R&T PROTON DIRECT IONIZATION

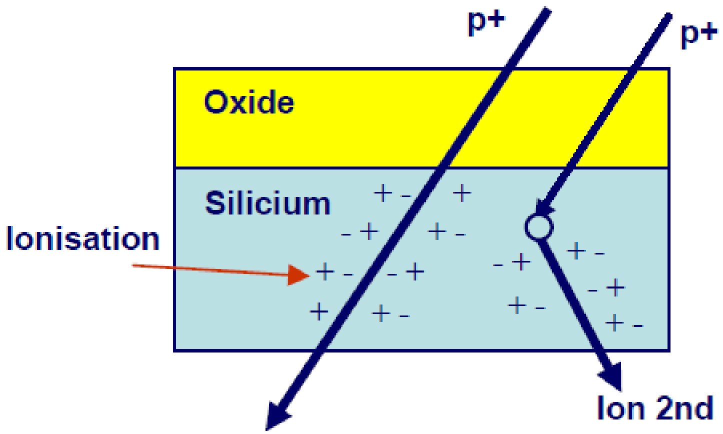
A Calculation Method for Proton Direct Ionization Induced SEU Rate from Experimental Data: Application to a Commercial 45nm FPGA

Nicolas Sukhaseum (TRAD)
Anne Samaras (TRAD)
Lionel Gouyet (TRAD)
Françoise Bezerra (CNES)

Introduction

- **Electronic device integration scale decrease → SEU sensitivity increase**

- **Technology nodes 90nm and lower (65nm, 45nm, 28nm…)**
  - **Necessary charge to upset a device low enough to be sensitive to proton direct ionization**



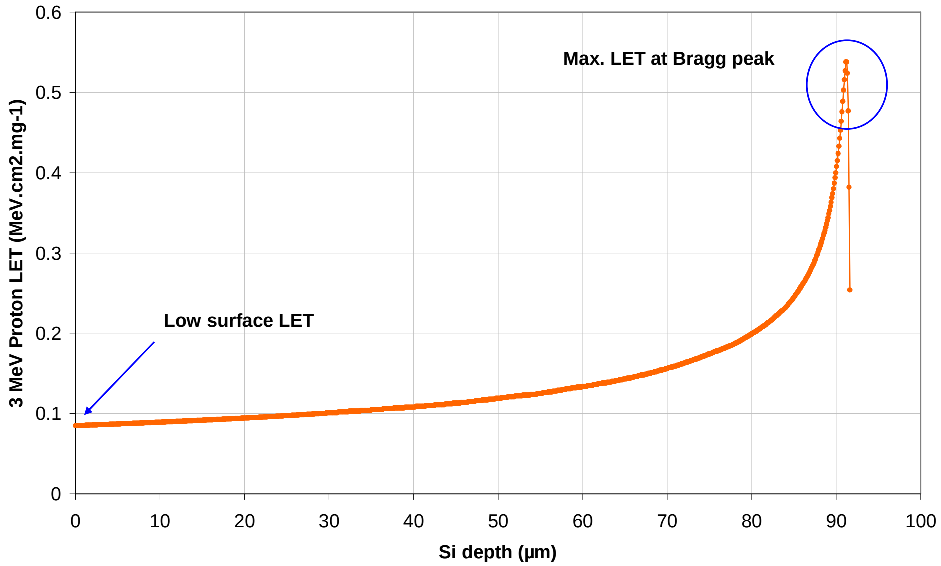
- **Proton caused SEU**
  - **Recoil atom**
    - Indirect event due to the charge generated by a secondary ion
  - **Direct ionization**
    - Charge generated by the incident proton leads to an event

- **The aim of this study was to propose a test method and a rate calculation for the proton direct ionization sensitivity**

Introduction

- **Maximum LET at end of path**
  - **Significant deposited charge over a small distance in the last silicon microns**

- **Proton direct ionization may occur when**
  - **Maximum generated charge in the device active erea**
    - Incident proton stops in the active area
  - **Device sensitive enough compared to the generated charge**
    - Low SEU critical charge



