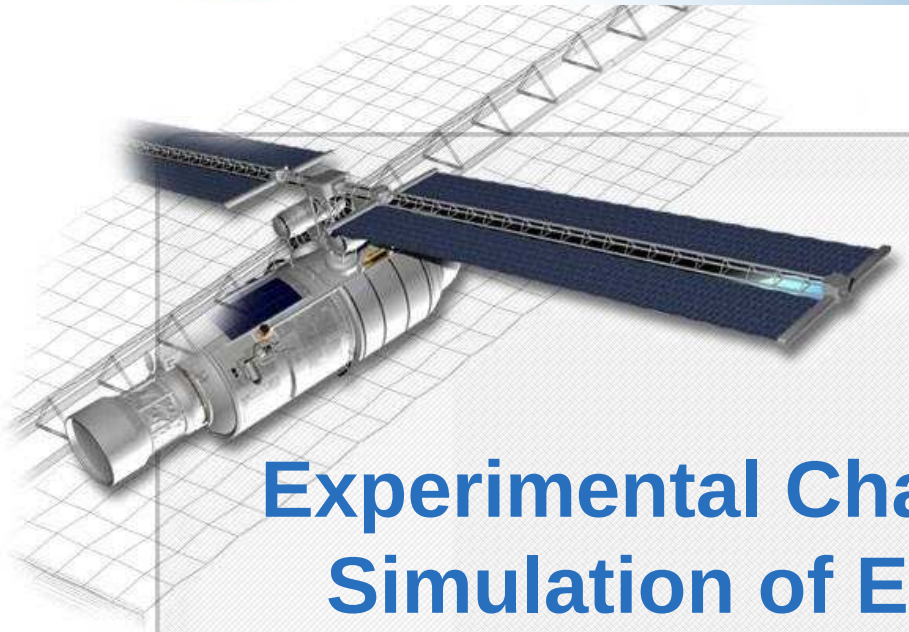


Experimental Characterization and Simulation of Electron-induced SEU in 45nm CMOS Technology

A. Samaras , P. Pourrouquet, N. Sukhaseum,
L. Gouyet, B. Vandevelde , N. Chatry,
R. Ecoffet, F. Bezerra and E. Lorfevre

Purpose of the study

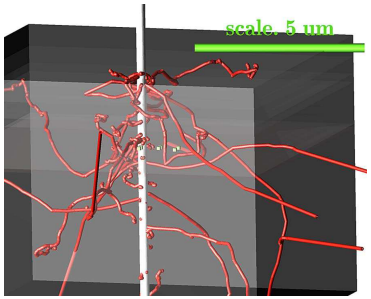
HI
p+

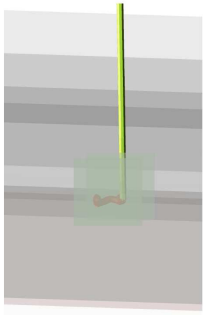
e-

SEU sensitivity of electronic devices under high energy electrons ?

Purpose of the study

δray => SEU
[King 2010]





X ray on aluminum attenuator => SEU
[King 2013]

Commercial devices potentially sensitive to primary electrons

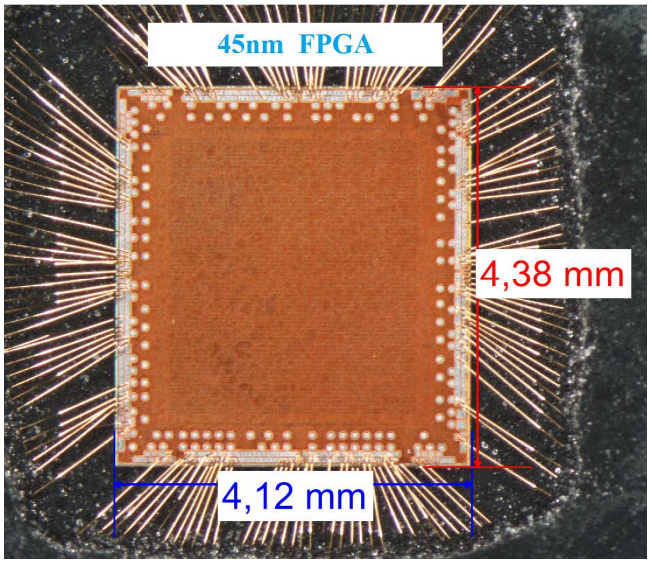
Aim of the study

- Component selection
- Test under primary electron beam
- Monte Carlo simulation
- SEU rate calculation

Device under test

The devices under test are 45nm CMOS copper process technology FPGA

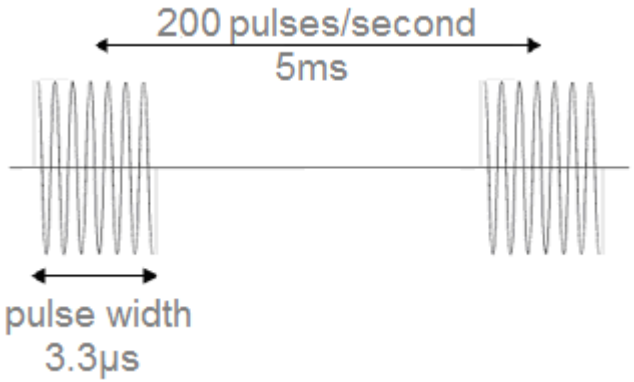
Device	FPGA
Function	SRAM based FPGA
Technology	45nm
Package	TQFP144
Date Code	1305
SRAM tested size	131072 x 4b



Irradiation Facility

Radiation tests performed at NPL (National Physical Laboratory, Teddington, UK)

