Lessons learnt, ideas and best practises for new equipment design

Joint Accelerator Performance Workshop 2024

10–12 December 2024
Royal Plaza Montreux & Spa

Rui Franqueira Ximenes, Antonio Perillo-Marcone, Daniel Valuch, Edouard Grenier-Boley, Francisco Galan, Giulia Romagnoli, Ida Johansen, James Storey, Marco Calviani , Miguel dos Santos, Nicola Solieri, Philippe Boisseaux-Bourgeois, Regis Seidenbinder, et al.

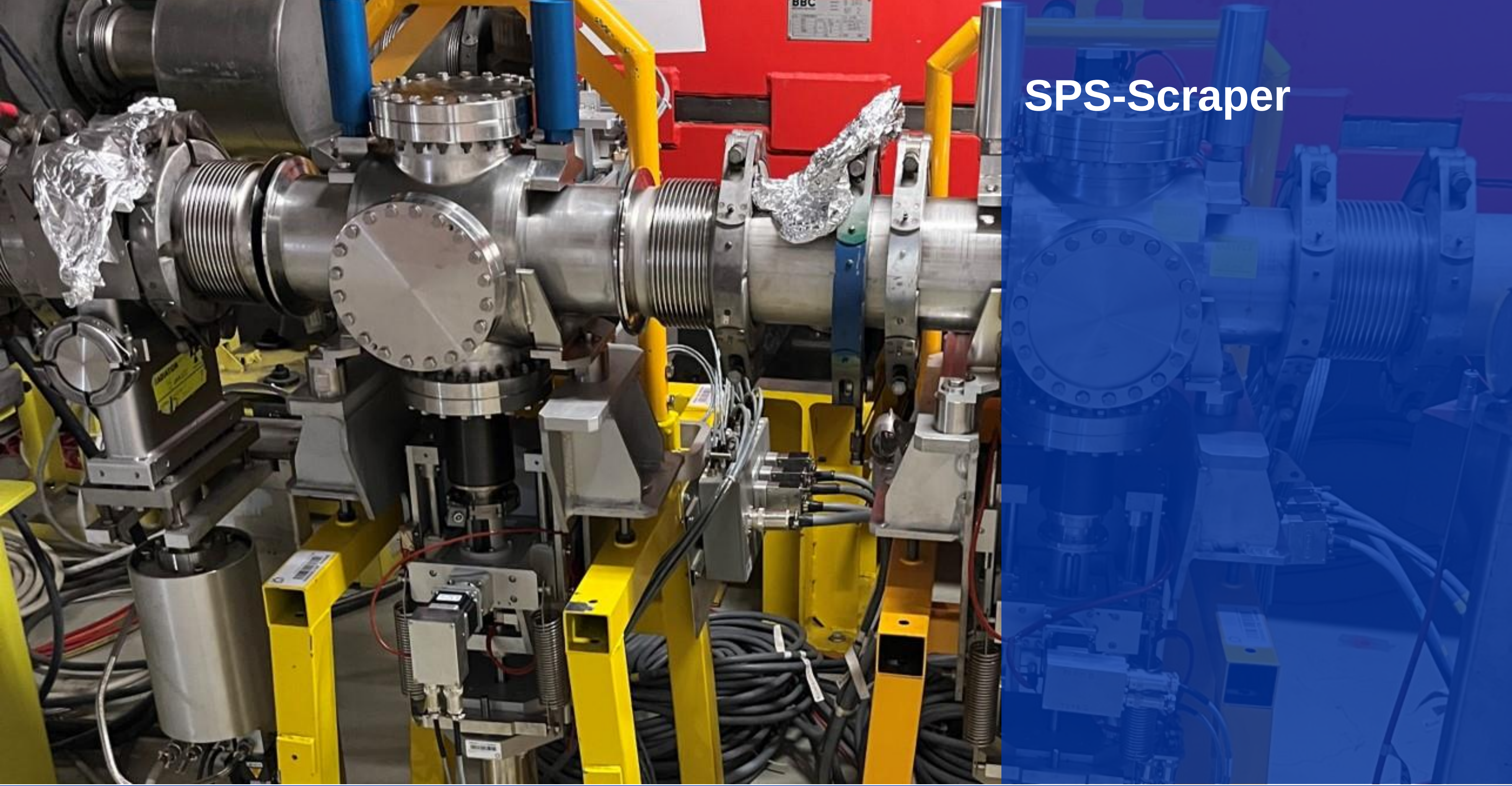
