
CERN
HSE
Occupational Health & Safety
and Environmental Protection unit

CROME

CERN New Radiation Monitoring System

For the Safety and Environment

Dr. Hamza BOUKABACHE

20/09/2022 – ATSR

Daniel Perrin, Clyde Laforge, Gael Ducos, Michel Pangallo, Amitabh Yadav, Markus Widorski, Doris Forkel-Wirth, Stefan Roesler

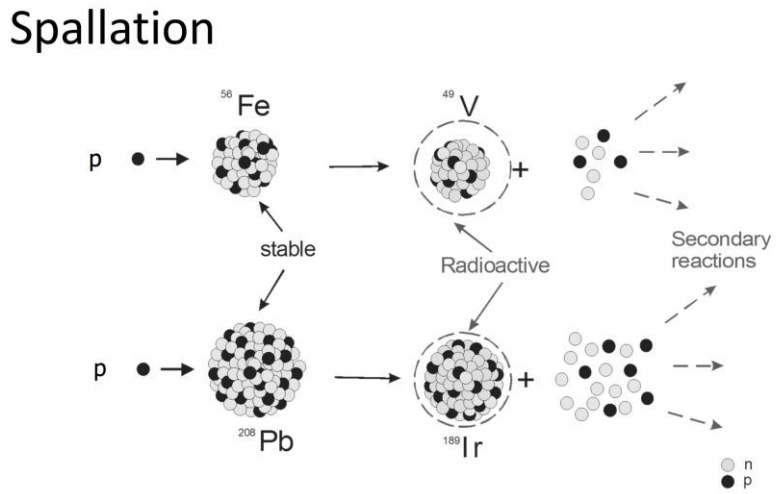
CROME **is CERN New Radiation Monitoring System for Safety and Environment**

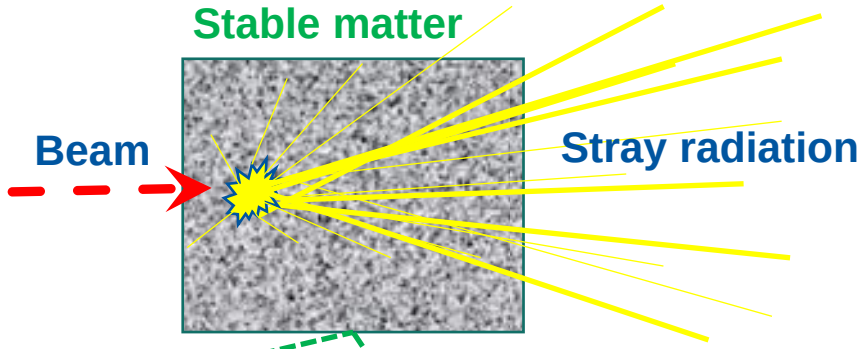
Why do we need a radiation monitoring system at CERN?

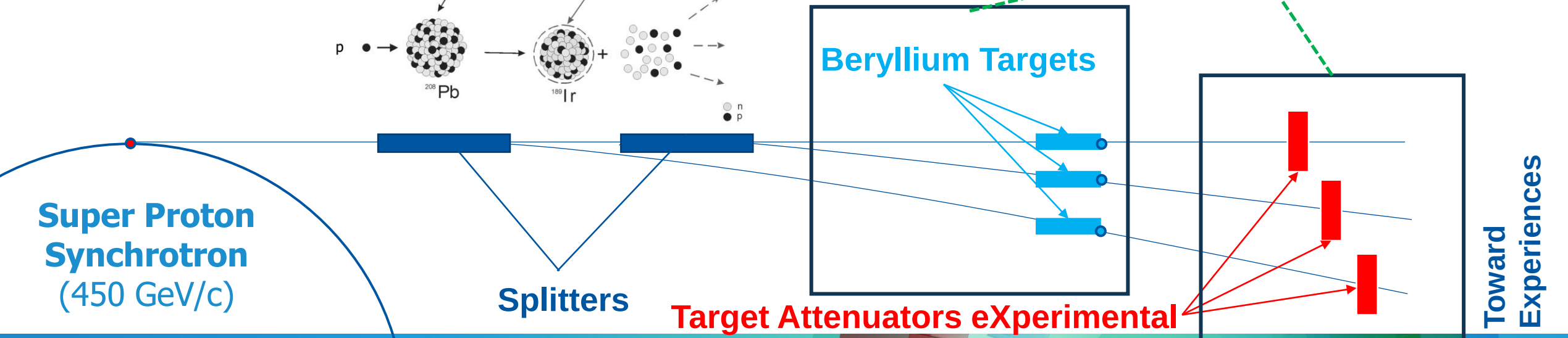
Why do we need a radiation instrumentation system

When Accelerators are in operation

The interaction beam-matter generates stray radiation

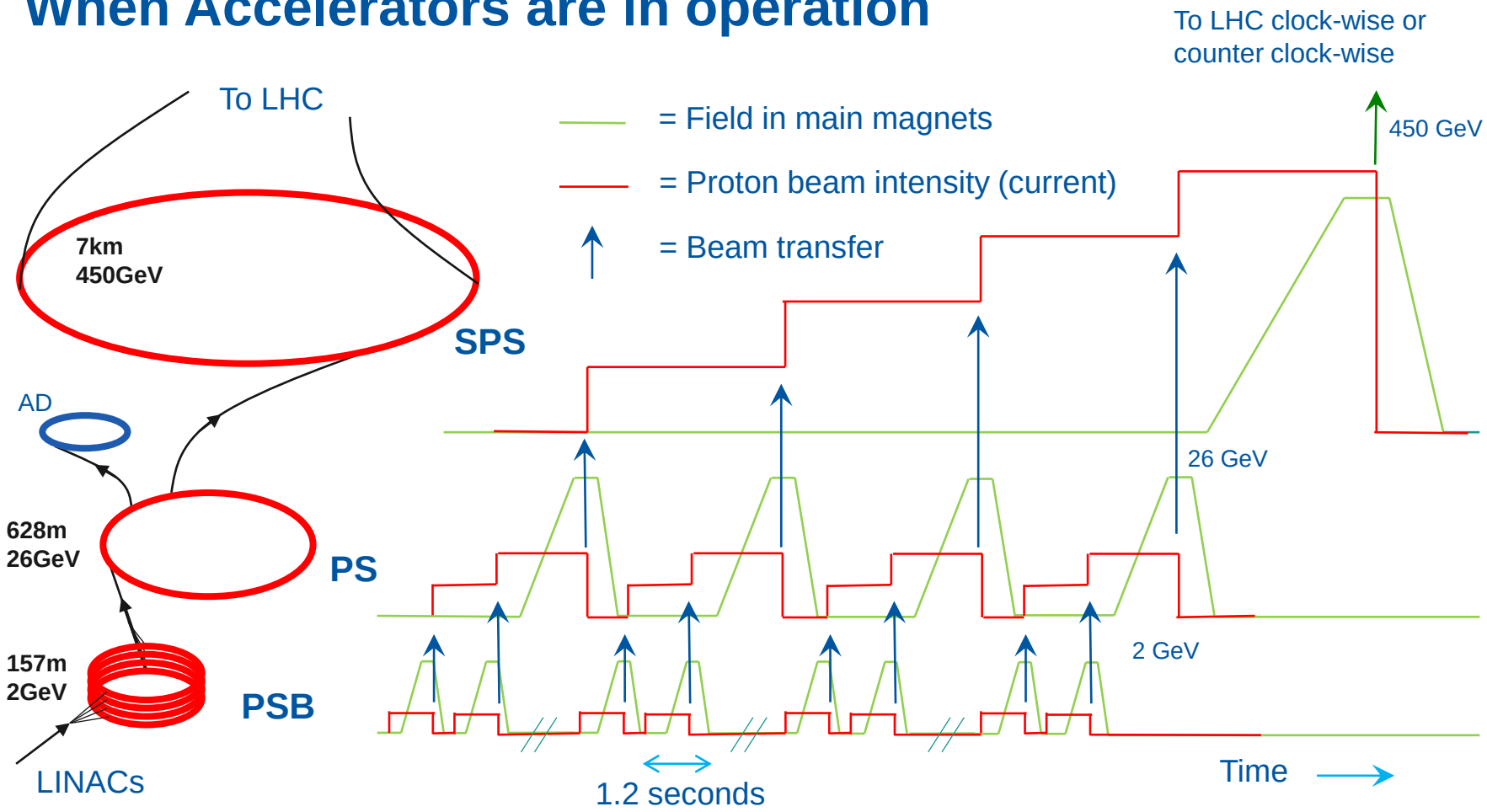


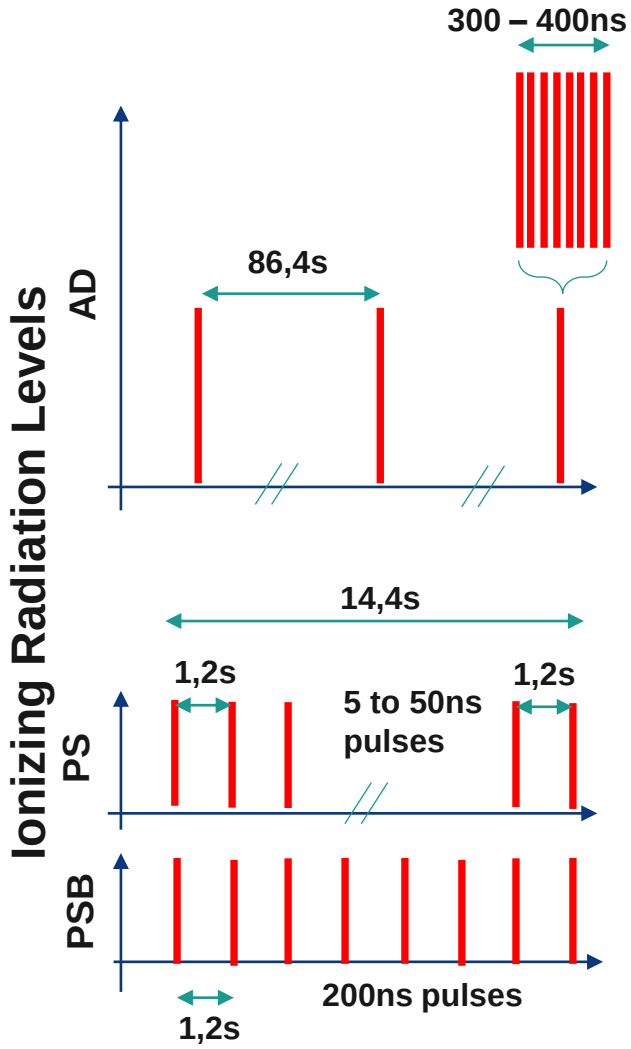




Why do we need a radiation monitoring

When Accelerators are in operation

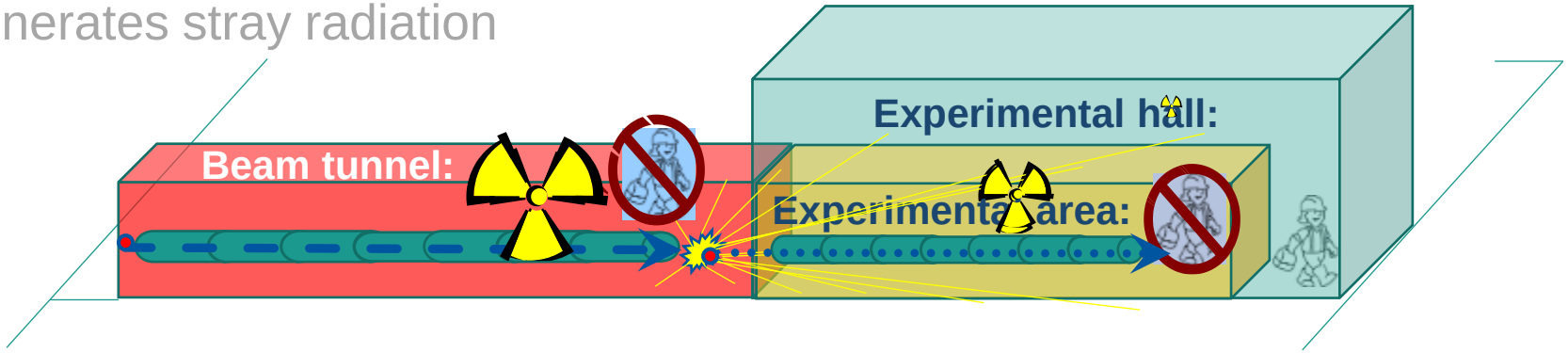




Why do we need a radiation instrumentation system

When Accelerators are in operation

The interaction beam-matter generates stray radiation



When Accelerators are stopped

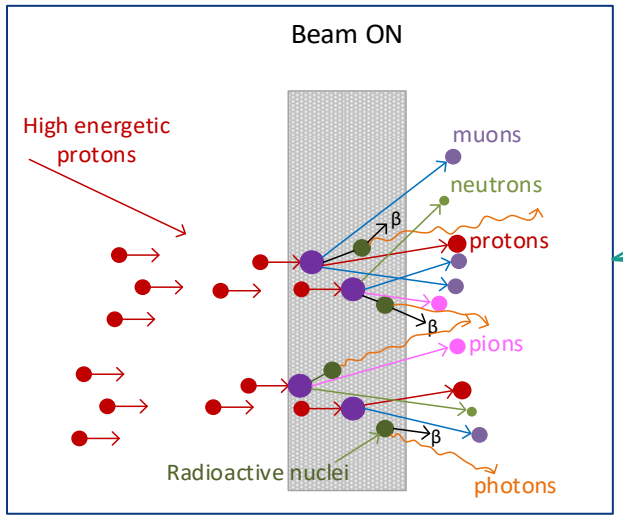
The interaction beam-matter has made the matter radioactive (activation)

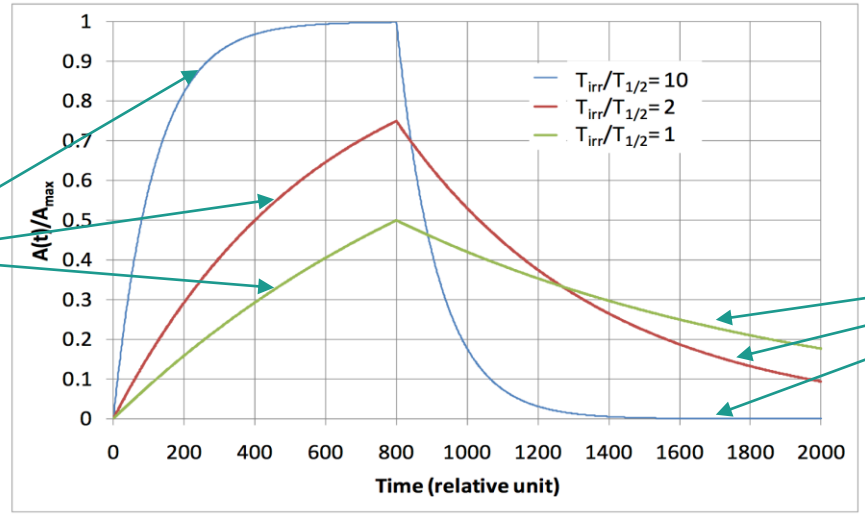
Areas with risks due to ionizing radiation are classified and continually monitored

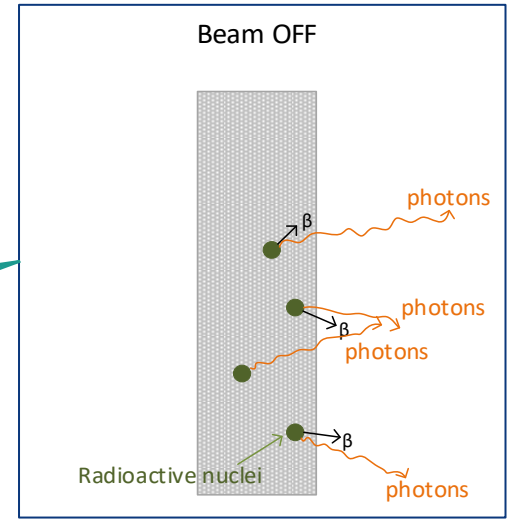
→

When the ambient dose rate is bellow the safety threshold and the survey is Ok : Accesses are re-opened

Why do we need a radiation instrumentation system







When Accelerators are stopped

The interaction beam-matter has made the matter radioactive (activation)

Areas with risks due to ionizing radiation are classified and continually monitored

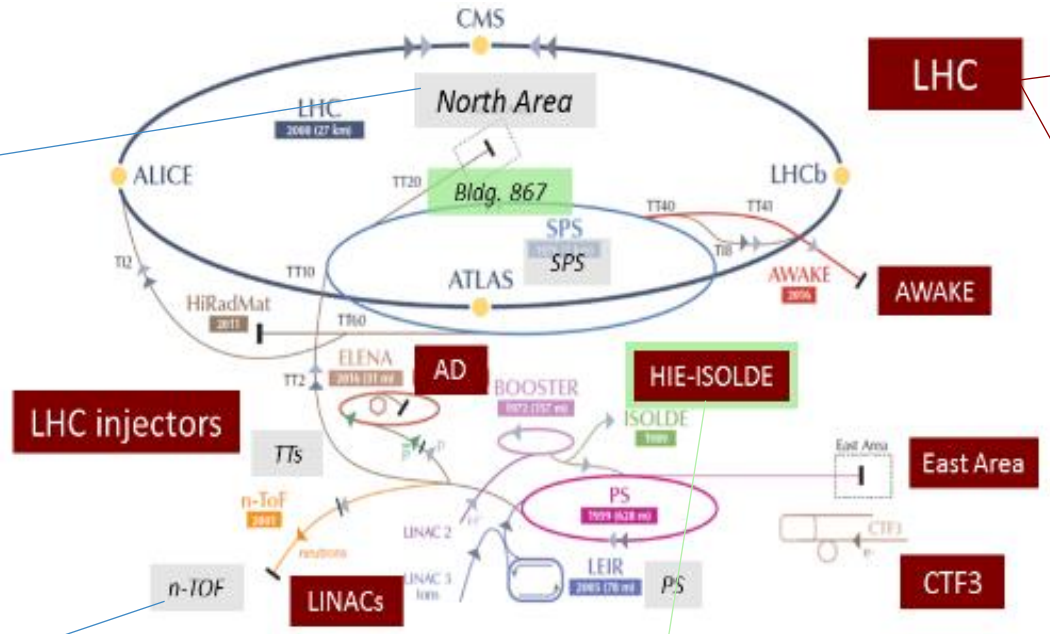
When the ambient dose rate is bellow the safety threshold and the survey is Ok : Accesses are re-opened

Radiation & Environmental Protection Before LS2

864 Radiation Protection channels & **523** Environmental channels

ARCON VME Chassis

Area Monitoring (ARCON)



