MUSCA SEP3 to investigate the Single Event Effects for Space Missions

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ONERA
THE FRENCH AEROSPACE LAB

return on innovation

2009-2010 CNES R&T

Motivations

Motivations at developing a new SEE predictive method ?

- Obsolescence of conventional methods
- Operational error rate calculation

  → **the device shall be considered within its material, radiation and operational environments**
- Analysis of SEE anomalies and calculation of dynamic rates

  → **“space weather” problematic and forecasting rate**
- New and relevant methodologies for modern devices

  → **To investigate the rate trends induced by technological roadmap**

  → **To prevent the emerging effects**

→ **MUSCA SEP3** developed by ONERA since 2007

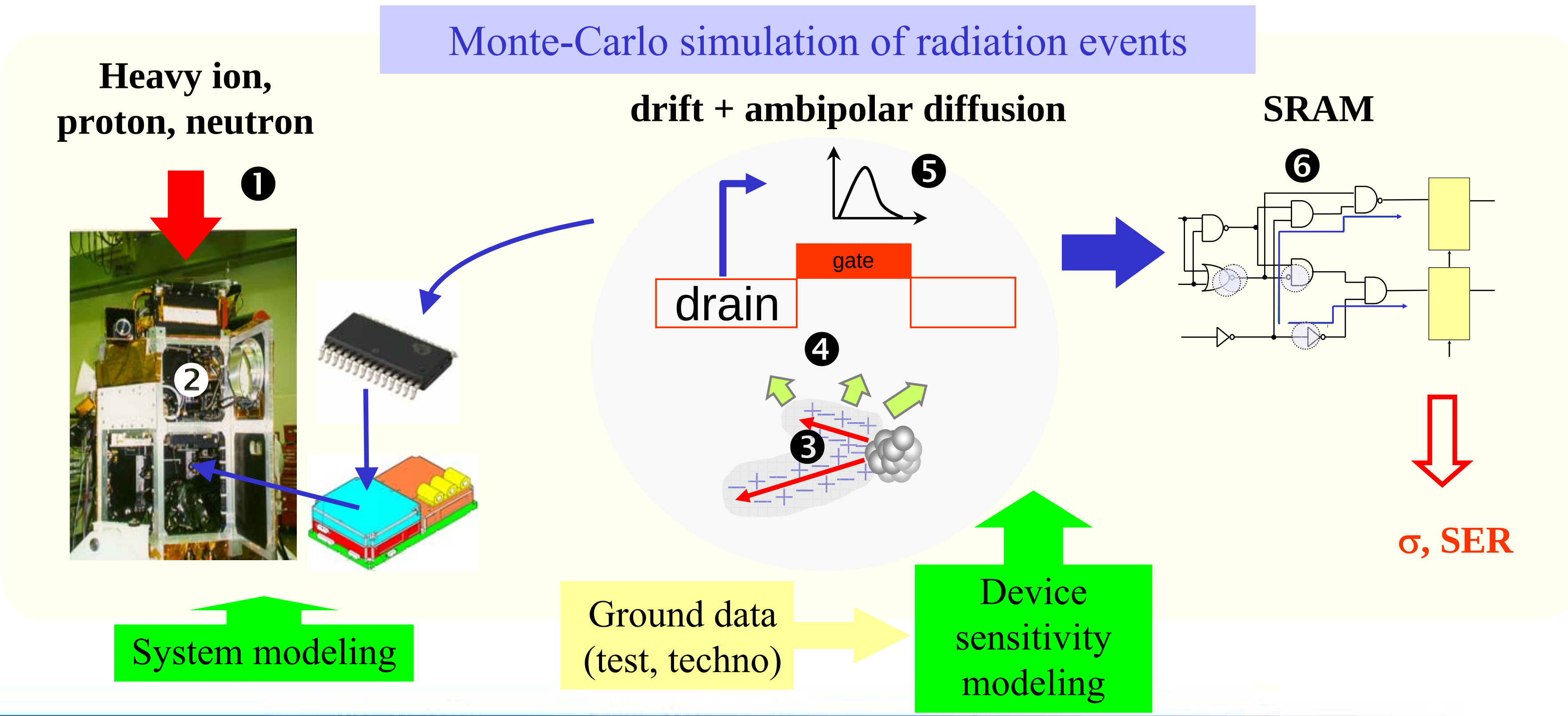
Pragmatic & global approach

Based on physical mechanisms & sequential modeling

Multi-scale approach

SEE: multi-scales and -physics scenario *(nsrec2009)*

1. Radiation field
2. Particle transport in materials
3. e/h & charge generation in semiconductor
4. e/h transport and charge collection mechanisms
5. Transient pulses at electrodes
6. Circuit and system effects: → **SEE occurrence**



