ESR14
Software-Defined Radio for Space Applications

J. Budroweit[1], M. Jaksch[1], A. Koelpin[2], R. Garcia Alia[3],A. Coronetti[3]
[1]DLR, 28359 Bremen, Germany
[2]B-TU, 28359 Bremen, Germany
[3]CERN, 1211 Geneva, Switzerland

RADSAGA System Level Test Review
November 12th, 2019

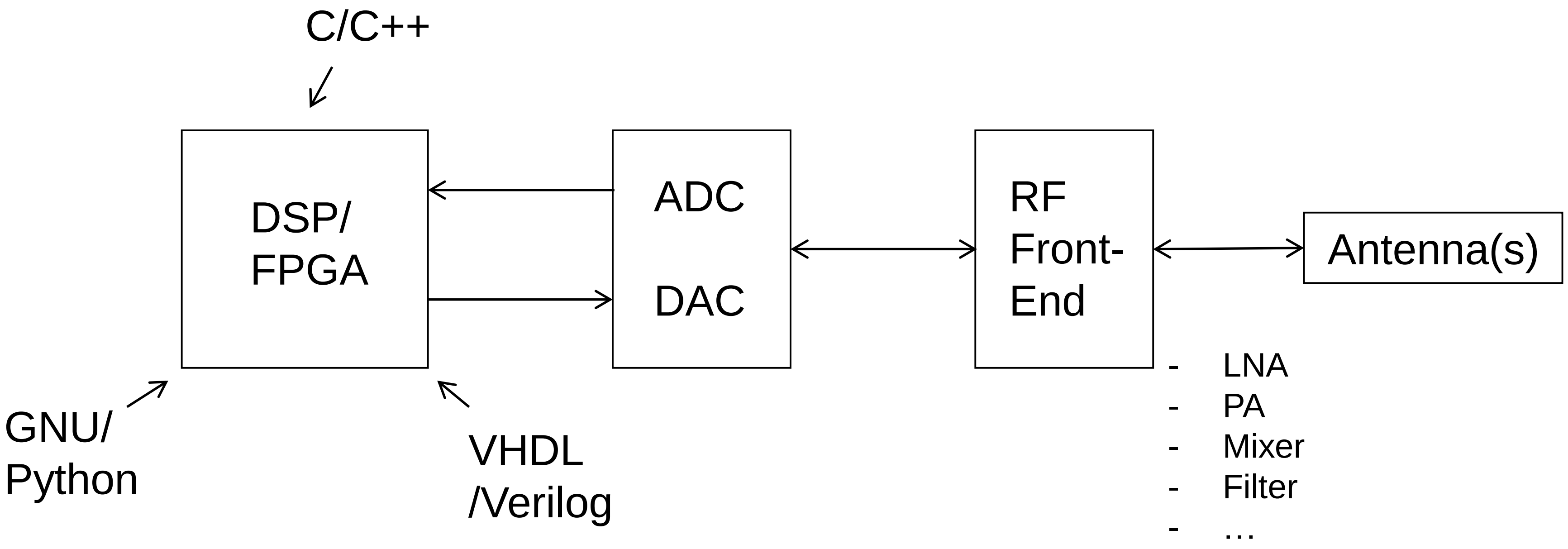
RADSAGA

RADSAGA is a project funded by the European Union's Horizon 2020 research and innovation programme under the MSC agreement no. 721624.

CERN

What is an SDR?

- A SDR usually defines the signal processing in software, implemented on an DSP or FPGA
- RF Front-End mostly untouched and tailored to specific application requirements



State of the art SDR systems for space applications

- SDRs are already established
- Commonly used for single applications / units
- Limited in operational frequency band

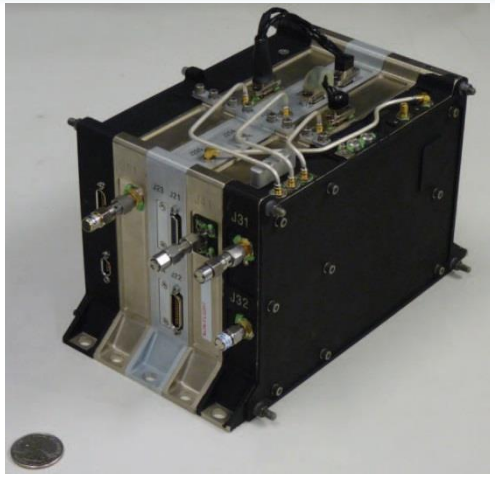
Two categories/approaches with a huge gap in between:

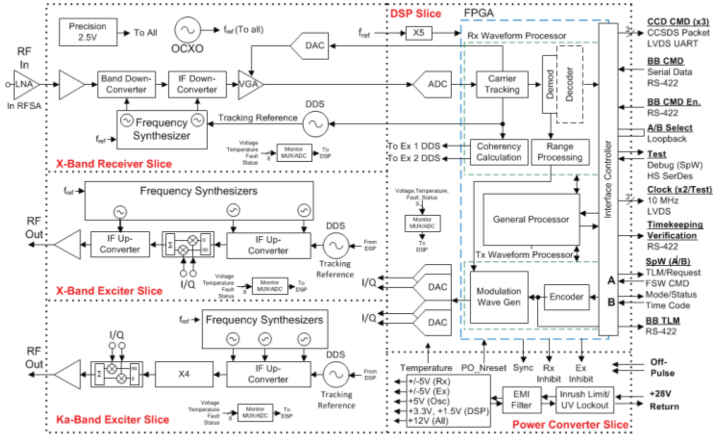
<u>(1) High reliability:</u>

- High mass and mechanical dimensions
- High costs
- Long lead-times
- High power consumption

<u>(2) Low reliability:</u>

- No radiation effect background
- Low frequency range (< S-Band)
- Non-conformances to mission ICD

