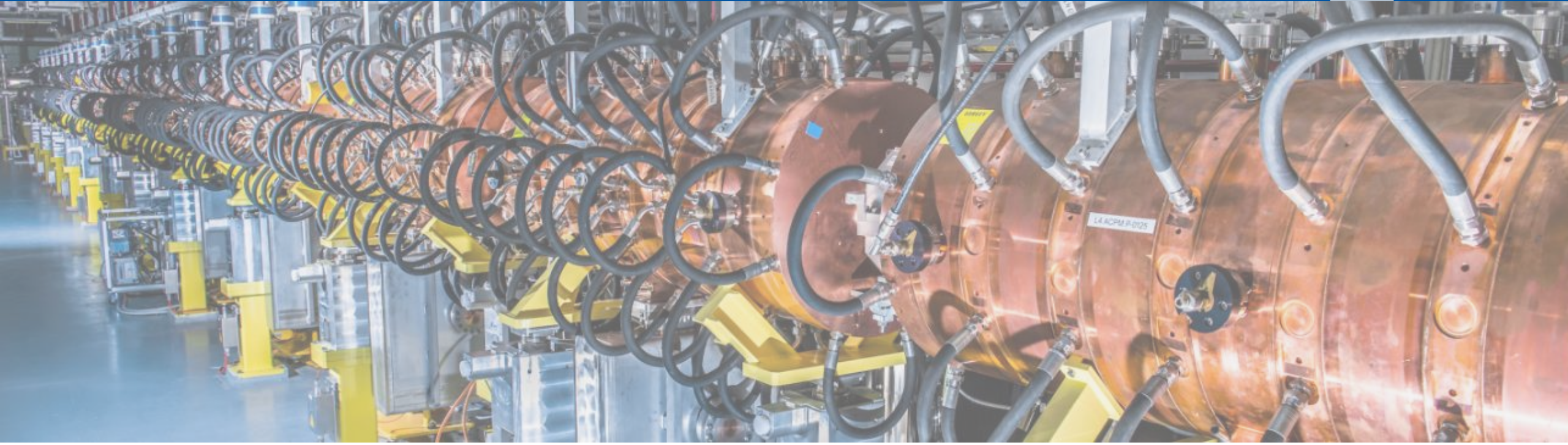

CERN

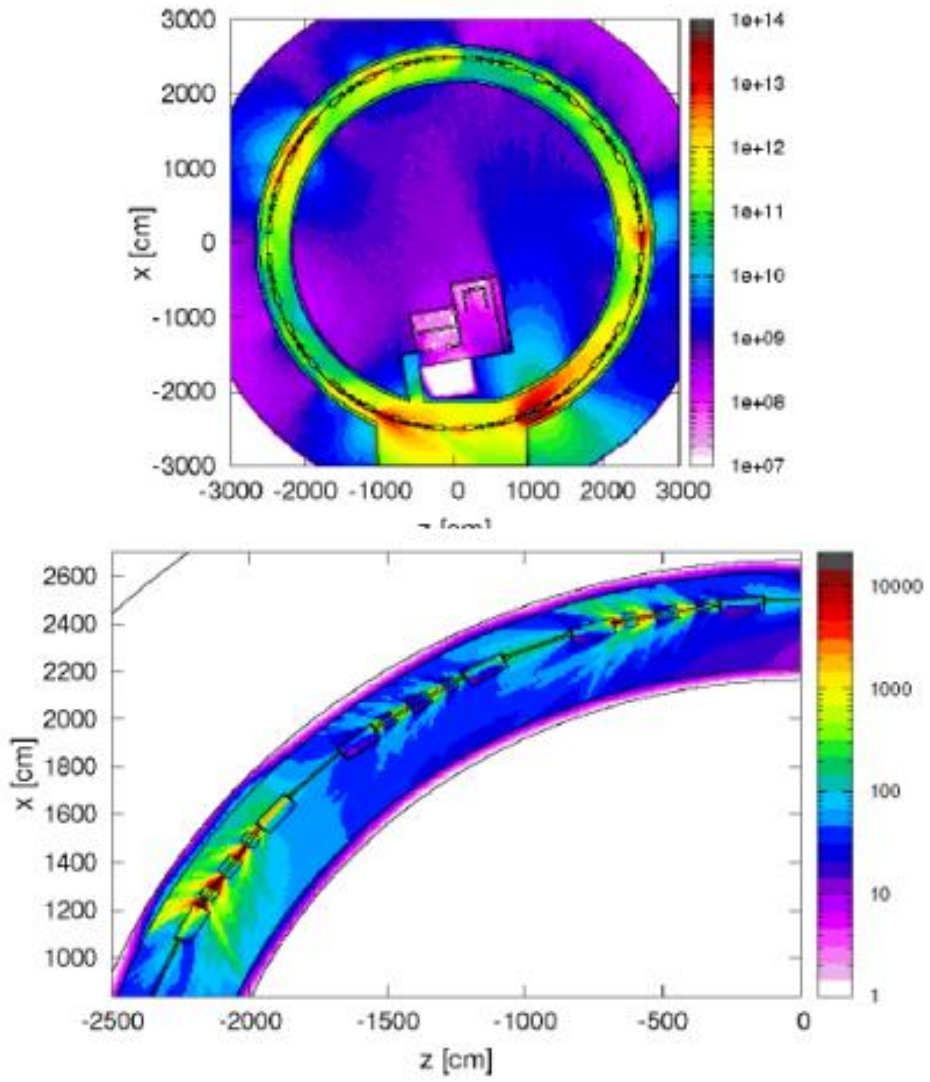


Overview of the CERN Injector Chain Radiation Environment and Equipment

Melanie Krawina, Rubén García Alía
EN – STI BMI
R2E annual meeting, December 2018

R2E beyond LHC

Importance of the Injector reliability



FLUKA simulations, PS booster. Done by **J. Saraiva**

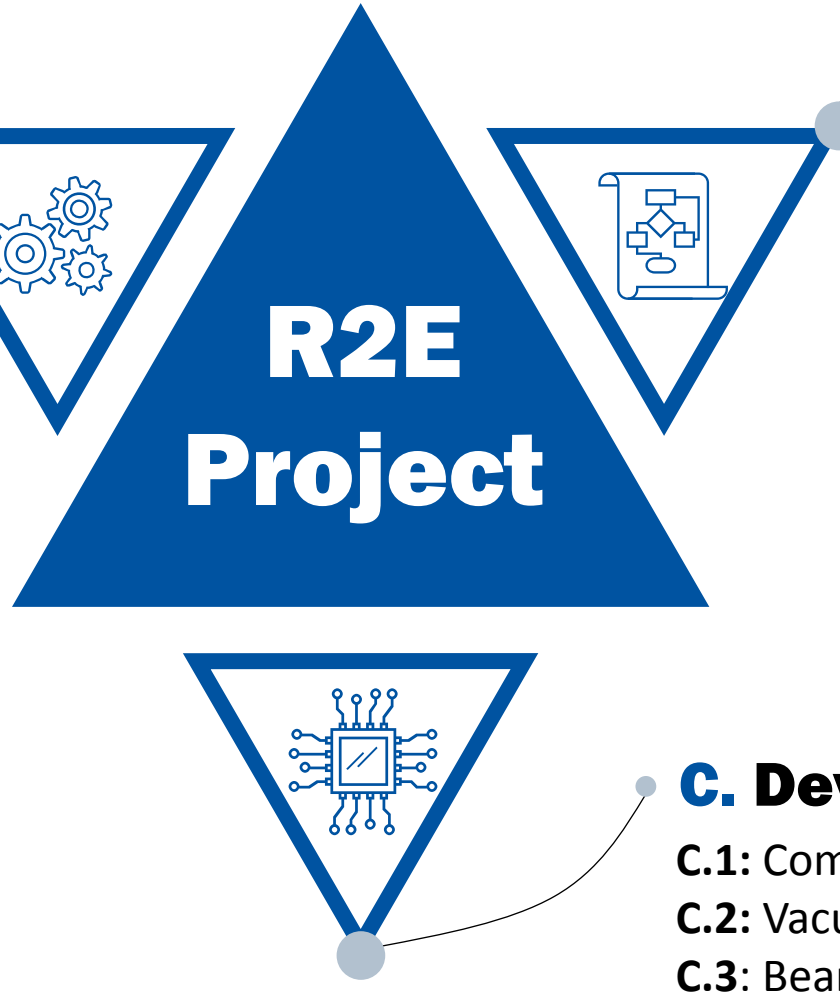
- The LHC injector system is becoming evermore critical for the availability of the LHC

