R2E assessment and mitigation of failures in the SPS access system

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on behalf of the R2E project

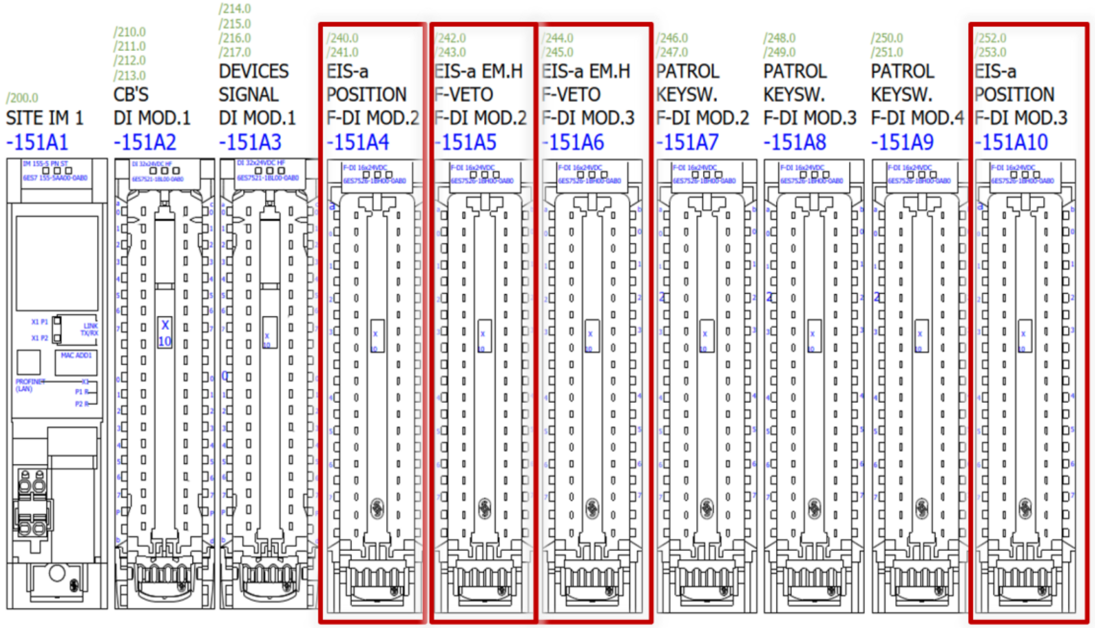
R2E Annual Meeting 1-2 March 2022
https://indico.cern.ch/event/1116677/

Introduction – SPS Access system

Access system is a safety-interlock architecture that controls the access to the machine.

- Safety PLC systems from Siemens.
  - In case of discrepancy, the affected modules go to failsafe state → **beam dump.**
- Input cards to:
  - **Elements Important for Safety (EIS):** personnel and material access devices, doors, moveable shielding walls and etc.
  - Patrol boxes.
- Recovery of the systems require manual reset of the modules.
- Underground and intermediate level racks.

Failures in the EIS-a input cards lead to **beam dump**.

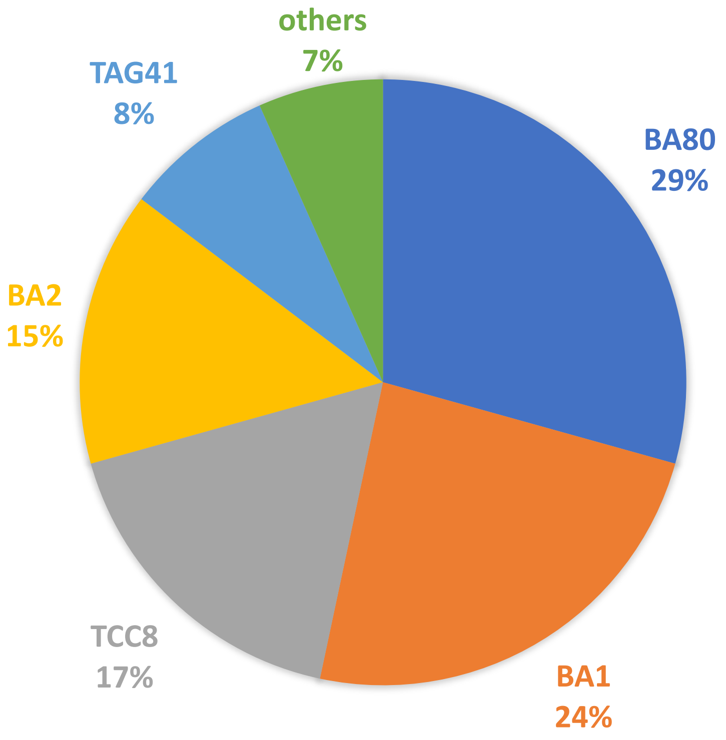


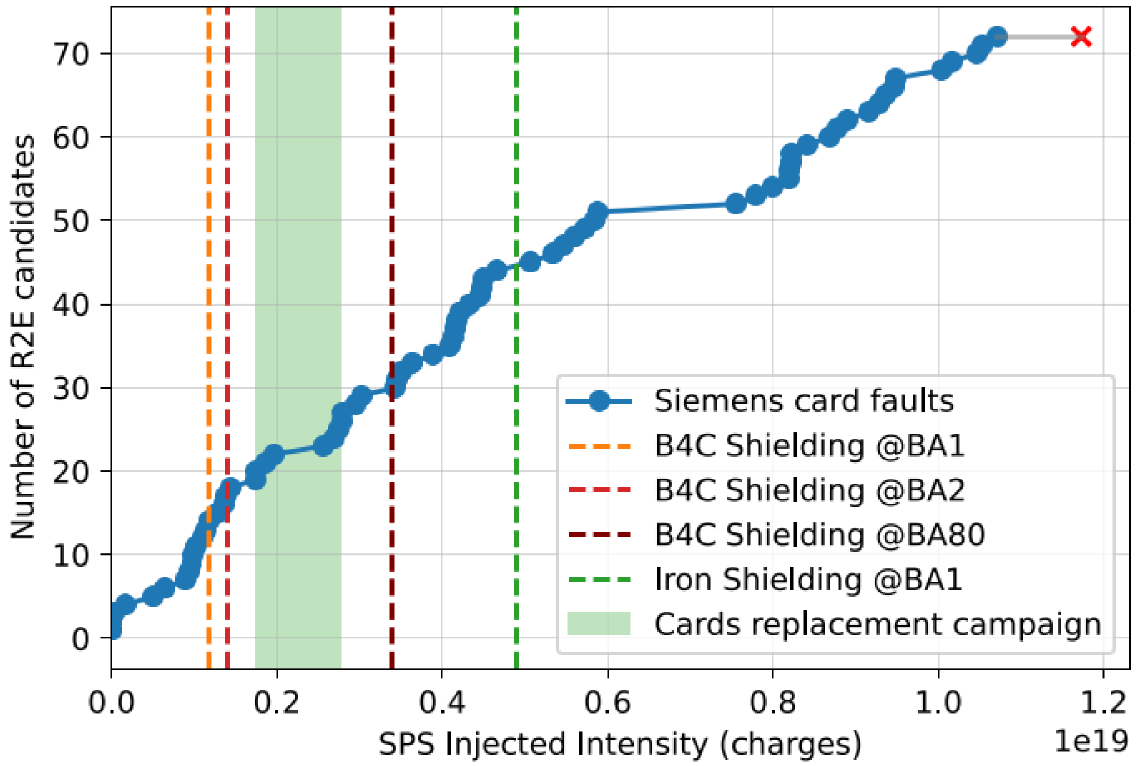
BA1 rack electrical drawing
Provided by Tomasz Ladzinski.

Failures in the patrol key box input cards don't lead to **beam dump**.

Overview: failure rate and SPS injected Intensity

- **Total of 75 R2E events** have been recorded in the input cards.
  - Not all of them lead to beam dump, but can possibly increase the downtime of the machine as the modules need to be manually reset during a beam stop.

