Wireless IoT in Particle Accelerators: A Proof of Concept with the IoT Radiation Monitor at CERN

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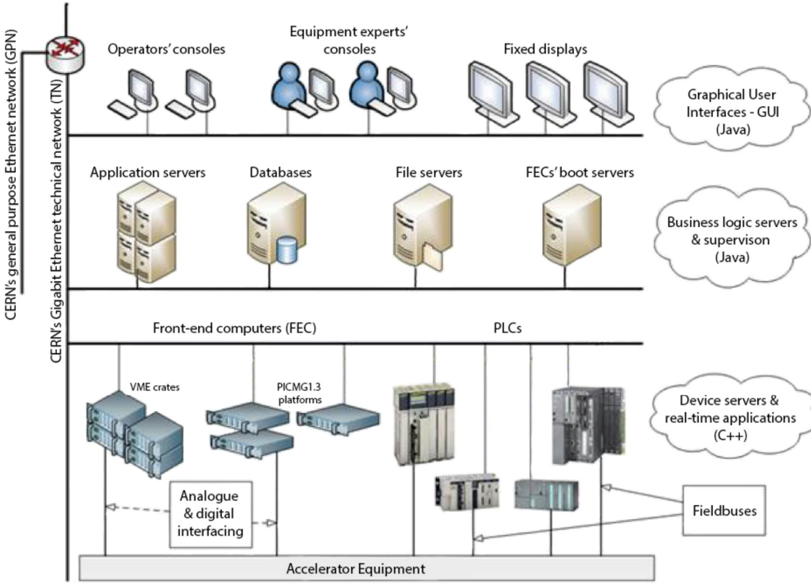
IoT – reference model and CERN control system

- Internet of Things: the term includes everything connected to the internet
- IoT in a particle accelerator is not a new concept
- All the equipment, sensors, devices in a particle accelerator are connected



Source [1,2]

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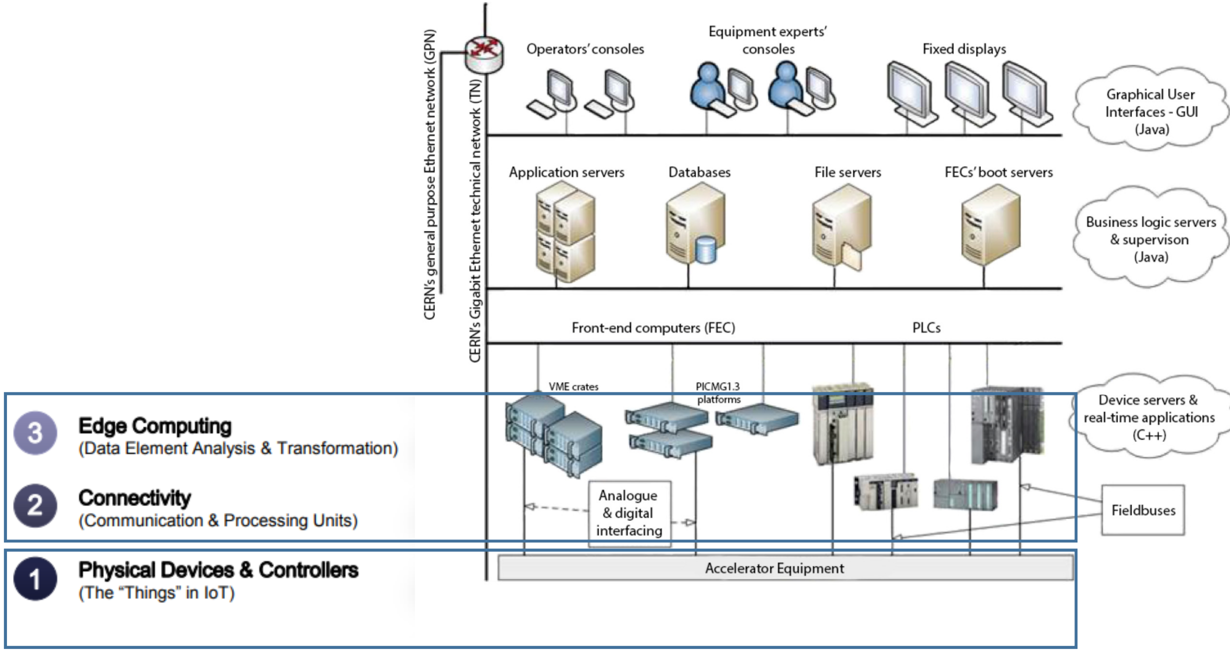