2024/12/10

Content

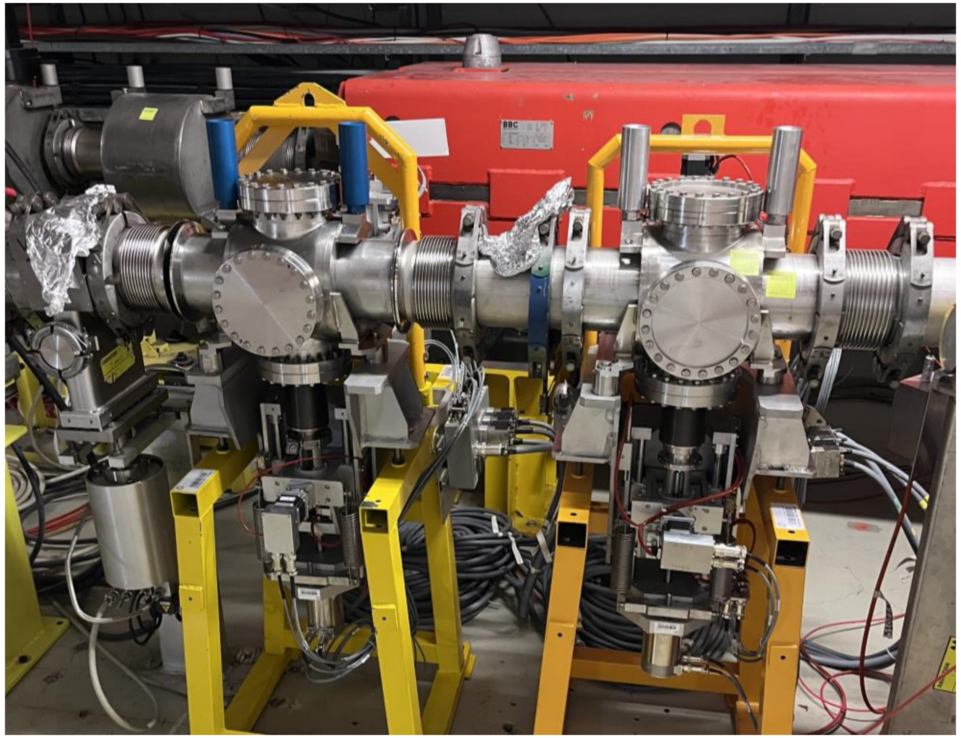
- **SPS-Scraper (SY-STI)**
- **SPS BGI (SY-BI)**
- **TDIS (SY-STI)**
- **HL LHC Beam Dumps (SY-STI)**
- **SBA Electro-valves (BE-EA)**

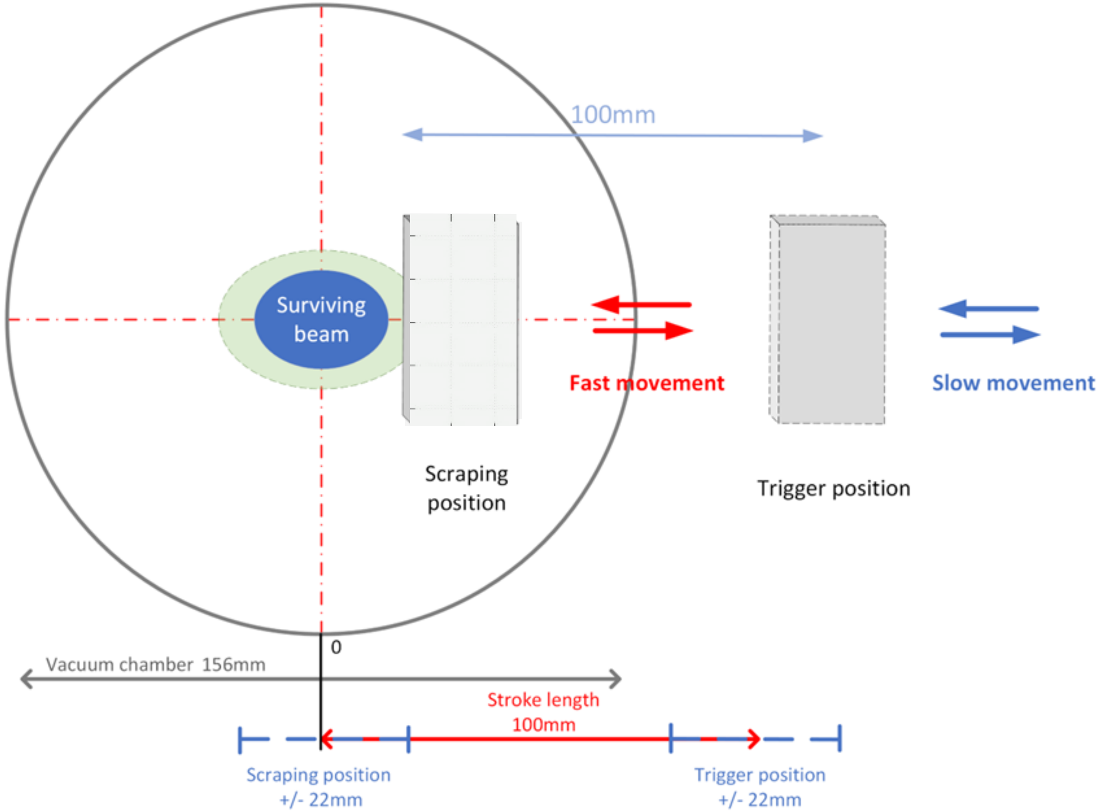
- **Summary | Best practises**

SPS-Scraper



SPS Scraper – V4 generation



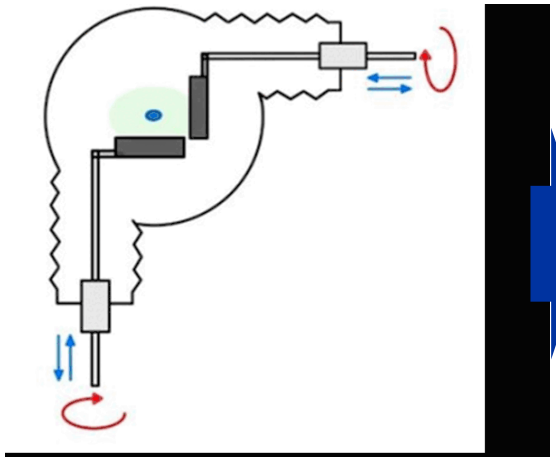


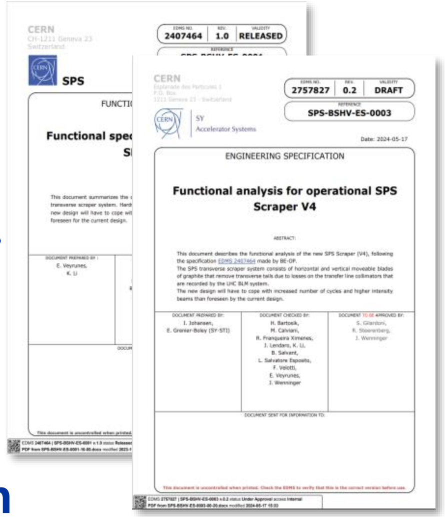
Purpose: Scrape halo before LHC injection

