

# W-MON

## CERN distributed network of sensors for real-time remote control of radioactivity and radiation

**D. Celeste, A. Curioni, L. Gallego-Manzano, F. Murtas,  
D. Perrin, S. Romano, M. Silari**

**CERN, 1211 Geneva 23, Switzerland**

**[fabrizio.murtas@cern.ch](mailto:fabrizio.murtas@cern.ch)**



## **Key technology developments for IoT / radiation measurements**

- Affordable solid-state radiation sensors
- Reliable and cheap micro-controllers and memories
- New developments in wireless communication (i.e. LPWAN)
- Low power microelectronics
- Host of new low power devices (e.g. GPS, Bluetooth)
- Efficient batteries

## **Relevant new trends in IoT**

- Machine learning / AI integrated in IoT
- Big data
- New emphasis on security measures applied to IoT

# The shortcomings of manual radiation monitoring

The radioactivity level of more than 100 metallic containers for ordinary waste is routinely monitored at CERN



1. Human operator introduces **variability/reliability** issues
2. Exact inventory/location of containers must be known to the operator at all times
3. **No automated** data logging/alarm system
4. **System blind** between last control and emptying of the bin
5. Only just above 10% of all containers are controlled
6. Contractor's cost + CERN supervision





Upgrade to an automated system



W-MON

# The requirements for an automatic system

1. The radiation to be monitored is mainly **gamma** rays
2. Sensitivity down to **background level**
3. **Robust** device: resistant to adverse weather, temperature variations, mechanical shocks
4. Must **operate unattended** and with **minimal maintenance**
5. **Low power consumption** (battery powered)
6. Integrated **data transmission** facilities (e.g. GSM, WiFi, RF,  ,  sigfox )
7. Acceptable **cost**
8. To connect to **REMUS** system, which provides data logging and alarm functions
9. Relevant **information**: alarm for radiation level above threshold, alarm for equipment malfunctioning (auto-diagnostic), location of the container (GPS), log of the use of the container (whether the lid has been opened)

# REMUS: Radiation and Environment Monitoring Unified Supervision

The left screenshot displays the 'Geographic view' of the facility. It features a central circular map with several monitoring points marked as green circles and labeled: 'Point 1', 'Point 2', 'Point 3', 'Point 4', 'Point 5', 'Point 6', 'Point 7', 'Point 8', 'Point 9', 'Point 10', 'Point 11', 'Point 12', 'Point 13', 'Point 14', 'Point 15', 'Point 16', 'Point 17', 'Point 18', 'Point 19', 'Point 20', 'Point 21', 'Point 22', 'Point 23', 'Point 24', 'Point 25', 'Point 26', 'Point 27', 'Point 28', 'Point 29', 'Point 30'. A legend at the bottom left identifies the points: 'Point 1: ALICE', 'Point 2: ATLAS', 'Point 3: CMS', 'Point 4: LHCb', 'Point 5: LHCb', 'Point 6: LHCb', 'Point 7: LHCb', 'Point 8: LHCb', 'Point 9: LHCb', 'Point 10: LHCb', 'Point 11: LHCb', 'Point 12: LHCb', 'Point 13: LHCb', 'Point 14: LHCb', 'Point 15: LHCb', 'Point 16: LHCb', 'Point 17: LHCb', 'Point 18: LHCb', 'Point 19: LHCb', 'Point 20: LHCb', 'Point 21: LHCb', 'Point 22: LHCb', 'Point 23: LHCb', 'Point 24: LHCb', 'Point 25: LHCb', 'Point 26: LHCb', 'Point 27: LHCb', 'Point 28: LHCb', 'Point 29: LHCb', 'Point 30: LHCb'. A data table at the bottom shows the following information:

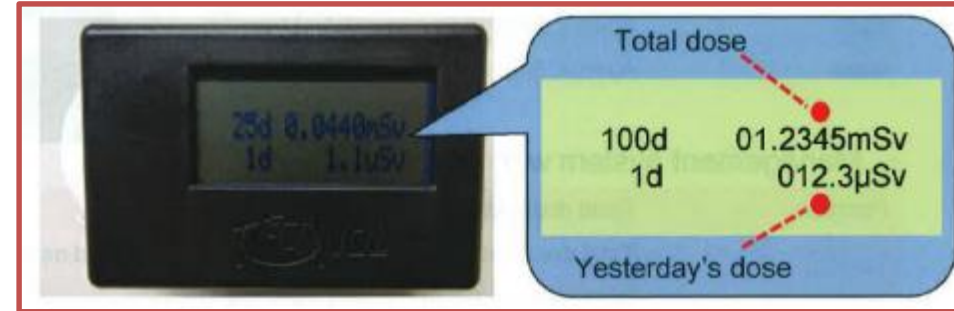
ID	Start time	End time	Status	Type	Zone	Description	Level	Priority
PS0001	10/18/2017 13:00:00	10/18/2017 13:00:00	Alarm off	System fault	Professional control room: US and corresponding	Professional control room: US and corresponding	0	Medium
PS0002	10/18/2017 13:00:00	10/18/2017 13:00:00	Alarm off	System fault	Professional control room: US and corresponding	Professional control room: US and corresponding	0	Medium
PS0003	10/18/2017 13:00:00	10/18/2017 13:00:00	Alarm off	System fault	Professional control room: US and corresponding	Professional control room: US and corresponding	0	Medium
PS0004	10/18/2017 13:00:00	10/18/2017 13:00:00	Alarm off	System fault	Professional control room: US and corresponding	Professional control room: US and corresponding	0	Medium
PS0005	10/18/2017 13:00:00	10/18/2017 13:00:00	Alarm off	System fault	Professional control room: US and corresponding	Professional control room: US and corresponding	0	Medium

The right screenshot displays the 'PS Control' view. It features a central aerial map of the facility with several control panels around it. The control panels are labeled with IDs and names: 'PS0001', 'PS0002', 'PS0003', 'PS0004', 'PS0005', 'PS0006', 'PS0007', 'PS0008', 'PS0009', 'PS0010', 'PS0011', 'PS0012', 'PS0013', 'PS0014', 'PS0015', 'PS0016', 'PS0017', 'PS0018', 'PS0019', 'PS0020', 'PS0021', 'PS0022', 'PS0023', 'PS0024', 'PS0025', 'PS0026', 'PS0027', 'PS0028', 'PS0029', 'PS0030'. A data table at the bottom shows the following information:

ID	Start time	End time	Status	Type	Zone	Description	Level	Priority
PS0001	10/18/2017 13:00:00	10/18/2017 13:00:00	Alarm off	System fault	Professional control room: US and corresponding	Professional control room: US and corresponding	0	Medium
PS0002	10/18/2017 13:00:00	10/18/2017 13:00:00	Alarm off	System fault	Professional control room: US and corresponding	Professional control room: US and corresponding	0	Medium
PS0003	10/18/2017 13:00:00	10/18/2017 13:00:00	Alarm off	System fault	Professional control room: US and corresponding	Professional control room: US and corresponding	0	Medium
PS0004	10/18/2017 13:00:00	10/18/2017 13:00:00	Alarm off	System fault	Professional control room: US and corresponding	Professional control room: US and corresponding	0	Medium
PS0005	10/18/2017 13:00:00	10/18/2017 13:00:00	Alarm off	System fault	Professional control room: US and corresponding	Professional control room: US and corresponding	0	Medium