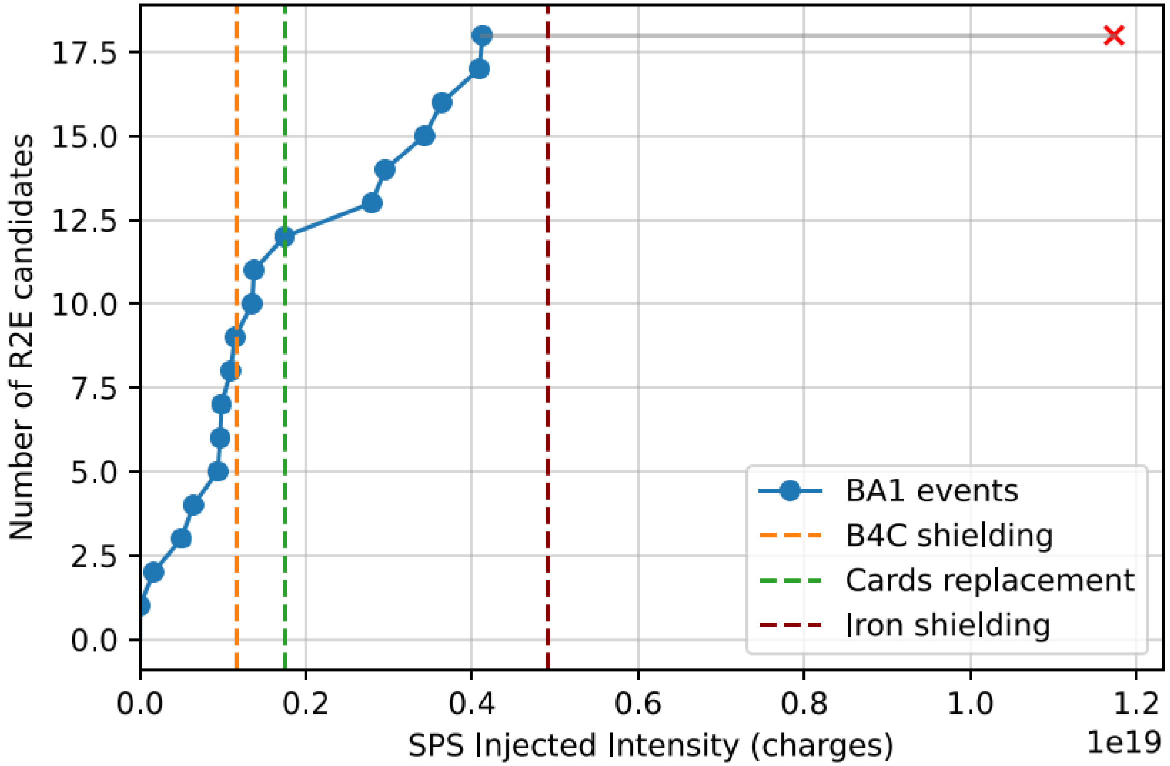




Heavy Shielding in BA1

- **40 cm Iron shielding installation (~ 17 T) on the 15th of September 2021.**
  - More info on the installation can be found in [T. Ladzinski's presentation] at 292nd IEFC meeting.

Shielding wall



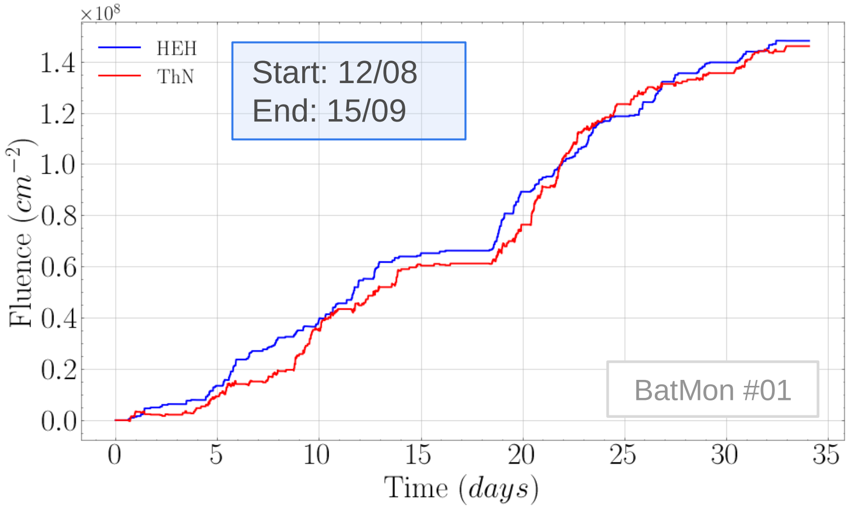
BA1 - Fluence measurements: BatMon*

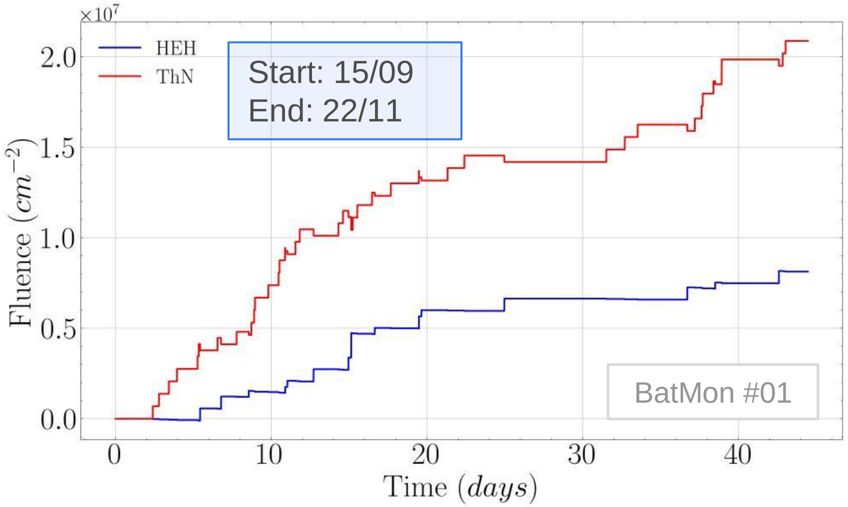
- **2x BatMon** installations: on the side of the rack facing the SPS tunnel and inside a boron carbide (B4C) layer facing the front of the rack

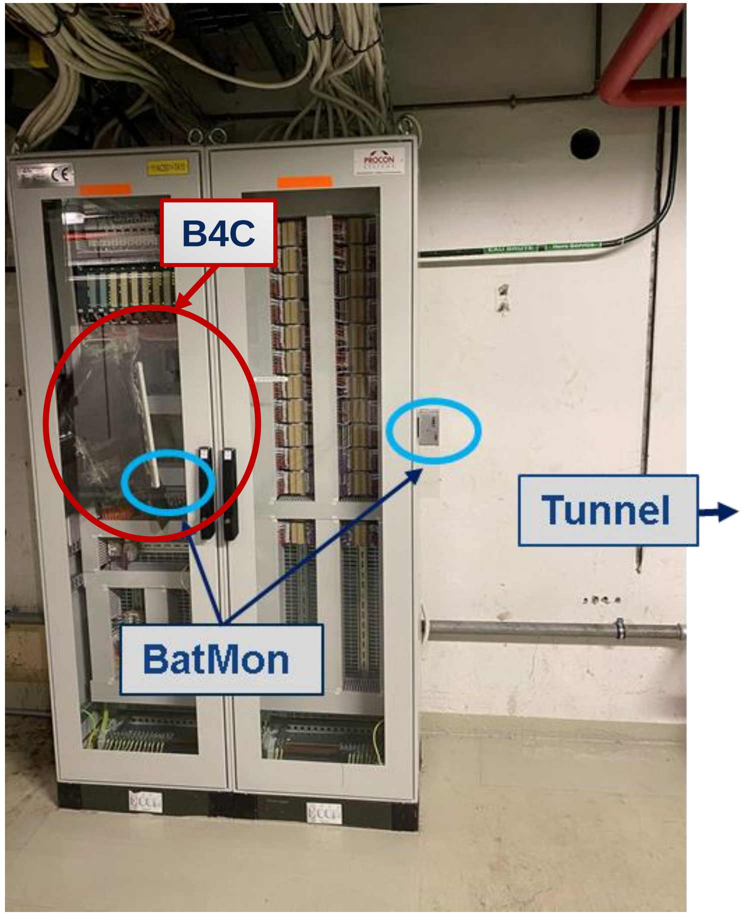
Before Iron shielding installation
Norm. HEH fluence = 5.6e-11 cm^{-2} /charge
Norm. ThN fluence = 5.5e-11 cm^{-2}/charge

47x reduction

After Iron shielding installation
Norm. HEH fluence = 1.2e-12 cm^{-2}/charge
Norm. ThN fluence = 3.1e-12 cm^{-2}/charge



