Developing Electronics for Radiation Environments

Salvatore Danzeca
CERN EN/SMM-RME

CERN | EN ENGINEERING DEPARTMENT

R2E

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Electronics Development for particle Accelerator

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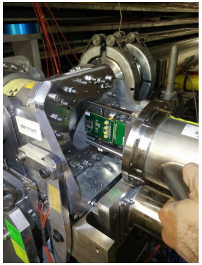

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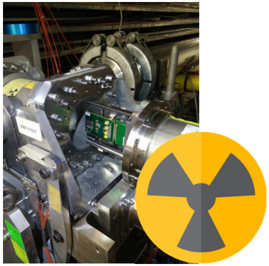
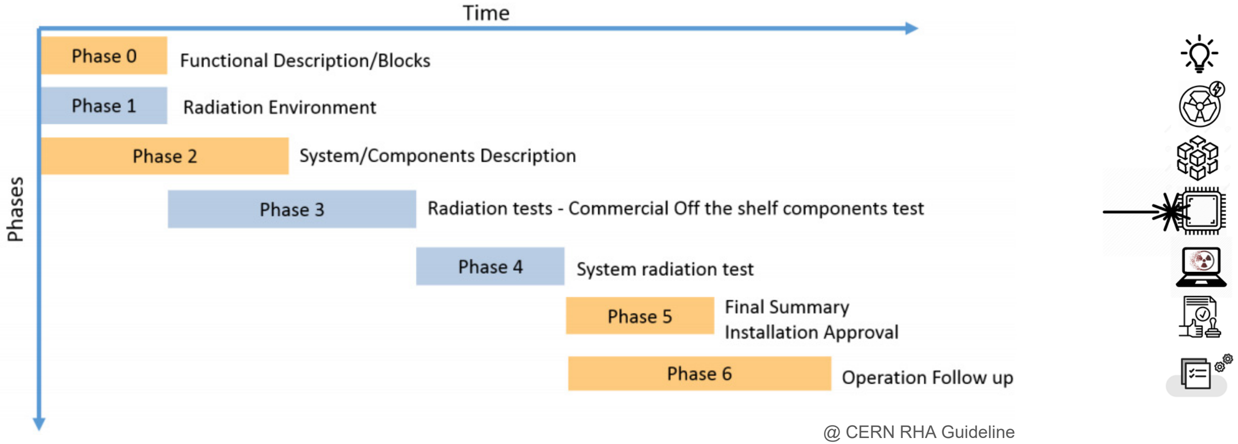


Development process and phasing

From component to system level qualification:



@ CERN RHA Guideline

- **Validation** of radiation tolerance at system level before final production

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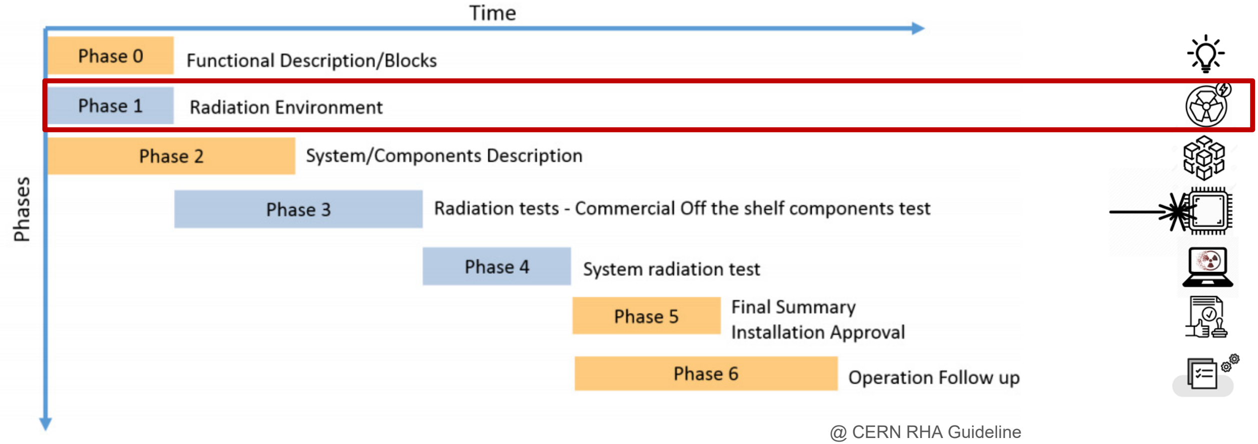