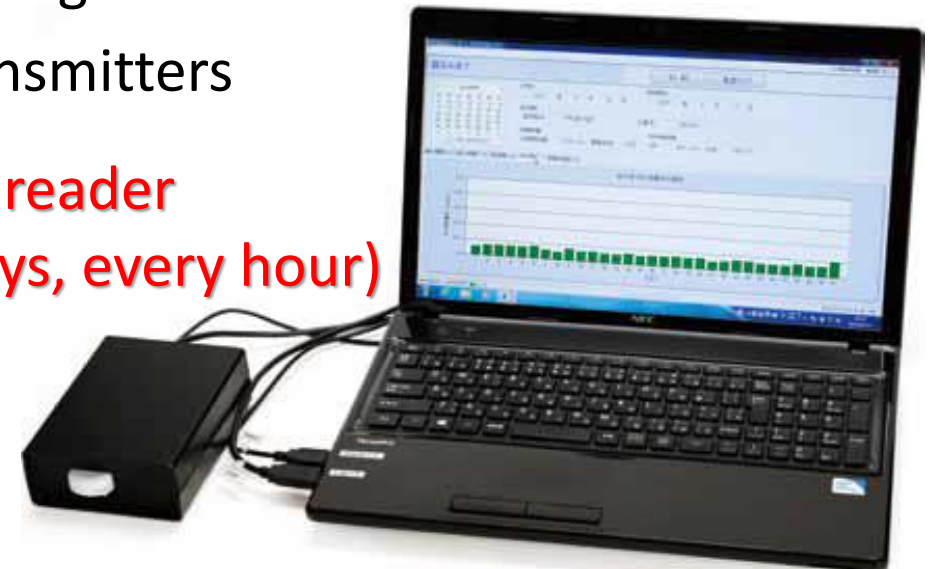
# The D-shuttle personal dosimeter (Chiyoda / AIST)



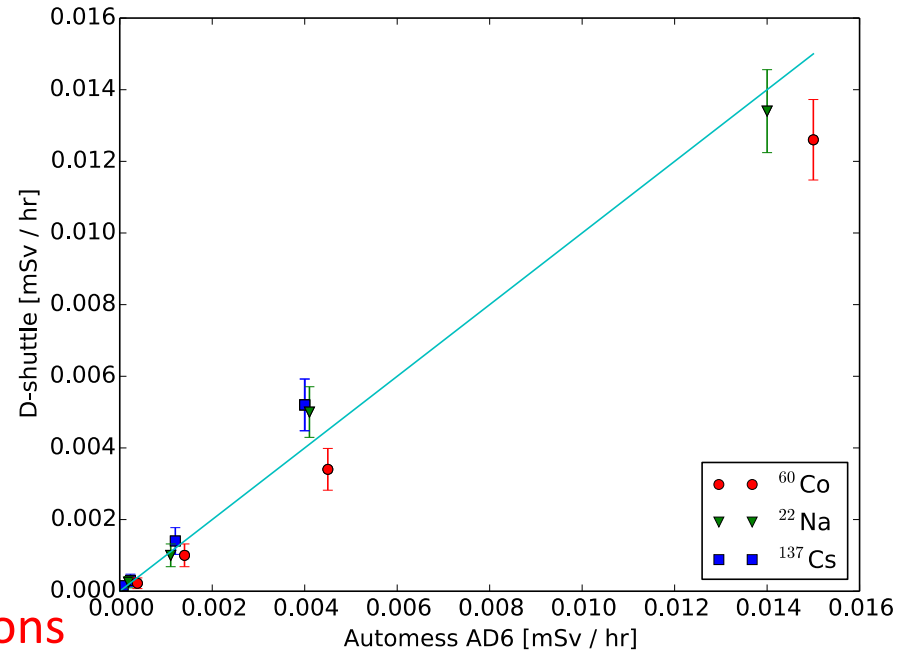
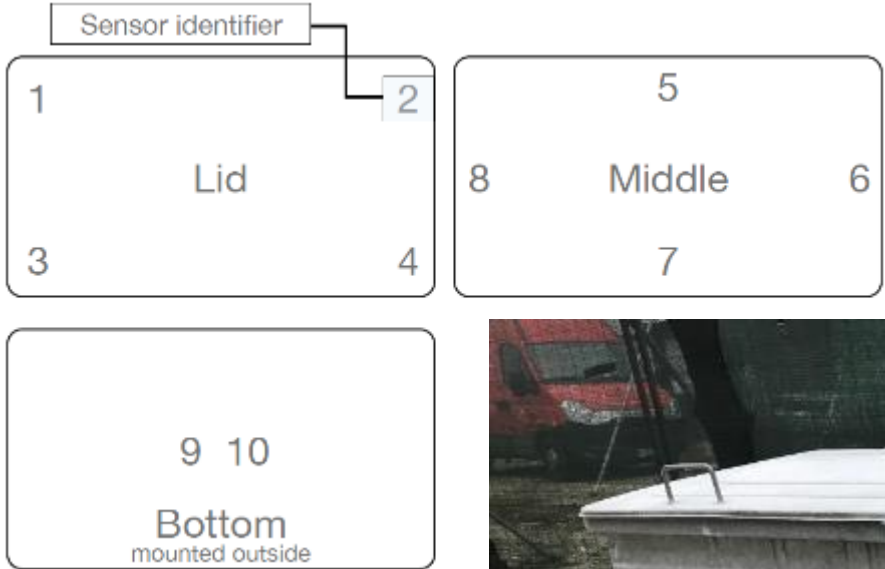
Personal reader (one day, integral dose)

- Hamamatsu Si PIN diode
- Electronic board with microprocessor and memory storage
- Communication board with optical and 2.4 GHz RF transmitters
- Shock sensor
- Lithium battery, lifetime 1 year
- Dose reading from 0.1  $\mu$ Sv to 100 mSv
- Size 68 mm x 32 mm x 14 mm
- Weight 23 g

History reader  
(400 days, every hour)