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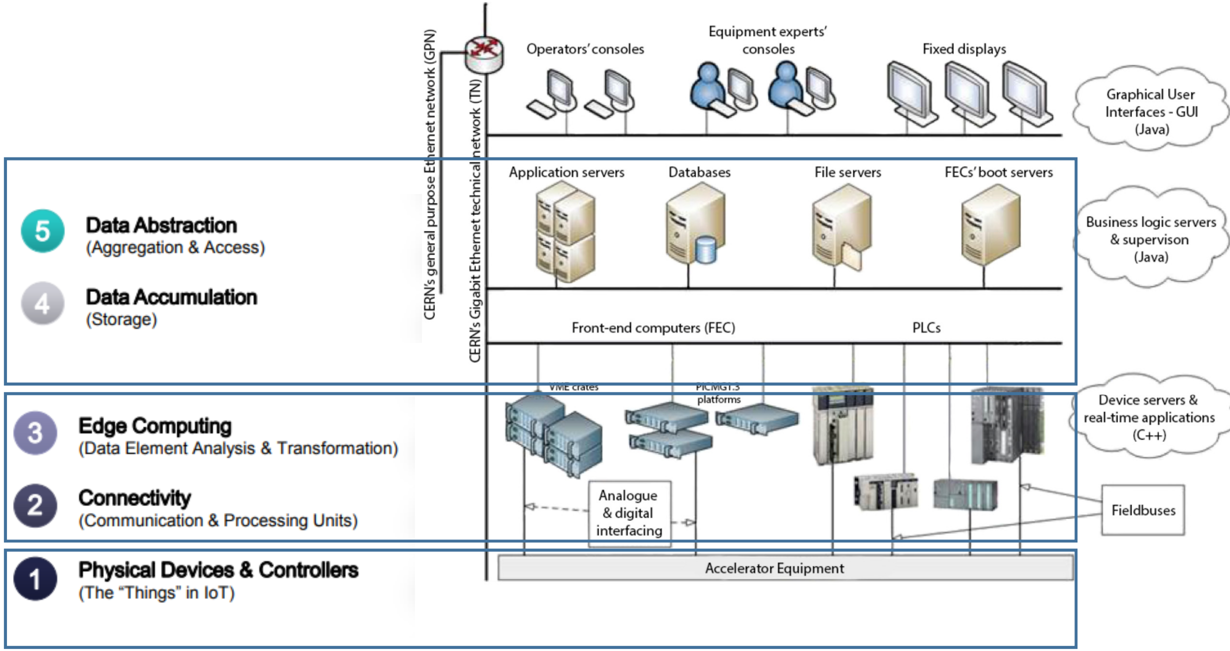

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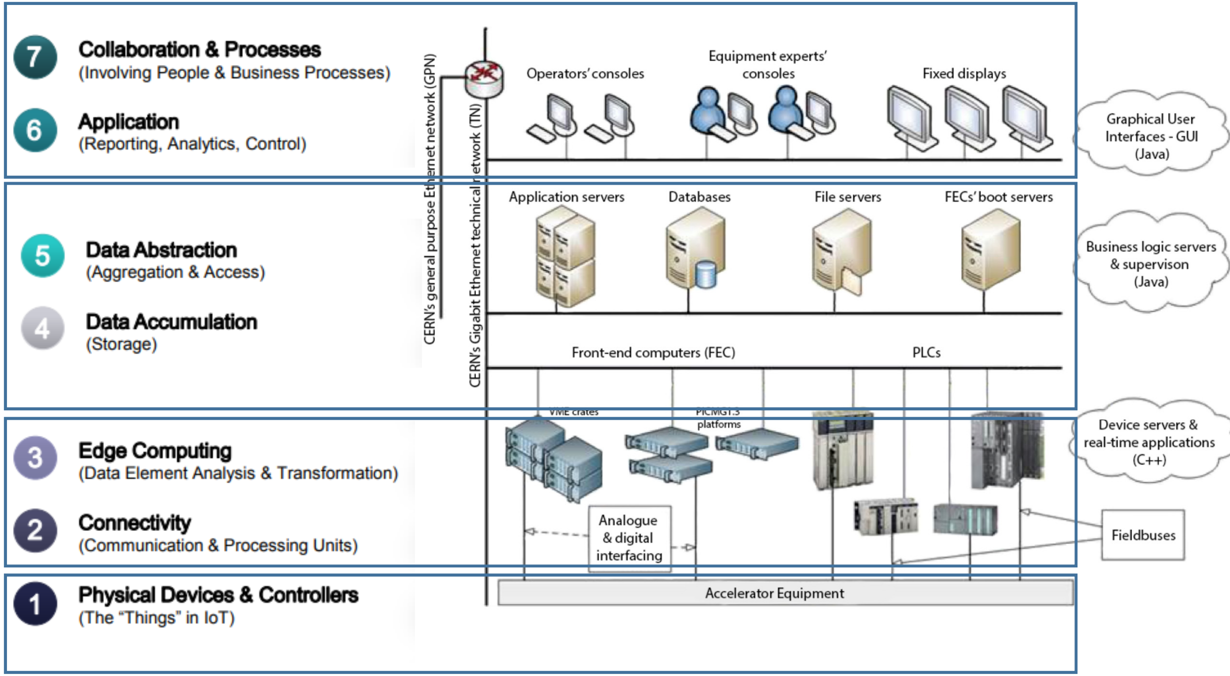