- **Legacy design** from ISR operation
- No initial cycle counting nor redesign for present use
- **Motor step losses** during 2023 (~0.05mm/cycle)
- **New requirements** for LIU beams

→ **Consolidation with 4th generation scraper**

SPS Scraper – V4 generation




CERN
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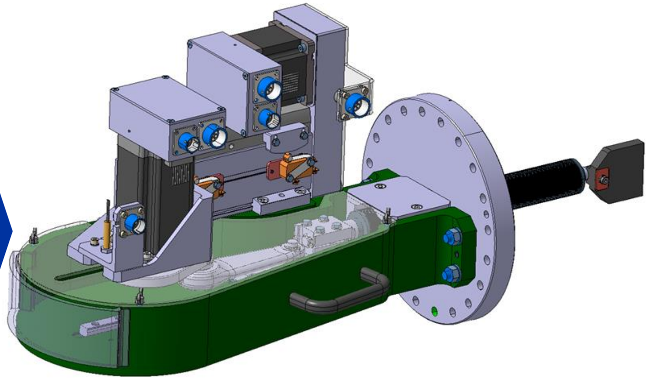
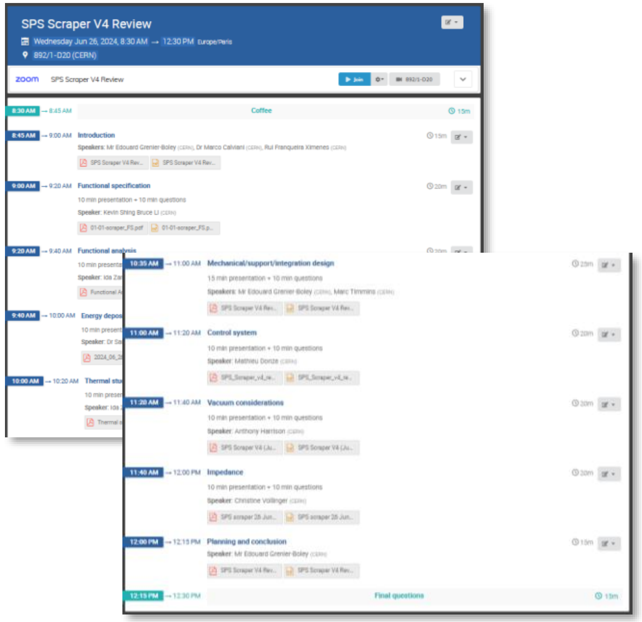
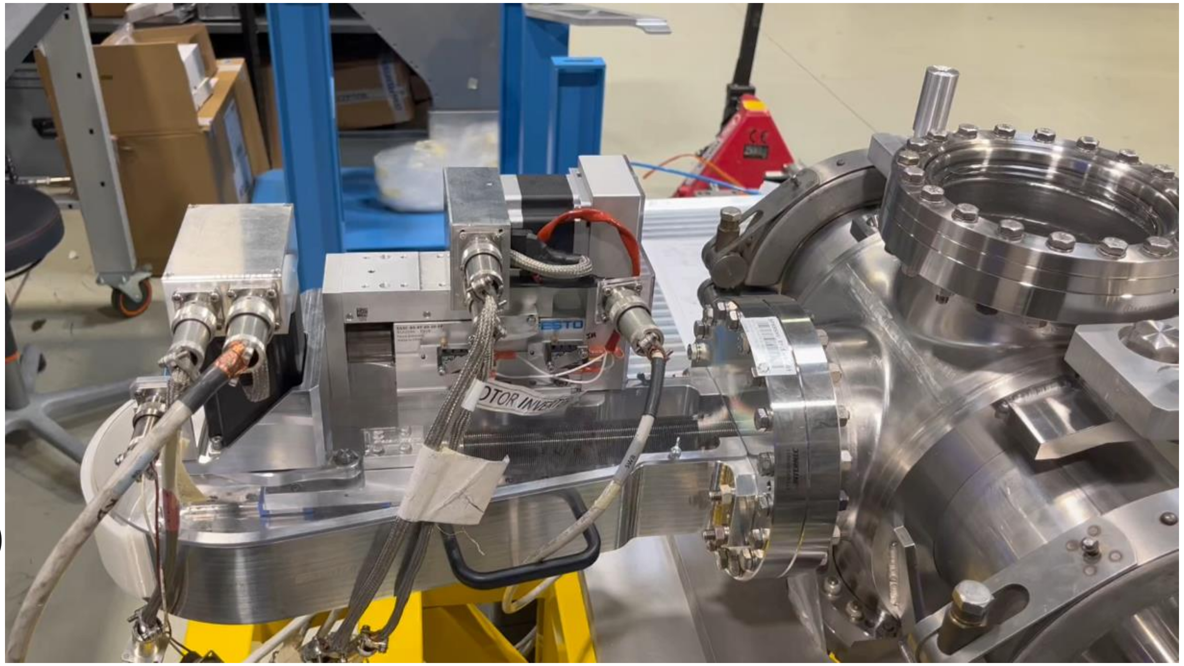
SPS-BSHV-ES-0003
ENGINEERING SPECIFICATION
Functional analysis for operational SPS Scraper V4