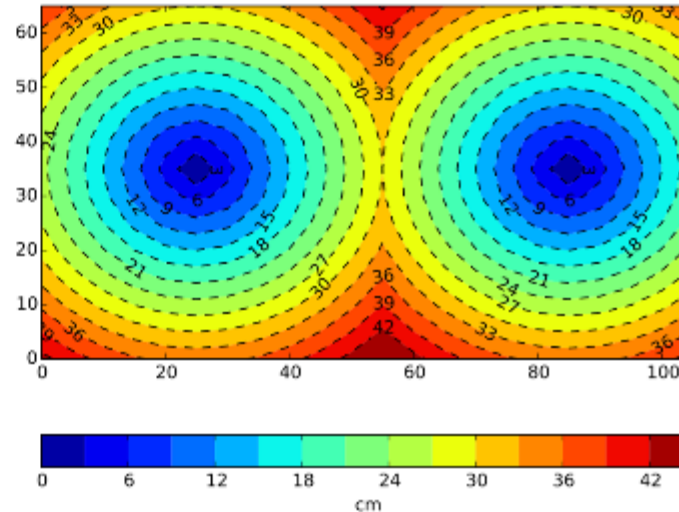
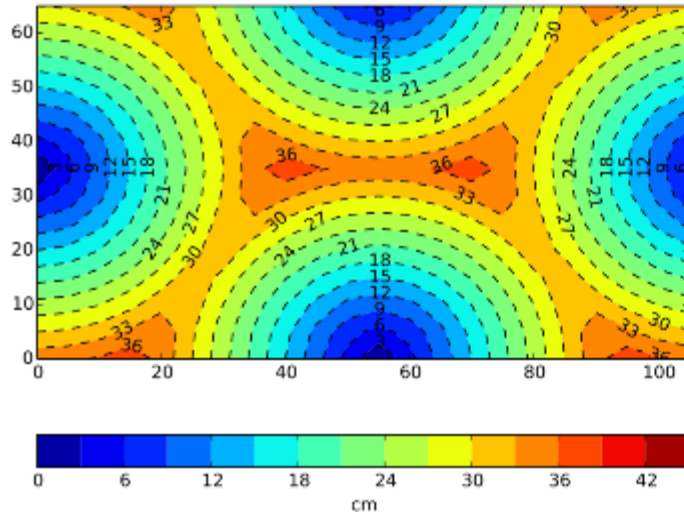
# Tests in operational conditions: sensors' coverage



Sensitivity: 10 counts per 0.1  $\mu\text{Sv}$  (= 10 cts/h per 0.1  $\mu\text{Sv/h}$ ) with  $^{137}\text{Cs}$  photons

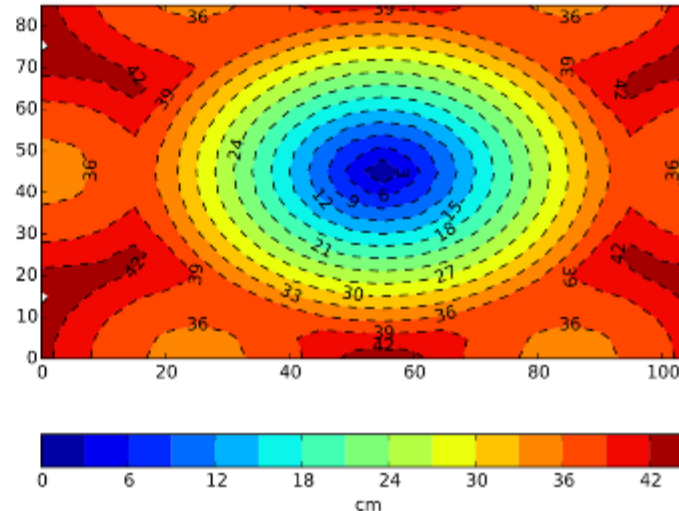
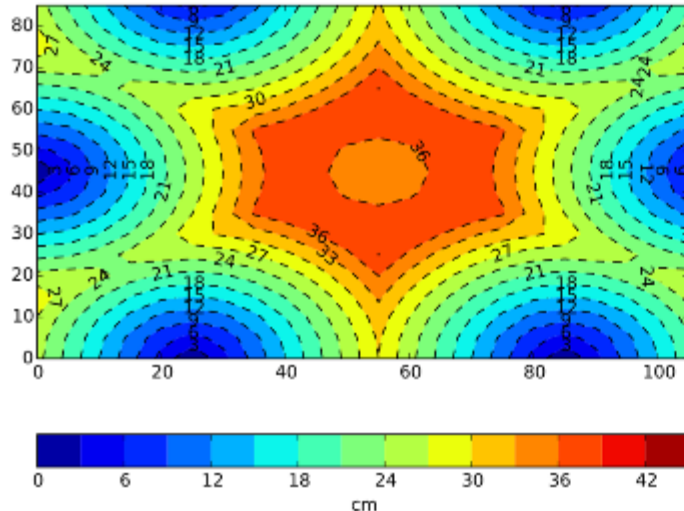
# Closest sensor distance maps

Horizontal Mid-plane



Top or bottom

Vertical Mid-plane



Side

Distance map: distance of closest sensor at any given position (in cm)

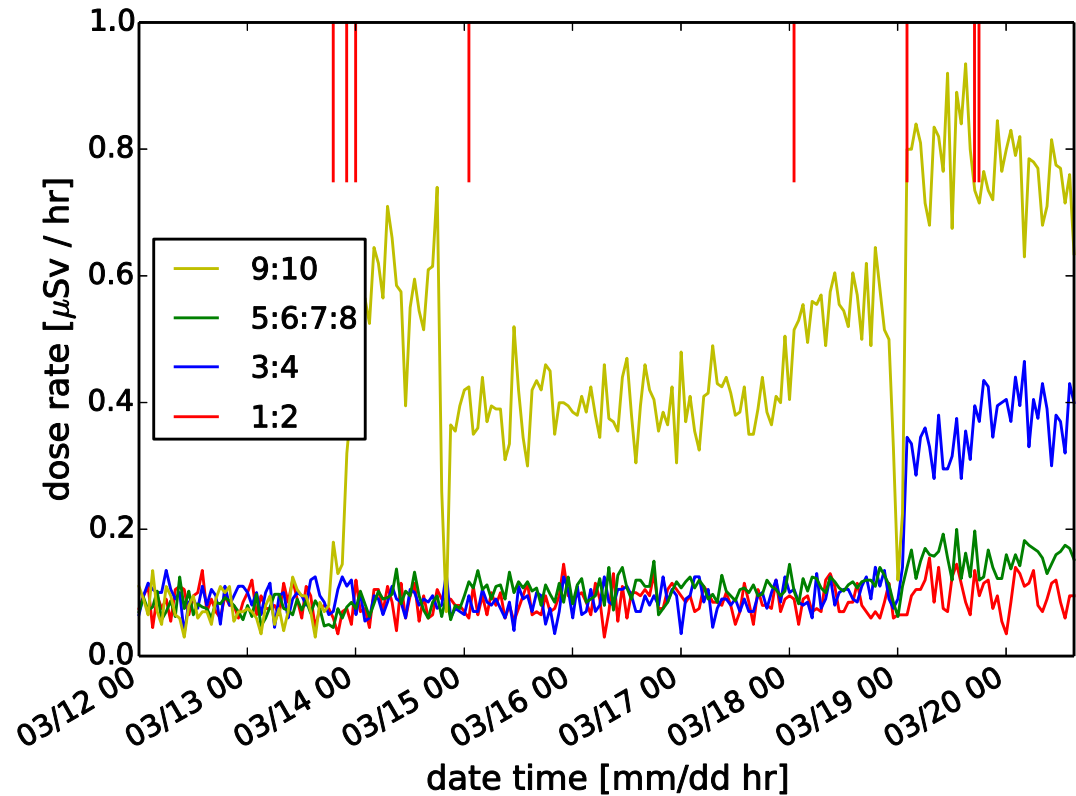


# Tests in operational conditions (10 sensors on the container)

cables from waste

pizza box from waste

D-shuttle



- Filling the waste container from the bottom
- The 2 dips are due to reading of the sensors [taken out for ~2 hours]
- The lower reading after #4 went in is due to the pieces rolling toward the sides