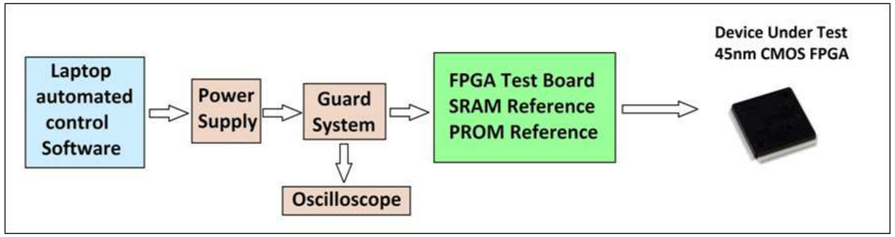
Experimental Characterization

Need for an SEU sensitive device

- **Small SEU critical charge**
  - Chances to see proton direct ionization
- **Important integration scale technology**
  - 45nm CMOS SRAM-based FPGA embedded BRAM
  - Two tested references of the same technology (different device size)
  - Same date code for all the samples of one reference

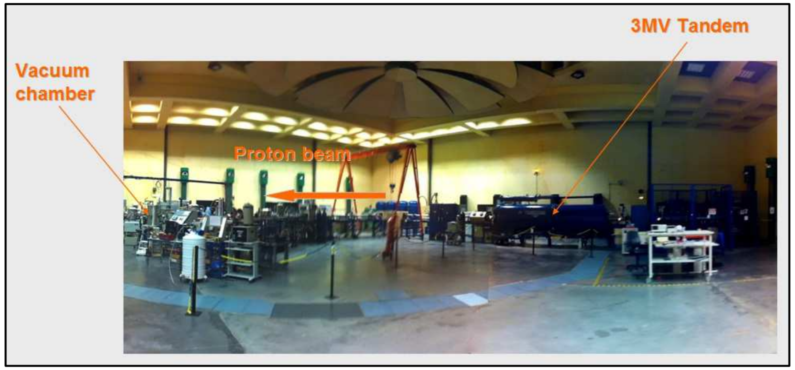
Experimental Characterization

- **Test bed developped by TRAD for low energy proton beam experiments**
  - SEU count
  - Stuck bit detection
  - SEFI management
  - SEL protection



Test configuration

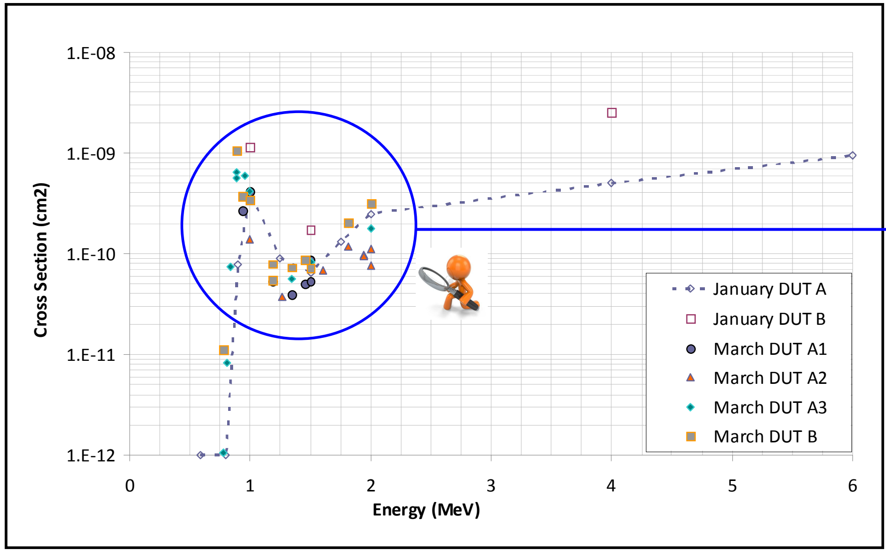
- **Irradiations performed at CNA (Centro Nacional de Aceleradores, Sevilla, Spain)**
  - 3MV Tandem accelerator
  - Incident proton energy 750keV to 6MeV
  - Tilted experiments 0° to 60°
    - Effective penetration depth variation