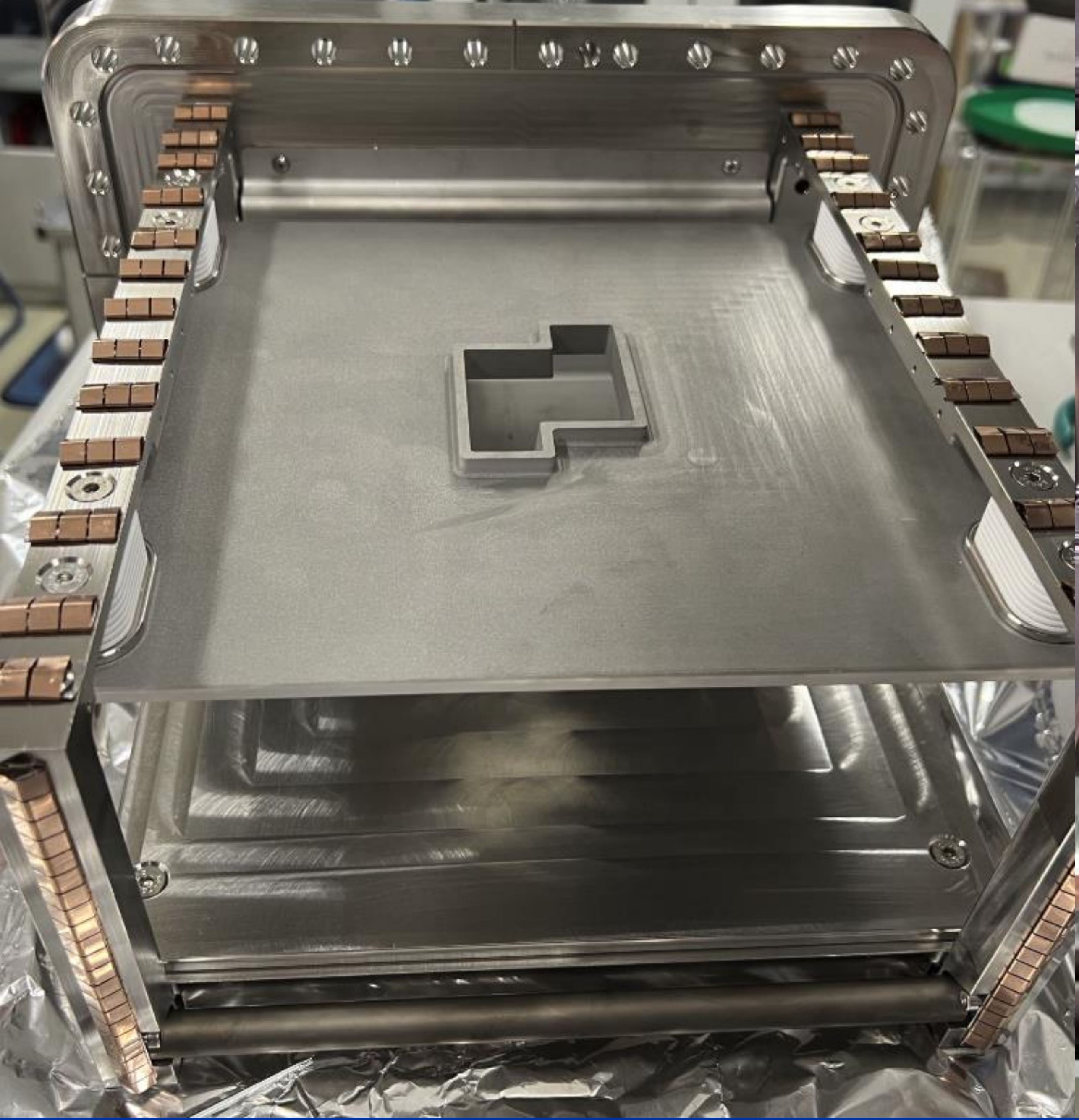




Design/Project approach

- Weekly project meeting with the different groups
- Functional specification EDMS 240764 jointly converged between OP & HW groups
- Brainstorming & functional analysis to correctly establish the need. (EDMS 2757827)
- Design review with multiple groups (self-inflected → normal STI/TCD approach)
- Prototype & offline cycling (4M, system/design validation)
- Pre-series to be tested in the machine during 2025





SPS BGI

SPS Beam Gas Ionisation beam profile monitors

BGI Profile Monitors

→ **Non-destructive continuous bunch-by-bunch** measurements of the **transverse beam profile**.

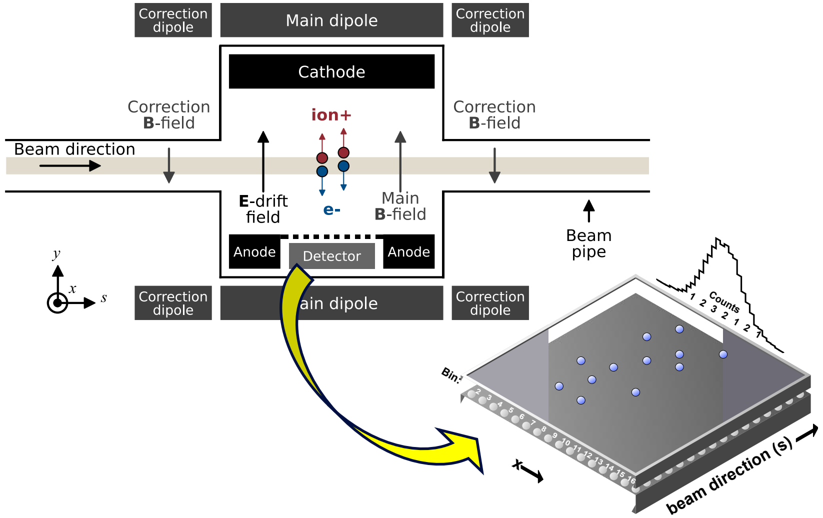
PS BGI's

- Funded by LHC Injector Upgrade (**LIU**) project;
- Prototype installed in YETS 2016/17;
- **PS BGIH & BGIV** installed in LS2;