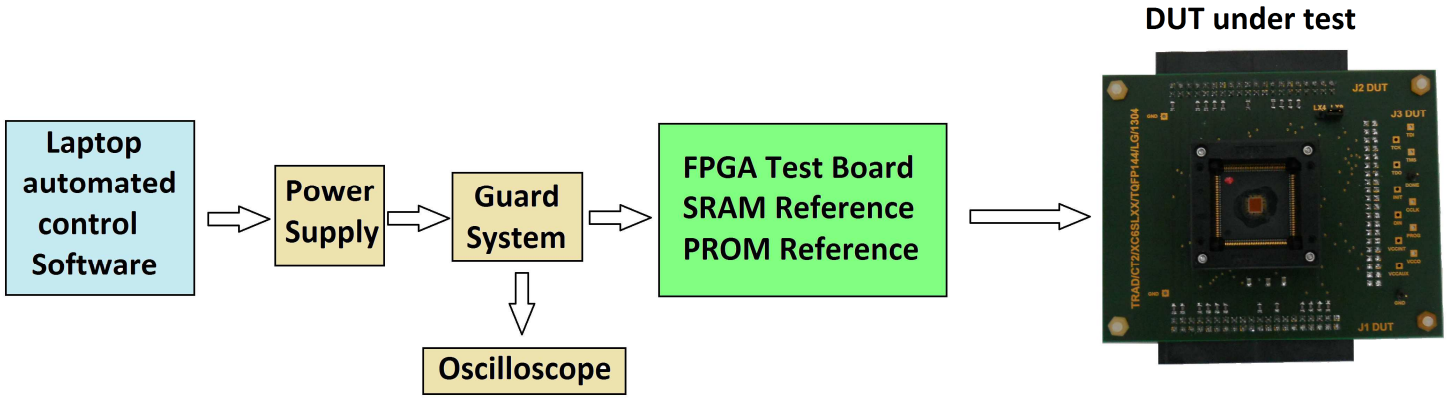
- Clinical Elekta Linac : standard clinical electron beam commonly used for external radiotherapy.
- Electrons energies [4MeV, 20MeV]
- Fluxes [0.5Gy/min, 5Gy/min]
- Maximum irradiation area : 250 x 250 mm²



⇨ **Dose Rate Peak = 1,3.10⁴ rad/s**

⇨ **Small enough to perform SEE tests without inducing Flash events**

Test bench description

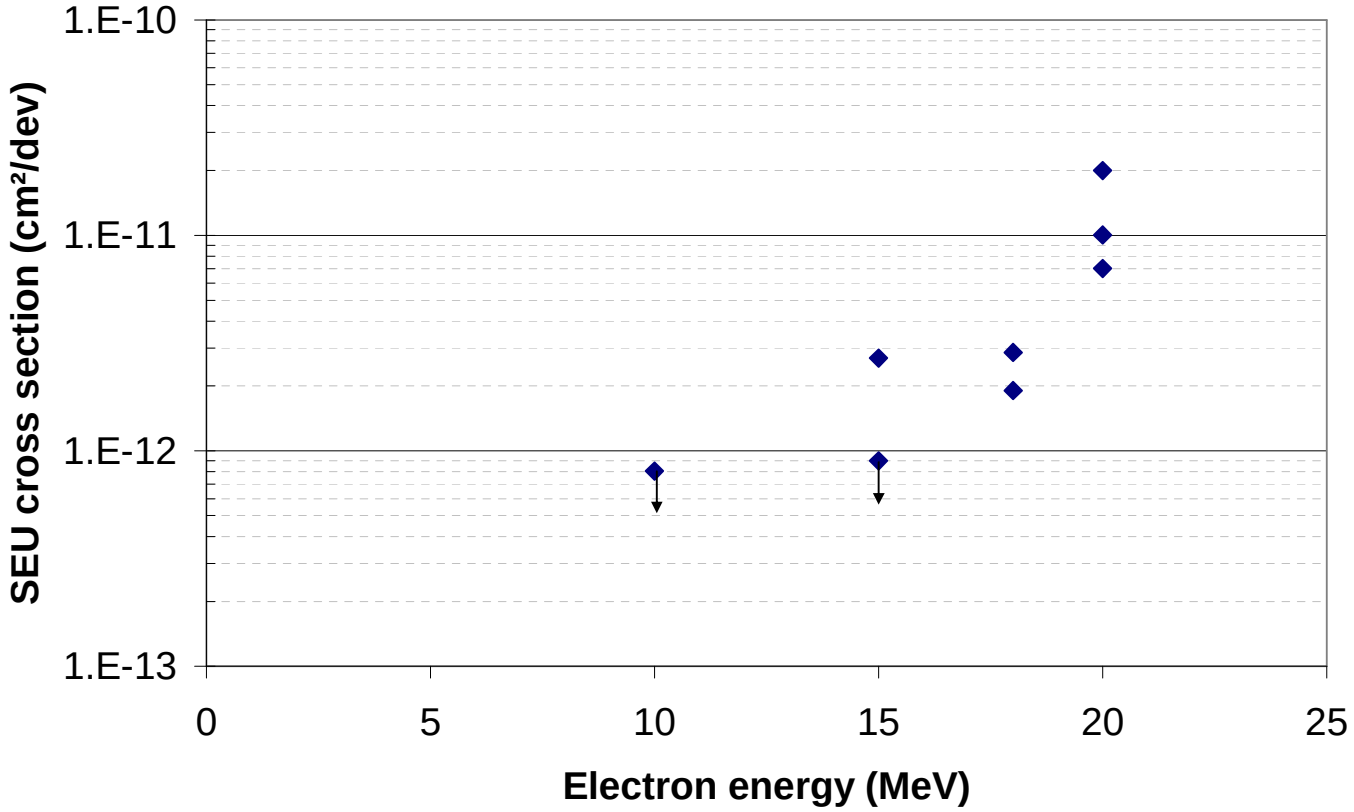


- **The test hardware is designed in order to perform an SEU characterization of the FPGA internal embedded RAM**
- **To increase the SEU sensitivity, the FPGA internal power supply was reduced :**

