Operational Experience of the LHC RADiation MONitoring (RADMON) System

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10th International Conference on Large Scale Applications and Radiations Hardness of Semiconductor Detectors

Florence, Italy
6 – 8 July 2011

Outline

- I. Radiation Monitoring project
- II. Radiation monitoring sensors
- III. Benchmark for Fluka simulations
- IV. RadMON Software
- V. Application
  - *LHC operation*
  - *Experimental test areas (CNRAD and H4IRRAD)*
- VI. Conclusion

Radiation monitoring project

- **Radiation monitoring project at CERN : Why ?**

- The effect of radiation on electronic components and systems→ Major issue
- Equipments → Affected by radiation damage

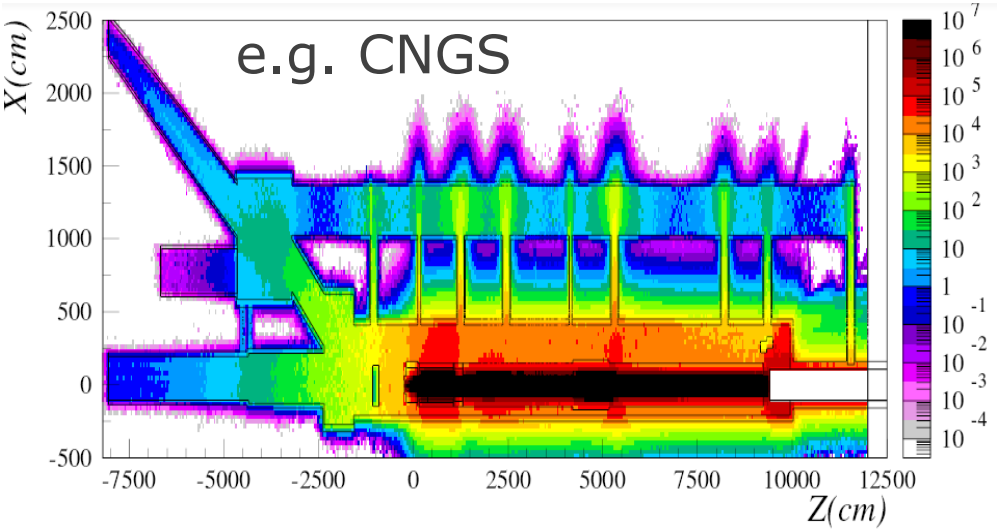
  → *Radiation level survey needed for damage and failure analysis.*

- Considerable uncertainty on the radiation environment in the tunnel and on the radiation tolerance of equipment..
- The radiation monitoring system will help to reduce this uncertainty by providing an early warning as the radiation levels at the location of the equipment increase.

- *Motivation:* Provide essential feedback on the LHC radiation levels in critical area (based on simulations)
- Estimation of the evolution of radiation levels while LHC intensities/luminosities increase.

Radiation monitoring project

- **Radiation monitoring project at CERN : What ?**



Ionization effect

TID (Total Ionizing Dose)

e.g. accumulation of charge in SiO_2 : *damage to microelectronic components*

Non-Ionizating effect

NIEL (Non Ionizing Energy Loss)

causing e.g. crystal defects in semiconductor crystals

Cumulative effects

Single event effect

Single Event Transients (SET), Latchup (SEL), Burnout (SEB), Gate Rupture (SEGR), Upset (SEU)

e.g. bit flip in SRAM memories (SEU)

Stochastic effect

Radiation monitoring project

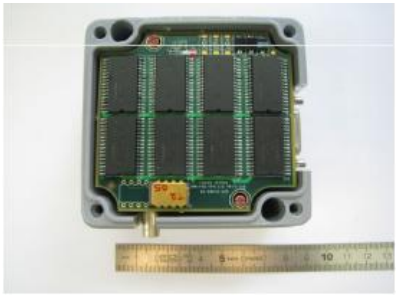
- **Radiation monitoring project at CERN : How ?**
  - RADMON on WorldFip bus:
    - About 400 devices installed in the LHC tunnel and in the shielded galleries
    - 1s rate measurement over the field bus WorldFip

      (TID, 1 MeV neutron eq. fluence, HEH and thermal neutron fluence)

RADMON

- RADMON battery driven → BATMON
  - To measure single spot where field bus is not available
  - Off line reading (TID, HEH fluence and 1 MeV neutron eq. fluence)

