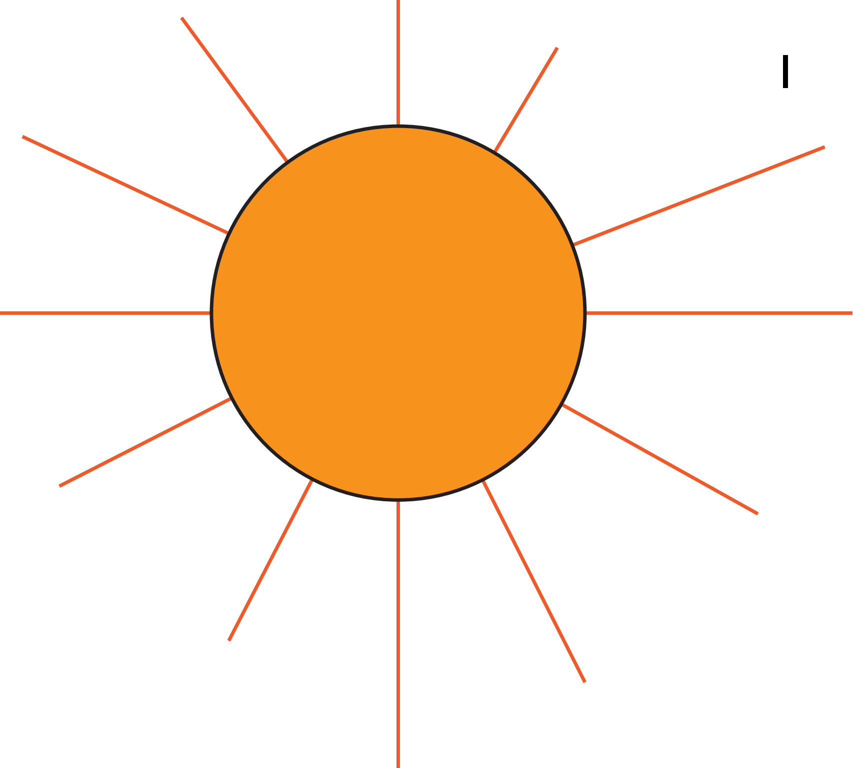
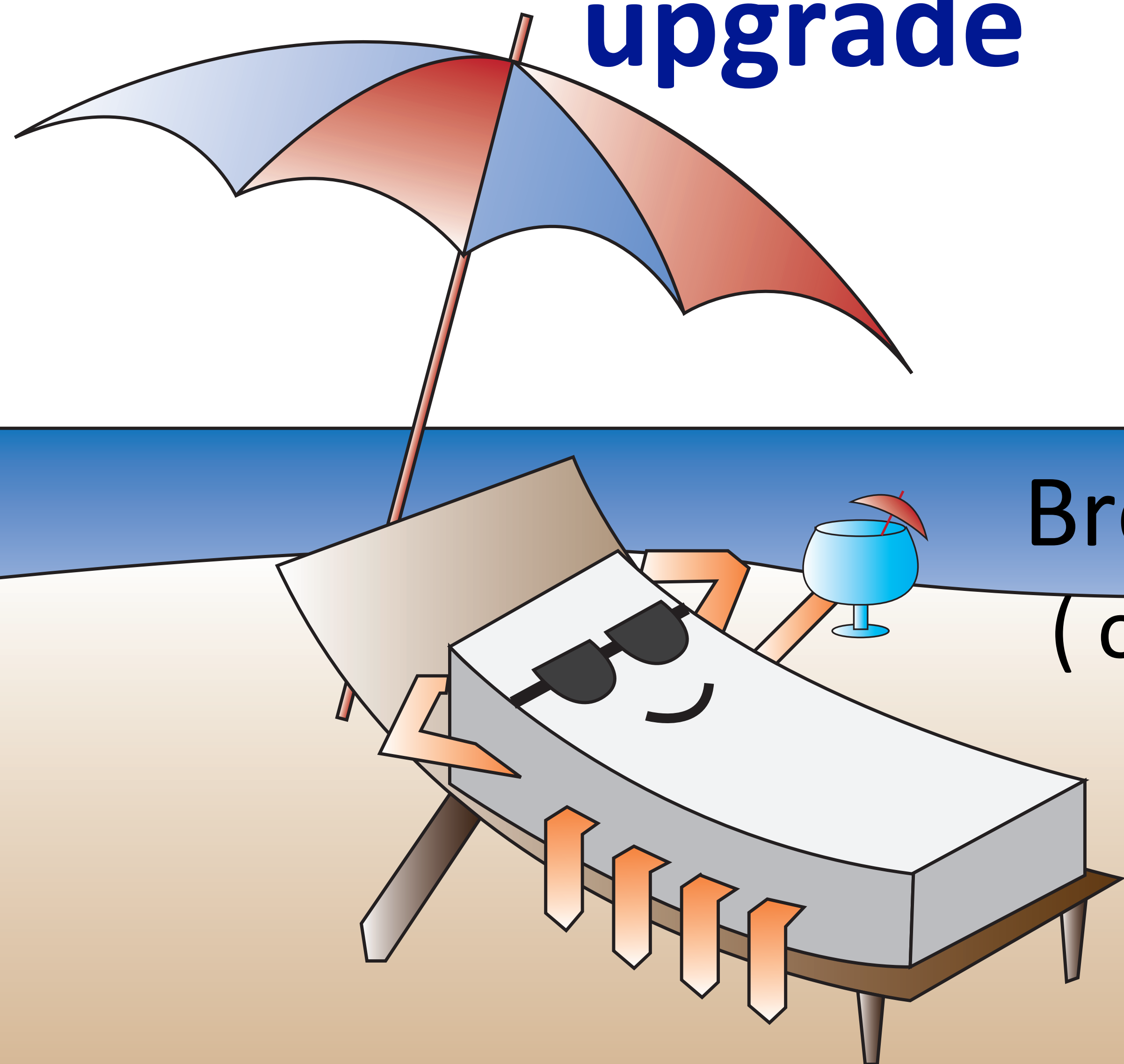
# Characterization of COTS ADC radiation properties for ATLAS LAr calorimeter readout upgrade





**Helio Takai**
Physics Department
Brookhaven National Laboratory
( on behalf of the ATLAS liquid argon calorimeter group)

ATLAS EXPERIMENT

Topical Workshop on Electronics for Particle Physics
Perugia, Italy, September 23-27, 2013

BROOKHAVEN NATIONAL LABORATORY

# Authors

Kai Chen, Hucheng Chen, Xueye Hu,
James Kierstead, Francesco Lanni,
Joseph Mead, Sergio Rescia, Hao Xu
and Helio Takai

