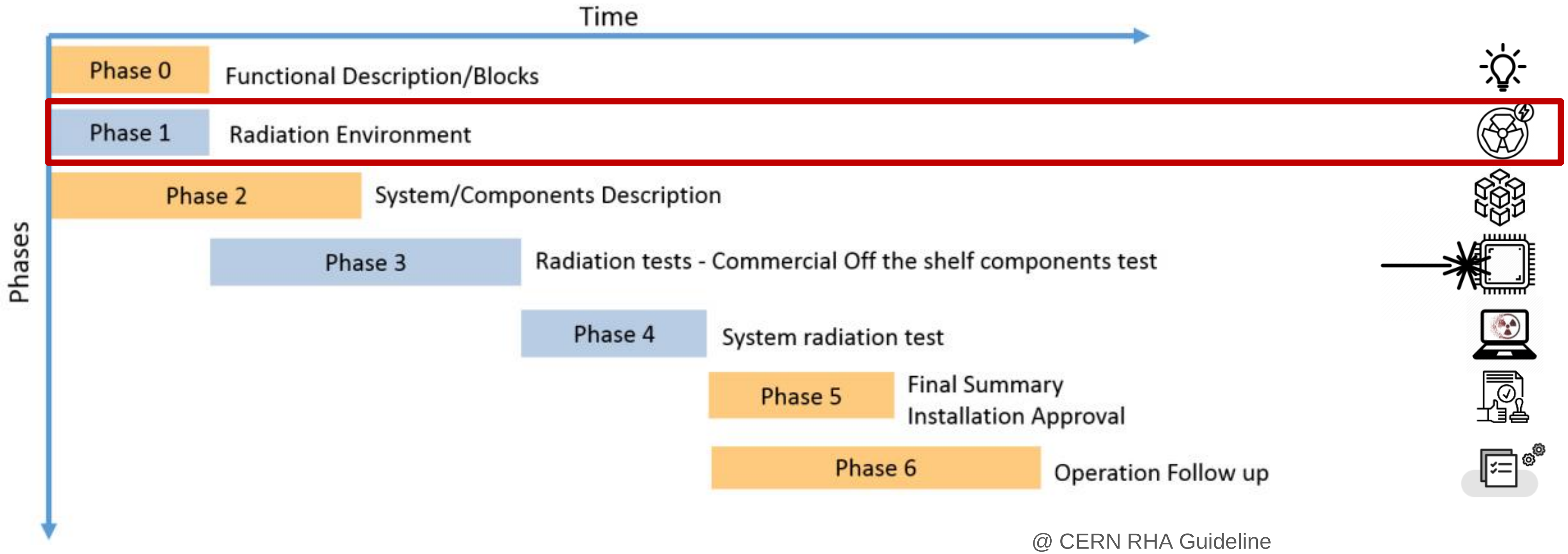
Developing Electronics for Radiation Environments

Salvatore Danzeca
CERN BE/CEM-EPR

Controls
Electronics &
Mechatronics

Electronic Development process and phasing

From component to system level qualification:

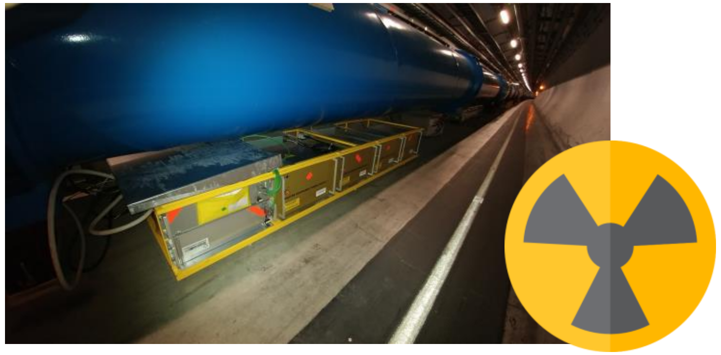


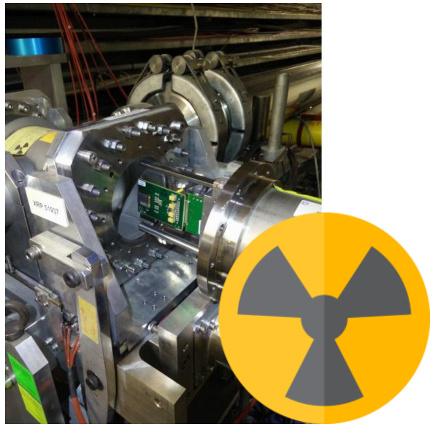
@ CERN RHA Guideline

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

Electronics Development for particle Accelerator

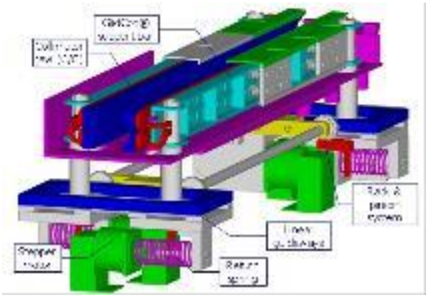
- Every particle accelerator needs electronics to be functional
- Electronics can be found in the control rooms
- Electronics can be found in the service galleries
- Electronics can be found close to the beam pipe
- Electronics can be found inside the beam pipe

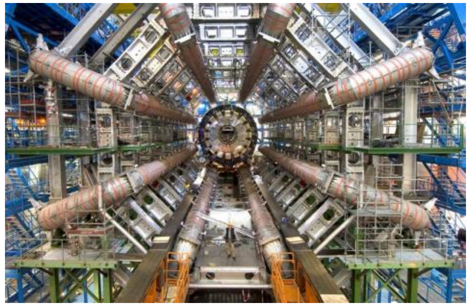


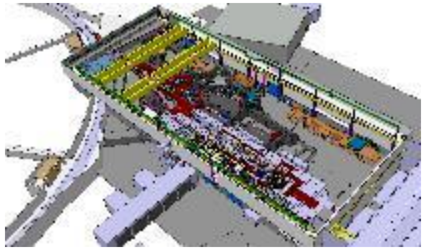


Accelerators: Radiation Sources

- 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)