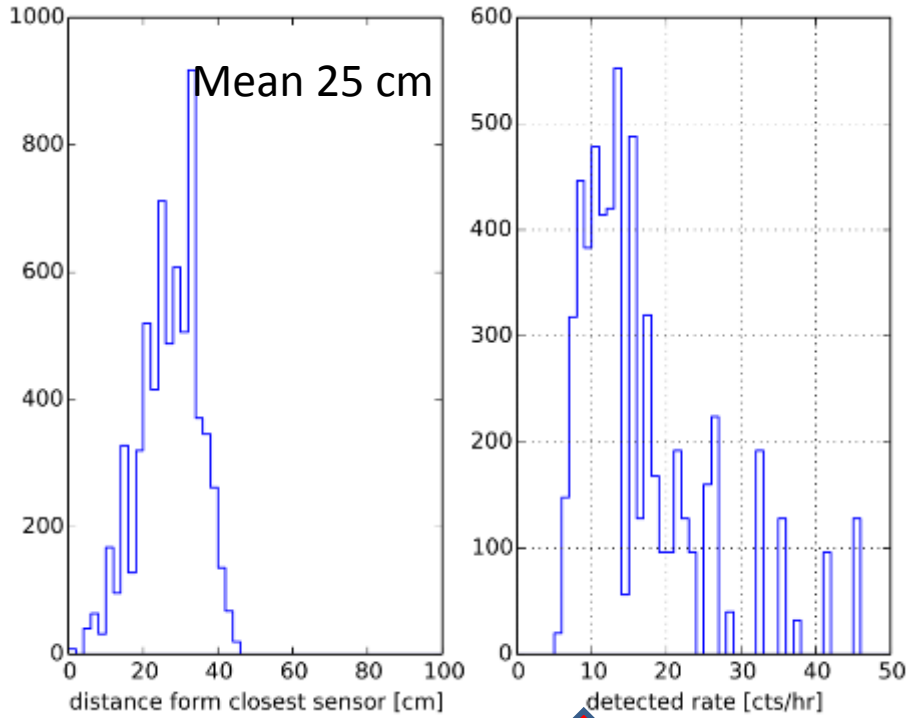
# Tests in operational conditions

- Operational test in realistic conditions ongoing since April 3<sup>rd</sup>
- A regular waste container **equipped with 8 sensors**
- Each sensor housed in a plastic waterproof box and protected by a light metal shield
- Over 8 months the stability of the response of the sensors has been tested against:
  - ✓ Temperature variations (from 5 °C to over 40 °C inside the container)
  - ✓ Rain and high humidity
  - ✓ Shaking test (in a washing machine!)
  - ✓ Shaking and mechanical shock during normal use of the container (filling, emptying, etc.)

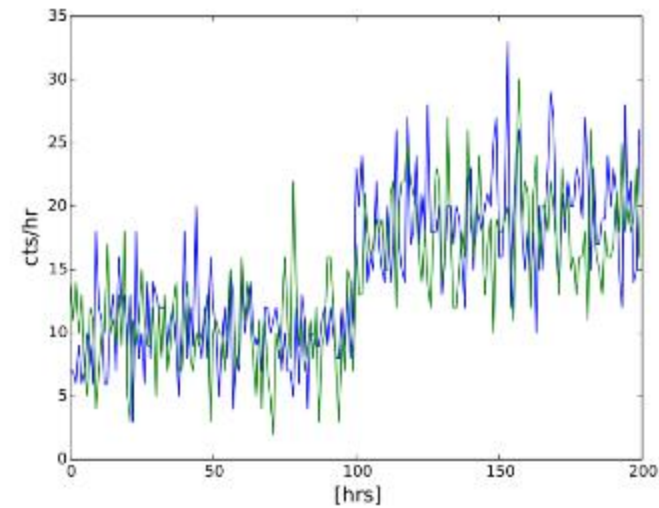
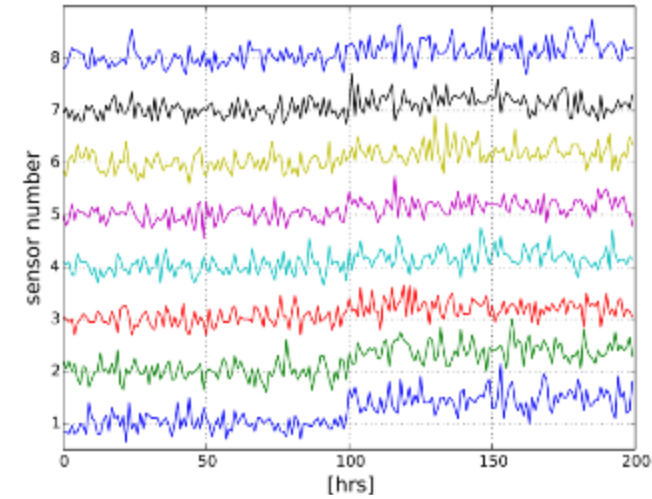