Outline

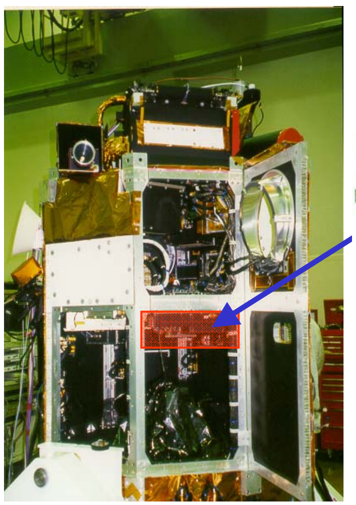
- Introduction
- Operational rate calculation: illustrations
  - Flight rates (SAC-C): mean and dynamic (flares)
  - Anomaly expertise
  - Heavy ion – proton link
  - Emerging effects
- Synthesis and perspective

SAC-C experiment

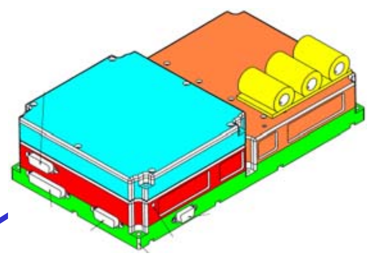
ICARE experiment on-board SAC-C :

- On-board the Argentinean satellite SAC-C (alt: 707km, incl: 98.2º)
- SEE data for more than 8 years in orbit (launch November 2000)

SAC-C

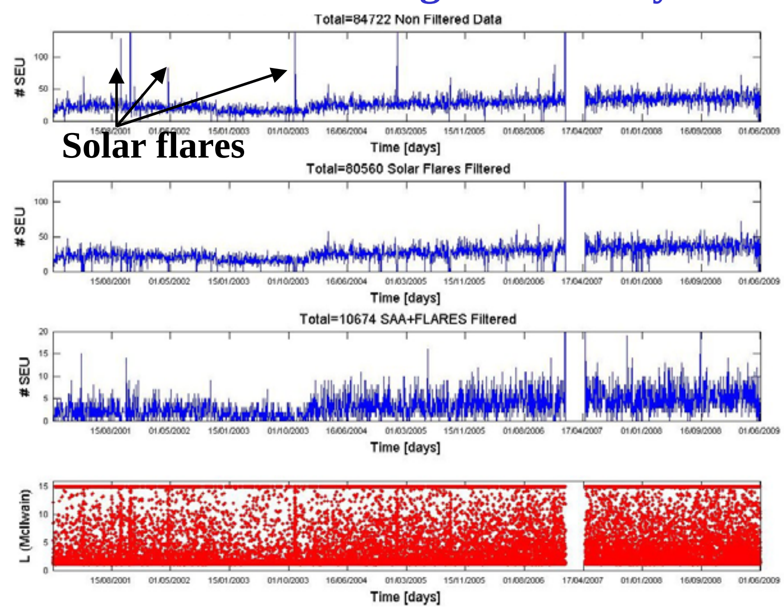


ICARE



SRAM and DRAM memories under test

Ex: KM684000 in-flight SEU daily rate



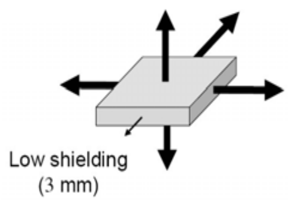
HM628512, KM684000 (SRAM4M)

SEE count at flares: conventional method overestimates by x 100-500

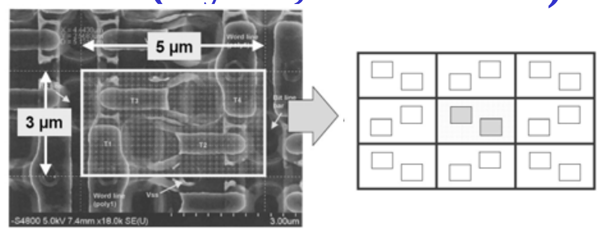
& multiple effects not considered

ICARE/SAC-C modeling

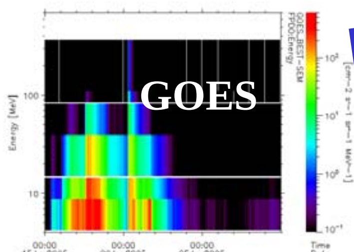
Structure



Reverse engineering (layout, dimensions)