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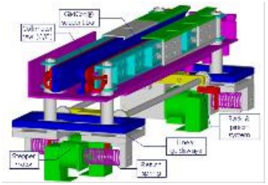
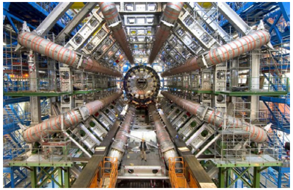
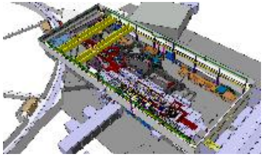
Accelerators: Radiation Sources

- Direct beam Losses
  - collimators and collimator like objects
    injection, extraction, dump
  - levels usually scale with beam intensity & energy
- Beam/Beam, Beam/Target Collisions
  - around experimental areas
  - scale with luminosity/p.o.t. & energy
- Beam-Residual-Gas
  - circular machines: all areas along the ring
  - scales with intensity, residual gas density & energy
- Synchrotron radiation (lepton machines)
- RF (e.g. during conditioning)

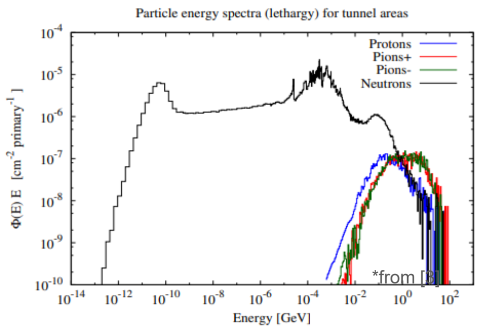






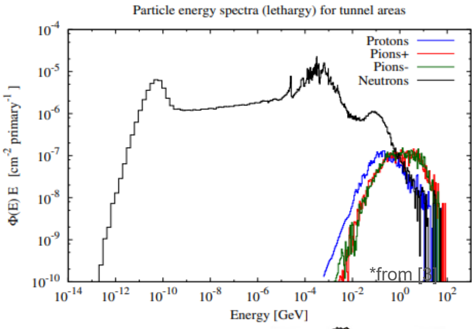
Not all places are the same…

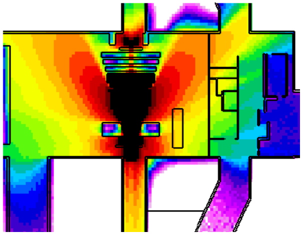
- Radiation environments
  - Energies + Type of particle + Levels -> Effects



Not all places are the same…

- Radiation environments
  - Energies + Type of particle + Levels -> Effects
- How to scale up for an electronic development that has to work for X years?
  - Identification of the scaling parameters
  - Simulations
  - Radiation measurements (meaningful quantities for the effects on the electronics)
- Radiation Design Margin
  - Until which radiation levels to test the components





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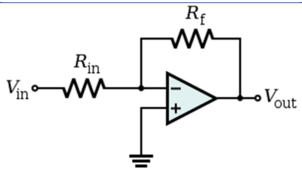
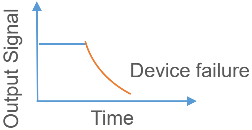
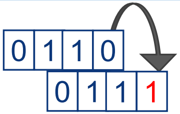
Radiation effects a (very) short summary

- **Cumulative Effects**
  - **Total Ionizing Dose**
  - **Displacement damage**

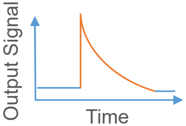




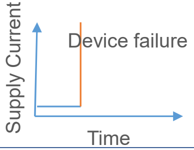
The SI unit of **DOSE** is the (Gy): 1 Gy = 1 J/kg
The unit used for the Displacement Damage is the Displacement Damage Equivalent Fluence DDEF: 1MeV eq n/cm2