- **Radiation levels are generally larger** than in the LHC (i.e. warm machines), however the electronic systems less complex and sensitive to radiation (i.e. analogue systems)
- The LHC injector upgrade (LIU) will include **more complex system** with state-of-the-art electronics, mostly based on COTS
- Furthermore LS2 and Hi-Lumi upgrade will **further increase the radiation levels** in the injectors

- A systematic Radiation Hardness Assurance approach needed for the injector chain to guarantee a successful after LS2 operation, as well as a dedicated environment evaluation related to LIU

The LHC-IC work-package

Place within the R2E work-package structure



A. Operations

A.1: Project Management
A.2: Radiation Working Group Support
A.3: Monitoring & Calculation Working Group Support
A.4: Materials Testing & External Facilities

A.5: LHC Injector Chain & Experimental Areas

B. Infrastructure

B.1: CERN Facilities
B.2: RadMON Monitoring System
B.3: Optical Fibre Dosimetry
B.4: Shielding & Relocation

C. Developments

C.1: Common Building Blocks
C.2: Vacuum
C.3: Beam Instrumentation
C.4: Quench Protection System
C.5: Power Converters

As introduced by **R. García Alía** yesterday

The LHC-IC work-package

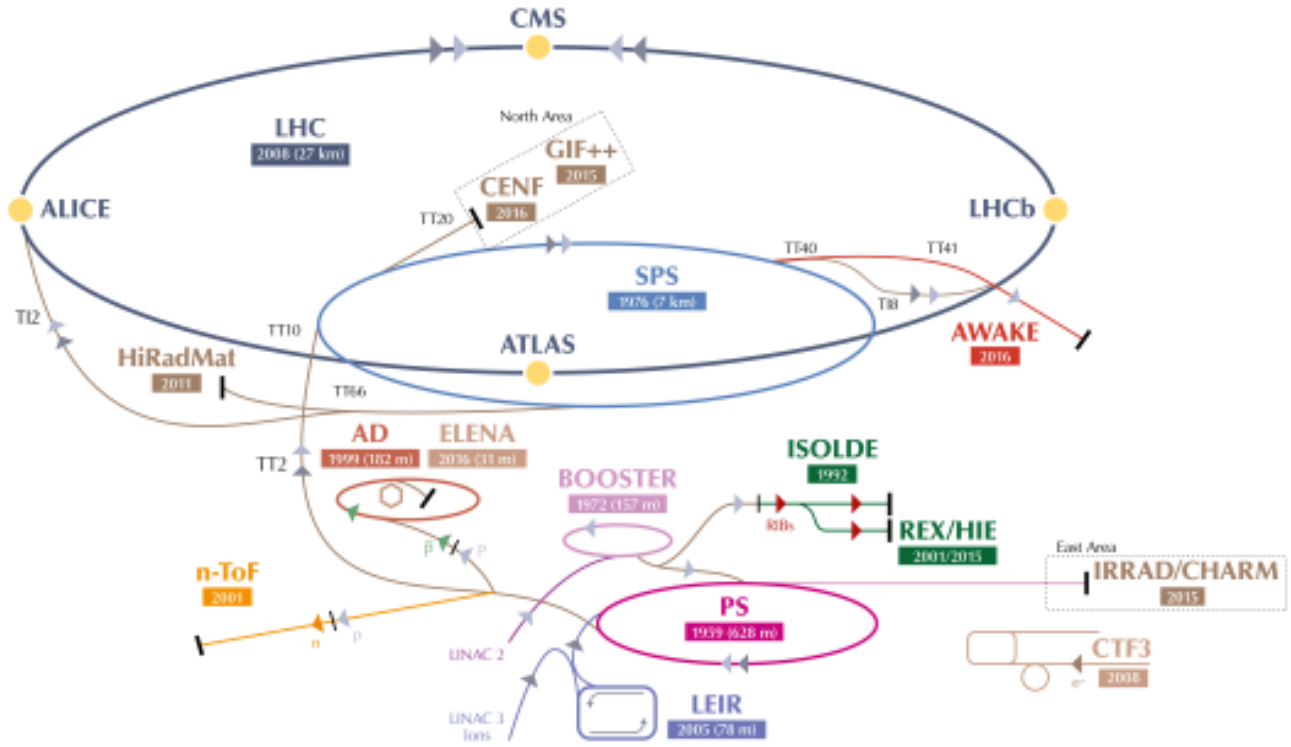
Overview and objectives

- Covers the **LHC injector chain** (LINAC4, PSB, PS, SPS) and the **Experimental Areas** (nTOF, AD, BDF test area …)

- Description and objectives:
  - Providing **radiation maps** and monitoring of radiation levels in strong collaboration with the MCWG (past: RP surveys for loss maps)
  - **FLUKA simulations** for benchmarking and prediction of future scenarios in strong collaboration with the EN-STI BMI
  - Developing a comprehensive **inventory list** of installed electronic systems and components
  - **Analyzing equipment failures** and developing strategies to reduce them
  - **Support to equipment groups** in the design, upgrade and **qualification of electronic equipment** to be installed in the accelerator tunnel or its vicinity
  - Design and implementation of dedicated **radiation shielding measures** or optional relocation measures
  - …