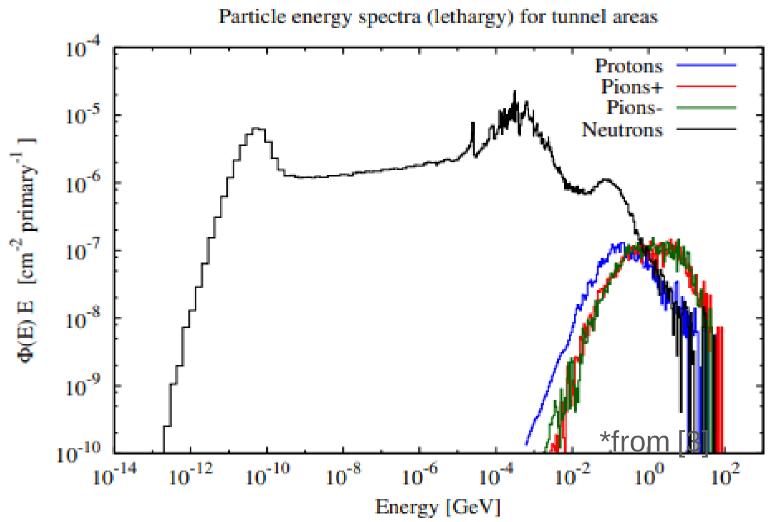


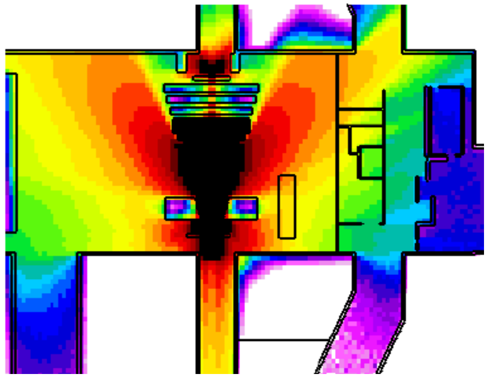




Not all places are the same…

- 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
  - How to test: facilities, representative environments



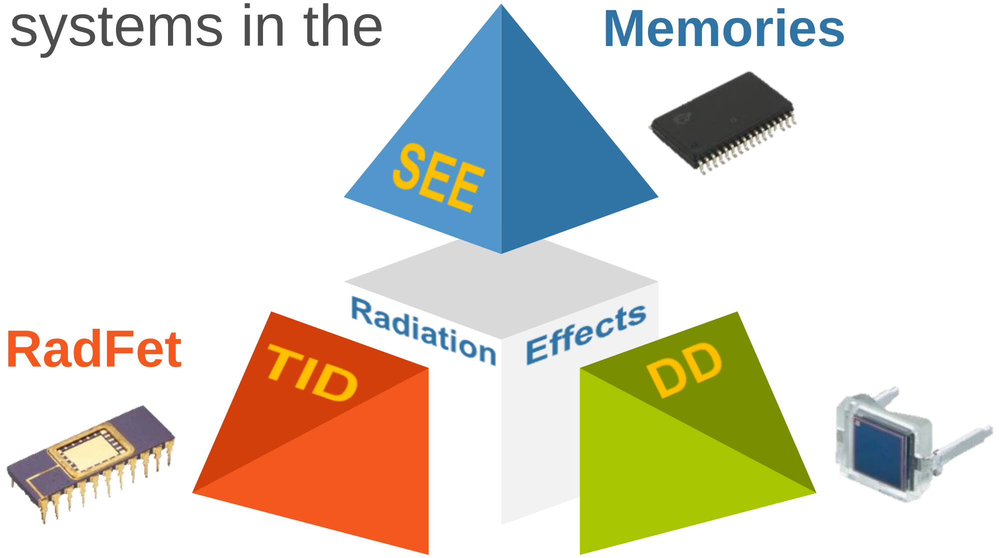


RadMon, an R2E instrument

Radiation tolerant full custom measurement system:

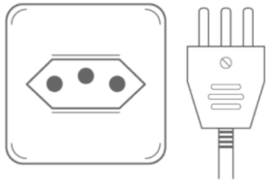
measures the **Total Ionizing Dose**, the **Displacement Damage** and the **High Energy Hadron Fluence** in order to:

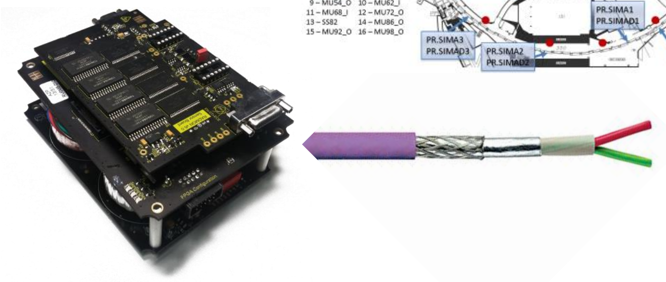
- Monitor the radiation levels on the electronics systems in the accelerators
- Anticipate the electronics degradation
- Investigate the cause of failures
- Simulation benchmarking

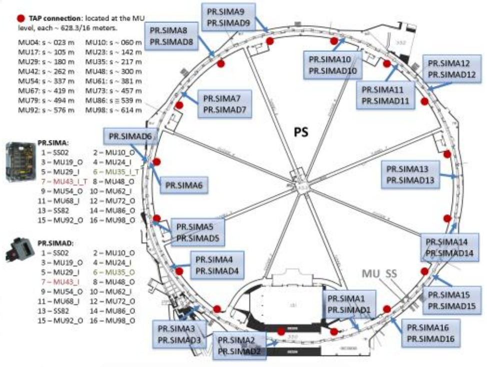


RadMon

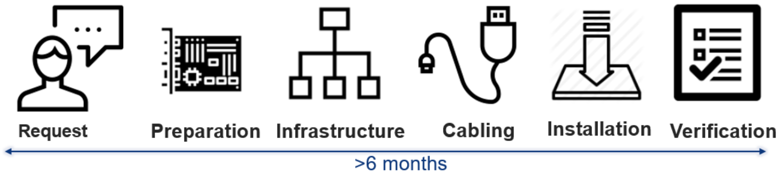
- **500 devices** are installed at CERN in different locations
  - **1 cable** for the communication (WorldFip)
  - **1 cable** for the power (230V)
- Fully integrated in the CERN infrastructure
  - 1 FEC (PC) to manage up to 32 devices
- Installed devices are **fixed** with limited movement possibilities