Single Event Upset



Single Event Transient



Single Event Latch-up (SEL)

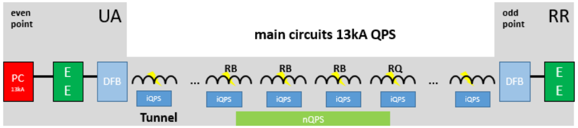
- **Single Event Effects (SEEs):**
  - **Stochastic/random events**
  - **Soft events: non destructive (SEU,SET)**
  - **Hard events: destructive (SEL,SEB)**

The SEEs are proportional to the **HEH** (>20MeV) fluence. The fluence unit is particles/cm^2

Parameters to be considered

- SEE cross section and impact on N devices

$$\sigma = \frac{N_{SEE}}{fluence}$$



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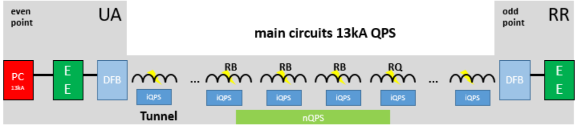

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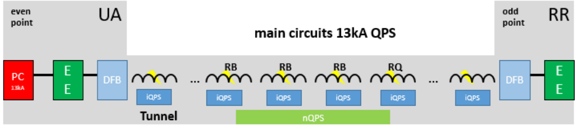
  - The cross section is function of the energy
  - Testing become more complex



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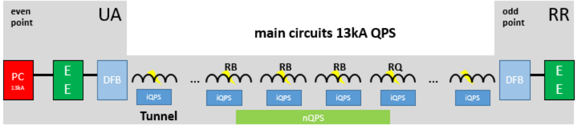

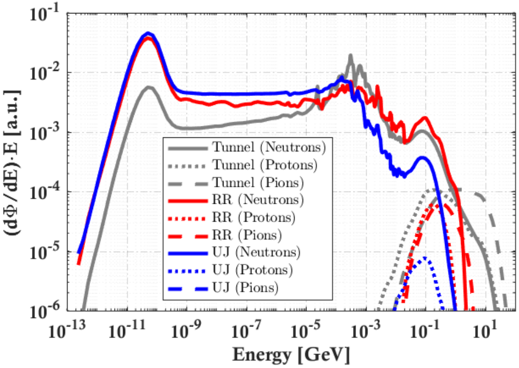

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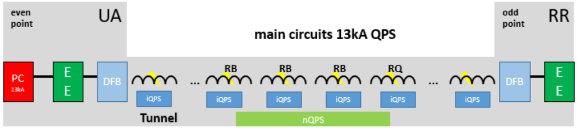
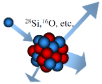
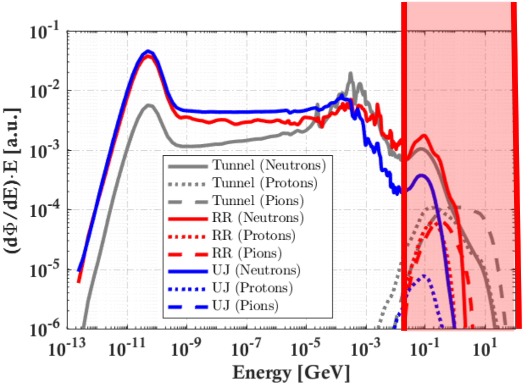




Inelastic interactions:
n+^{28}Si→^{25}Mg+α
→ ^{28}Al+p
→ ^{27}Al+d
→^{24}Mg+n+α
→^{26}Mg+^{3}He
+p/n/π/etc.->Cu/W/Hf,…



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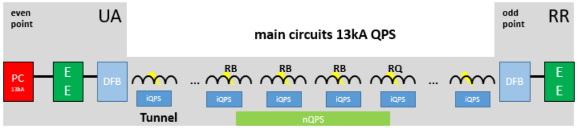