GRAMS

Area Radiation Monitoring

RAMSES

Induced Activity Monitors

Water Monitors

Stray Rad Monitors

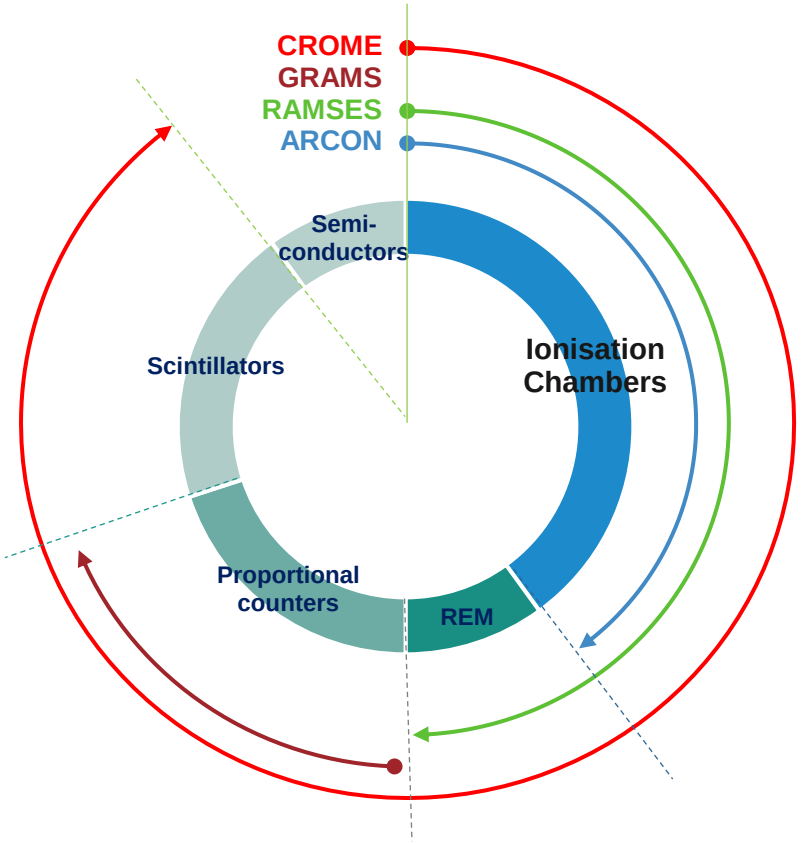
Ventilation Monitors

Radiation & Environmental Protection

CROME Requirement - 2015

- **Development of a new generation of monitoring system**

  This system provides:
  - Continuous real-time monitoring of ambient dose equivalent rates over 9 decades
  - Alarm and interlock functionality with a probability of failure down to 10e-7
  - Long term permanent and reliable data logging by linking to a SCADA supervision
  - Edge computing : Powerful processing capabilities for embedded calculation
  - Versatile interface



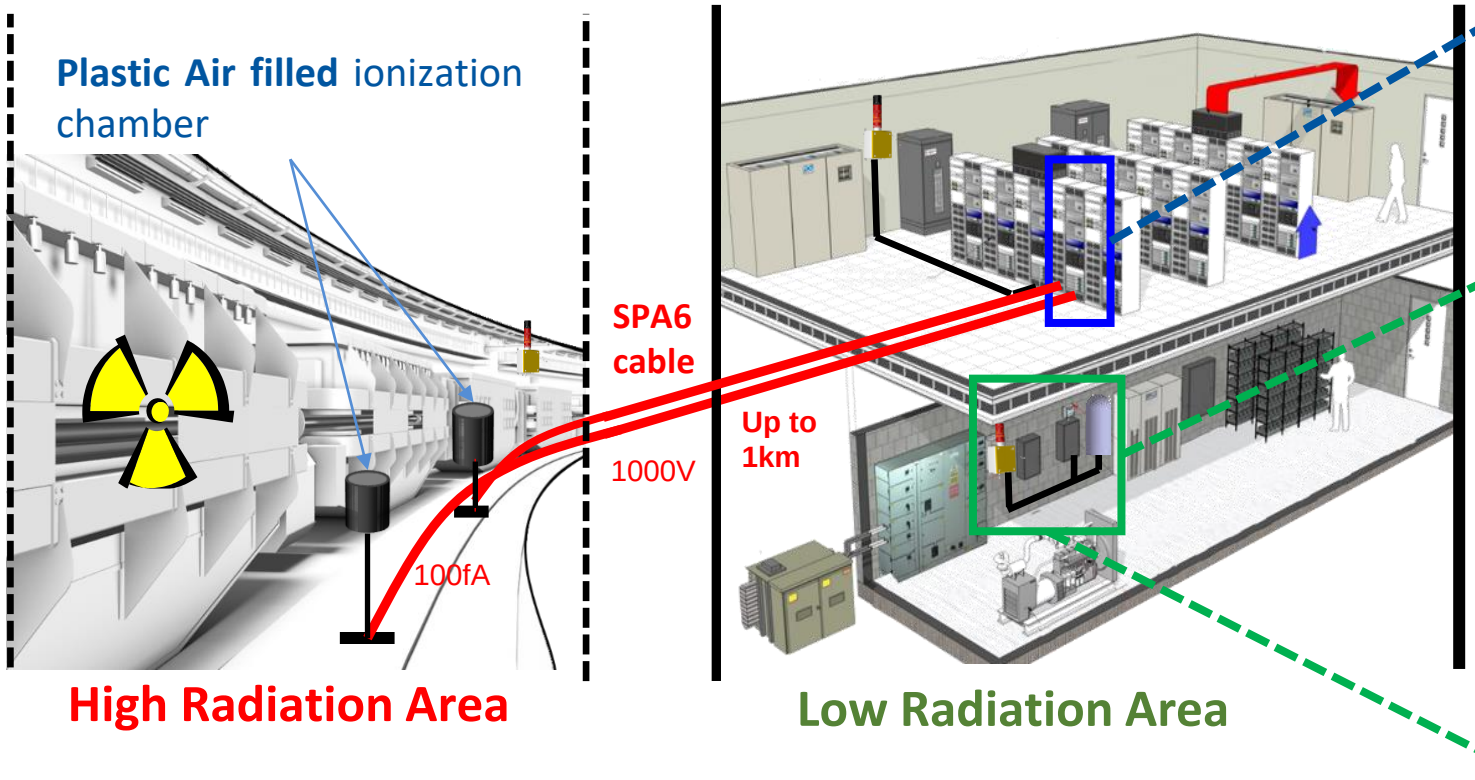
- **Replacing ARCON system**
- **Preparing for future, RAMSES** : 14 years of operation

What is CROME ?

CERN Radiation Monitoring Electronics (CROME)

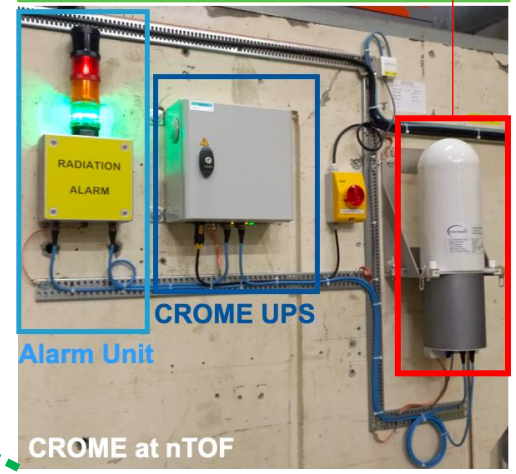
Two configurations :

Conceptual view of CROME at CERN



Radiation Monitoring and processing units

Bulk



Rackable

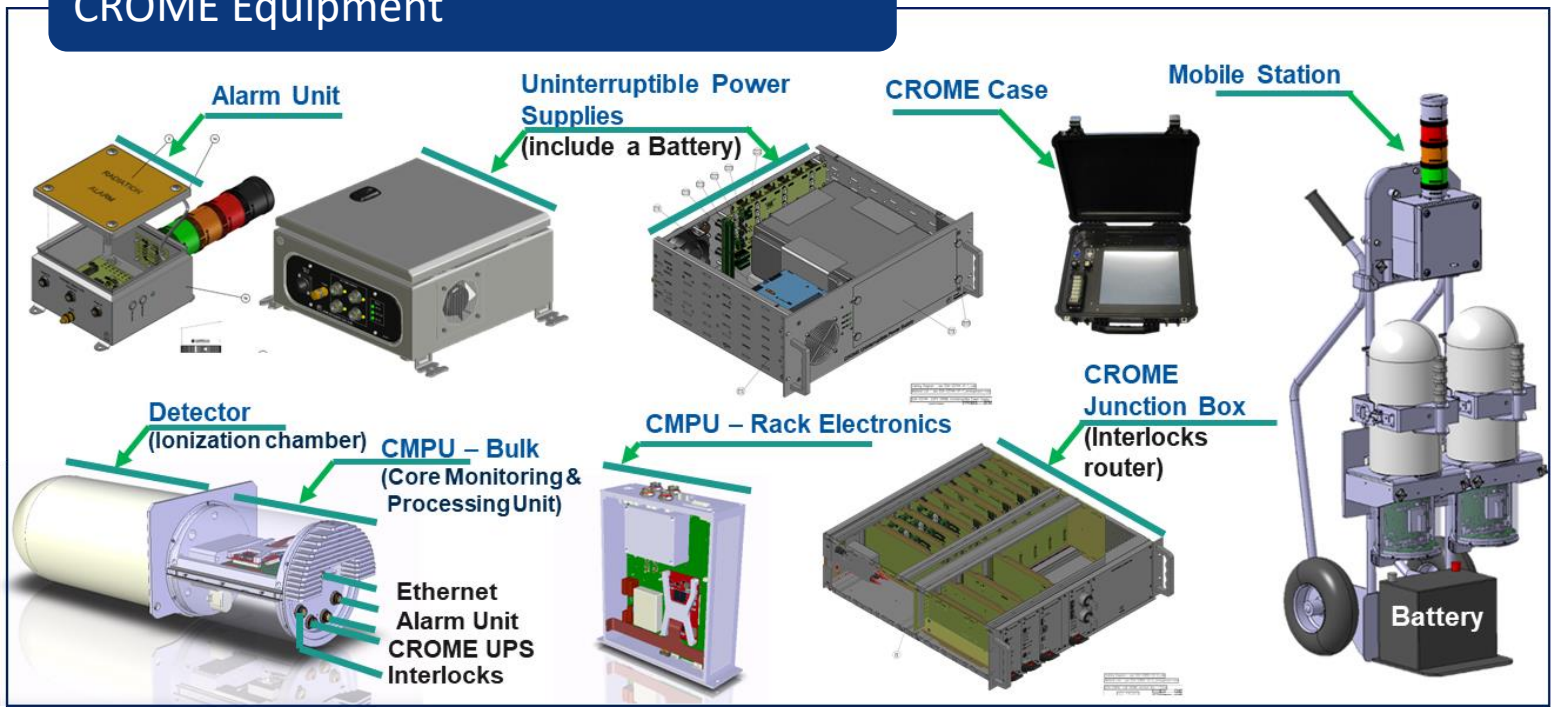
Uninterruptible Power Supply
Includes a battery for continuous operation