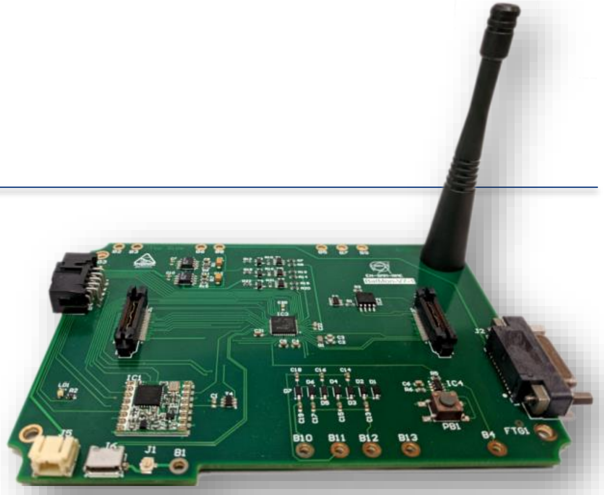


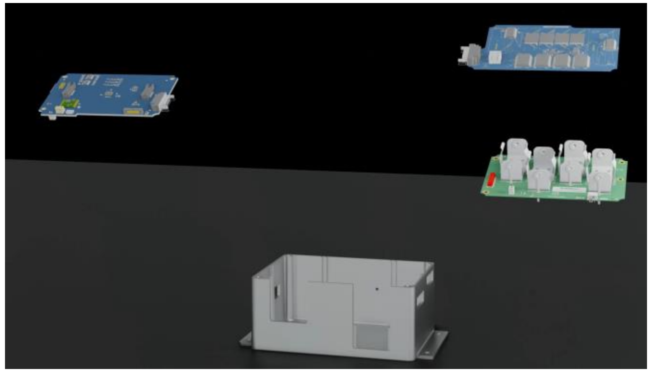
- **In operation**: users request measurements in locations where the RadMons are not installed
  - Requests arrive few days before the technical stops
  - Cables pulling and extensions are not an option during technical stops
  - Deployment of tens of devices in different locations is not feasible in a couple of days



.. IoT Radiation Monitor: IoTRadMON

- IoT Radiation Monitor:
  - Monitor and control radiation sensors
  - Low power : Battery powered
  - Reliable under radiation
  - Wireless communication over km range using LoRaWAN
    - Fully LoRaWan compliant
    - User configurable transmission time
  - In case of LoraWAN unavailability on-board FLASH storage is used
  - Modular architecture to host several type of sensors





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- [1] M. Brugger , “Radiation Damage to Electronics at the LHC,” *Conf.Proc.*, vol. C1205201, pp. 3734–3736, 2012.
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- [4] “Radiation effects in the LHC experiments and impact on operation and performance,” *Indico*. https://indico.cern.ch/event/769192/ (accessed Aug. 19, 2020).
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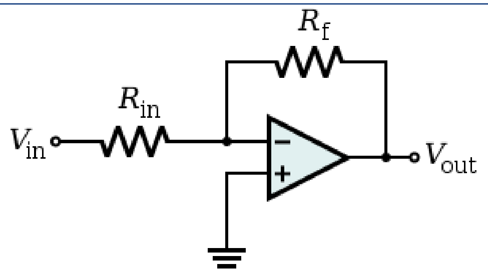
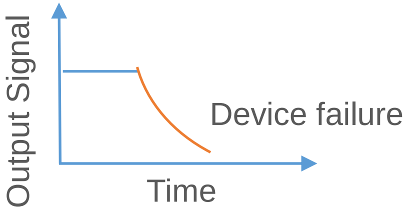
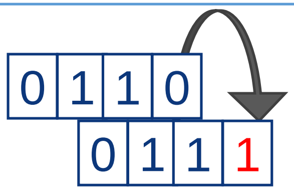
Radiation effects a (very) short summary

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

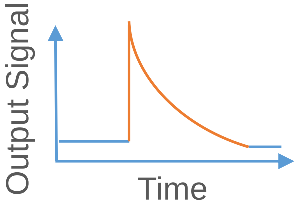




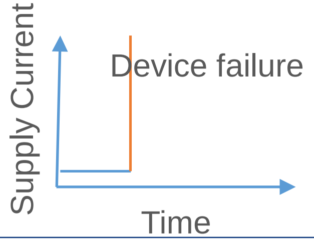
The SI unit of **DOSE** is the (Gy): 1 Gy = 1 J/kg
The unit used for the Displacement Damage is the Displacement Damage Equivalent Fluence DDEF: 1MeV eq n/cm2



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

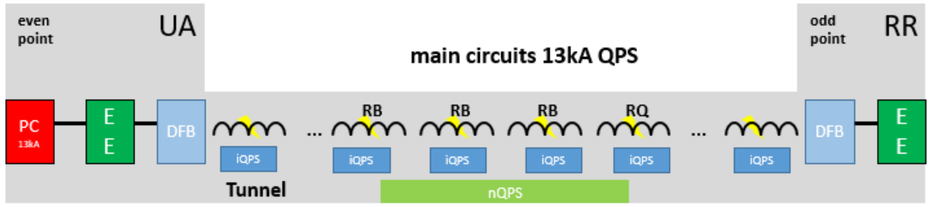
Parameters to be considered

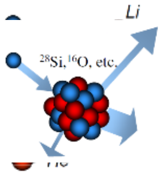
- SEE cross section and impact on N devices

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

$$N_{Failure} = \mathbf{N_{devices}} * \sigma * fluence$$

- SEE sensitivity as function of the spectra
  - The cross section is function of the energy
  - Testing become more complex