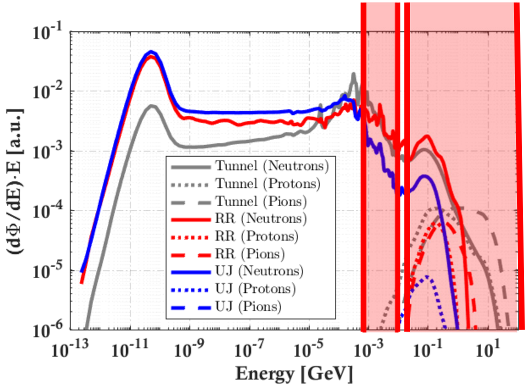

Low energy charged hadrons: direct ionization (relevant for very sensitive technologies)

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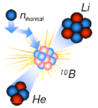
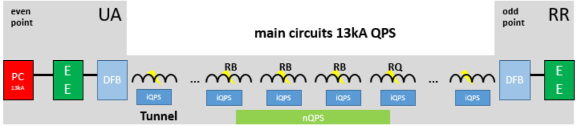
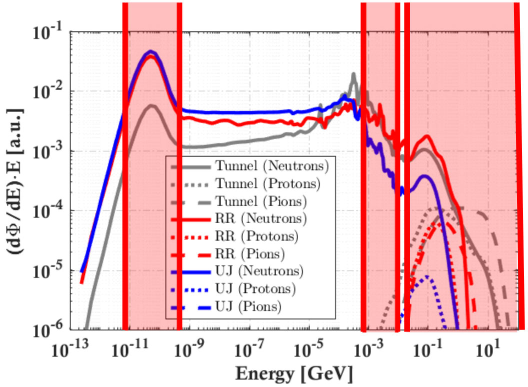


Thermal neutrons:
$n + {}^{10}B \rightarrow {}^{7}Li + {}^{4}He$





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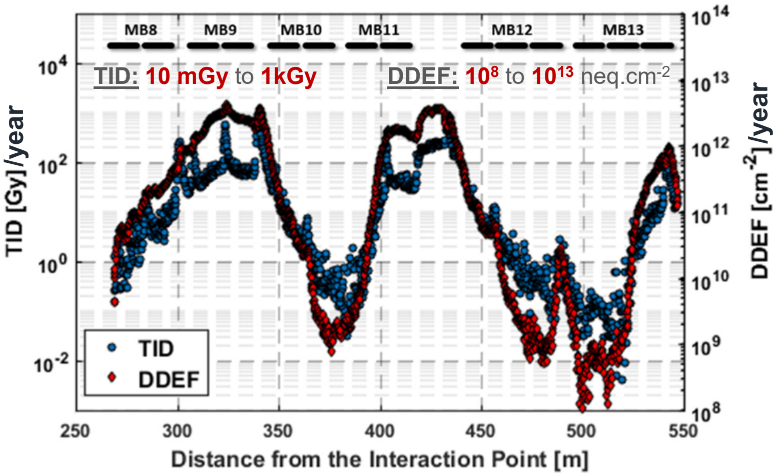

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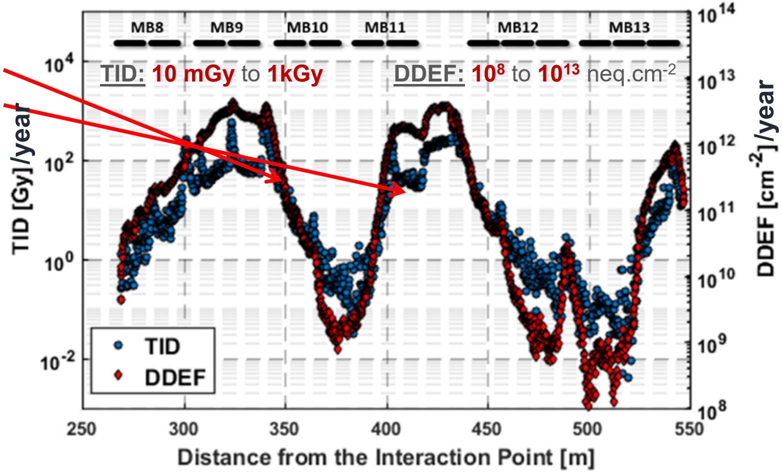