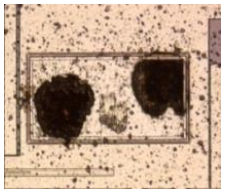
BATMON



- Very stable system including several hundred of monitors
- Fullfils specific LHC requirements
- Can be applied to a much larger context

Radiation monitoring sensors

Radiation damage in semiconductors



Single Events

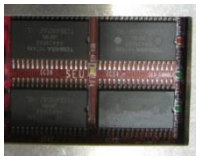
Effect in the Device

Displacement

Dose

SEU counter

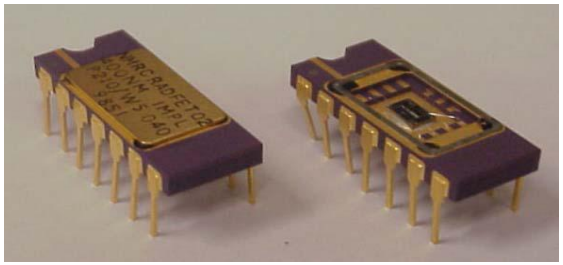
Toshiba memory AF



Effect in the Device

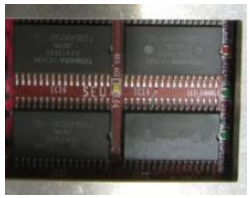
PIN diodes

RadFETs

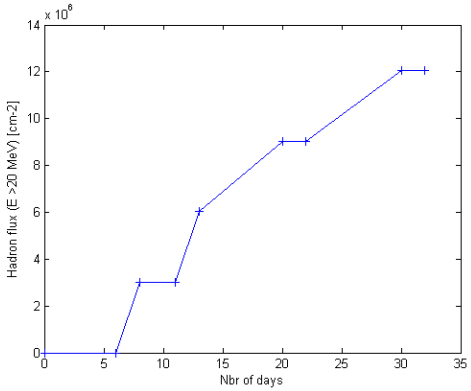


Radiation monitoring sensors

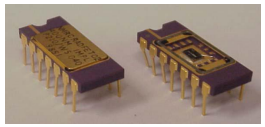
Static RAM



- Measure radiation induced voltage spikes over reversed bias p-n junction
- Number of “0-1” in SRAM proportional to the hadron fluence.
- Measurement at 3 V and 5 V allows to estimate HEH and the thermal neutrons fluence[1,2].

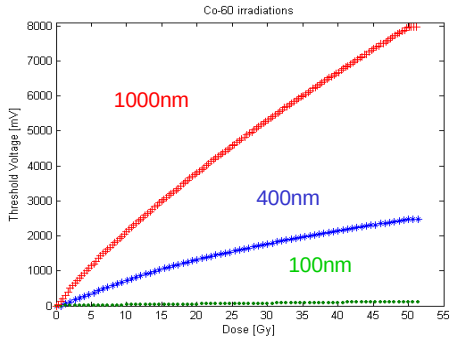


[1] For more details on the estimation please refer to **D. Kramer et al. “Radecs 2010 proceedings”**.
[2] Calibration study will be presented by **“ K. Roeed et al. at Radecs 2011 conference”**.



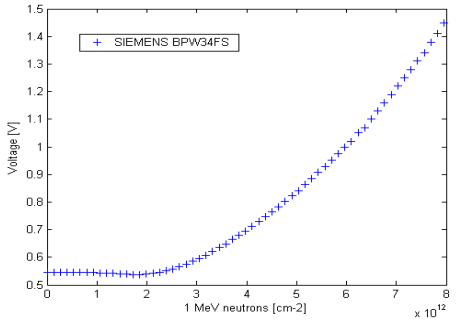
RadFET

- Measure trapped charge in gate oxide (SiO_2)
- At constant current: ΔV proportional to Total Ionizing Dose (TID)
- Different oxide thicknesses → different sensitivities