Environment



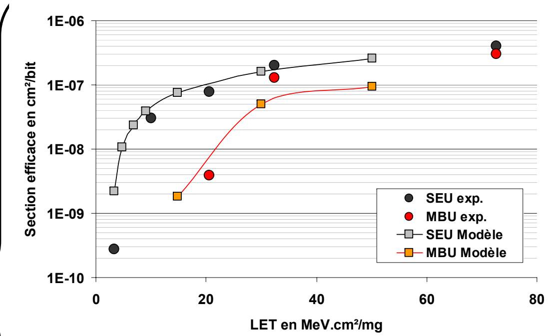
+ OMERE tool

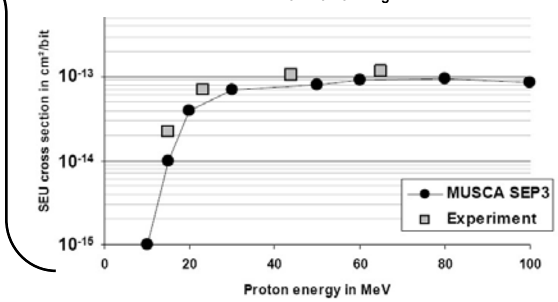
MUSCA SEP³

Device parameters

(r_{lat}, r_{depth}, Q_{crit} , circuit)

ground data (SEU and MBU)



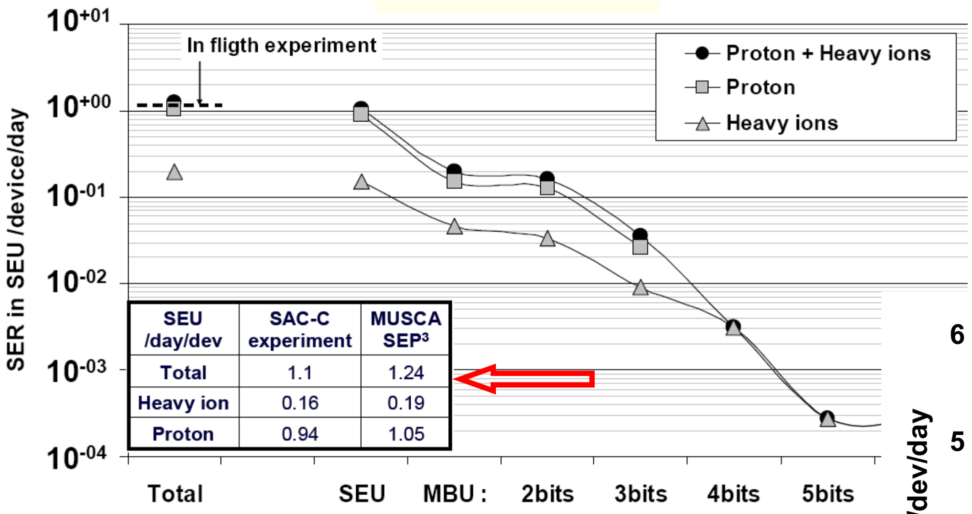


SAC-C experiments: mean rate (nsrec2009)

Calculated rate compared with "cumulated "in-flight data

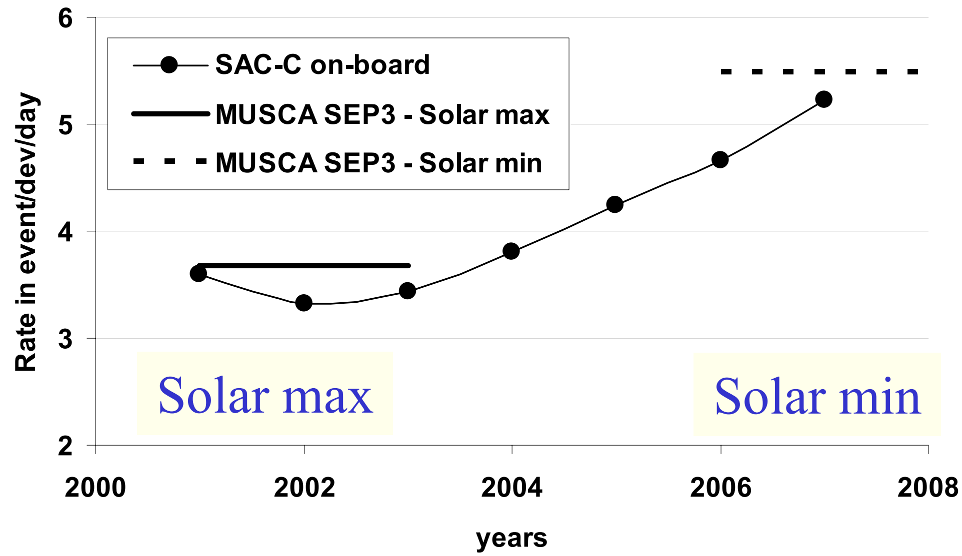
- Analysis of the orbit: radiation belts and cosmic contributions