CROME Ecosystem

CROME Software

QEMU ... **Romulus** LIBRARY v7

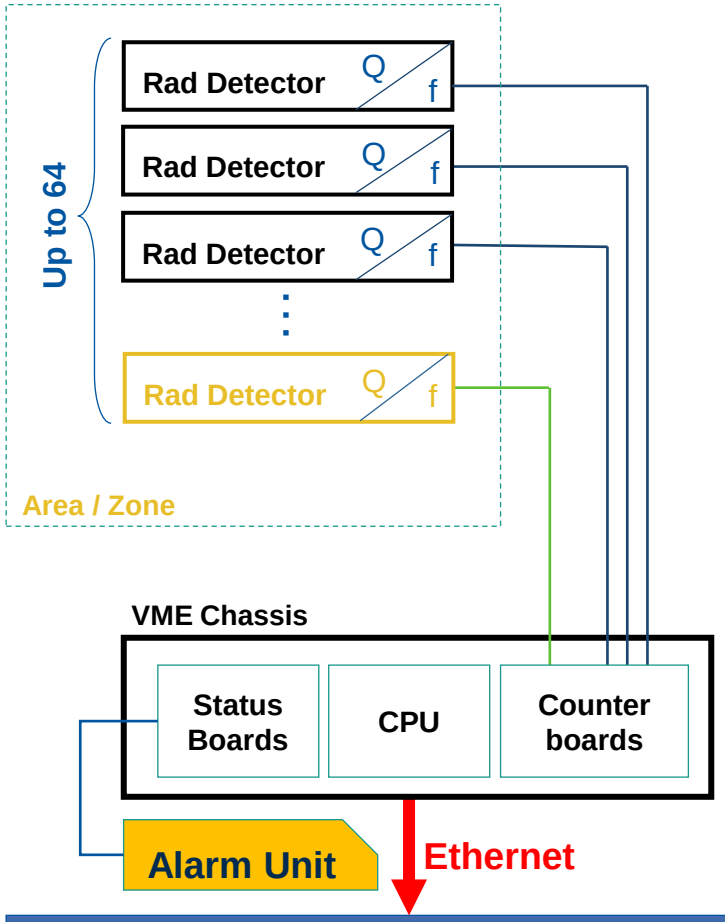
CROME Equipment



Production Capabilities

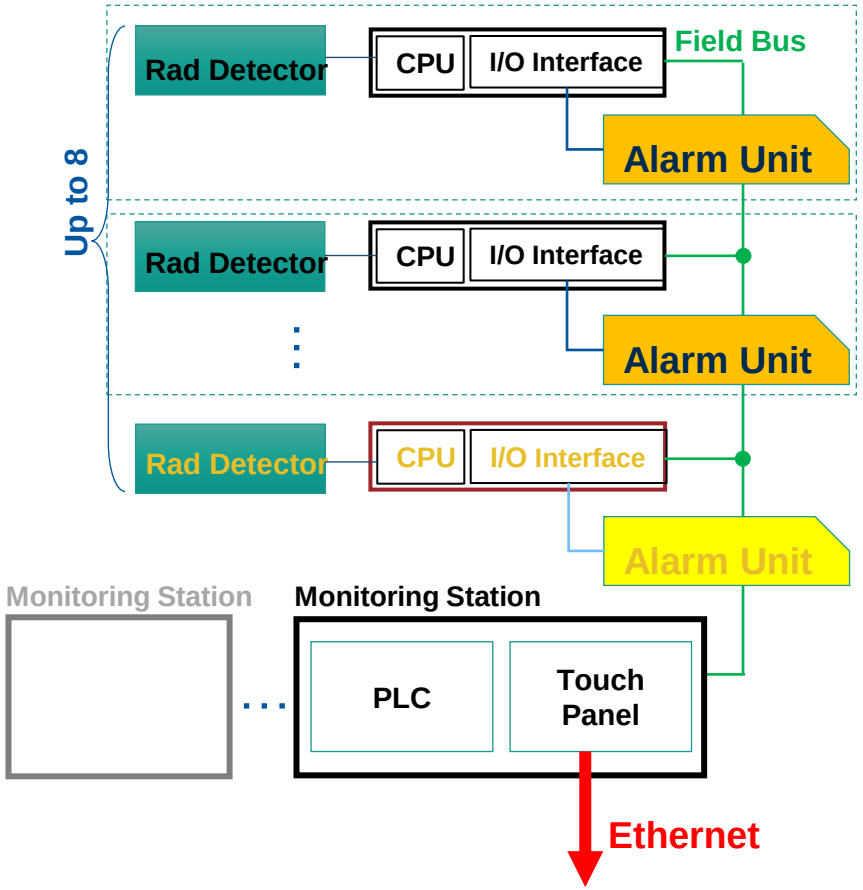
ARCON

Centralized Architecture



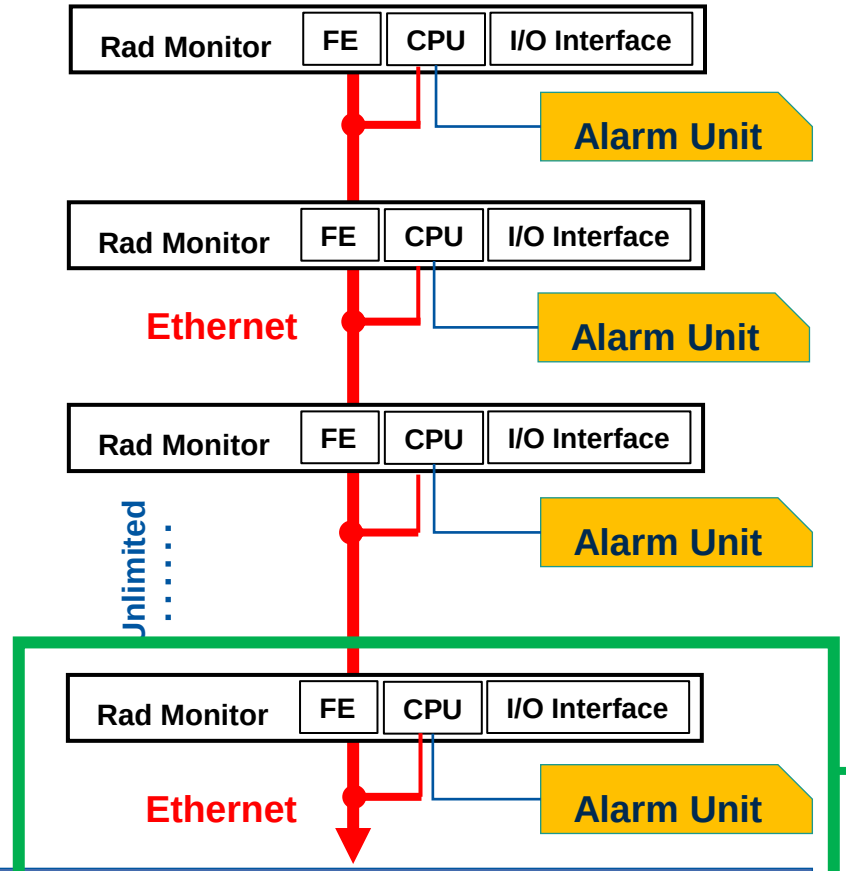
RAMSES

Federated Architecture



CROME

Modular Architecture

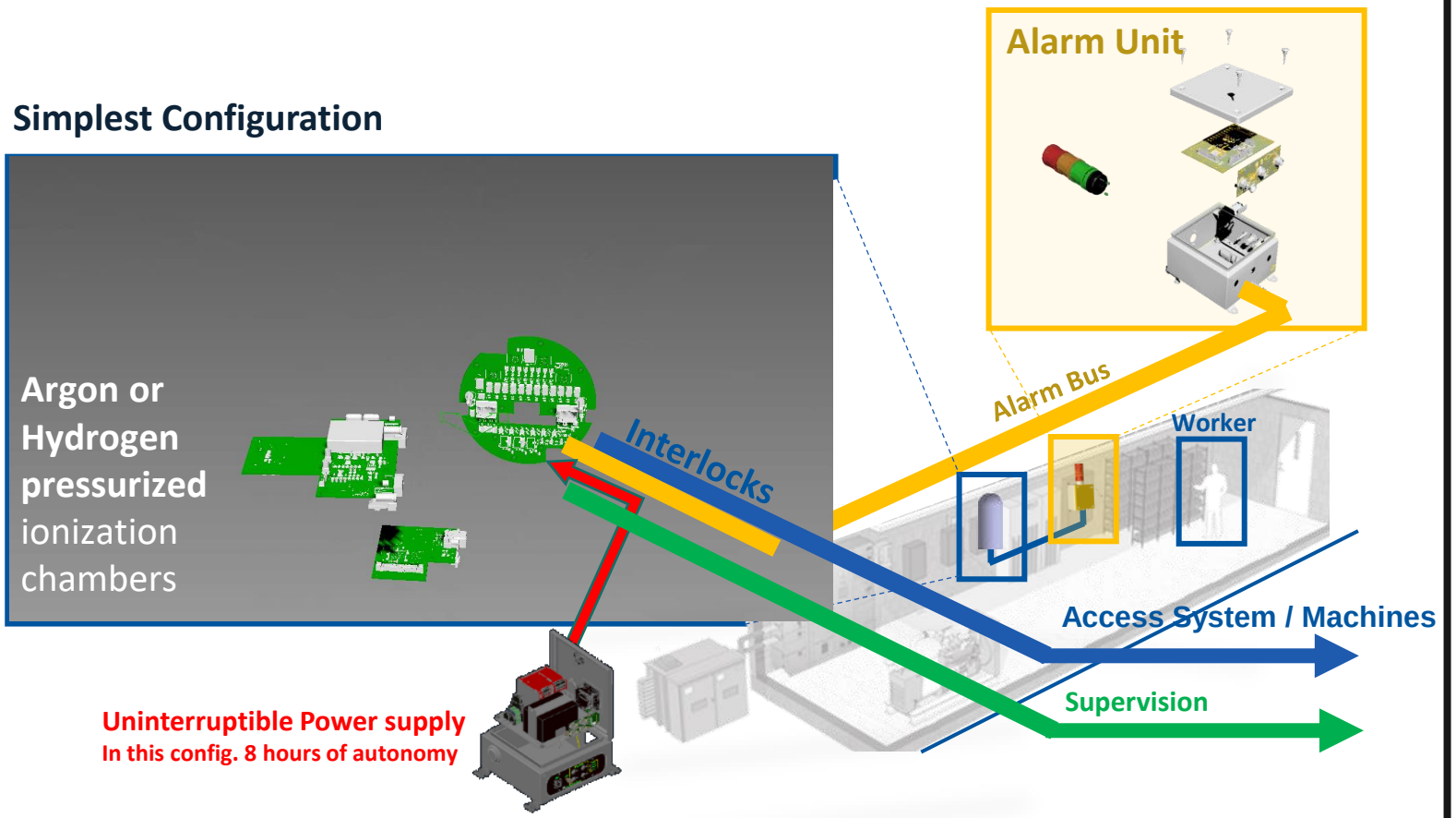


SCADA - Supervision

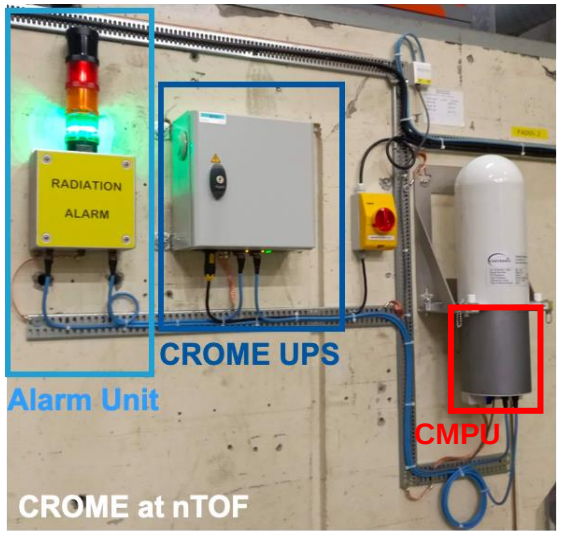
CERN Radiation Monitoring Electronics (CROME)

CROME Bulk System for low radiation areas :

Simplest Configuration



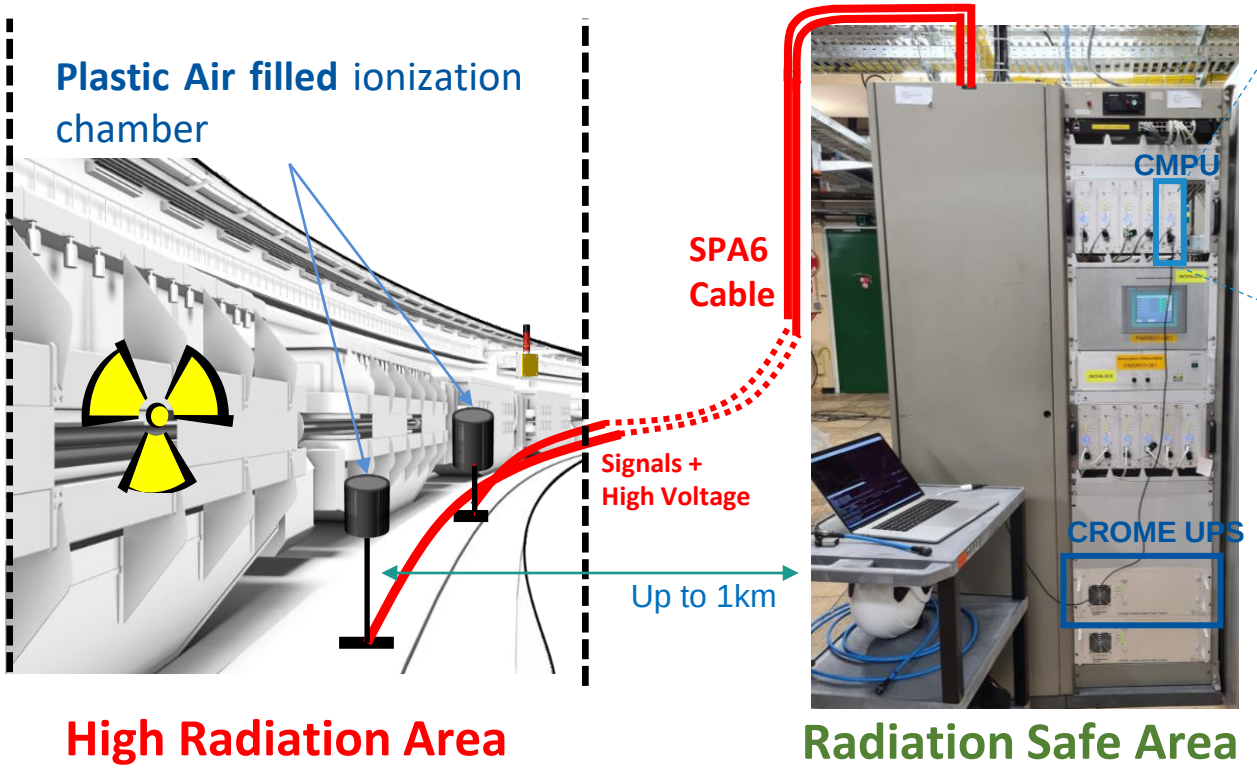
CROME Bulk (Wall-mount) Version

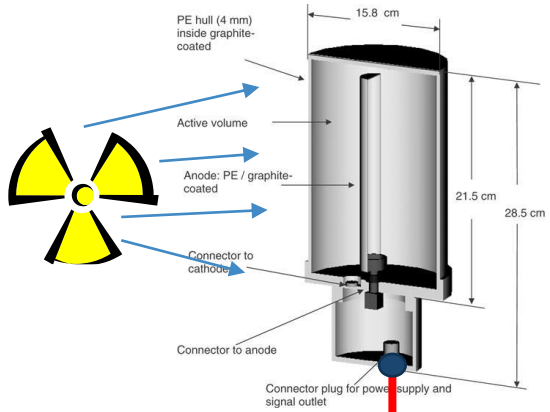


CERN Radiation Monitoring Electronics

CROME Rack System for high radiation areas :

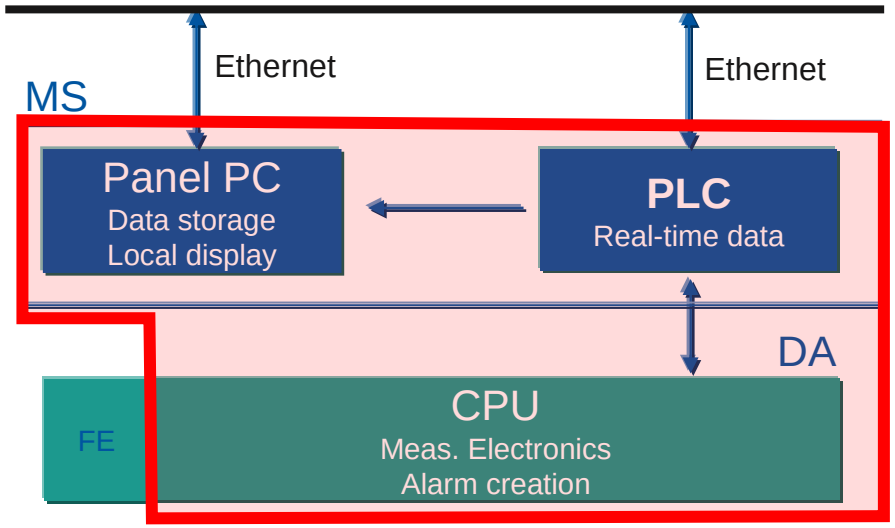
CROME Rack-mount Version at CERN at the PS Booster



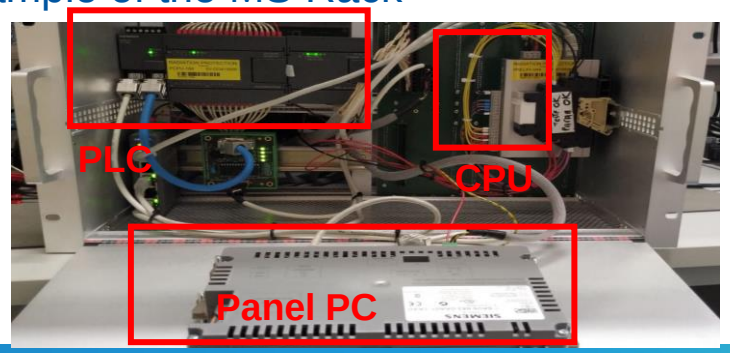


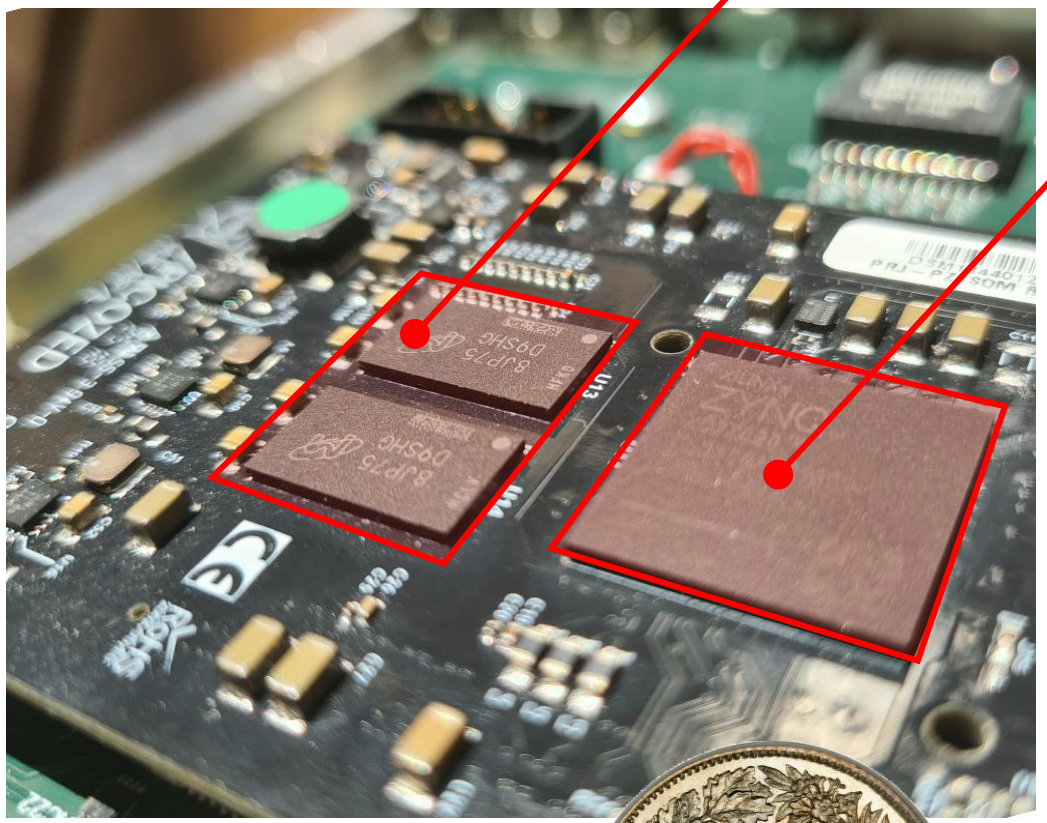
CERN Radiation Monitoring Electronics (CROME)

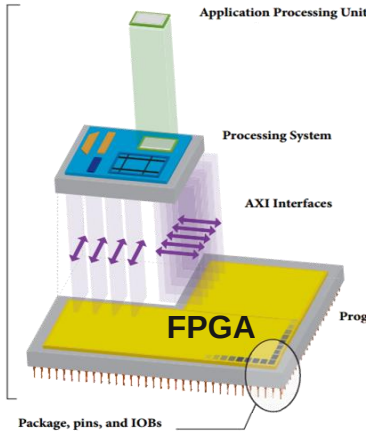
RAMSES System (Outsourced 2004)



Example of the MS Rack

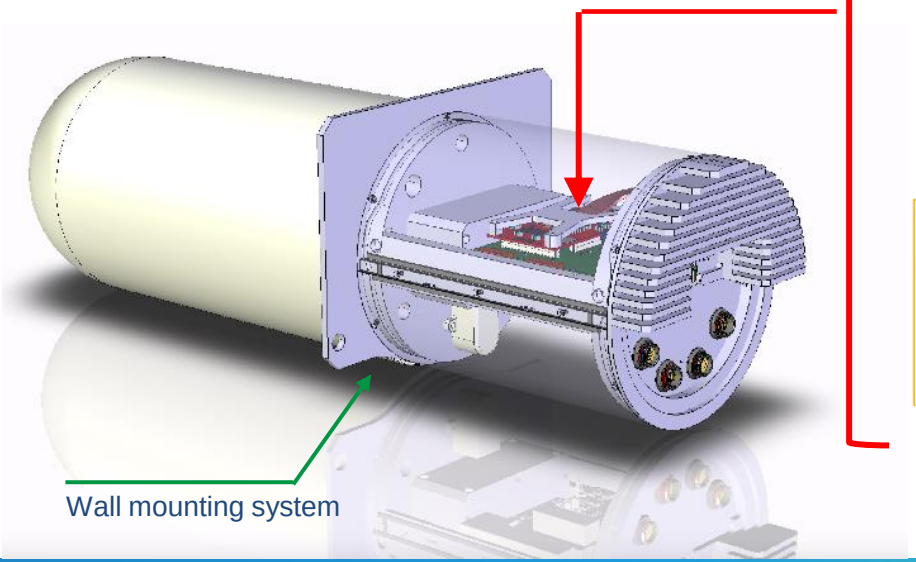


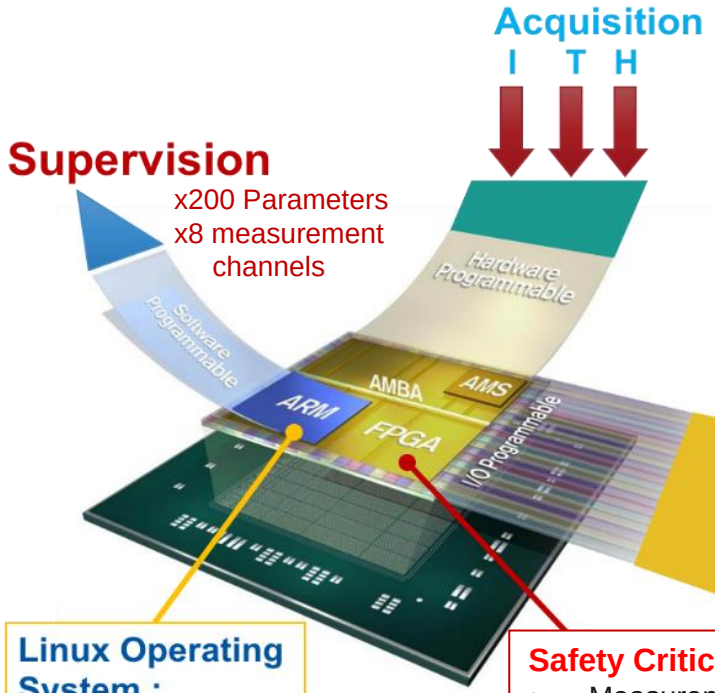




CERN Radiation Monitoring Electronics (CROME)

Highly Integrated Solution :