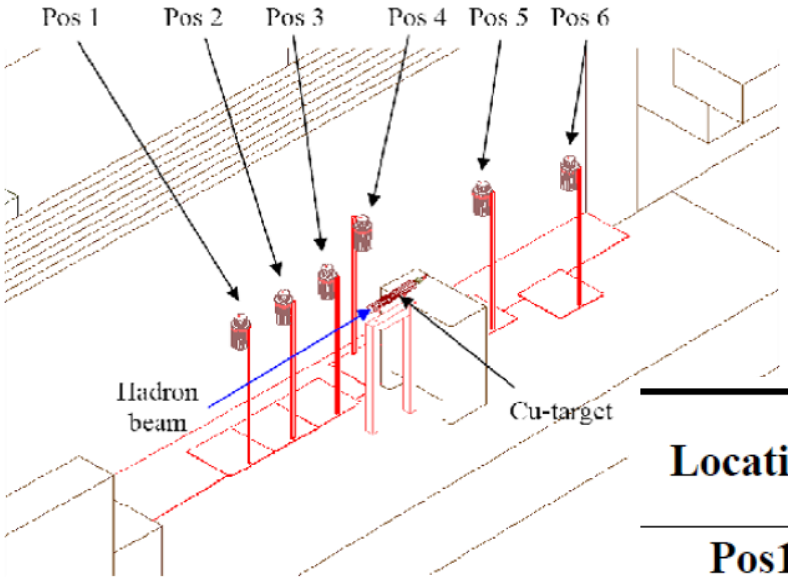


P-I-N diode

- At constant current: ΔV proportional to 1 MeV eq. Neutron fluence (Φ_{eq})
- Measure conductivity variation at high forward injection