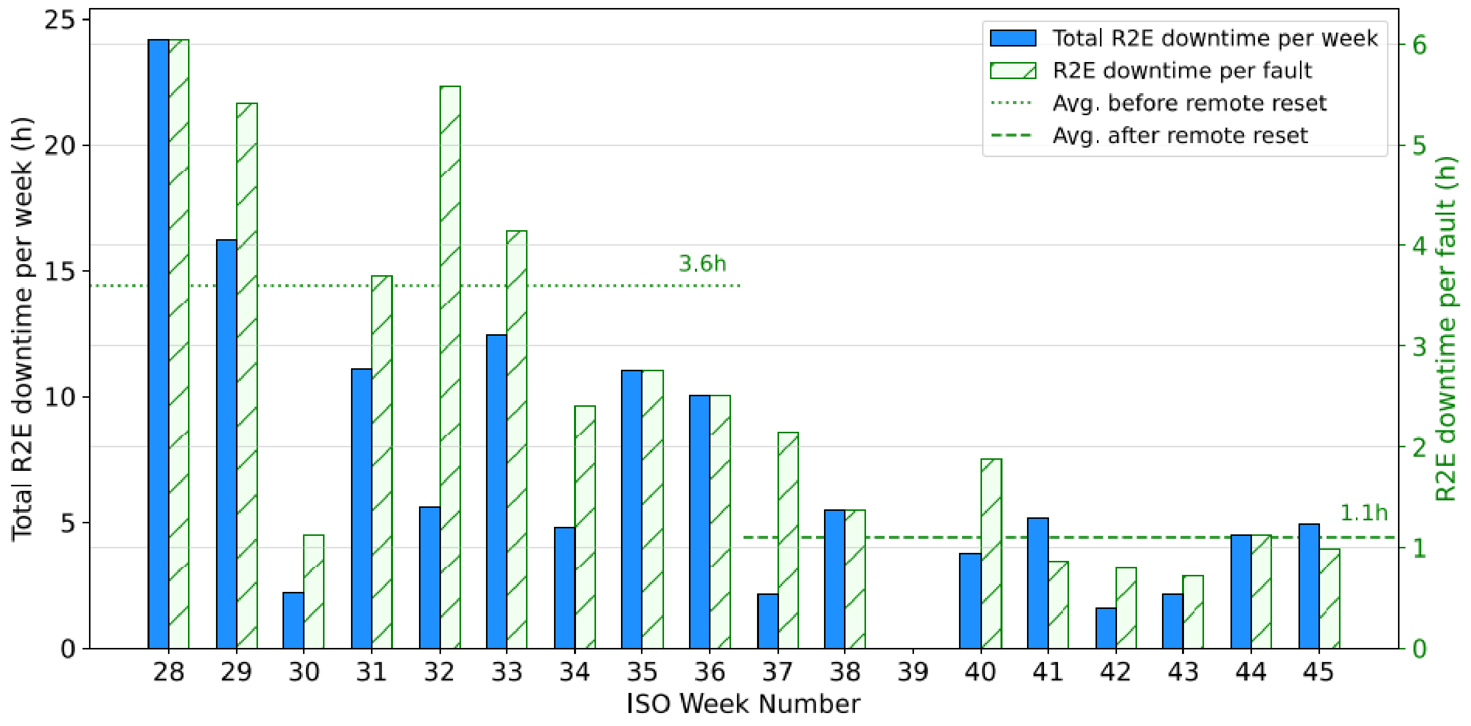




*Input from M. Brucoli, A. Zimmaro, A. Amodio and S. Danzeca [EDMS 2620946]

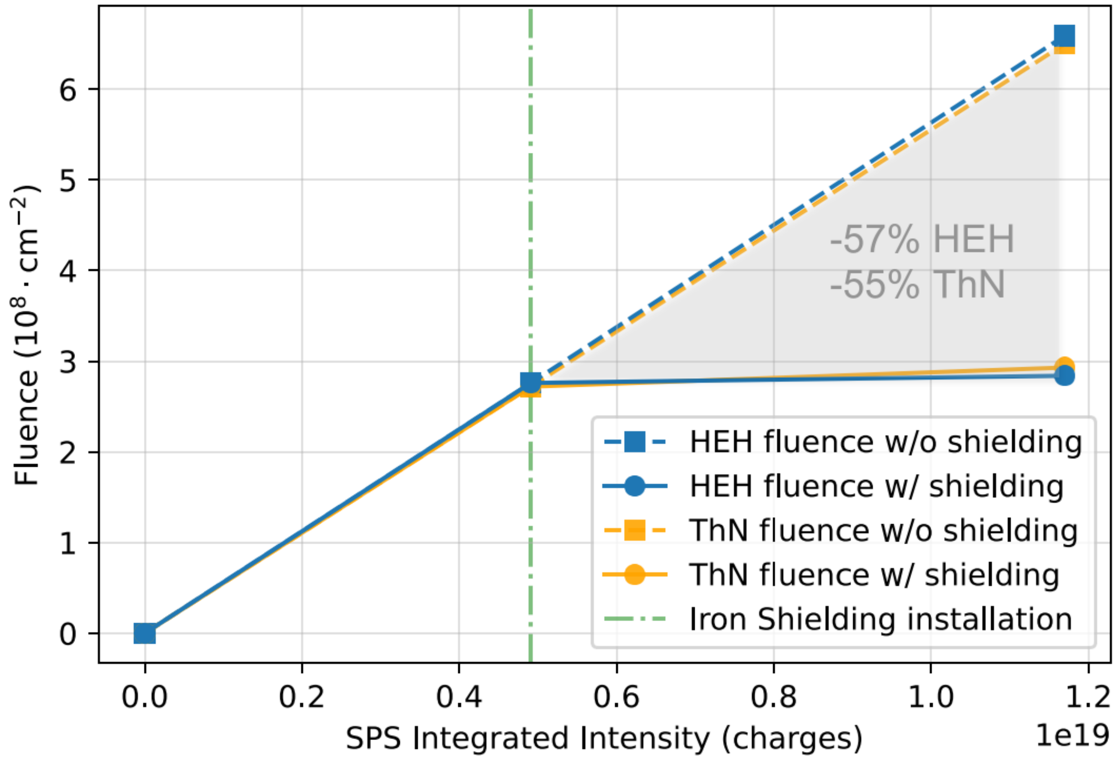
Alternatives to heavy shielding

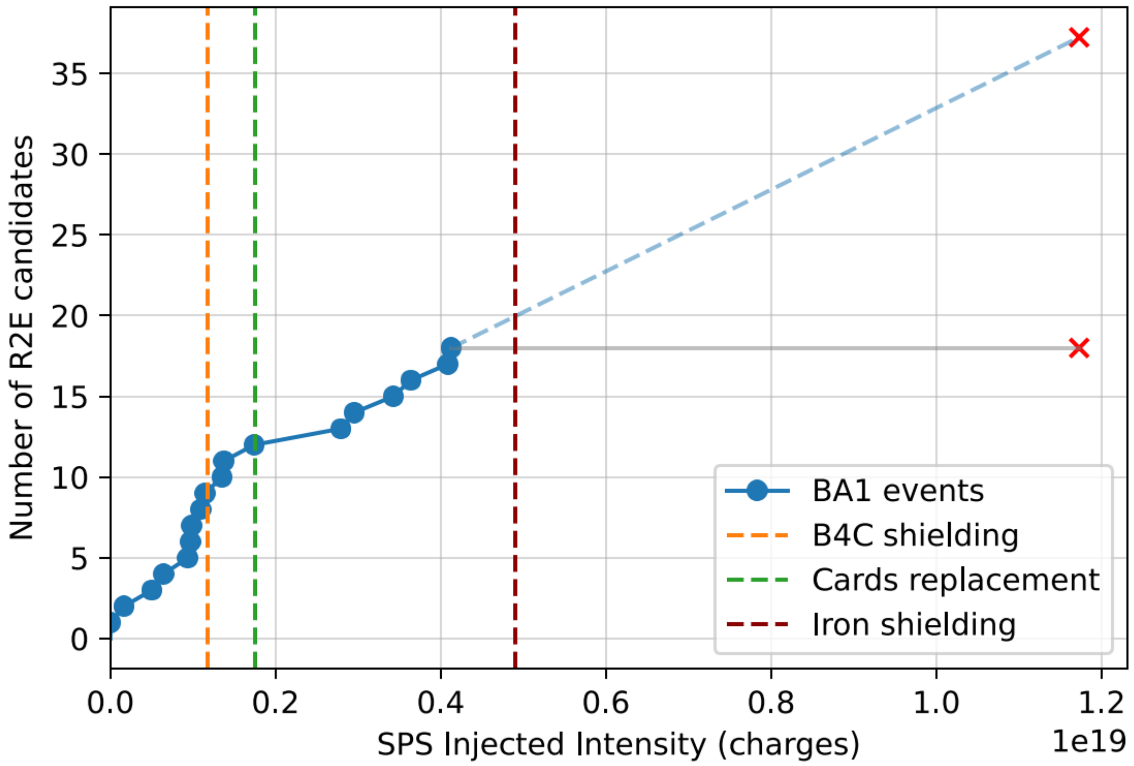
- Relocation of racks during YETS2021-2022.
- Before the relocation campaign, the SPS PPS project team investigated alternatives to **prevent the direct beam dump** and to **reduce the recovery time**.
- **Remote reset** of cards:
  - Reduction **from 3.6h to 1.1h average downtime** per fault (about 70% reduction).
  - Suppression of the cool-down time previously required for the manual reset of modules.
  - More info at [T. Ladzinski's presentation] at 293rd IEFC meeting.