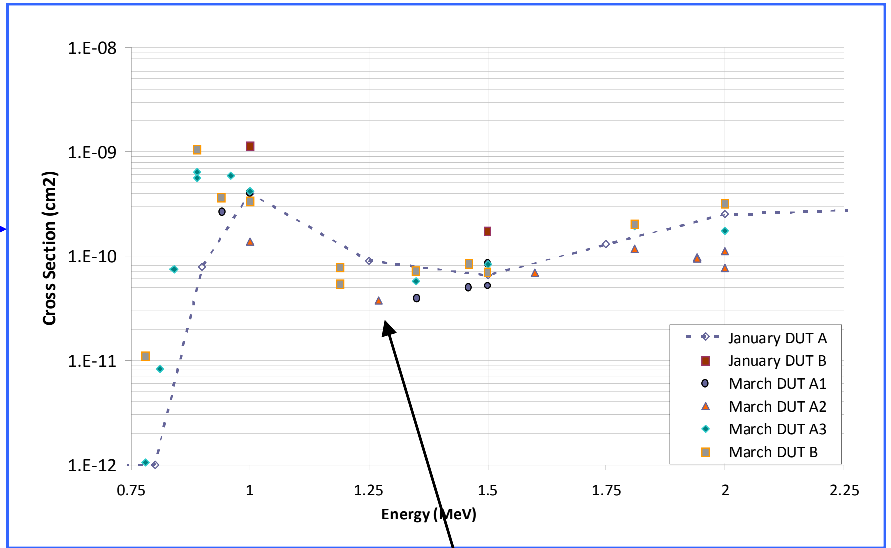
CNA proton facility

Test Results

Proton cross section σ(E)



Proton cross section σ(E) between 0.75 and 2.25 MeV



Irradiation 2MeV, 60° displayed at 1.27MeV

- **Cross section increase below 1.5MeV**
  - Direct ionization sensitivity of the tested devices

- **Irradiations at different energies and tilt angles**
  - Tilted irradiations are plotted on the graph at the energy corresponding to the same effective range in silicon

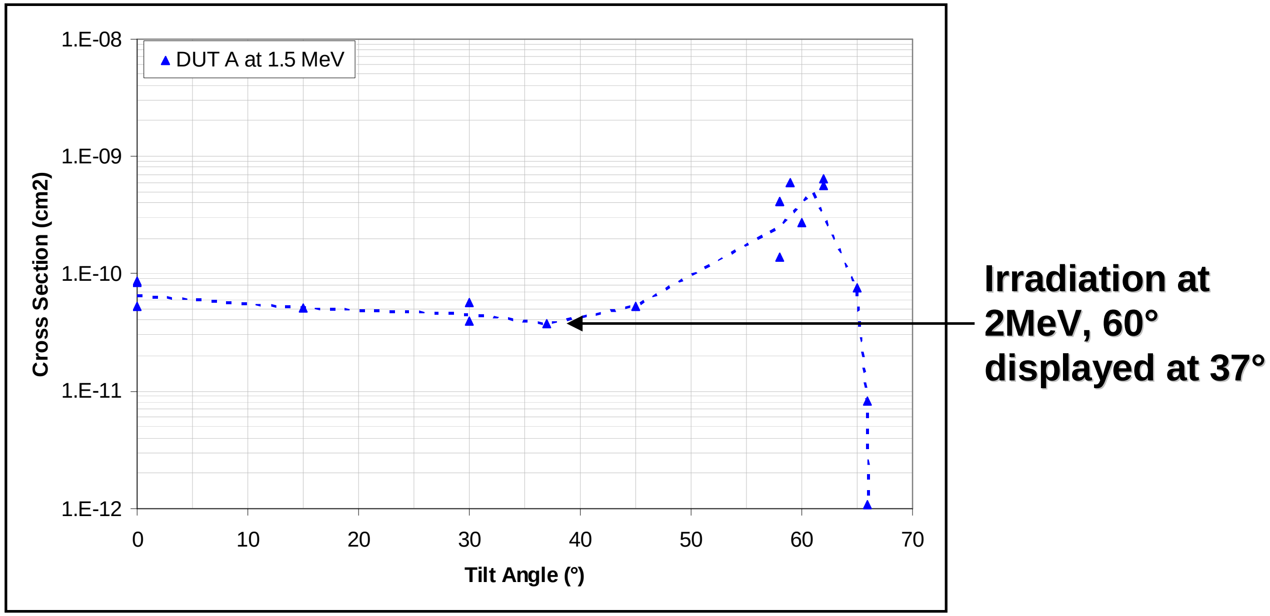
Test Results

- The experimental data is compiled in order to calculated a rate
- Reconstructed cross section curve at fixed energy as a function of the tilt angle
  - Based on the penetration depth value

R (2 MeV, 60°)
=
R (1.27 MeV, 0°)
=
R (1.5 MeV, 37°)

- At 1.5 MeV, cross section values at normal incidence are not representative of the direct ionization sensitivity