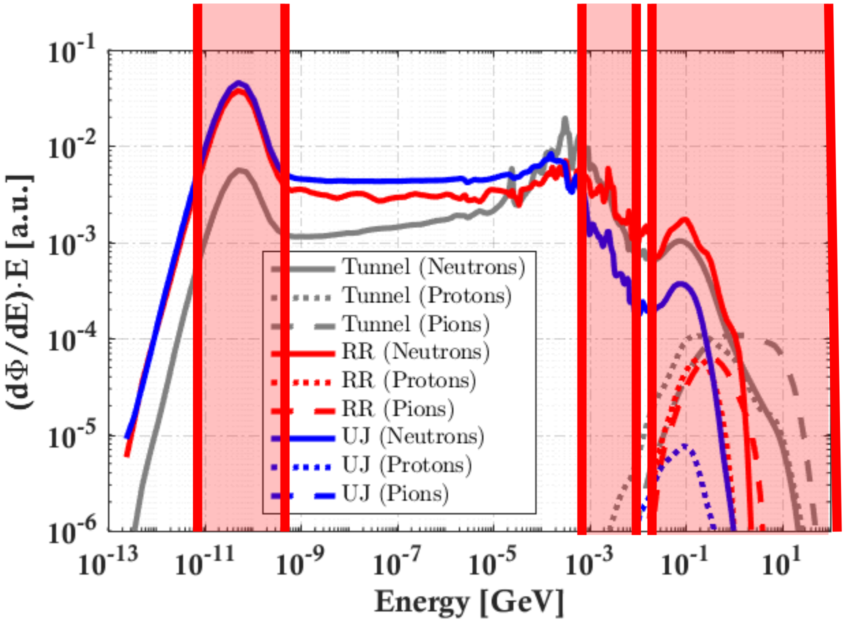




Inelastic interactions:
$n+^{28}Si \rightarrow ^{25}Mg+\alpha$
$\rightarrow ^{28}Al+p$
$\rightarrow ^{27}Al+d$
$\rightarrow ^{24}Mg+n+\alpha$
$\rightarrow ^{26}Mg+^{3}He$
$+p/n/\pi/etc. \rightarrow Cu/W/Hf,…$

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

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



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- [3] M. Cecchetto, “Impact of thermal and intermediate energy neutrons on the semiconductor memories for the CERN accelerators,” *CERN Document Server*, Sep. 04, 2017. https://cds.cern.ch/record/2282268 (accessed Aug. 25, 2020).
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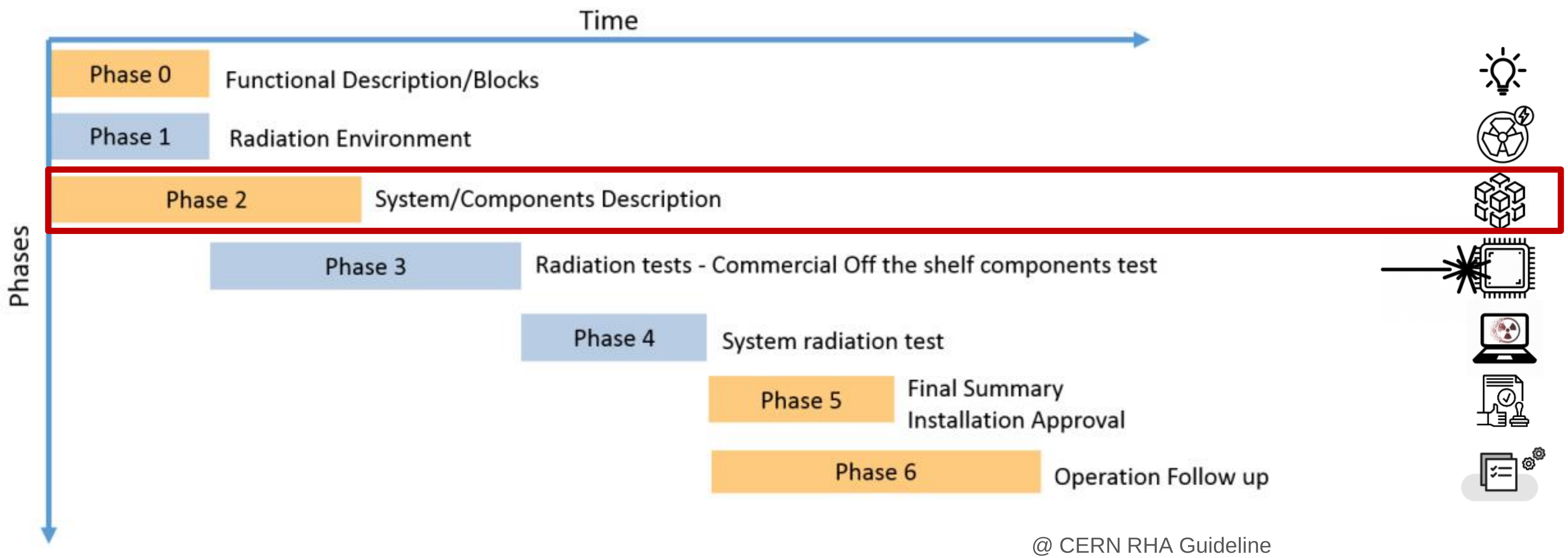
Development process and phasing

From component to system level qualification:



@ CERN RHA Guideline

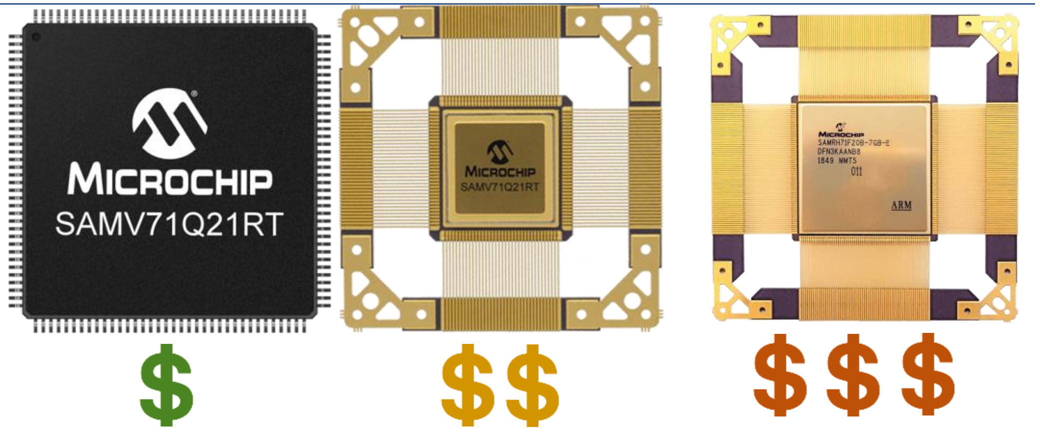
Criticality

- “**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 : Commercial Off The Shelf components
  - Plastic packages, industrial and automotive grade