Impact of the Iron Shielding

- Assuming the radiation levels scale proportionally with the SPS intensity

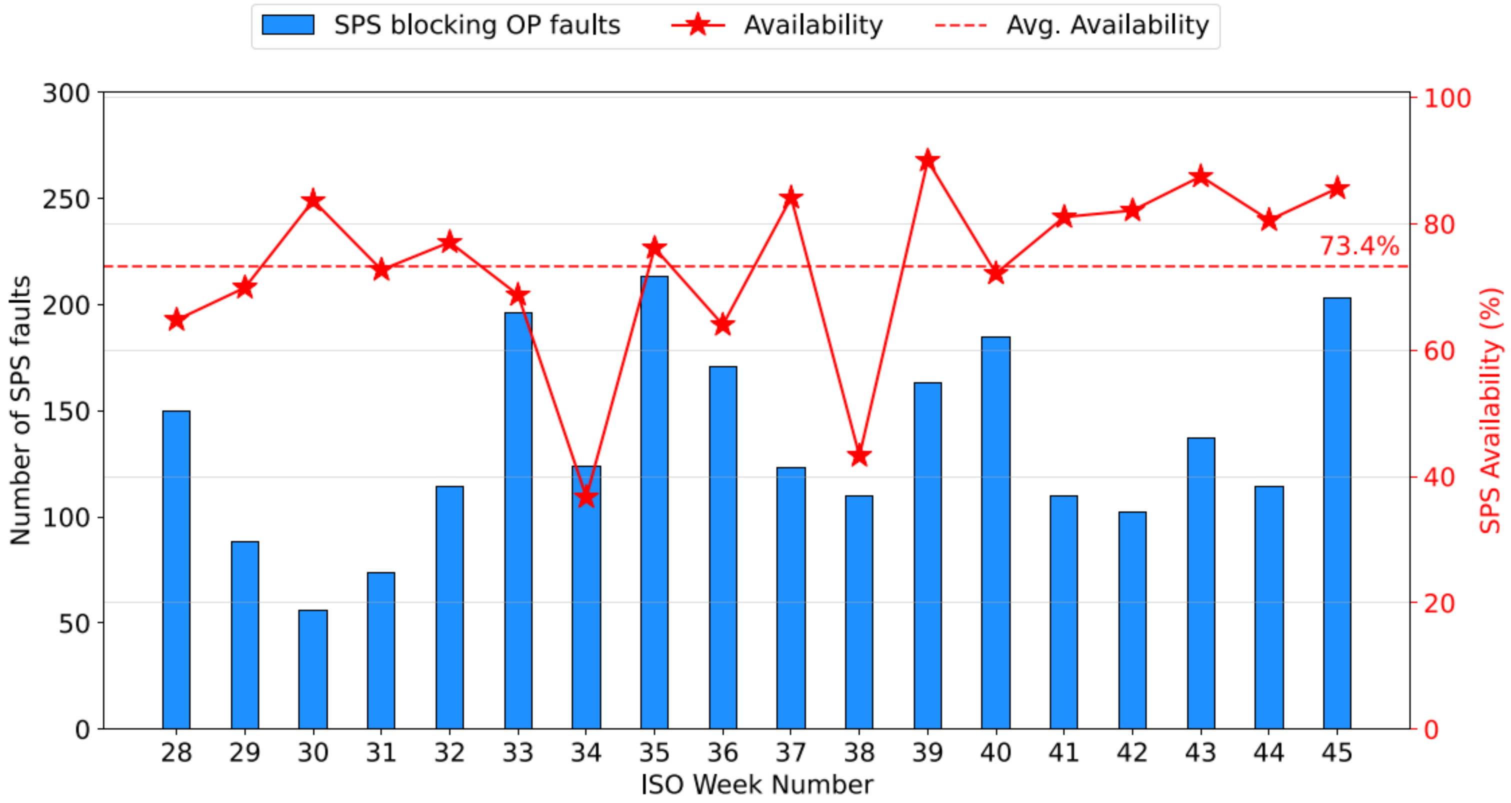




SPS Availability in 2021

- Using the Accelerator Fault Tracking (AFT) tool, the beam availability is calculated since the week of start of **SPS North Area Physics** [Week 28].

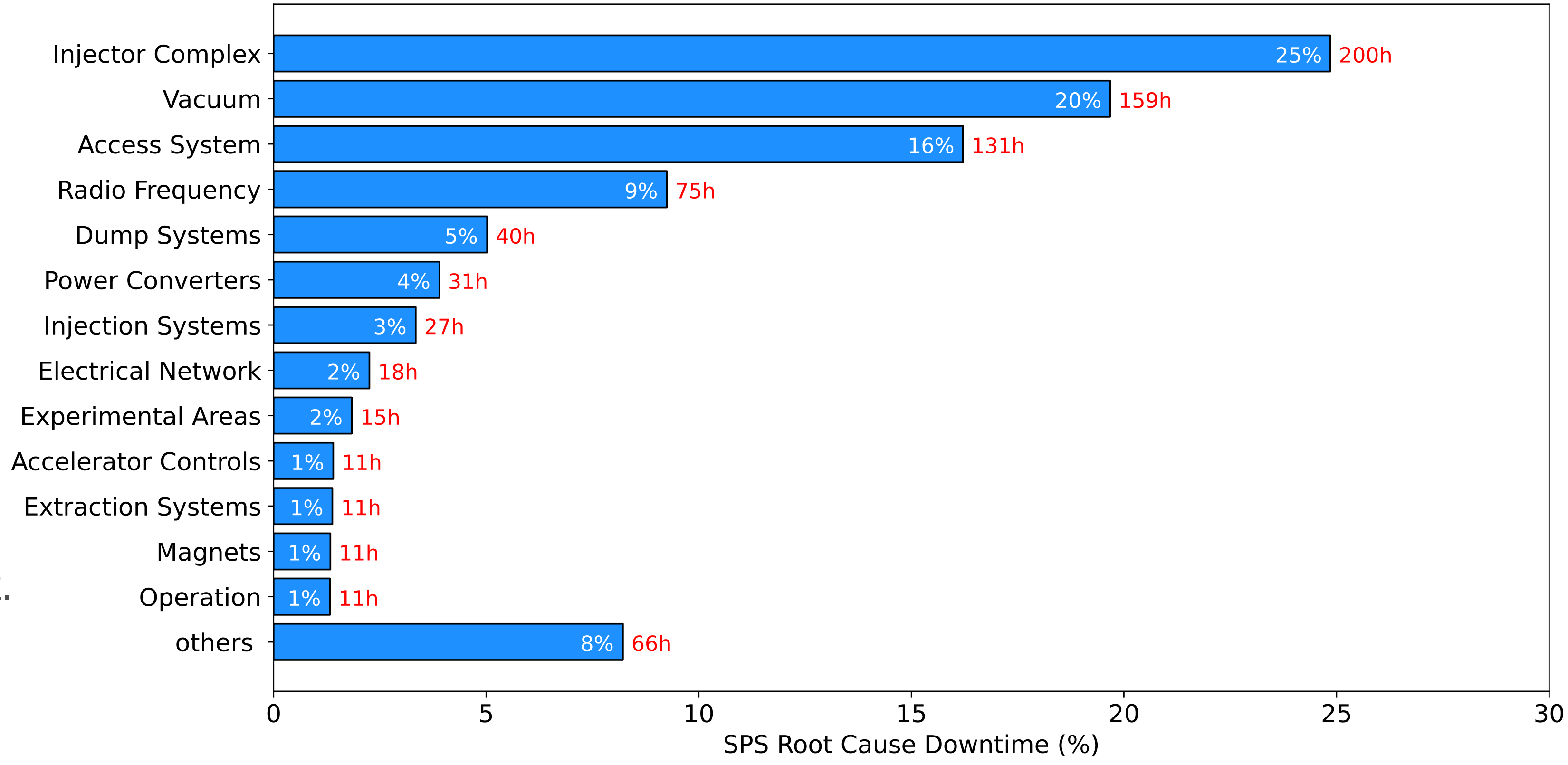
- **Global availability** of **73.4%**
  - 2641 faults
  - 806 h downtime



*Thanks to Andrea Apollonio for the support with AFT tool.