*Brookhaven National Laboratory*

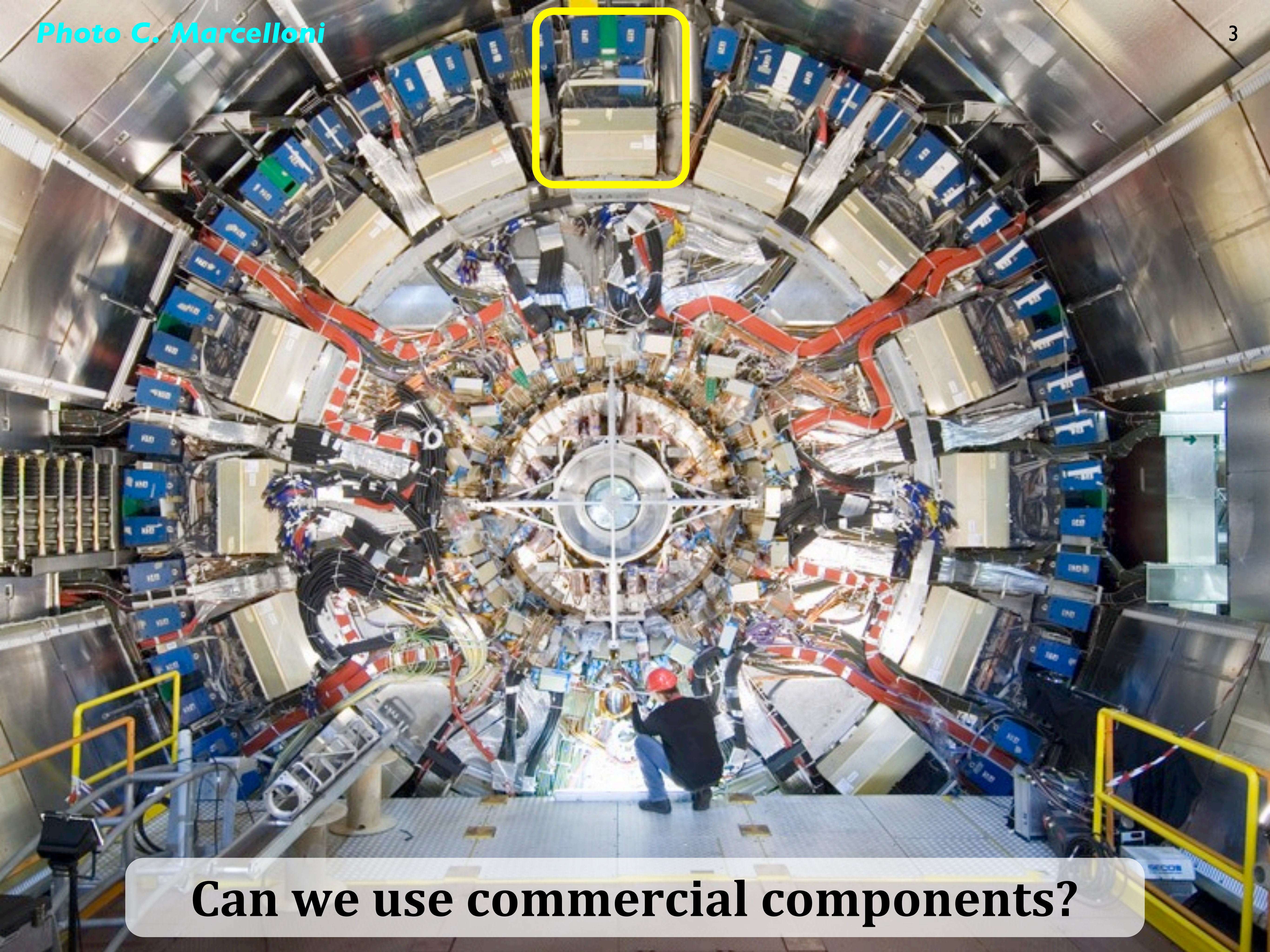


Photo C. Marcelloni
Can we use commercial components?

# The Yin and Yang of COTS

Large number of design options.

Do they really fit my needs?

I can purchase a production lot

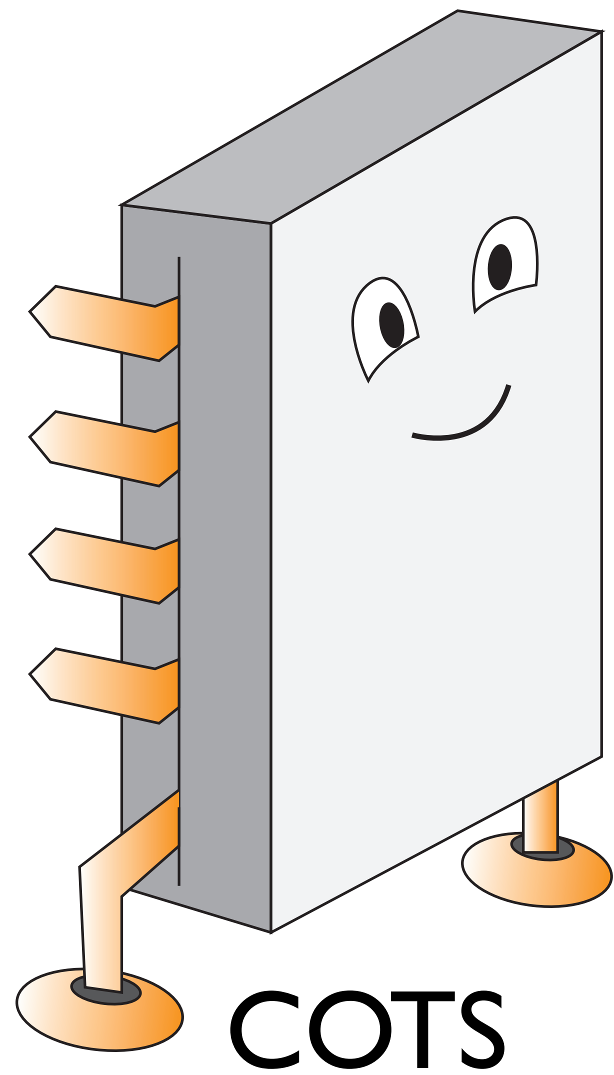
Parts become obsolete

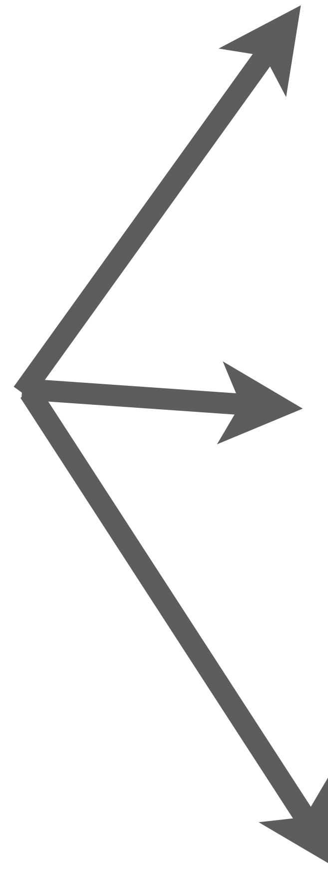
Small feature size components are more radiation tolerant

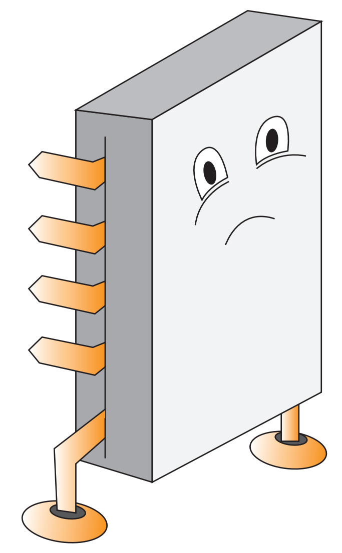
Are they really radiation tolerant?

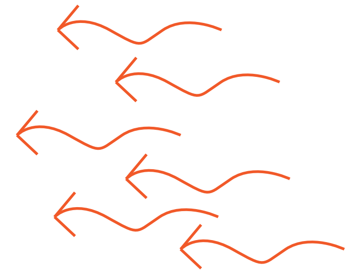
I can perform tests and qualify them for radiation

I worry about production variabilities

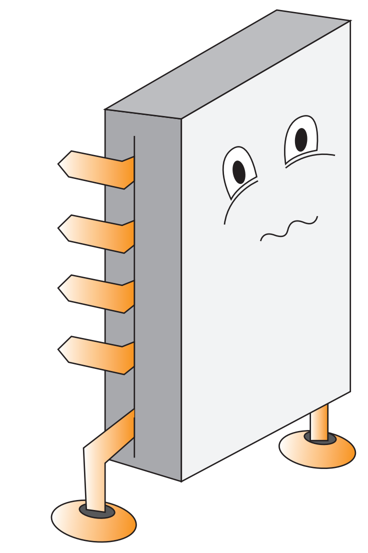


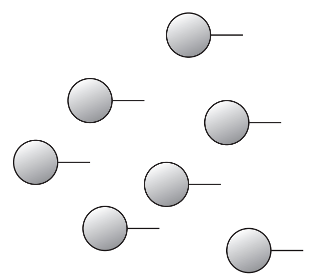





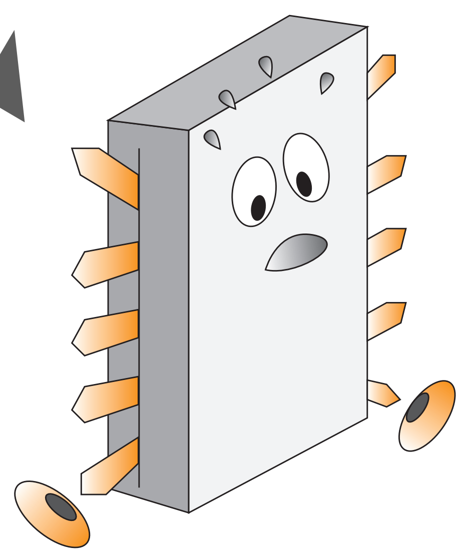


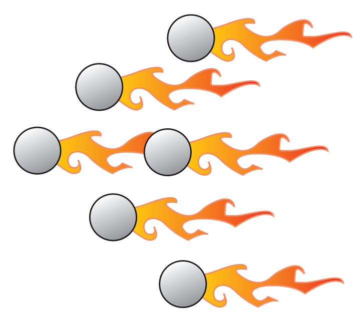
ionization dose





displacement damage or NIEL





single event effects

# The Background in the Barrel LAr Crates



The radiation background in the ATLAS Barrel electronics crates is composed of hadrons, electrons and photons produced in the last stages of the particle shower in the calorimeters itself.

