SEE FLUX AND SPECTRAL HARDNESS CALIBRATION OF NEUTRON SPALLATION AND MIXED FIELD FACILITIES

Matteo Cecchetto

R. García Alía, P. Fernández-Martínez, R. Ferraro, S. Danzeca

R2E Annual Meeting

DEC, 11-12TH | CERN, 774/R-013

Indico link: https://indico.cern.ch/event/760345/

Introduction

- Single Event Effect (SEE) failure rate for electronic components to be used in mixed field environments (accelerator) **has to be quantified by reproducing the spectrum condition in dedicated test facilities**.
- The availability of a method to compare different radiation environments is essential, because differences in neutron and **High Energy Hadrons (HEH>20 MeV)** spectra can play an important role.
- The approach applied for the characterization of both spallation (ChipIR) and mixed filed (CHARM) facilities relies in **employing SEU and SEL based detectors:**

SEU: The memory is assumed to be equally sensitive to HEH above 20 MeV and a weighting function has to be accounted for the intermediate energy neutrons, considered from 0.2 MeV to 20 MeV, where the cross section is strongly energy dependent.

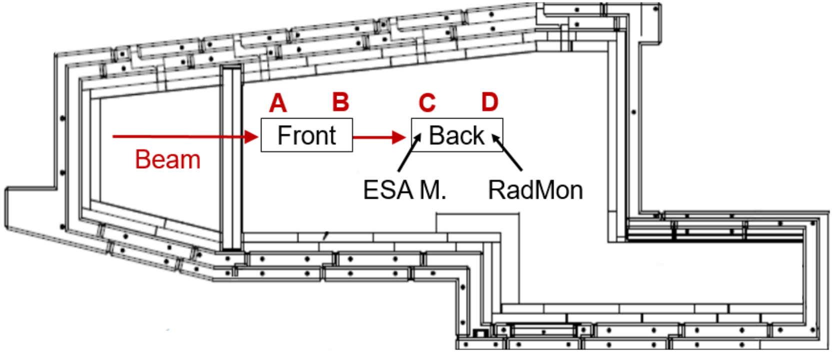
$$\varphi_{HEHeq} = \underbrace{\int_{0.2MeV}^{20MeV} w(E) \frac{d\varphi_n(E)}{dE} dE}_{} + \int_{20MeV}^{+\infty} \frac{d\varphi_{HEH}(E)}{dE} dE$$

Intermediate energy neutrons start to be a major concern with scaling of technology.

SEL: COTS memories with a strong energy dependence on the SEL cross section are employed to correlate the spectral hardness of the facilities, supported by a FLUKA model.

ChipIr facility

- The **ChipIr** (Chip Irradiation) facility (UK), provides a broad **neutron atmospheric like spectrum.**
  - Energies from the thermal neutrons up to 800 MeV
  - Neutrons produced by colliding protons against a tungsten target.
  - The flux was measured using multi-foils activation.
- It was **investigated** in order to verify its capability of **reproducing the SEU and SEL cross sections** typically observed in mixed field environments, such as CHARM.