SPS Root Cause Downtime by System

- SPS Unavailability of **26.6% (806h).**
- Top 3 root cause:
  - Injectors
  - Vacuum
  - **Access System: 16% (131h)**
- **78%** of R2E faults and **97%** of R2E downtime (127h).
  - Average downtime of 2.4h per fault.
- The SPS access system R2E faults leads to **4.3% of SPS unavailability in 2021.**



*Raw data accessible through AFT by clicking here.

SPS access system relocation summary

- Information from https://edms.cern.ch/document/2669636/1.0
- Ten electronics (double) racks were relocated from intermediate level to the surface in several locations of the SPS, in order to mitigate the observed radiation to electronics effects:

  BA1, BA2, BA3, BA4, BA5, BA6, BA7, BA80, TCC8, ECN3

- Racks on TSG4 (AWAKE) could not be relocated on the surface, hence a dedicated study is presented hereafter.

Example in BA80: the rack was relocated on the surface

TSG4 - AWAKE request and general overview

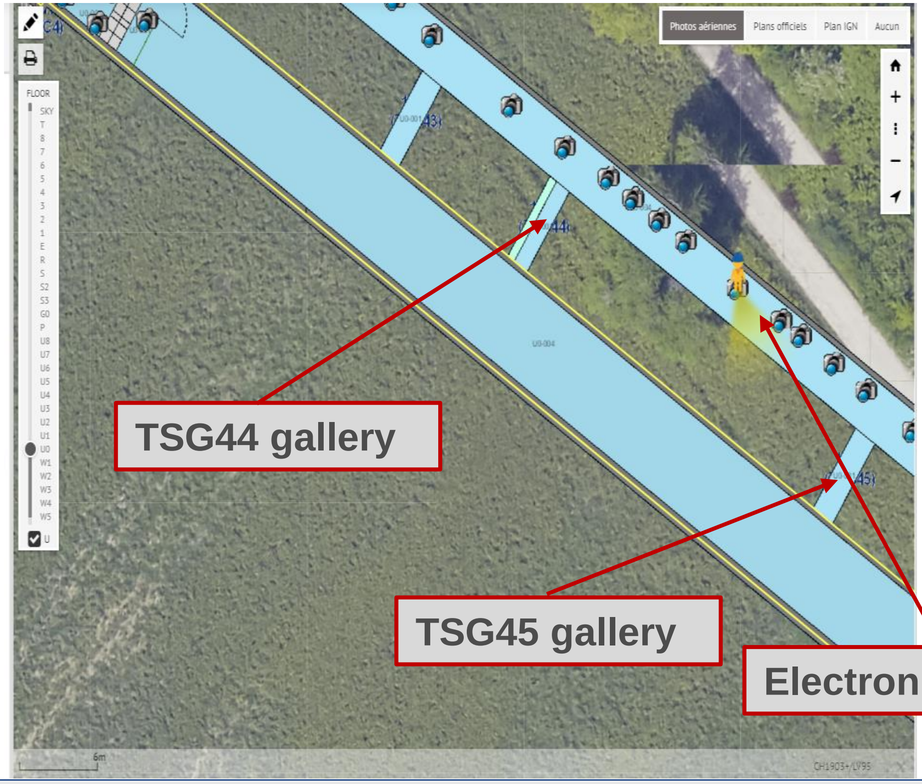
- Observed 6 Single Event Upsets (SEUs) in the Access System racks between the TSG44 and TSG45 side-galleries close to the ventilation duct (VD1) in 2021.

Radiation source:

- 400 GeV protons on the AWAKE target (He).

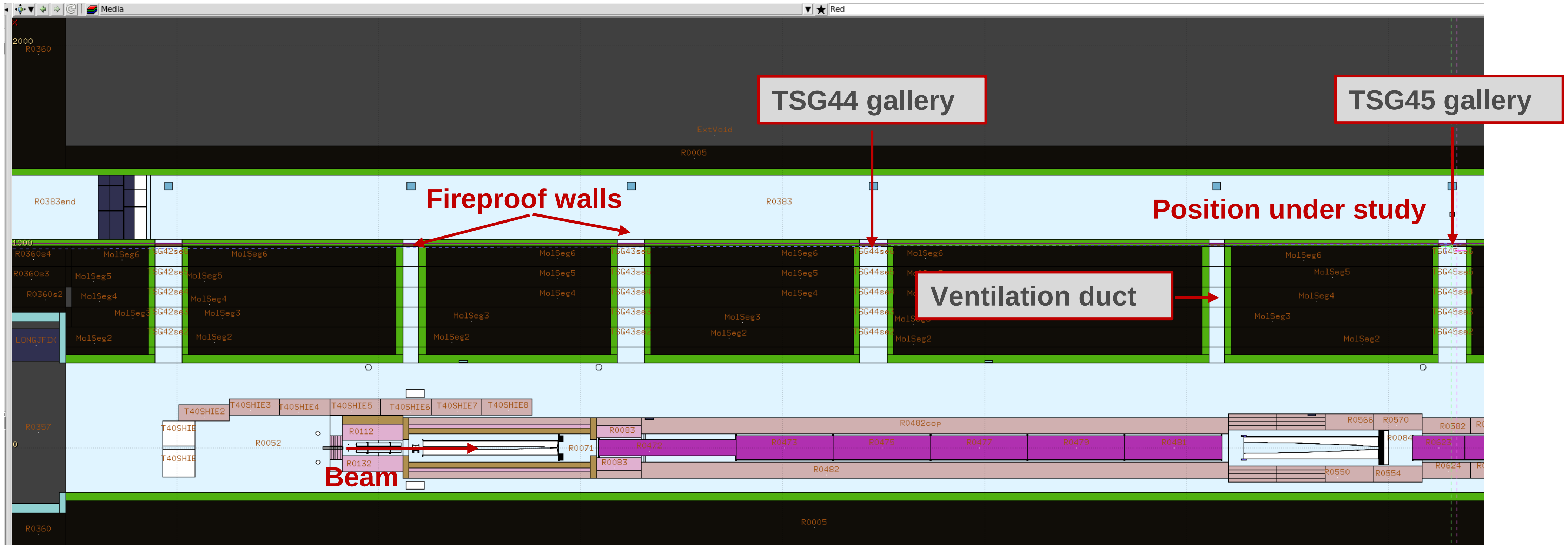
Assessment:

- Radiation levels between vent. duct and TSG45 at the position of the rack.
- High Energy Hadrons (HEH) and Thermal neutron (ThN) fluences.
- BatMon measurements vs simulations
- Possible shielding strategies.