| | Simulation ($fb^{-1}$) | Safety Factor | Test Target (3000 fb) |
|---|---|---|---|
| Ionizing Dose | 3.0 rad | 10 | 90 krad * |
| 1 Mev eq. neutron ** | $2.0 \times 10^{9}$ | 2 | $1.2 \times 10^{13}$ (1 Mev n) |
| Hadrons (>20 MeV) | $2.84 \times 10^{8}$ | 2 | $2 \times 10^{12}$ ( >20 MeV) |

* Enhanced Low Dose Rate Sensitivity (ELDRS)
** NIEL is not a concern for CMOS technology

# Irradiation Facilities



## Ionizing dose

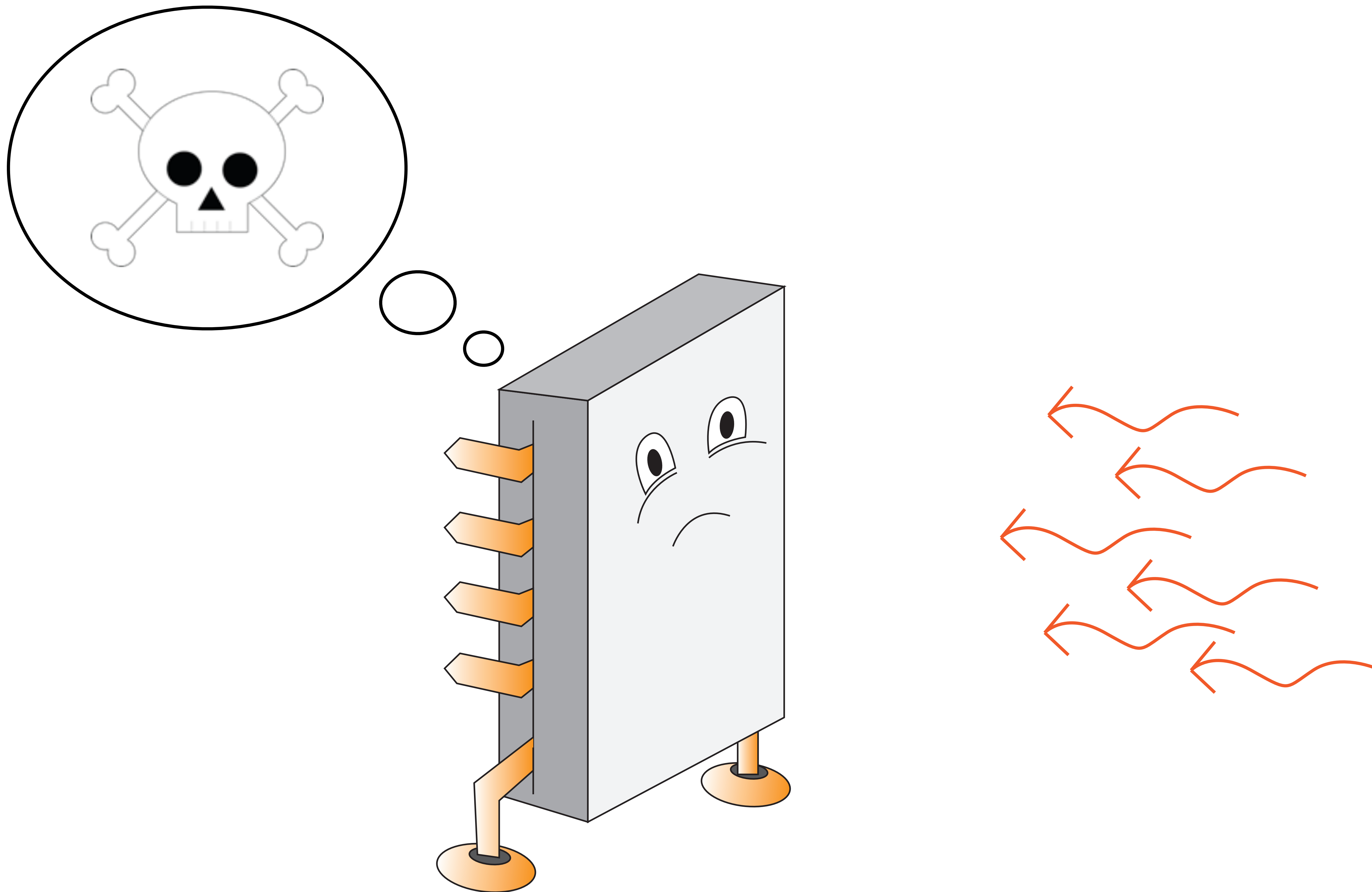
1. Solid State Gamma Irradiation Facility (BNL)

## Single Event Effects

1. LANSCE WNR (Los Alamos, NM) - *neutrons (high energy)*
2. Mass General Hospital (Boston, MA) - *protons (216 MeV)*
3. IUCF (Bloomington,IN) - *protons (200 MeV)*
4. H4IRRAD (CERN) - *not available*
5. TSL at Uppsala, high energy neutrons and protons
6. 14 MeV neutron source @BNL