R2E requests for the IC

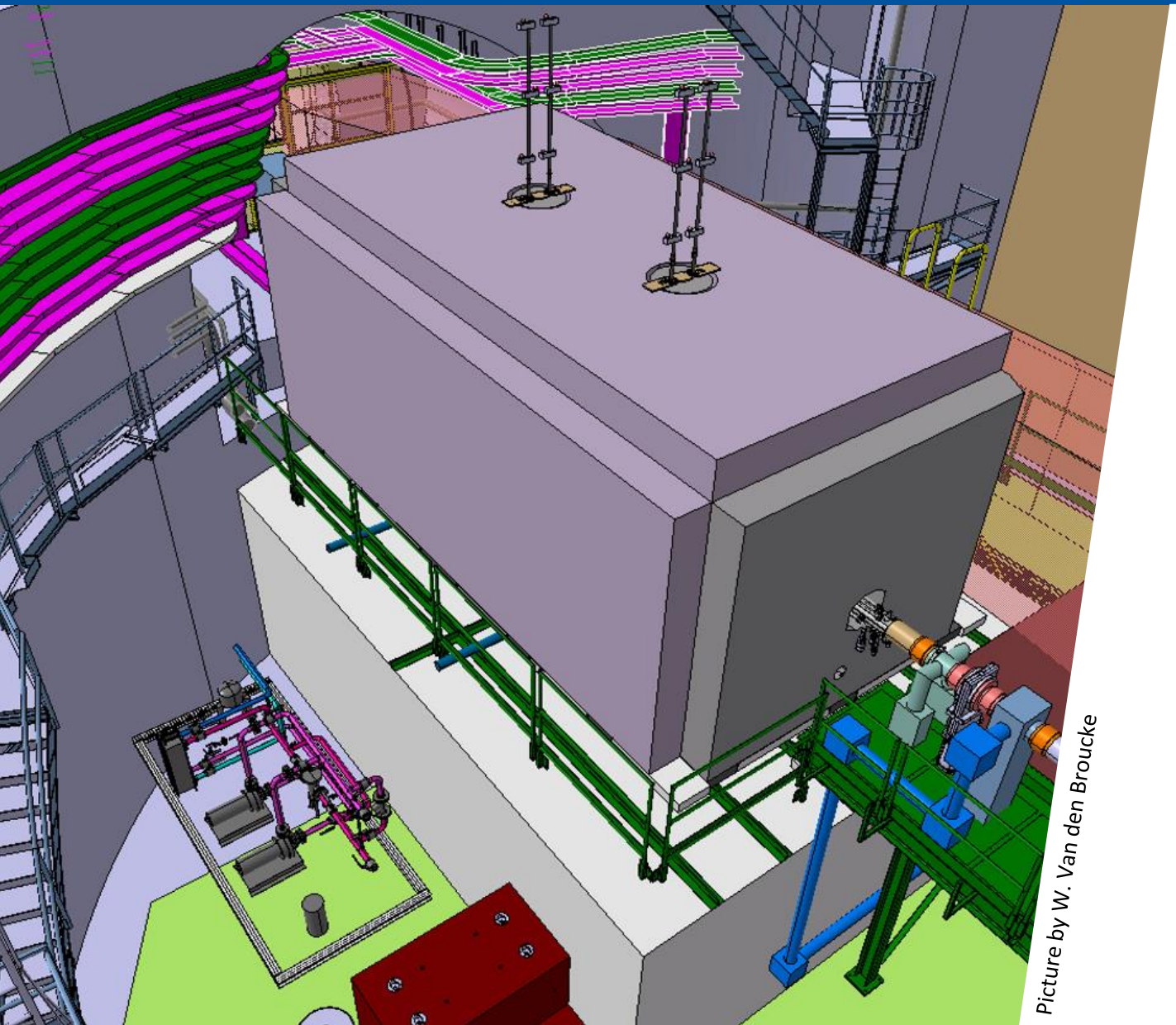
Over the last couple of months



- **LINAC4**
  - Possible R2E induced failures at preamplifiers close to the stripping foil (**BE-BI**), mitigation actions
- **PSB**
  - Upgrade of the BTV system, radiation maps needed (**BE-BI**)
  - Benchmark of FLUKA radiation maps with OF sensors (**EN-EA**)
- **SPS**
  - LSS5 installation BTV system, radiation map and mitigation actions (**BE-BI**)
  - LSS5 CV skid installation, mitigation action (**EN-CV**)
  - LSS5 BCTW relocation, radiation map and mitigation action (**BE-BI**)
  - LSS4/LSS6 gamma factory electronics. Radiation map
- **AD**
  - Upgrade of the BTV system, relocation of sensitive equipment
- **BDF test area**
  - Possible R2E induced failures in PLCs, mitigation actions (**EN-STI**)

Case Study: SPS LSS5 dump

R2E requests for SPS LSS5 dump area



Picture by W. Van den Broucke

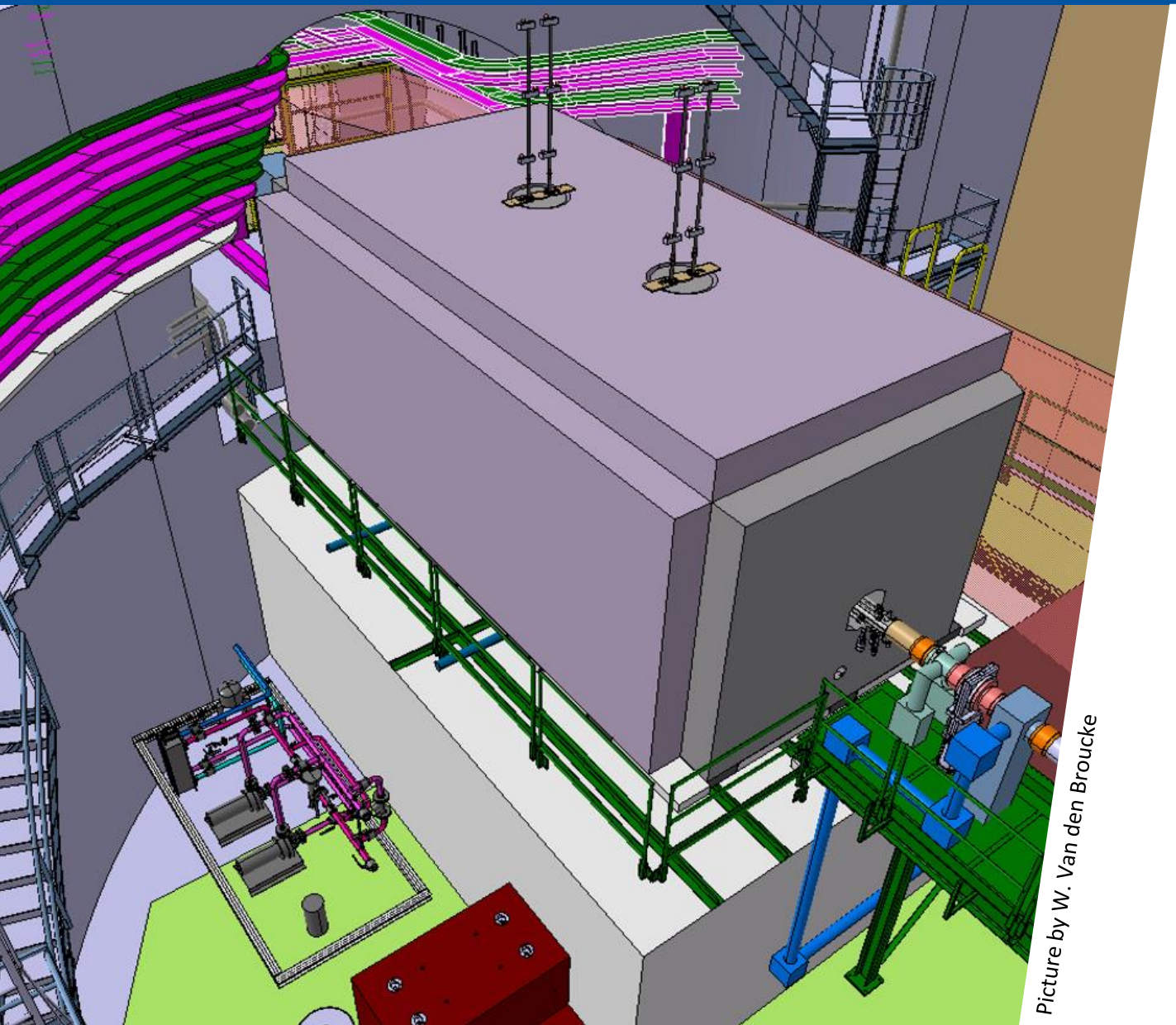
- **SPS LSS5 – EXCX5 cavern**, new beam dump region in Sextant 5 after relocation from LSS1
- Historically low-radiation levels, different equipment stored here
- New radiation environment due to beam

- Three different requests for this area received for three different applications and different groups
- All of them solved or ongoing activities, thanks to the **collective effort of the whole R2E team**

To highlight the efforts and describe the objectives of the LHC Injector Chain work package, region will be presented as case study.