Vcc = 0.672V

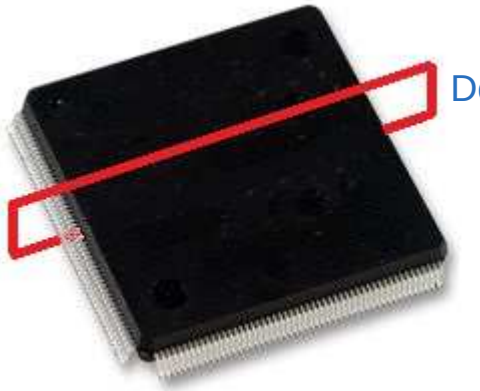
- **< minimum data retention voltage**
- **high enough to keep the device functional**

Radiation Test Results

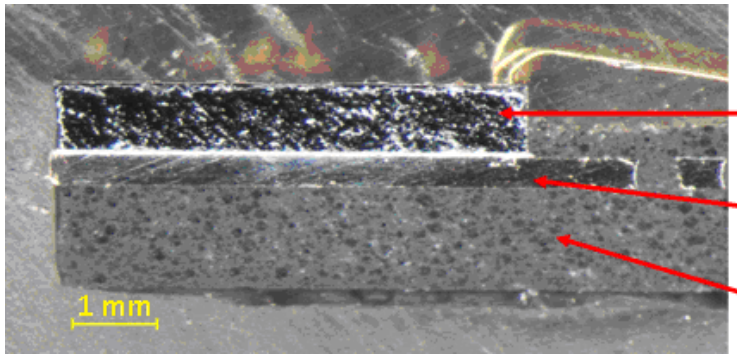


- No SEFI
- No SEL
- No loss of functionality and SEU susceptibility dependence observed up to the final TID level
- No Flux incidence on SEU susceptibility

Monte-Carlo Simulation

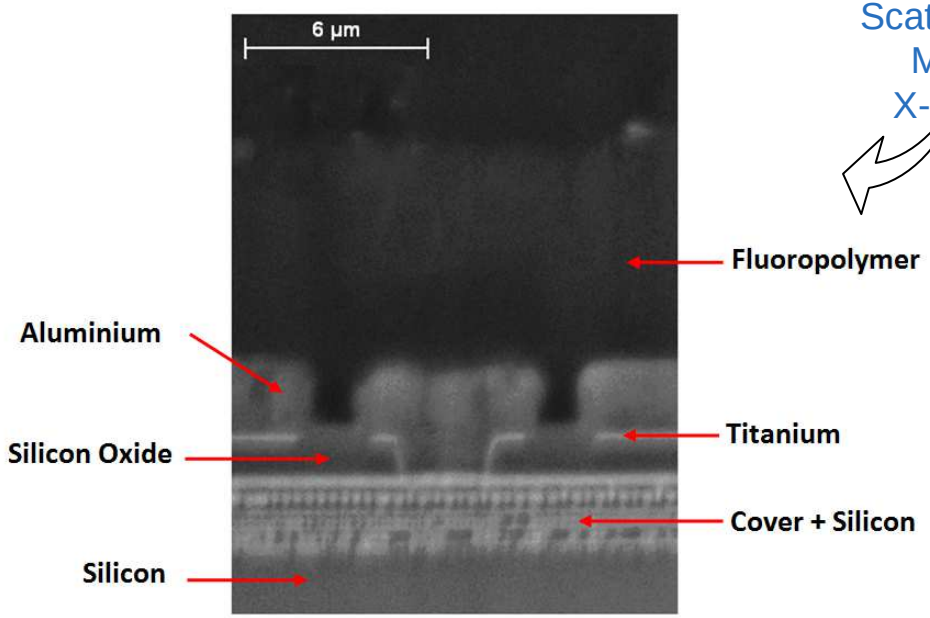


Device cut perpendicularly to the die surface



Scattering Electron Microscopy & X-Ray analysis

- Technological cross sections performed on FPGA.
- ⇨ Composition and thickness of the back end of line (BEOL) layers