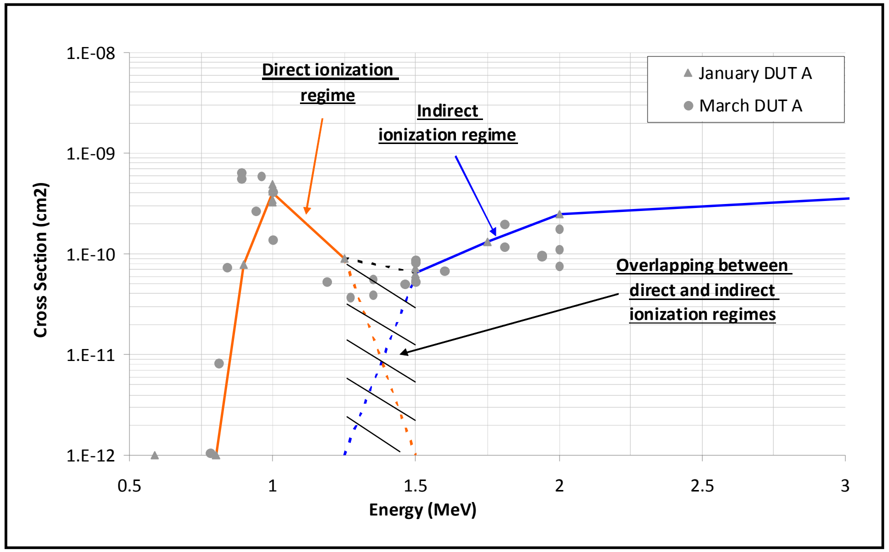
Reconstructed cross section σ(θ) at 1.5 MeV

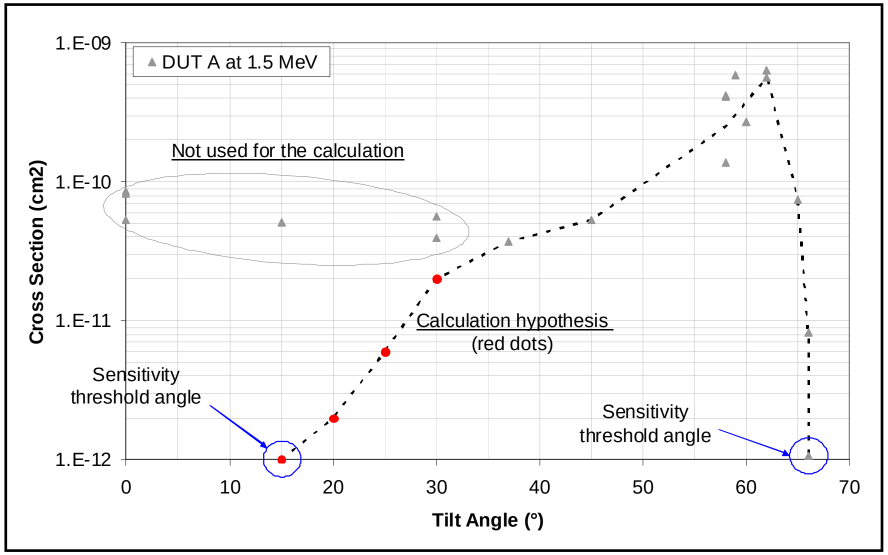


Data Analysis

- **Between 1,25 and 1,5 MeV, the relative proportion of direct events decreases with respect to the indirect events increase**
  - **There is an energy range in which the direct and indirect ionization regimes overlap**

- **In order to focus on direct ionization, the test data is completed by a calculation hypothesis**
  - **The two sensitivity threshold angles appearing on the graph are used to define the direct ionization sensitive layer**