SPS

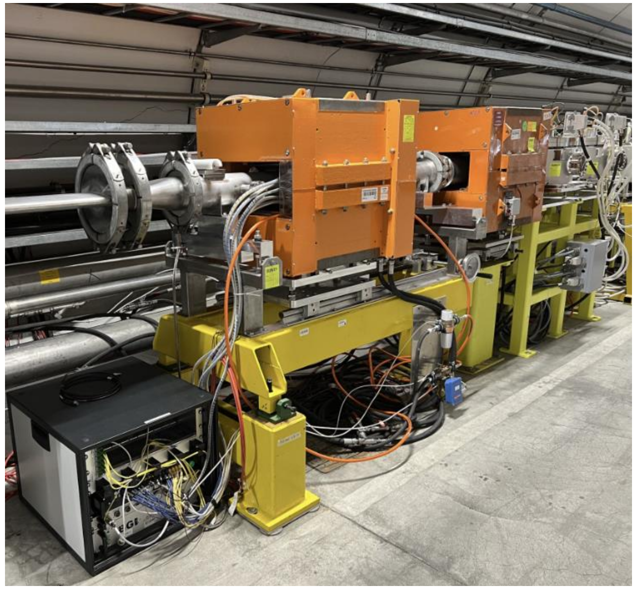
- Funded by **CONS**;
- **SPS BGIH** installed during YETS 23/24, then 2nd version during TS1 2024;
- **SPS BGIV** installed during TS1, but failed leak test after installation and was removed.

- → **SPS BGI shows interferance** with AWAKE & LHC25NS beams leading to lose of communication from TimePix3, reset and corrupted data. → **EMI, SEU ?**



*Measure beam profile by **counting** # ionisation electrons detected in each column (centre). Timepix3 electronics (right).* Refs. IBIC 2017, IBIC 2019, IBIC 2021

PS BGIH at SS #82



SPS BGIH at 51634

Investigations at ATS EMC Lab

Direct Coupling Measurements

→ 1kHz RF modulation up to 1GHz and 500W (10% beam power) between stretched wire and i) HV cable and ii) Timepix3 signals

- -45dB **coupling between stretched wire & HV cable**
- **No coupling to Timepix3** signals

Cable Immunity

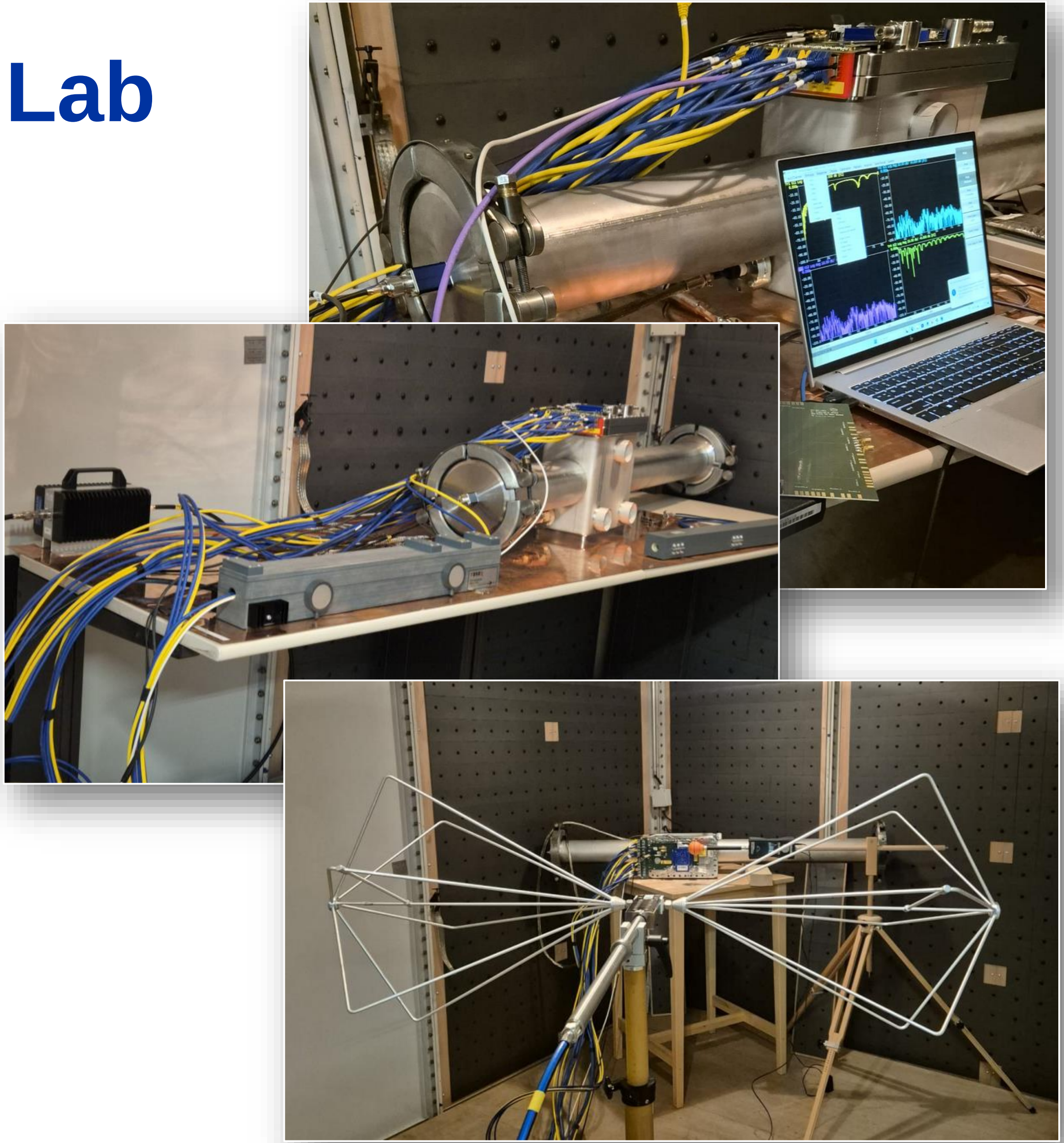
→ Injected RF (1 kHz modulated) at various frequencies & power levels through clamp into a) signal cables, and b) low voltage cables.