Case Study: SPS LSS5 dump

R2E requests for SPS LSS5 dump area



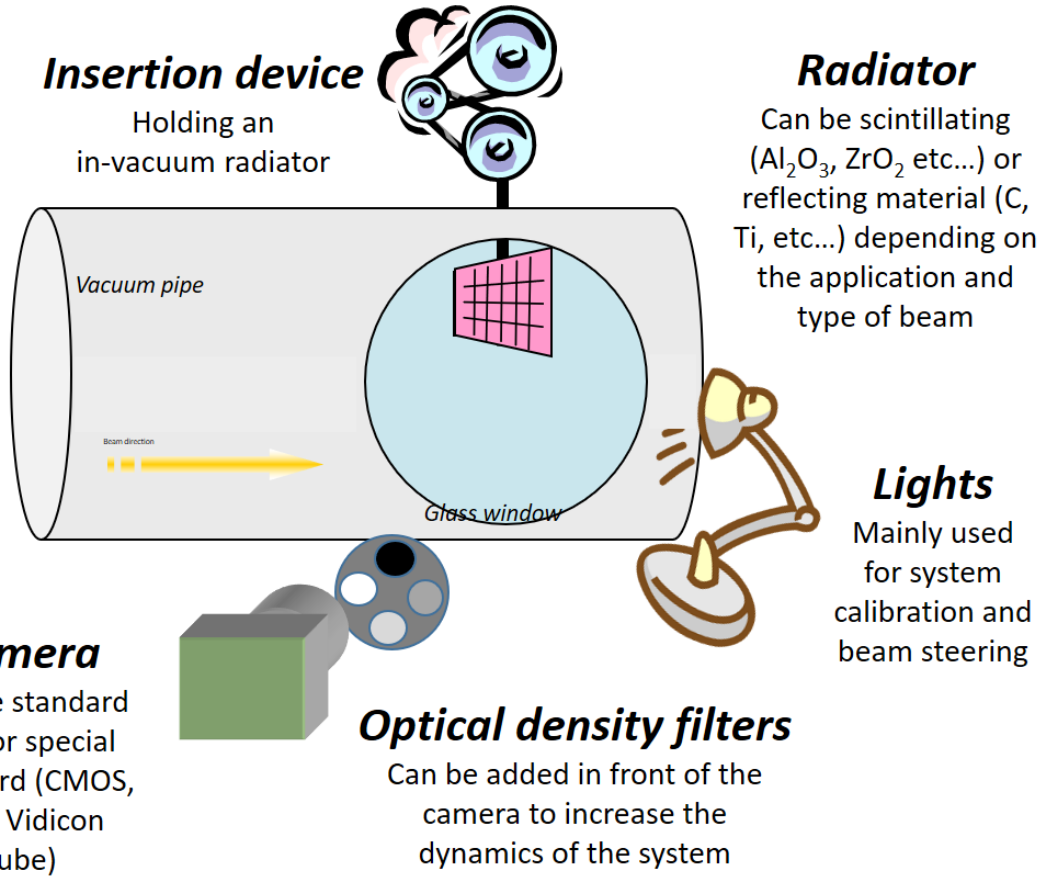
Picture by W. Van den Broucke

Requests that will be highlighted:

1. BTV systems (BE-BI)
2. Beam dump cooling and ventilation (CV) skid (EN-CV)
3. BCTW system (BE-BI)

SPS LSS5 dump | BTV systems

Overview BTV system



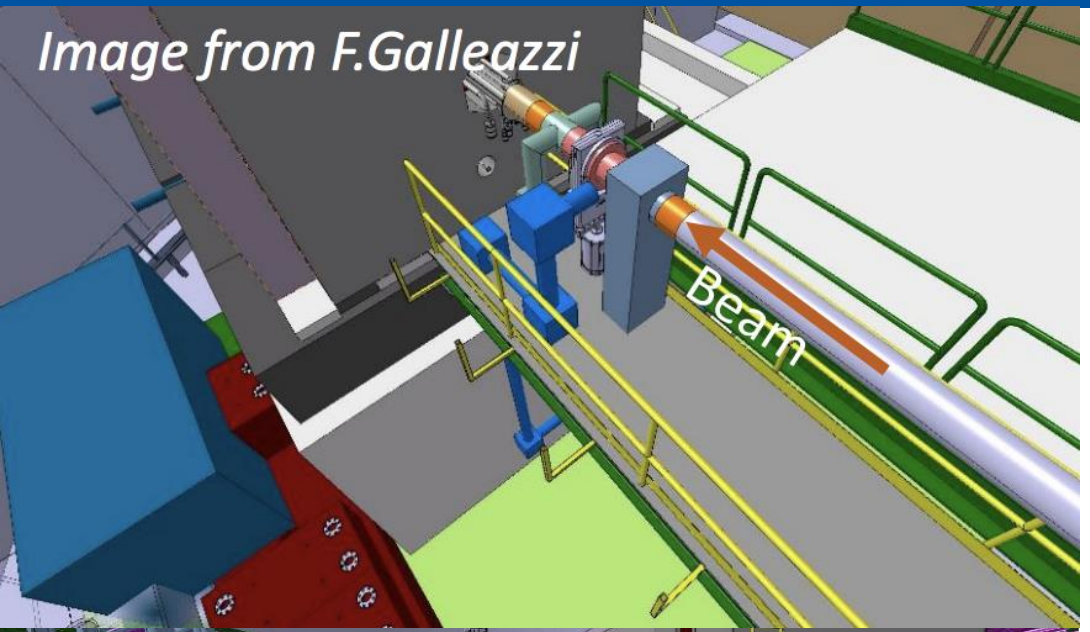
Animation provided by **S. Burger**

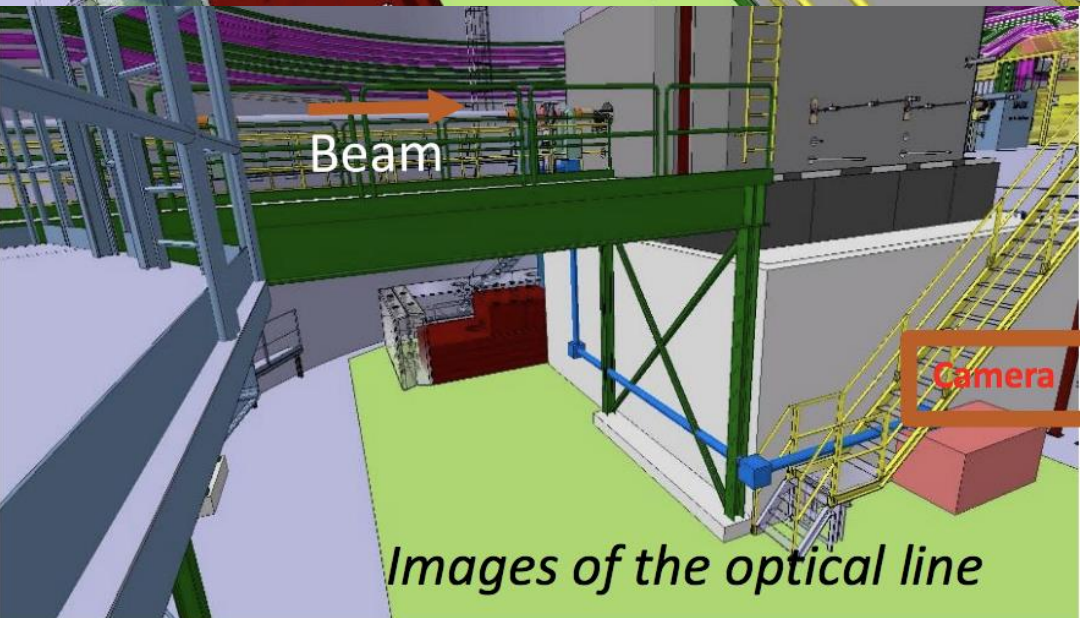
Already explained by **T. Lefevre** yesterday, in a nutshell:

- BI department provides operation parameters of the beam, key values: position, size, profile, length, Intensity …
- **BTV (Beam TV)** system used, consisting of i) a luminescent beam screen/radiator that is inserted into the vacuum chamber ii) a detector (camera) that observes/detects emitted light.
- Up to now based on analogue cameras (standard CCD) or ”radhard” solutions (tube based, ThermoFisher …) used at CERN -> Upgrade to digital COTS ones

SPS LSS5 dump | BTV systems

Problem statement





Pictures provided by **S. Burger**

1.) BTV system

- Upgrade from analogue CCD sensors to digital (higher performance, image rate, resolution …) – Digital more sensitive to SEU!
- New camera will be purely commercial and no information regarding sensitivity to radiation

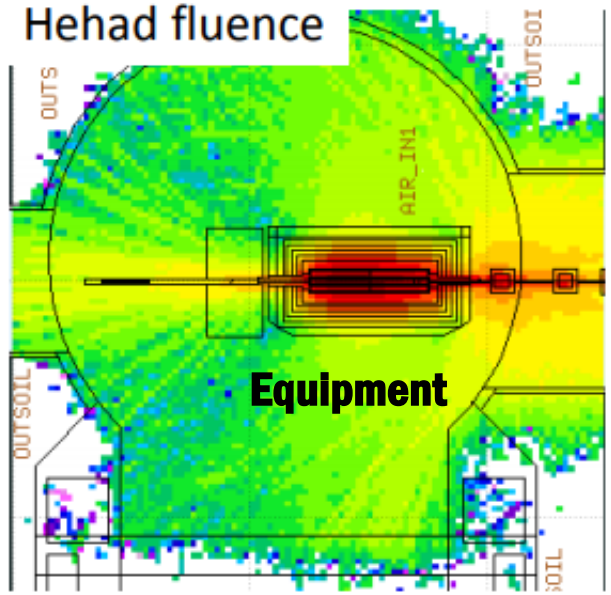
- **Qualification campaign** of BASLER camera at CHARM conducted in 2016 (see *EDMS 1736143*)
  - Key findings:
    - **TID**: ~150 Gy lifetime limit
    - **SEU**:
      - SEU sensitive, power-cycle resets (Φ_{SEU} = 1.5E9 HEH/cm2)
      - total limit of ~5E11 HEH/cm2 over lifetime

Target values camera for ECX5 :

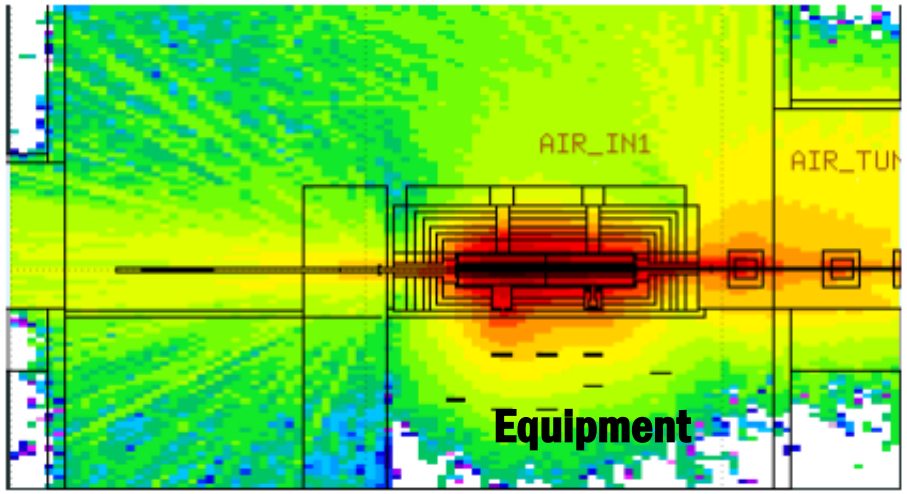
- **< 10Gy/y**
- **< 1E8 HEHeq/cm2/y**

SPS LSS5 dump | BTV systems

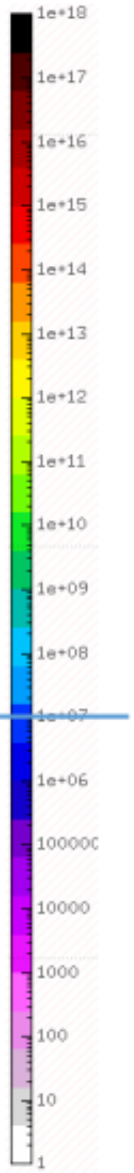
Analysis



FLUKA Top-view



FLUKA Side-view



Φ [cm^{-2}year^{-1}]

FLUKA simulations, LSS5. Done by **D. Björkman**
Results scaled **to 2E18 protons/year**

1.) BTV cameras – FLUKA studies

- Different positions were tested during FLUKA study - Only reasonable location close to the cavern floor (beam approx. 6m above), on the side of the beam dump abutment
- **Mirror system will be installed** to carry the image from the actual beam location to the sensor

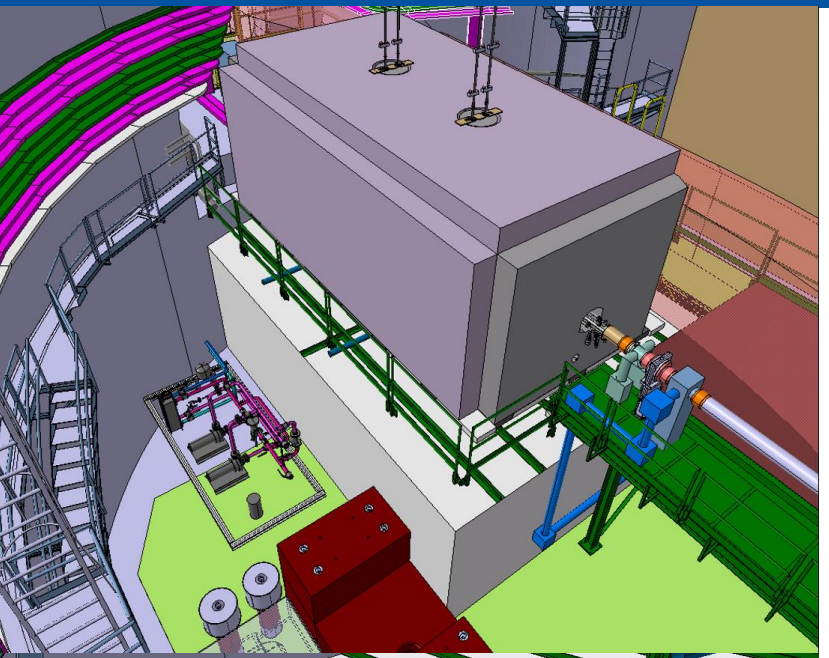
- **TID:** 0.01 < x < 10 Gy/y -> within target values
- **HEHeq** fluence: 1E9 < x < 1E12 HEH/cm2/y -> bottleneck!