HM628512



SEU /day/dev	SAC-C experiment	MUSCA SEP³
Total	1.1	1.24
Heavy ion	0.16	0.19
Proton	0.94	1.05

KM684000



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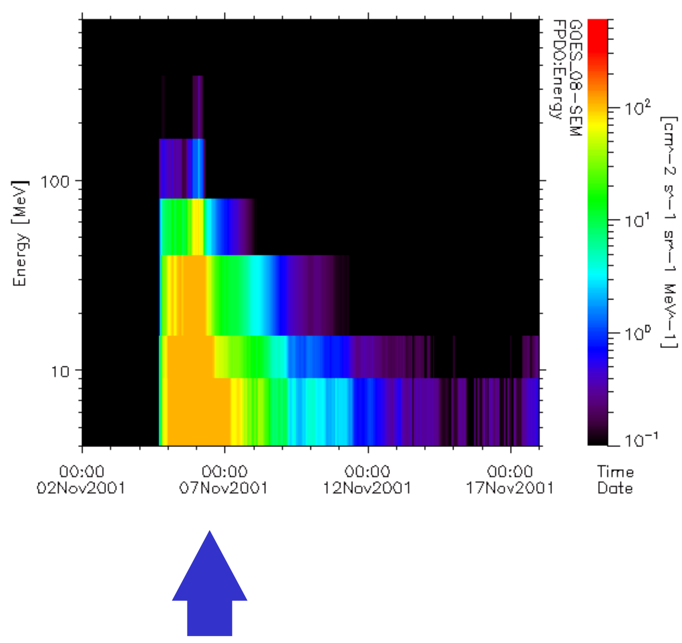
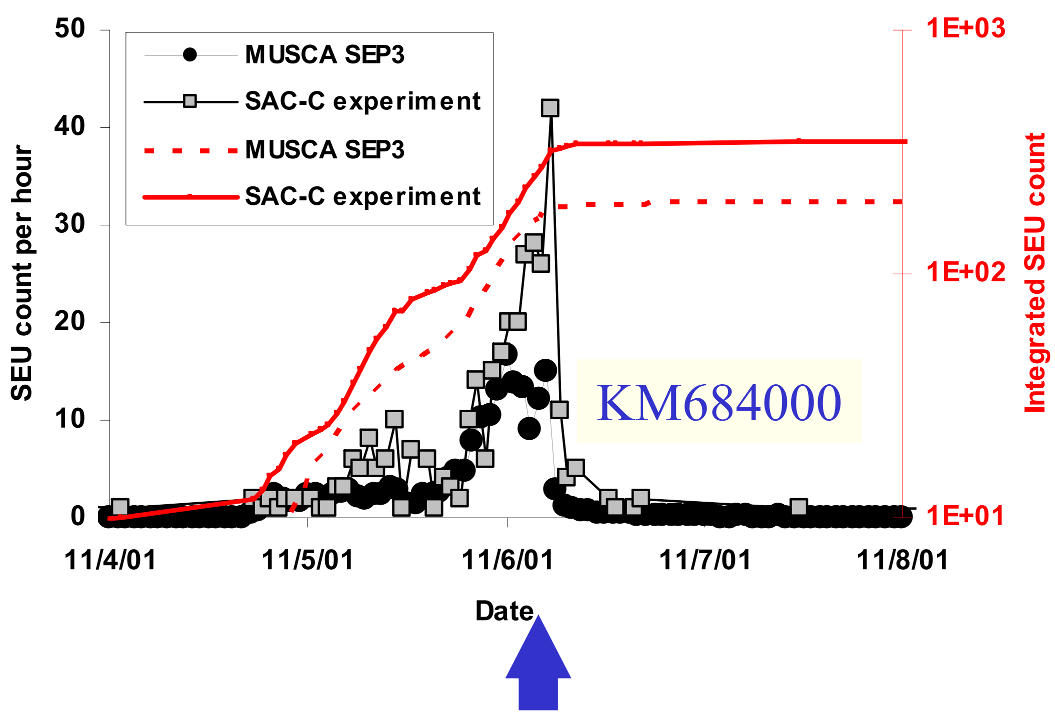
Calculated rate compared with in-flight SEE count (Nov 2001)

- KM684000 (total capacity 24Mbits)
- SEU count per hour and total SEU count during the event