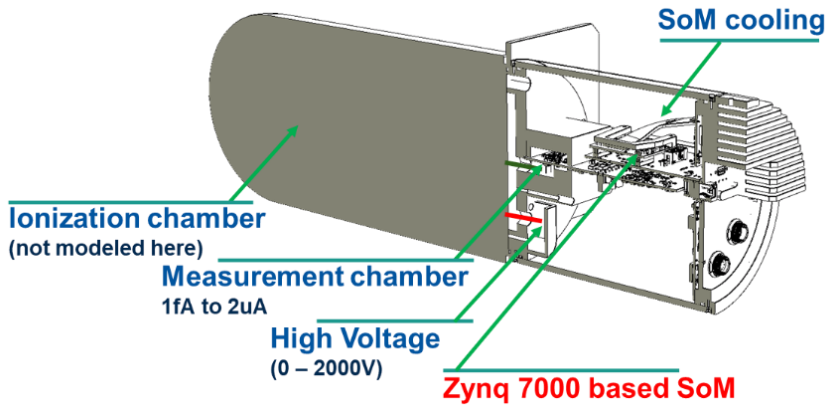
36 Millions of possible combinations

Interlocks

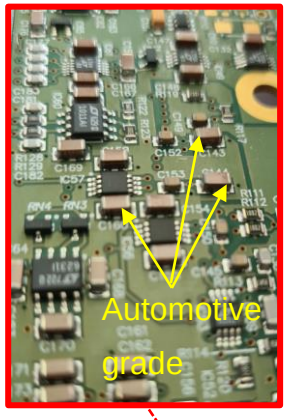
Alarm Units communication

Linux Operating System :
- Data storage and management
- Supervision
- …

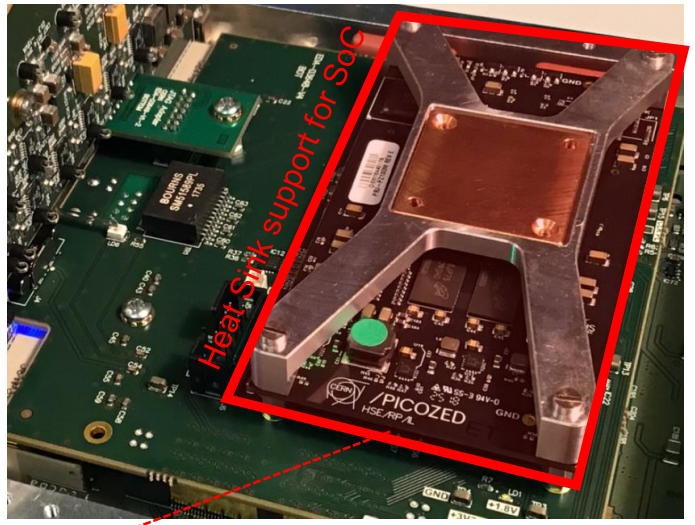
Safety Critical part :
- Measurement algorithms
- Real Time temperature compensation
- Dose rate calculations
- Cumulated dose calculation
- Interlock generation
- …



CERN Radiation Monitoring Electronics (CROME)

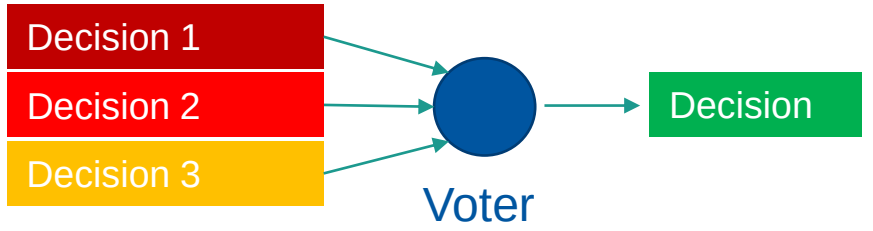


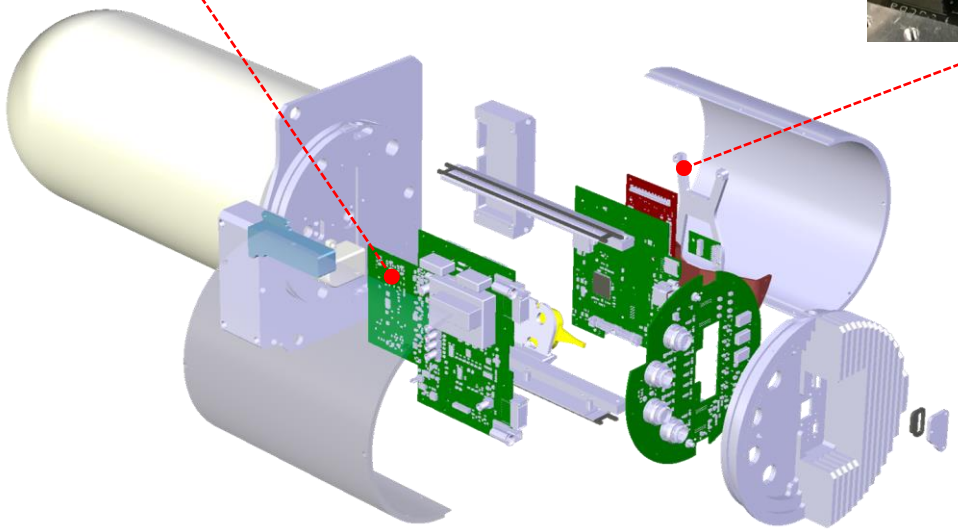
- **All the components have been individually analyzed** (> 3000 references)
- **Critical components have been replaced**
- **Redundancies**

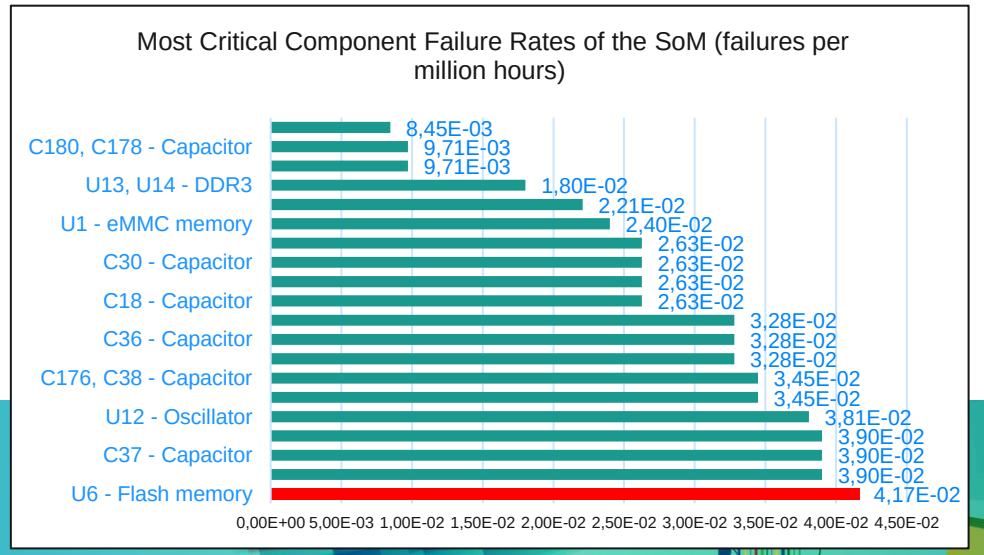


Critical decisions are taken into the FPGA section of the SoC (38 billion of possible combinations)

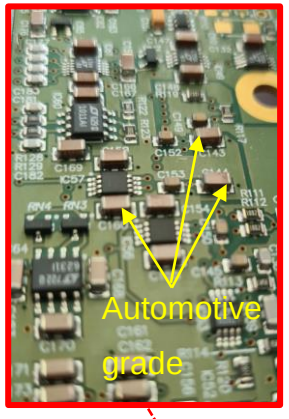
- ✓ SIL2 compatible floating point calculation engine
- ✓ Developed a safe architecture (memories are protected, data is exchanged and checked with checksums)
- ✓ Direct democracy with a global triplication :



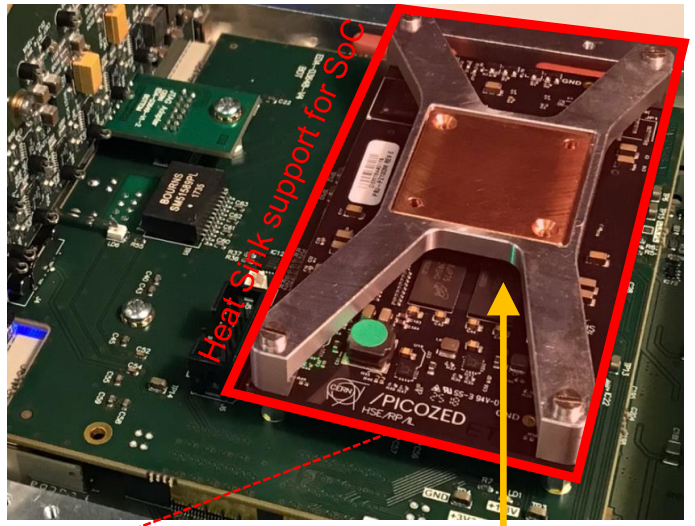


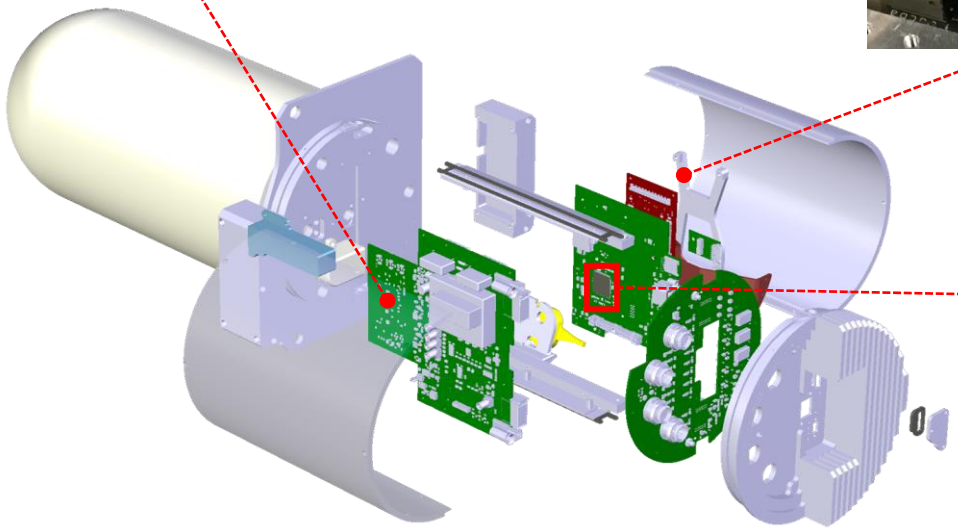


CERN Radiation Monitoring Electronics (CROME)

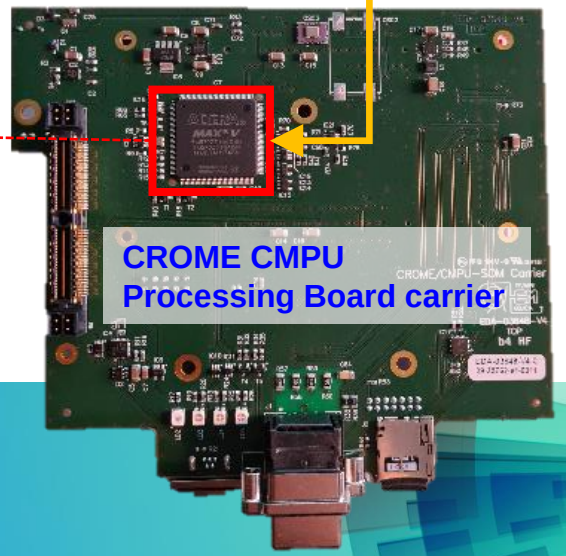


- **All the components have been individually analyzed** (> 3000 references)
- **Critical components have been replaced**
- **Redundancies**



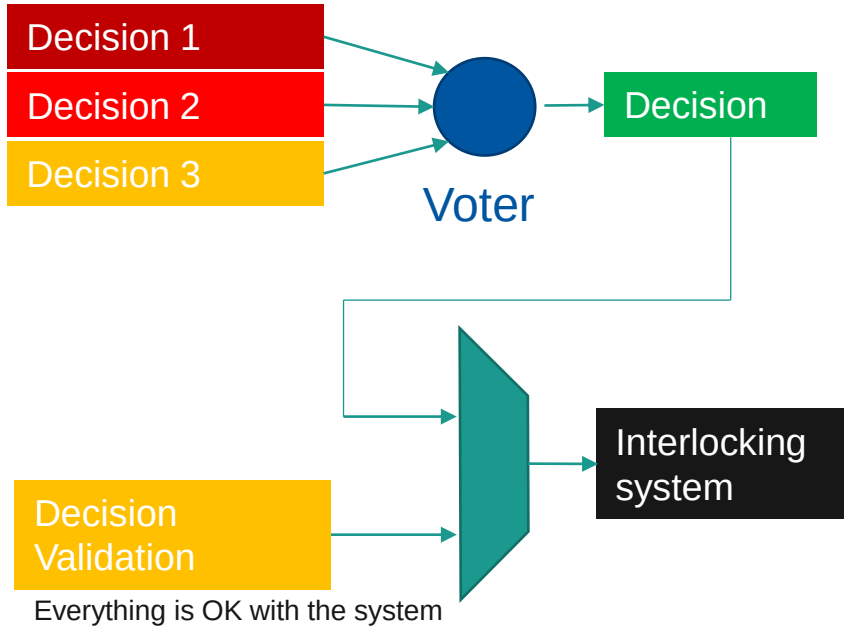


Extended testability
97% of dangerous failures



Critical decisions are taken into the FPGA section of the SoC (38 billion of possible combinations)

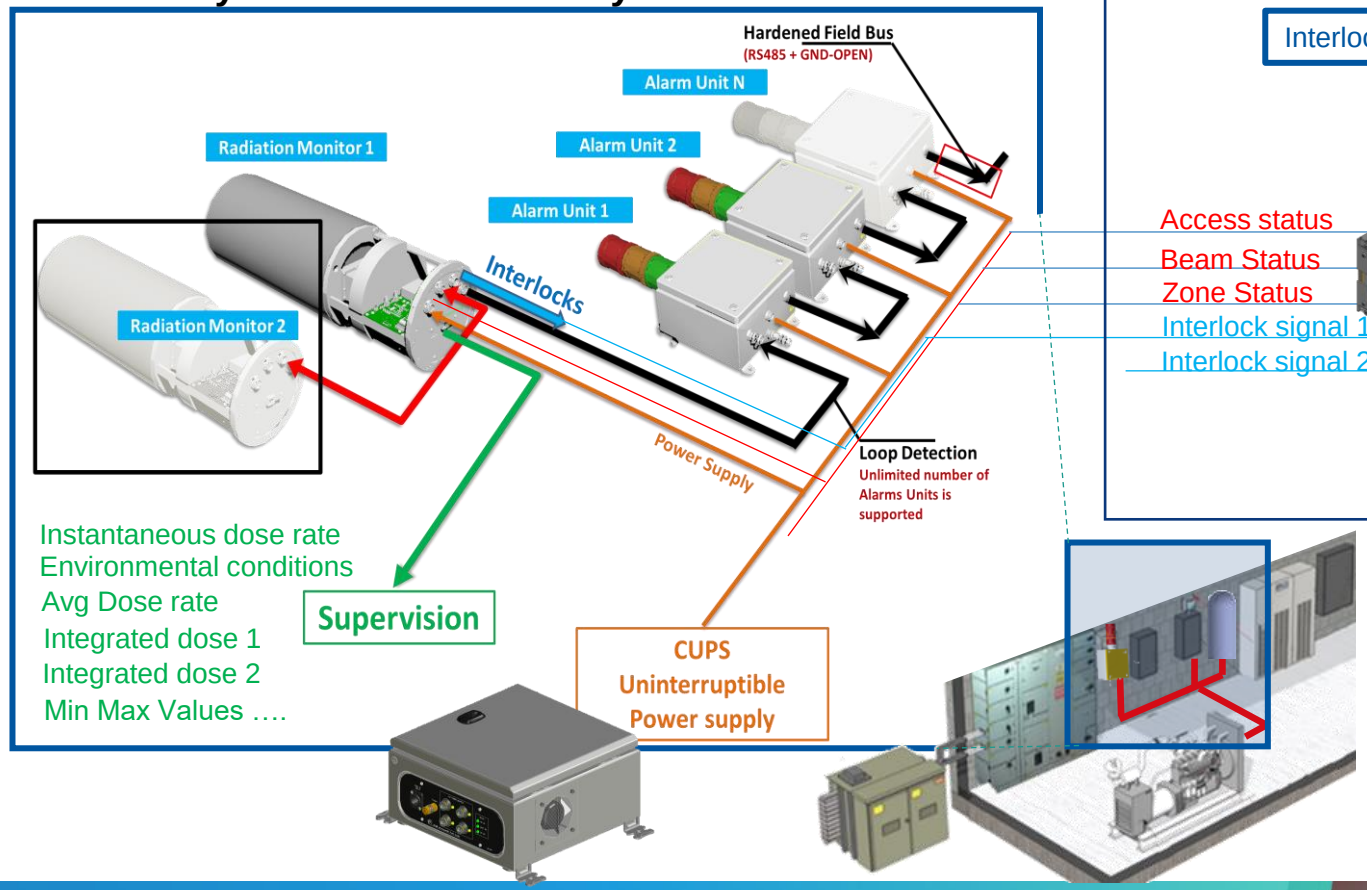
- ✓ SIL2 compatible floating point calculation engine
- ✓ Developed a safe architecture (memories are protected, data is exchanged and checked with checksums)
- ✓ Direct democracy with a global triplication :



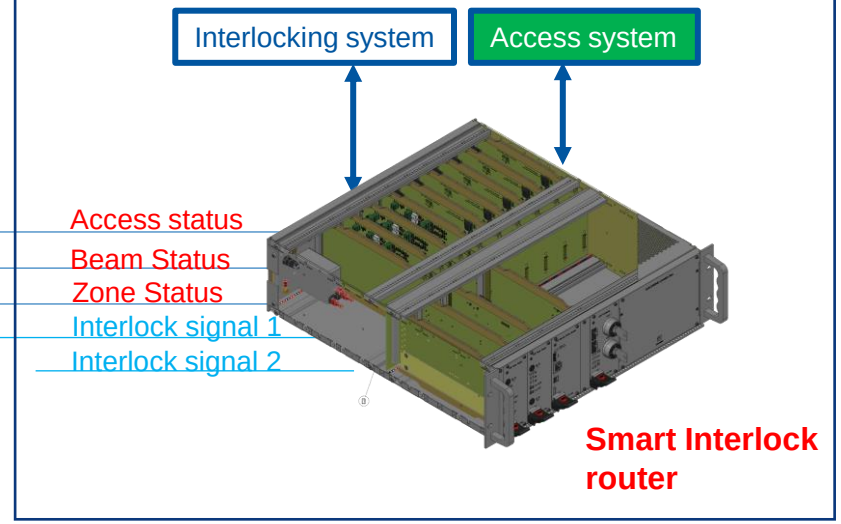
$$PFH = 8{,}24 \cdot 10^{-8} fpmh$$

CERN Radiation Monitoring Electronics (CROME)