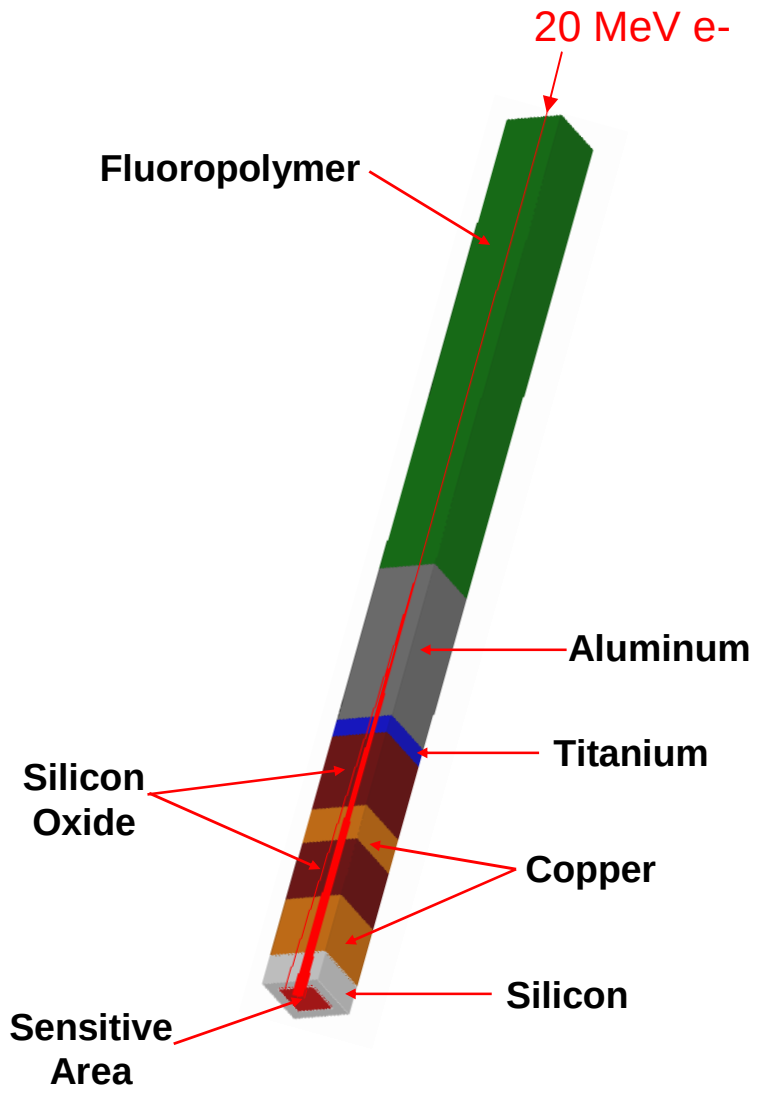


Monte-Carlo Simulation

GEANT4 Monte Carlo simulation

Hypothesis:

- **Charge deposition = ionizing energy loss of :**
  - primary electrons,
  - secondary electrons,
  - recoil atoms

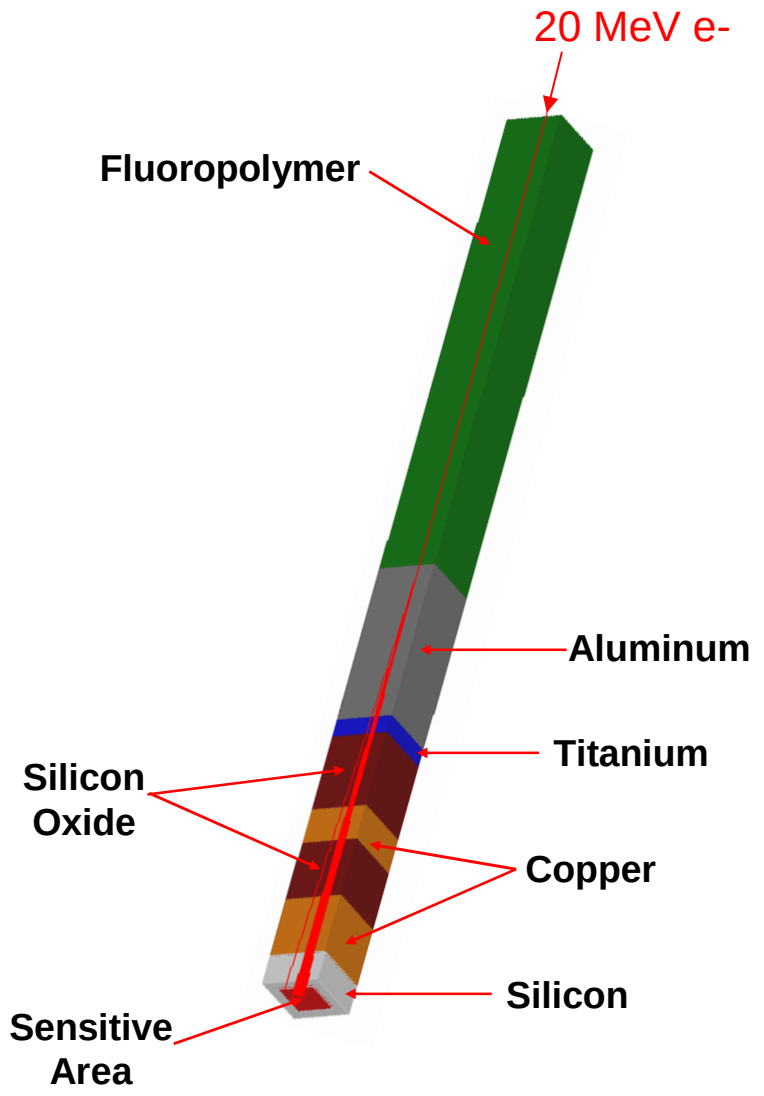


Monte-Carlo Simulation

GEANT4 Monte Carlo simulation

Hypothesis:

- **Charge deposition = ionizing energy loss of :**
  - primary electrons,
  - secondary electrons,
  - recoil atoms
- **Primary electrons tracked one by one**
  - ⇨ Detected events due to a single primary particle

