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The opportunities and limitations of the system-level testing

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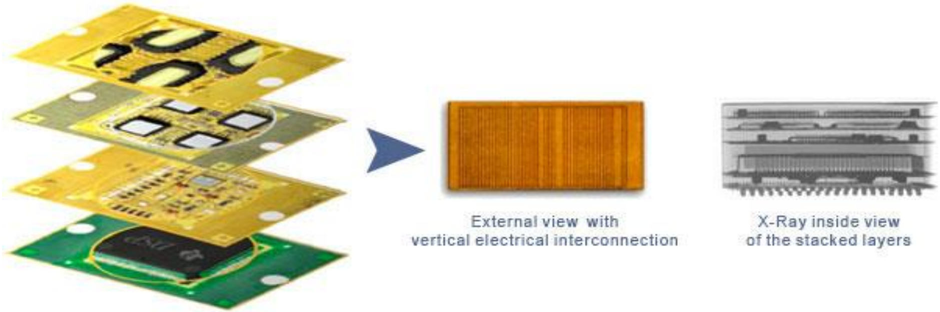
RADSAGA began in March 2017 and will run for 5 years.

Presentation outline

- ☐ Work context
- ☐ Overview of performed radiation tests
- ☐ Opportunities given by system-level testing
- ☐ Limiting factors of qualification
- ☐ Limited qualification scenarios for both TID and SEE

Work context

- Research performed as a strong collaboration of academia: the University of Montpellier, and industry: the 3D PLUS company – manufacturer of the System-in-Package (SiP) modules for Space.
- The main motivation of this work: to simplify radiation qualification process for the SiP modules.
- Current qualification approach is based on the component-level testing.



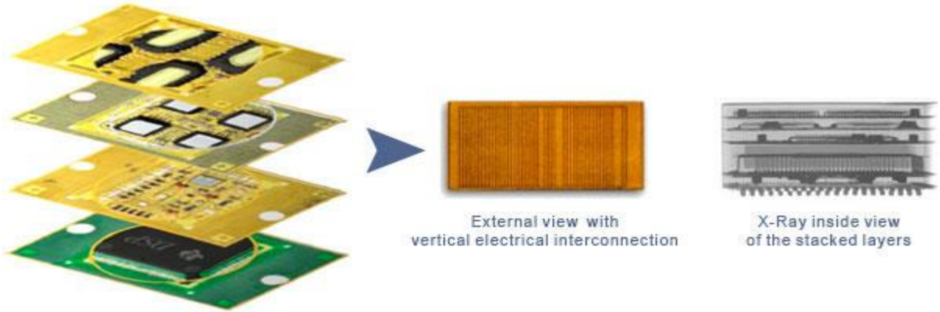
External view with vertical electrical interconnection

X-Ray inside view of the stacked layers

Work context

- The first goal of this study was to understand opportunities and challenges related to system-level testing of electronics and to qualification by system-level testing.

- The second goal was to propose tracks for a methodology for qualification of System-in-Package modules that could be further used to construct qualification guidelines or standard.



Performed radiation tests

Various system-level radiation tests were performed during this study:

☐ SEE tests with:	HE heavy ions (GANIL) UHE heavy ions (CHARM) laser (Univ. Montpellier*) SE heavy ions (UCL)
☐ SEE and TID tests at CHARM mixed-field (CERN)	
☐ TID tests with:	X-Rays (Univ. Montpellier*) Co-60 source (Univ. Montpellier*)

*Laser, X-Rays and Co-60 tests have been performed using the PRESERVE Platform which has been funded by the Occitanie Region and the EU via ERDF funds.

System Under Test description

For all test campaigns, the same test vehicle was used – the Point-of-Load DC/DC converter SiP module developed by 3D PLUS:

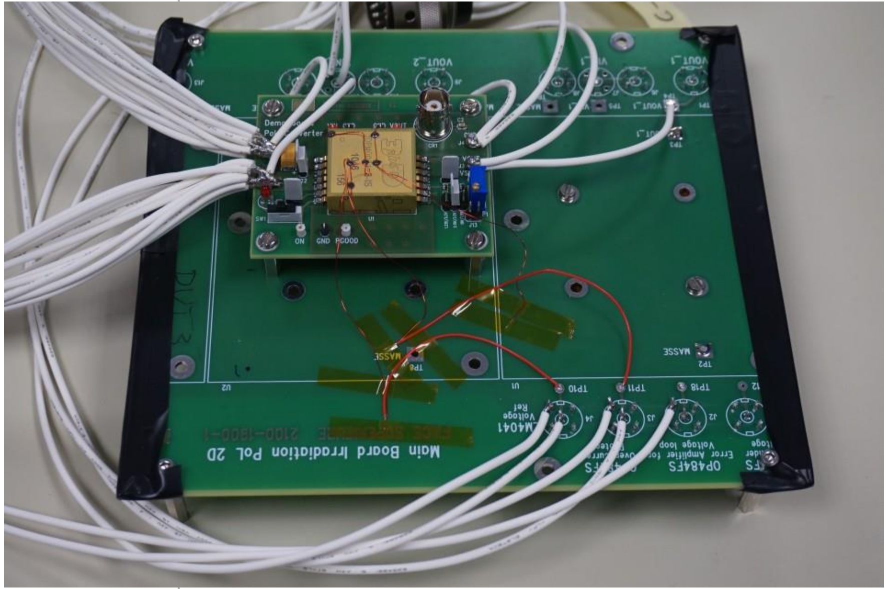
- ☐ consists of 26 active COTS components
- ☐ qualified up to 50 krad basing on the component-level tests

Motivation to choose the PoL:

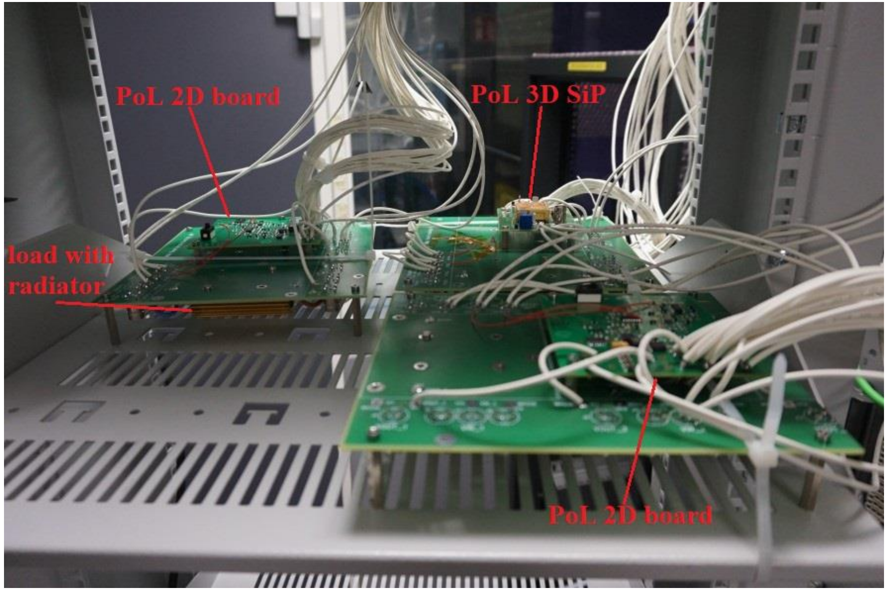
- ☐ project timeline and availability of different 3D PLUS SiPs
- ☐ moderate complexity of PoL, component-level test results available
- ☐ availability of easy-to-manufacture, 2D prototype board
- ☐ PoL parameters are relatively easy to characterize/measure

System Under Test description

Two Point-of-Load converter prototype 2D boards and one System-in-Package module, all of them installed on their motherboards.

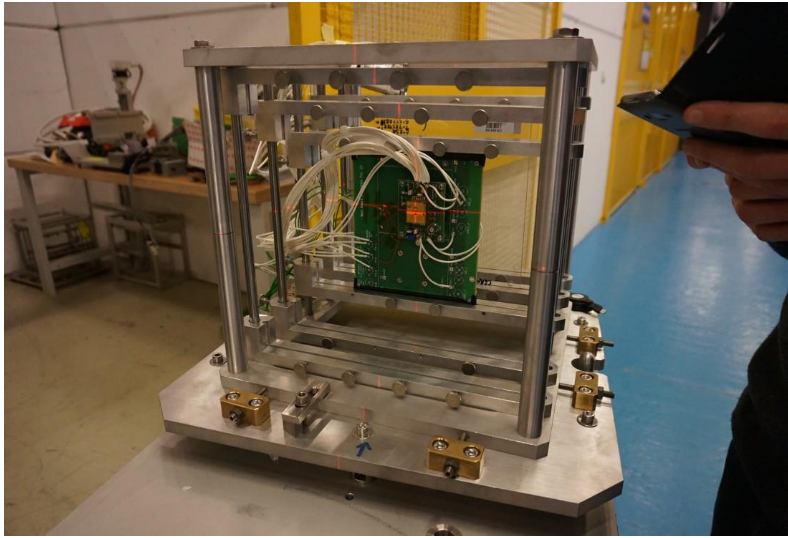


Point-of-Load converter System-in-Package module from 3D PLUS installed on the auxiliary board and further on the motherboard



SEE tests with UHE heavy ions (CHARM)

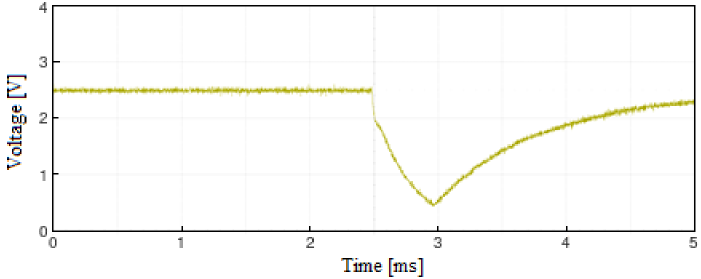
- ❑ lead ion, ultra high energy: 5.4 GeV/n
- ❑ unique opportunity to perform SEE tests of the SiP module – thanks to high penetration of heavy ions
- ❑ low LET (8 MeV·cm^2/mg), but still useful for soft error characterization: several thounds of SETs were observed
- ❑ system-level propagation of the SET was observed (and further investigated with laser tests)

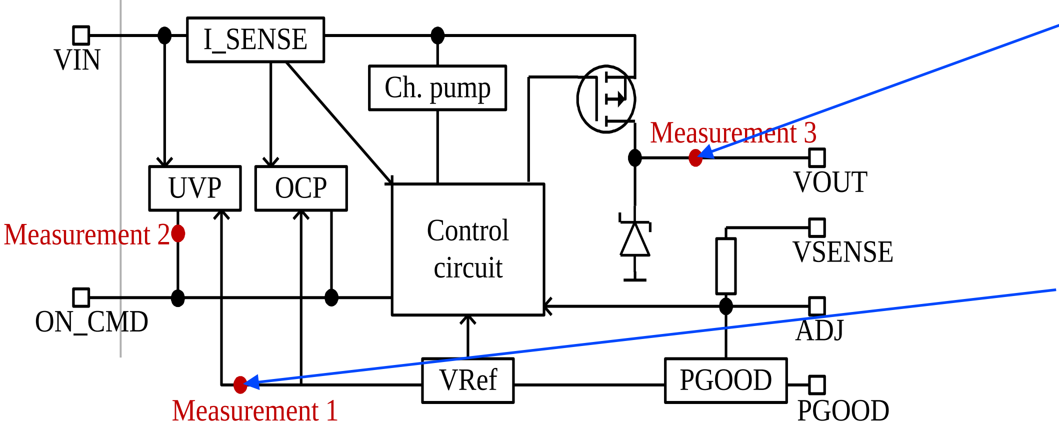


Test preparation area: PoL SiP installed in the Montrac. Beam alignment made through laser available on preparation table.