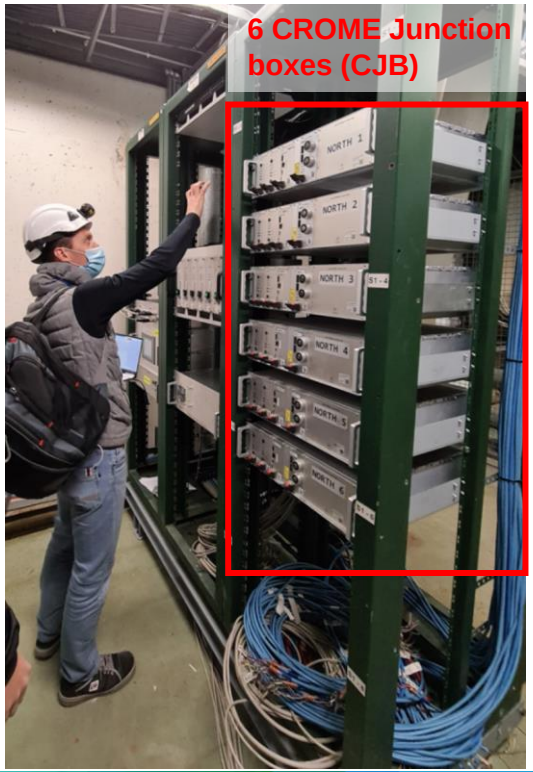
Redundancy can be extended at system level



CROME Junction Box

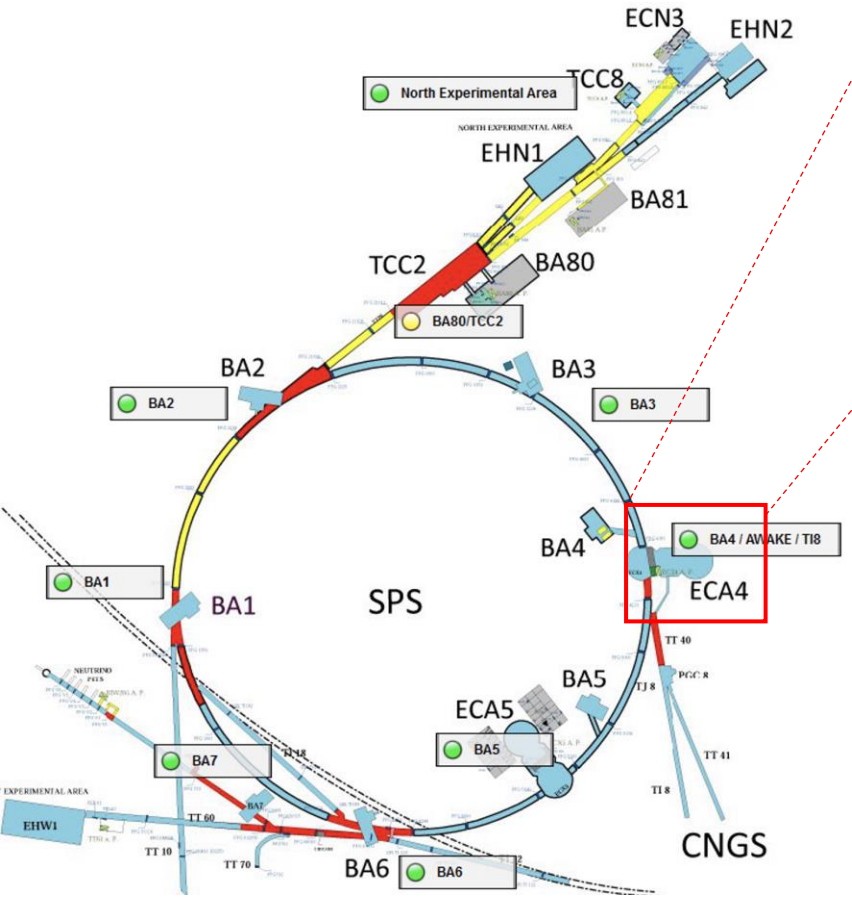


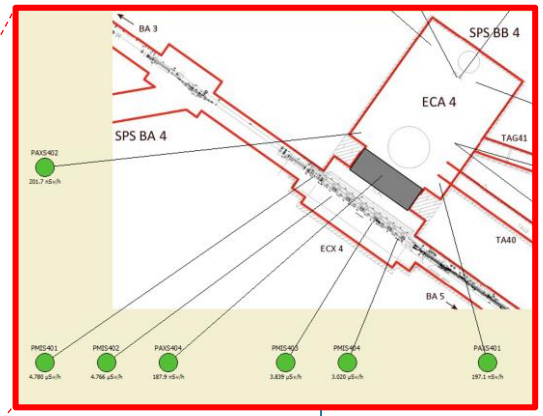
North Area (EHN1)

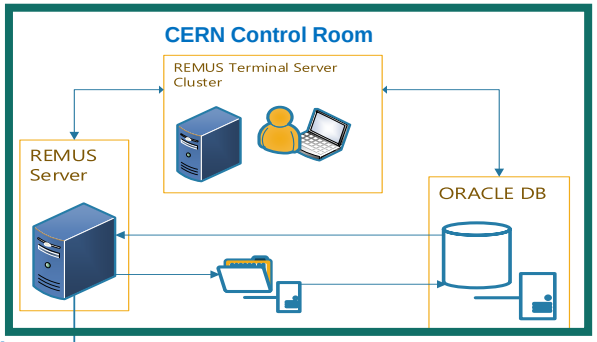


CERN Radiation Monitoring Electronics (CROME)

CROME Network







Technical Network

IT Socket

Rack 1

6 Ethernet connections

CROME Rack Chassis
Up to **6** Modules

- Real Time Measurements
- Events
- Status
- Historical Values

IT Socket

Rack 2

12 Ethernet connections

2 CROME Rack Chassis
Up to **12** Modules

- Real Time Measurements
- Events
- Status
- Historical Values

IT Socket

Rack3

1 Eth connection

CROME Junction Box
- Status

IT Socket

1 Eth connection

CROME Radiation Monitor

- Real Time Measurements
- Events
- Status
- Historical Values

IT Socket

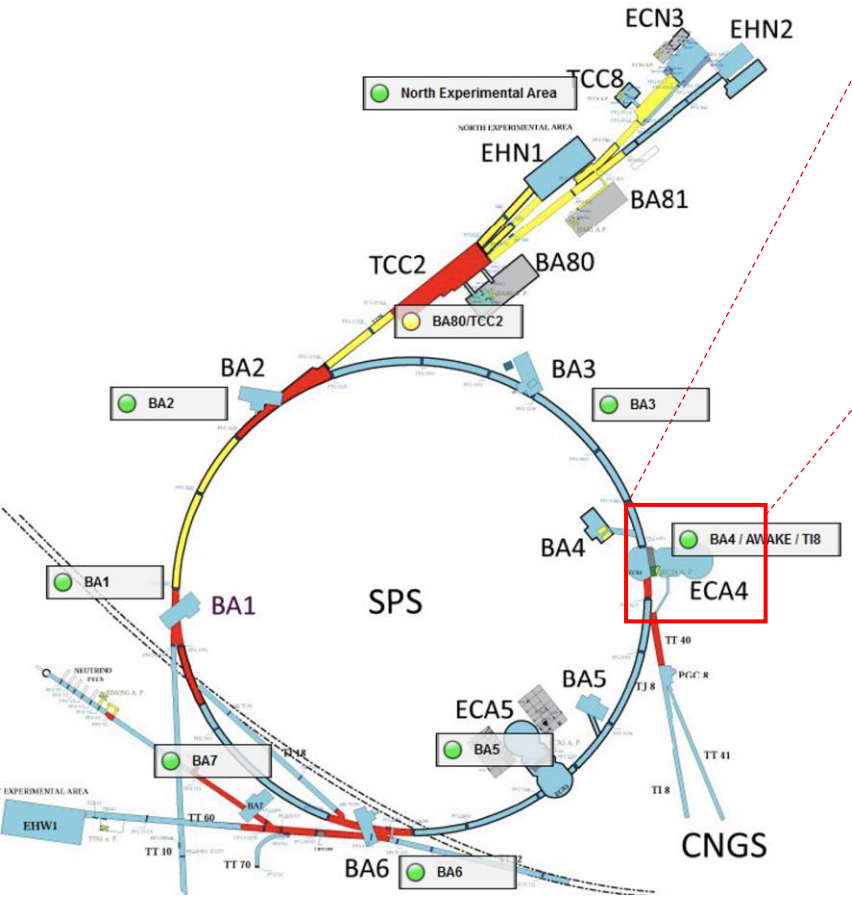
1 Eth connection

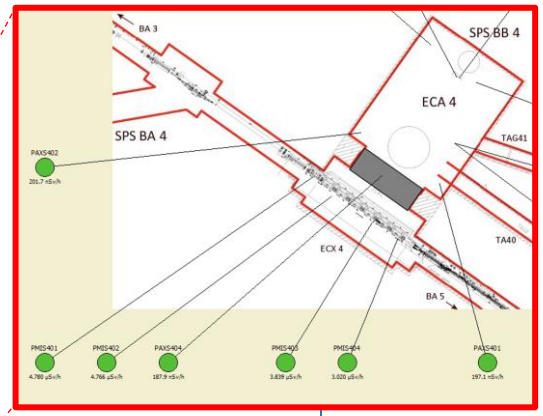
CROME Radiation Monitor

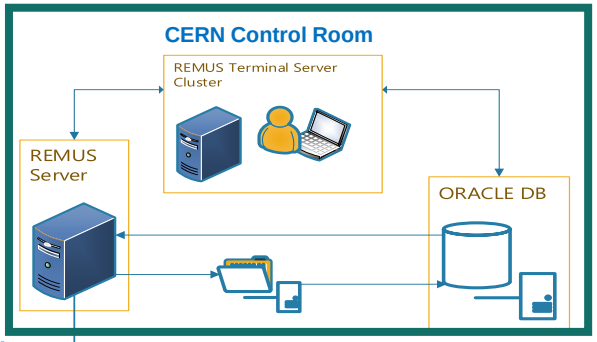
- Real Time Measurements
- Events
- Status
- Historical Values

CERN Radiation Monitoring Electronics (CROME)

CROME Network

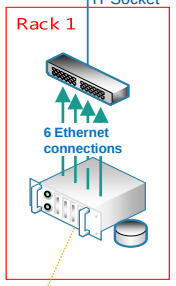






Technical Network

IT Socket



CROME Rack Chassis
Up to **6 Modules**

- **Real Time Measurement**
- **Events**
- **Status**
- **Historical Values**

ETH HDR	IP HDR	TCP HDR	ROMULUS Data Frame	ETH CHK

Real-Time Stream : (port n+1)

Requests : (port n)

- Historical data retrieval
- Events retrievals (ex. Alarms, Alerts, failures …)
- Statuses
- Remote Parametrization (x 84 params.)

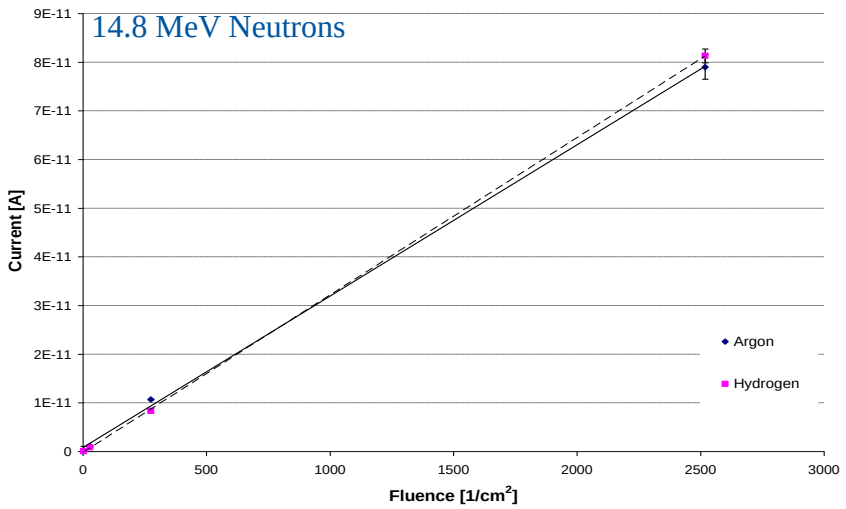
Response : (port n)

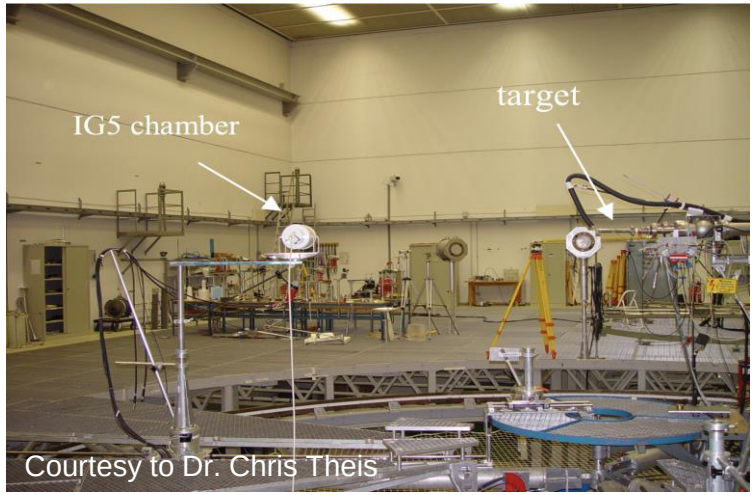
CERN TN

What can we do with CROME ?

Static characterization

Detector Linearity



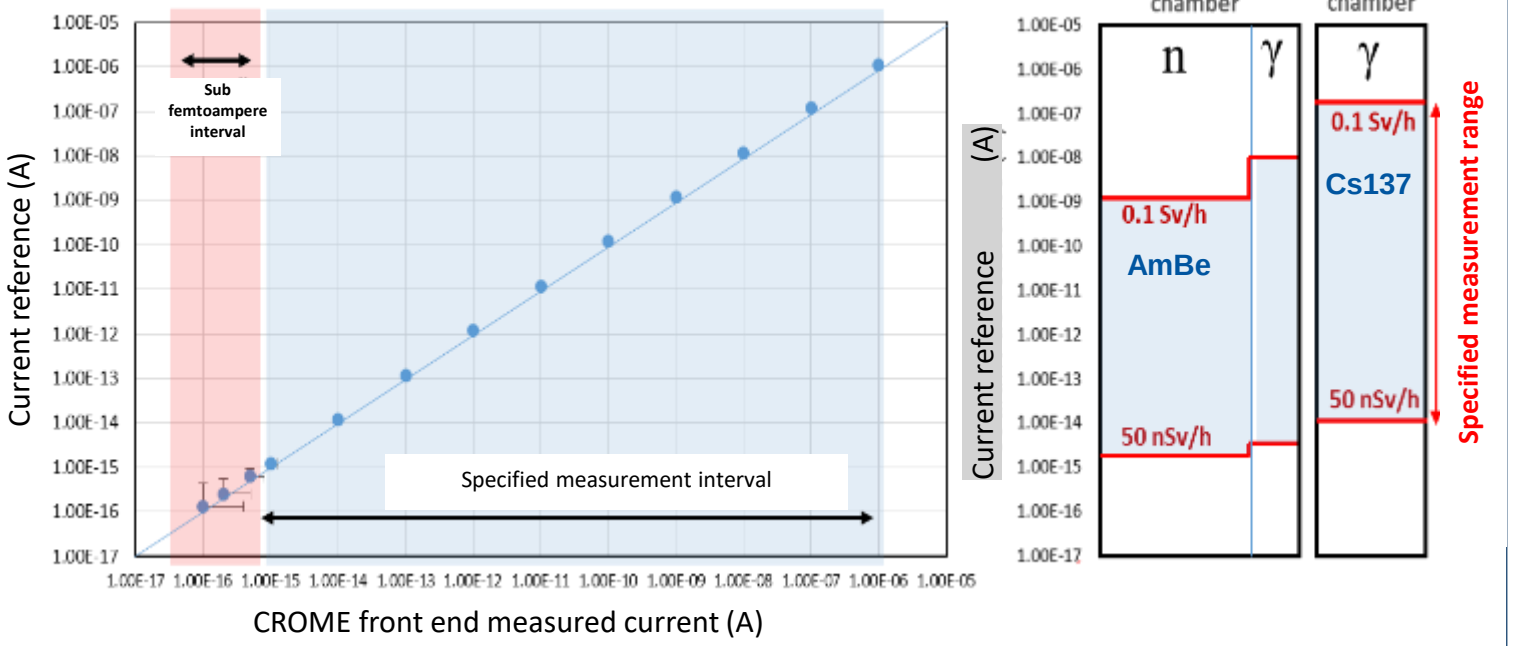


Experiment at the PTB (Physikalisch-Technische-Bundesanstalt) (Germany)

Front-end Performances Linearity

LNE – Certified Lab in Paris (France)