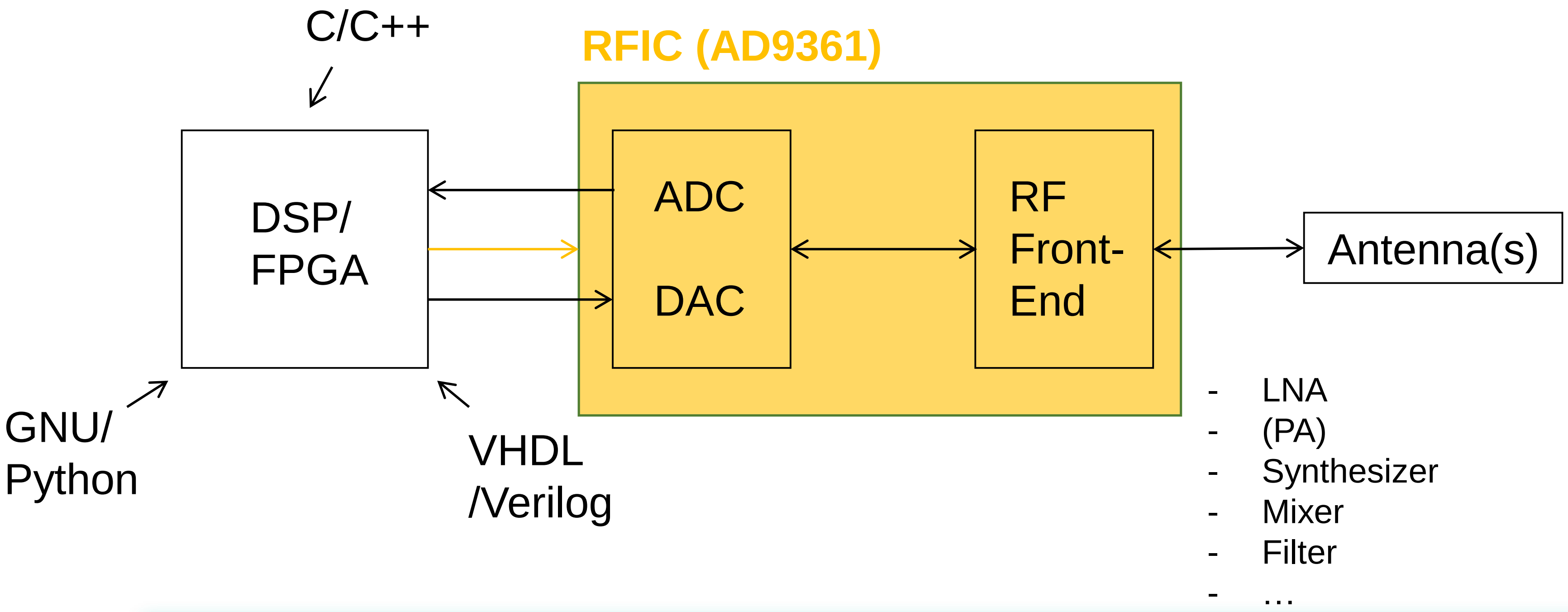




Source: Frontier Radio platform by JHU/APL

A new approach using new technologies

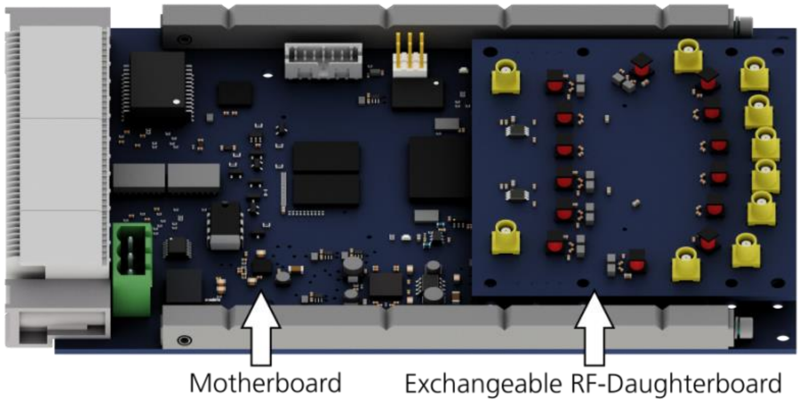
- A SDR usually defines the signal processing in software, implemented on an DSP or FPGA
- RF Front-End mostly untouched and tailored to specific application requirements



Motivation

Generic Software-Defined Radio Platform

- Flexible radio platform for space applications
- Radio system that allows simple re-use and modification from mission to mission
- Small and integrated design with low power and mechanical properties suitable to operate on small satellites
- Low budget driven design with use high performance technologies (e.g. FPGAs/Processors)
- Radiation tolerant system design with “higher” claim on reliability aspects (e.g. for TM/TC operations)

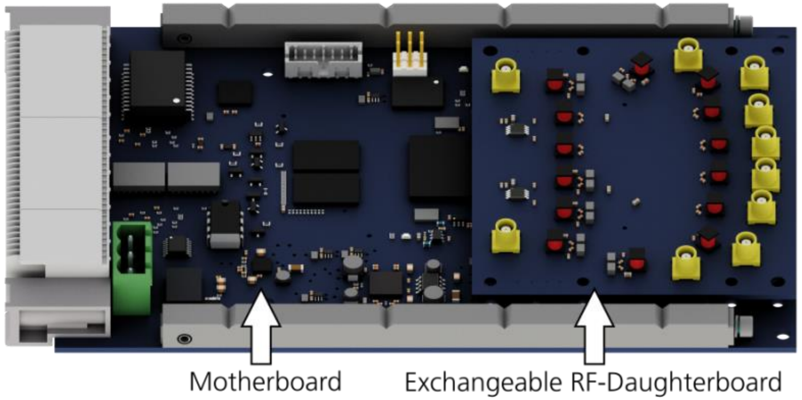


Motivation

<u>Novel Aspects</u>

- Independencies from frequency band limitations for TM&TC (VHF, UHF,L S/C-Band…)
- Single radio platform for multiple applications (two/three/four in one)
- Reconfiguration and operation of multiple applications (e.g. TM&TC or/and ADS-B or/and AIS or/and Spectral Monitoring)
- Better utilization of given resources (power, weight, …)
- Strong focus on radiation tolerances on system level (no destructive events and low soft-failure rates)

➢ Primary (but not limited) target for earth observation and radio frequency applications in Low Earth Orbit (LEO) missions with < 2 years of operation



Test Requirements:
- TID tolerance > 100 Gy(Si)
- No destructive SEEs
- Moderate SEFI rates

Challenges

- Making modern sate-of-the-art technologies available for space, in a sufficient way, is the biggest challenge due to:

  - Unknown reliability characteristics for space
  - Harsh environment in space
    - Thermal stress
    - Vacuum condition
    - Radiation (TID, SEE)
    - Microgravity
    - Atomic oxygen