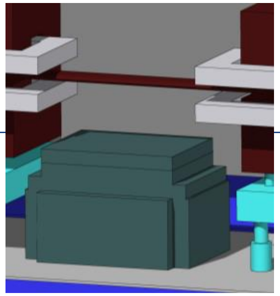
COTS Radiation tolerant

- 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

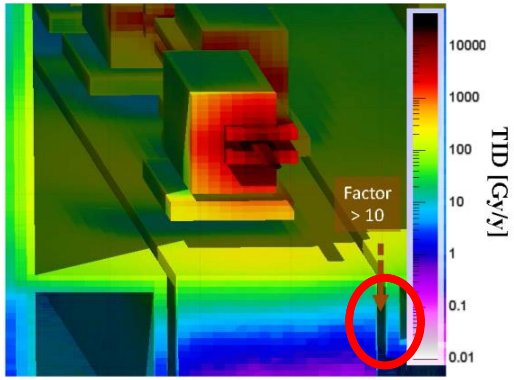
Selection and Testing

- 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)

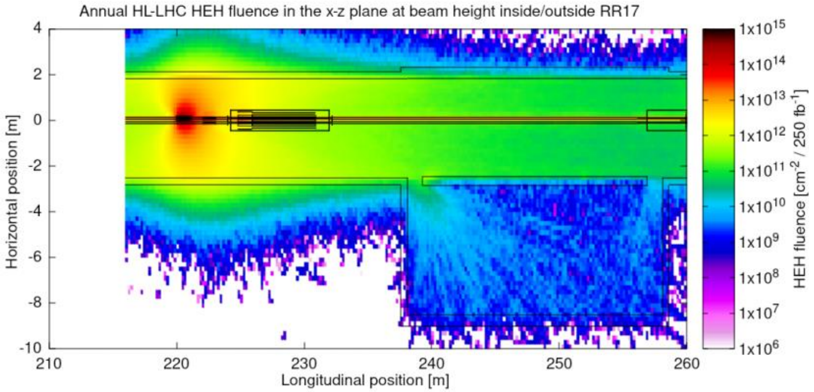
Mitigations



- 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)

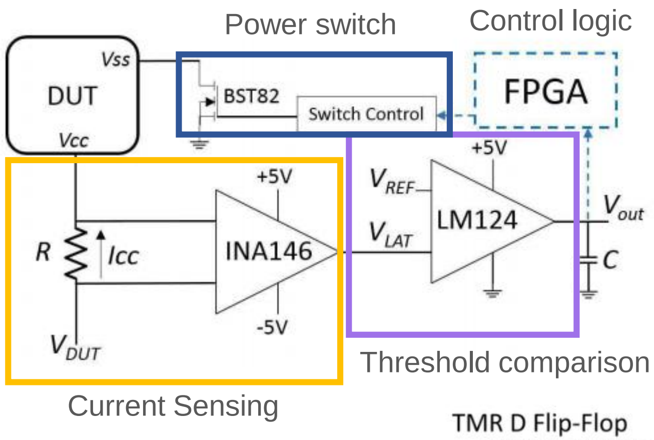


- Some examples
  - Ex: Cast Iron Shielding to increase amplifier lifetime in PS
  - Ex (more exotic): BPM electronics at the PS complex
  - Ex: LHC RR and UJ

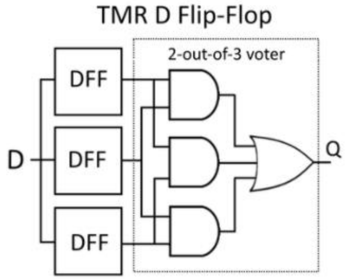


Improve the reliability: Mitigation

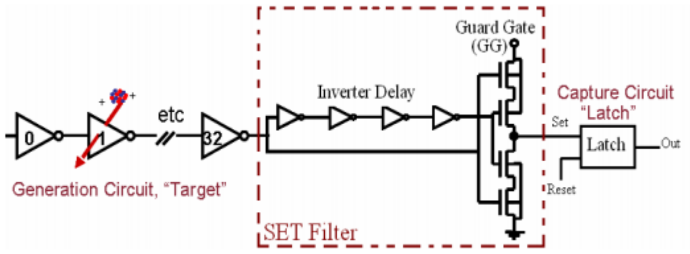
- SEL latch-up circuit and automatic reset



- SEU mitigation with Triple Modular Redundancy



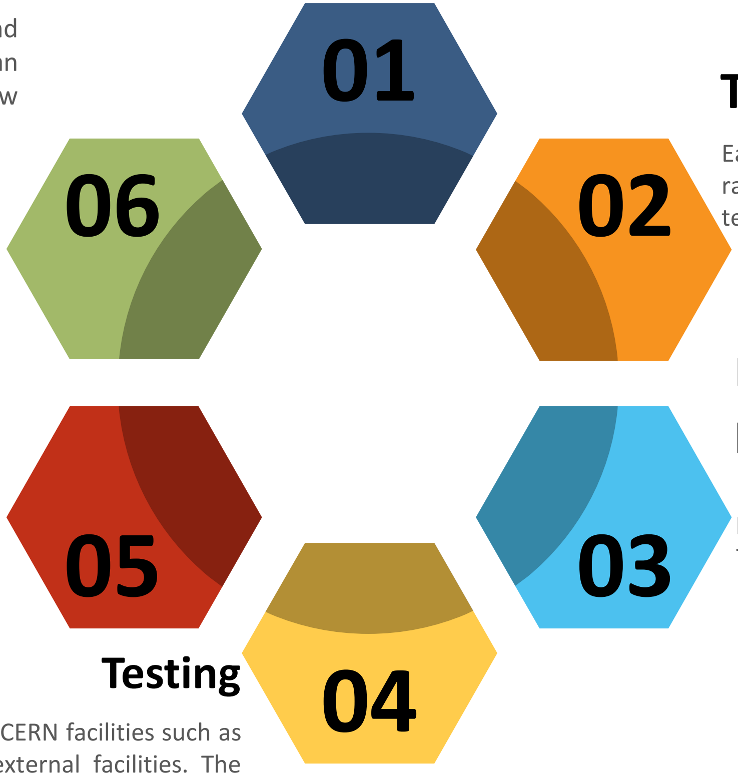
- SET filtering



BE-CEM-EPR Radiation test service

Request collection

The requests for radiation testing are collected and processed selecting the most suitable methodology and facilities