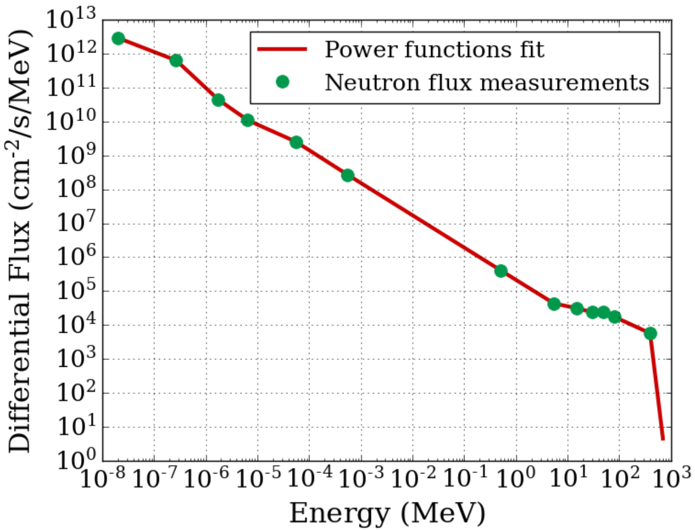
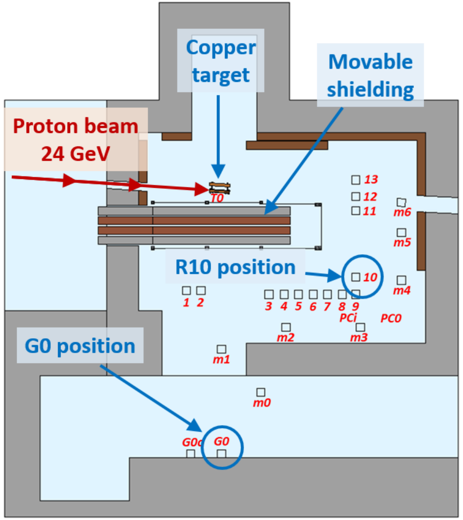
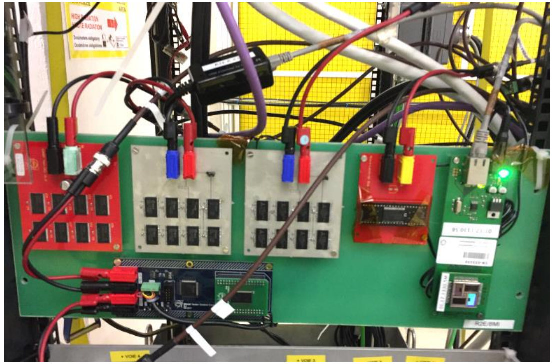


Figure 1: ChipIr spectrum

CHARM facility

- CHARM generates a **mixed-field** mainly composed by **neutrons, protons** and **pions** from the interaction of 24 GeV proton beam with a copper target.
- R10 (hard spectrum) and G0 (soft spectrum) were employed.





SEU and SEL boards tested in R10

ChipIR flux cross-calibration

- The flux calibration was carried out with:
  1) **ESA SEU Monitor** (0.25 µm SRAM memory)
  2) RadMon system (**Toshiba** 400 nm, **Cypress** 90 nm).
  - **Excellent HEHeq agreement within 1%** was obtained with the RadMon;
  - **Thermal neutron flux within the uncertainty** (quite high due to the very low ThN flux compared to the HEH one).
- the intermediate energy neutron response (i.e. PTB at 5, 8 and 14 MeV) is essential to derive the flux from the ESA Monitor and Cypress memories.

HEHeq [cm^{-2}/s]				ThN [cm^{-2}/s]	
ESA M.	*Spectrum*	*RadMon*	*Spectrum*	*RadMon*	*Spectrum*
2.97×10^6 $\pm$*20%*	3.44×10^6	3.09×10^6 $\pm$*21%*	3.07×10^6	3.49×10^4 *+2.8×10*^{5}	1.60×10^5

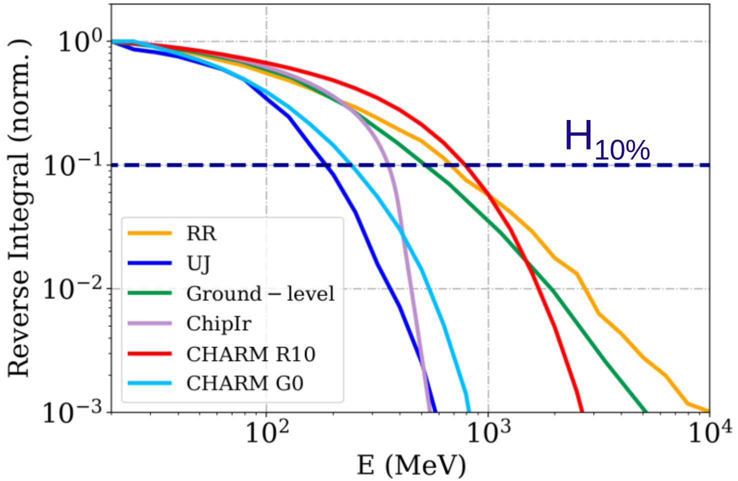
SPECTRAL HARDNESS ASSESSMENT – SEL measurements