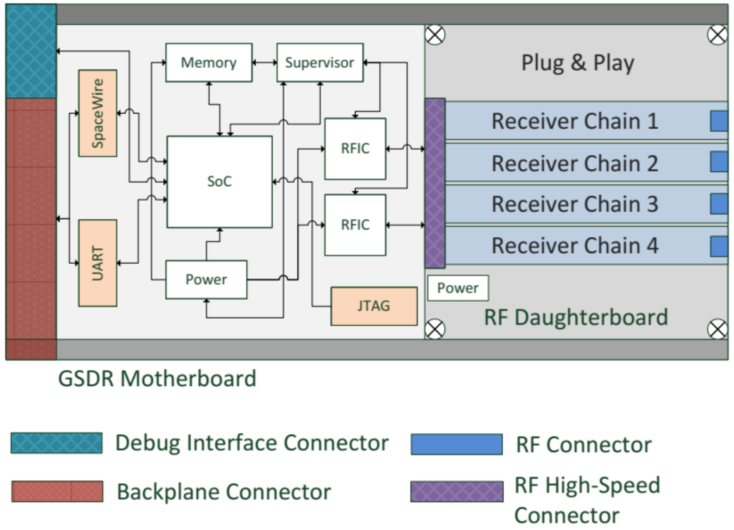
- Trade-off between cost, efficiency and reliability -> **Fault-Tolerant Design**!

Fault-Tolerant design approach - Hardware design with cost-efficient effort

1. Reliability prediction analysis
2. Analysis of radiation data bases and test data on COTS components with suitable candidates for the SDR system design
3. Selection of well-known devices with certain product traceability
4. Radiation testing of selected “unknown” devices (e.g. AD9361)
5. RadHard or Rad-Tolerant alternatives
6. System-level mitigation on expected effects:
   - Redundancies, voting
   - Latchup-protection
   - OVP (SET)
   - Configuration scrubbing
   - EDAC mechanisms
   - Usage of watchdogs
   - Safe system-reset (e.g., prevent eFuse setting corruption)

7. **Testing on system-level to verify the hardening strategies (e.g., radiation)**

Topical SDR electronics of the test

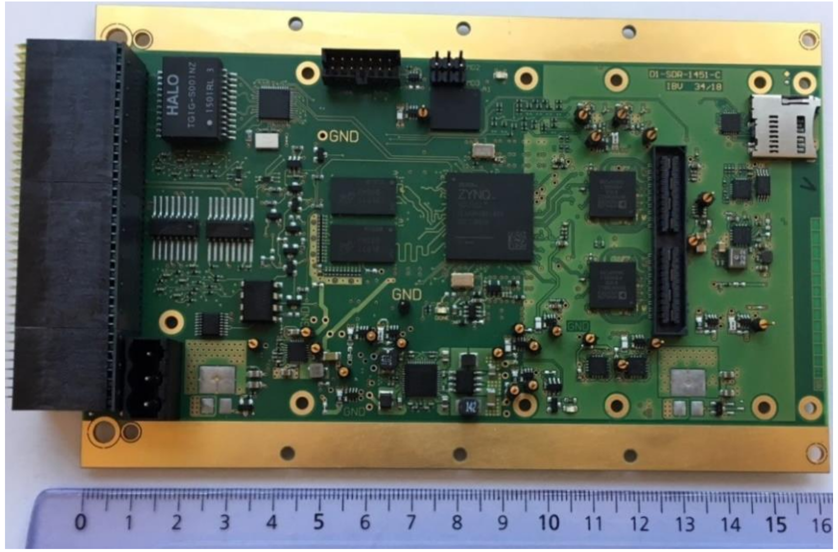


<u>SDR core electronics</u>

- RFIC (AD9361)
- Zynq-7000 (ZC7020)
- 2x512 GB DDR3 SDRAM (Micron)
- 1 GB NAND (Micron)
- RS422, LVDS driver (TI)
- Supervisory circuit