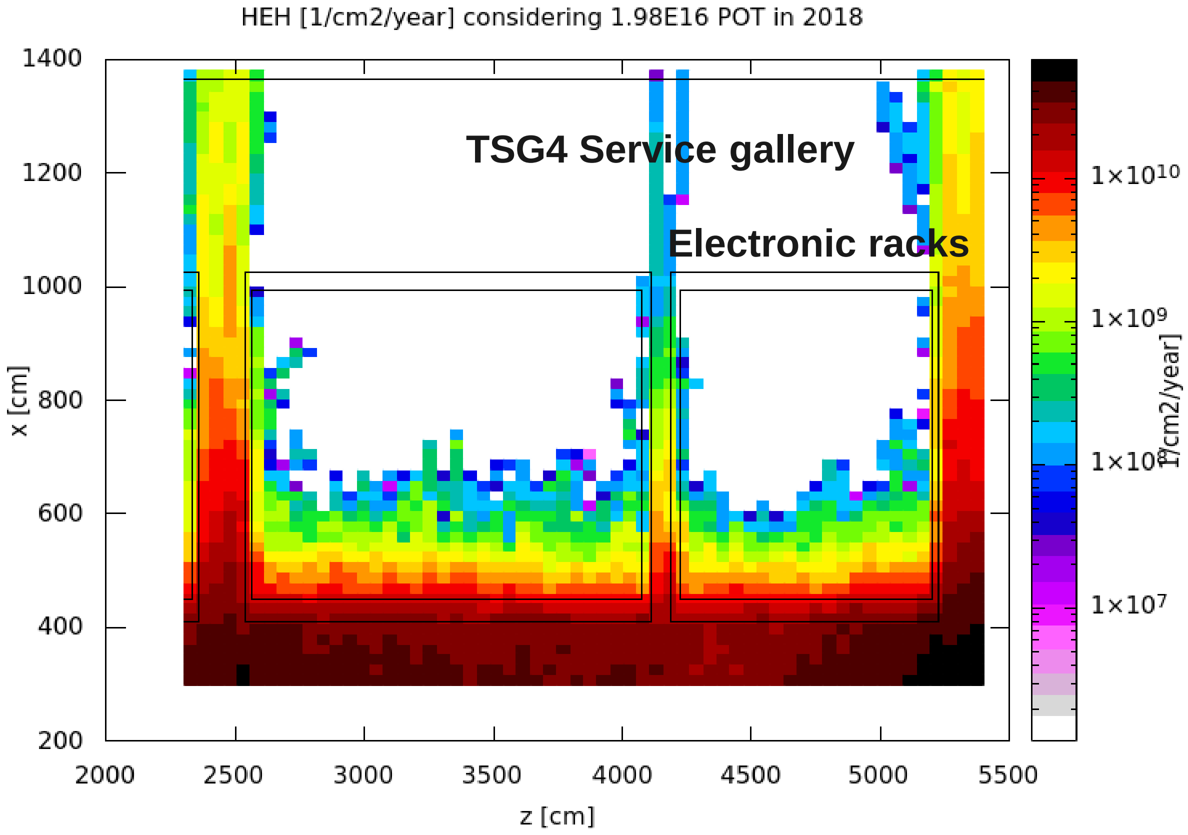
FLUKA geometry

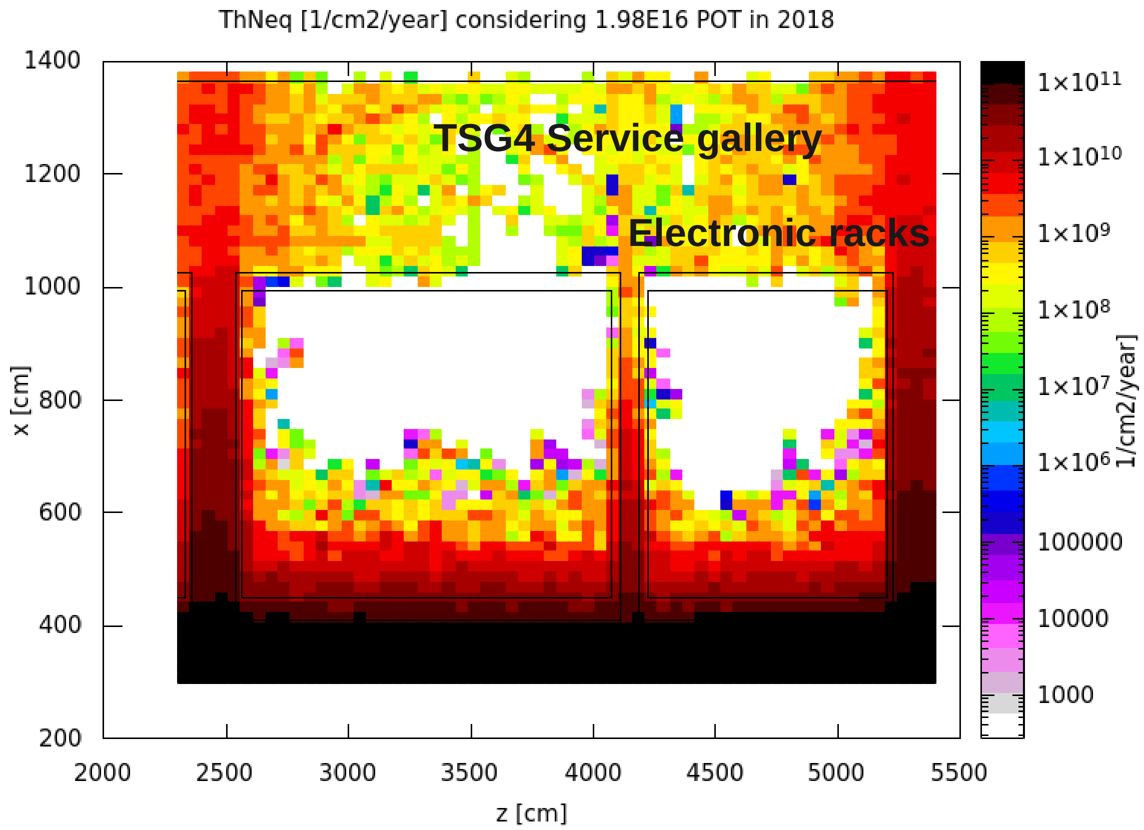
- FLUKA geometry (input from E. Nowak, C.Ahdida, HSE/RP).



HEHeq and ThNeq overview (protons delivered in 2018)

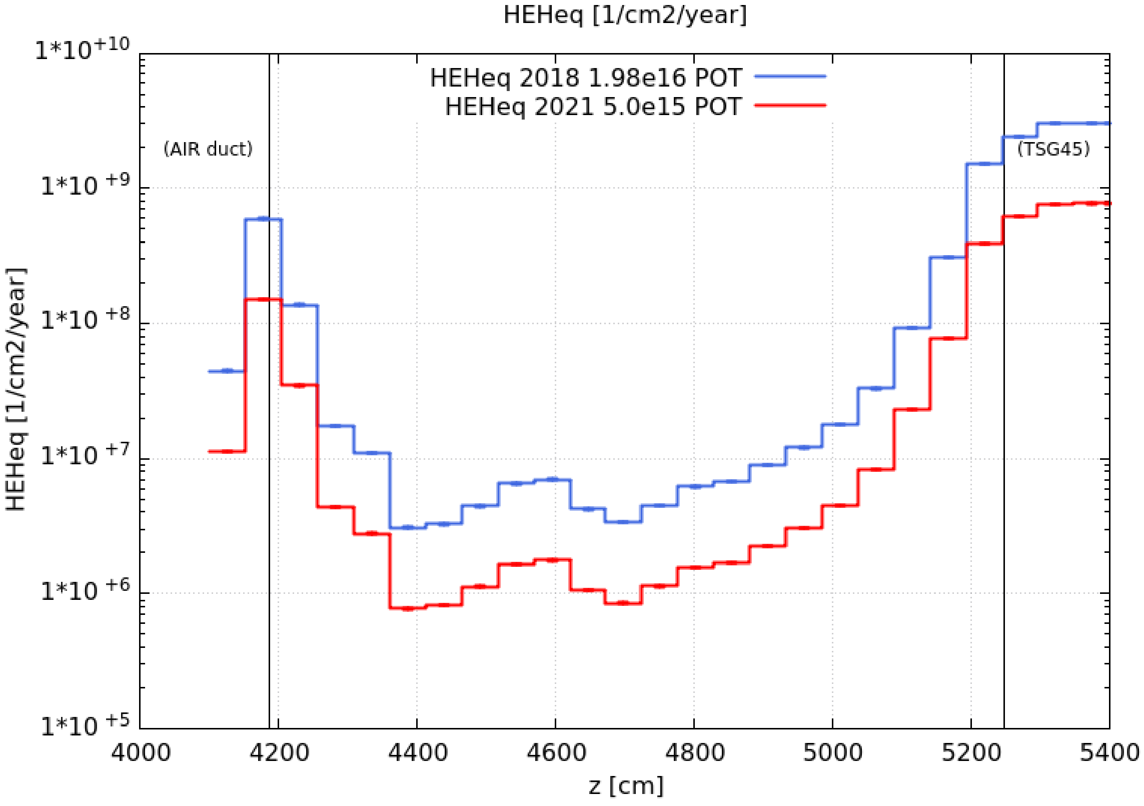
- The beamline is on the bottom of the picture (top view), while the service gallery on the top part.