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IoT – reference model and CERN control system

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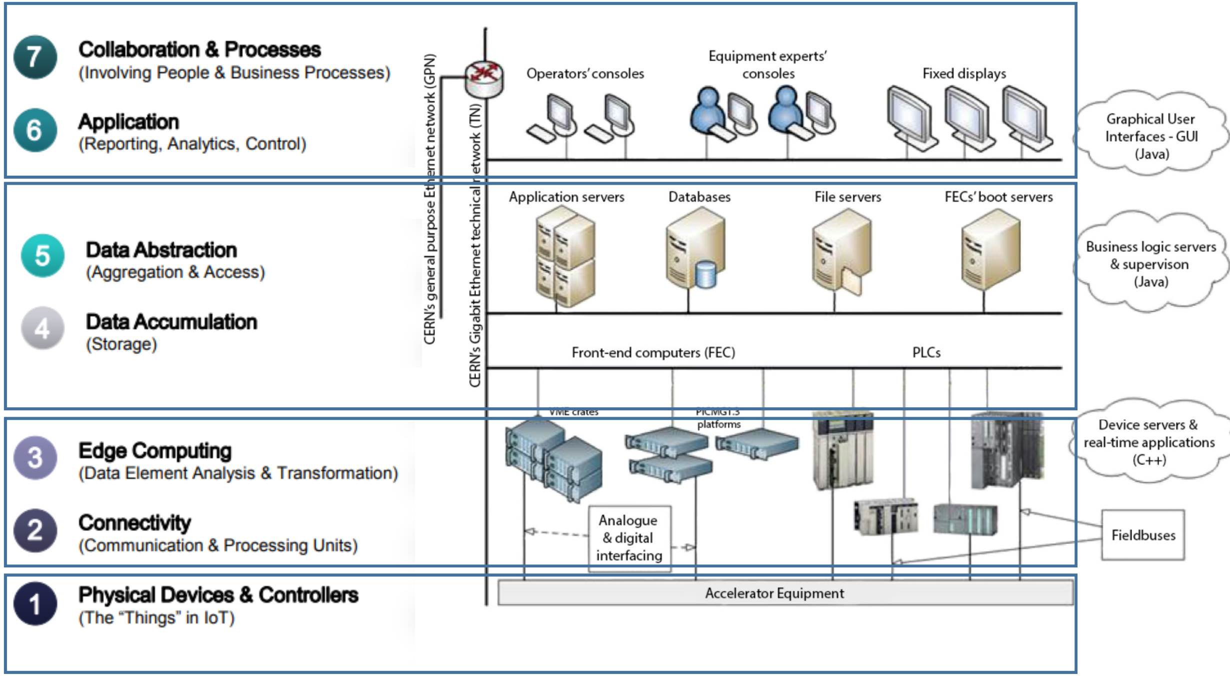
- IoT in a particle accelerator is not a new concept
- All the equipment, sensors, devices in a particle accelerator are connected
- All these connections are based on a **wired infrastructure**



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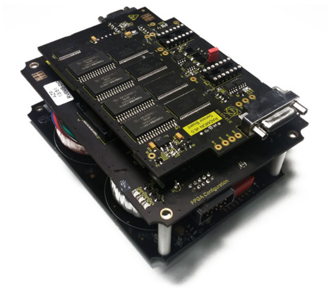
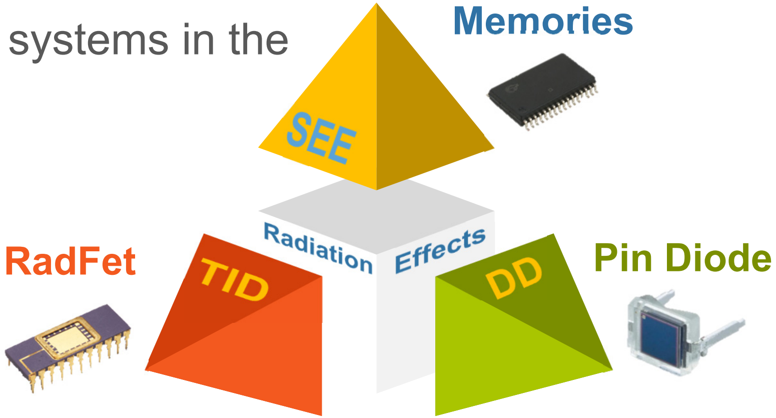
Background: the **RadMon**

RadMon is a device capable of measuring the radiation level where the electronic systems are installed

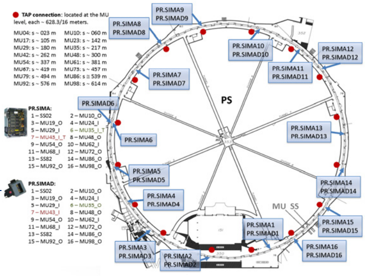


It measures the **Total Ionizing Dose**, the **Displacement Damage** and the **High Energy Hadron Fluence** in order to:

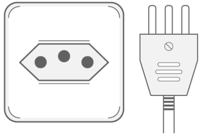
- Monitor the radiation levels on the electronics systems in the accelerators
- Anticipate the electronics degradation
- Investigate the cause of failures
- Simulation benchmarking

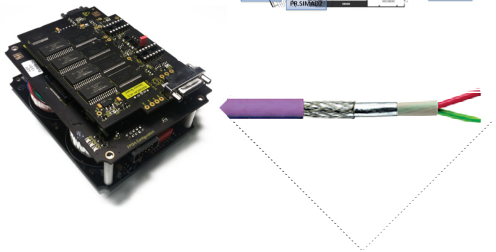


RadMon System

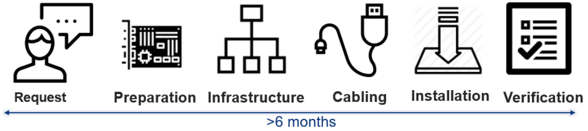


- **500 devices** are installed at CERN in different locations
    - **1 cable** for the communication (WorldFip)
    - **1 cable** for the power (230V)
  - Fully integrated in the CERN infrastructure
    - 1 FEC (PC) to manage up to 32 devices
  - Installed devices are **fixed** with limited movement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



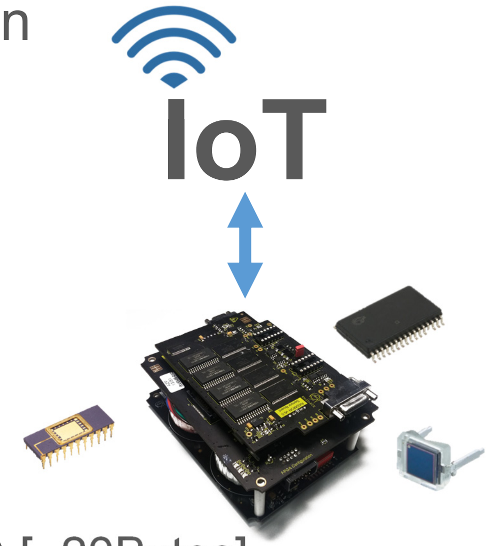


- **In operation**: users request measurements in locations where the RadMons are not installed
  - Requests arrive few days before the technical stops
  - Cables pulling and extensions are not an option during technical stops
  - Deployment of tens of devices in different locations is not feasible in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



The ideal solution to fulfill the requirements

- Same capabilities and performance of the RadMon
  - Radiation Tolerant
  - Wireless communication
  - Battery powered lasting for at least 1 year
  - Easy to configure before the installation
  - Easy to read in operation
  - Low Cost
  - Data rate: measurements every hour (up to one per day) [~20Bytes]



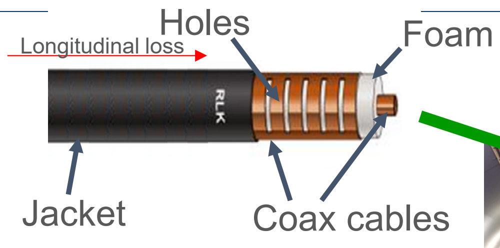
Different types of LPWAN technologies

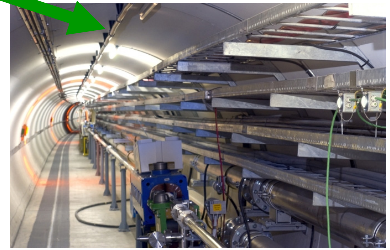
- Low Power Wide Area Networks (LPWAN) are conceived for embedded devices with low power and low data rate applications

	LoraWAN	SigFox	NB-IOT
Frequency	**Unlicensed ISM 868MHz**	**Unlicensed ISM 868MHz**	**Licensed LTE frequencies**
Maximum data rate	**50kbps**	**100bps**	**200kbps**
Range	**5km, 20km**	**10km , 40km**	**1km, 10km**
Interference immunity	High	High	Low
Authentication	Yes	No	Yes
Adaptive data rate	Yes	No	No
Allow private network	**Yes**	**No**	**No**

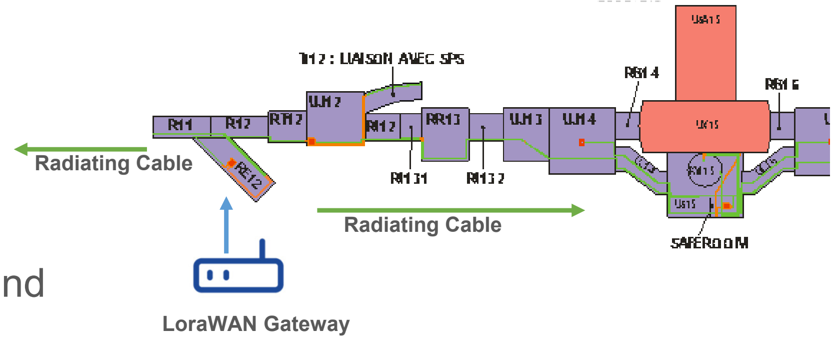
Tunnels networking solutions

- **Radiating cable:**
  - Optimized for
    - Safety network: TETRA@400MHz,
    - Cellular : LTE@800MHz, UMTS@900MHz
  - Installed in all the accelerators and experimental areas
  - Losses too high to offer Wi-Fi (2.4/5GHz) over long distances