- **Could reproduce problems seen in the tunnel** (sensitive <100 MHz and at 400 MHz).

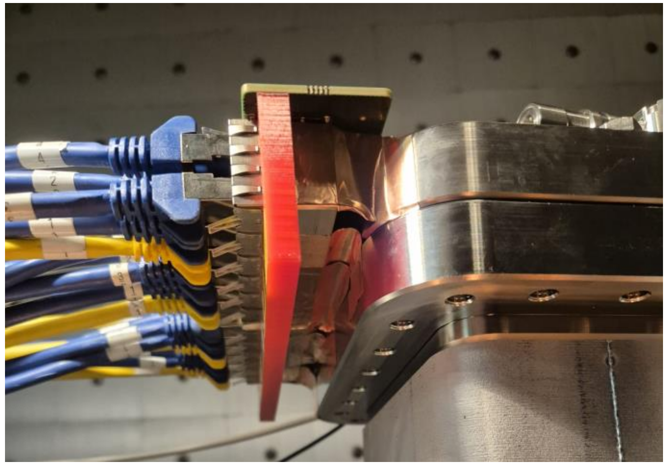
Radiated Immunity

→ expose setup to radiated RF at up-to 1.28 GHz and 50V/m.

- **Perturbations and partial corruption of pixel matrix** observed at 80 MHz and 320 MHz.

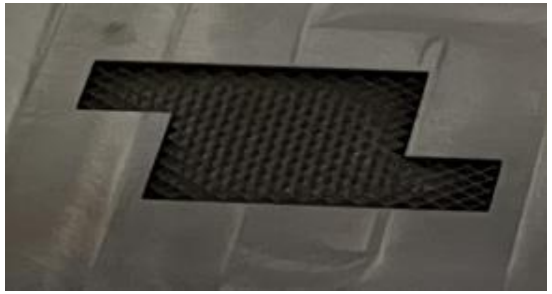


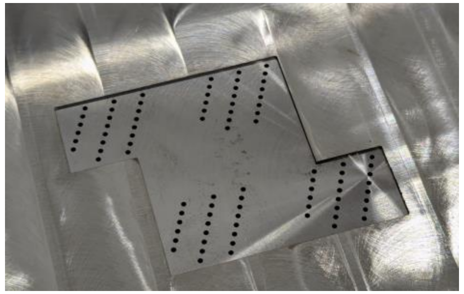
EMC Lab Findings & Actions



- Radiated RF from the HV cable, caused by beam coupling to the cathode, then coupling to signal cables, is a plausible mechanism for the SPS BGI problems.
- Direct interference from the beam to the Timepix3 is not ruled out.

→ **+ BGI Review**





Actions during YETS 24/25:

- **Add shielding** to both HV & signal cables;
- **Fit ferrites** to the HV cable.
- On the new SPS BGI-Vertical install **denser Faraday shield** over the detectors.

Situation Today

BGI Horizontal

- Instrument installed with "Diamond" RF shield
- Magnets in doublet configuration

BGI Vertical

- Prototype instrument installed
- Magnets in doublet configuration

After YETS 24/25

BGI Horizontal

- Same instrument with "Diamond" RF shield
- External HV countermeasures
- Magnets in triplet configuration (*)

BGI Vertical

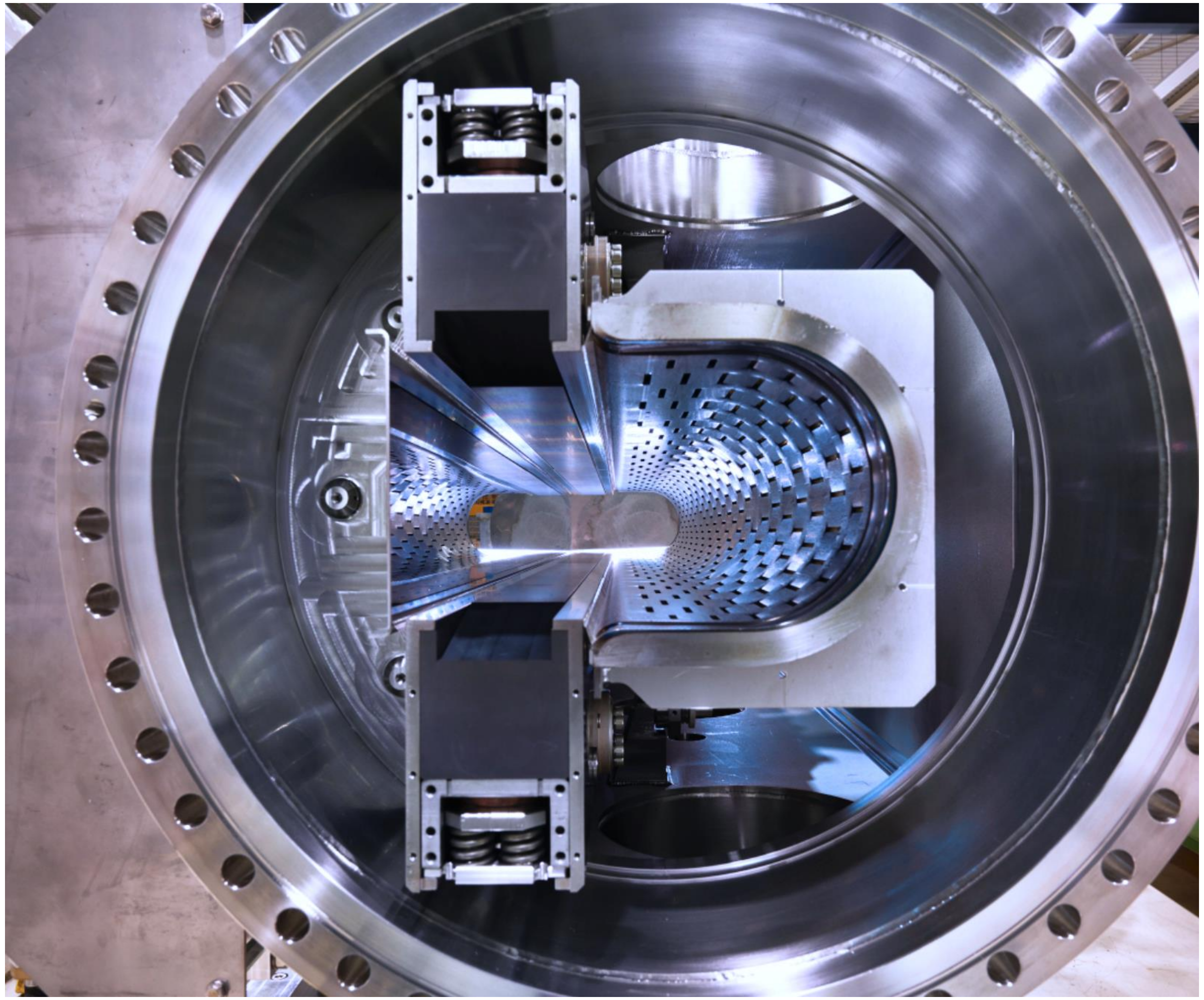
- New instrument with "Denser" RF shield
- External HV countermeasures
- Magnets in triplet configuration (*)