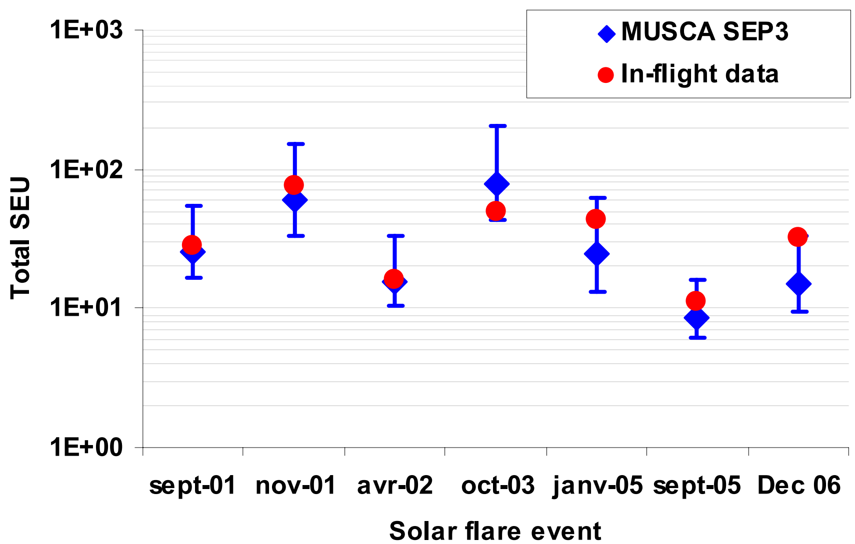


SAC-C experiments: sporadic events

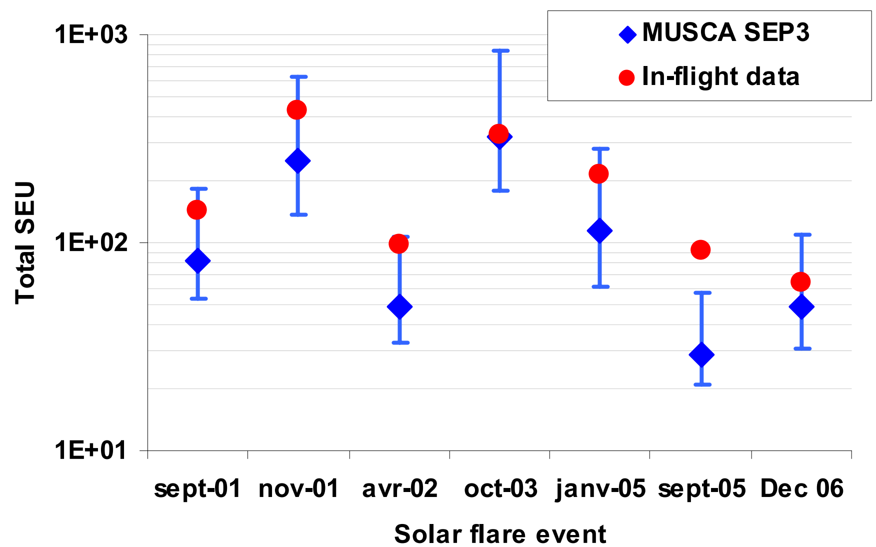
Calculated rate compared with in-flight SEE count at flares

- Total SEU counts for 7 different solar events
- Bars : upper/lower bounds induced by a 20% variation of the device parameters

HM628512



KM684000



Anomaly expertise

Example: "hard" device response

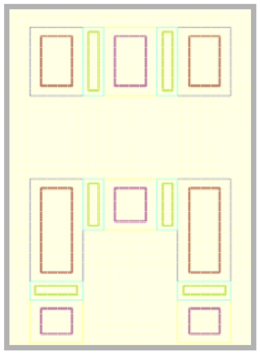
- Ground tests: heavy ion low SEU sensitivity (high threshold LET)

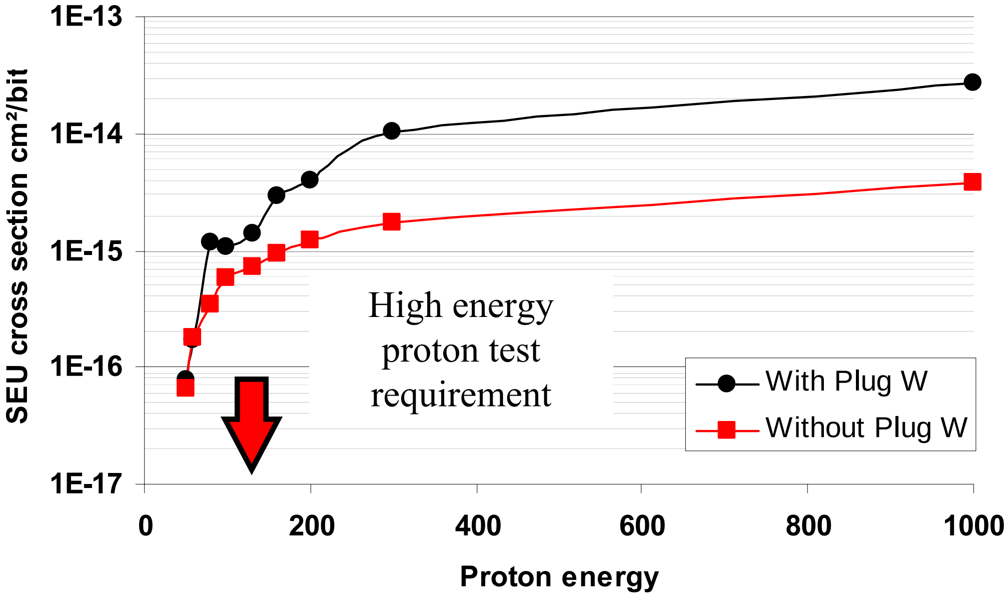
→ low (no) SEU sensitivity to proton expected