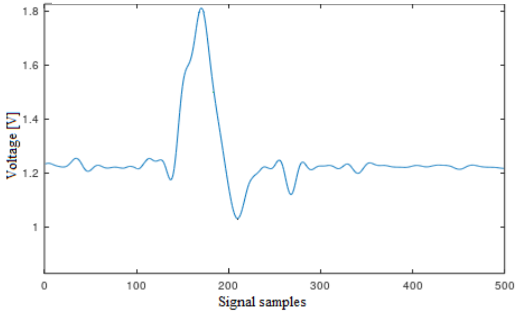
SEE tests with laser (1)

- main goal: to investigate „rare event” observed during UHE heavy ions test – propagation of SETs leading to power cycling of the PoL
- hypothesis: transients from the voltage reference chip are propagating to the undervoltage protection circuit and trigger system reset
- voltage reference chip was irradiated and 3 different parameters were monitored



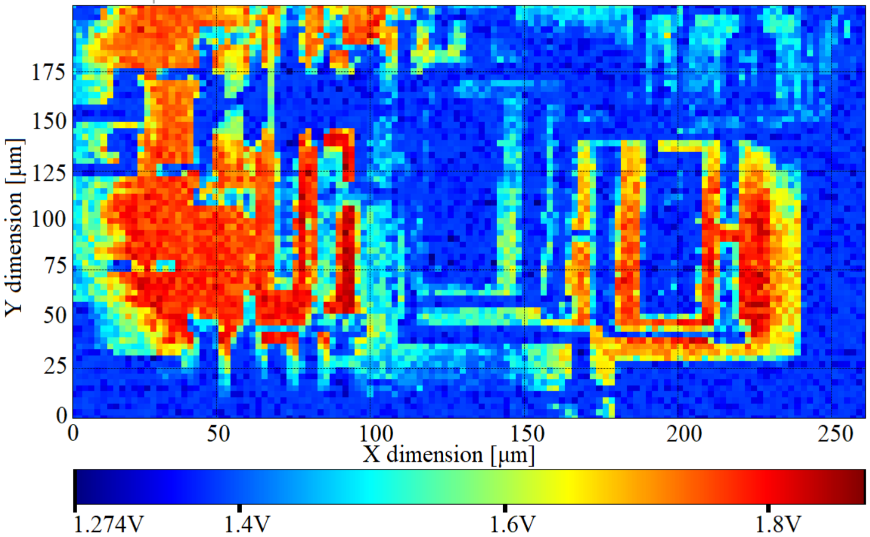


PoL simplified block diagram

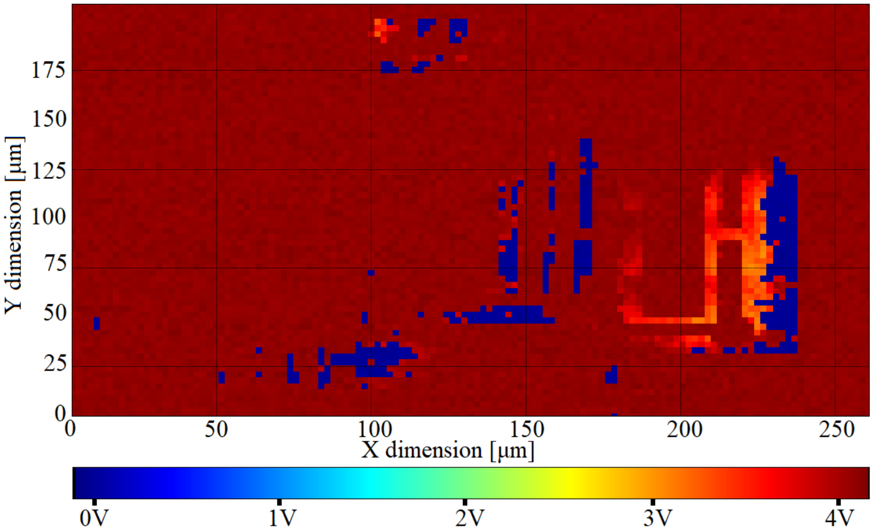


SEE tests with laser (2)

transients with the highest maximum value were not the ones that propagated



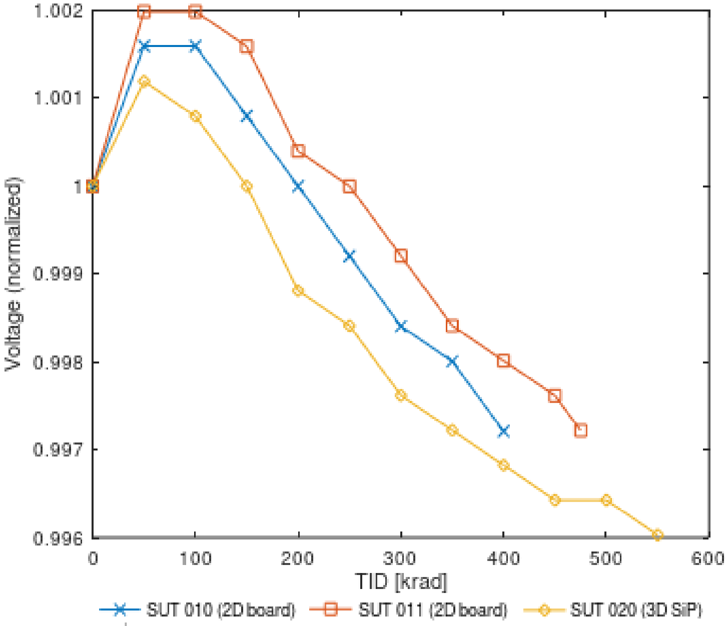
Maximum values of VRef output (measurement 1) corresponding to laser pulse hits at different points of VRef die.



