IoT BatMon: Wireless radiation monitoring at CERN

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R2E Annual Meeting – 1-2 March, 2022
https://indico.cern.ch/event/1116677/

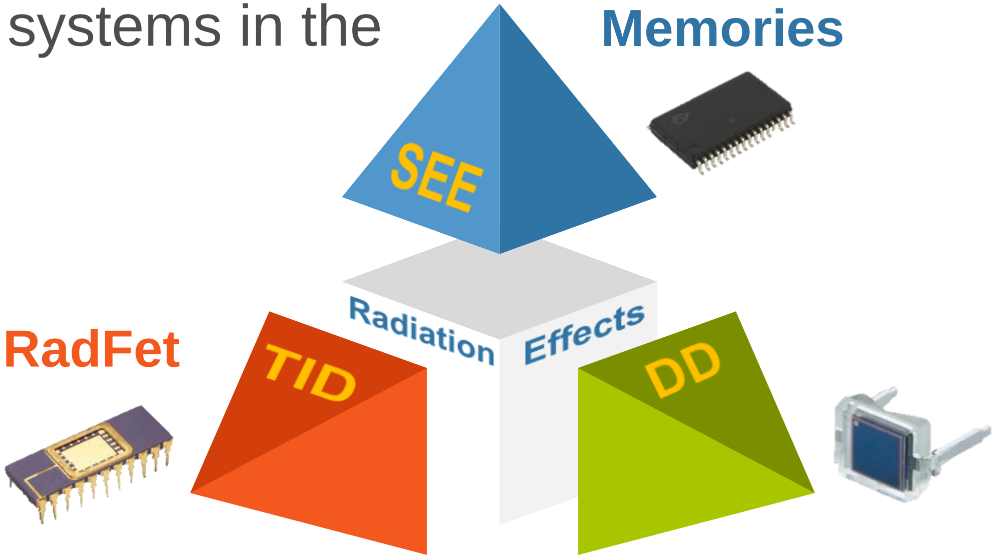
CERN BEAMS Controls Electronics & Mechatronics R2E

Background: the **RadMon**, an R2E instrument

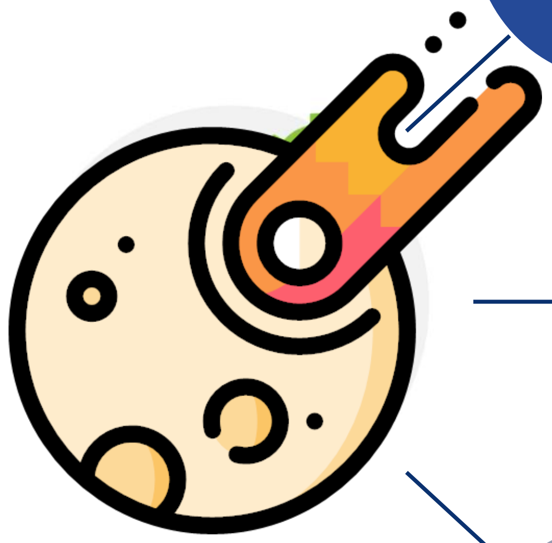
Radiation tolerant full custom measurement system:

measures the **Total Ionizing Dose**, the **Displacement Damage** and the **High Energy Hadron and Thermal Neutron 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



Impact in developing a new system



Better Service

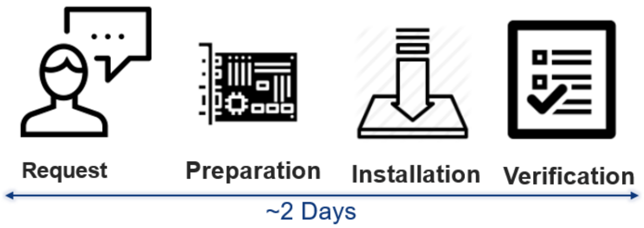
Deployment of tens of devices in different locations in a couple of days is not possible with the RadMon

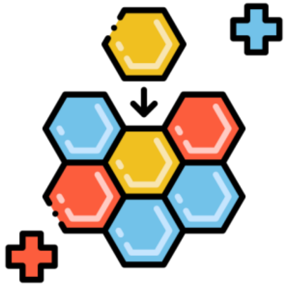
Innovation

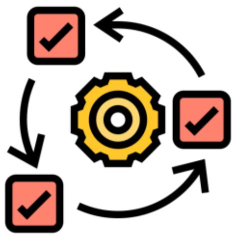
- Flexibility
- Modularity
- Radiation Tolerant Wireless
- Stand alone system
- IoT industrial infrastructure

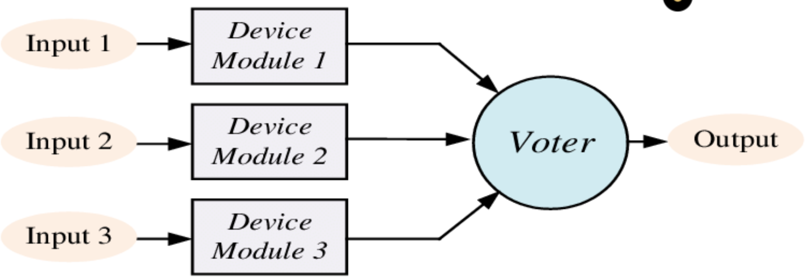
System Level testing strategy

Assessment and validation of new procedure and mitigation technique at system level

