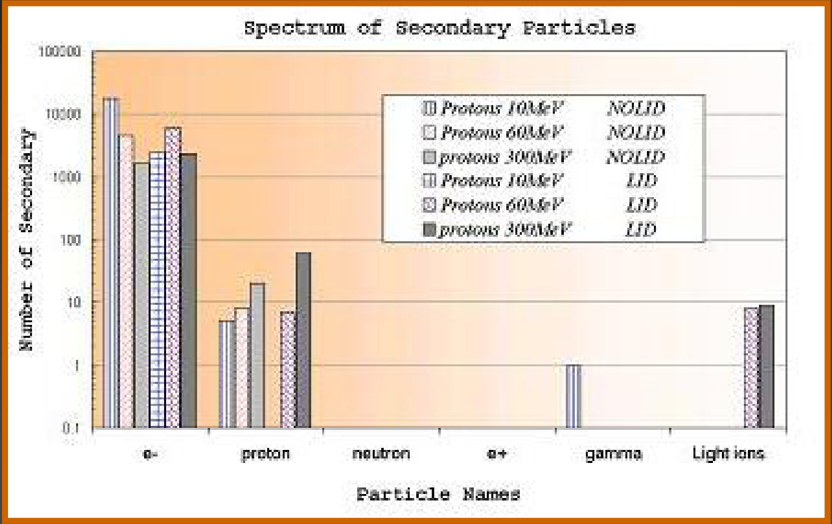


- 6 Package layers:

  250 µm lid (1) made of Kovar, adhesive(5), attach pad(6) and the base (7)

Secondary particles and Packaging

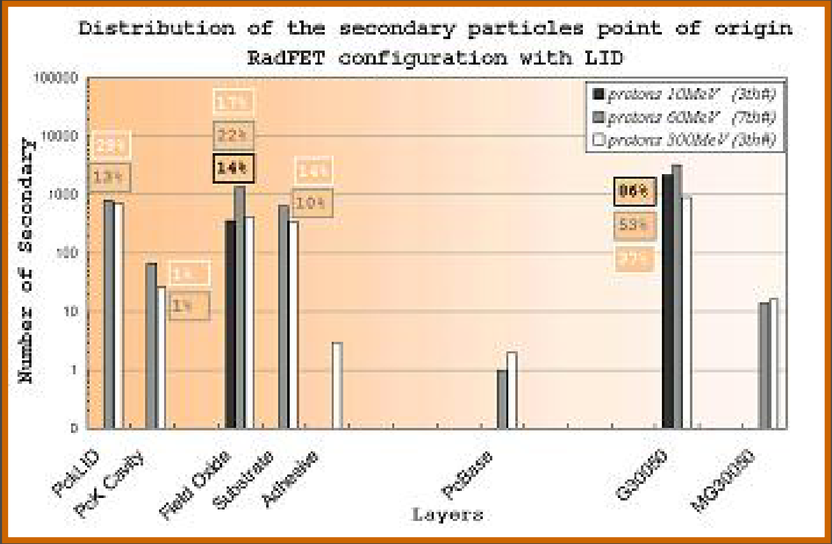
Similarly to the simple example, Dose Effects :



1- Are mostly due to :

- Electrons
- Protons

2- Depend on Packaging configuration :



Conclusions I

- A simple field-effect transistor example is constructed;
  - 3 packaging layers;
  - A gate oxide as sensitive volume;
  - A gate a source and a drain.
- The example also includes
  - Cuts per regions
  - Physics list consists of general physics, decay, low energy electromagnetic physics, as well as ions, proton (anti-proton), neutron (anti-neutron) elastic and inelastic processes.
  - Calculation of Total ionising Dose deposited in the gate oxide.

Conclusions II

- AIDA analysis creating histograms and tuples
  - Deposited energy,
  - Type of particles hitting the gate oxide,
  - Layer where secondary particles are generated,
  - Energy of incident particles,
  - Total ionising dose deposited in the gate oxide.

- The improvement of this work as a Geant4 example may benefit from comments!