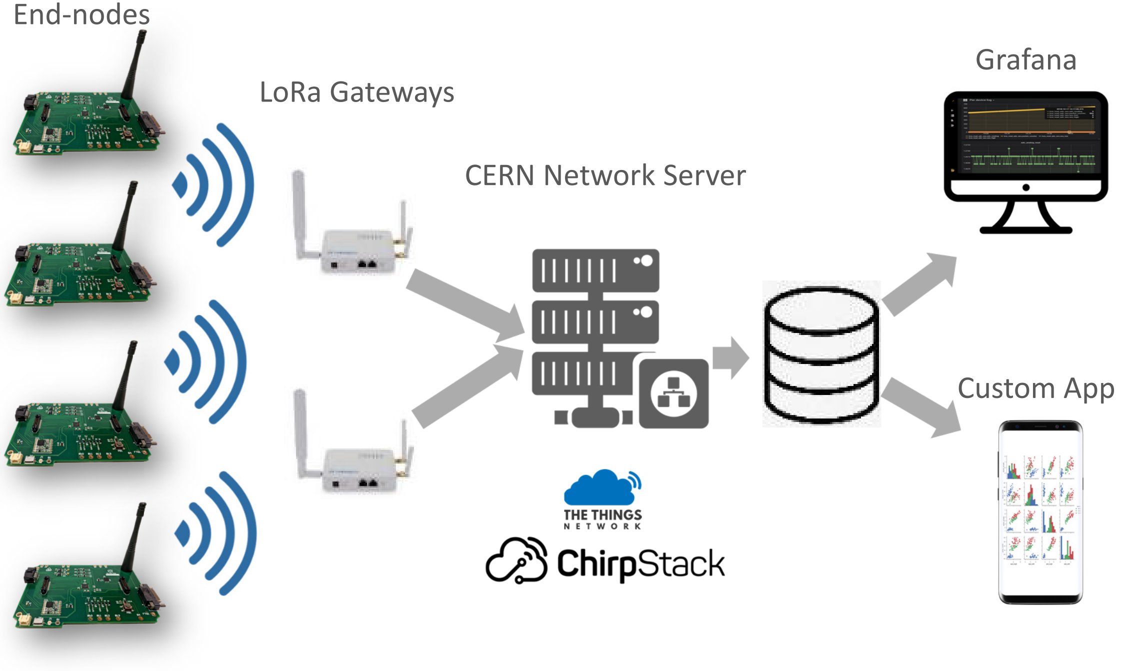


- **LoraWan** deployment in the **LHC** :
  - Injecting in the radiating cable for the TETRA and LTE
  - Gateways in all the REs service galleries in the LHC and TI8 transfer lines



LoRaWAN architecture at CERN

- In a LoRaWAN™ data transmitted by a node is typically received by multiple gateways.
- Each gateway will forward the received packet from the end-node to the network server
- The intelligence and complexity is in the network server
  - manages the network
  - filters redundant packets
  - performs security checks
  - performs adaptive data rate
  - etc.