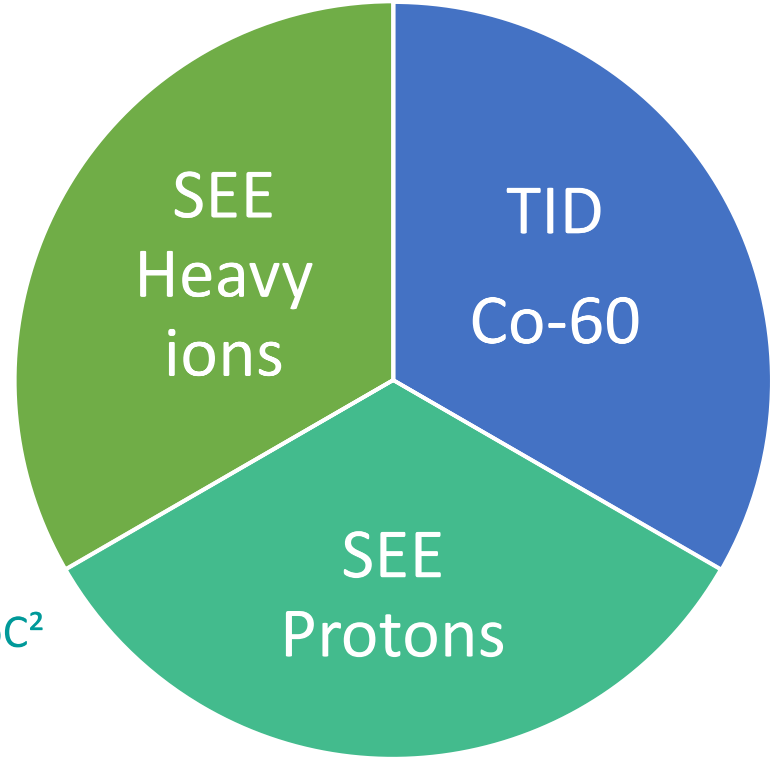
Risk mitigation due to RadHard alternatives (if required)

- ➢ Interfaces, power, clocking and supervising devices are replaceable with RadHard solutions
- ➢ Unavoidable COTS devices with certain screening level and radiation data are available



Link to existing and available test data for non-RadHard devices

Zynq7000 SoC[2]
AD9361[3]
NAND Flash[2]
DDR3 SDRAM[2]
…



Zynq7000 SoC[2]
AD9361[3]
NAND Flash[2]
DDR3 SDRAM[2]
…

Zynq7000 SoC[2]
AD9361[3]
NAND Flash[2]
DDR3 SDRAM[2]
…

Why testing on system level?

- Other "unknown" components on the PCB?
- Failure Propagation?
- Global functionality?
- Validation of radiation effects mitigation?

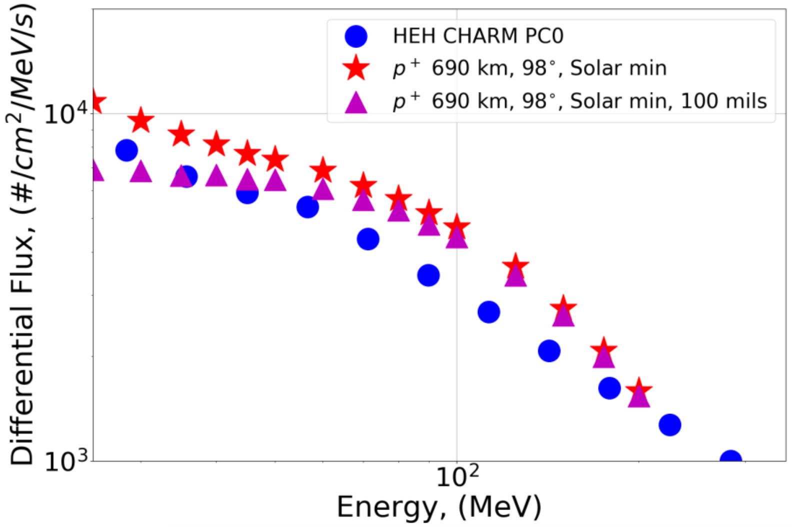
[2]Published test data
[3]Experiments performed by DLR

Suitable facilities for system level testing (in EU)

- Other "unknown" components on the PCB?
- Failure Propagation?
- Global functionality?
- Validation of radiation effects mitigation?

Issues with system level testing →

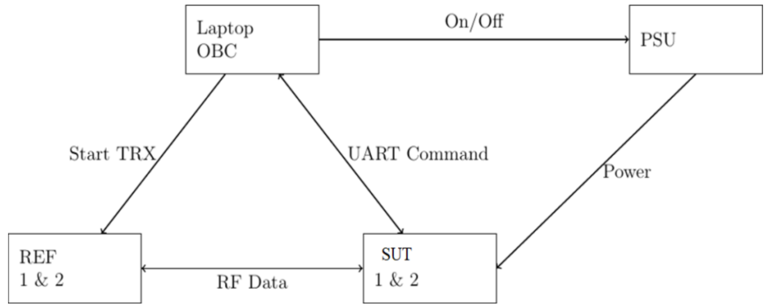
- Deep penetration beams
- Global/Broad beam size
- Environment representativeness



	PSI-KVI	UCL-RADEF	CHARM
Broad beam size	− +	−	+ +
LEO representativeness	+	− +	+
Deep penetration	+	− −	+