Fluka/RadMON Benchmark

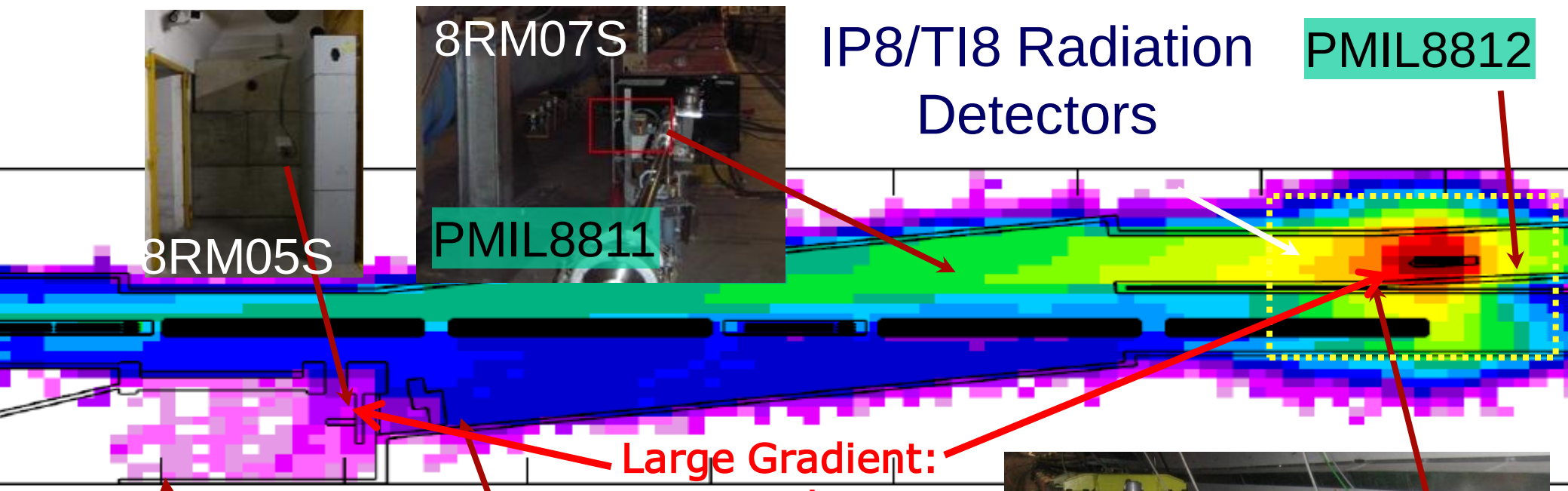


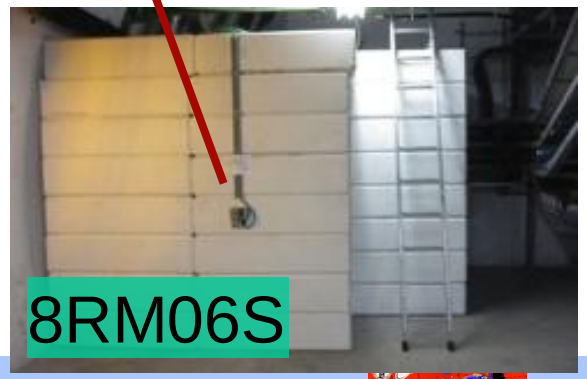
- **CERF Benchmark**

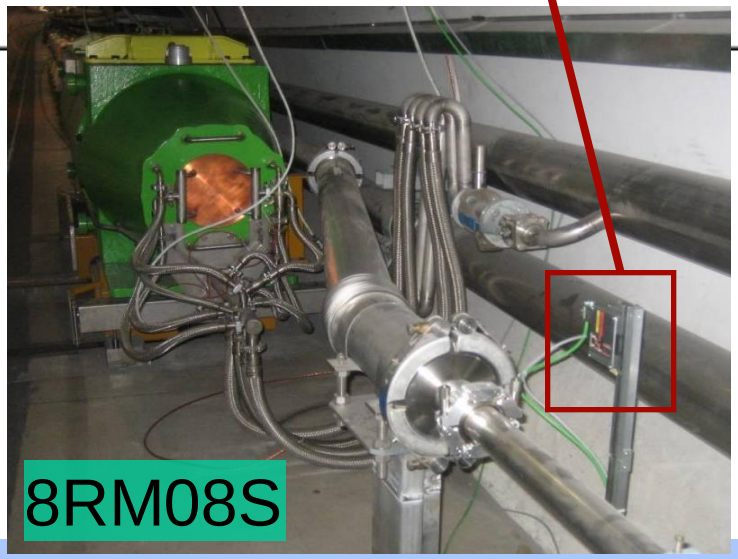
Location	RadMon [Error]	FLUKA [Error]	Ratio (R/F)
Pos1	3.77×10^{-4} [20.0%]	4.17×10^{-4} [5.1%]	0.90
Pos2	5.76×10^{-4} [20.0%]	5.76×10^{-4} [4.6%]	1.00
Pos3	1.99×10^{-3} [20.0%]	1.97×10^{-3} [2.8%]	1.04
Pos4	1.75×10^{-3} [20.0%]	1.71×10^{-3} [3.4%]	1.02
Pos5	1.53×10^{-3} [20.0%]	1.67×10^{-3} [3.2%]	0.92
Pos6	2.19×10^{-3} [20.0%]	2.19×10^{-3} [2.9%]	1.00

M. Brugger et al., " FLUKA CAPABILITIES AND CERN APPLICATIONS FOR THE STUDY OF RADIATION DAMAGE TO ELECTRONICS AT HIGH-ENERGY HADRON ACCELERATORS", presented at the "Monte-Carlo Conference 2010 in Tokyo", accepted for publication in "Progress in Nuclear Science and Technology", PNST10184-R1 (2010).