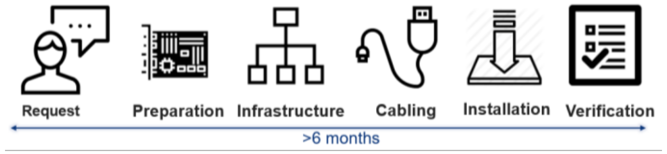








Challenges



Wireless:

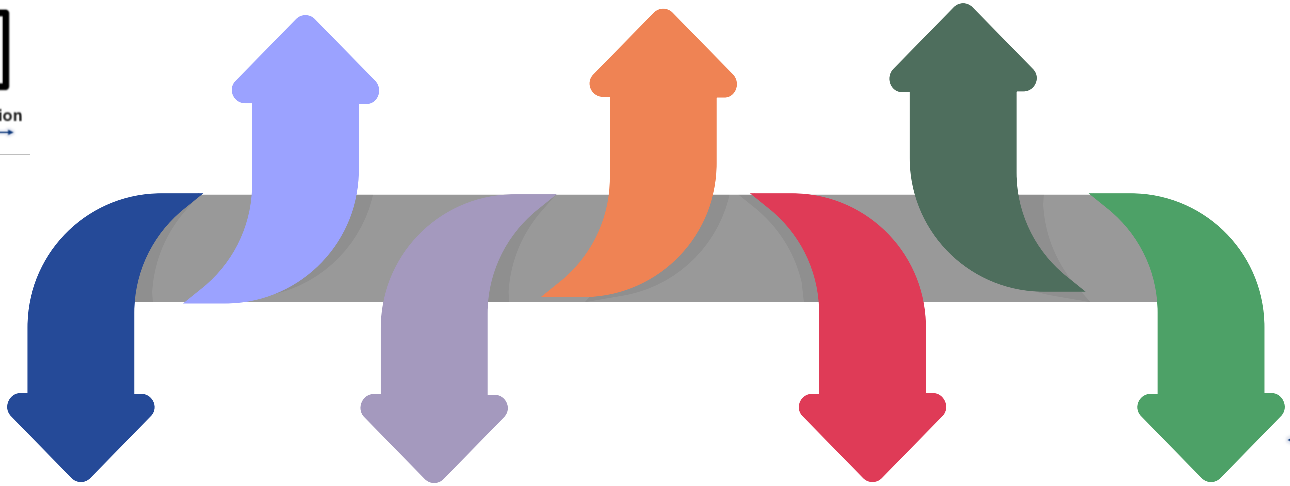
- Mobility
- **Easy** to install

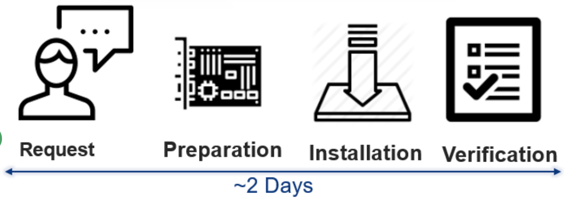
Low cost:

- Based on COTS

Easy to configure:

- **Preparation time reduced**





RadMon:

- Same **capabilities** and **performance** of the RadMon

Low Power:

- Battery powered lasting **for at least 1 year**
- **No** continuos maintenance required

Radiation Tolerant:

- Suitable for an environment such as the LHC

Easy to Read:

- **Prompt** results and **faster** analysis

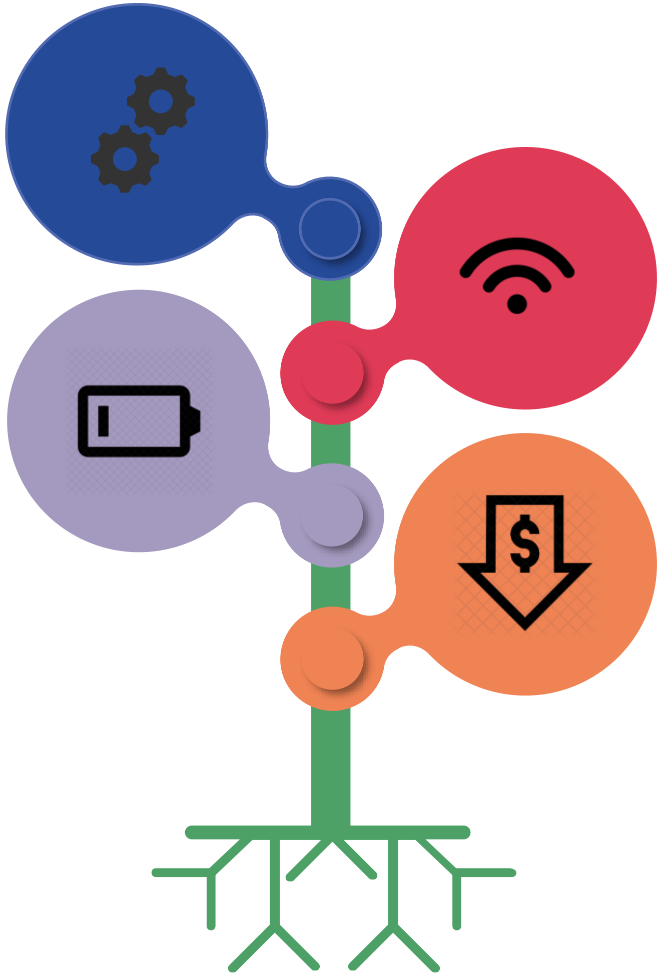
The BatMon: Over the Challenges

Easy to configure

System reconfigurable wireless or via cable

Low Power

Use of low-power components and a microcontroller safeguards battery lifetime



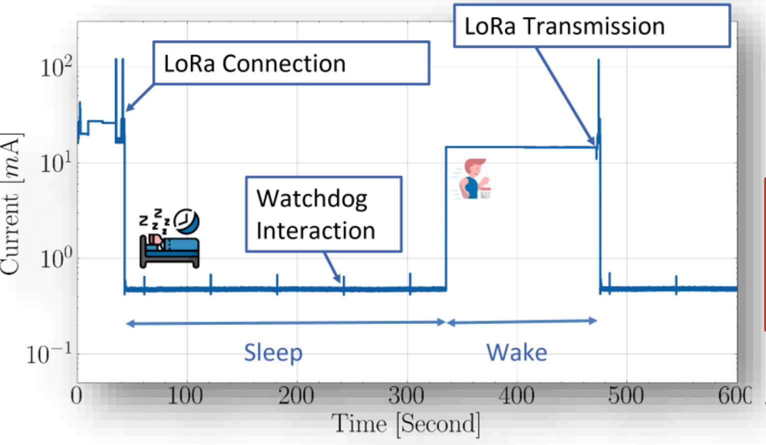
Wireless

LoRa technology perfectely fits the constraints of low power and wide area coverage

Low Cost

The system is based on qualified COTS

Wireless BatMon: from prototype to operations



Measurement Period	I_{mean} *[mA]*	*Lifetime τ [Month]*
5 Minutes	7.1	3.31
1 Hour	1	22.9
24 Hours	0.49	47.36

Lifetime calculated with **all 4 batteries equipped**

A first layer of validation without Radiation:

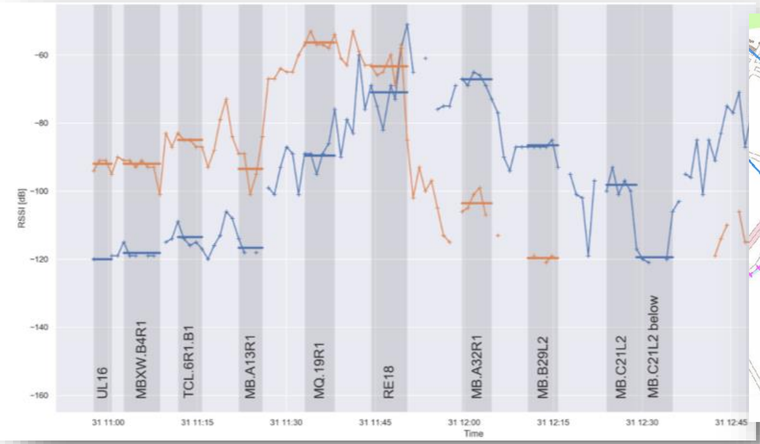
1) Expected system life based on power consumption
2) System Functionality Validation
3) Test in Magnetic Field

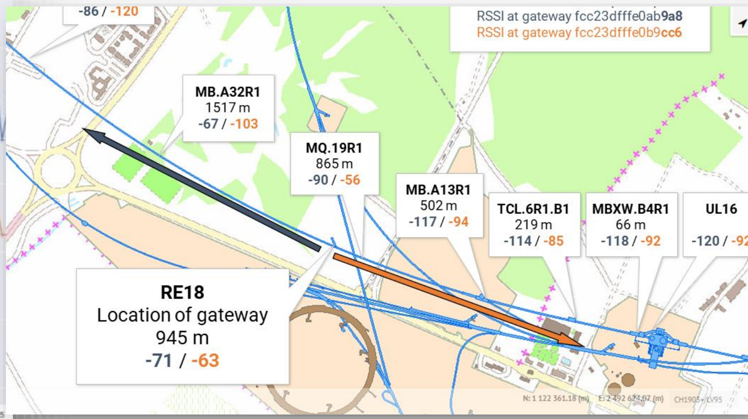
Performances can be degraded by Radiation Effects

BATMON consumption per operation cycle and lifetime

PROTOTYPE (2016-2021)

ELECTRICAL VALIDATION (2020-2021)