# Tests in operational conditions

150 kBq  $^{137}\text{Cs}$  source  
in the centre of the container

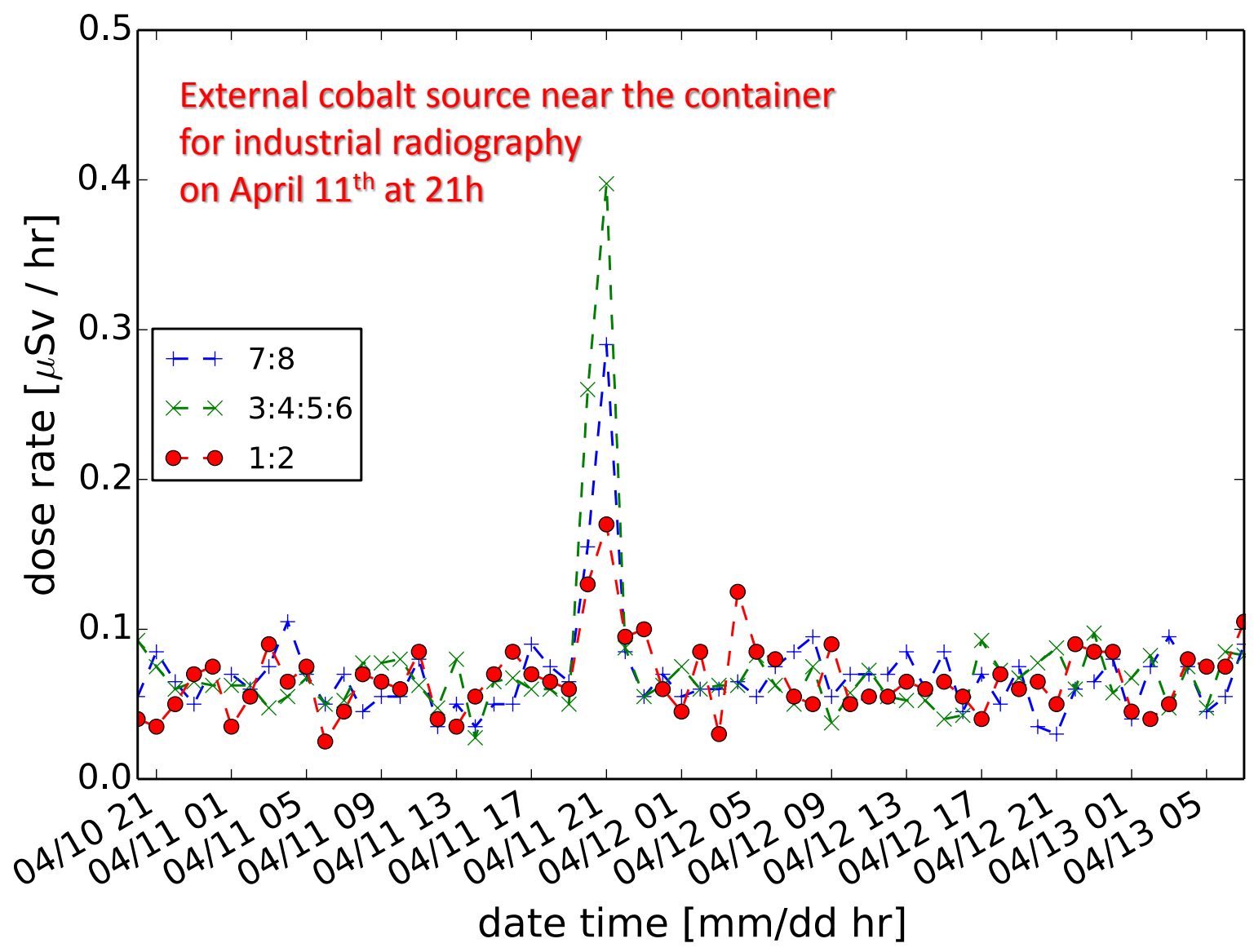


Background would be 10 cts/h



8 sensors, source on the bottom at [55,0,-45]