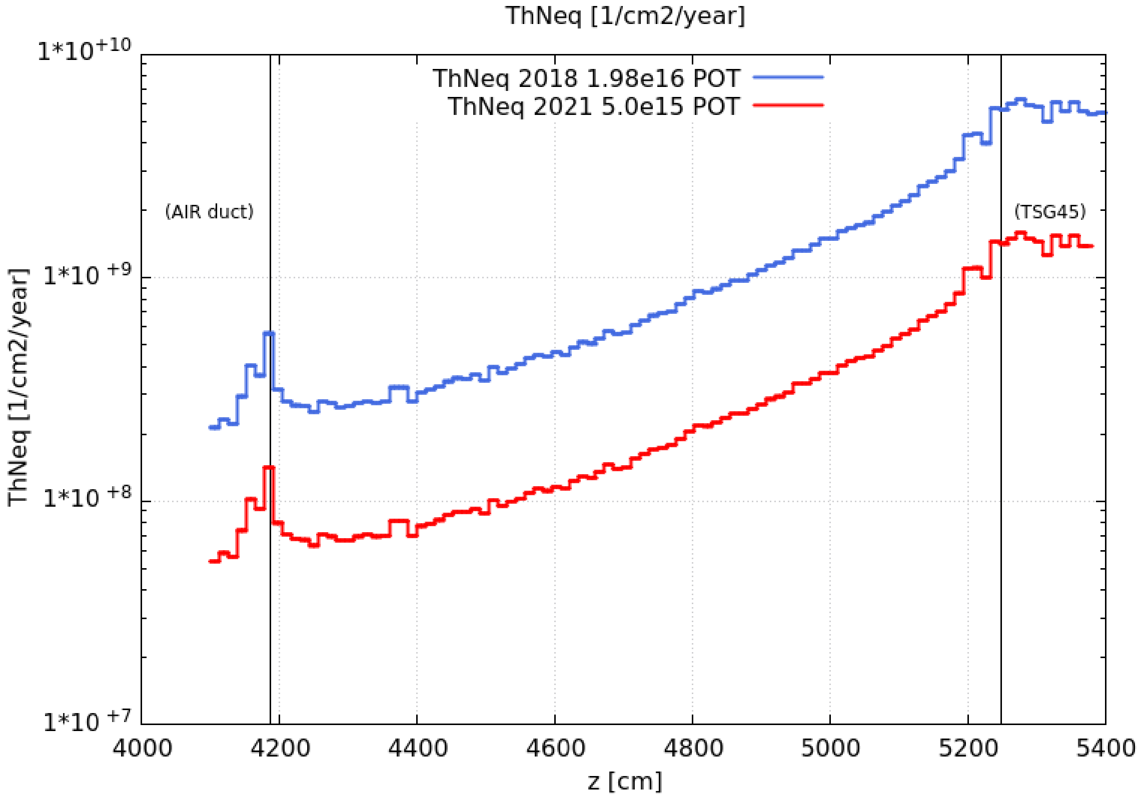




HEHeq and ThNeq fluence in 2018 and 2021

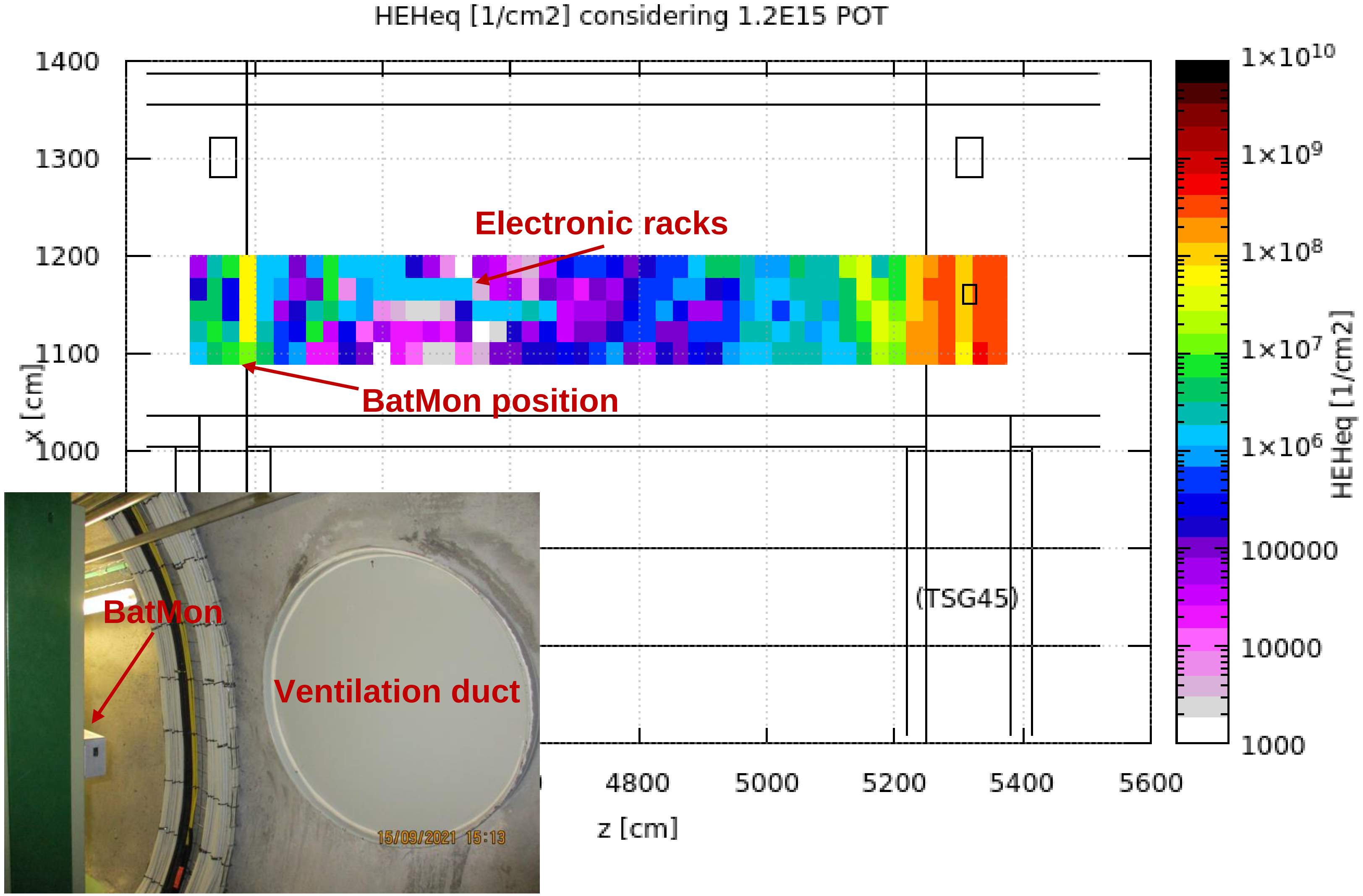
Radiation levels [cm^{-2}/year] between ventilation duct (to the left) and TSG45 gallery (to the right) for the full 2018 and 2021 operation.





HEHeq - FLUKA simulations – BatMon position

- HEHeq top view scoring at the height of the BatMon (~1m above the floor).
- Very strong HEHeq and ThNeq fluence gradient at BatMon location.
- Hence, the agreement with measurements can be considered within “order of magnitude’’.