Minimum values of OpAmp output (measurement 2) corresponding to laser pulse hits at different points of VRef die.

T. Rajkowski et al., *Analysis of SET Propagation in a System in Package Point of Load Converter*, IEEE Transactions on Nuclear Science, vol. 67, no. 7, pp. 1494– 1502, Jul. 2020

TID tests with X-Rays and Co-60 source (1)

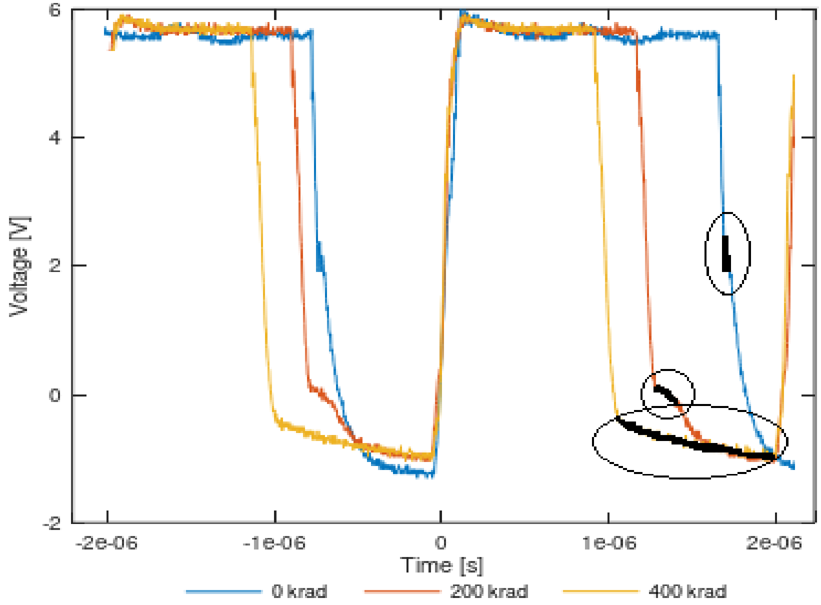


Output voltage of SUTs as a function of the Total Ionizing Dose (X-Rays test)

- ❑ 3 PoL boards and 2 3D PoL SiP were irradiated
- ❑ around 30 different parameters were characterized for each SUT

- ❑ PoL was functional up to more than 400 krad at X-Rays (high dose rate) and more than 118 krad under Co-60 irradiation (low dose rate)
- ❑ …PoL TID qualification level was 50 krad

TID tests with X-Rays and Co-60 source (2)



SUT010 MOSFET driver waveforms recorded at steps 0, 200, 400 krad. Black color marks switching time for each irradiation step.

- ❑ SUT failure finally tracked down to the failure of the MOSFET transistor switching time
- ❑ The root cause of the system failure could be discovered thanks to the high observability of the SUT parameters

T. Rajkowski et al., *Analysis of system level TID test results of a System in Package Point of Load converter*, NSREC2020 conference

Opportunities given by system-level testing

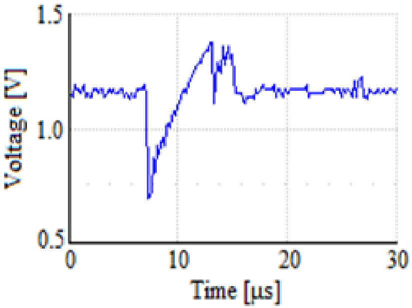
- ❑ Margins given by the system are incorporated in test results
- ❑ Results of the system-level tests may be the source of valuable information about the system details and radiation performance:
  - ❑ fault propagation in the system
  - ❑ mitigation techniques efficiency
  - ❑ relative sensitivity of the components
  - ❑ system-level error signatures
  - ❑ information about complex failure modes
  - ❑ information about synergistic effects at system level

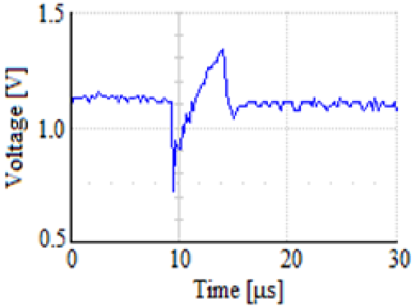
Limiting factors of qualification

- ❑ Definition of the worst case test conditions
  - ❑ For the component-level tests, worst case configuration is well defined and described in standards and literature
  - ❑ At system-level, environmental worst-case conditions might be different for different parts in the system (depending on the component technology)
  - ❑ Each system might have its own, specific worst-case configuration (internal state, input/output voltage, output load, clock frequency, etc.)
  - ❑ This worst-case configuration is mostly related to the system internal design and might be difficult to predict without complex analysis – or testing

Limiting factors of qualification

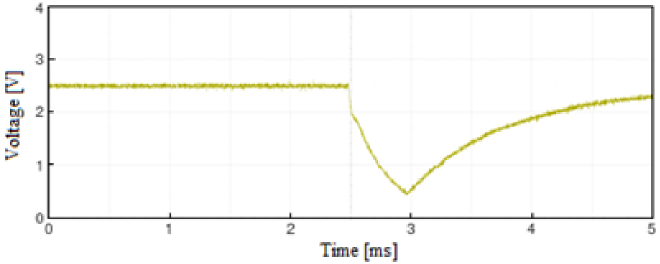
- ❑ Definition of the worst case test conditions
  example from UHE heavy ion test of PoL at CHARM





specific SET signature due to high flux of heavy ions (environmental condition)

+ reduced supply voltage (configuration condition)