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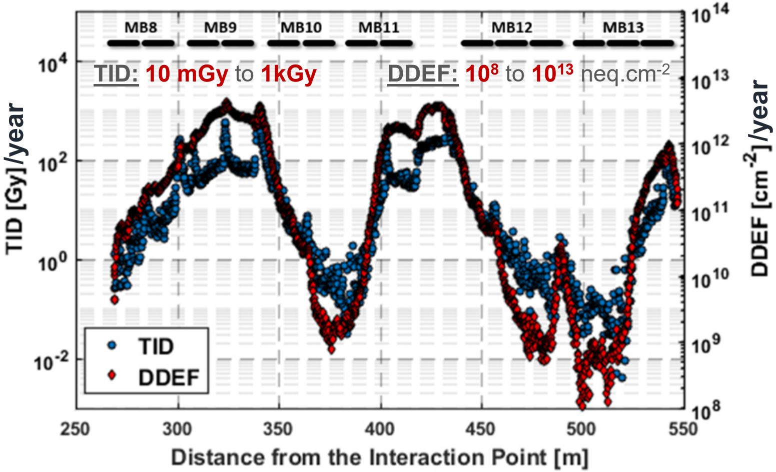
X 20 !



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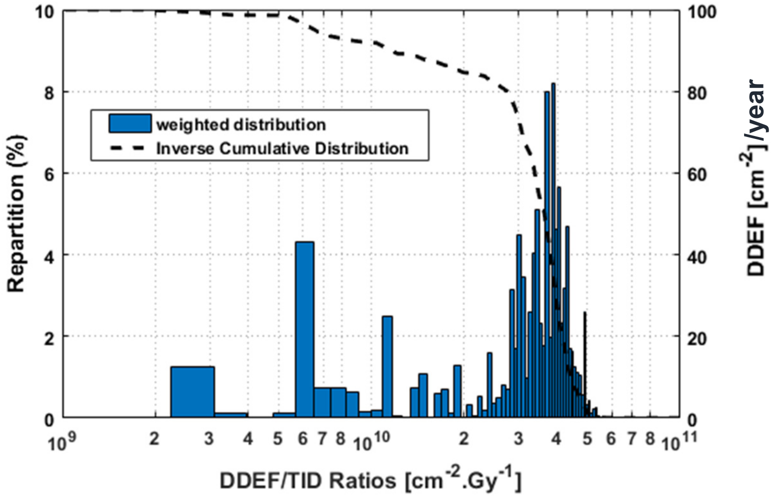
- Wide variety of **DDEF/TID Ratio**:

  → From **10^9** up to **10^{11} neq.(Si)cm^{-2}.Gy^{-1}**

  → A system/part can be exposed up to 100 times more DD for the same TID depending on location



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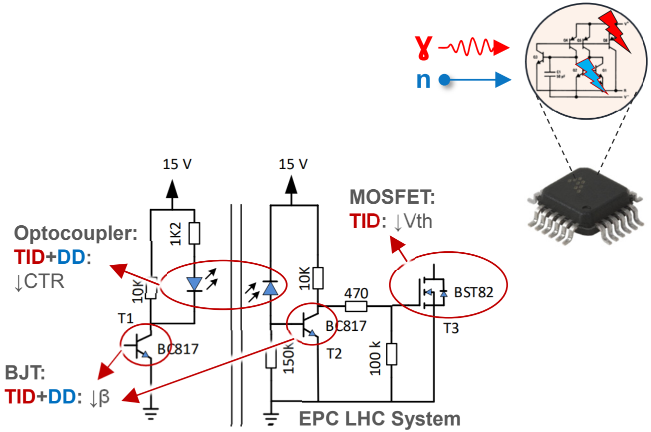