Actual flight data have shown no SEU induced by cosmic rays but protons!

=> Investigation to check for materials effects

6T SRAM SOI - Q_{crit} = 100 fC





Need to describe the device with multi material approach

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Proton ↔ heavy ion link (1)

Additional SEE data deduced from ground tests

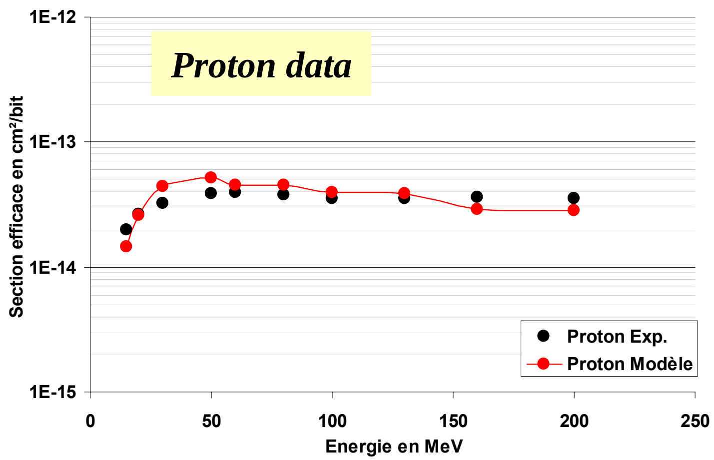
To overcome limitations of testing, reduce costs …

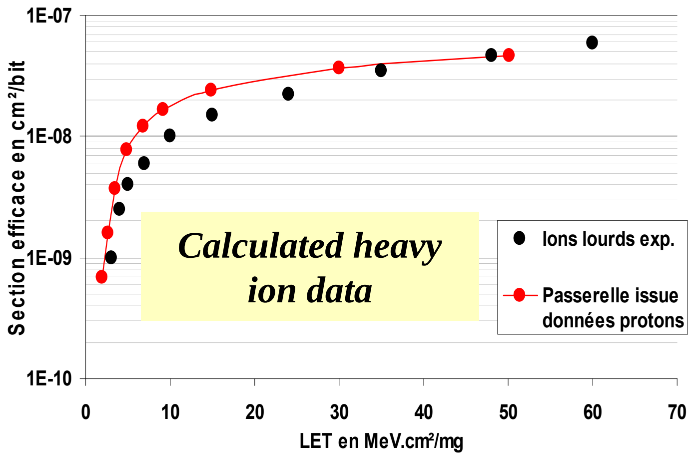
Ground data (x-section)
Proton, heavy ion, neutron, Cf…

→ **device parameters** →

MUSCA SEP³
Additional SEE sensitivities
Heavy ion, proton, neutron, operational …

Example: SRAM 6T Atmel
AT60142F-DC1 4Mbits
(ESA SEU monitor)