New COFRAC certification – Linearity characterisation

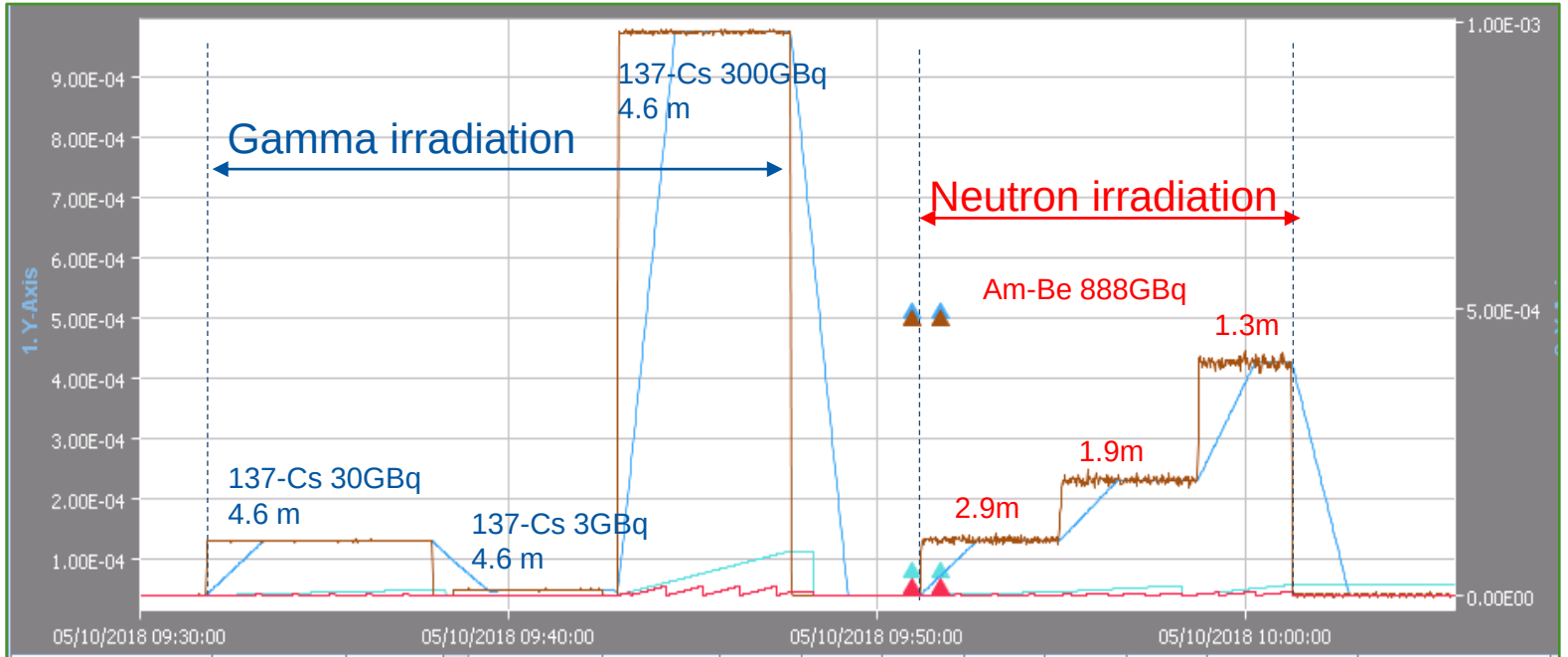


Static Characterization

Calculation of the Calibration Factor

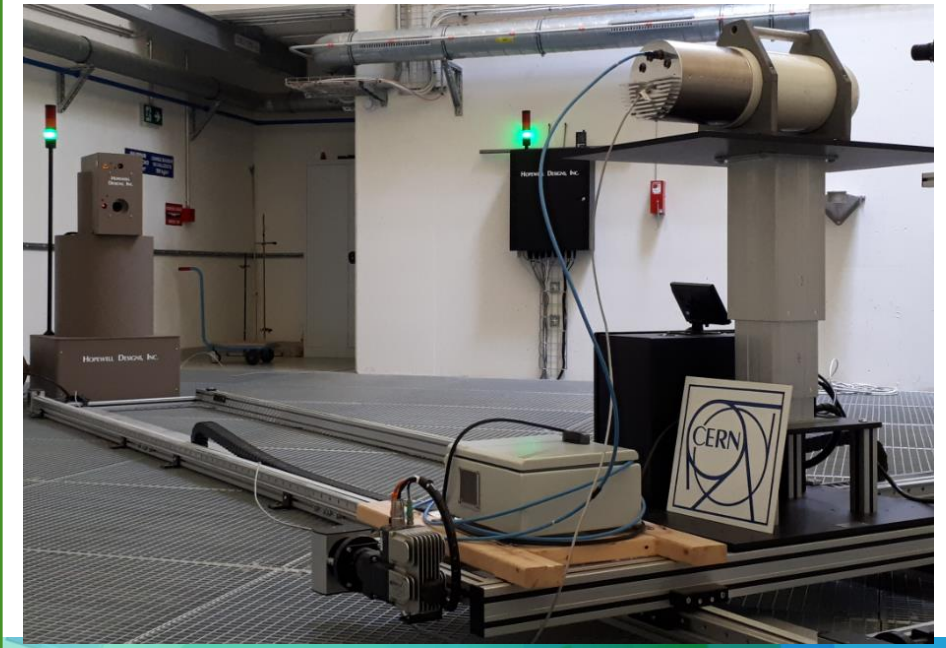
Calibration	05/10/2018		
IG5-H20		Inv	ProtoA2 002
Coeff. d'etalonnage gamma:	1.03	+/-	0.08 (k=2)
Coeff. d'etalonnage neutron:	1.00	+/-	0.06 (k=2)
Calibration valid until:	05/10/2021		

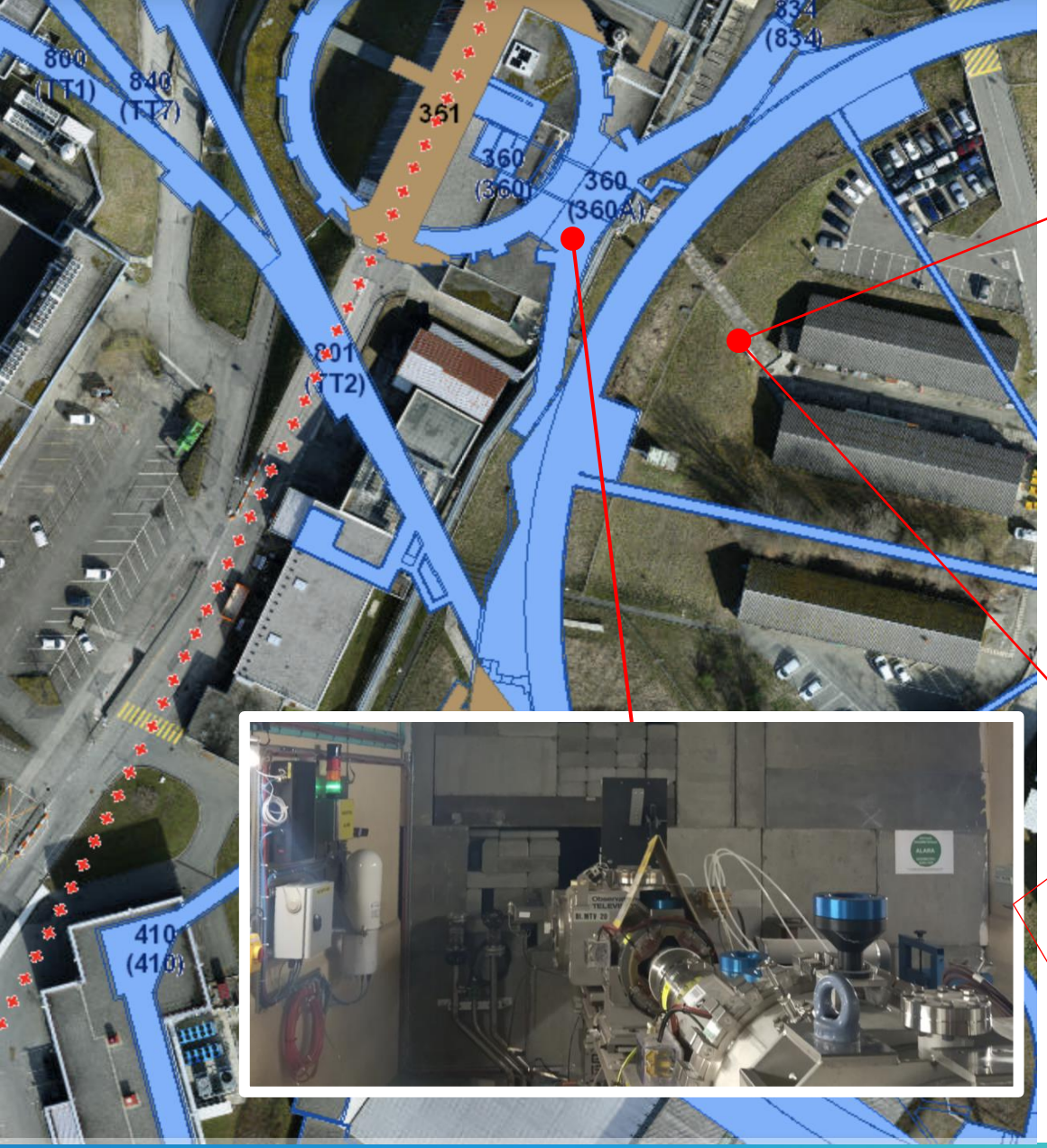
CROME-REMUS Integration – Calibration

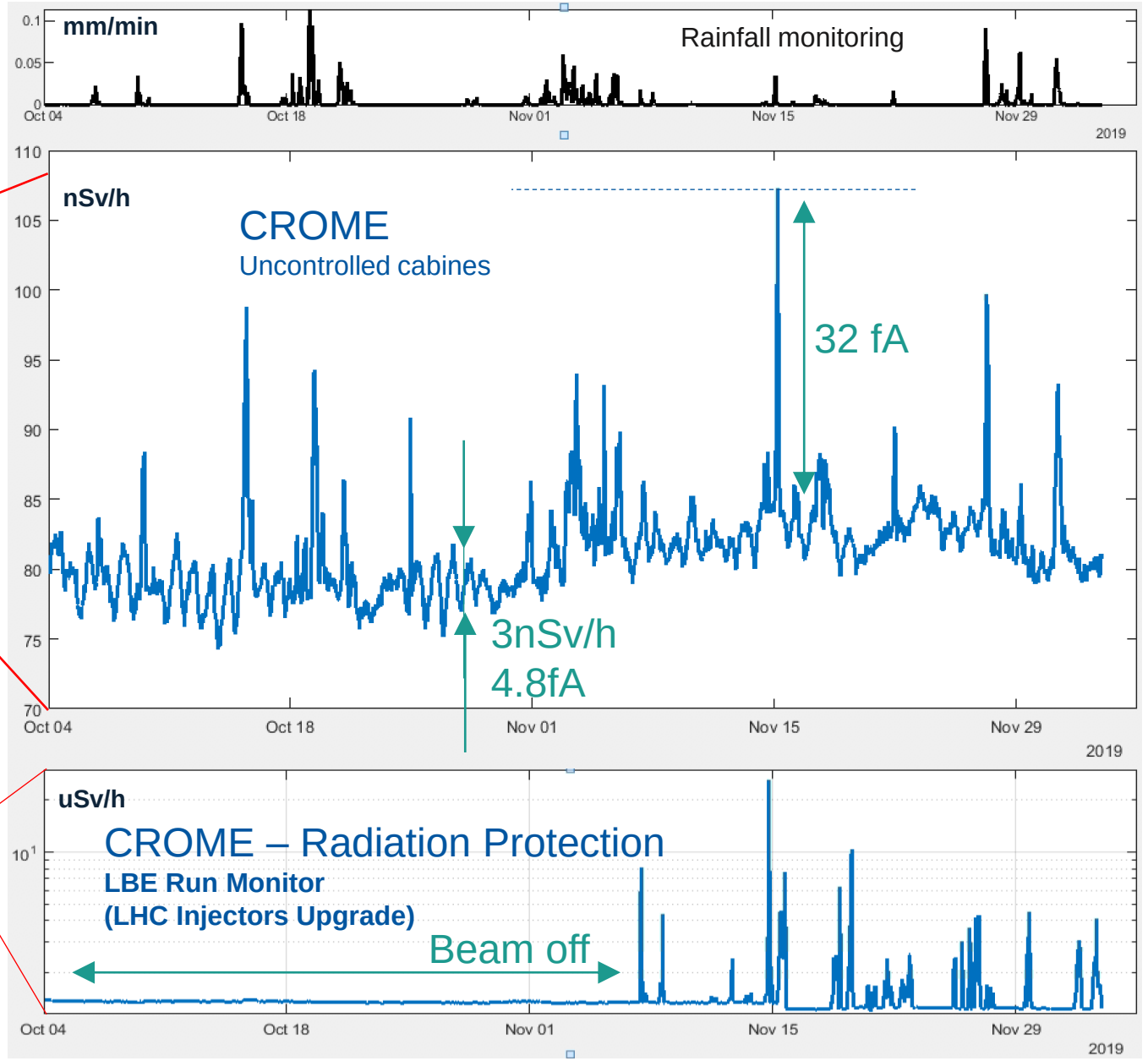


Channel	Color	Unit	2nd Y-Axis	Visible	Integral	Mean	Min	Max	SD (σ)	SEM (σ...	Thresholds	Prior param change
CROME002_MS		Sv/h	☑	☑							☐	17/10/2018
CROME002_AVRG		Sv/h	☑	☑							☐	17/10/2018
CROME002_TEMP		°C	☐	☐							☐	17/10/2018
CROME002_INT1		Sv	☑	☑							☐	17/10/2018
CROME002_HR		n.d.	☐	☐							☐	17/10/2018
CROME002_HV		V	☐	☐							☐	17/10/2018
CROME002_INT2		Sv	☑	☑							☐	17/10/2018
CROME002_MAX		Sv/h	☐	☐							☐	17/10/2018
CROME002_MIN		Sv/h	☐	☐							☐	17/10/2018

CROME System Under Calibration




800
(TT1)
840
(TT7)
361
360
(360)
360
(360A)
834
(834)
801
(TT2)
410
(410)


mm/min
Rainfall monitoring
0.1
0.05
0
Oct 04
Oct 18
Nov 01
Nov 15
Nov 29
2019
nSv/h
CROME
Uncontrolled cabines
32 fA
3nSv/h
4.8fA
110
105
100
95
90
85
80
75
70
uSv/h
CROME – Radiation Protection
LBE Run Monitor
(LHC Injectors Upgrade)
Beam off
10^1

Slow – High precision operation mode

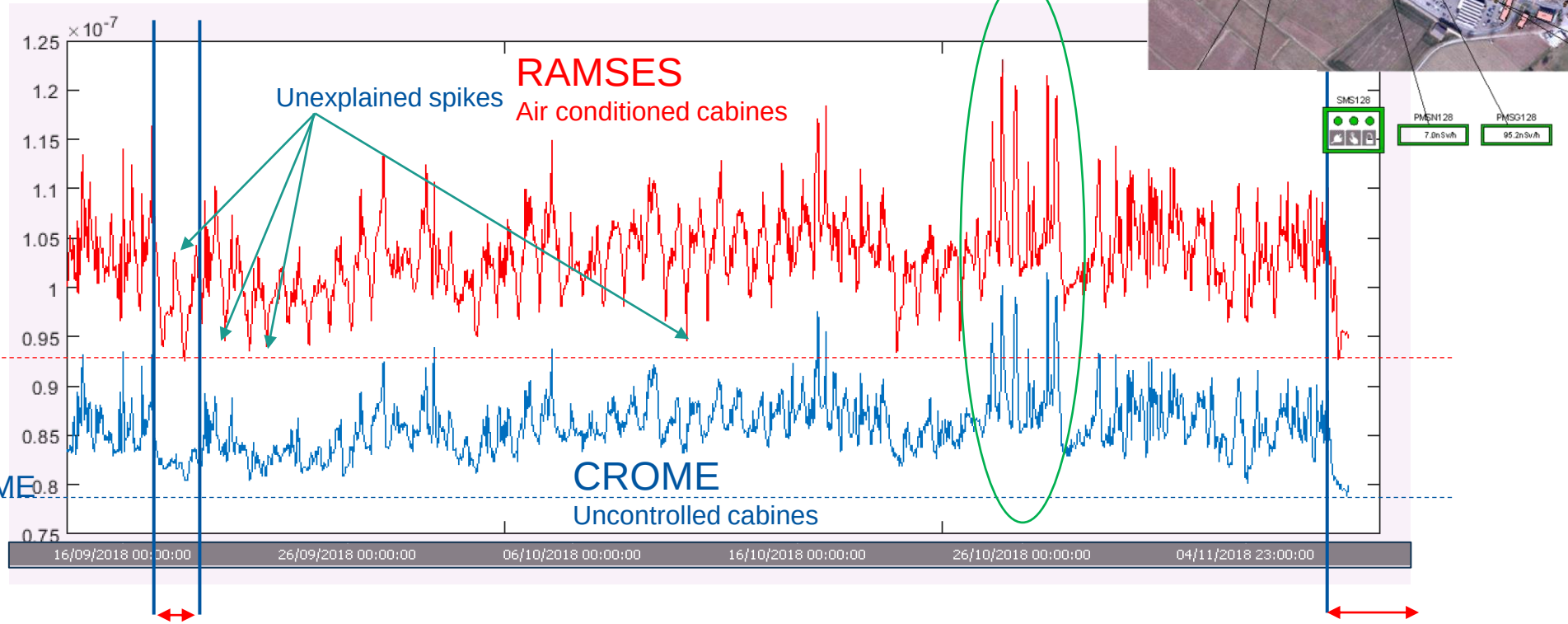
Air-conditioned cabin

Floor DR
for RAMSES

Floor DR for CROME

Sv/h

Spikes due to rain
They have been correlated to rain fall monitors



Beam off

2 months of Data

Beam off

4G connection with CERN

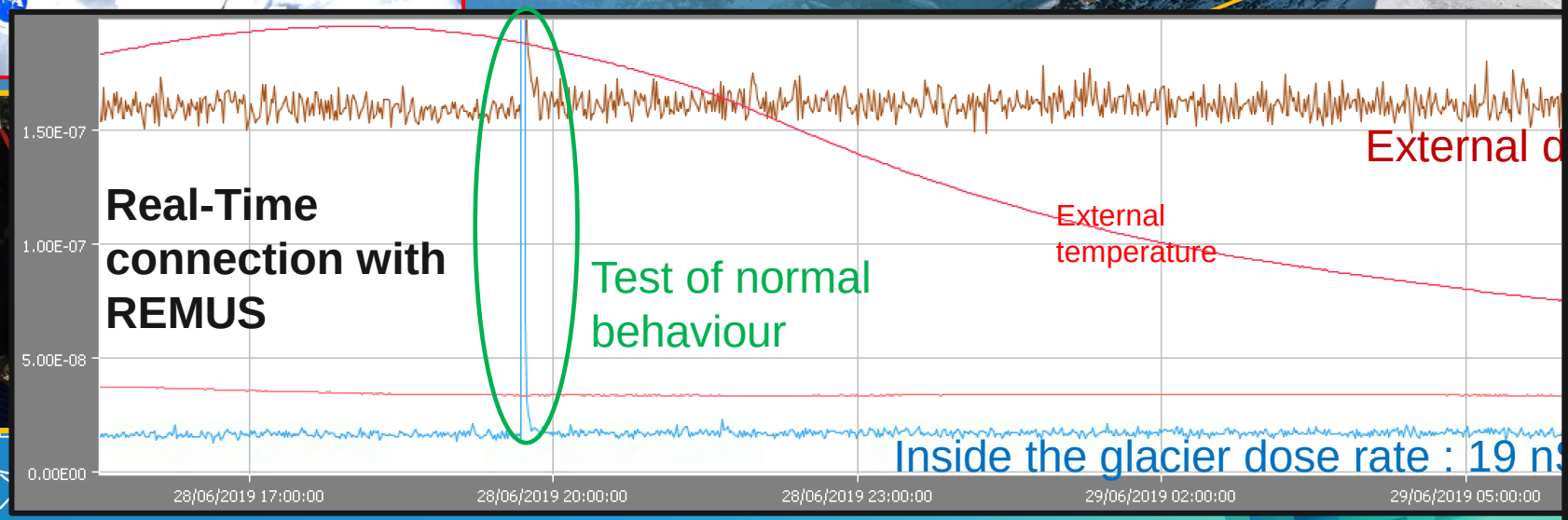
CROME device at the surface of the glacier 3880m

CROME device inside the glacier

4G connection with CERN

CROME device at the surface of the glacier 3880m

CROME device inside the glacier



Nice system !
Where can I buy it ?