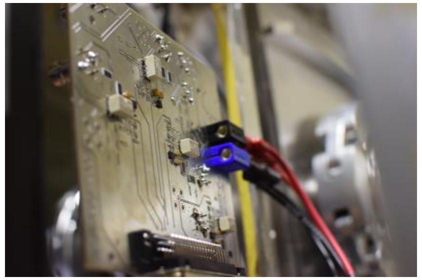


Test planning and structure

Each component/system is analyzed, and all the possible radiation effects are taken into account for planning the test and structure it

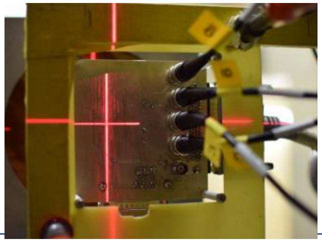
Board and instrumentation preparation

For each component a dedicated set of test board is prepared and the associated instrumentation is chosen to face the complexity of the radiation test



Testing

The test are carried out at CERN facilities such as CHARM or Co60 and in external facilities. The transport, personnel and instrumentation are selected considering the peculiar aspect of each facility



Result analysis

The results are analyzed during and after the tests for each component considering the end application and the possible operational issues

Database and Publication

The results are collected, stored and in EDMS and published in the RADWG database to allow an easy research of the best candidates for the new radiation tolerant des

EDMS

References

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Development process and phasing

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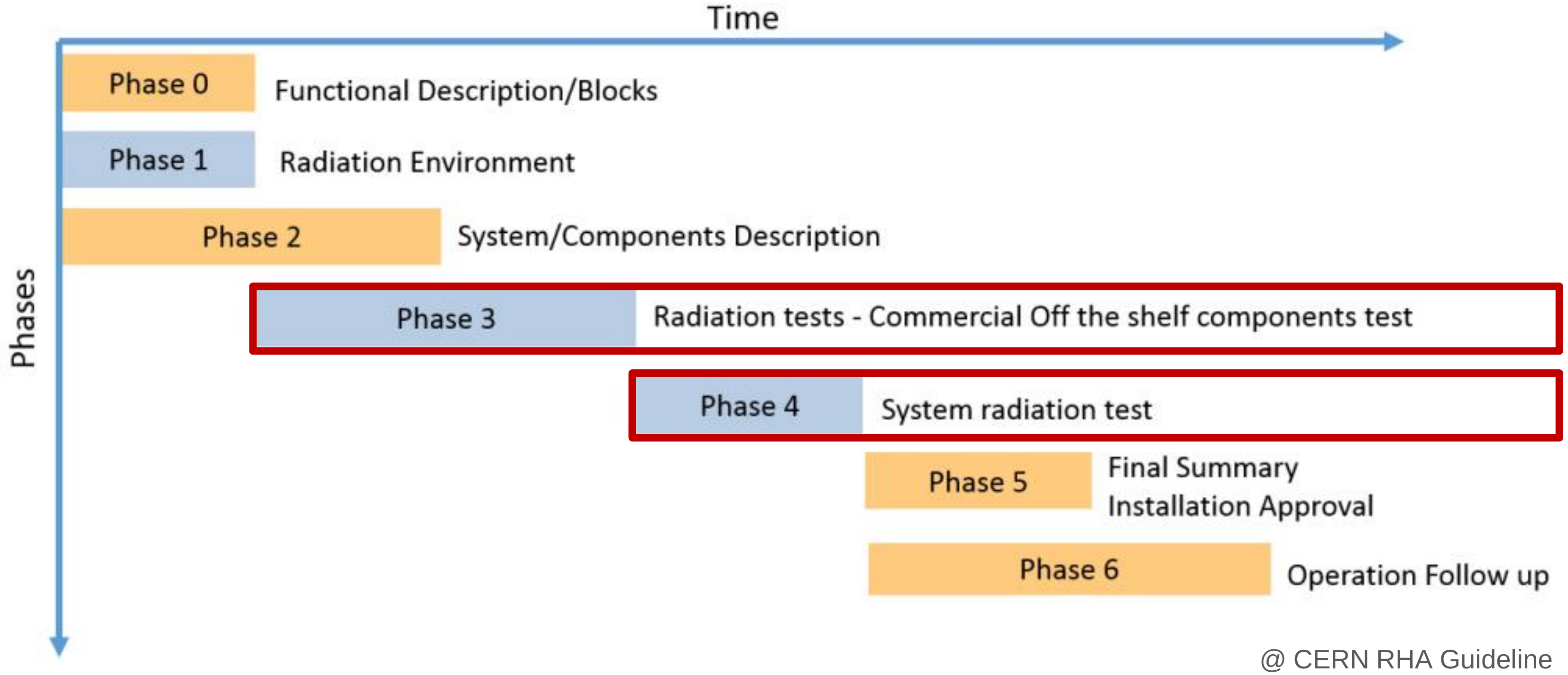


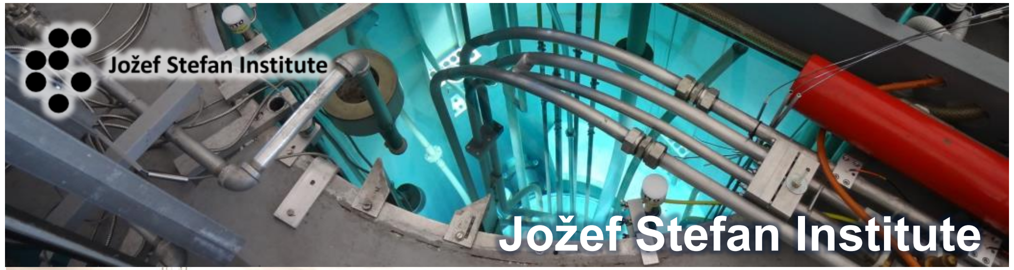
@ CERN RHA Guideline

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

Where do we test: Key point is the facilities



PSI-PIF – Switzerland, Viligen
- 30-220 MeV Proton beam
- 5x5 cm Area
- Combined **SEE**, **TID**, **DD** Tests
- **5 Years collaboration agreement with CERN**