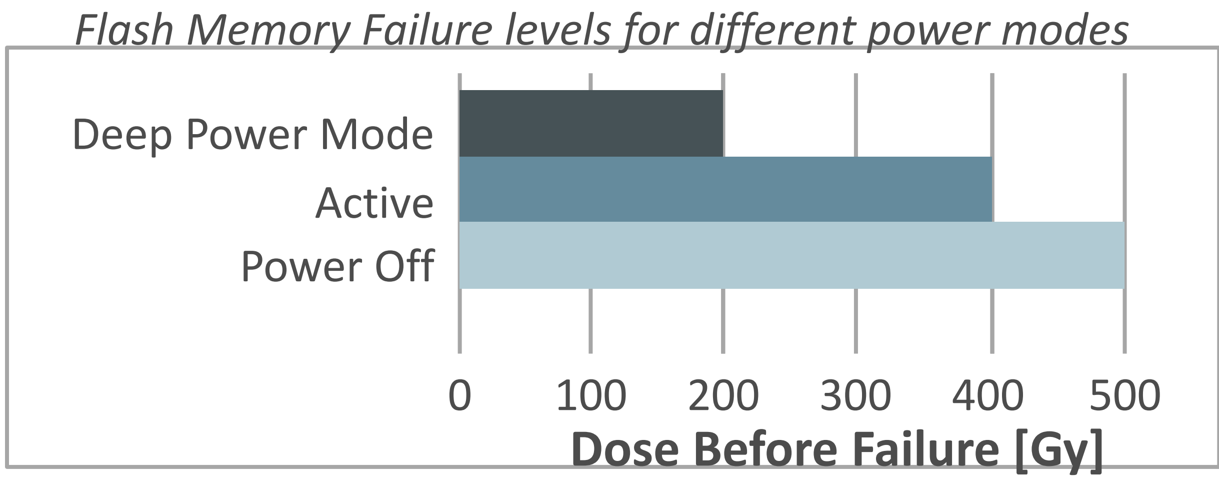


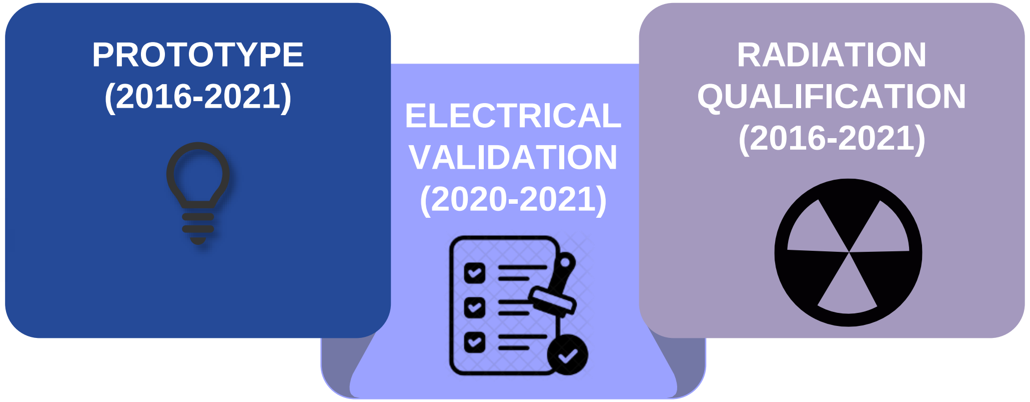


Wireless BatMon: from prototype to operations

The Radiation Qualification is made of 2 phases:

- **Component level qualification:**
  - **Low Power** components can embed new power-saving features that can present **new failure modes** and impact the lifetime
  - **All BatMon COTS qualified at PSI**
- **System Level Qualification:**
  - Normally performed at **CHARM** → Unavailable until the end of 2021
  - Alternative approach splitting into different validation steps