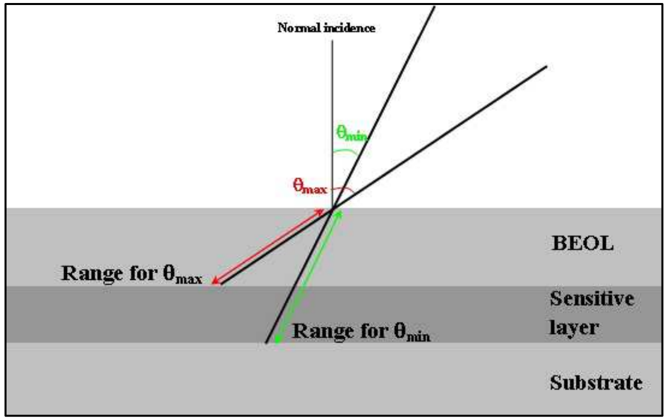


Data Analysis

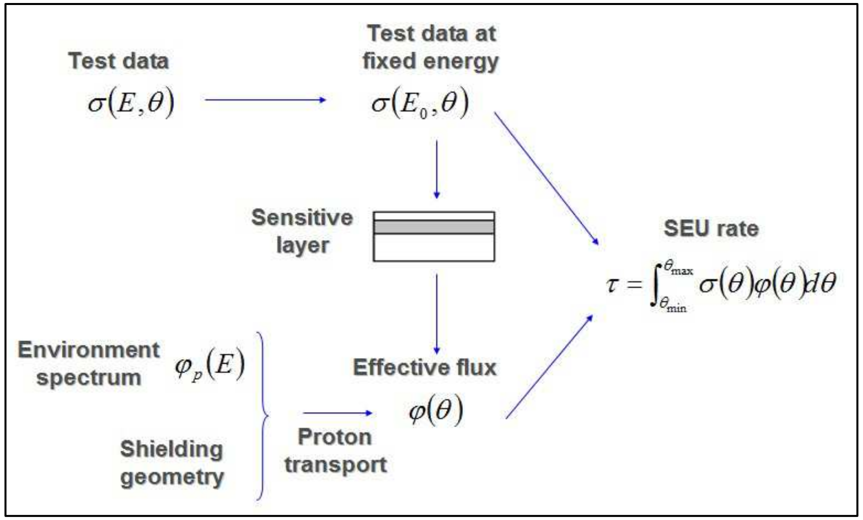
- **Sensitive layer depth and thickness calculated with respect to the threshold angles**
  - **15° and 66° in the example of DUT A at 1.5MeV**

- **It is assumed that an incident proton has to stop in the sensitive layer in order to be likely to create an event by direct ionization**
  - **Effective flux φ(θ) to take into account at each angle defined by the proportion of protons from the environment spectrum with a path ending in the sensitive layer**

- **At a tilt θ, over all the incident protons stopping in the sensitive layer, the ratio of particles leading to an event is given by the measured cross section σ(θ)**



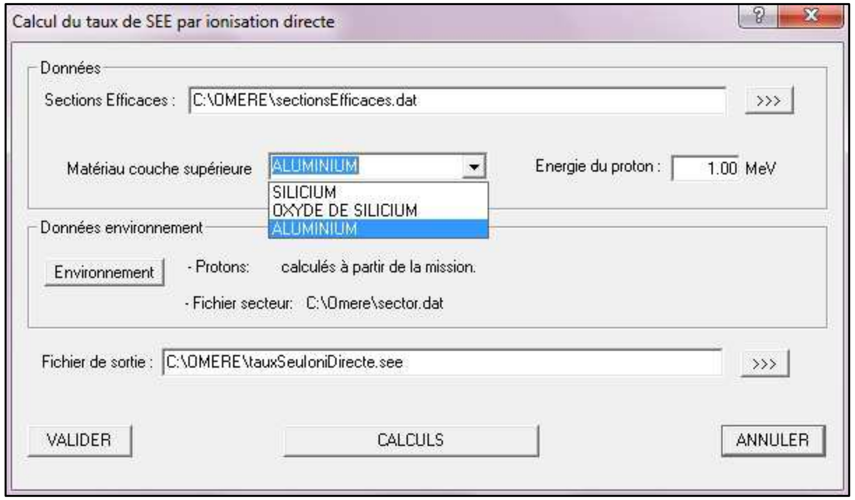
Sensitive layer calculation



Calculation methodology

Rate Calculation

- **SEU rate calculation**
  - **OMERE 4.0 beta-version proton direct ionization module**
  - **Comparison with indirect event proton rate**
    - σ_{sat}=1.10-9cm2, E_0=1,5MeV, W=20 and S=1



Direct ionization module window

Environment	*Indirect ionization*	*Direct ionization*
	(dev-1.day-1)	*(dev-1.day-1)*
LEO (incl. 51.5°, alt. 400 km)	**$8,5.10^{-4}$**	**$3,3.10^{-6}$**
LEO (incl. 98°, alt. 800 km)	**$8,5.10^{-3}$**	**$4,5.10^{-5}$**

SEU rates (AP8 min, ESP 80%, 1 g.cm^{-2})

Conclusion

- **All study details given in NSREC 2014 proceedings**
  - **Paper identifier PB-5**
    - "A Calculation Method for Proton Direct Ionization Induced SEU Rate from Experimental Data: Application to a Commercial 45nm FPGA" (N. Sukhaseum, A. Samaras)

- **Perspectives**
  - **Experimental characterization**
    - During the tests, the tilt was performed in only one direction. A possible improvement of the experimental approach is to check that tilting along another direction would lead to the same results.
  - **Software development**
    - The beta-version of OMERE developed within the framework of this study accepts as input only one cross section curve, expressed as a function of the angle, at fixed energy. The software abilities could be improved to perform the data analysis automatically from all test measurements.

  - **CNES R&T Direct Ionization 2015 study**