BatMon vs FLUKA fluences comparison

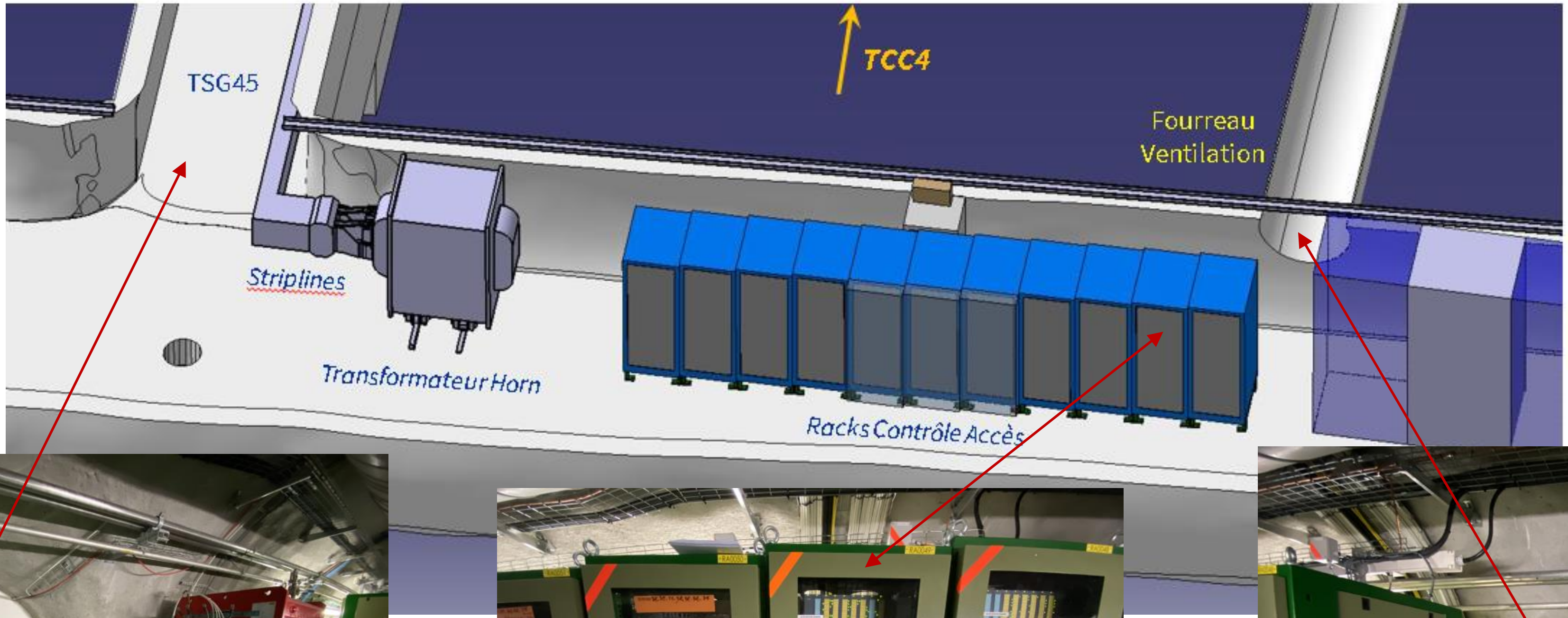
- Good HEHeq agreement between FLUKA and BatMon (~20%).
- ThNeq fluence present a factor of ~10 difference between FLUKA and BatMon.
- We should take into account that the BatMon SEU statistics was quite low (~50 events) corresponding to about **10 days of acquisition** (**1.2e15 POT** delivered in AWAKE).

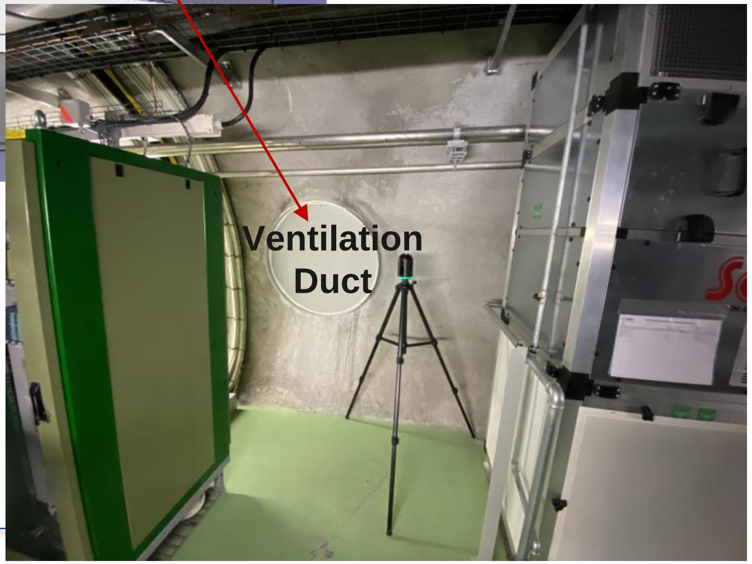
	BatMon* Measurement	**FLUKA Simulation**
HEHeq [cm^{-2}]	8.7e6	7.0e6
ThNeq [cm^{-2}]	2.9e6	3.1e7

*From A. Zimmaro, M.Brucoli, A. Amodio, S. Danzeca EDMS 2671023

Shielding implementation (visit on 20/01/2022)

Integration from F. Galleazzi https://indico.cern.ch/event/1119557/





Shielding solutions

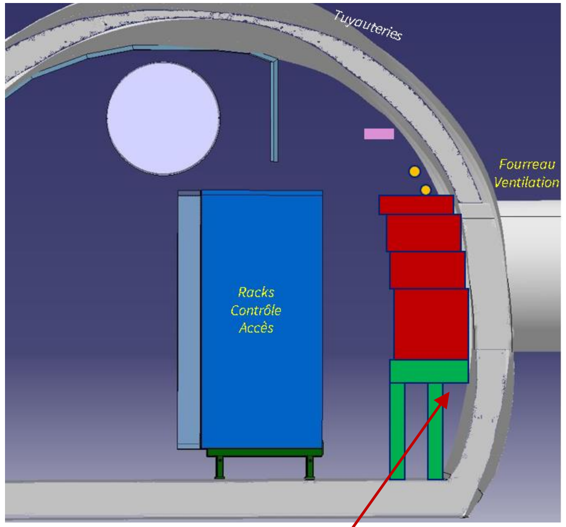
Integration layout from F. Galleazzi (https://indico.cern.ch/event/1119557/)
F. Delsaux, C.Bertone, S. Fumey

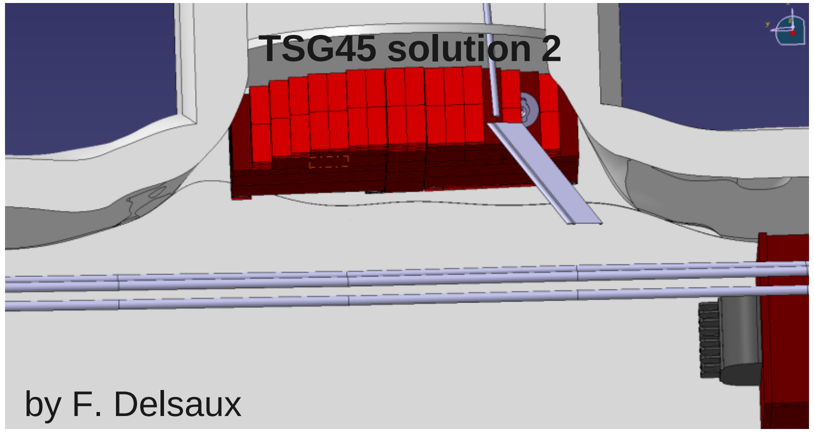
Installation of **40 cm thick iron wall** for TSG45 and ventilation duct to reduce radiation levels in the TSG gallery.

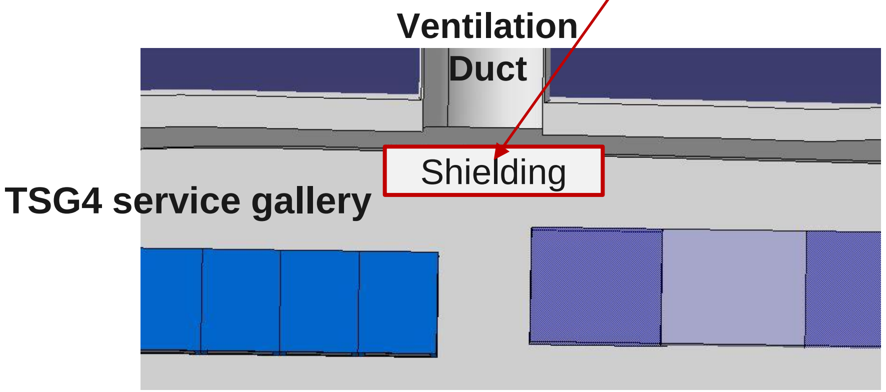
Possible solutions:

1) Shielding at the end of the duct, hence installed on the main TSG4 service gallery. ⇨ **Ventilation duct**

2) Shielding (almost) inside the end of the gallery. ⇨ **TSG45**







Conclusions

- R2E mitigation measures were taken after failures on the SPS access system.
  - **Heavy shielding** installation (BA1).
  - Most of electronics racks at intermediate level were **relocated** on the surface (10 locations).
  - Great reduction on the downtime thanks to the **remote reset** of the modules.
- The Access System has a high direct impact on the availability of the SPS.
  - R2E faults leads to **4.3% of SPS unavailability in 2021**.
- Some racks in AWAKE (between the ventilation duct and TSG45 in the TSG4 gallery) could not be relocated:
  - **HEHeq** and **ThNeq** fluences present a **strong gradient** between the two galleries and even within the racks and are high enough to potentially induce SEUs.
  - Works to implement 40 cm **iron shielding for TSG45 and the ventilation duct** started in order to reduce radiation levels in the TSG4 gallery.

More info about the analysis presented: https://indico.cern.ch/event/1123290/

Thank you for
your attention!