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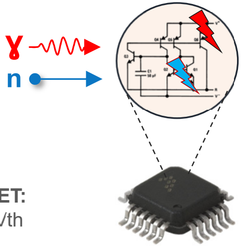

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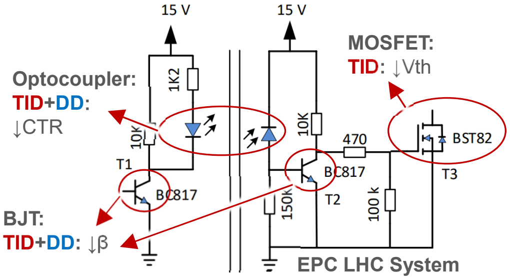

- Not always possible to decouple TID/DD effects:
  - **Parts:** Optoelectronic/bipolar (Synergistic effects), ICs (lack of information on internal circuits)

→ Testing in realistic DD/TID ratios is critical to have representative degradation profiles

References

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Development process and phasing

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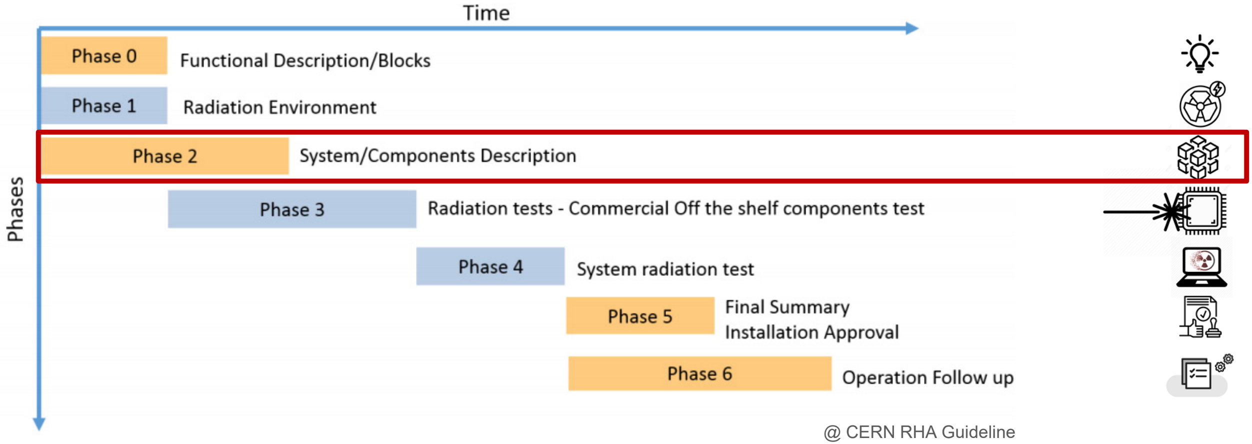


@ CERN RHA Guideline

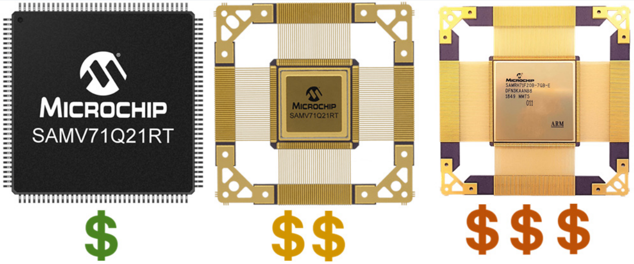
Criticality

- “**Criticality analysis** is defined as the process of assigning assets a criticality rating based on their potential risk of failure.”
- A severity classification to each identified failure mode analyzed according to the failure effect (consequence)
  - Ex : Machine protection system, missing interlocking -> **Level 1**
  - Ex : Pick-up amplifiers for transverse feedback BPM, complete malfuncitoning -> **Level 2** (Without them no intensity rump up)
  - Ex : Monitoring of the vibration of the tunnel, not logging : Level 4

Severity	Level	Dependability	Consequences
Catastrophic	1		
Critical	2		
Major	3		
Minor or Negligible	4		