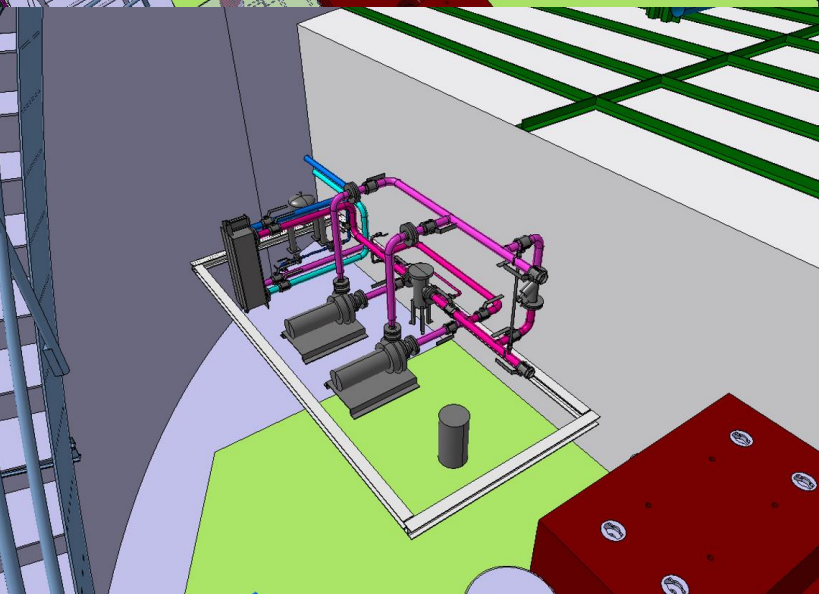
- Additional full iron shielding surround the sensitive equipment of the camera itself -> reduction of HEHeq fluence to ~**2.5E7 HEH/cm2/y**

-> Prevention through shielding

SPS LSS5 dump | CV skid

Problem statement





2.) CV skid

- Cooling station close to the LSS5 beam dump, to minimize the volume of contaminated water
- Will be installed at the floor, includes different electronics (purely COTS) with no qualification tests conducted, that will be subject to beam and dump radiation

- Most critical components of the setup are **Pressure Transmitters** and **Pressure Difference Transmitters** (PT and PDT), other components analogue

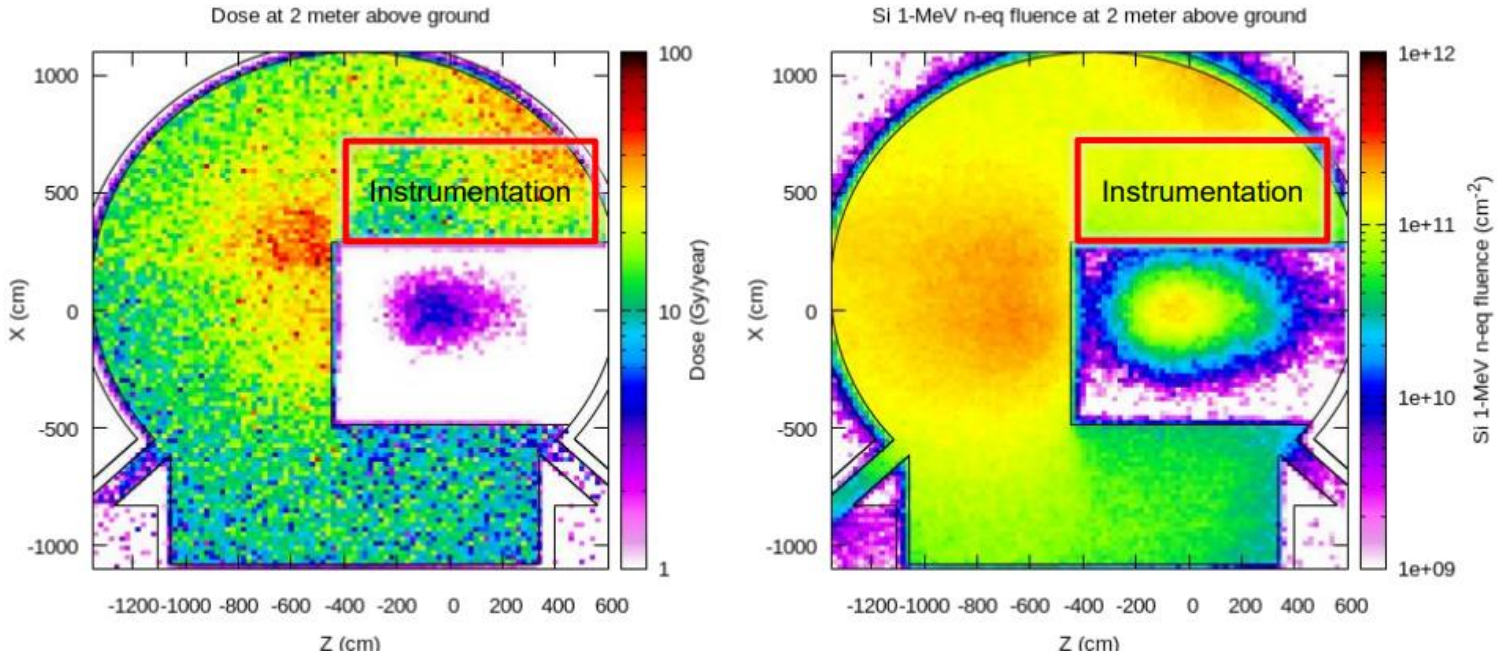
- Since no qualification tests have been conducted by the equipment group or us in the past, no reference values for the sensitivity known

- FLUKA simulations conducted to analyze the radiation environment and see if there resulting levels are a thread for COTS equipment

Pictures by W. Van den Broucke

SPS LSS5 dump | CV skid

Analysis



FLUKA simulations by **J. Briz,** Results scaled to **1.7E18 POT/y**

FLUKA values (1m above ground)