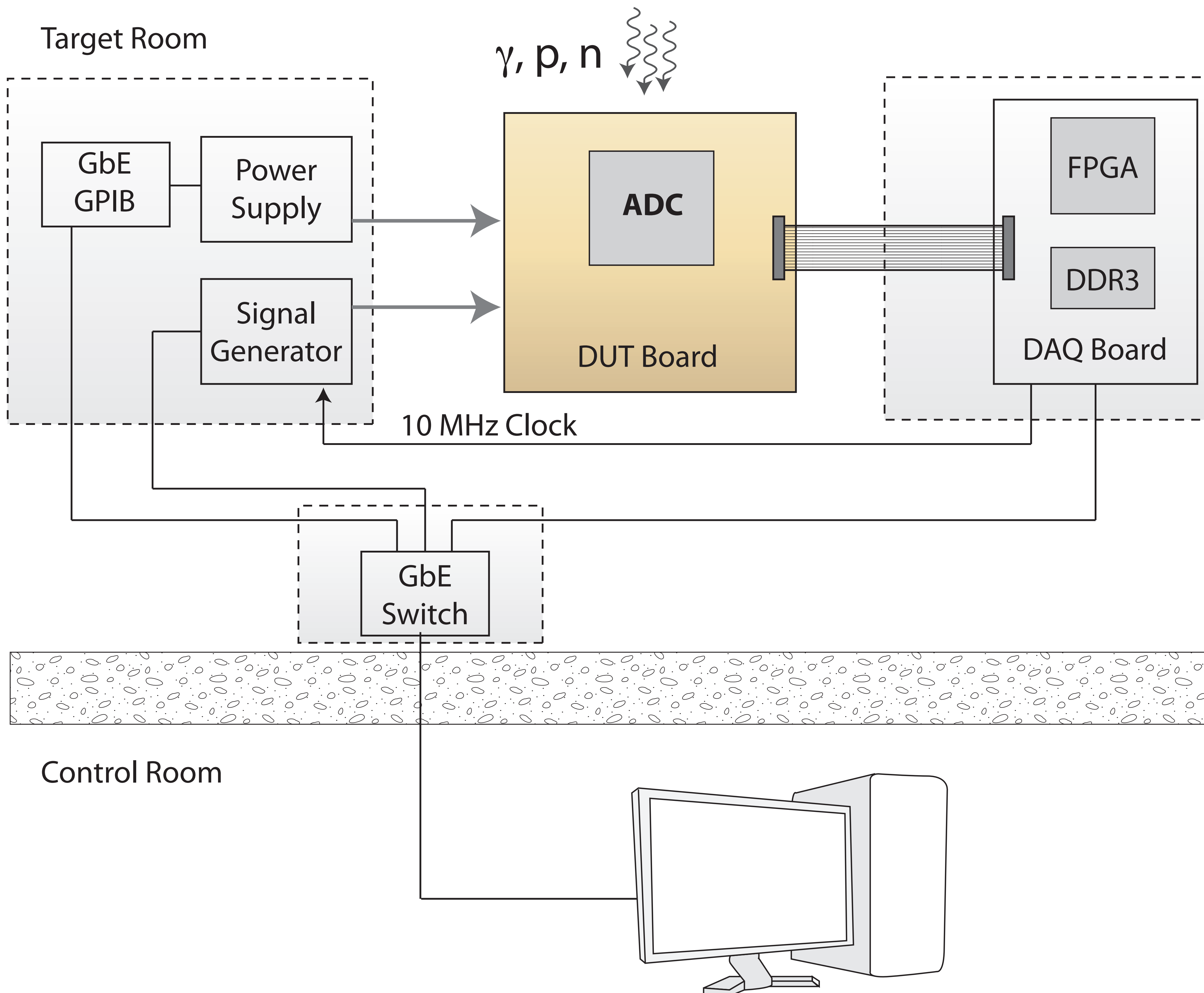
## Displacement Damage

1. Reactor, UMASS at Lowell



# Ionization Dose Effects

# Experimental Setup



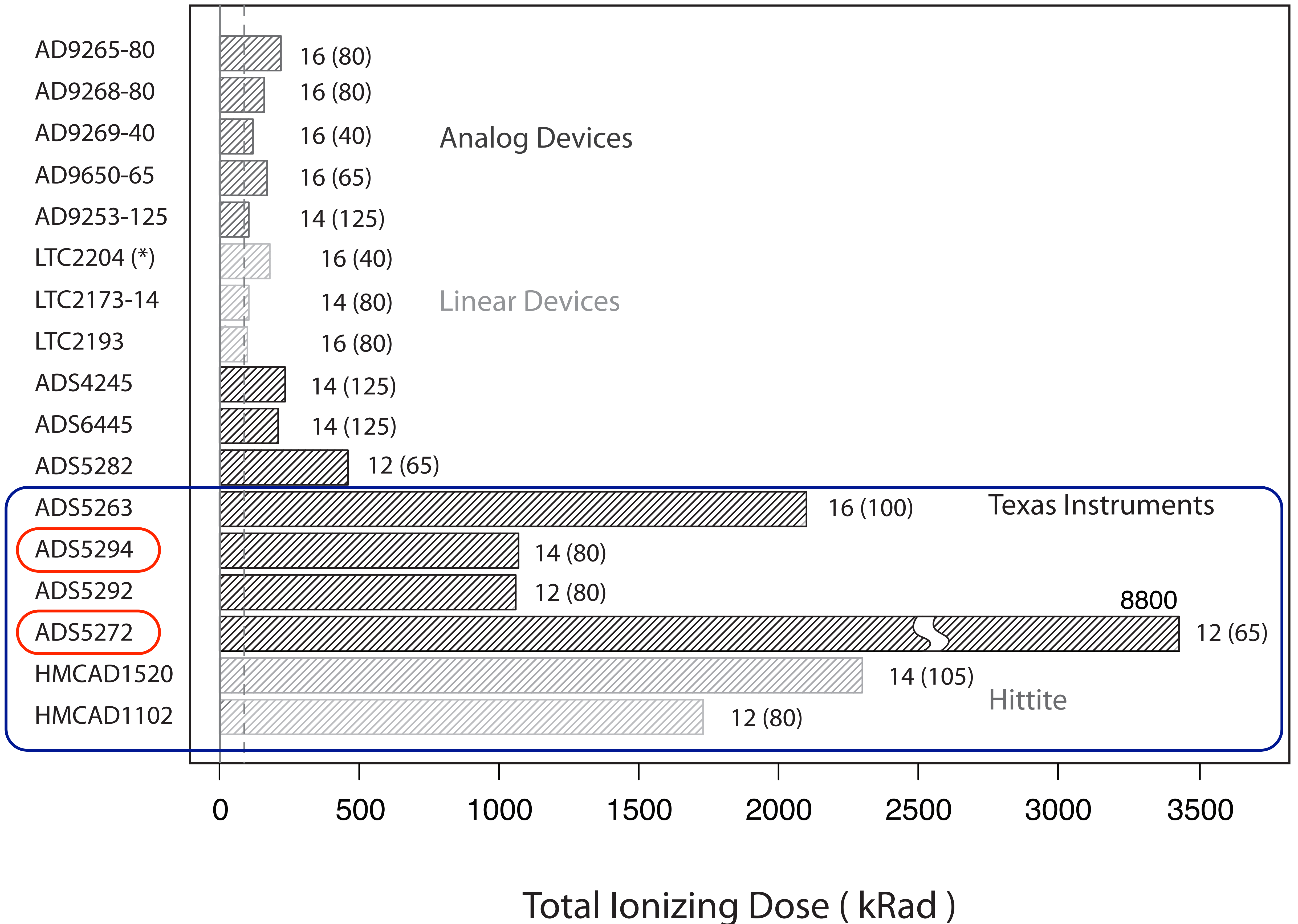

*Setup used for TID and SEE studies*

# Total Ionizing Dose

| ADC | Dynamic Range [$bit$] | F [$MHz$] | Analog Input Span [$V_{p-p}$] | Channels per Chip | $P_{total}$ per Channel [$mW$] | Feature Size (nm) | Vendor | TID [$kRad(Si)$] |
|---|---|---|---|---|---|---|---|---|
| AD9265-80 | 16 | 80 | 2 | 1 | 210 | 180 | ADI | ~220 |
| AD9268-80 | 16 | 80 | 2 | 2 | 190 | 180 | ADI | ~160 |
| AD9269-40 | 16 | 40 | 2 | 2 | 61 | 180 | ADI | ~120 |
| AD9650-65 | 16 | 65 | 2.7 | 2 | 175 | 180 | ADI | ~170 |
| AD9253-125 | 14 | 125 | 2 | 4 | 110 | 180 | ADI | ~105 |
| LTC2204 | 16 | 40 | 2.25 | 1 | 480 | 350 | Linear | ~180 |
| LTC2173-14 | 14 | 80 | 2 | 4 | 94 | 180 | Linear | ~105 |
| LTC2193 | 16 | 80 | 2 | 2 | 125 | 180 | Linear | ~100 |
| ADS4245 | 14 | 125 | 2 | 2 | 140 | 180 | TI | ~235 |
| ADS6445 | 14 | 125 | 2 | 4 | 320 | 180 | TI | ~210 |
| ADS5282 | 12 | 65 | 2 | 8 | 77 | 180 | TI | ~460 |
| ADS5263 | 16 | 100 | 4 | 4 | 280 | 180 | TI | ~2100 |
| ADS5294 | 14 | 80 | 2 | 8 | 77 | 180 | TI | ~1070 |
| ADS5292 | 12 | 80 | 2 | 8 | 66 | 180 | TI | ~1060 |
| ADS5272 | 12 | 65 | 2.03 | 8 | 125 | 180 | TI | ~8800 |
| HMCAD1520 | 14 | 105 | 2 | 4 | 133 | 180 | Hittite | ~2300 |
| HMCAD1102 | 12 | 80 | 2 | 8 | 59 | 180 | Hittite | ~1730 |