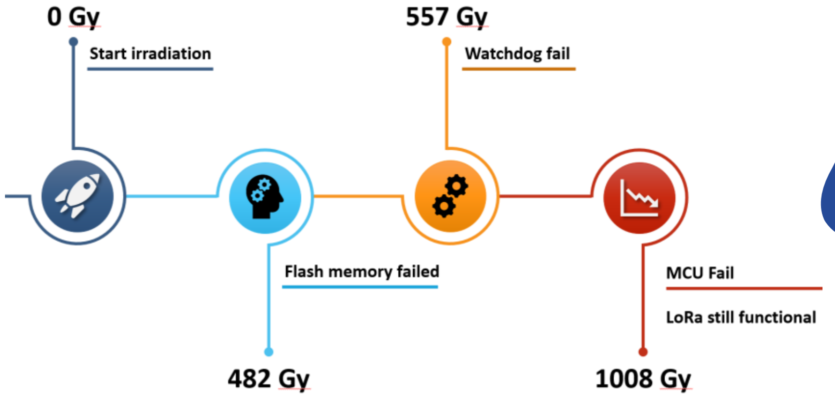


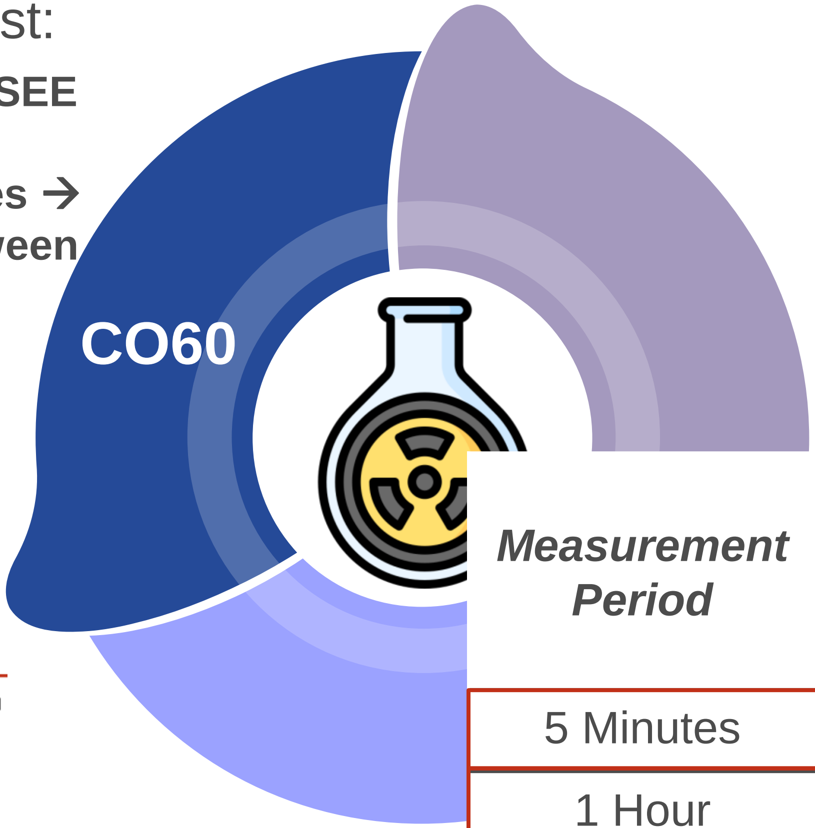


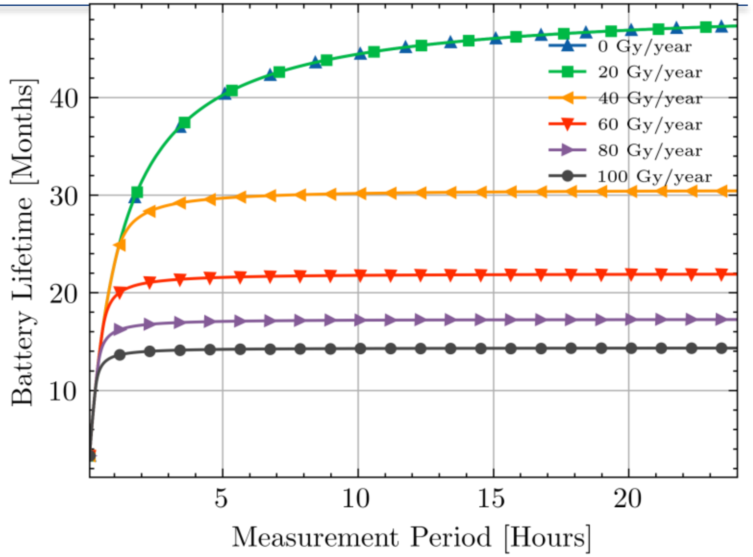
System Radiation Qualification: TID

Co60 sources for system-level test:

- **Isolate TID contribution → No SEE**
- **Irradiate whole system(s),**
- **Using representative dose rates → Estimate the dependency between Battery lifetime and dose delivered.**







Measurement Period	***Lifetime τ 0 Gy/year [Month]***	***Lifetime τ 40 Gy/year [Month]***	***Lifetime τ 80 Gy/year [Month]***
5 Minutes	3.3	3.3	3.3
1 Hour	22.9	22.9	**15.9**
24 Hours	47.36	**30.4**	**17.3**

Lifetime calculated with **all 4 batteries equipped**

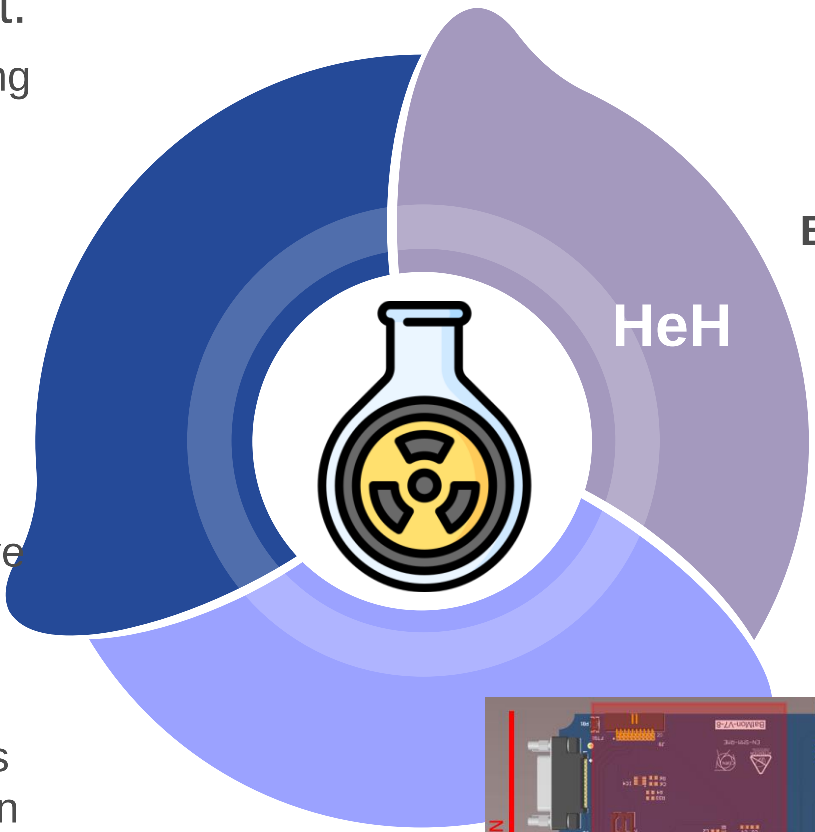
System Radiation Qualification: HeH

Proton beam for system-level test:

- Isolate SEE contributions targeting different subsystems
- Inducing all TID, DD, and SEE
- Tuning proton flux
- **Not possible to irradiate whole system(s),**

Alternative R&D approach:

- From the data obtained from component level qualification, it was known that the most sensitive component to HeH was the Microcontroller.
- The system was divided into two macro-subsystems, which always included the microcontroller within them.
- They have been tested **separately**