Design choice – Radiation Tolerance

- Which components to use for the system?
  - Radiation Hard
  - Radiation Tolerant
  - Commercial Off The Shelf (COTS)



- Radiation hard:
  - Radiation hardened electronics is the electronics that have been developed, packaged, and sold to provide some level of protection against radiation in a **particular environment**
  - Rad Hard for space: Ceramic package - Fault Tolerance by Design - qualified process technology - mitigation techniques at design level – Radiation Performance: SEL immune up to xx Mev.cm2/mg TID up to yy Krad (Si).
- Radiation Tolerant
  - Rad Tol for space: Ceramic & Hermetic packages, extended temperature range -55C to 125C, extended qualification flow equivalent to QML-V or QML-Q space grade. Radiation performance: SEL LET > xx MeV.cm2/mg, and TID up to yy Krad (Si).
- COTS
  - Plastic packages, industrial and automotive grade

COTS Radiation tolerant

- In the 1999 P. Jarron defined a COTS Radiation tolerant as “a standard component which has by chance a good robustness against radiation effects”
- Implies: Radiation testing
- COTS RadTol are the main choice for distributed systems with hundreds/thousands devices in radiation environment
  - Higher performances compared to the RadHard
  - Cost effective
  - Lead time

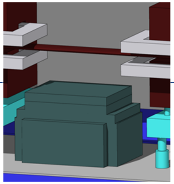
Selection and Testing

- Testing of all components can be a long process
- Minimize the risks: USE Radiation Data
  - CERN: https://radwg.web.cern.ch/
  - ESA : ESCIES
  - IEEE Radiation Effects Data Workshop
  - NASA: RADHOME and NEPP
- Three main strategies:
  1. select unknown COTS and test
  2. test again previously selected COTS
  3. select & accept COTS with existing radiation data
- Lot qualification?
  - For critical applications: all the lots should be qualified (include strategy 1 and 2)

Mitigations

- Is it possible to shield the electronics?
- Impact:
  - Economical
  - Spatial
  - Accessibility
  - Operational (if put in place late)
  - Radiation effects still to be considered (in particular SEE)
- Some examples

Mitigations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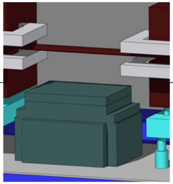
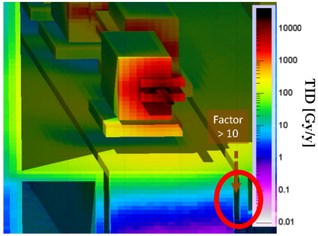
  - Ex: Cast Iron Shielding to increase amplifier lifetime in PS

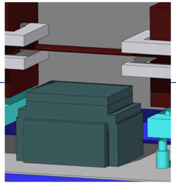
Mitigations

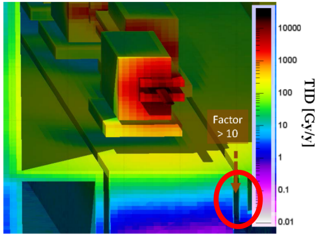

- Is it possible to shield the electronics?
- Impact:
  - Economical
  - Spatial
  - Accessibility
  - Operational (if put in place late)
  - Radiation effects still to be considered (in particular SEE)
- Some examples
  - Ex: Cast Iron Shielding to increase amplifier lifetime in PS
  - Ex (more exotic): BPM electronics at the PS complex



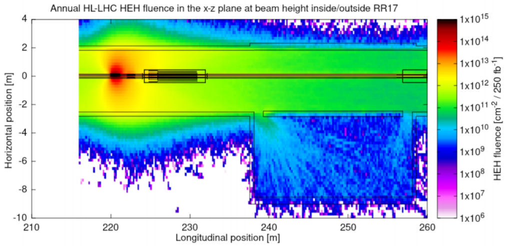
Mitigations


- Is it possible to shield the electronics?
- Impact:
  - Economical
  - Spatial
  - Accessibility
  - Operational (if put in place late)
  - Radiation effects still to be considered (in particular SEE)