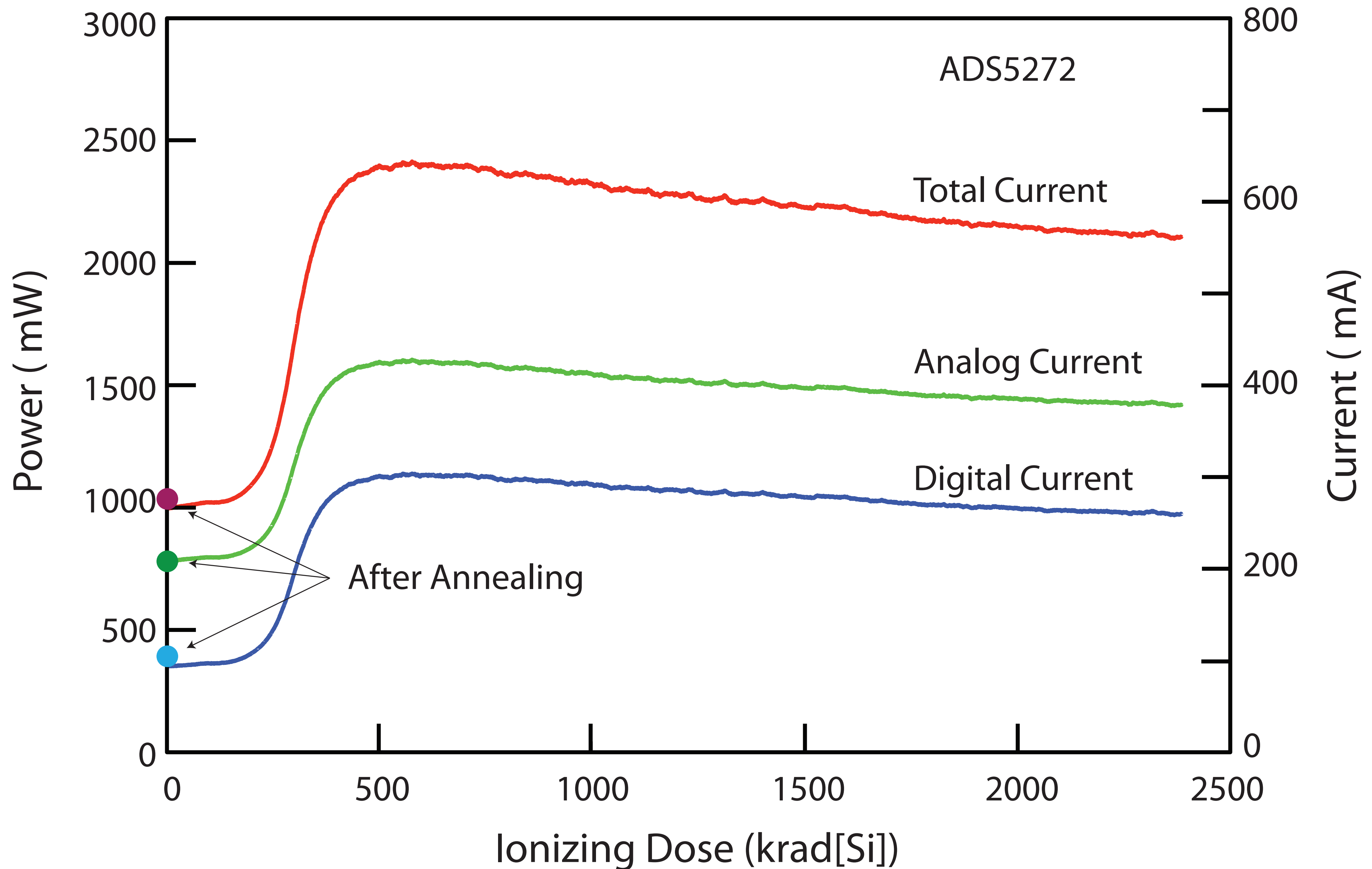
# Total Ionizing Dose





# Performance and Annealing

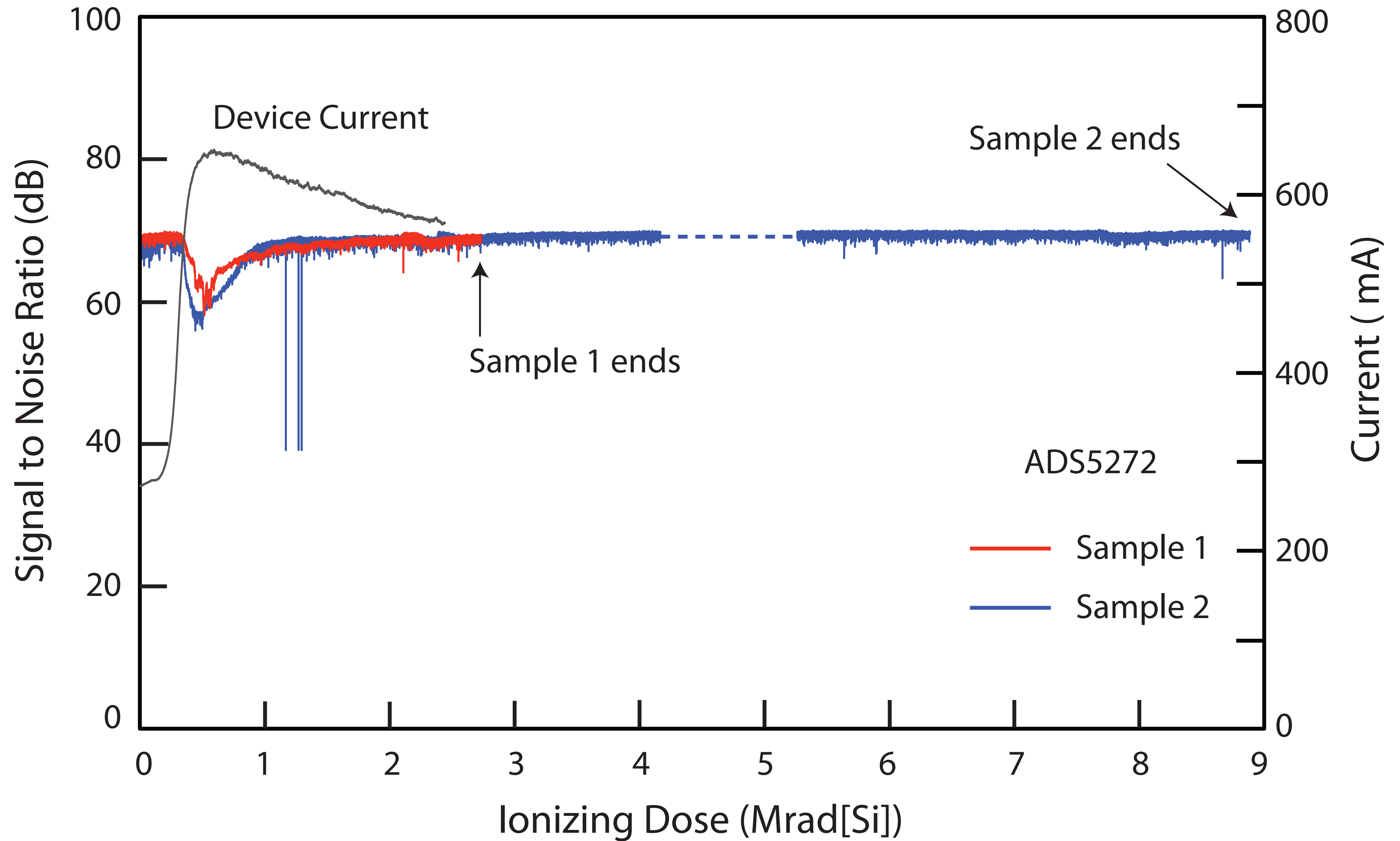





20 ADS5272 samples are now being tested following ATLAS guidelines. The first two samples show room temperature annealing.