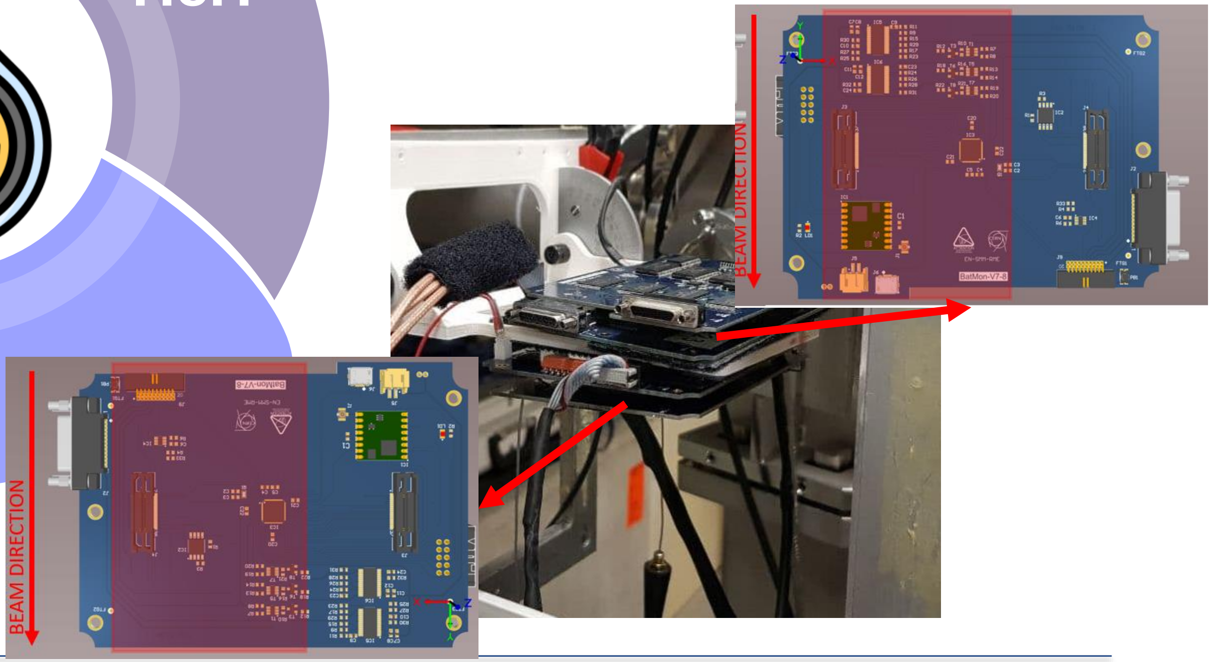
Two main contributions to system SEE:

1) Microcontroller (stuck program)
2) Communication Controller (stuck program)

→ Recovered by external watchdog

BATMON Total SEE Response: $6.5 \cdot 10^{-11}$ cm^2

- Expected Failure Rate in Operation



System Radiation Qualification: Thermal Neutron

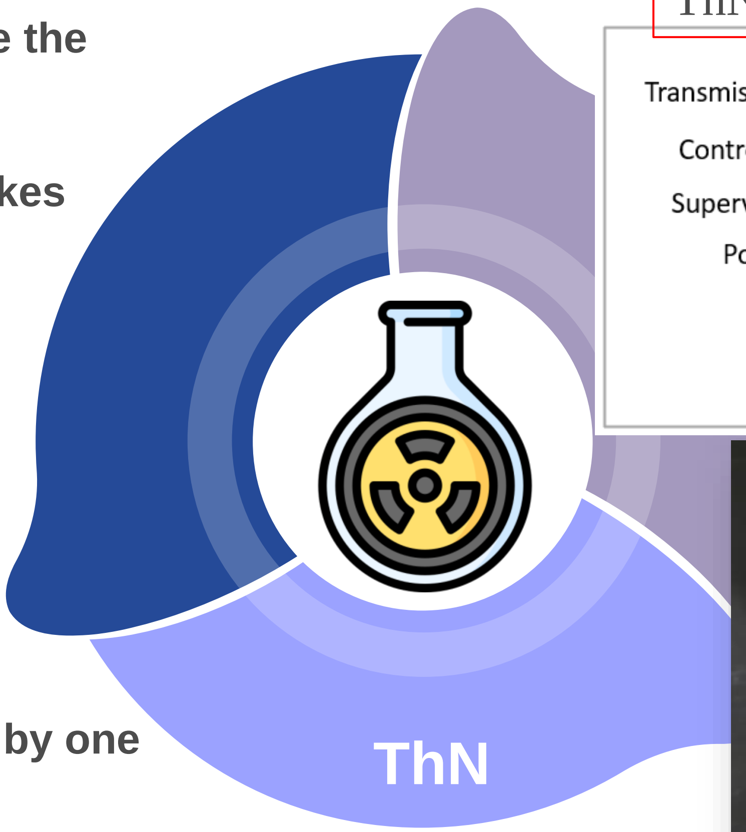
- **Radiation Monitoring System for accelerator must be able to measure the contribution of ThN.**
- **The possible presence of B10 in the manufacture of the components makes this qualification step necessary.**

ThN beam for system-level test:

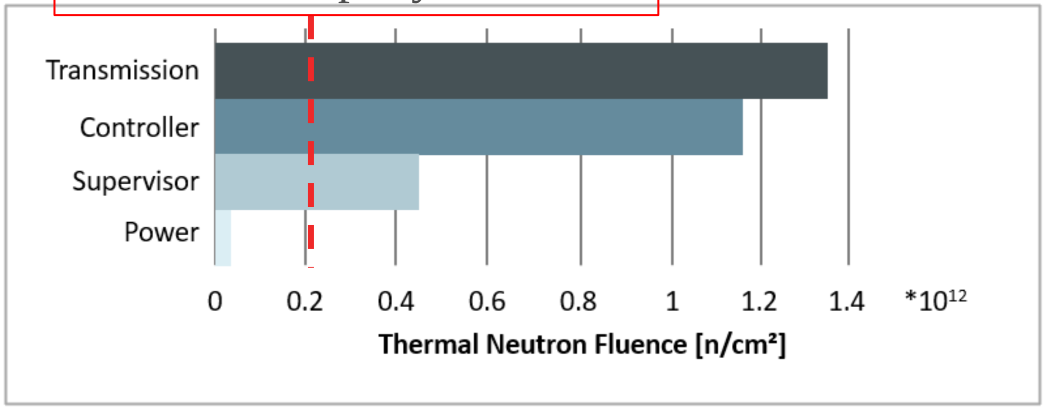
- **Evaluate Measurement performance of the system**
- **Investigate possible sensitivity to ThN.**
- **Not possible to irradiate whole system(s)**