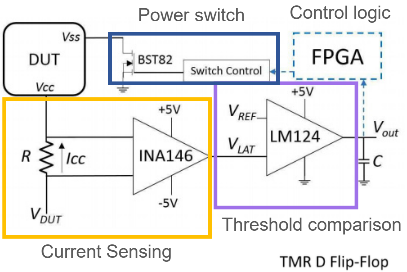


- Some examples
  - Ex: Cast Iron Shielding to increase amplifier lifetime in PS
  - Ex (more exotic): BPM electronics at the PS complex
  - Ex: LHC RR and UJ

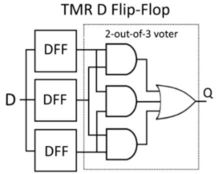


Improve the reliability: Mitigation

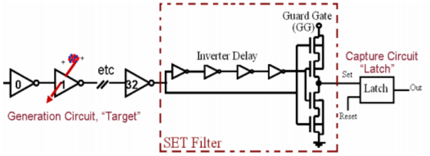
- SEL latch-up circuit and automatic reset



- SEU mitigation with Triple Modular Redundancy



- SET filtering



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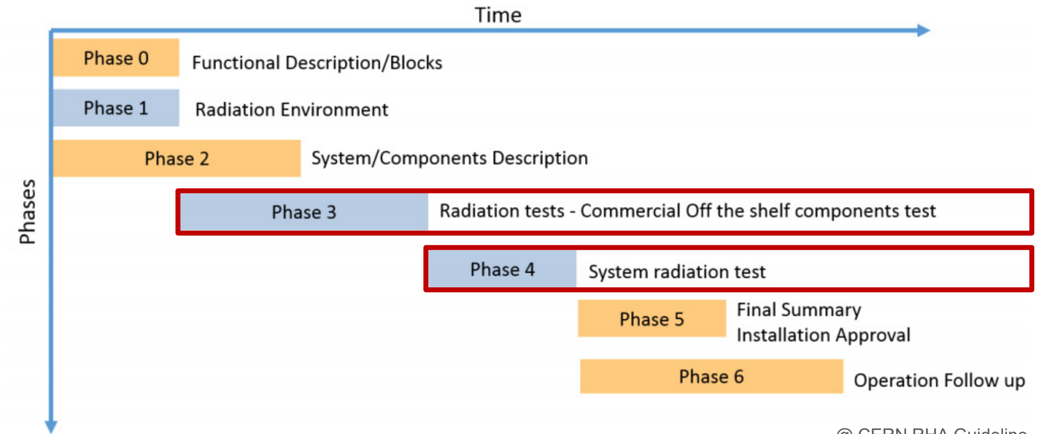
- [5] R. Secondo, “Upgrades of the RadMon V6 and its Integration on a Nanosatellite for the Analysis and the Comparative Study of the CHARM and Low Earth Orbit Environments,” *CERN Document Server*, Jul. 28, 2017. https://cds.cern.ch/record/2276097 (accessed Aug. 31, 2020).

Development process and phasing

From component to system level qualification:



@ CERN RHA Guideline

Component level tests:
- **TID:** Gamma (Co_{60})
- **DD:** Neutrons
- **SEE+TID+DD:** Protons
- **SEE:** Thermal neutrons
- **SEL:** Protons and Heavy Ions

System level tests
- **SEE+TID+DD:** Mixed-Field

Relevant Facilities

Conclusion

- Knowledge of the radiation environment is fundamental for any development
  - Radiation Design Margin
- Radiation effects are strongly dependent on the environment
  - Radiation testing methodology
- System development and components selection should be done considering:
  - Criticality
  - Number of systems to be deployed
- COTS Rad Tolerant are the main used but this implies
  - Radiation testing
  - Use of radiation data
  - Strategy for procurement and qualification
- Mitigations are possible: physical (shielding) and hardware
- Qualification of components and system should be done in relevant facilities

Thank you for your attention!

Many thanks to R.G.Alia, R.Ferraro and all the RME section