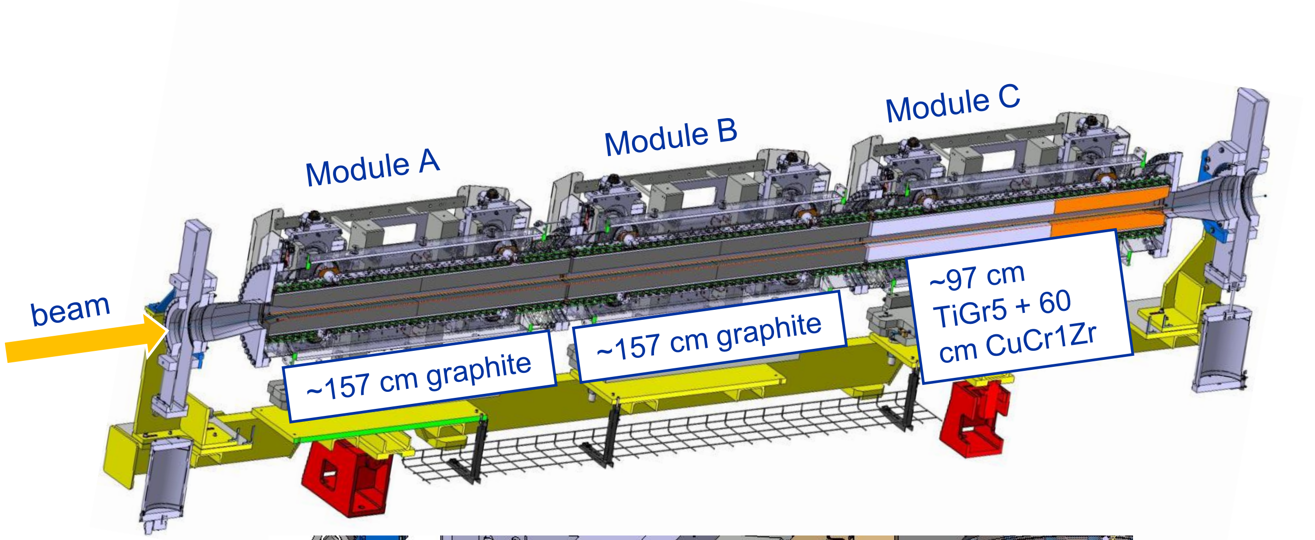
(*) ECR 3168184 "Modification of magnetic bump for operation of the BGI profile monitors in SPS LSS5.