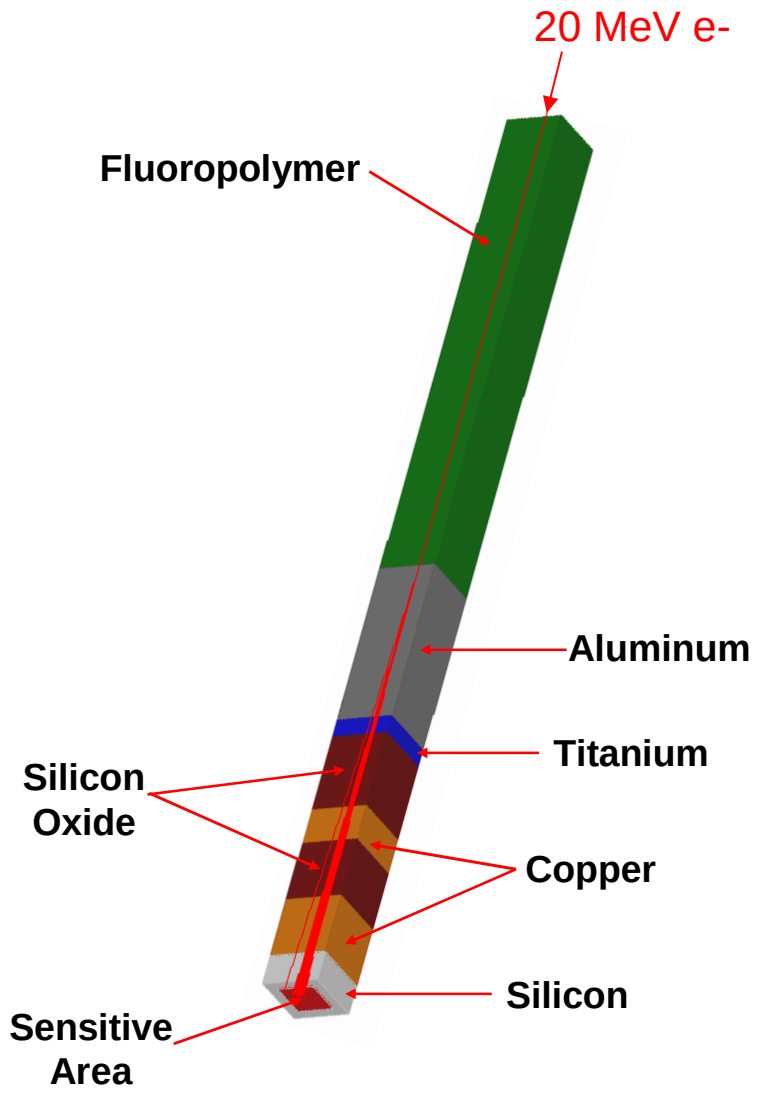


Monte-Carlo Simulation

GEANT4 Monte Carlo simulation

Hypothesis:

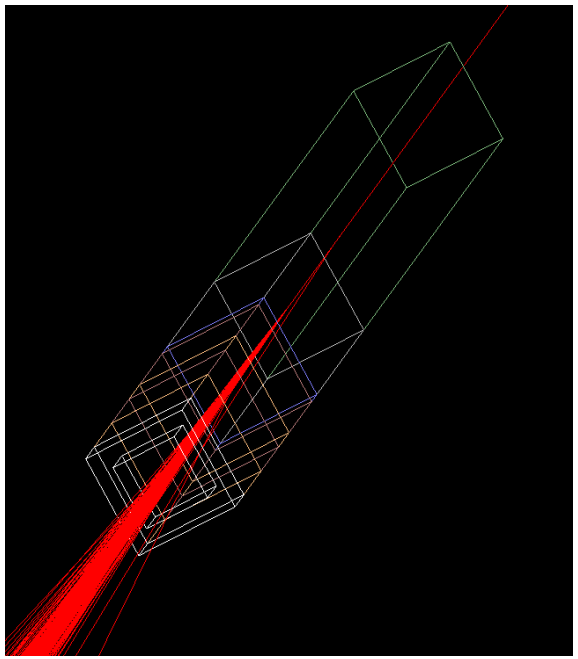
- **Charge deposition = ionizing energy loss of :**
  - primary electrons,
  - secondary electrons,
  - recoil atoms
- **Primary electrons tracked one by one**
  - ⇨ Detected events due to a single primary particle
- **Temporal condition = 10ps**
  - Collection of charges from several secondary electrons generated in a same time lapse