R&D approach testing subsystem one by one to obtain global sensitivity

✓ No sensibility observed on any subsystems



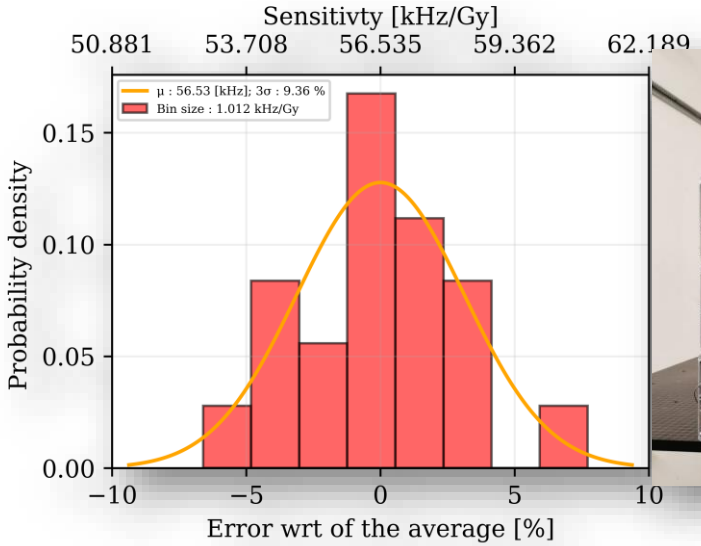
Dispersion Suppressor (DS)
ThN Fluence per year



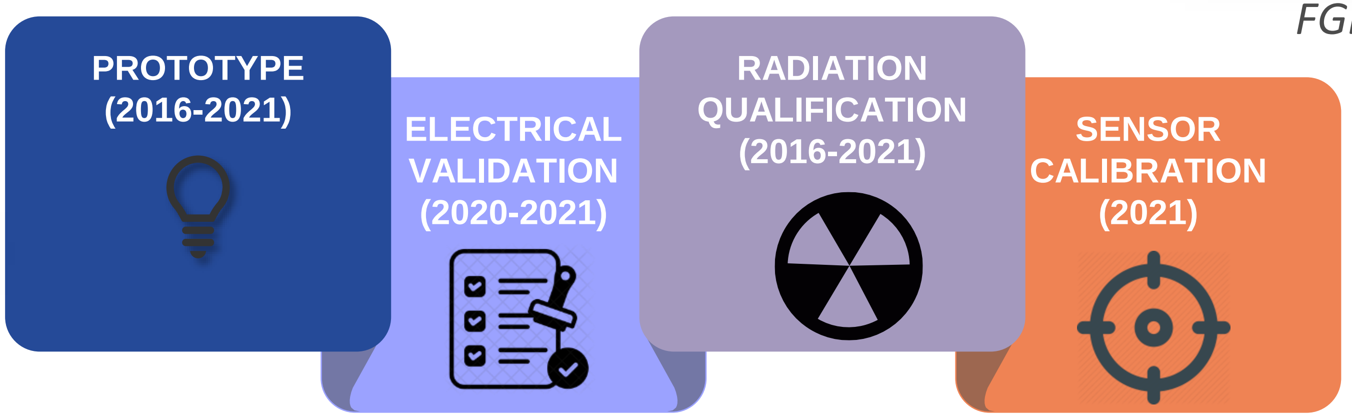
Wireless BatMon: from prototype to operations

System flexibility allows:

- Individual radiation sensitivity calibration.
- Mass system calibration is possible in large radiation facilities since no cables are required



FGDOS TID Sensor sensitivity spread



System Expected Lifetime and failure Rate

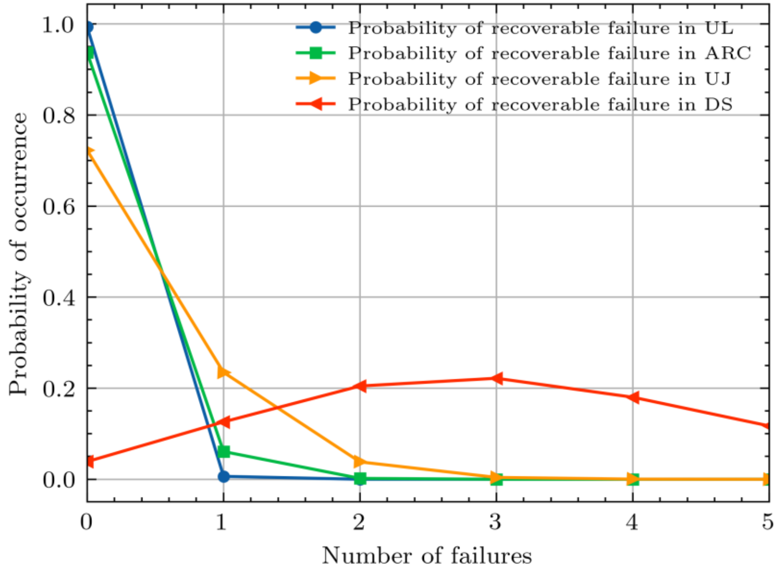
- 2 main information are retrieved from this alternative approach:
  - System Sensitivity
  - Radiation Lifetime