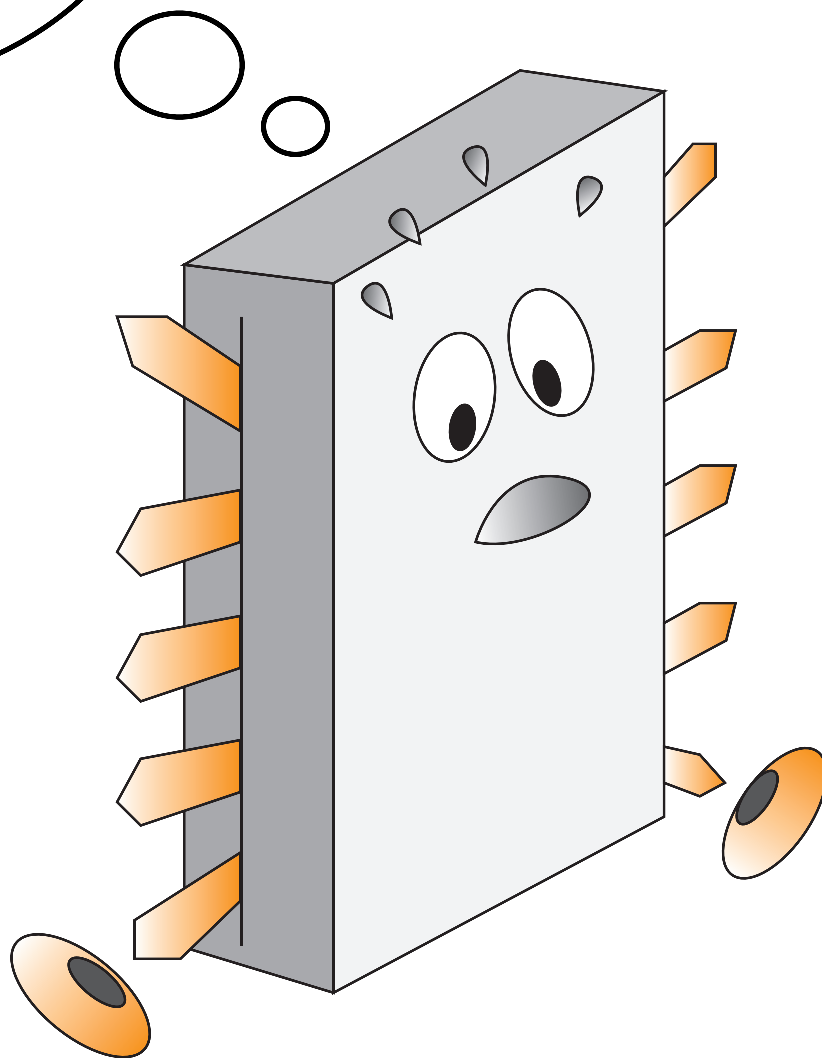
# Performance and Annealing

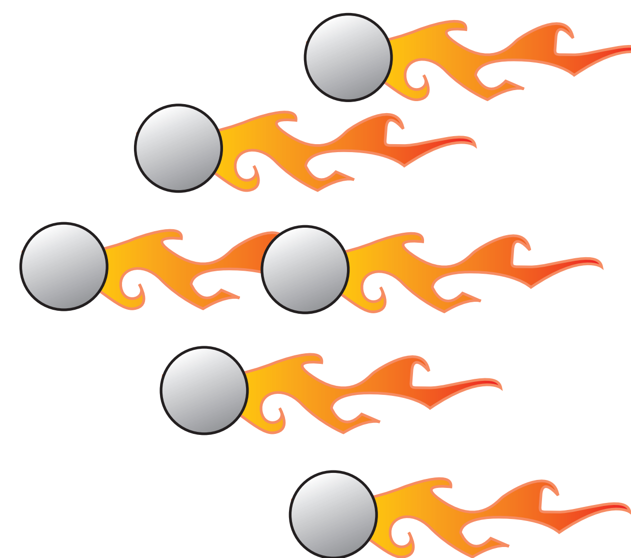





Signal to noise ratio as function of total ionizing dose for ADS5272

Latch Up?
SEFI?