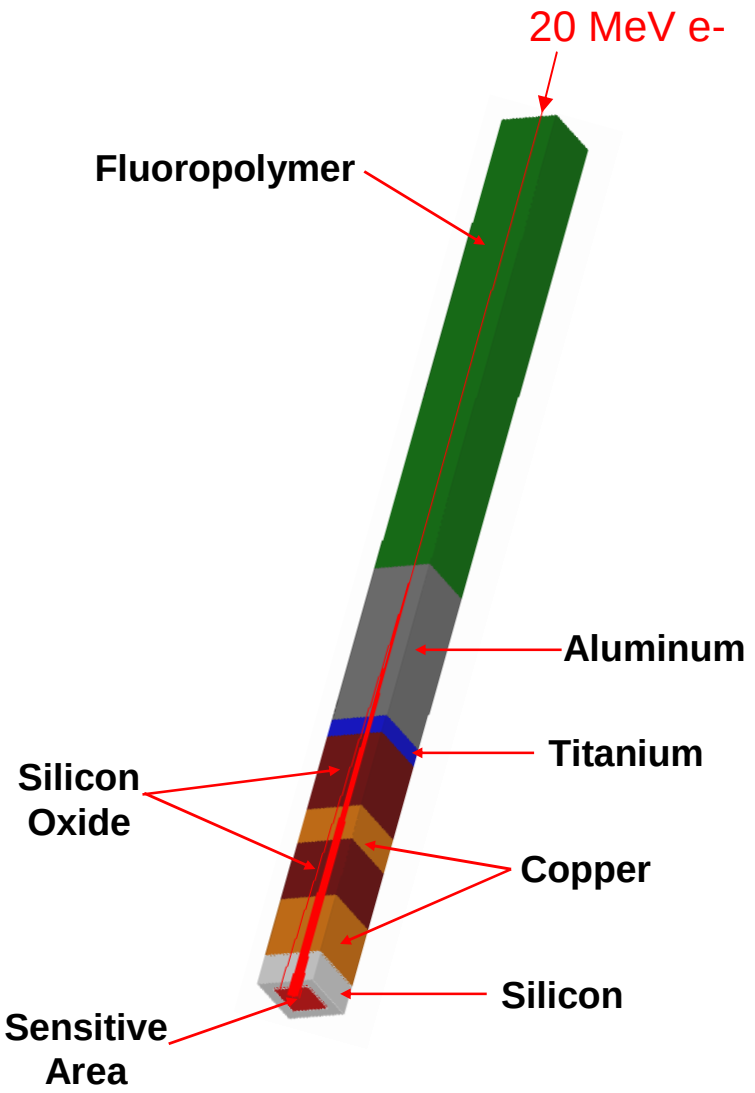


Monte-Carlo Simulation

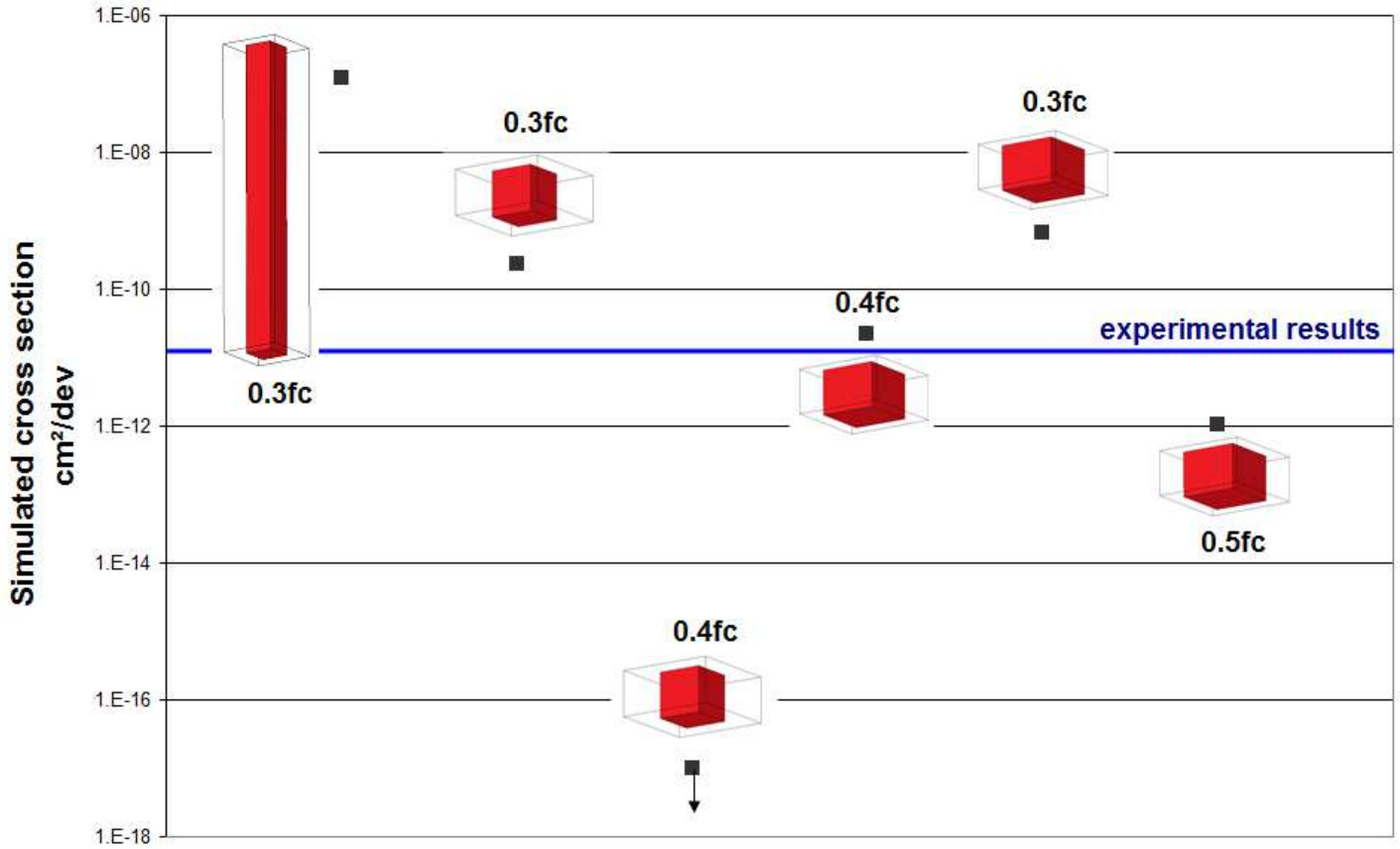
Simulation results :