- **Samsung** (180 nm) and **Alliance** (200 nm) are SRAM memories with a **strong SEL cross section energy dependence** due to the presence of tungsten, deployed as detectors.
- Assessment in:
  - **operational environments**: **JEDEC**, **accelerator (UJ, RR alcoves)**
  - **test facilities**: **ChipIR**, **CHARM (G0, R10 positions)**.

  UJ, RR, R10 and G0 are composed by neutrons, protons, pions.

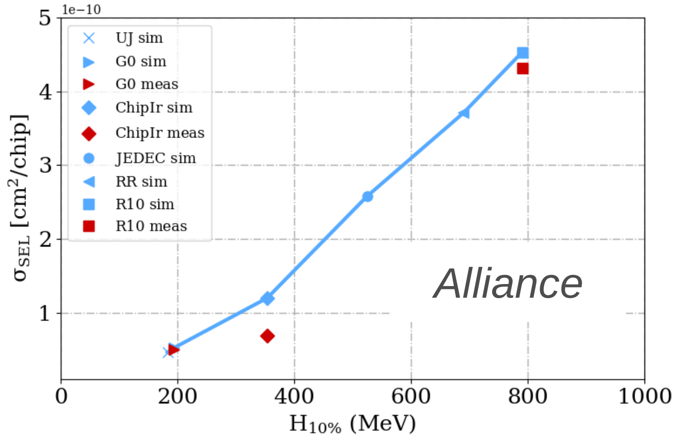
- The **spectral hardness** is quantified through the **$H_{10\%}$ factor**, representative of the energy above which 10% of the total **HEH flux** is still present in the spectrum, (visible in the **reverse integral)**.

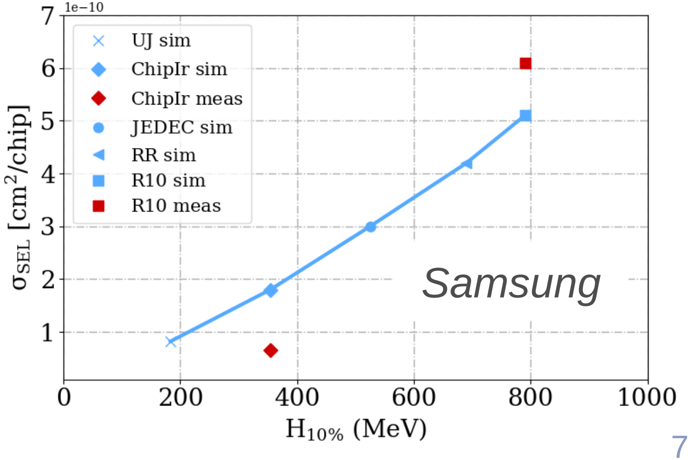
MeV	UJ	G0	ChipIr	JEDEC	RR	R10	Tunnel
$H_{10\%}$	183	194	354	525	690	790	1800



SPECTRAL HARDNESS ASSESSMENT – SEL FLUKA simulations

- The **FLUKA model** retrieves the SEL XS up to several GeV, given the **spectrum**, **Sensitive Volume** (SV) thickness and **geometrical parameters** of the memories.
- The SV surface is 4x20 µm^2 and 0.48 µm^3/cell of tungsten are considered.
  - **Measurements and simulations are in agreement** within 60% over a very broad energy and cross section range. Considering the experimental uncertainties of about 30%, the agreement is satisfactory.