System level testing: Failure detection and mitigation

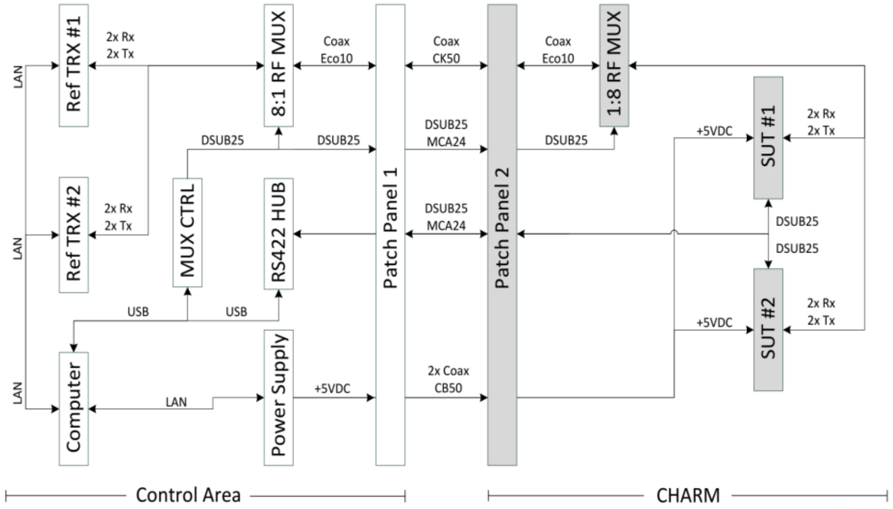
- Two SUTs in a complex setup due to limited RF interfaces



On system-level

- Potential destructive events due to high current and voltage states
  - Sub-voltage latch-up detection and detection
  - Overvoltage detection and protection

- Single event failure interrupt
  - System-Watchdog executes reset if heart-beat disappears
  - Time-Out of command response (power-cycle)
  - Soft-Watchdog (on program/application level)



On component-level

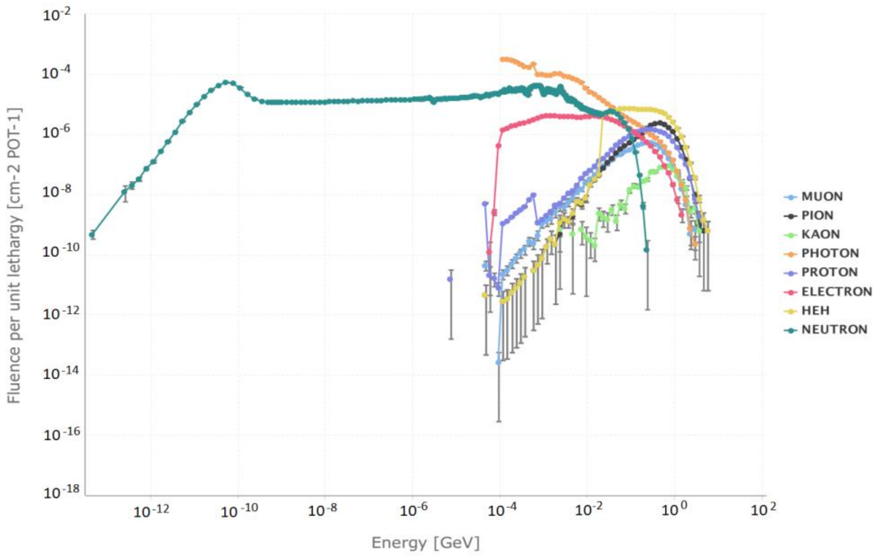
- RF-Transceiver deep failure mitigation
- NAND Flash supervisory (Boot device)