= the worst case

Limiting factors of qualification

- Irradiation source issues
  - Particularly for SEE tests:
    - Beam penetration
    - Beam size
    - LET homogeneity
  - Less relevant for TID tests:
    - Co-60 source has high penetration and usually test area size is also accurate for even big systems

Limiting factors of qualification

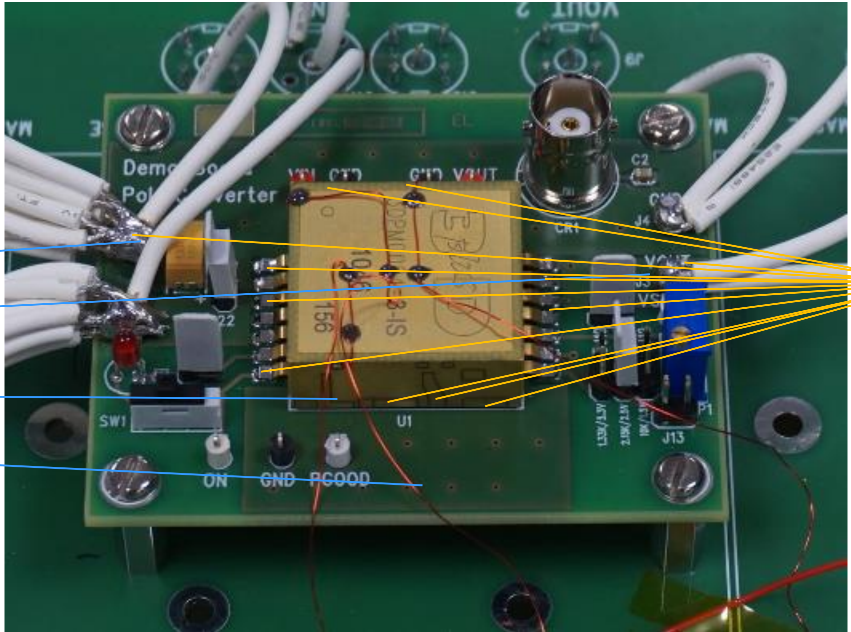
- Observability of parameters
  - Why important?
    - monitoring of events during irradiation
    - assessment of the system health during or after irradiation
    - crucial for tracking of failure root cause in the system
  - Limitations
    - SEE campaigns: in situ/in flux testing
    - mechanical constraints, test setup complexity
    - „white box” vs „black box”

Limiting factors of qualification

❑ Observability of parameters

example from UHE heavy ion test of PoL at CHARM and X-Rays test of PoL at University of Montpellier

heavy ion tests -
4 nodes monitored:
- I_{SUP}
- V_{OUT}
- V_{REF}
- V_{LOOP}



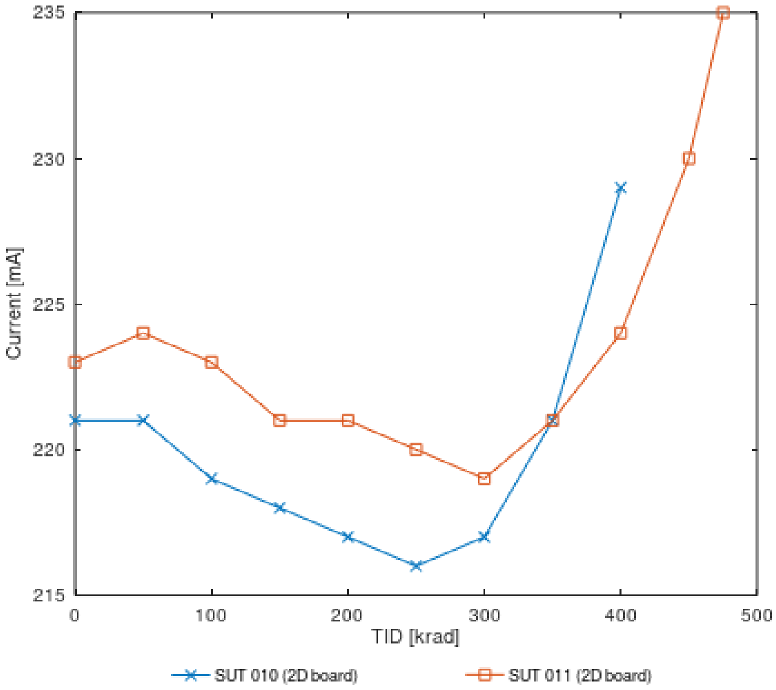
X-Rays tests -
33 nodes
monitored:
I_{SUP}, V_{OUT}, V_{REF}, V_{LOOP}, V_{OUT}, V_{IN_DRIVER}, $V_{PWM\text{-}LATCH}$, I_{SENSE}, V_{BOOST}, $V_{OUT\text{-}COMP}$, $V_{DUTY\text{-}C}$, …

Limiting factors of qualification

- Number of SUT samples to test
  - For the component level tests, the ESCC specifications recommend 11 samples for TID (5 biased, 5 unbiased and 1 control) and 3 samples for SEE (parts from same production lots)
  - For system-level SEE tests, 3 SUT samples are recommended to get information on part-to-part variability
  - each sample should be tested in each relevant configuration (see: worst case definition)
  - For system-level TID tests, 5 SUT samples for each configuration (e.g. bias configuration) should also be sufficient
  - Increasing test fluence or total dose level will increase value of the results obtained for given SUT unit, but will not compensate fully the limited number of test samples and limited statistics

Limiting factors of qualification

- ☐ Number of SUT samples to test
  example of X-Rays test of PoL at University of Montpellier