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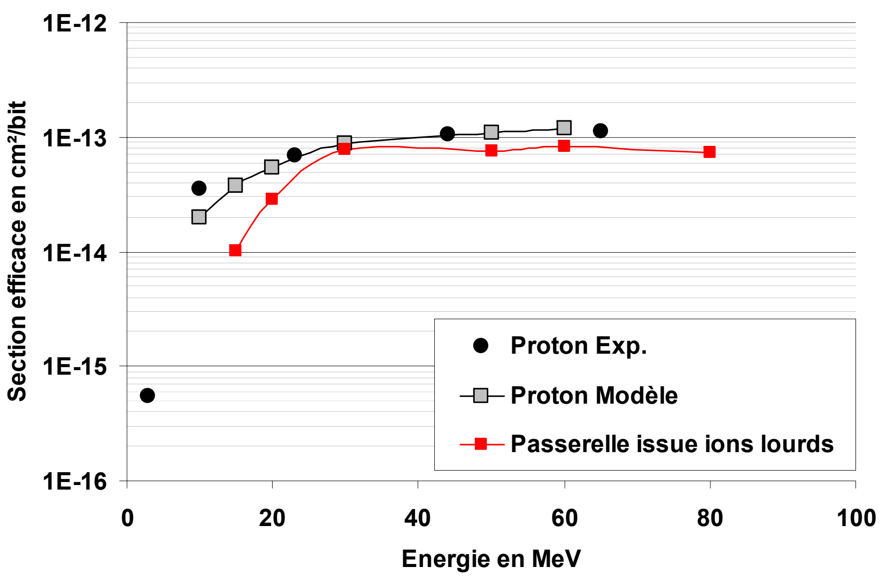
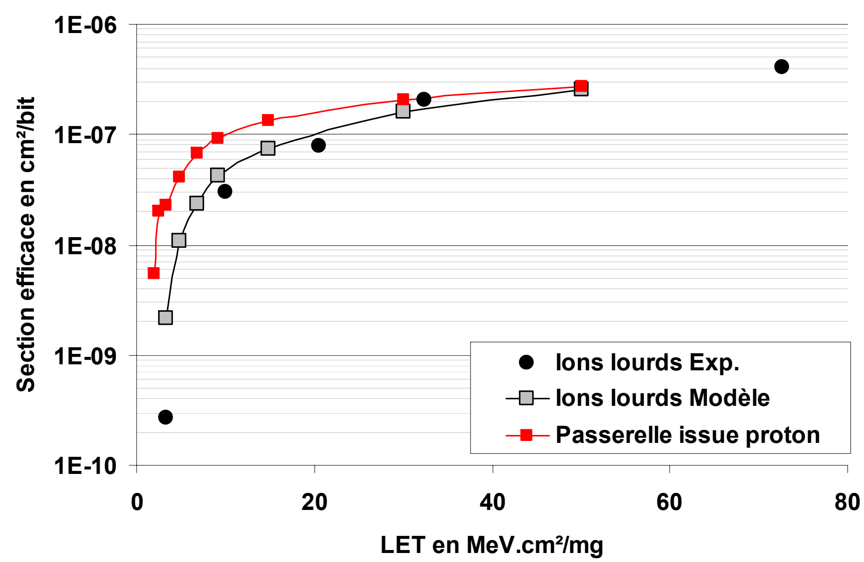
Proton ↔ heavy ion link (2)

HM628512 (SAC-C device)

Heavy ions ⇨ protons



Protons ⇨ Heavy ions

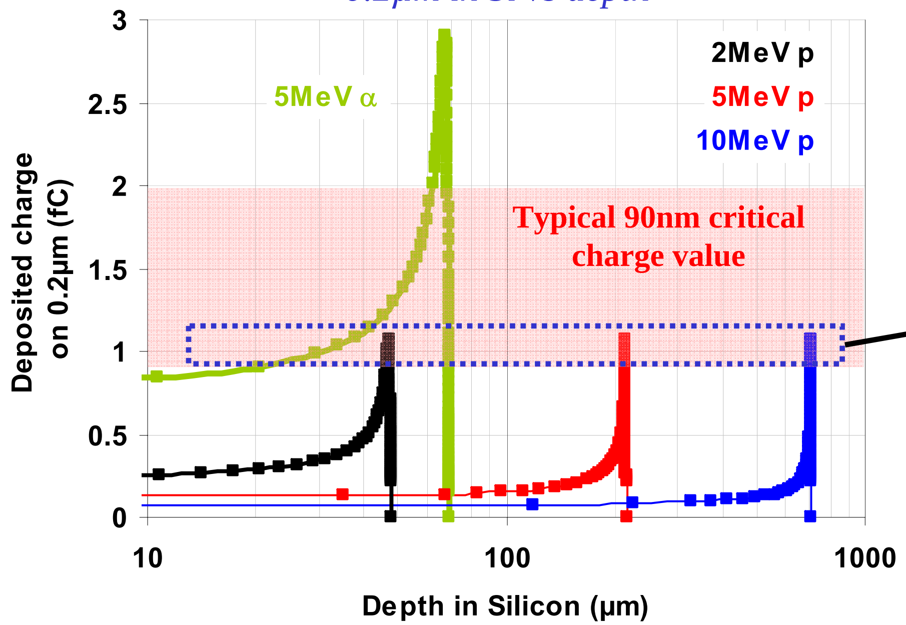


Emerging effects (radecs2009)

Technological roadmap

- Process integration, material introduction and circuitry complexity
  - ➢ SEU sensitivity threshold reduction

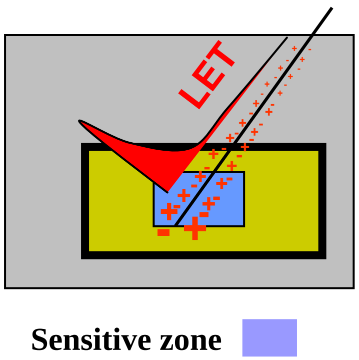
Variation of the charge deposited every 0.2µm in Si vs depth



First reported in 2008: NSREC and IBM J. Res. & Dev.