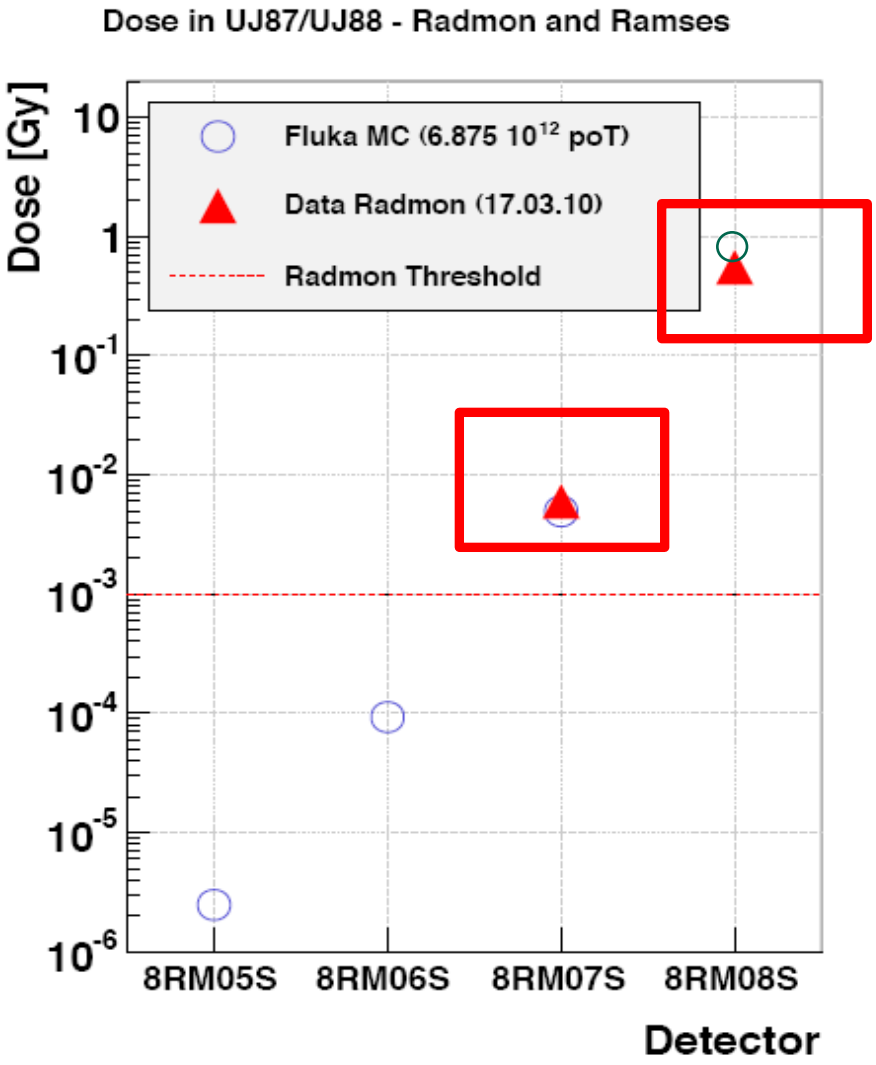
Fluka/RadMON Benchmark

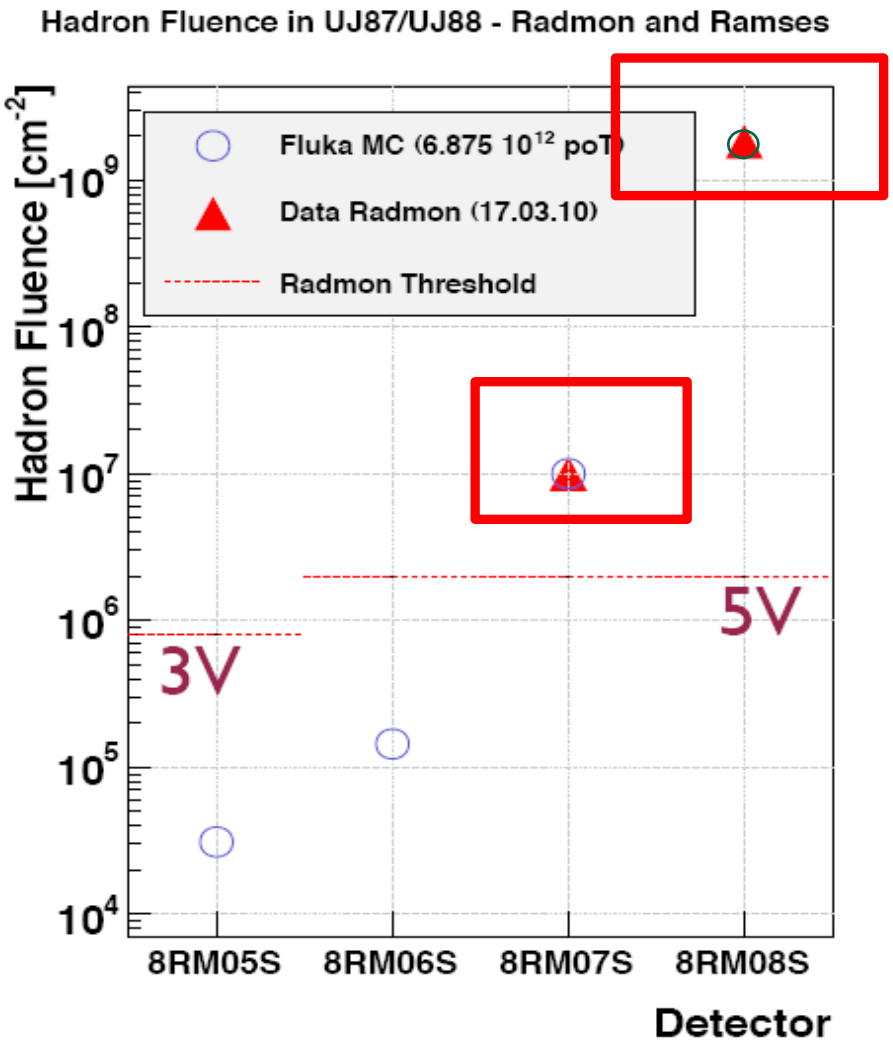






Fluka/RadMON Benchmark





RadMON Software

- *Calibration database*

What is it ?