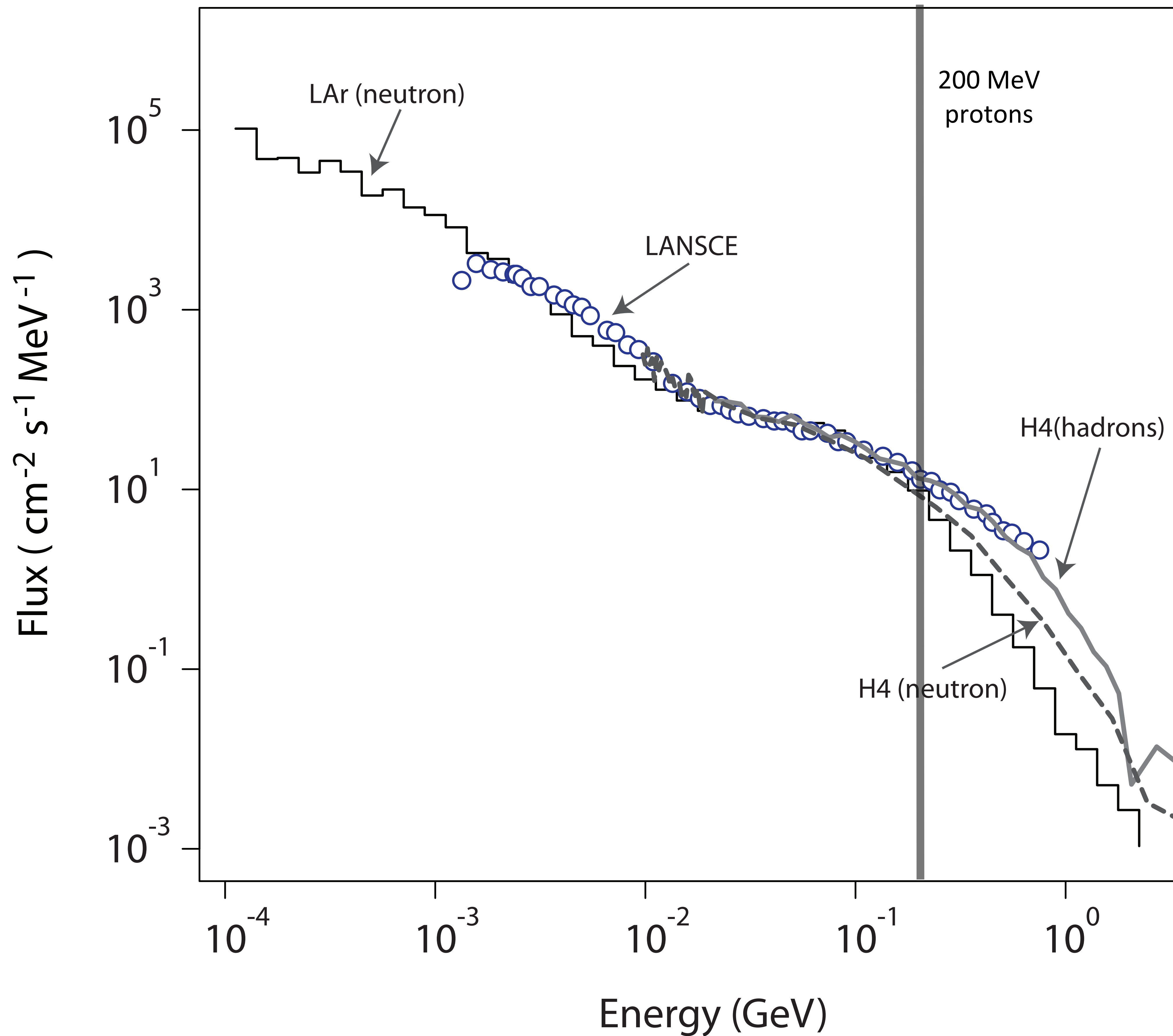


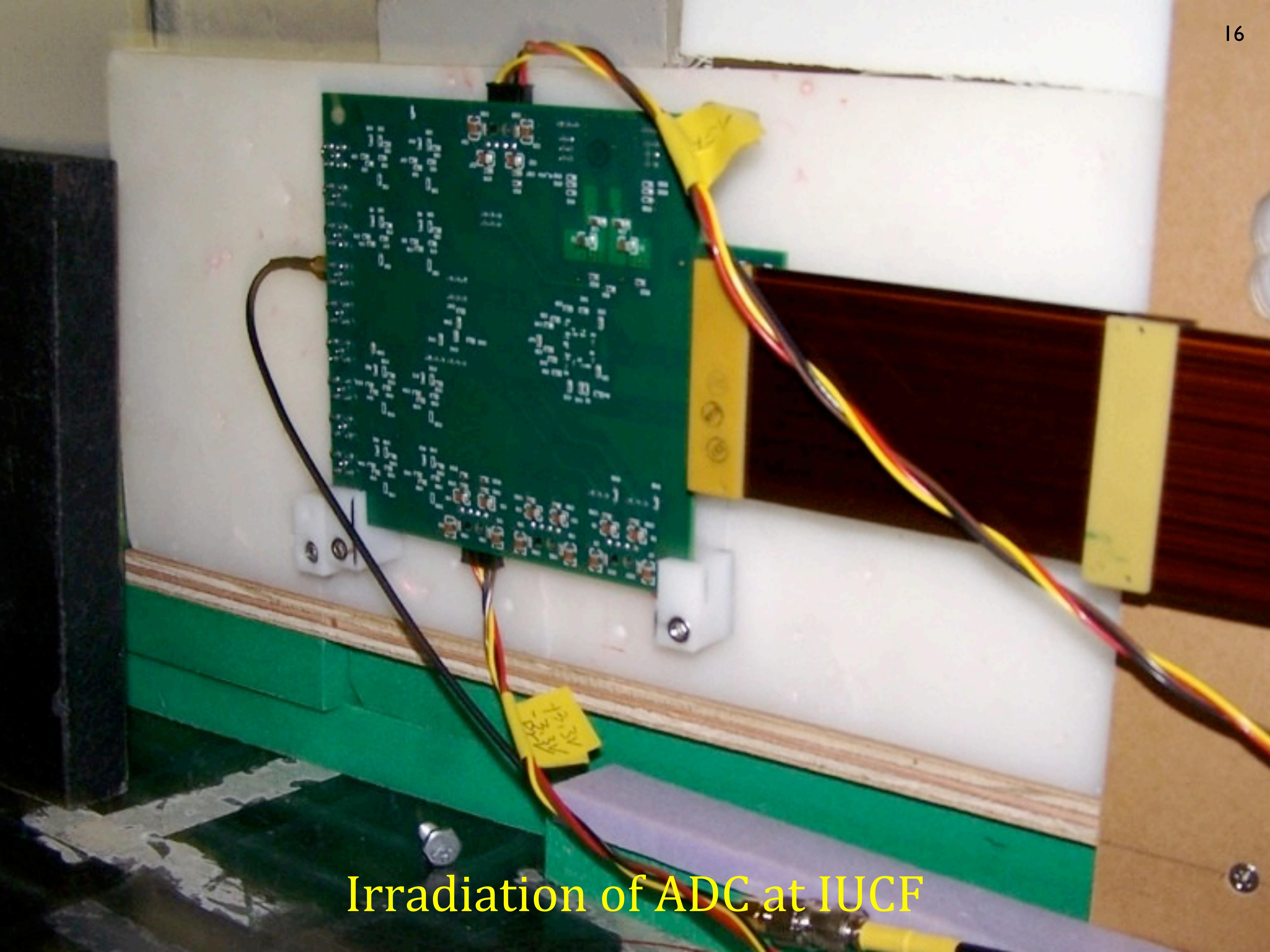


Single Event Effects

# The Appropriateness of Test Facilities



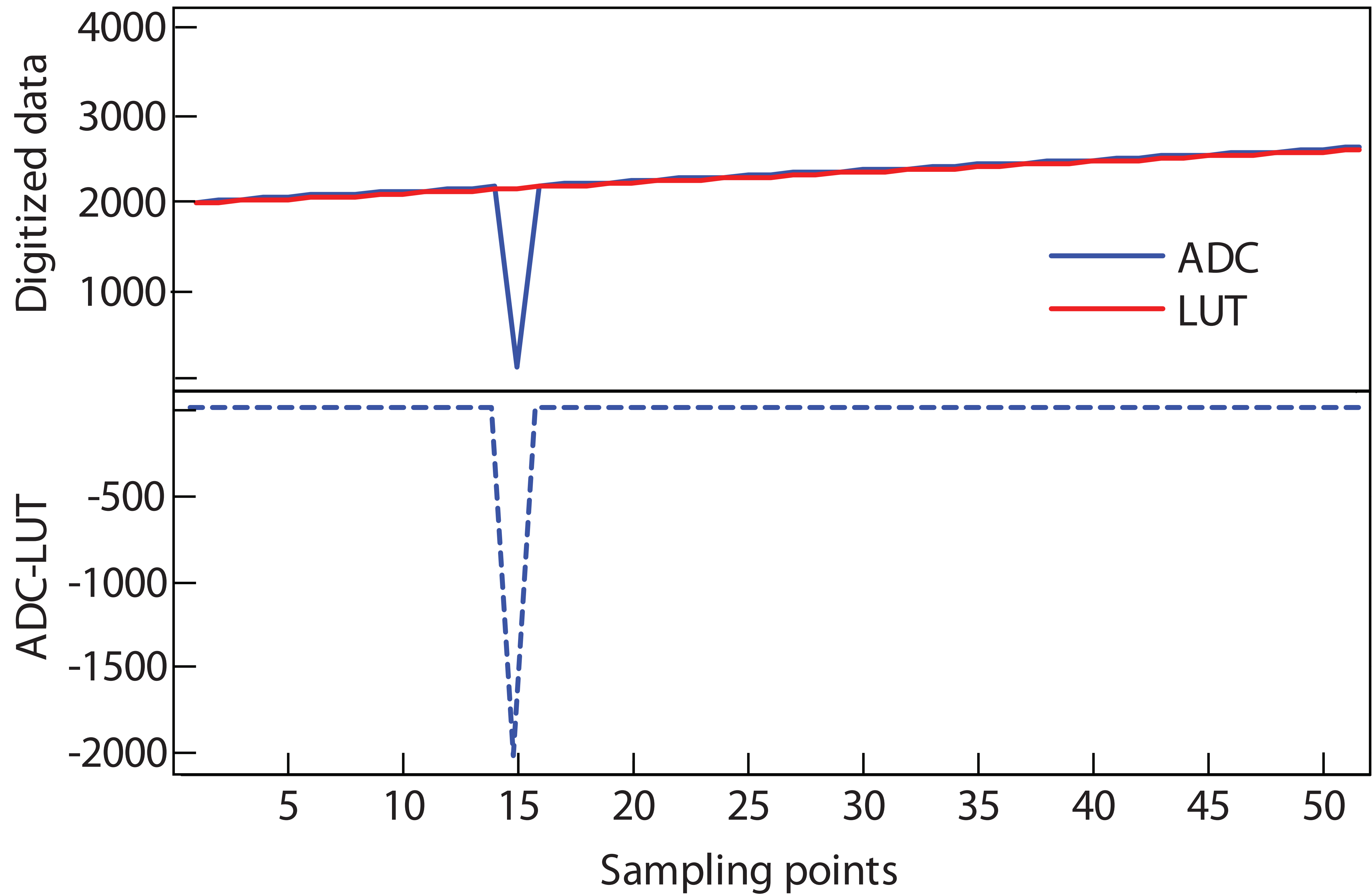



Irradiation of ADC at IUCF

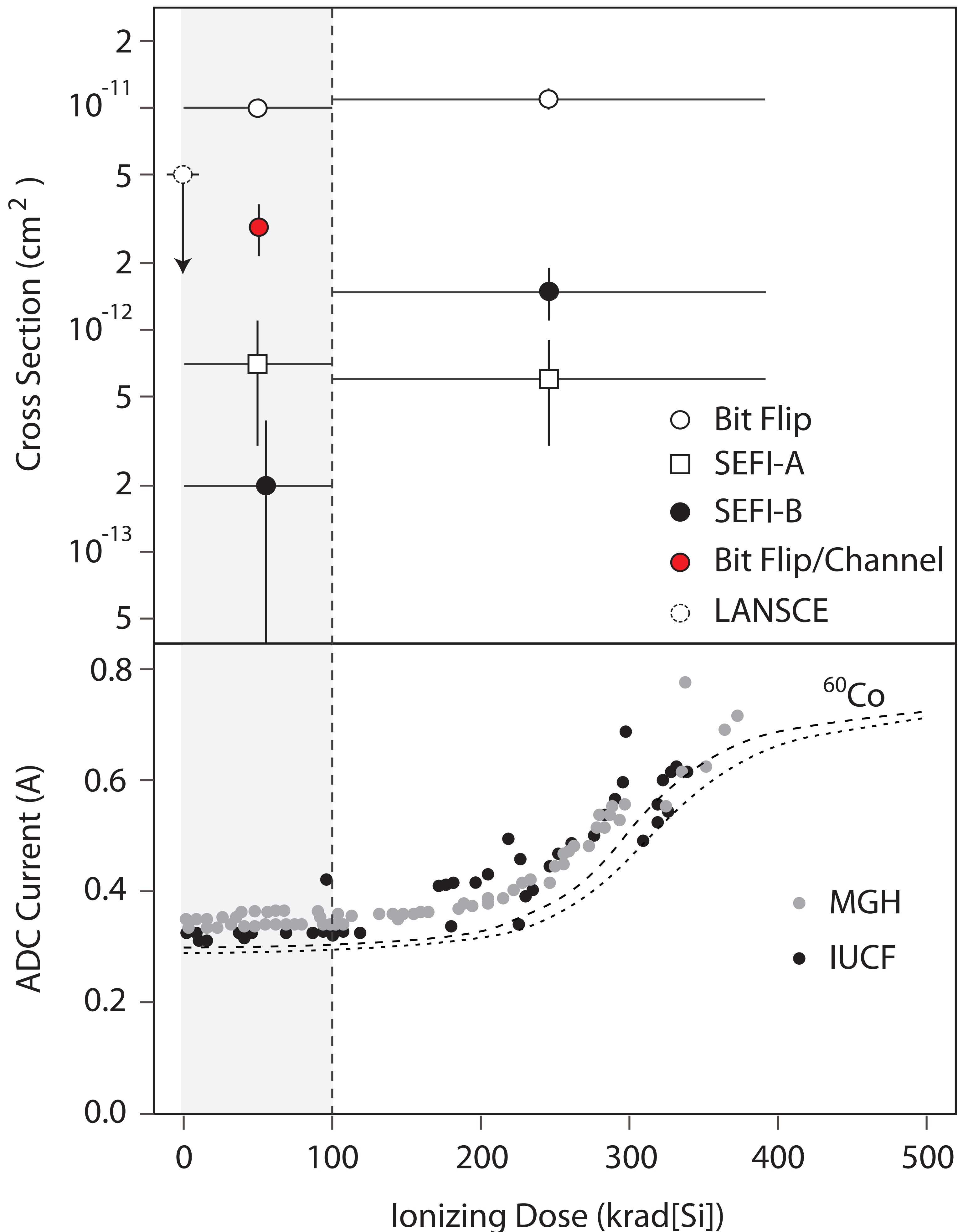
Irradiation of ADC and FPGA at LANSCE WNR