SEU = combined energy deposition of primary and secondary electrons





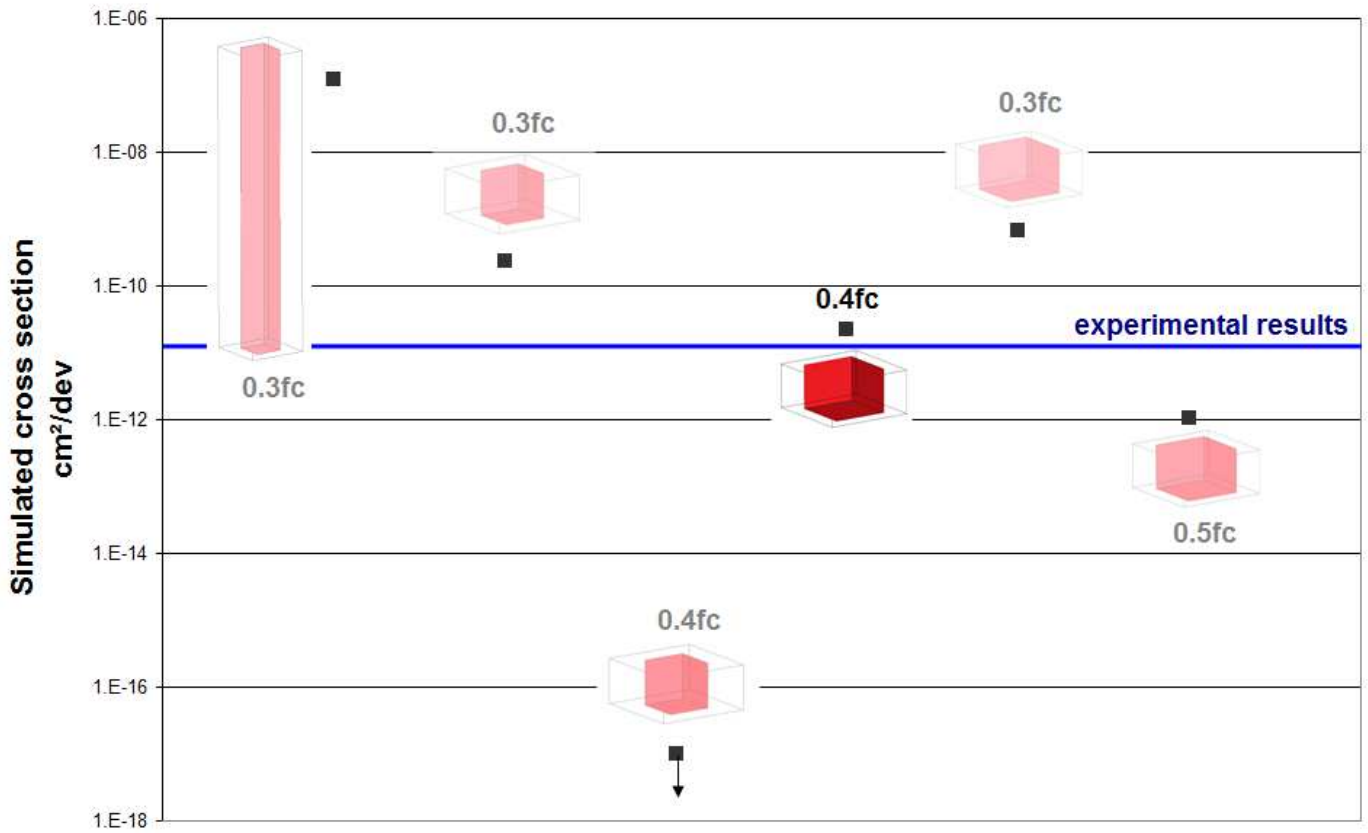
Monte-Carlo Simulation



Simulated cross section depend on

- **Critical charge**
- **Sensitive area**
- **Thickness**

Monte-Carlo Simulation



Critical charge = 0.4fc
Sensitive area = 0.4 µm²
Thickness = 0.05µm

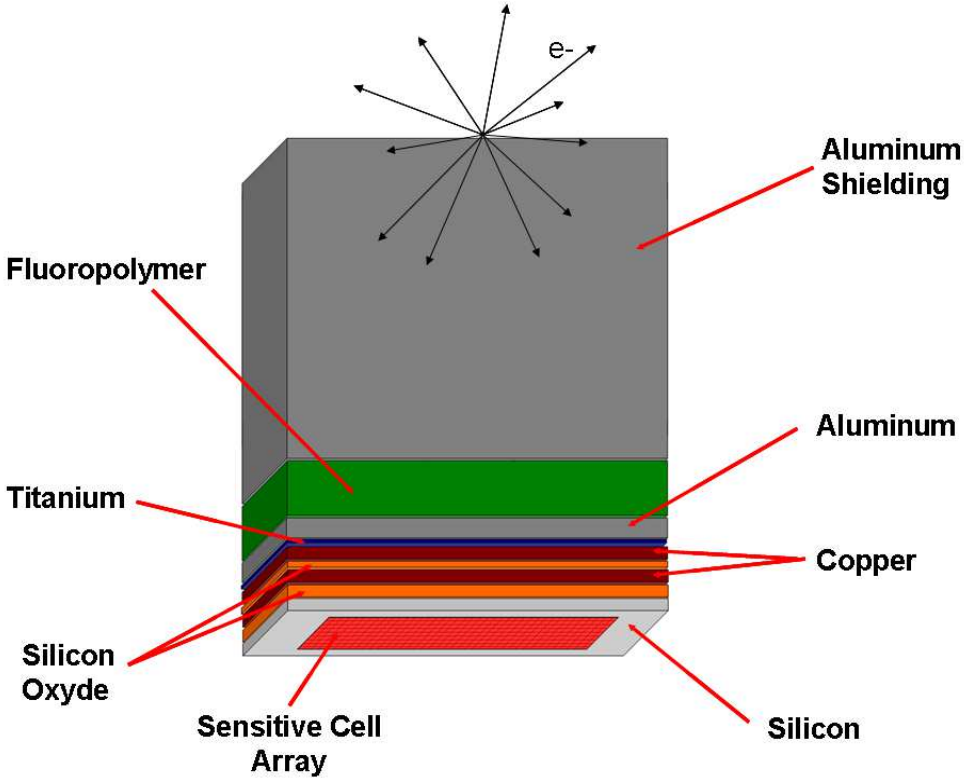
representative of the device and test condition (low bias voltage)