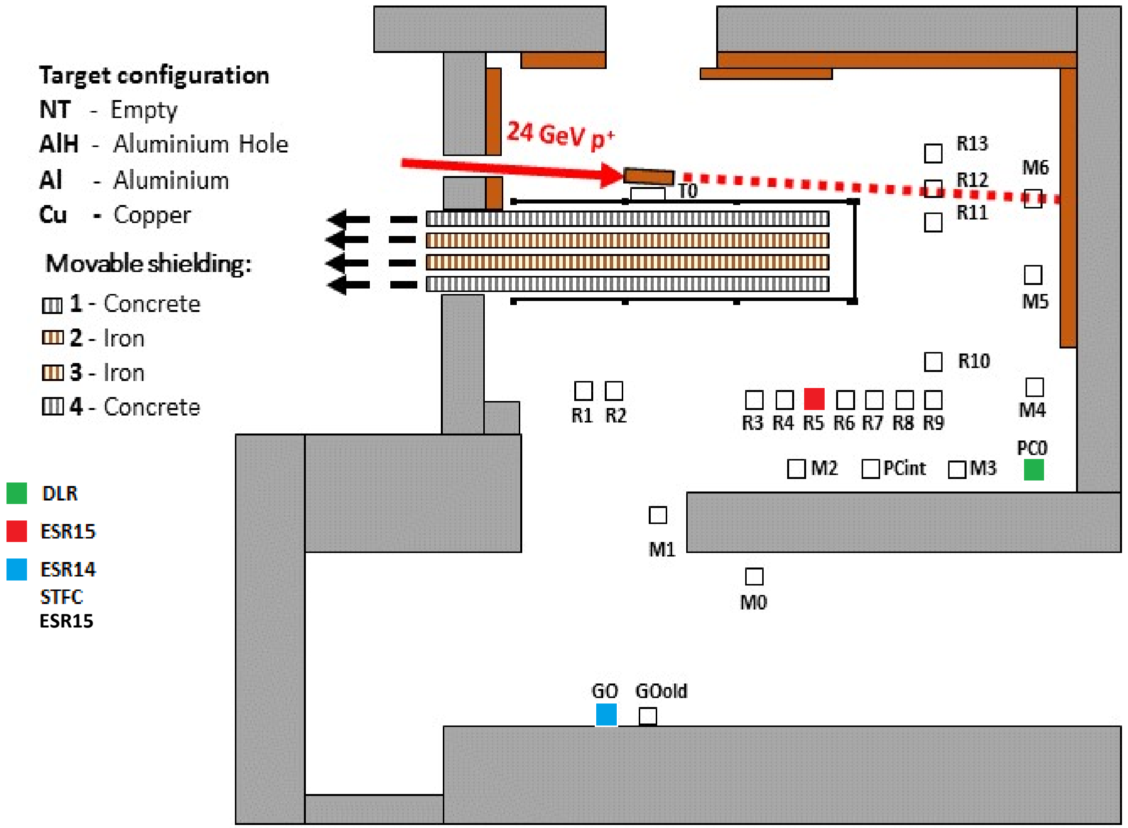
System level testing: facility

Test performed at PC0 in CHARM:

- ~1.02×10^7 HEH/cm^2/spill
- ~0.44 rad(Si)/spill

➢ Fluence 2.170×10^{11} #/cm^2 and a TID of 9.25 krad(Si)