# Tests in operational conditions

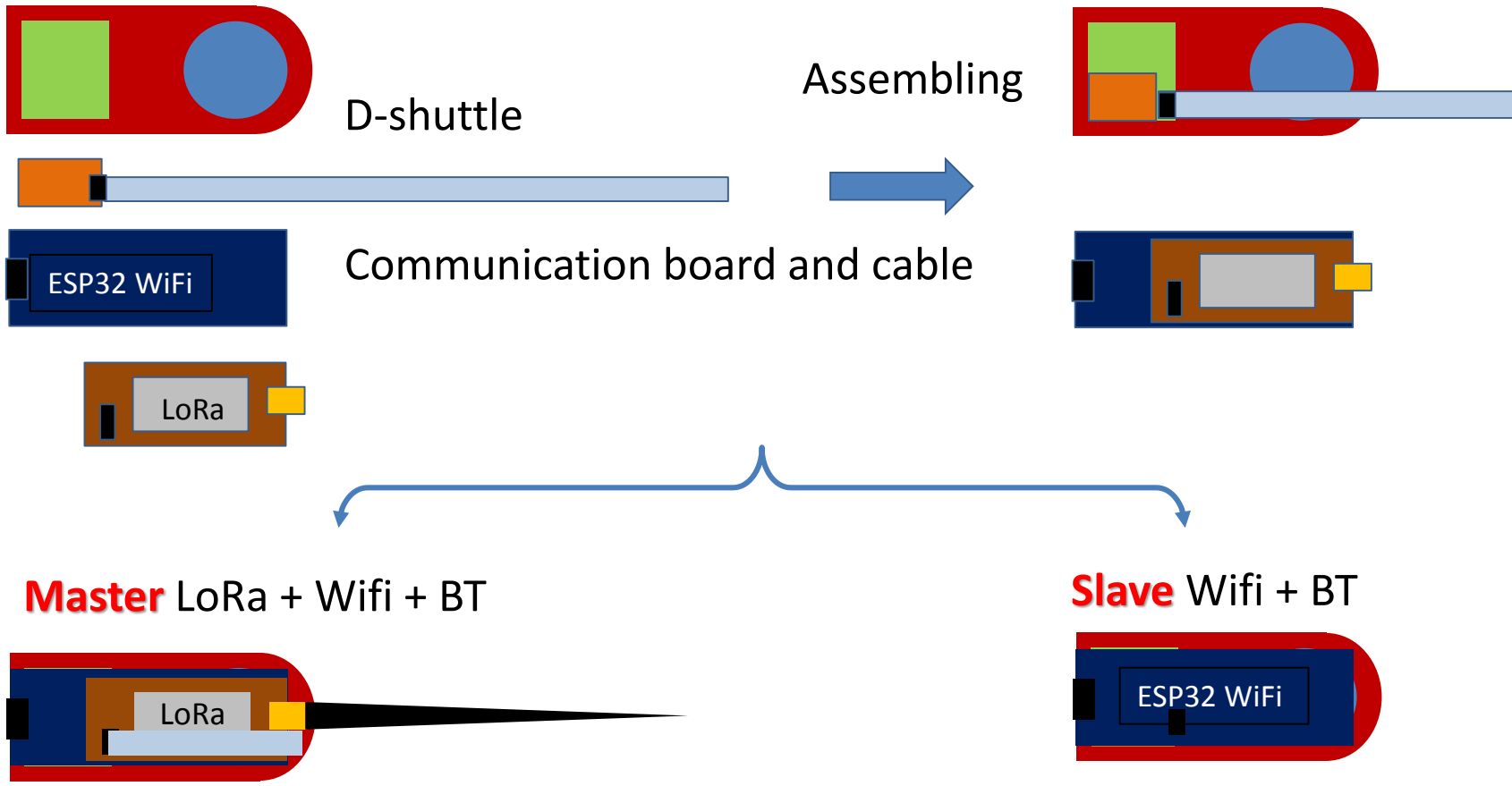


**We have the sensor ...**

**Now we need to communicate automatically  
the measurements**



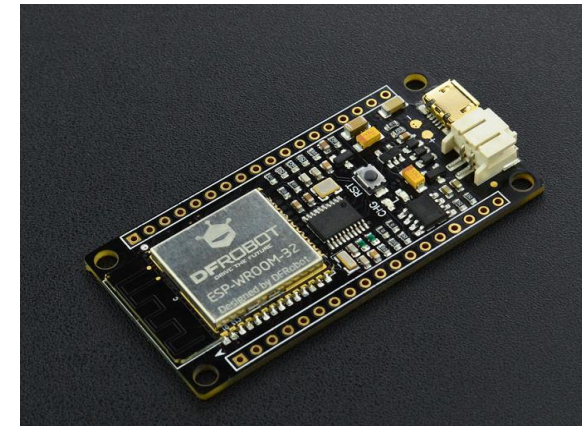
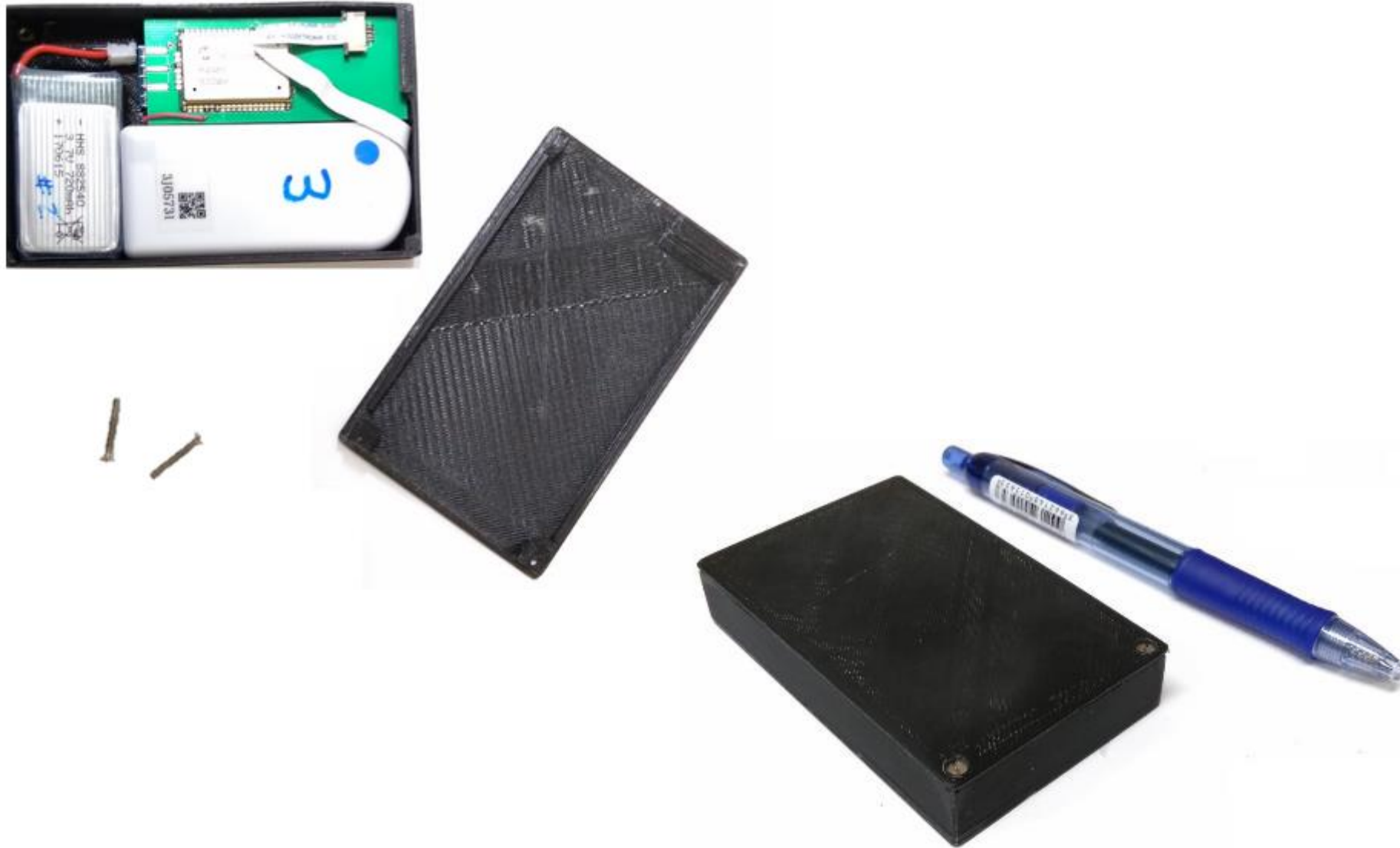
# D-shuttle assemblies for wireless communication



LoRa gateway



# The present W-MON slave prototype



Firebeatle **ESP32**

**USA**

3.3 V

WiFi

**Bluetooth !!**

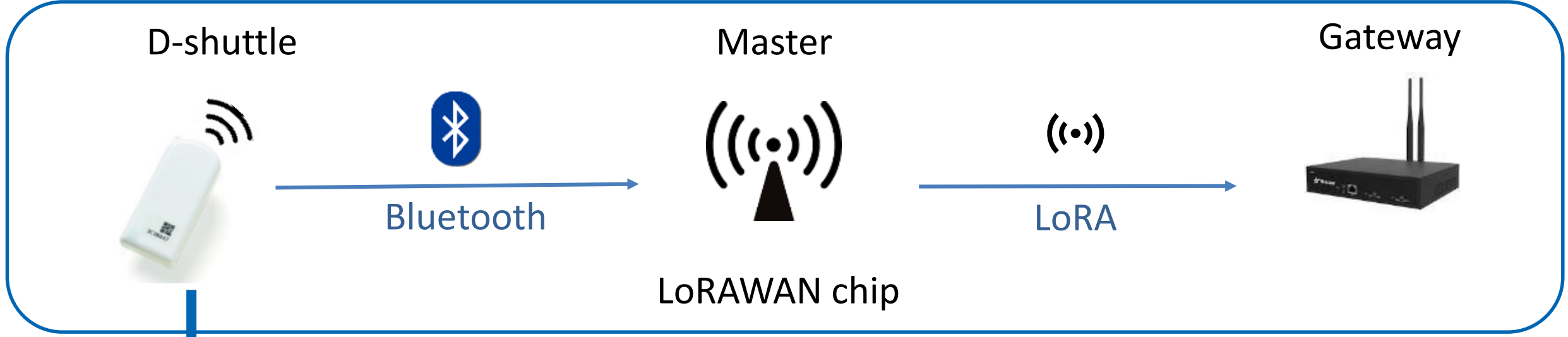
Very low consumption

Standby 10 uA

**Rechargeable**

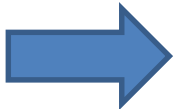
**16 euro**

# New W-MON communication



**Before:**

- RF data transfer
- Optical data transfer
- Manual trigger by an external magnetic field



**Now:**

- BT transfer
- Micro-controller
  - trigger
  - decode data packets



# Data transmission

```
12/10/2016, 18:34:49 [b95db3ba.522be8]
[msg.payload] : string
Dose = 1795.99 uSv

12/10/2016, 18:35:19 [b95db3ba.522be8]
[msg.payload] : string
Dose = 1796.00 uSv

12/10/2016, 18:35:49 [b95db3ba.522be8]
[msg.payload] : string
Dose = 1796.01 uSv

12/10/2016, 18:36:19 [b95db3ba.522be8]
[msg.payload] : string
Dose = 1796.02 uSv

12/10/2016, 18:36:49 [b95db3ba.522be8]
[msg.payload] : string
Dose = 1796.06 uSv

12/10/2016, 18:37:19 [b95db3ba.522be8]
[msg.payload] : string
Dose = 1796.34 uSv

12/10/2016, 18:37:49 [b95db3ba.522be8]
[msg.payload] : string
Dose = 1796.67 uSv

12/10/2016, 18:38:19 [b95db3ba.522be8]
[msg.payload] : string
Dose = 1797.02 uSv

12/10/2016, 18:38:49 [b95db3ba.522be8]
[msg.payload] : string
Dose = 1797.03 uSv
```

NOISE generated by CERN  
*communication board*  
(now solved)