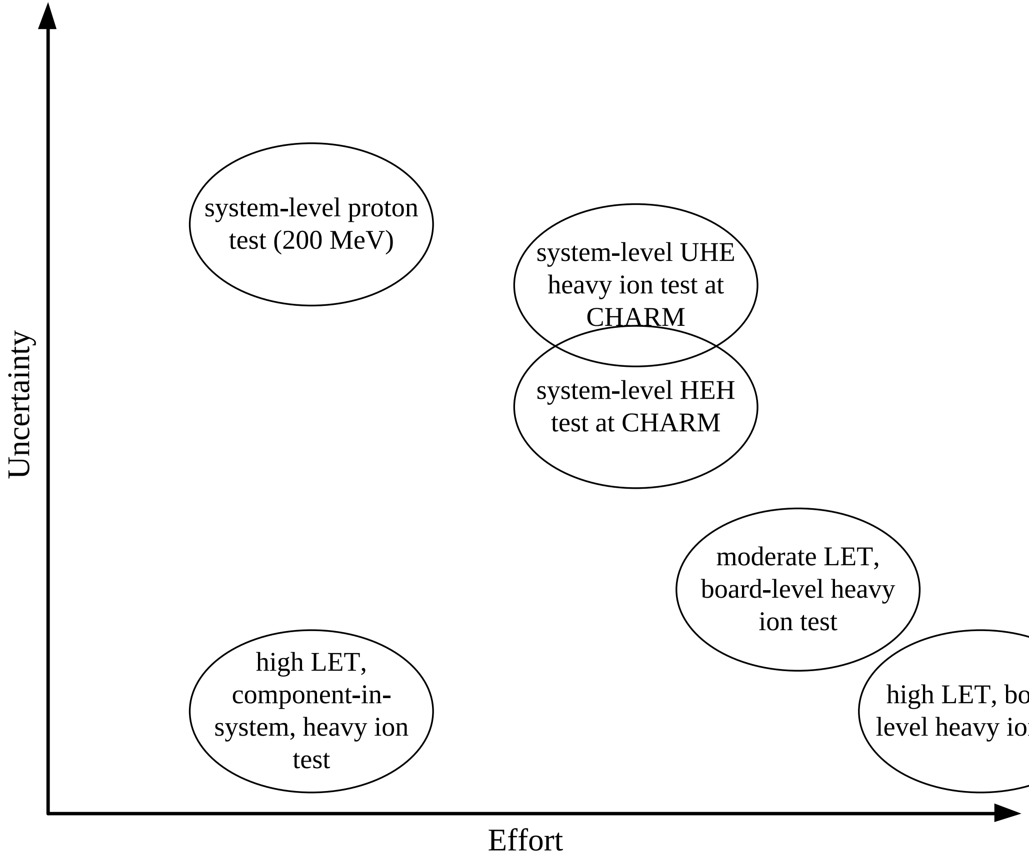


Current consumption subtraction for SUTs: OFF current subtracted from ON current (X-Ray irradiation)

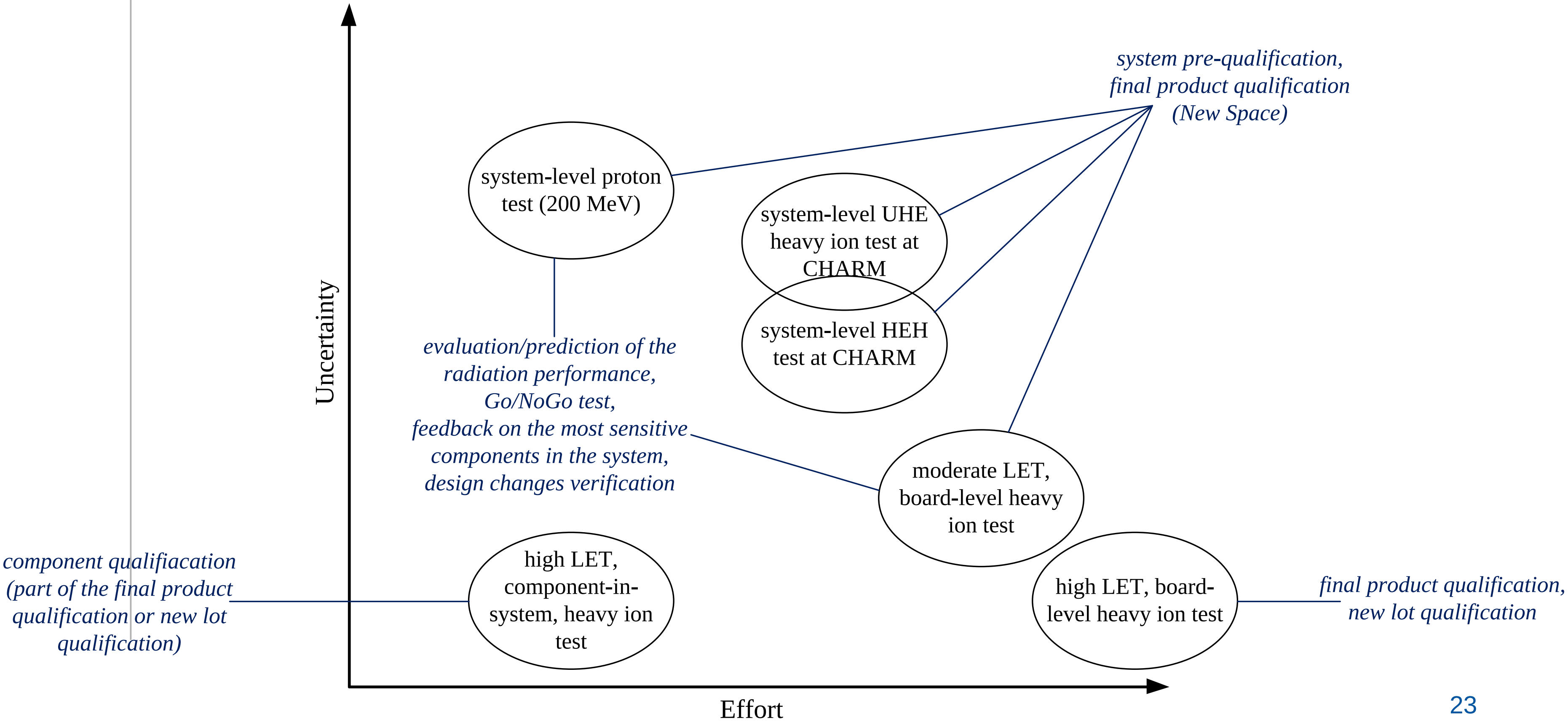
Limited qualification scenarios

- Following test regime that overcomes described limitations, gives high confidence that the system will perform correctly in the target environment
- This confidence comes at the cost of a significant test effort, which may be justified for e.g. final product qualification or for new lot qualification
- On the other hand, there are some applications that may profit from the system-level test approach, but which may have less predictable test outcome – and in these cases the use of complete qualification tests might be not justified
- Limited qualification scenarios for both TID and SEE are proposed and discussed in terms of related test effort and uncertainty of obtained results