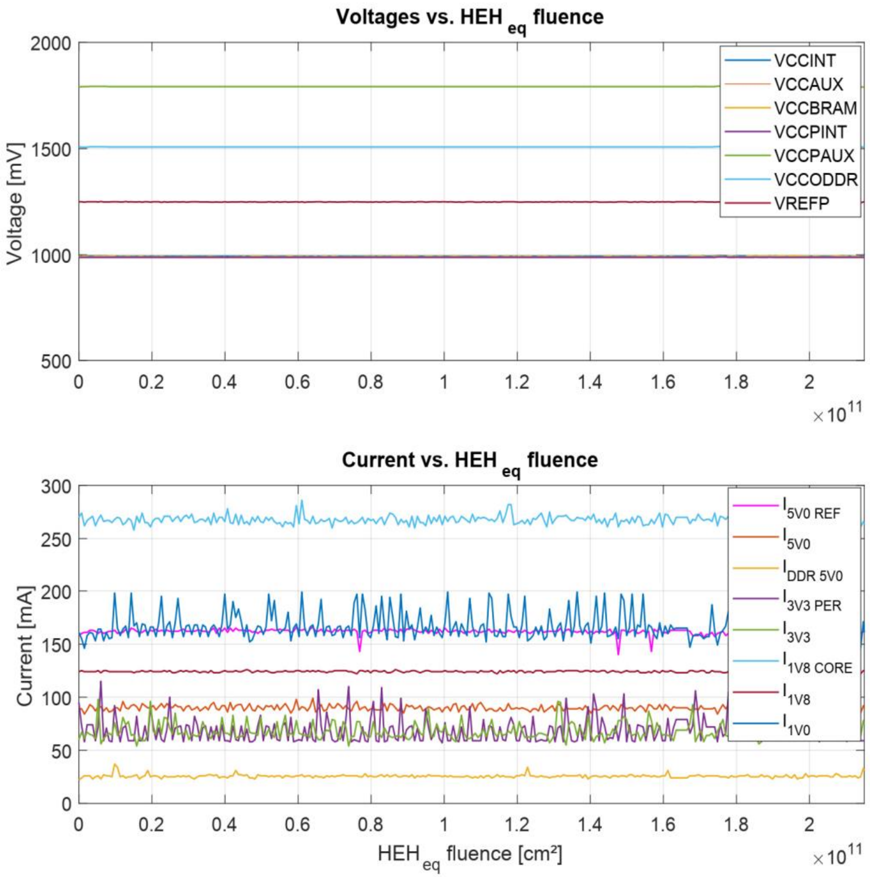


System level testing: results

- System(s) run with multiple tasks on request
  - HK-Data, RF-Data aq., Spectrogram, …
- No degradation of voltage and current due to TID
- No SELs or destructive failures
- Ability to perform self-recovery

Type	#Event	#Spills	HEHeq Fluence [/cm²]	Cross-Section [device/cm²]
Reboot	5320	21236	2.170×10^{11}	**2.451×10^{-8}**
Power-cycle	75	21236	2.170×10^{11}	**3.456×10^{-10}**

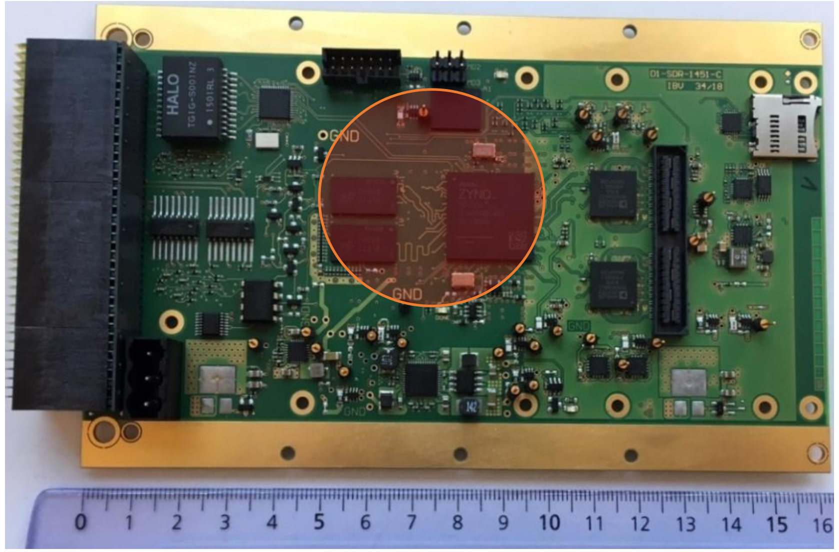
- 100% recovery from failure to valid system operation
- No interrupted boot-processes observed (process takes ~15sec)
- 95% of all failures were system crashes (Zynq+DDR3)
- No invalid data on boot devices (NAND Flash)
- Data fly-by storage on SD-Card critical (SD-Card broken)
  - SUT#2 (partially) not able to response on requested tasks



System level testing: link to component-level testing

- RF Transceiver has been irradiated to Proton (max. 190MeV)
    - Low SEU rate in configuration registers
    - Very low SEFI rate
    - No SEFI seen in CHARM, only minor SEUs

- Zynq+DDR3 has been irradiated by proton (max. 190MeV)
    - Same configuration and software were used as in CHARM (only exception: SD-Card was not used for intermediate data storage)
    - No RF-board in use (no RF data captured)
    - Fluence: 5.0×10^{8} #/cm^{2}
    - Comparable saturation of cross-section
        - ~2.6×10^{-8} cm^{2}/device (proton)
        - 2.451×10^{-8} cm^{2}/device (CHARM)



Qualification/Test methodologies (summary)

Applicable to (non-HighRel) space missions:

- Validation of destructive SEEs (e.g., through heavy ion) on component-level
  - Critical components that are not available in RadHard (e.g., Zynq or AD9361)
  - No test data are available and are not outdated

- Soft error testing of multiple components (groups) well covered through system-level testing
  - Too many tests to be done on sub-components
  - Failure propagation and interaction not covered on component-level testing

- Results for mix-field radiation testing are comparable to proton-only results in terms of cross-section saturation.