No gamma source

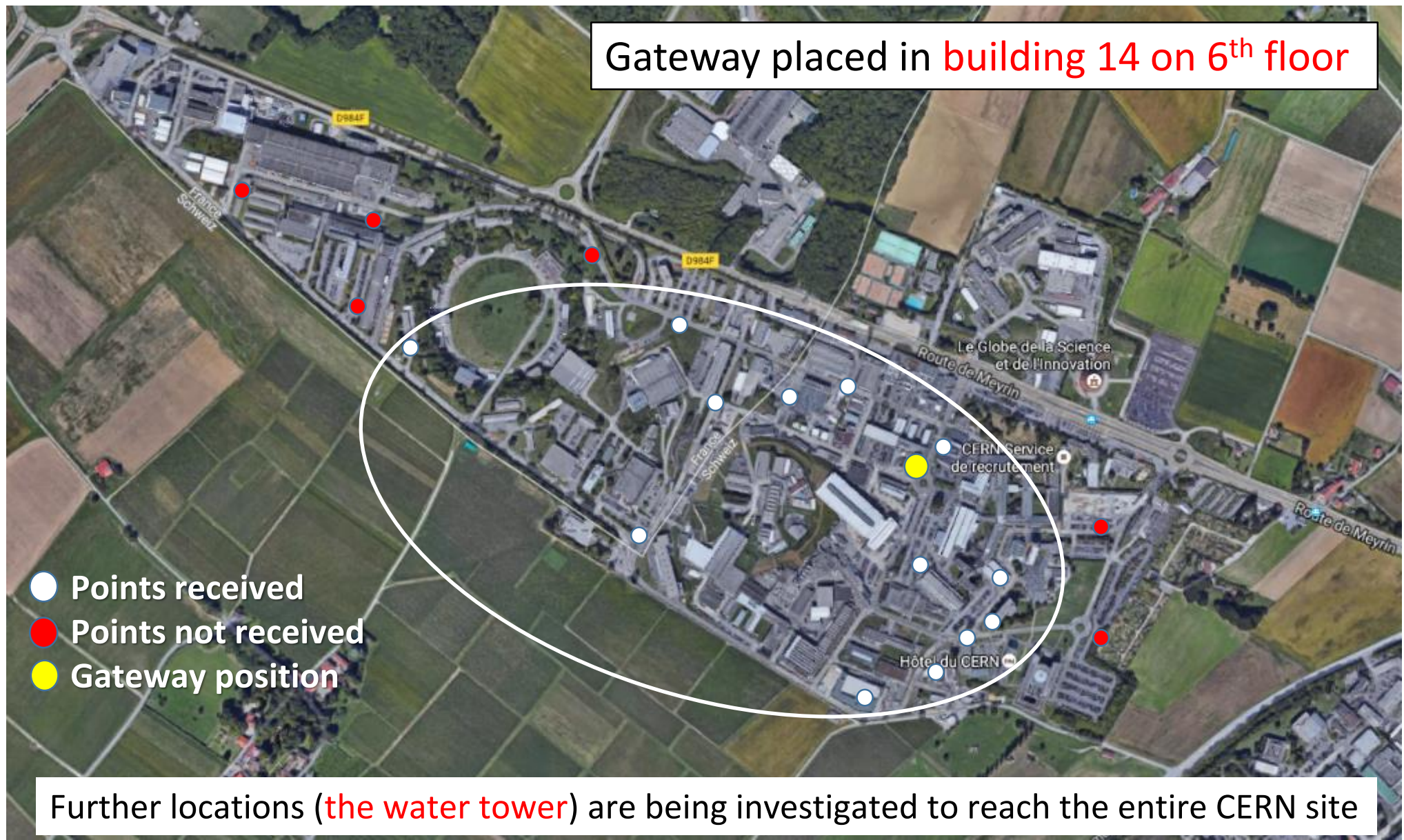
Gamma source

Decoded and transmitted data  
from D-shuttle to remote PC  
through the LoRa  
communication protocol