Low-energy proton SEU test results on 65nm SOI SRAM

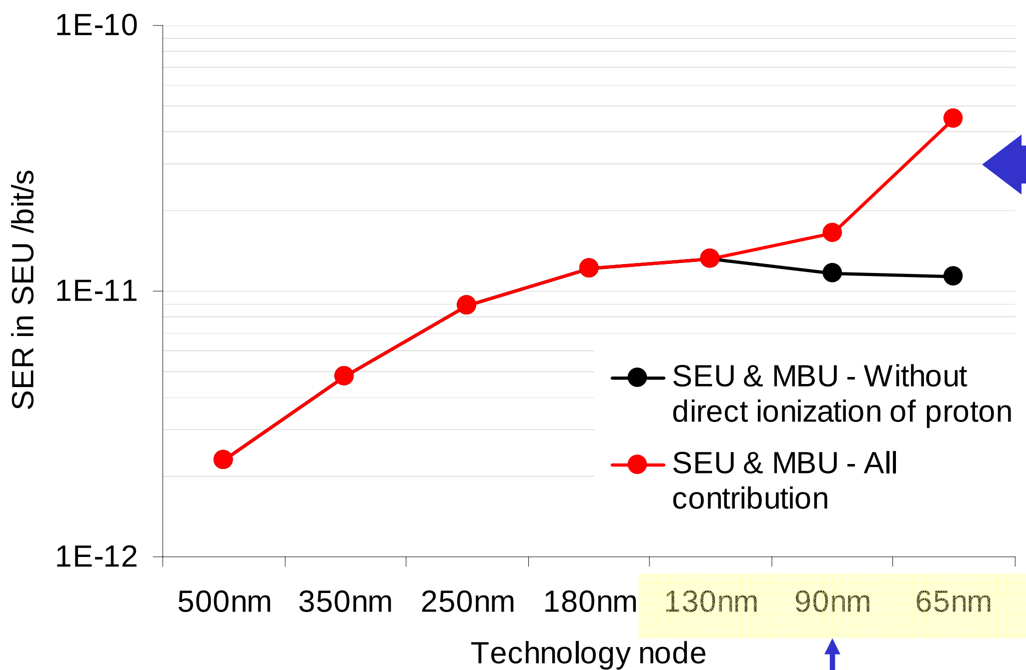
Deposited charge by proton at **Bragg peak** is able to induce an SEU by **direct ionization**



Emerging effects

Impact of proton direct ionization for space missions

- What about if 500 -> 65nm technologies on-board SAC-C orbit



Direct ionization with proton becomes preponderant

	Heavy ion	Nuclear proton	Ionizing proton
130nm	25 %	75 %	**0 %**
90nm	23 %	59 %	**18 %**
65 nm	1 %	19 %	**75 %**

2008-2010: SEU sensitivities confirmed by IBM and BAE system ground testing

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Synthesis

The SER conventional approach is no longer valid

- Multi-physics Monte-Carlo approach is relevant to perform SER operational calculations
- MUSCA SEP^3 validation steps for ground and operational configurations (SRAM 350-65nm)

MUSCA SEP^3 development designed to

- Provide operational SERs (belts, cosmic and solar flares)
- Allow for investigating the SEE trends (technological roadmap)
- Direct proton ionization is an important challenge
  - low-energy proton testing is mandatory for $\leq$ 90nm technologies
  - associated with prediction to deduce the operational effect (shielding)

A reliable predictive approach requires a correct description of the environment dynamics but also of the shielding configuration

Perspective

MUSCA SEP^3 engineer tool development (r&t cnes)

- ONERA, CNES and TRAD working group
- 1st version available 2011 (dedicated to agencies, end-users …)

!!! research activities -> engineering tool

Research activities (onera, r&t cnes)

- Track effects
- Addict: collection model
- Extension to other SEE phenomena
  - SET in CMOS technology (logic chains → complex devices)
  - Destructive effects (1st attempt to use MUSCA for simulating SEL and SEB in 2010)