- **TID**: 4 Gy/y
- **1MeV Neq**: 1.2E11 n/cm2/y
- **HEHeq**: 2E10 HEH/cm2/y

General R2E levels for COTS

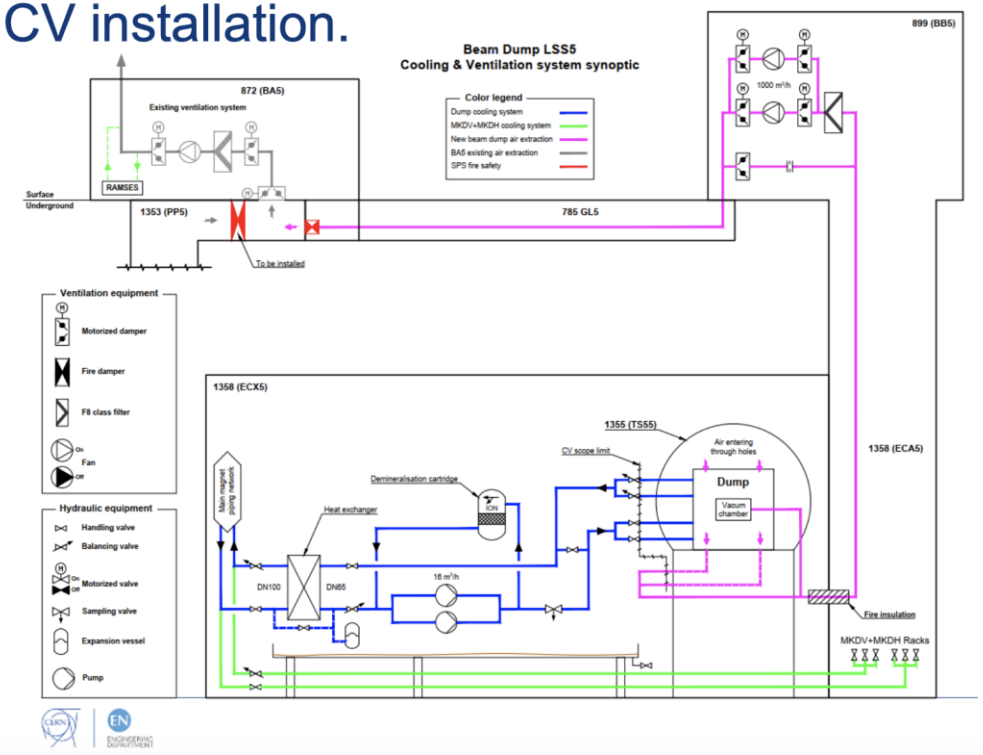
- **TID**: 10 Gy (lifetime)
- **1MeV Neq**: 1E12 n/cm2 (lifetime)
- **HEHeq**: 1E7 HEH/cm2/y

- Radiation environment **highly critical for COTS systems**. No qualification tests, therefore no information regarding sensitivity -> shielding actions probably not suitable since the levels would still be too high
- ECA5 shielded area: lower levels than ECX5 but pose still a threat with 1E7 HEH/cm2/y. Also limitation with distance through cables/contaminated water

SPS LSS5 dump | CV skid

Analysis

CV installation.



Pictures by W. Van den Broucke

Commercial rad-hard solutions (e.g Rosemount for NPP)

- Qualified for TID, no knowledge about behavior in mixed-field
- Niche market, therefore high costs due to certifications and R&D involved
- Price per unit: ~7000$

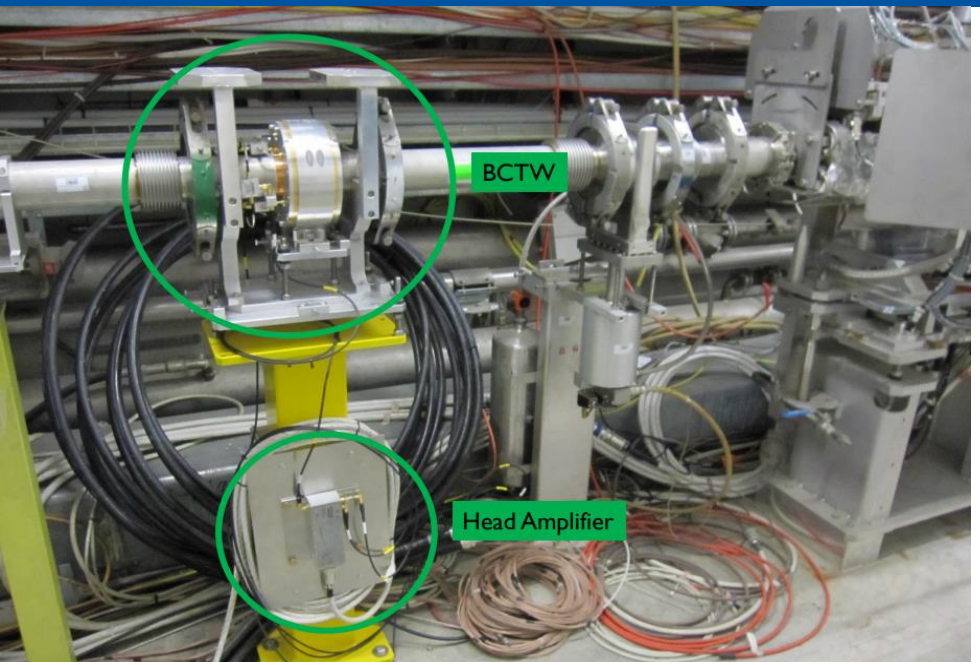
In-house development (proposed by S. Danzeca)

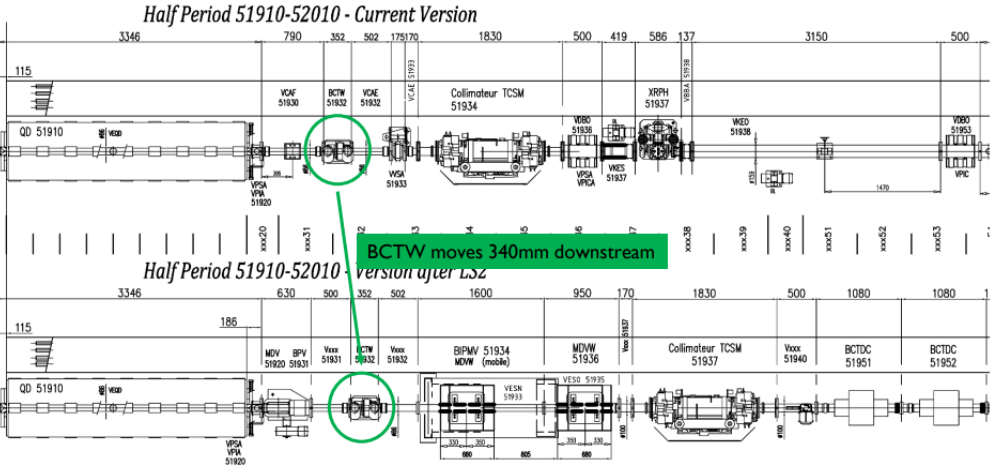
- Standard pressure transmitter from CERN store (e.g SensorTechnics CTE7000)
- Separation of i) piezo sensor and ii) sensitive electronics
  - Electronics deported into BB5 (control cubicle)
  - Piezo sensor stays with skid

-> Prevention through in-house development

SPS LSS5 dump | BCTW

Problem statement





Pictures by **T. Levens**

3.) BCTW

- BCTW moved in LSS5 region, located **down stream of the beam dump**
- BCTW for the SPS is a copy of the design developed for the LHC
- Specific location at LSS5 chosen due i) aperture of the monitor ii) short cable distance to the rack and iii) historically low radiation levels