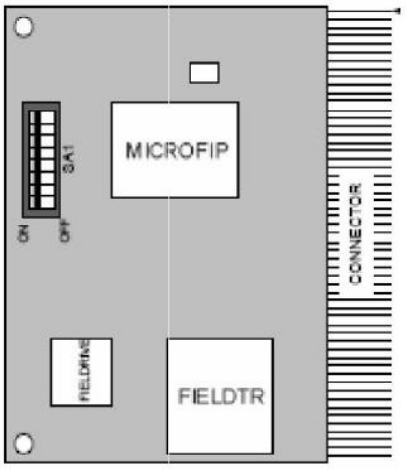
- A web application designed to store configuration data for RadMon devices.
- Provides tools for viewing multiple/specific RadMon devices.
- Generates the configuration files for RadMon FESA system.

Why do we need it ?

- Single point of data storage
- Reduces generation time and potential for inconsistencies when generating configuration files.
- Accessible from entire CERN network

RadMON Software

- *RadMON FIP Library*
- Software library to communicate with RadMON devices via WorldFIP bus
  - Initialize devices
  - read/write commands
  - status information
- Read characteristics of radiation devices in a device's location
- Provides external applications with API to
  - Configure protocol
  - Operate on devices
  - Access partially interpreted data
- Provides direct access to device via toolset
  - RadMON monitor
    - Direct access to calibrated device data
  - RadMON raw data monitor
    - For diagnostic purpose



WorldFIP - MicroFIP interface[3]

[3] http://cern-worldfip. web.cern.ch/cern-worldfip/docs.php

Application

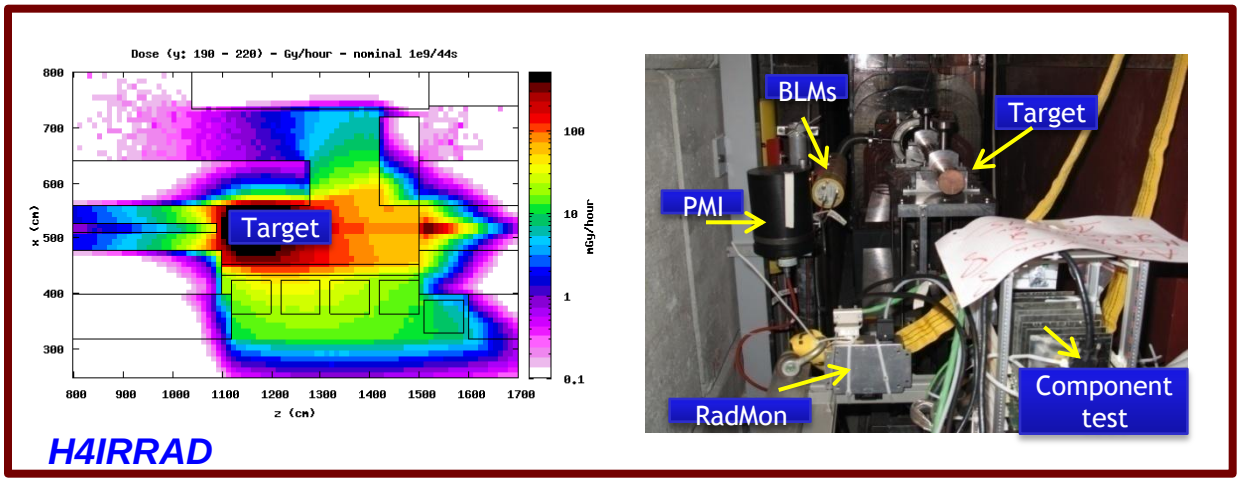
- **LHC operation: Main objectives during circulating beam in LHC ?**
- Monitor the radiation field → degradation of electronics due to radiation when beam “on”
- Correlate observed failures with respective radiation levels, e. g. during abnormal beam losses:
  - Propose appropriate radiation tolerant components in case of radiation induced failures
  - Anticipate replacement of electronics that degraded due to cumulative radiation damage effects