# “Bit-Flip”





# SEE cross sections for ADS5272




**SEFI** - Single Event Functional Interrupt.

**SEFI-A**: Can be reset by an external signal. Device recovers in 200 ns.

**SEFI-B**: Requires a Power Cycle.

*Quoted values are per device. Each ADC digitizes 8 channels.*

# Summary for ADS 5272 and ADS 5294

*Quoted values are per device. Each ADC digitizes 8 channels.*

| SEE Measurement | ADS5272 (<100 kRad) | ADS5272 ( >100 kRad) | ADS5294 |
|---|---|---|---|
| SEFI A ($cm^{-2}$) | $(0.7 \pm 0.4) \times 10^{-12}$ | $(0.6 \pm 0.3) \times 10^{-12}$ | $(7.4 \pm 1.2) \times 10^{-12}$ |
| SEFI B ($cm^{-2}$) | $(0.2 \pm 0.2) \times 10^{-12}$ | $(1.5 \pm 0.4) \times 10^{-12}$ | – |
| SEU ($cm^{-2} bit^{-1}$) | $(1.4 \pm 0.1) \times 10^{-12}$ | $(1.6 \pm 0.1) \times 10^{-12}$ | $(1.8 \pm 0.2) \times 10^{-11}$ |

**ADS5272 -** Identified SEU, and two types of SEFI. One that is recoverable via external reset and a second that requires a power cycle.

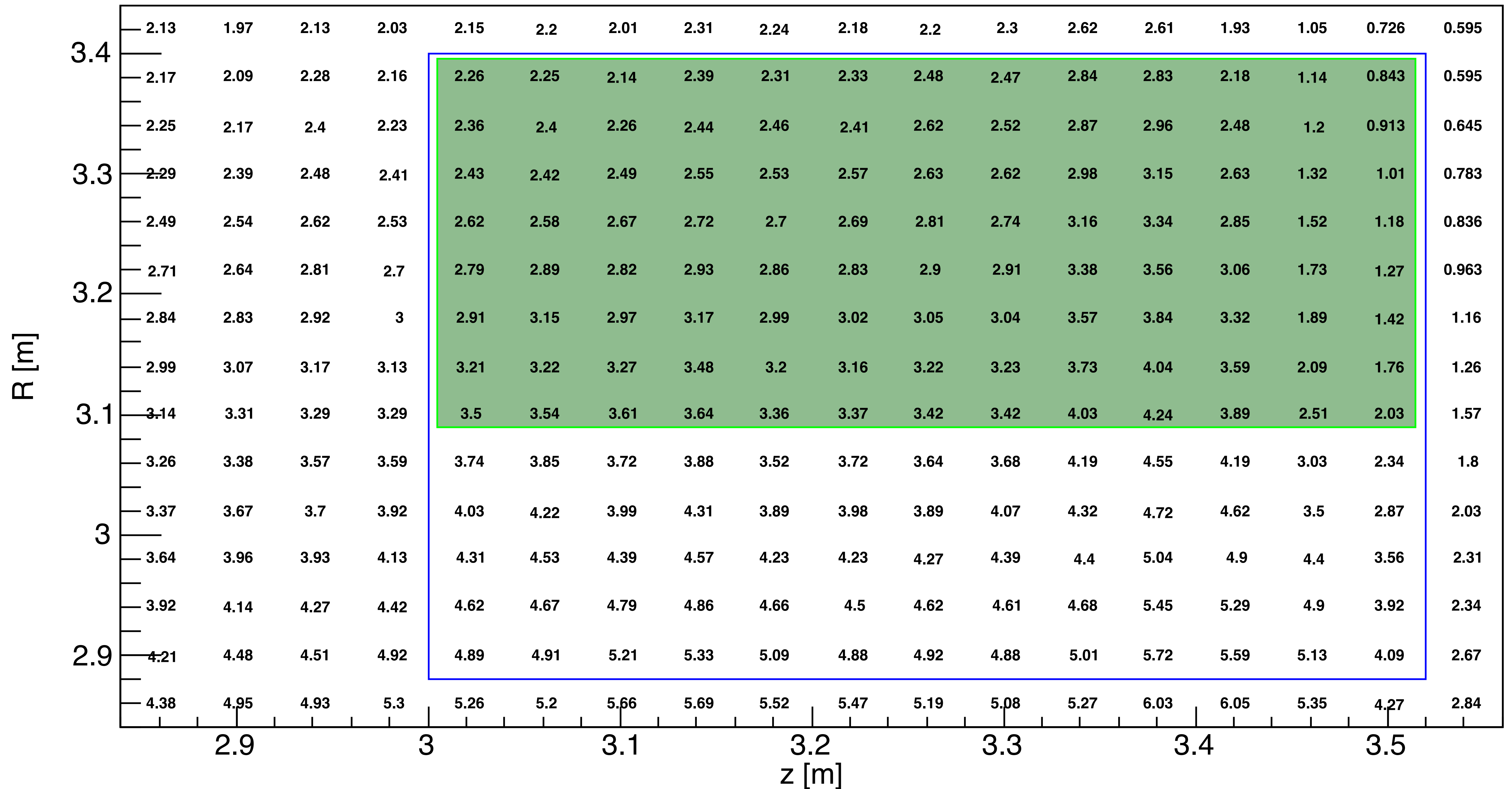
**ADS5294** - There is no dependence on total dose for SEFI. SEFI requires reprogramming of three registers, that takes less than 5 $\mu s$.

In both devices the probability of bit flip is independent of the bit position.

# Rates and Mitigation

LAr EMB Front-End Crates: SEE fluence @ 14 TeV [x10$^{8}$ hadrons cm$^{2}$/fb$^{-1}$]

Digital Section: $\langle\Phi\rangle$ = 2.84 ± 0.59 / $\Phi_{MAX}$ = 4.24 - SF=2



# Rates and Mitigation

For LAr barrel trigger boards in phase 2, the **SEFI-B rate** is:

$$\text{SEFI-B/h} = \frac{2 \cdot 2.84\times10^{8} \cdot 2 \cdot 2\times10^{-13} \cdot 2500}{10\ \text{h}} \sim 0.5\ /\text{fill}$$

*safety factor* (2); *fluence fb⁻¹* → $2.84\times10^{8}$; *integrated luminosity (fb)* → 2; *cross section* → $2\times10^{-13}$; *number of devices* → 2500; *one fill* → 10 h

SEFI type A can be cleared issuing resets periodically during, e.g. gaps in the accelerator cycles ( f = 11 kHz).

# Summary

- Qualification procedure for COTS ADC was established.
- Seventeen COTS ADCs were tested for their tolerance to ionizing dose. They all perform up to 100 krad, with six withstanding doses larger than 1 Mrad.
- Annealing tests reveal recovering to baseline even for larger doses. Controlled annealing tests is underway for 20 ADS5272 samples for ELDRS studies.
- ADS5272 and ADS5294 were selected for SEU tests. Bit Flips and SEFIs were observed and their cross sections measured.
- The ADS5272 has two types of SEFI. One type can be cleared by an external reset, and the second needs a power cycle.