  →
  - Expected Failure rate in operation
  - Expected lifetime in operation

- This approach has allowed developing a specific methodology for qualifying this type of system:
  - **A. Zimmaro et al., *'Testing and Validation Methodology for a Radiation Monitoring Systems for Electronics in Particle Accelerators,'* in proc. Transactions on Nuclear Science 2022**

- Further tests performed at CHARM using the BatMon have shown that accelerated tests (High Flux) for system qualification, may hide some failure modes in case of microcontroller-based design.
- These limitations of accelerated testing for system-level qualification will be presented in a new specific work at RADECS 2022.

Position	Doserate per year [Gy/Year]	Expected Lifetime [Year]
UL	0,2	1375
UJ	10	27,5
ARC	2	137,5
DS	100	2,75



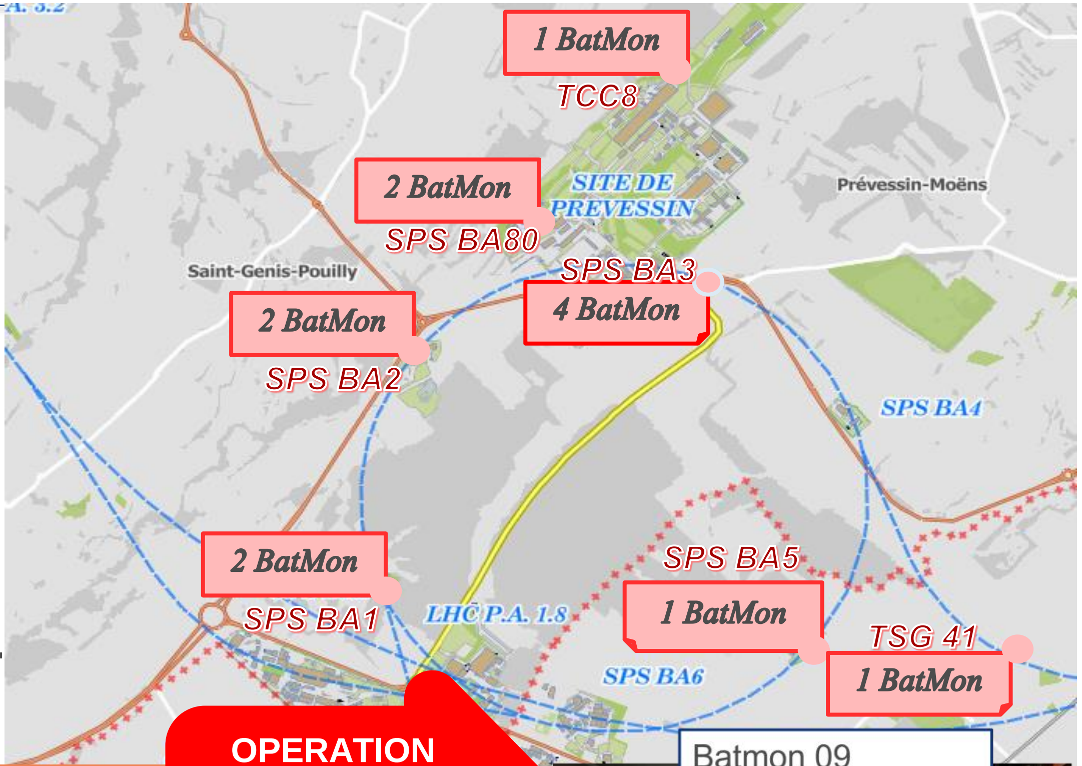
System failure rate for specific HL-LHC environments and 1 year of operation using the Homogeneous Poisson Process.

Wireless BatMon: from prototype to operations

- To characterize the radiation levels of specific areas in SPS, users requested measurements through the MCWG. However:
  - ➢ <u>*No power and data (Wordfip) network*</u> for these locations.
  - ➢ The time windows available for the measurements were generally very short , which means <u>*low radiation levels*</u> could be cumulated.

but these requirements couldn't be fulfilled by using the RadMons → BatMon can!

- **13** BatMons have been installed in **2021** in 7 positions
  - ➢ No LoRa Coverage for these locations → maximum sampling rate (300 s) and use the system in passive mode (measurements saved in non-volatile memory)
  - ➢ Lifetime of ~**40** days leading to some devices turning off before the next access.



PROTOTYPE (2016-2021)

ELECTRICAL VALIDATION (2020-2021)

RADIATION QUALIFICATION (2016-2021)

SENSOR CALIBRATION (2021)

OPERATION (From 2021)

Conclusions

- This presentation illustrated the process BatMon went through from the first prototype to operation.
  - The different steps of this process were discussed.
  - An **alternative** approach for system-level qualification was proposed
  - It allowed **developing a new methodology** for the qualification of radiation monitoring systems for accelerators
- The BatMon has been already deployed successfully in different SPS areas where the RadMon can not be used
- In 2022, the possible deployment of BatMon in the **LHC** will allow testing of the LoRa Wide Area coverage capability.
- Its testing in **CHARM** allowed to discover **new limitation for system level qualification** through the use of only accelerated test which will be the subject of a future study to be presented at RADECS 2022
- New R&D solutions to improve the performance of the platform are in the pipeline and will be tested during this year.

Thank you for your attention!

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