Limited qualification scenarios: SEE



Limited qualification scenarios: SEE



Uncertainty

Effort

system-level proton test (200 MeV)

system-level UHE heavy ion test at CHARM

system-level HEH test at CHARM

moderate LET, board-level heavy ion test

high LET, component-in-system, heavy ion test

high LET, board-level heavy ion test

system pre-qualification, final product qualification (New Space)

evaluation/prediction of the radiation performance, Go/NoGo test, feedback on the most sensitive components in the system, design changes verification

component qualifiacation (part of the final product qualification or new lot qualification)

final product qualification, new lot qualification

Conclusions

- Overview of system-level tests of 3D PLUS SiP PoL module was given
- Opportunities given by system-level testing were discussed
- Main opportunities and limitations for the qualification based on the system-level radiation tests were discussed
- Limited qualification scenarios were proposed

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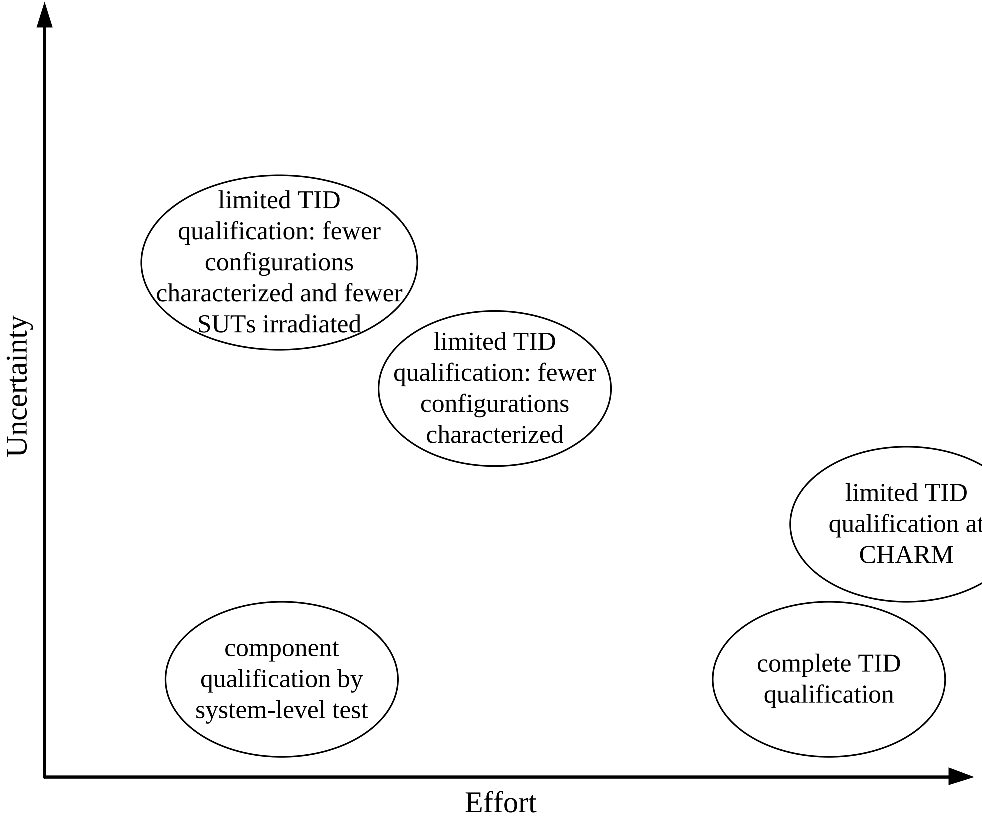
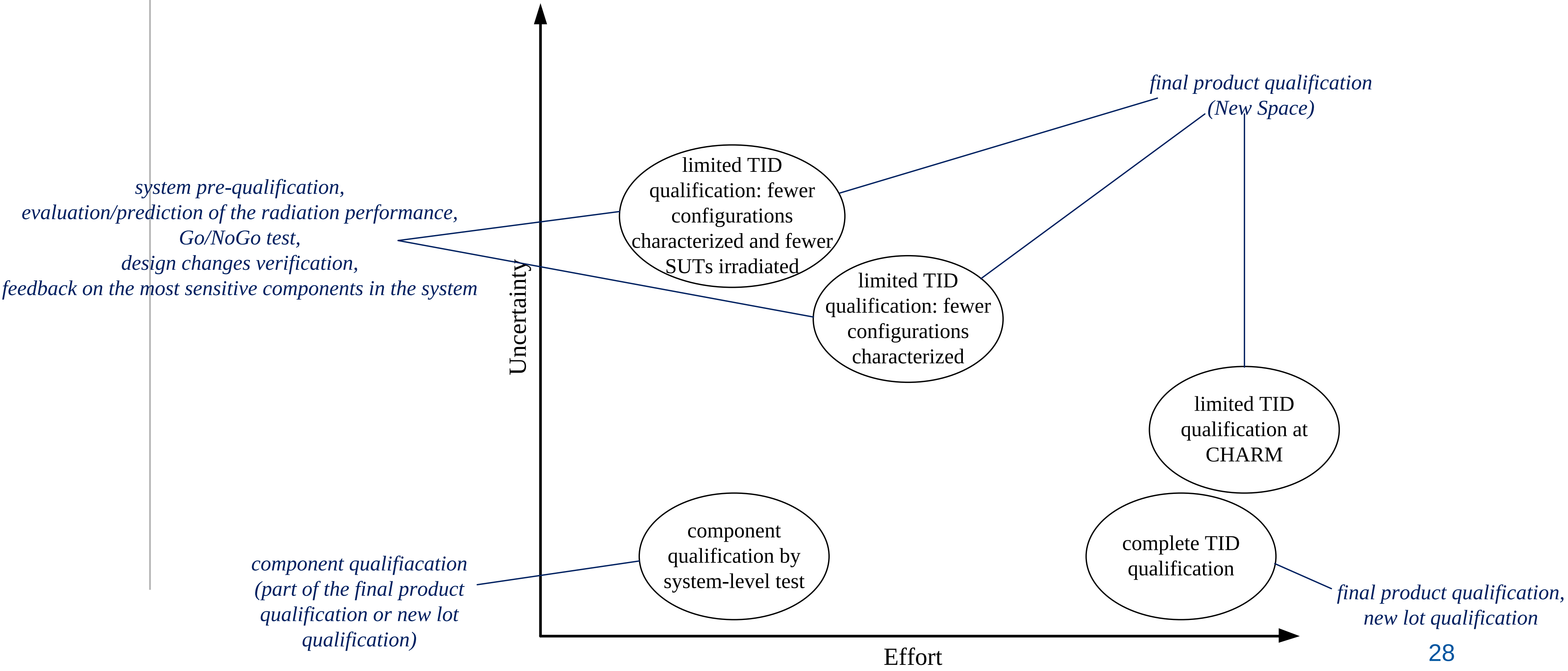
Thank you for your attention!