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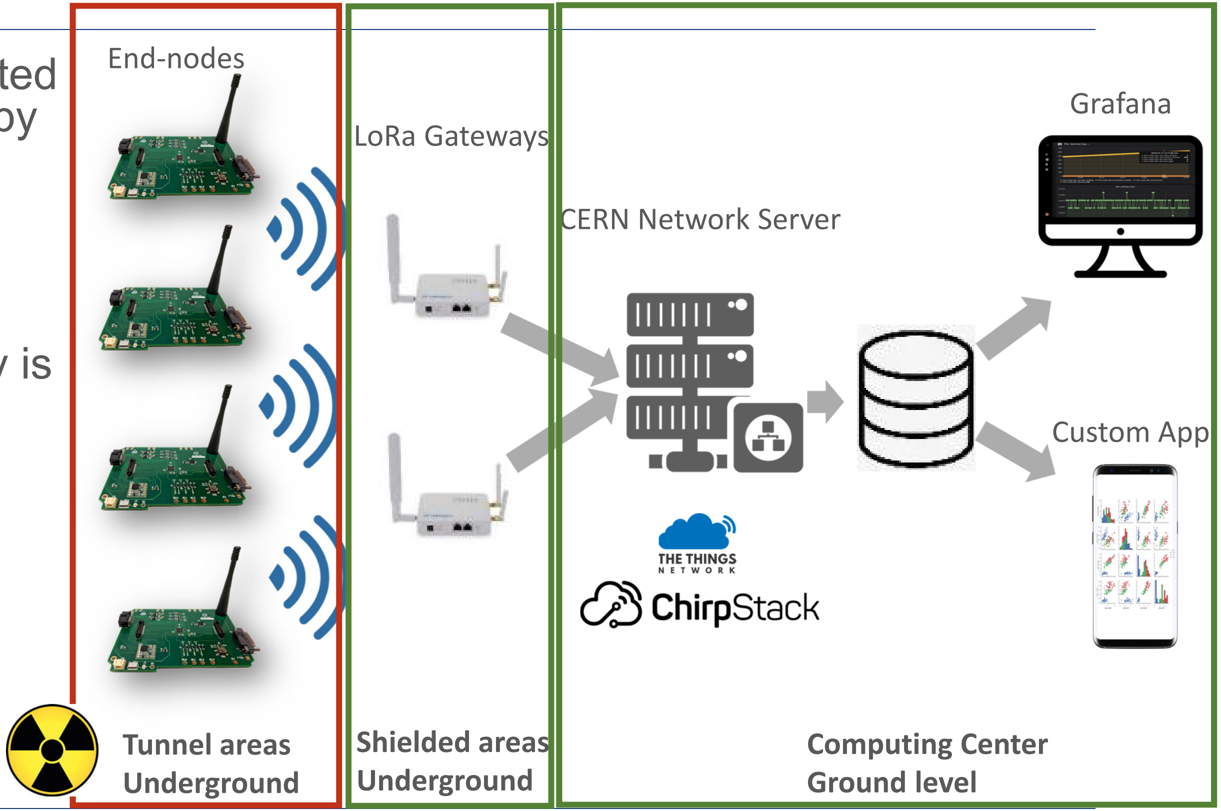
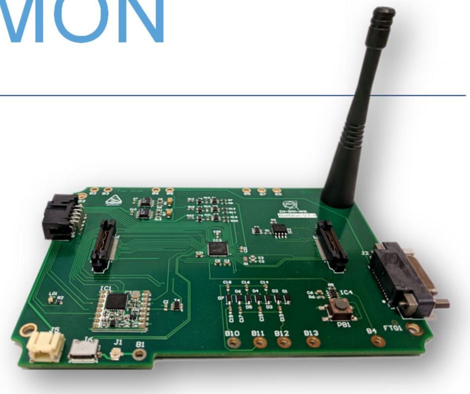