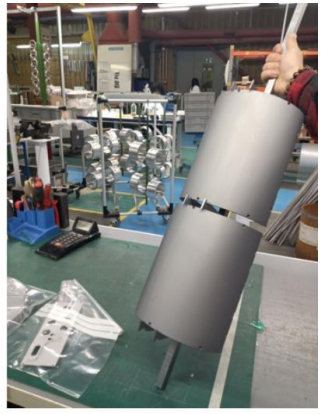
CROME Production

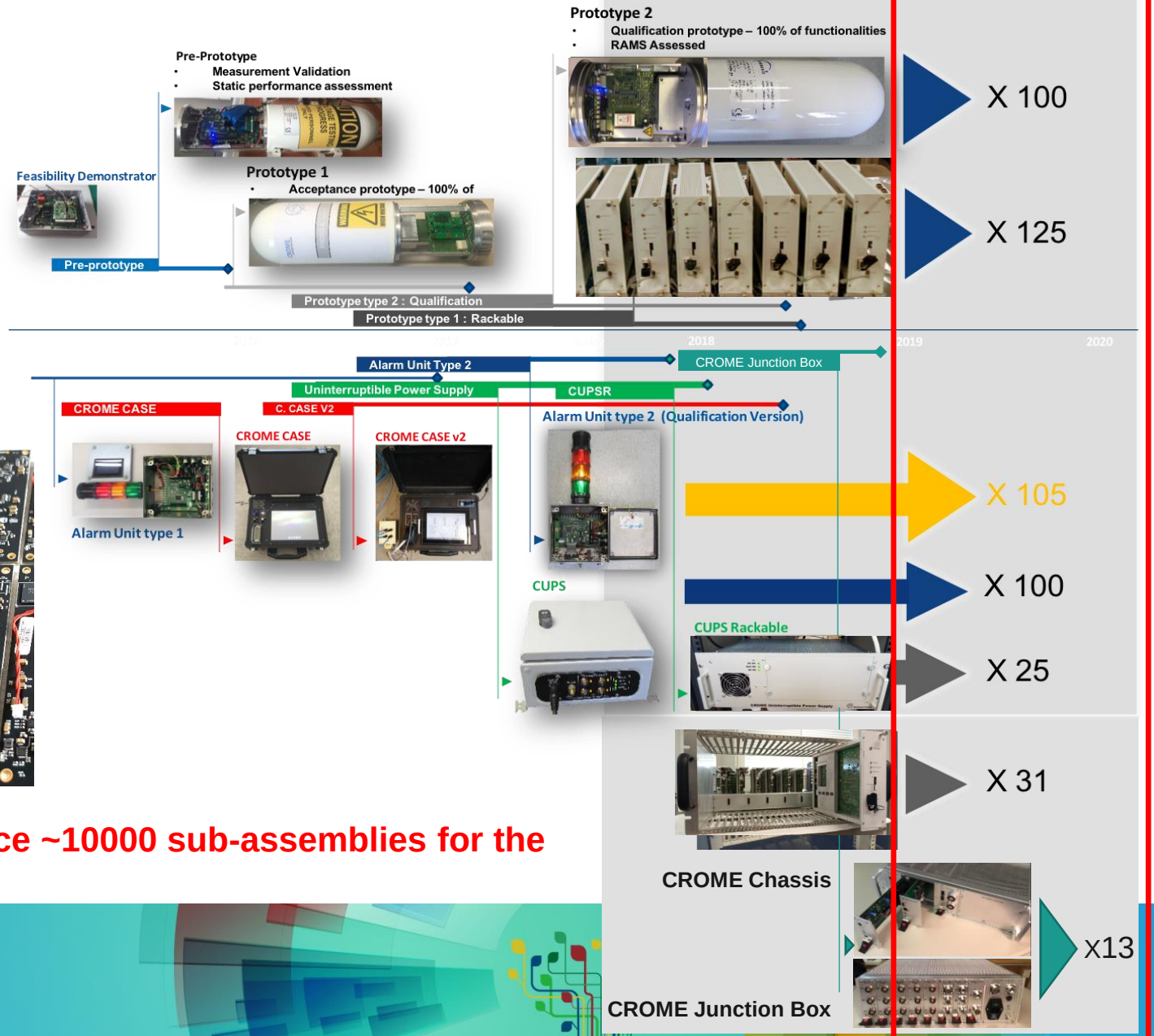
In 2018, 8 different fully operational equipment were completely designed :

- >3000 different electronic components references
- 25 EDA (every one include CADs and BOMs)
- 62 mechanical plans





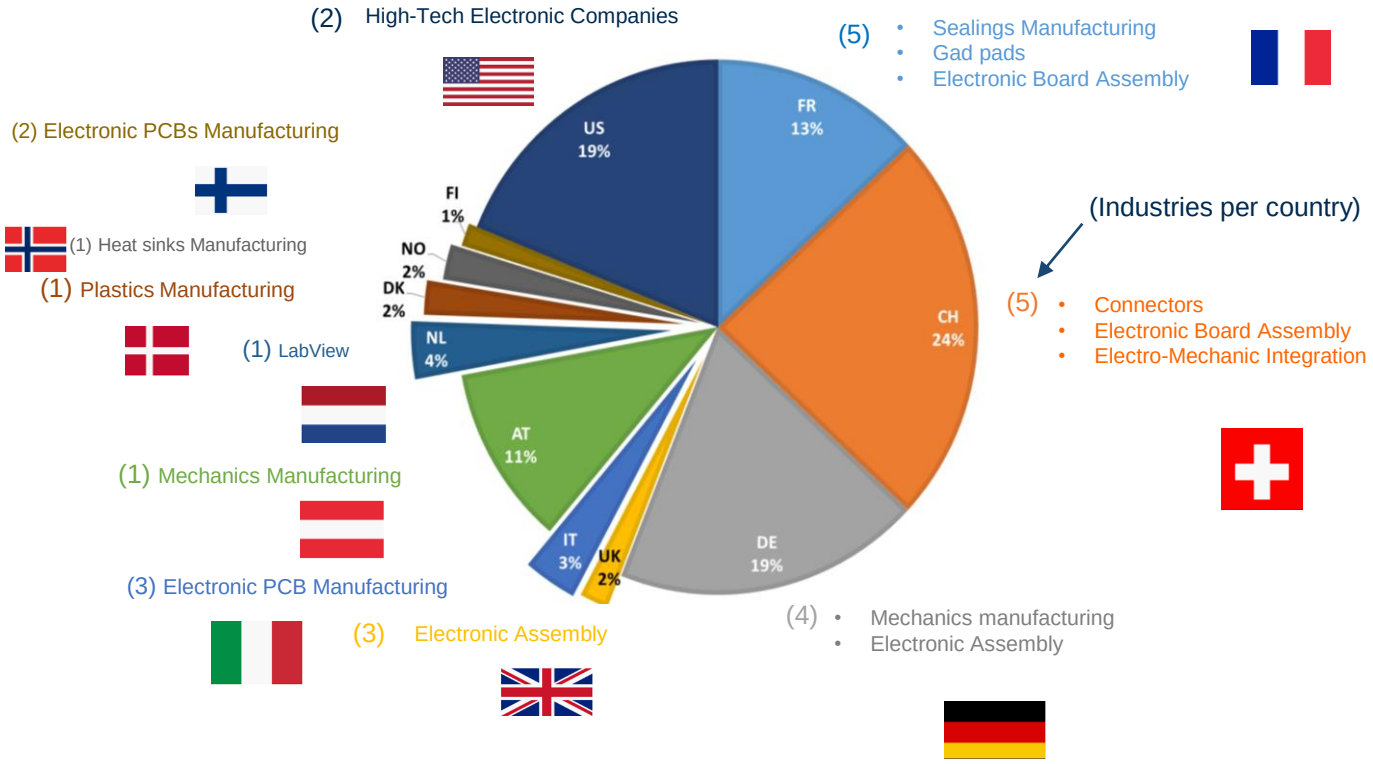


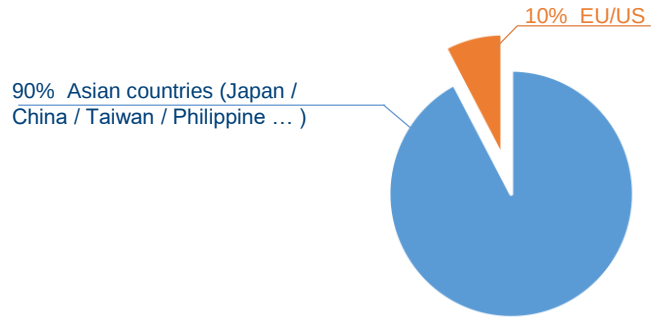
→ **Definition of the manufacturing process to produce ~10000 sub-assemblies for the assembly of 500 devices**

CROME Production: Chain of Value

CROME Industrial Fabrication in 2018/2019 (without CERN)



Contract Manufacturers (28 Industries)

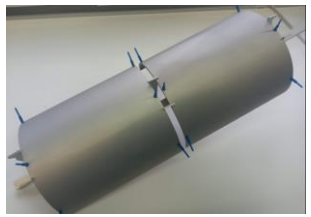


CROME Electronics Suppliers in 2018/19 (without CERN) of orders (5 main distributors)

Raw Material Procurement

CROME Assembly

Assembly and integration of CROME Bulk version

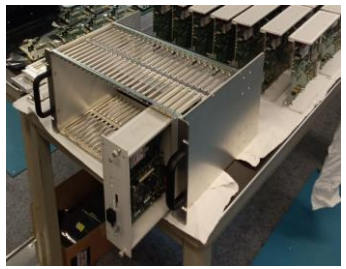


HW integration automated tests

Temperature stress validation

Temperature compensation

Assembly and integration of CROME Rackable version



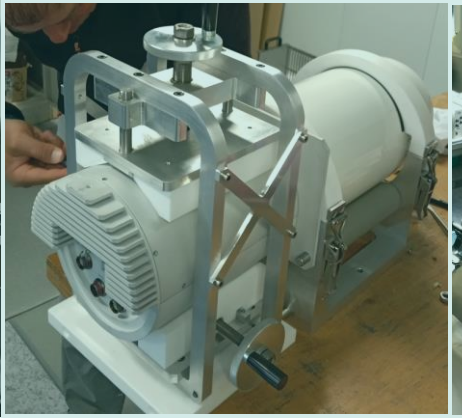

Automated current calibration

HW integration automated tests

CROME Team

x100

Detector integration

Stability tests

x125

Temperature tests of CROME Rackable versions

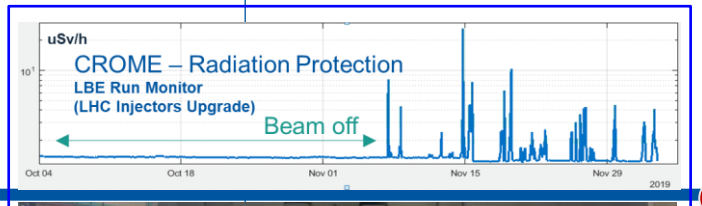
Long-term tests of CROME Rackable versions

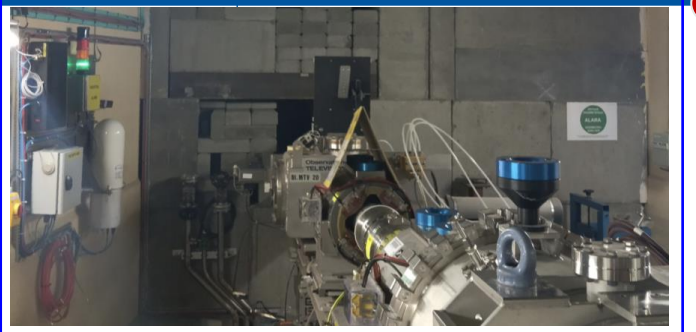
CROME deployment

Fully fledged and interlocked operational CROME system

Presentation of CROME system to FR/CH authorities (Tri-partite meeting)

September 2019





First operational installation of CROME

Mars 2020

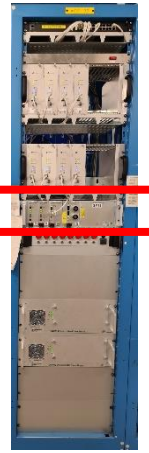
20 Induced activity monitors

CROME at Booster

CROME at PS

CROME at n-TOF

August 2020



Acceptance tests of CROME at SM18

4 MS

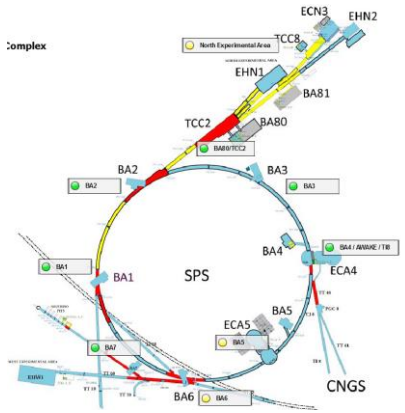
HL-LHC

CROME deployment

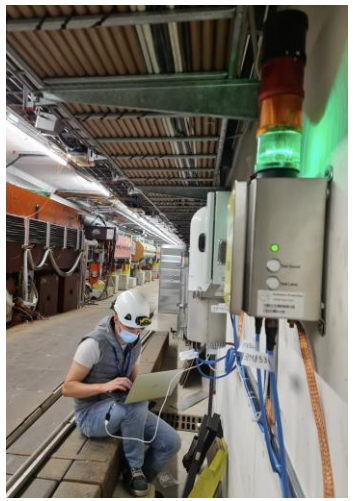
October 2020

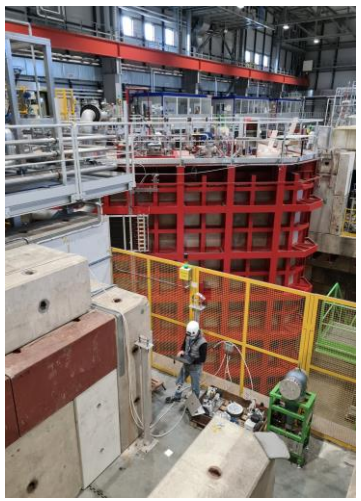
61 Monitoring stations

SPS



51 Monitoring stations





North Area

June 2021

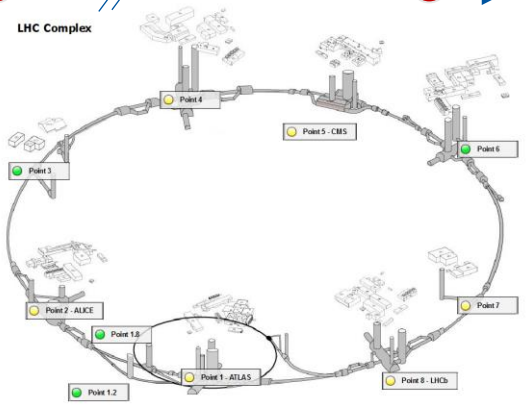
RAMSES2CROME Consolidation

CROME manufacturing and RAMSES replacement (444 MS) at LHC

Stray radiation monitors for environment monitoring (31 MS)

2023

2027

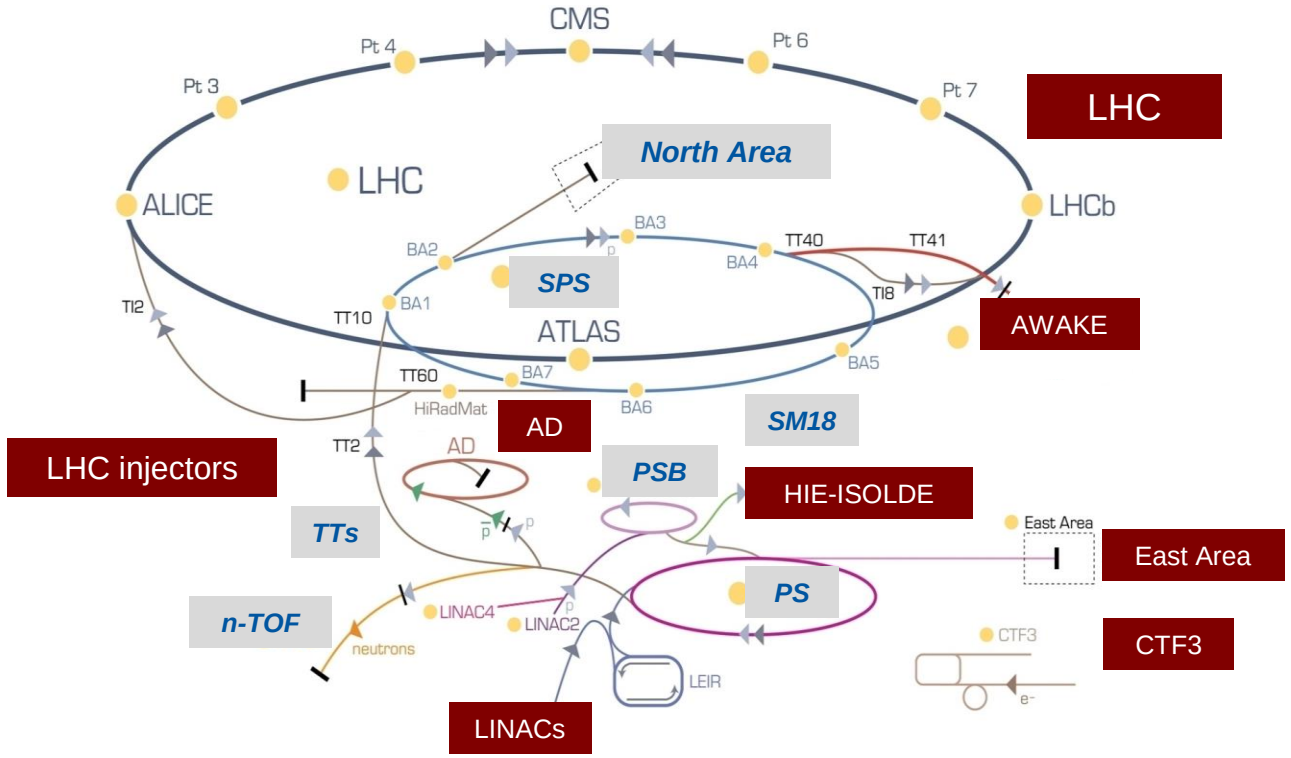


Conclusion

Radiation & Environmental Protection After LS2

CROME **2021 – 532 equipment** (153 Rad. Monitors + 70 Alarms Units)

CROME **2028 – 1050 equipment** (436 Rad. Monitors + 170 Alarm Units)