Backup slides

Limited qualification scenarios: TID



Limited qualification scenarios: TID



final product qualification (New Space)

limited TID qualification: fewer configurations characterized and fewer SUTs irradiated

system pre-qualification,
evaluation/prediction of the radiation performance,
Go/NoGo test,
design changes verification,
feedback on the most sensitive components in the system

limited TID qualification: fewer configurations characterized

limited TID qualification at CHARM

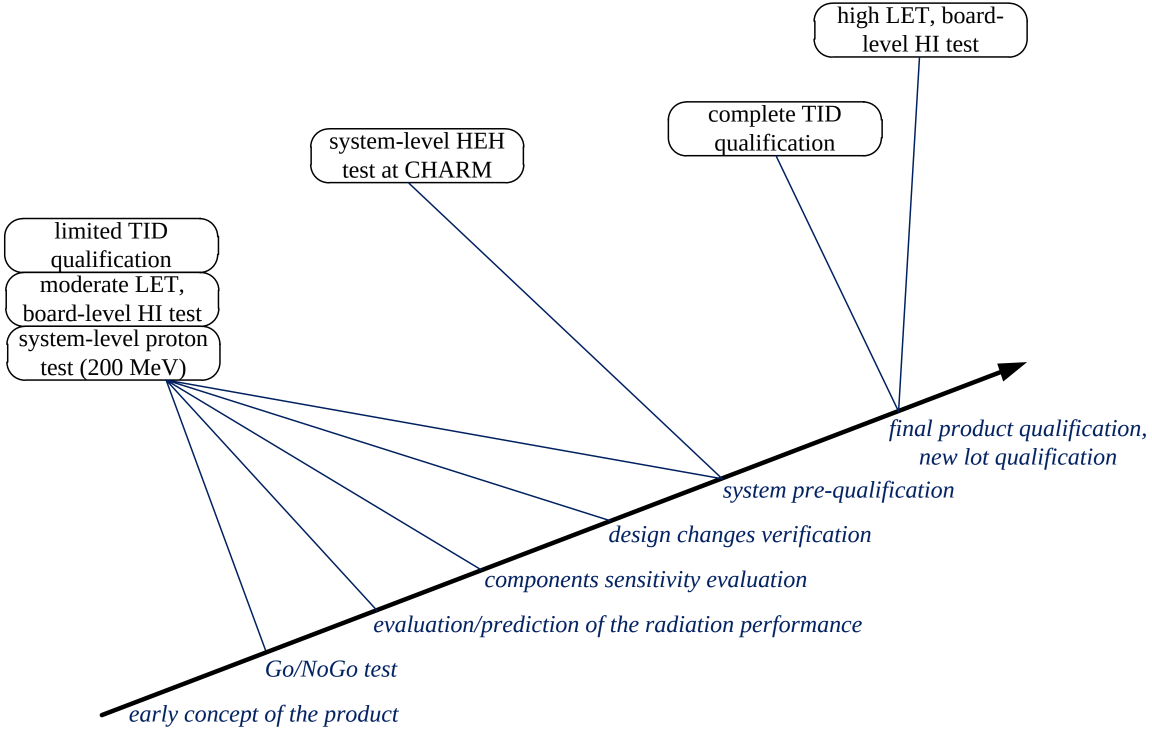
component qualification by system-level test

component qualifiacation (part of the final product qualification or new lot qualification)

complete TID qualification

final product qualification, new lot qualification

Limited qualification scenarios usability for high reliability product development



„Redesign risk” concept

Redesign risk” might be also considered as one of parameters to evaluate attractiveness of system-level limited qualification in the industrial approach

- ❑ we can perform simpler and cheaper limited qualification in the beginning of the product design flow
- ❑ then, the final qualification would be the complete qualification
- ❑ there is a risk of the negative result of qualification – but it might be treated as the risk of the product redesign, not the risk of the mission failure
- ❑ financial attractiveness will depend on the risk evaluation