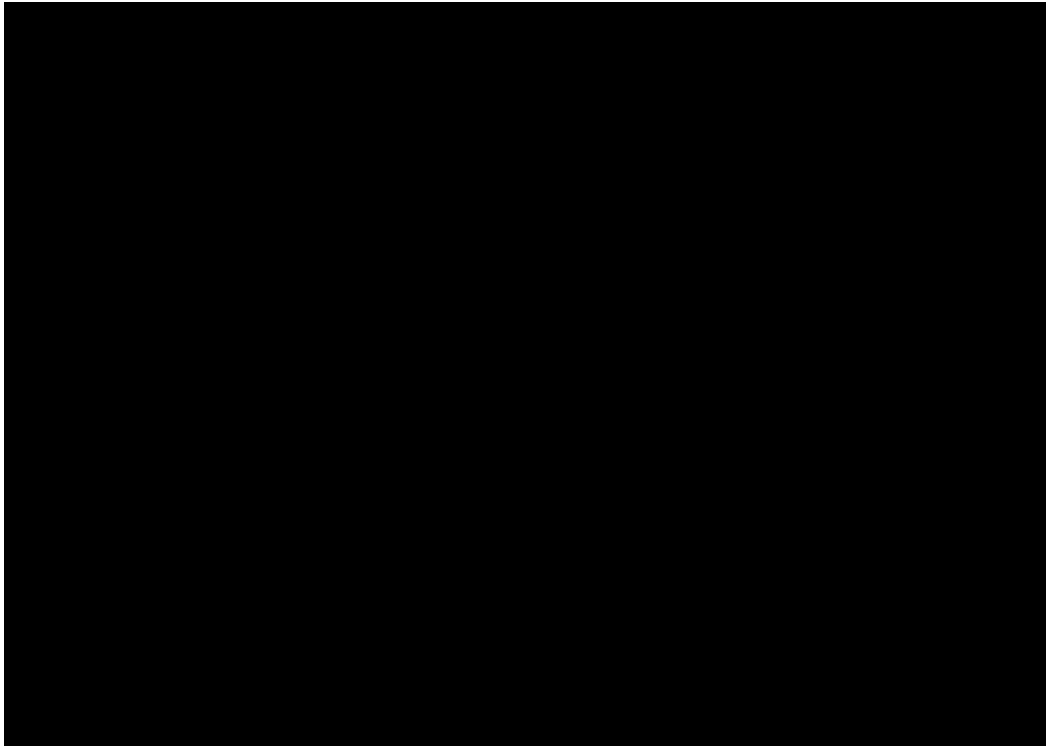
.. IoT Radiation Monitor: IoTRadMON



- 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

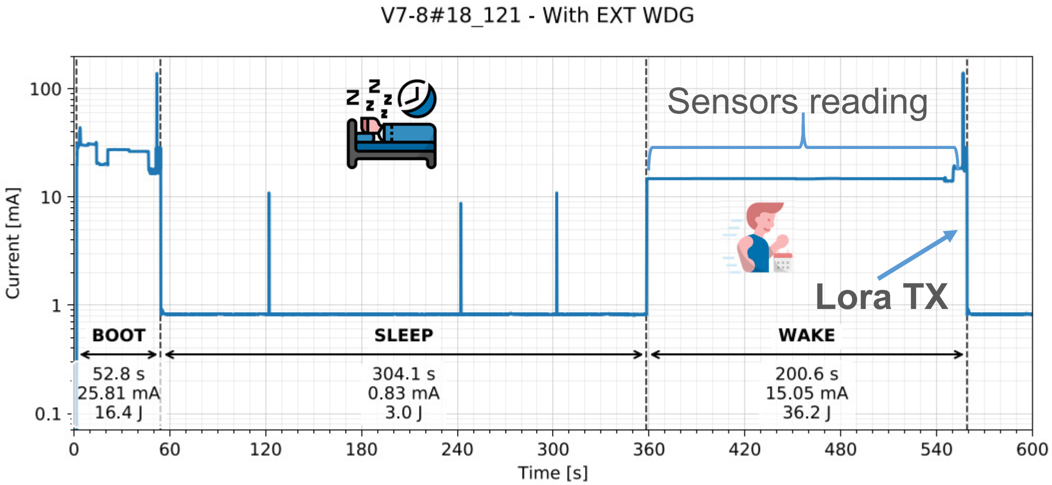
IoT Radiation Monitor: IoTRadMON

- Video



Design for Low Power

- Duty cycle mode:
  - Wake up, measure and send only when it is necessary
  - Sleep current is 20x smaller
- The wireless TX current consumption is negligible
- Sensors reading is the most power consuming



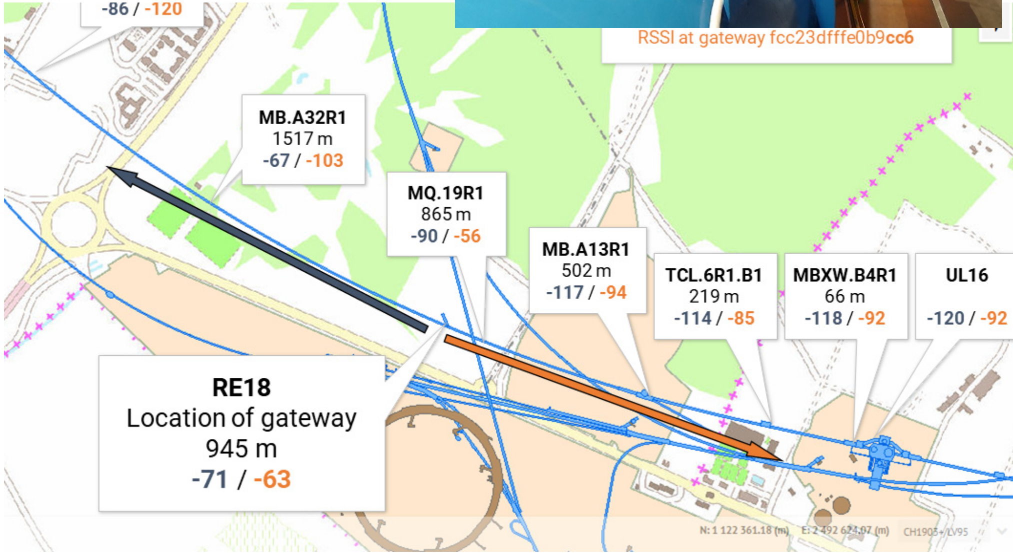
Measurement Period	Lifetime τ [Month]
5 Minutes	3.31
1 Hour	22.9
24 Hours	47.36

Radiation Tolerance

- The platform has been tested following the CERN guidelines
- All the components have been tested separately in a proton facility at 200 MeV
- System level testing has been performed at Co60 and CHARM mixed field radiation facility
- Failure rate in operation is the following for the HL-LHC [11] :
  - **Tunnel (9R5 DS area):** **TID**: ~ 100 Gy /year, **HEH :** ~$3 \cdot 10^{12}$ HEH.cm^{-2} /year
    - **Lifetime :** **~ 3** years
    - **# resets** :**~ 200**/year/device
  - **Shielded area (RR17-L1):** **TID**: ~ 25 Gy /year, **HEH :** ~$1.4 \cdot 10^{10}$ HEH.cm^{-2} /year,
    - **Lifetime:** **40** years
    - **# resets** :**> 1** /year/device

LHC tests and operation

- 2x gateways installed in UPS RE18 injecting LORAWAN.
- Every ~ 200 mt collected 5 packets
  - Received Signal Strength Indicator measurements
- Very successful test with around 2 km of coverage at point 1 [12].
- After these tests the entire LHC has been equipped with gateways in every RE service gallery in the underground.
- LoRaWAN now covers the entire LHC