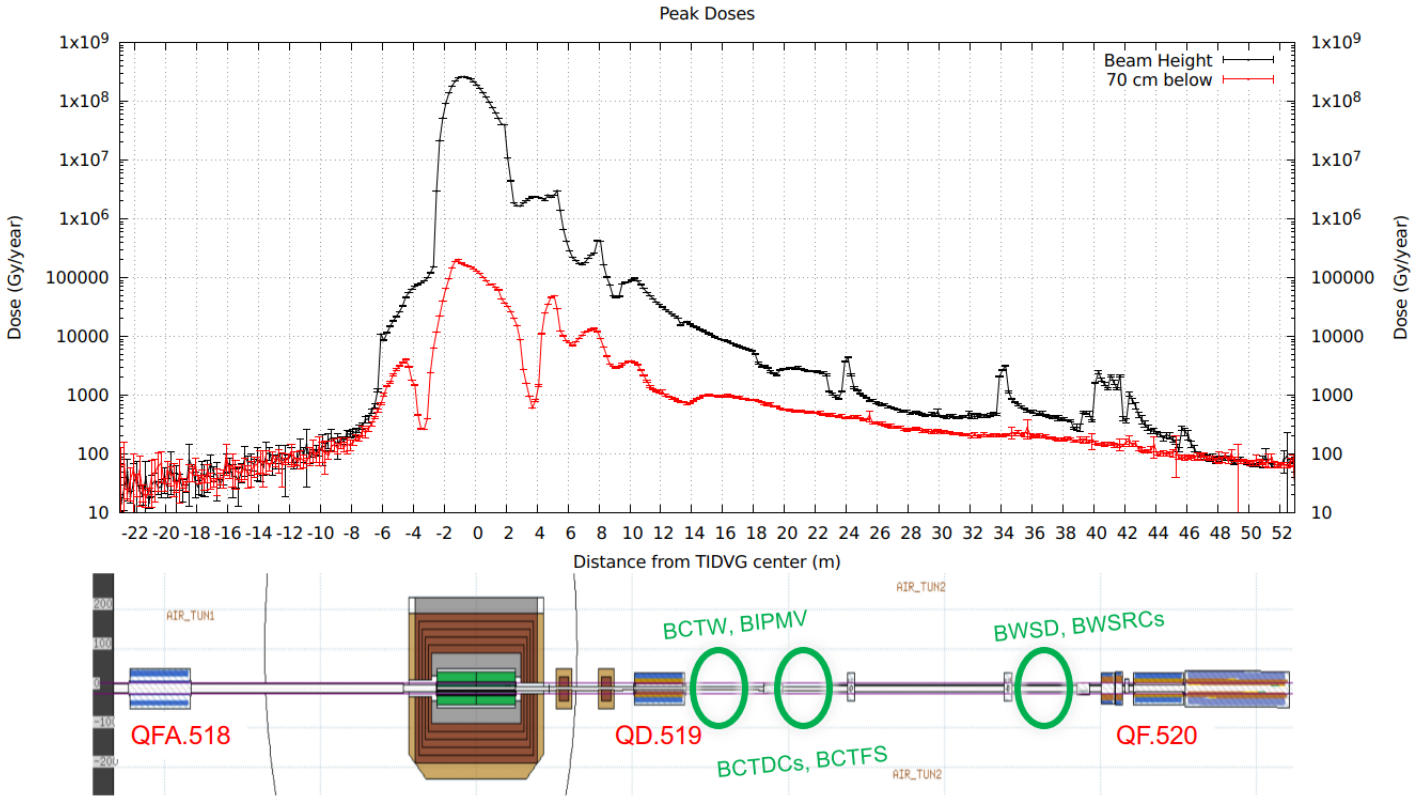
- **BCTW monitor** rises concerns regarding degradation of materials (PTFE in cables, glues …) and residual activation of the monitor poses thread to personnel at interventions

- **Head Amplifier** critical components given through i) op-amps (qualified up to 1kGy at OSI, see *EDMS: 1738241*) and ii) regulators.

- Other BE/BI equipment installed in the same region: DC current transformer (DCCT), Fast Beam Current Transformer (FBCT) and Beam Gas Ionisation profile monitors (BGI) …

SPS LSS5 dump | BCTW

Analysis



FLUKA simulation by **J. Briz,** Results scaled to 1.7E18 protons/year

3.) BCTW

FLUKA values obtained for beam height:

- **TID**: ~ 10 kGy/y
- **1MeV Neq**: 9E12 n/cm2/y
- **HEHeq**: 6E12 HEH/cm2/y

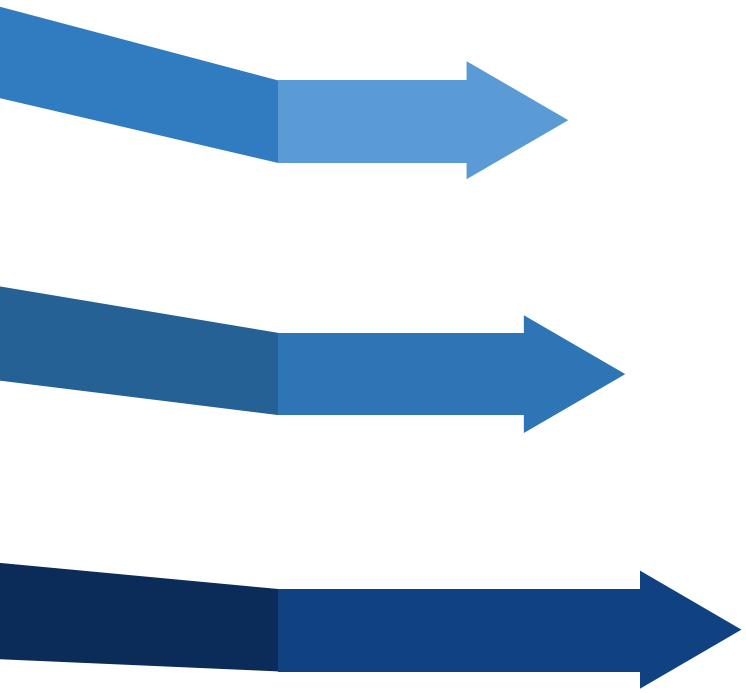
FLUKA values obtained for 70cm below beam

- **TID**: ~ 1 kGy/y
- **1MeV Neq**: 2E12 n/cm2/y
- **HEHeq**: 6E11 HEH/cm2/y

In comparison with previous geometry (e.g larger dump aperture), dose levels increase in a factor of 10 for beam height, and a factor 3 for below the beam -> **no low radiation levels anymore an highly critical for systems**

-> Prevention through relocation from LSS5 to LSS3

Ongoing Tasks



Global goal: guaranteeing reliability of the LHC required for High-Luminosity project, by reducing/mitigating R2E issues in the Injector Chain

How?

1) Providing **radiation maps and long-term monitoring** of the radiation levels in the LHC injector chain (reach a monitoring and calculation level similar to LHC) – Strong collaboration with MCWG and EN-STI BMI
2) Development of a **comprehensive inventory list** of installed electronic systems and components, linked with dedicated qualification studies
3) Analyzing equipment failure, development of strategies of long- and short-term mitigation actions.
4) Support to the equipment groups in the design, upgrade and qualification of electronic equipment installed in LHC Injector Chain

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Special thanks to: Jose Briz, Luigi Esposito, Daniel Björkman, Stephane Brugger, Salvatore Danzeca, Elisa Guillermain, Tom Levens, Pierre Mondon, Willy Van Den Broucke, Francesco Cerutti

List of references

Injector Chain Environment

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- **J.P. de Carvalho Saraiva**, Injector Chain Website
- **E. Guillermain et al.**, Study of the SPS radiation environment, Technical Note SPS-SI-EN-001

BTV

- **D. Björkman**, SPS LSS5 – FLUKA calculation for the radiation environment und Updated Simulations
- **S. Burger**, BTV SBDS Status and Plans
- **S. Burger**, Irradiation test of Commercial (BASLER) digital cameras @ CHARM and CHARM EDMS report
- **S. Burger,** BI projects involving camera

CV skid

- **J.Briz and L. Esposito,** FLUKA simulations for Radiation Doses at LSS5 Dump Cooling Station
- **P. Mondon and W. Van den Broucke**, Cooling station instrumentation SPS Beam Dump

BCTW

- **T. Levens,** SPS BCTW R2E aspects
- **J. Briz and L. Esposito,** LSS5 dump: Radiation Levels at BCTW.51932 location
- **T. Levens et al.,** SPS wall-current transformer (BCTW) relocation from LSS5 to LSS3, ENGINEERING CHANGE REQUEST SPS-BCTW-EC-0003