SEU rate calculation for JUICE mission

SEU rate calculation for JUICE mission in standard supply condition

Hypothesis:

- 15 mm aluminum plate = shielding spacecraft estimation
- Two isotropic electron spectra have been considered:
  - Worst Case flux, (worst case mission location),
  - Average flux over the scientific phase of the JUICE mission



SEU rate calculation for JUICE mission

Monte Carlo Simulation:

- **Sensitive area = 0.4µm²**
- **Thickness = 0.05µm**
- **Critical charge = 0.5 fC**
  - **standard bias voltage**

ITRS roadmap 45nm SRAM technology in standard condition

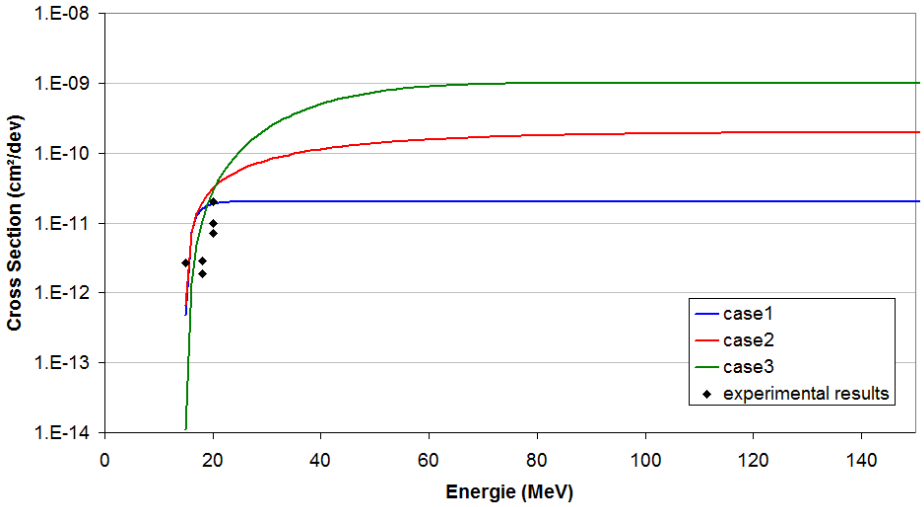
	Worst case flux	Average flux
SEU rate per device per day Monte Carlo	19.5	2.58E-01

SEU rate calculation for JUICE mission

OMERE Software

Isotropic angular distribution of secondary electrons

SEU electron rate determined using the same method as for proton rate calculation



		Worst case flux	Average flux
SEU rate per device per day OMERE	case1	1.07E-01	2.26E-03
	case2	3.8E-01	7.38E-03
	case3	1.34	2.43E-02

Conclusion

⇨ **SEU Test under high energy electron beam**

⇨ **NPL facility limited at 20MeV**

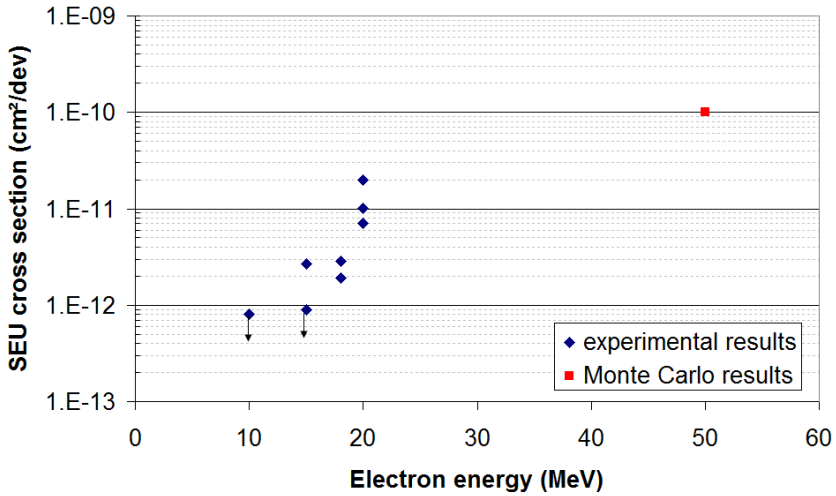
⇨ **Simulations support this conclusion**

⇨ **SEU are induced by primary and secondary electrons**

⇨ **SEU rate for the entire JUICE mission**

Perspectives

- **Radiation Test :**
  - New irradiation facility ⇨ E > 20MeV
- **Monte Carlo Simulation :**
  - Collaboration with device designers ⇨ device description
- **Radiation test and Monte Carlo simulation combination**
  - Radiation test up to 20 MeV
  - Radiation test ⇨ Simulation parameters
  - Monte Carlo simulation ⇨ saturation cross section



NSREC 2014 & TNS publication :

A. Samaras, P Pourrouquet, N. Sukhaseum, L. Gouyet ;B. Vandevelde, N. Chatry, R. Ecoffet, F. Bezerra, E. Lorfevre

« Experimental Characterization and Simulation of Electron-Induced SEU in 45-nm CMOS Technology »,

IEEE Trans. Nucl. Sci., vol. 61 no. 6, p 3055 - 3060, Dec. 2014

Experimental Characterization and Simulation of Electron-induced SEU in 45nm CMOS Technology

QUESTIONS