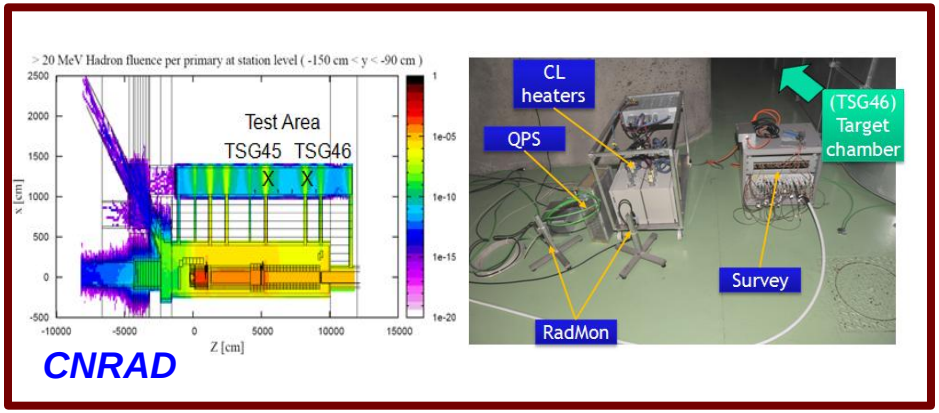
- Collimation, radiation in RRs due to collision products, …
- Measure shielding efficiency – confirm staged implementation
- Cross check with simulation results

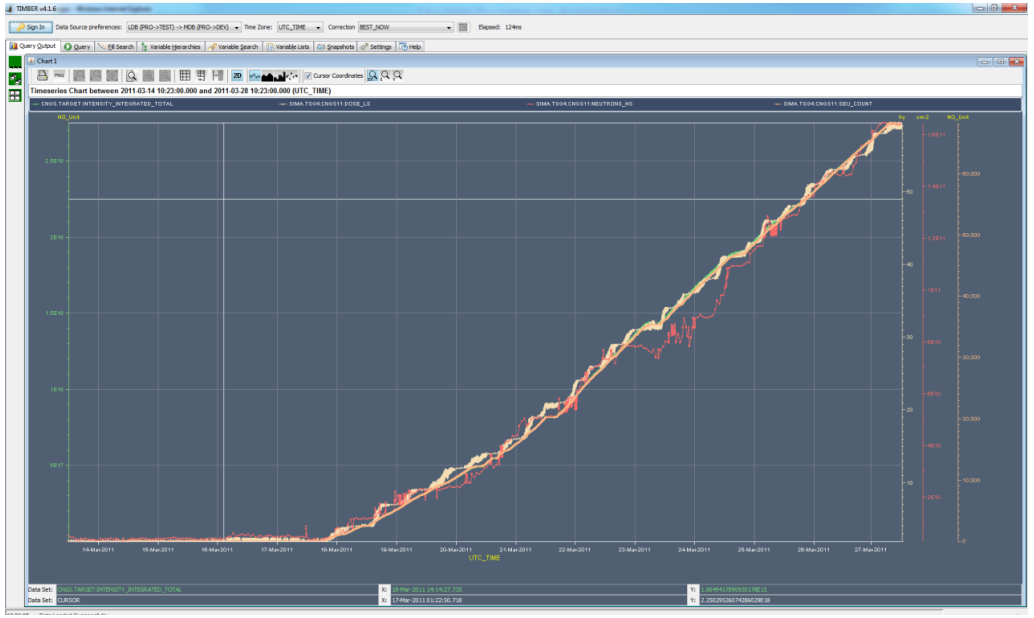
RadMON

Application

- **Experimental test Areas**
- RadMONs are installed in CERN radiation facilities and tests areas (CERF, CNRAD, H4IRRAD)
- Monitoring of the mixed field for the equipment under test
- Continuous reiteration to improve the calibration (cross check with other sensors BLM, PMI, and benchmark for simulations)







Conclusion

- A Radiation monitoring system has been developed at CERN.
- Fluka/RadMON benchmark is performed for LHC locations and experimental test areas.
- RadFETs and p-i-n diode dosimeters are used for monitoring TID and Φ_{eq} respectively.
- SRAM memories are used for monitoring the HEH fluence and well as the thermal neutrons fluence.
- A RadMON software has been designed:
  - To communicate with the RadMONs via a WorldFIP filed bus.
  - To configure the RadMON Fesa system & visualize the data remotely via tools available on the CERN network. (e. g. Timber)
- A Battery system has been developed to access zone where no field bus are available.
- Used in the LHC accelerator as well as in radiation facilities and experimental test areas.