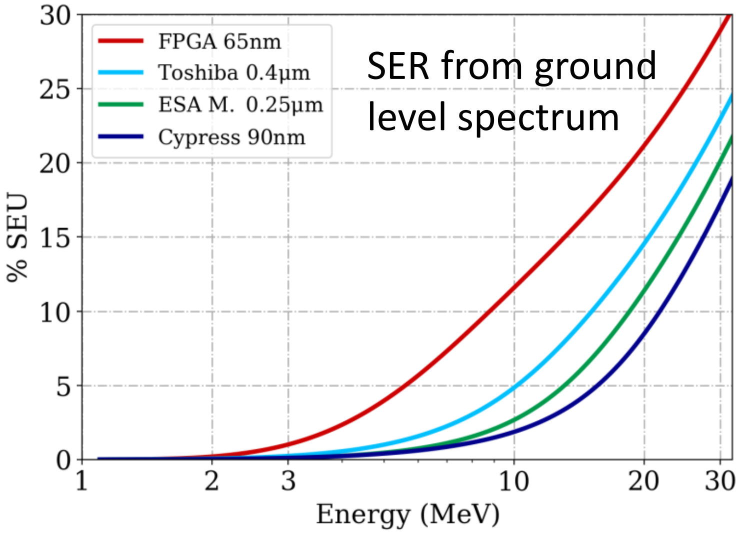


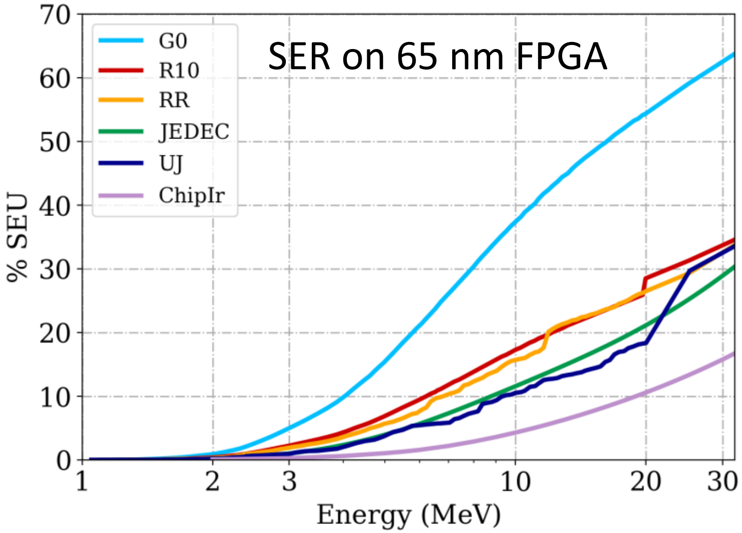


Strong risk of qualifying components for SEEs in environments with a lower spectral hardness than the operational one.

SER induced by intermediate energy neutrons (1)

- SER on ESA Monitor, Toshiba, Cypress and a 65 nm FPGA* is evaluated in the 1-3 MeV, 1-10 MeV, 1-20 MeV energy intervals.
- 65nm FPGA with a G0-like spectrum ➡ **more than 50% of the SEUs are induced by neutrons below 20 MeV.**





*D. Lambert et al., "Single Event Upsets Induced by a few MeV Neutrons in SRAMs and FPGAs," in 2017 IEEE Radiation Effects Data Workshop (REDW)

SER induced by intermediate energy neutrons (2)

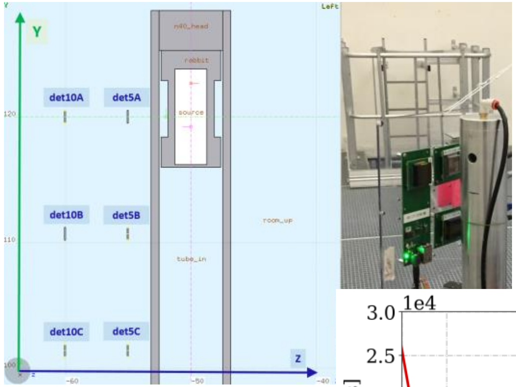
- **1-3 MeV** ➡ negligible impact.
- **1-10 MeV** ➡ up to **12%** of SER for JEDEC, ChipIR, UJ.
  up to **36%** for CHARM G0 position.
- **1-20 MeV** ➡ up to **21%** of SER for **ground level**, **26%** in **accelerator applications** and up to **54%** for G0.