JSI – Slovenia, Ljubljana
- Triga Mark II Nuclear Reactor
- **DD**, TID
- cm to meter scale areas depending on DUT size
- **Punctual use, possibility to make a contract**

CC60 – Switzerland, CERN
- 10 Tb Cobalt 60 Source
- From few to tens of cm depending on device size
- **TID** Tests
- **Available all the year**

CHARM – Switzerland, CERN
- Representative LHC Radiation mixed-fields
- Up to two racks can placed (2x1.5m)
- SEE, TID, DD
- **Not available during technical stops**

System level testing: CHARM mixed field facility

CHARM = CERN High energy AcceleRator Mixed field facility

Main mission: Radiation tests of electronic equipment and components

in a radiation environment similar to the one of the accelerator

Large dimension of the irradiation room
- Large volumes electronic equipment
- Full systems

Numerous representative radiation fields
- Mixed-Particle-Energy: Tunnel and Shielded areas
- TID, DD, Soft and Hard Single Event effects testing

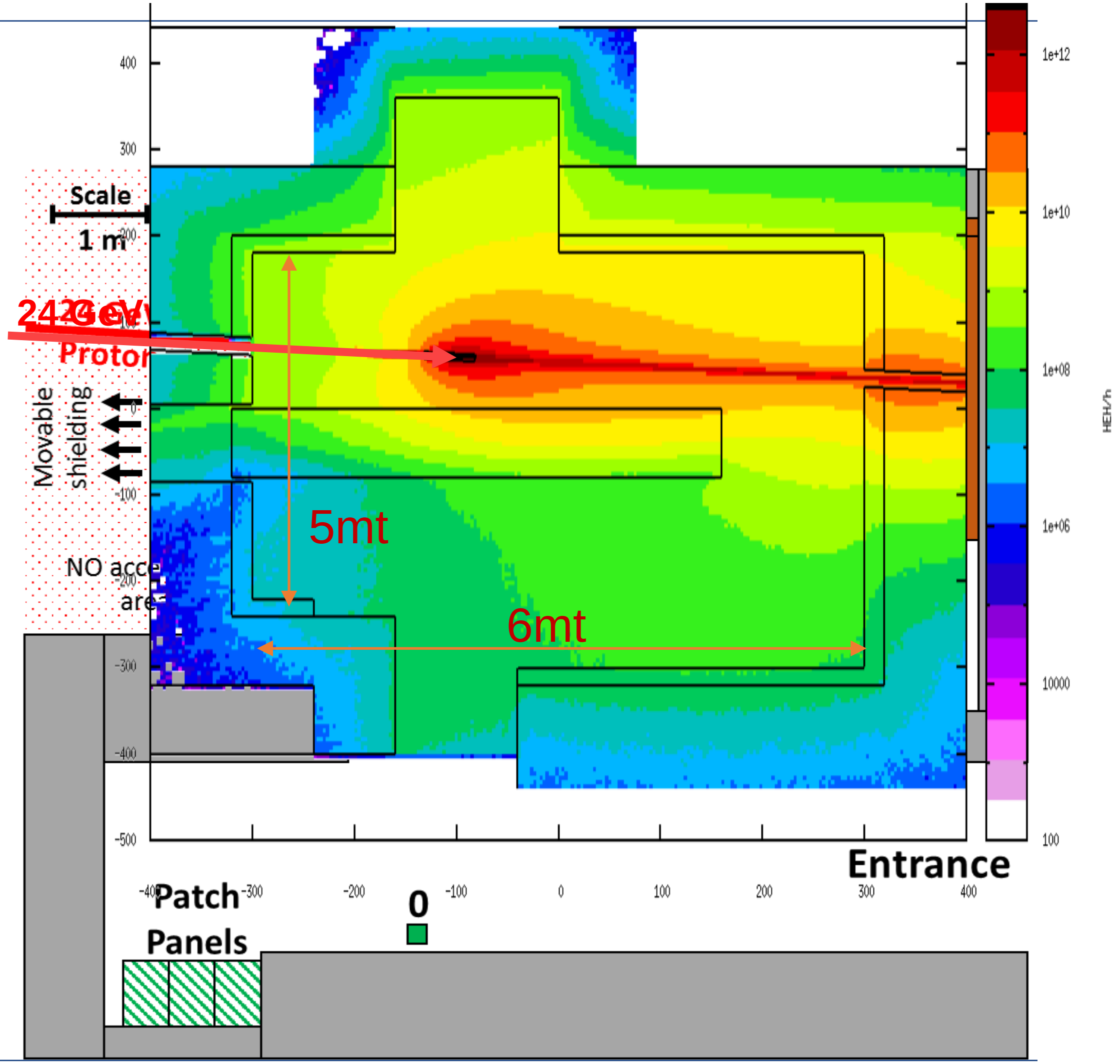
CHARM!

