# Radiation testing campaign results for understanding the suitability of FPGAs in detector electronics.

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The use of a **Field Programmable Gate Array (FPGA)** in high energy physics experiments is only limited by our ability **to mitigate single event effects** induced by the high energy hadrons present in the radiation field.

**Radiation induced failures on electronics are tested in facilities:**

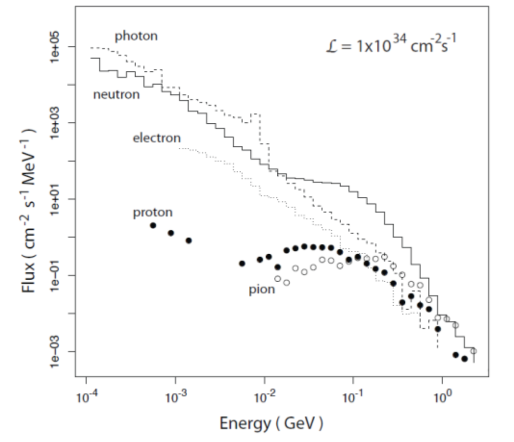
- With particle energy spectra similar to the expected High Energy Physics (HEP) environment
- At high rates to find single event effects with small cross sections

**Electronic devices will be affected by:**

- Single Event effects
- Total ionizing dose
- Displacement damage

| | Simulation (one year) | Safety Factor | Test Target* (10 years) |
|---|---|---|---|
| Ionizing Dose | 3.0 rad | 10 | 100 krad |
| 1 MeV eq. Neutron | $6.0 \times 10^{11}$ cm$^{-2}$ | 2 | $1.2 \times 10^{13}$ cm$^{-2}$ |
| Hadrons (>20 MeV) | $8.5 \times 10^{10}$ cm$^{-2}$ | 2 | $2 \times 10^{12}$ cm$^{-2}$ |

*1 LHC year = $10^7$ s, $\sigma_{pp}$ = 80 mb, Luminosity = $5 \times 10^{34}$ cm$^{-2}$s$^{-1}$




**Xilinx Kintex 7** performance tested under irradiation

**Rad-hard techniques must prevent:**

- Build up of configuration errors in CRAM
- Errors that "breaks" SEC/DED code in BRAM
- Corruption on transmitted data
- Transmitter/receiver de-synchronization

FPGA sensitive to Single Event Upset (SEU) → Mitigation → Triple Modular Redundancy (TMR) / Scrubbing

**H4IRRAD**, CERN:

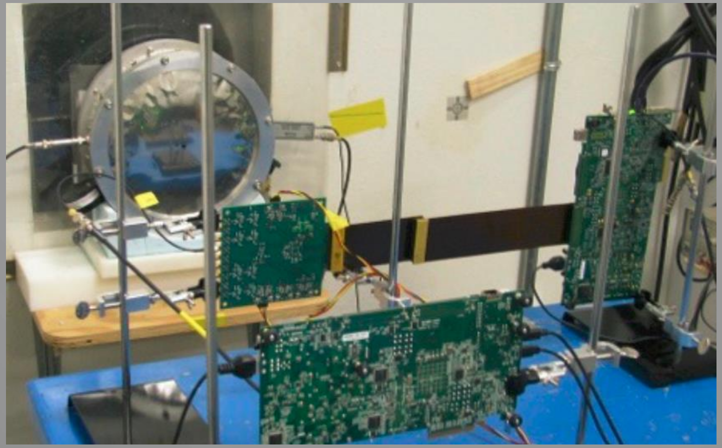
- **mixed-field (hadrons and neutrons)**
  - **CRAM and BRAM cross section** measurements

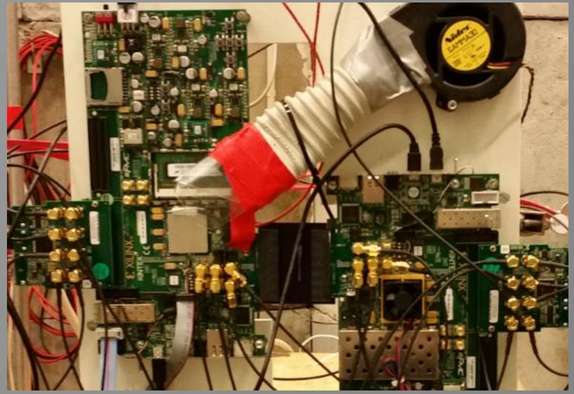
**LANSCE - WNR** (Los Alamos):

- **neutrons (max energy 800 MeV)**, wide spectrum similar to cosmic ray background
  - **CRAM and BRAM cross section** measurements

**The Svedberg Laboratory (TSL)**, Sweden:

- **neutrons** (**max energy 200 MeV**)
  - **CRAM and BRAM cross section** measurements
- **180 MeV protons**
  - **CRAM and BRAM cross section** measurements
  - performance of the **GTX transceivers**





## Cross section comparison

| | CRAM ($cm^2$/bit) | BRAM ($cm^2$/bit) | Fluence (particle/$cm^2$) |
|---|---|---|---|
| H4IRRAD - Hadron | $1.50 \times 10^{-14}$ | $1.40 \times 10^{-14}$ | $1.8 \times 10^{9}$ |
| LANSCE - Neutron | $6.89 \times 10^{-15}$ | $6.15 \times 10^{-15}$ | $5.7 \times 10^{10}$ |
| TSL - Neutron | $6.55 \times 10^{-15}$ | - | $>5.7 \times 10^{10}$ |
| TSL - Proton | $8.29 \times 10^{-15}$ | $8.19 \times 10^{-15}$ | $1.3 \times 10^{13}$ |

## CONCLUSION AND OUTLOOK

- **No permanent operational failures** observed
- **TMR plus multi-level scrubbing** essential to mitigate SEU in Kintex 7 FPGAs.
- In the full scale **ATLAS** LAr calorimeter system we could estimate **a lane failure every 6.5 minutes.**

**Future experiments** are planned with improved TMR and scrubbing mitigation strategies to further reduce the present error rates.