The development, production and ARCON replacement with 532 equipment allowed us to internalize all the knowhow

CROME Majors Technical Innovations

- Unified solution for radiation and environmental monitoring without modifications

  → Among the best current measurement sensitivity in the scientific state of the art [1] [2]

- Among the very first systems at CERN/ATLAS/CMS/LHCb that uses Heterogeneous System on Chip based processing and control system

  (Indico : SoC at CERN)

- First Safety System at CERN to use SoC

- First verification methodology for safety critical FPGA at CERN [3]

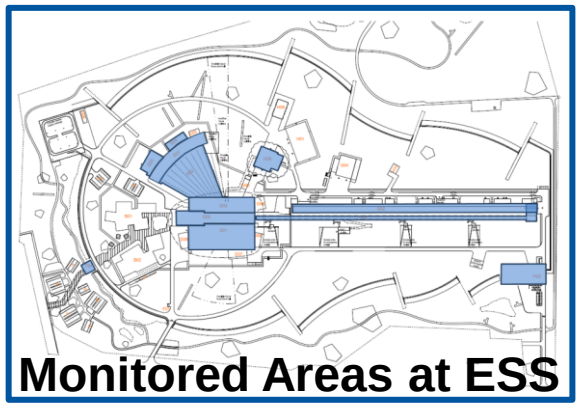
[1] Towards A novel modular architecture for CERN radiation monitoring, H. BOUKABACHE et al., Radiation Protection Dosimetry, 01 December 2016

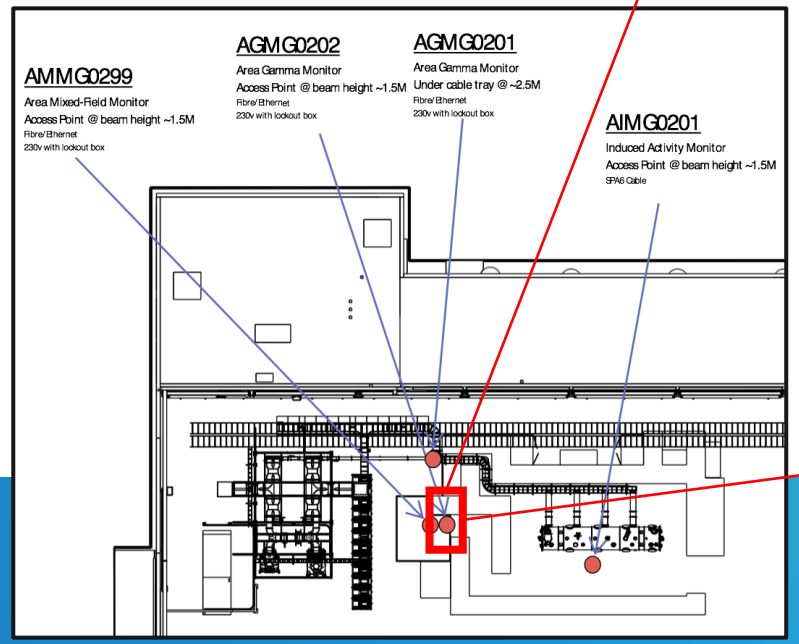
[2] Comparative analysis of ultra-low current measurement topologies with implementation in 130nm technology S.K. MOHANAN, H. et al. IEEE ACCESS

[3] A functional verification methodology for highly configurable, continuously operating safety- critical FPGA designs: Applied to the CERN RadiatiOn Monitoring Electronics (CROME) K. CEESAY-SEIT et al. Conference: 39th International Conference on Computer Safety, Reliability and Security.

CROME at ESS

Cryogenic test stand (TS2b) and Normal Conducting LINAC



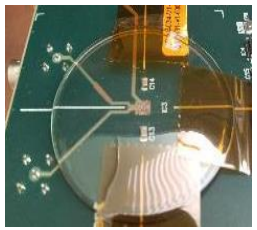


Ionizing radiation monitoring using CROME at ESS

Outlooks : Prepare for the future

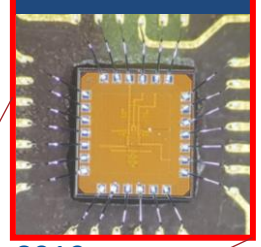
Prepare for future with new upgrades

Accurate 0

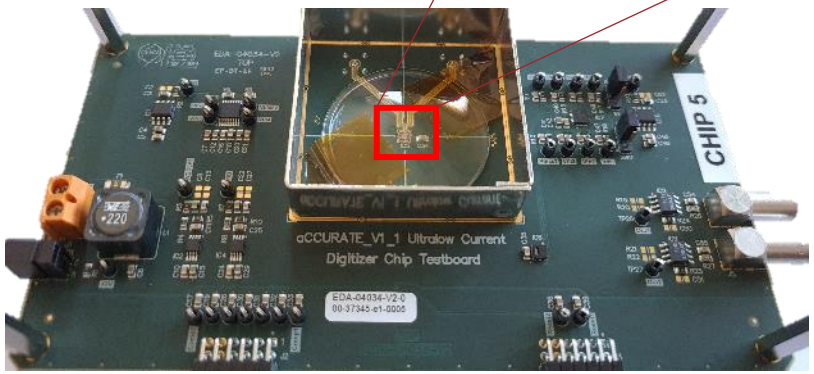


2018

Accurate 1



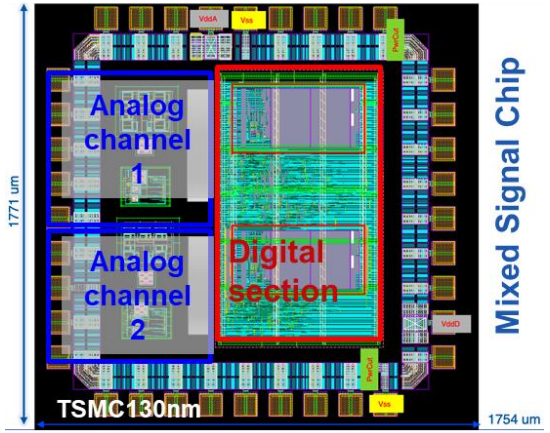
2019



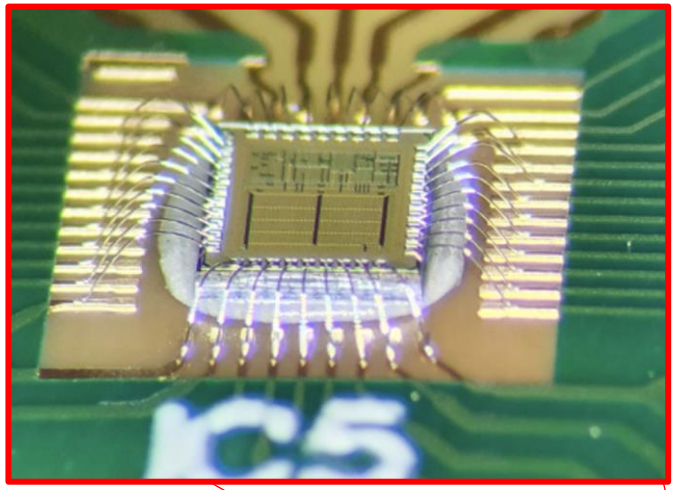
Accurate 1 characterization

A new development

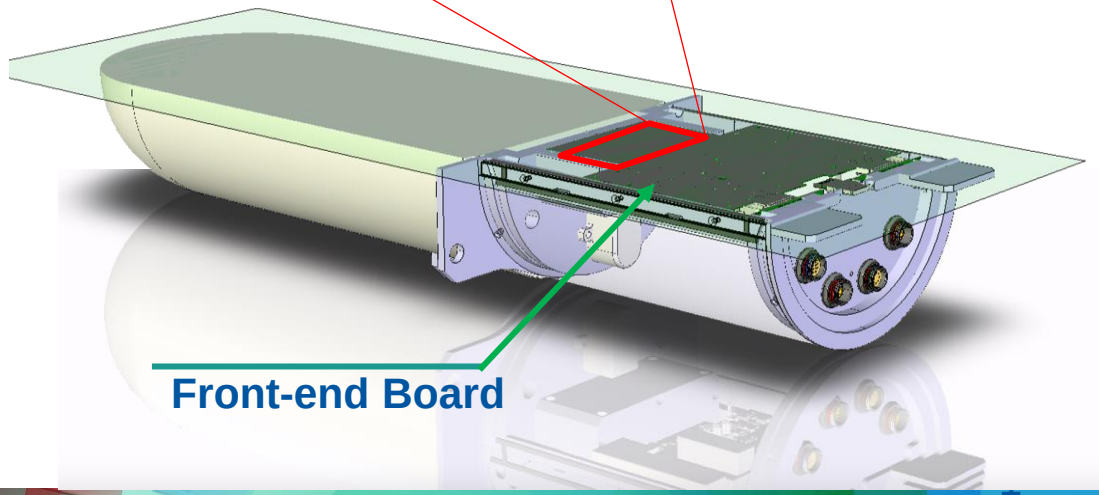
Accurate 2



2020



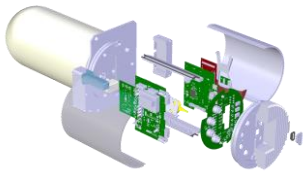
Preparing for future with an integrated solution



Outlooks : Prepare for the future

CROME Development

Full in house development of CERN new radiation monitoring system for safety and envirenement



2018

ARCON Replacement
End of CROME Project

Replacement of ARCON by CROME at the PSB, PS, SPS, SM18, ENH1

2021

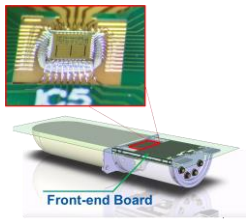
ACCURATE

R&D

2023

Lamda Protoype

CROME Ecosystem with Accurate Chip Front End



2025

RAMSES Replacement
RAMSES2CROME Project

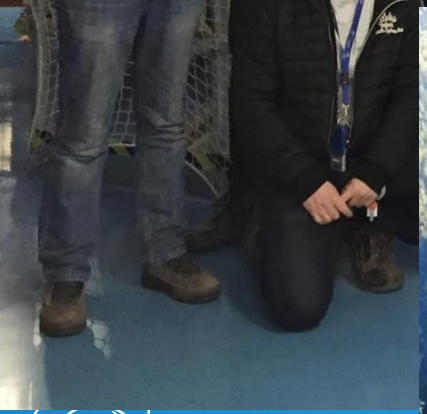
Deployment of CROME everywhere at CERN

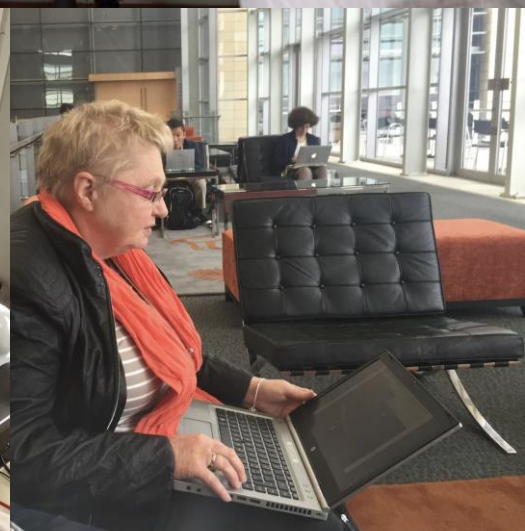
2028

CROME Consolidation

Replacement of CROME by the new generaton of CERN Radiation Monitoring System

Thank you very much for your attention



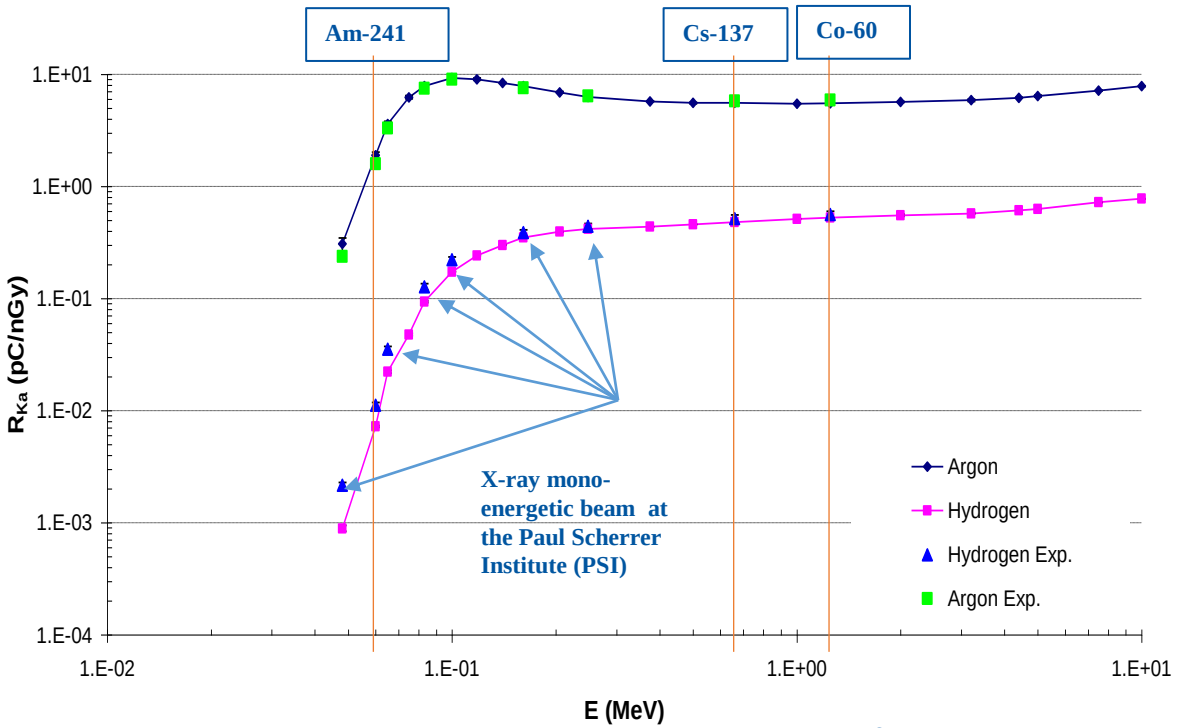


www.cern.ch

Detector Static Characterization

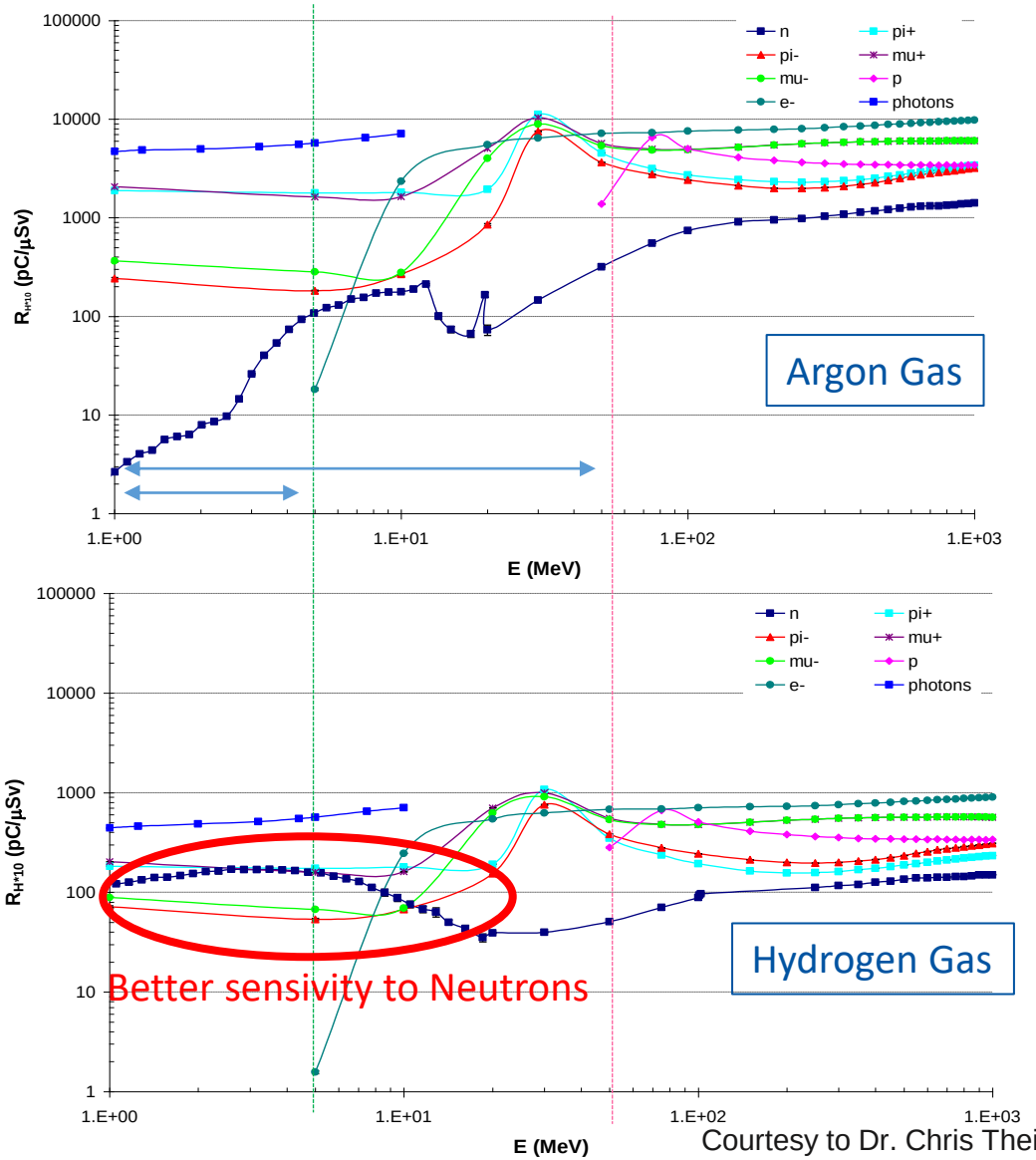
Detection spectrum

Response to Gamma ray



Calculated response to photons expressed in terms of created charge per energy released in matter for argon- and hydrogen-filled IG5 chambers

Response to Mixed Fields



Courtesy to Dr. Chris Theis

CROME System Reliability

SIL Verification according to IEC 61508

Safety Integrity Requirements :

To achieve a definite SIL, the SIF must meet all safety requirements.

1- Systematic Safety Integrity (Process Quality Assurance)

2- Hardware Safety Integrity

2.1 - Architectural Constraints

3- Software Safety Integrity

	SIL1	SIL2	SIL3	SIL4
Systematic safety integrity		x		
Hardware safety integrity			x	
Software integrity			x	
Overall safety integrity		x		