How CHARM works

PRIMARY PROTONS IMPINGE THE TARGET: A SECONDARY RADIATION FIELD IS CREATED

3 KEY ELEMENTS:

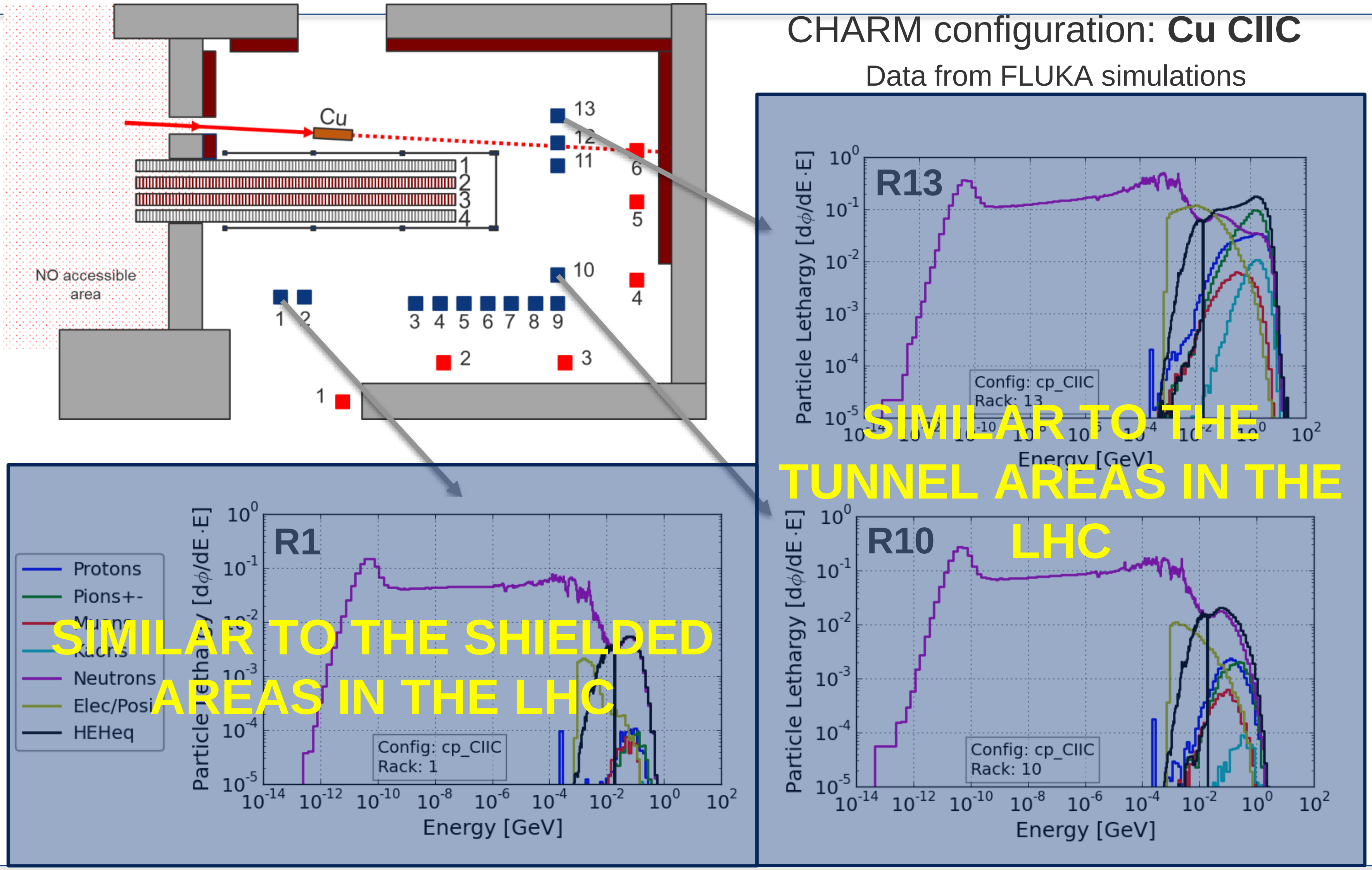
1. Target — Target
2. Movable Shielding — Concrete, Iron
3. Positions — Conveyer, Montrac



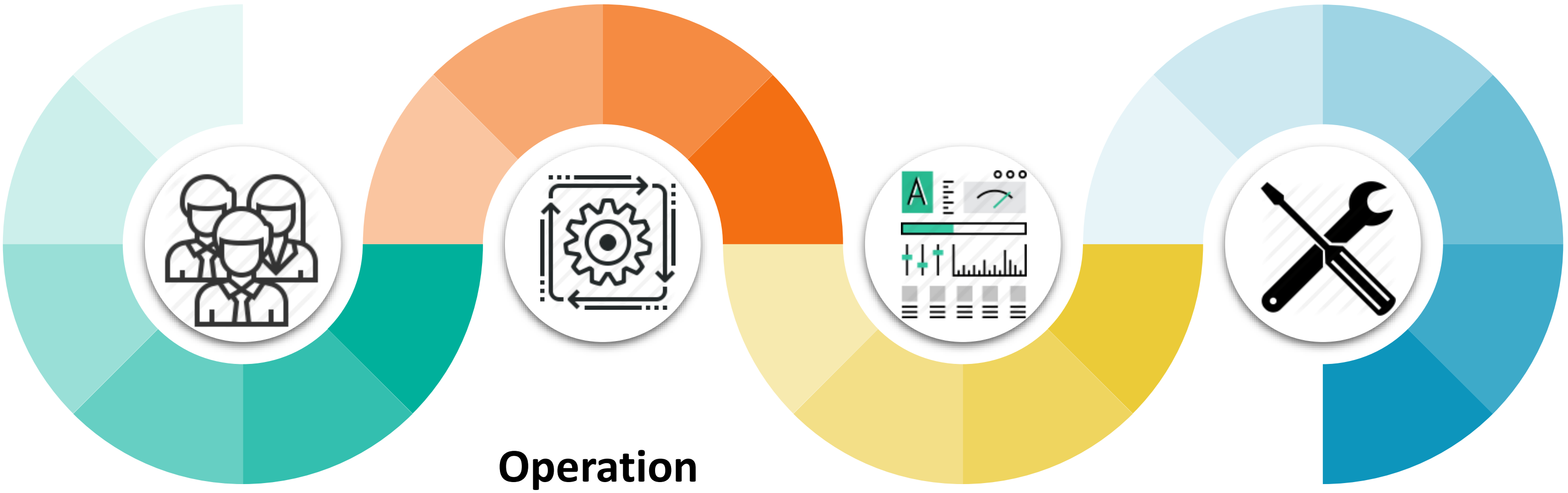
Spectra vs position

CHARM configuration: **Cu CIIC**

Data from FLUKA simulations



BE-CEM-EPR Radiation test Facilities : Services



Coordination

The user requests are collected and processed reserving the most suitable slots in the facilities. Multiple requests are accommodated in the same slot to be more effective

Operation

The facility operation includes the preparation the installation and the removal of the setup. Big part of the operation is also the beam steering, verification and follow-up.

Dosimetry

Continuous monitoring is essential to provide the users with reliable measurements. The users receive the dosimetry document for their tests

Maintenance, Upgrade

During all the course of the facilities lifetime they are maintained and improved to fulfill the increasing amount of requests

Conclusion

- Knowledge of the radiation environment is fundamental for any development
  - Radiation Design Margin & Effects
- Radiation effects are strongly dependent on the environment
  - Radiation testing methodology
- System development and components selection should be done considering:
  - Criticality and single/distributed system
- COTS Rad Tolerant are the ones mainly used for accelerator equipment, 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!

CHARM virtual tour