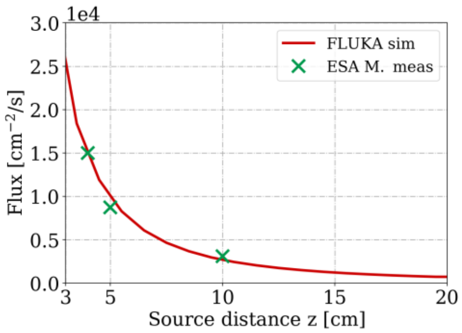
1-20 MeV	Spect %	ESA M.	Toshiba	Cypress	FPGA
UJ	39.4	9.6	12.3	7.1	18.4
G0	84.1	39.2	31	24.1	54.4
ChipIr	15.3	6.7	8.2	5	10.6
JEDEC	43.4	11.4	14.5	8.5	21.1
RR	56	17.8	13.5	9.9	26.5
R10	60.5	19.2	15.1	11.7	28.5

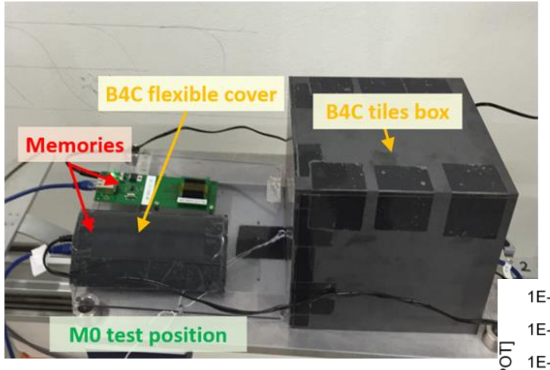
SER (%) impact of different spectra

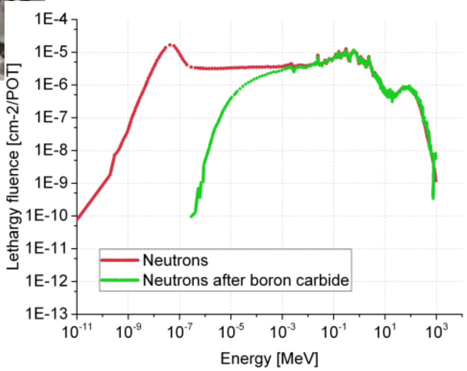
Complementary work/Outlook

- The use of the Am-Be neutron source at CERN for SEU/SEE setup validation and evaluation of sensitivity to intermediate energy neutrons.
- The impact of thermal neutrons, for which an important sensitivity has been measured for highly integrated technologies.









Conclusions

- The **procedure of cross-calibrating spallation and mixed-field facility through SEU detectors** have been shown to be valid, with an excellent agreement on the HEH flux.
- The approach of determining the **spectrum hardness through SEL measurements** have been applied to ChipIr and CHARM. Compatible cross sections have been **extracted through a FLUKA model**, which therefore **enables the calculations** for environments in which measurements are not directly feasible, as **for atmospheric and LCH areas**.
- The spectral hardness of **ChipIr enables for tests dedicated to some accelerator applications** as shielded areas. However, tunnel and more energetic alcoves exhibit **harder spectra, reproducible in CHARM**.
- Considering the SEU rate of memories down to 65 nm, 1-10 MeV and 1-20 MeV ranges induce respectively up to 12% and 21% of the total SER in ground level applications, reaching up to 36% and 54% in accelerator environments.
- **Intermediate energy neutrons (1-20 MeV) yield a larger SER contribution in accelerator rather than atmospheric applications**.