Dose recorded every 30 seconds



# Lora range test @ CERN



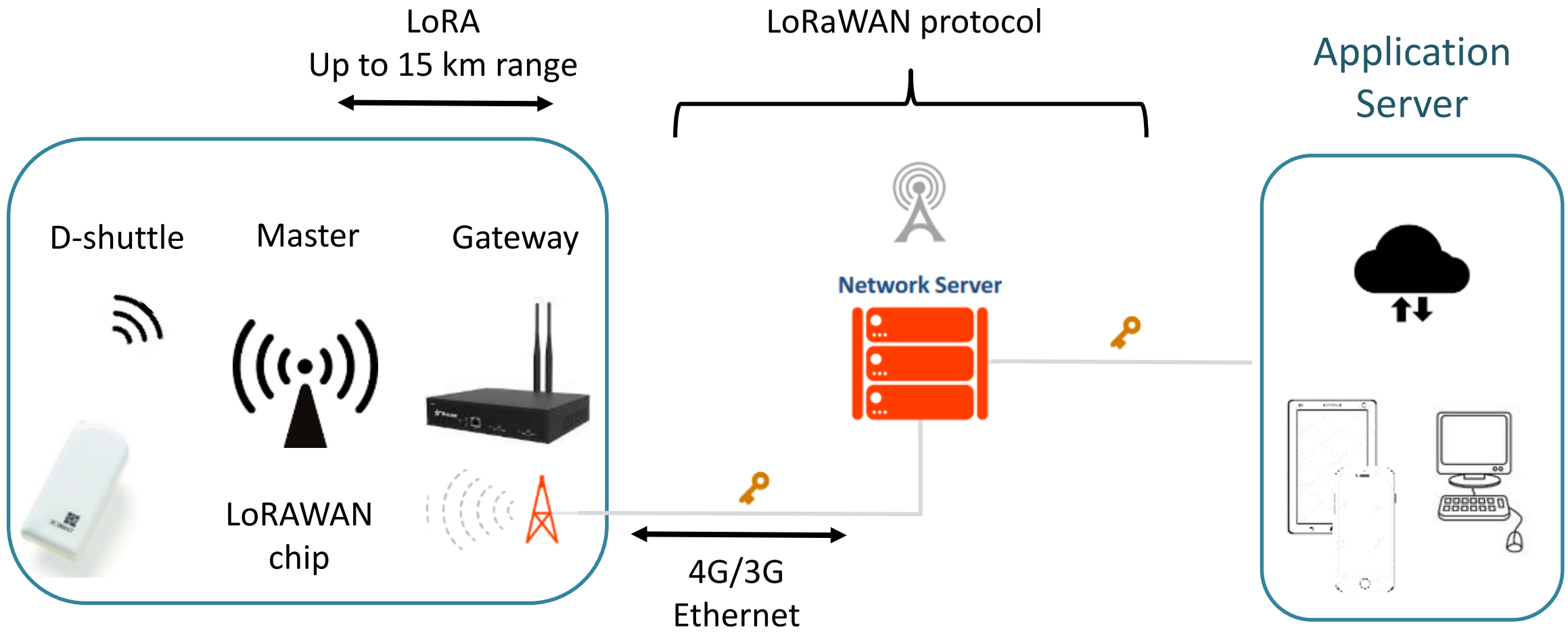


# W-MON architecture



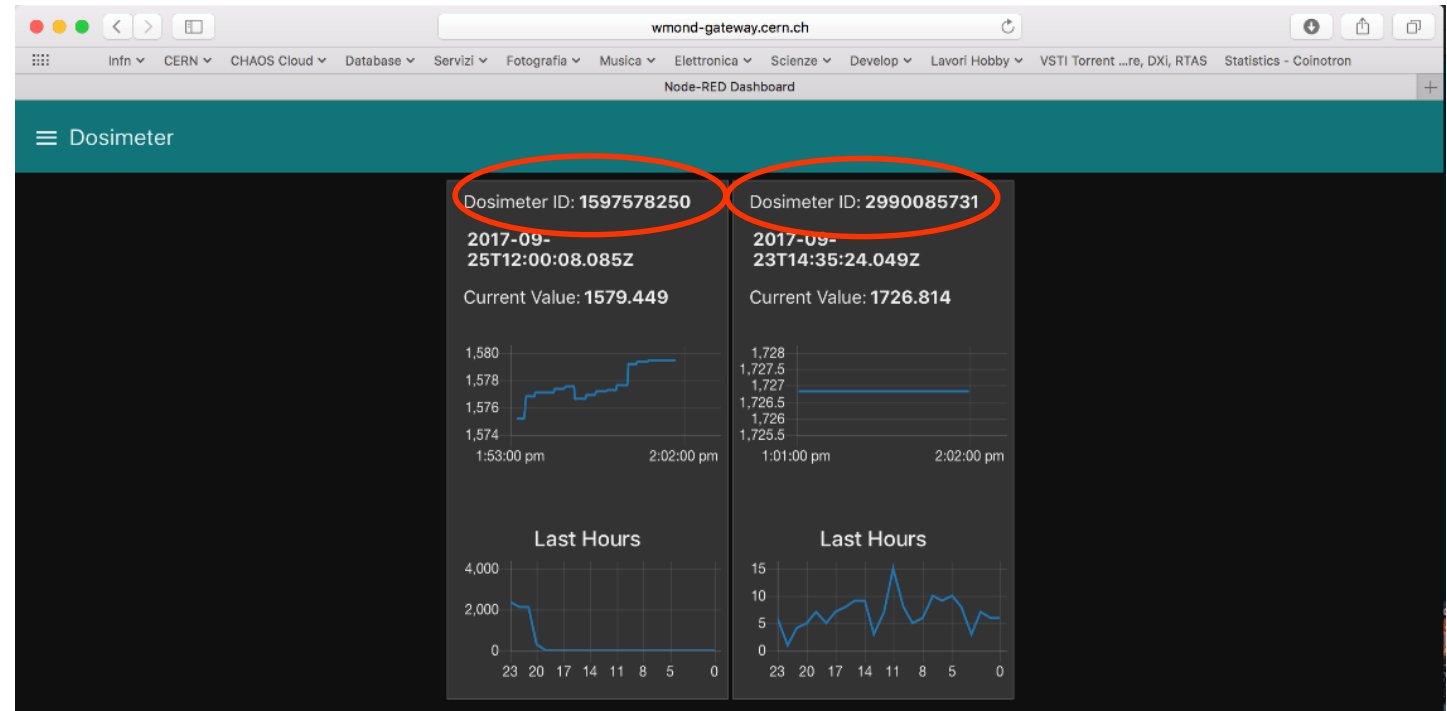
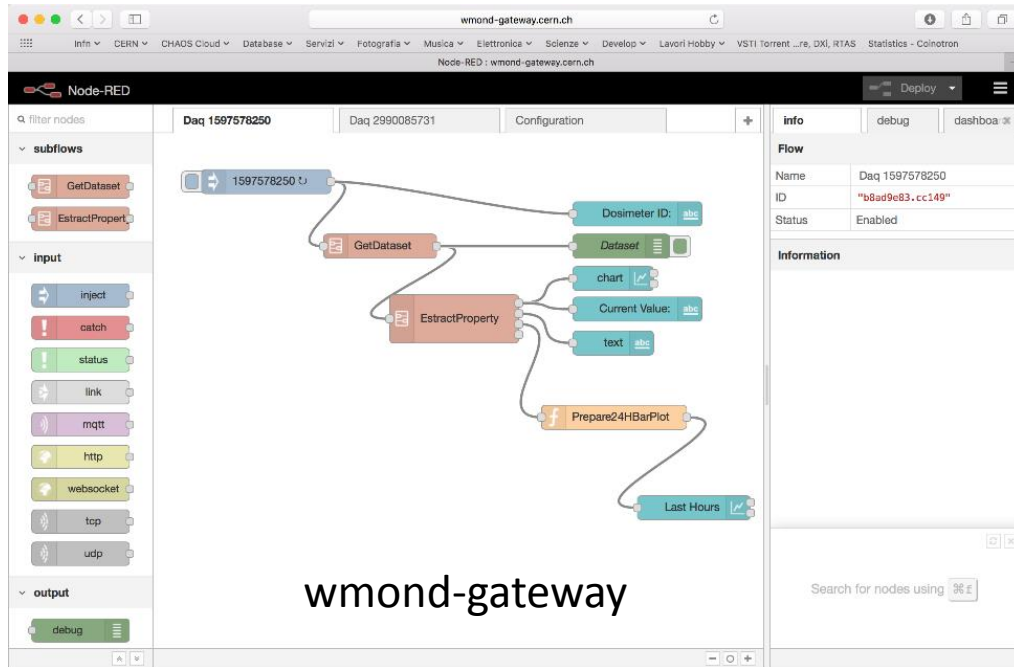
- 1) The master waits for the data from the dosimeters through WiFi
- 2) Sends all data through LoRa
- 3) Synchronizes the slaves and everybody gets back to sleep for one hour

# Long Range Wide Area Network - LoRaWAN



Low bit rate -> Low consumption / Frequency band 868 MHz (EU), (920-925 MHz Japan)

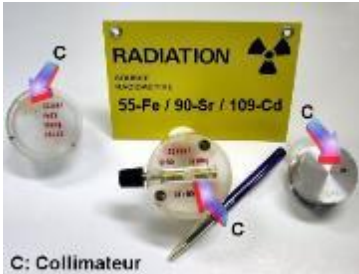
With Node-red a Web monitor page has been realized



1. LoRa range test extended over the entire CERN sites
2. Compatibility tests of LoRa with existing CERN IT infrastructure – **Ongoing**
3. Set-up data transfer to REMUS – **Ongoing**
4. Optimize/reduce power consumption!
5. Test with one or two containers equipped with 8 to 10 D-shuttles, BT and LoRa communication, data transfer to REMUS – **November 2017**
6. Pilot phase with 10 – 20 containers – **Summer 2018**
7. Full scale project – **End 2018**

# Potential perspectives @ CERN

- **Distributed network of sensors: environmental monitoring** of large areas, providing the environmental gamma dose in real time with high granularity
- **Personal dosimetry:** D-shuttle/DIS/DMS comparison
- **Automatic tracking of radioactive sources**
- **Tracking of transport of radioactive materials**





# Thank you !