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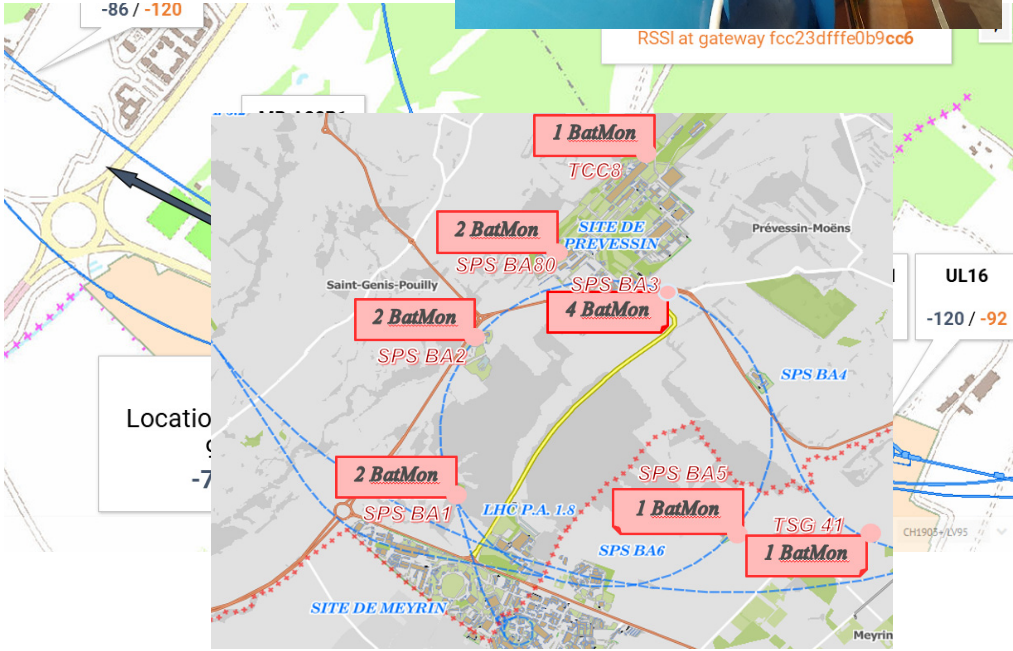
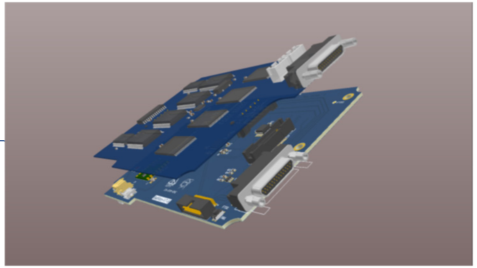
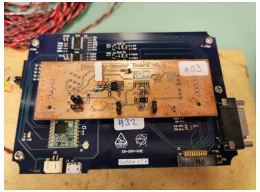


- In 2021 has been in operation in SPS to follow-up the SPS access system failures (13 devices)
  - Y. Q. Aguiar *et al.*, "Implications and Mitigation of Radiation Effects on the CERN SPS Operation during 2021", MOPOMS044,

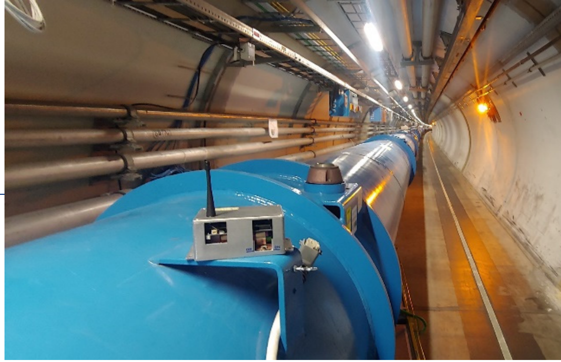
Application independent



- The platform is application independent
- Allow any user to develop its own sensor board
- Interface it with the IoT MinIOT platform
- Send data via LoRa
- Use cases:
  - Temperature and Humidy sensor card for Survey
  - TE/VSC is interested to use the platform for mobile vacuum gauges and sensors
  - HSE-RP is using the platform for the waste bin project



Conclusions



- Wireless IoT is quite a new concept, mainly in the radiation areas
- Several wireless technologies can be adopted: LoraWAN
- IoT Radiation Monitor
  - Is a modular battery system with a (battery) lifetime lasting from a few months to several years
  - Capable of communicating via LoRaWan infrastructure
  - Radiation tolerant: can be deployed in the harshest places of the LHC and still being capable of measuring
- IoT Radiation Monitor can be used as an application-independent generic-platform with the benefits:
  - Lean installation, operation and maintenance
  - Higher observability: massive deployment
  - Higher availability: shorter accesses
  - Huge cost reduction: cable free
- We can say we are ready to move towards a **"SMART IoT Accelerator"**

References

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Thank you for your attention!

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