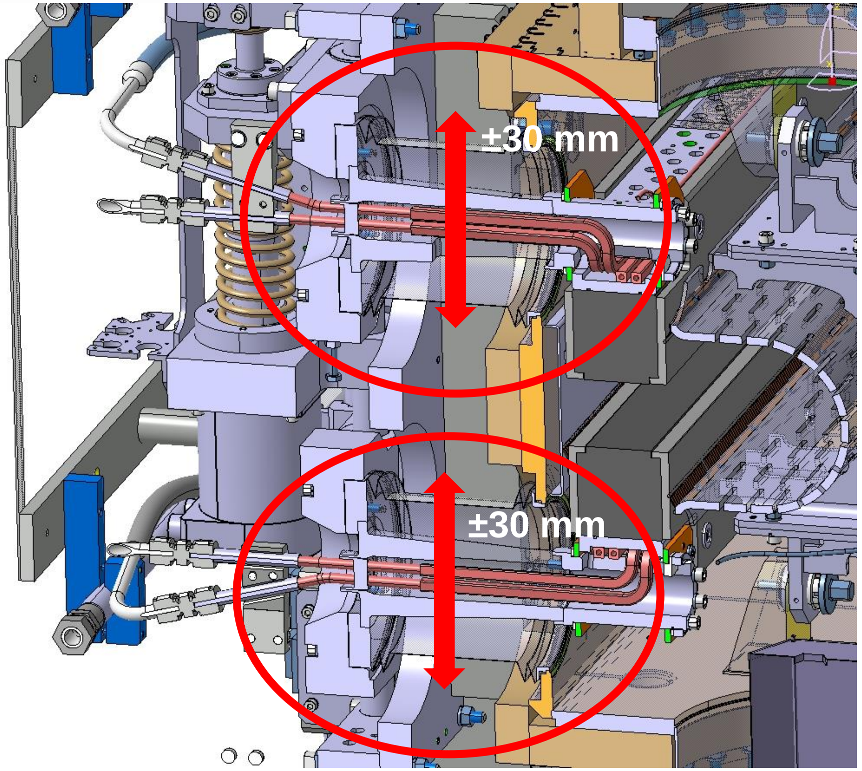
TDIS

Target Dump Injection Segmented

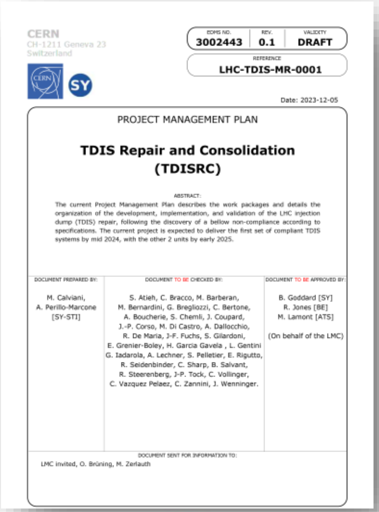
TDIS




Module A
Module B
Module C
beam
~157 cm graphite
~157 cm graphite
~97 cm
TiGr5 + 60
cm CuCr1Zr


±30 mm
±30 mm

TDIS Repair & Consolidation Project | Bellows QA


CERN
CH-1211 Geneva 23
Switzerland

EDMS NO.	REV.	VALIDITY
3002443	0.1	DRAFT

REFERENCE
LHC-TDIS-MR-0001

Date: 2023-12-05

PROJECT MANAGEMENT PLAN

TDIS Repair and Consolidation (TDISRC)

ABSTRACT:
The current Project Management Plan describes the work packages and details the organization of the development, implementation, and validation of the LHC injection dump (TDIS) repair, following the discovery of a bellow non-compliance according to specifications. The current project is expected to deliver the first set of compliant TDIS systems by mid 2024, with the other 2 units by early 2025.

DOCUMENT PREPARED BY:	DOCUMENT TO BE CHECKED BY:	DOCUMENT TO BE APPROVED BY:
M. Calviani, A. Perillo-Marcone [SY-STI]	S. Atieh, C. Bracco, M. Barberan, M. Bernardini, G. Bregliozzi, C. Bertone, A. Boucherie, S. Chemli, J. Coupard, J.-P. Corso, M. Di Castro, A. Dallocchio, R. De Maria, J-F. Fuchs, S. Gilardoni, E. Grenier-Boley, H. Garcia Gavela , L. Gentini G. Iadarola, A. Lechner, S. Pelletier, E. Rigutto, R. Seidenbinder, C. Sharp, B. Salvant, R. Steerenberg, J-P. Tock, C. Vollinger, C. Vazquez Pelaez, C. Zannini, J. Wenninger.	B. Goddard [SY] R. Jones [BE] M. Lamont [ATS] (On behalf of the LMC)

DOCUMENT SENT FOR INFORMATION TO:
LMC invited, O. Brüning, M. Zerlauth

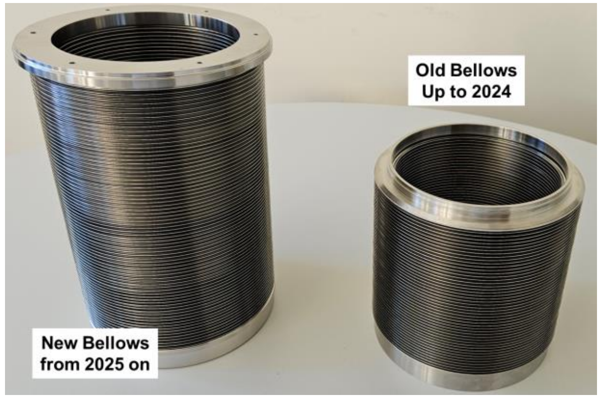
→ **Project Management Plan** EDMS 3002443 with clear set of WP responsibilities and deliverables.

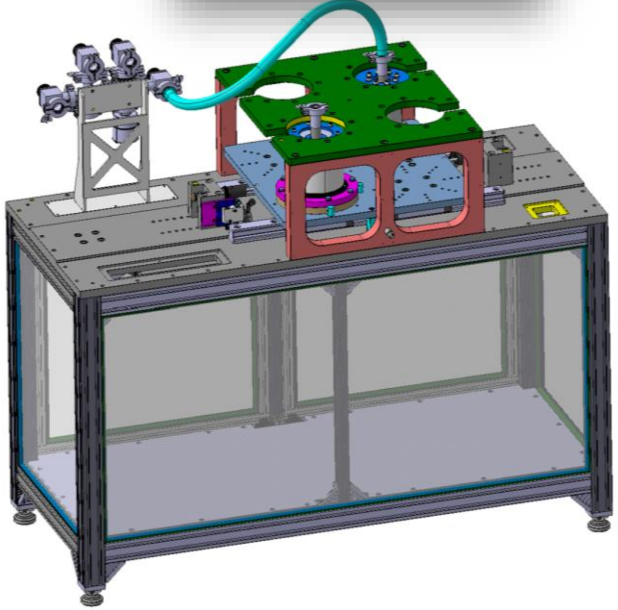
Operation risk mitigation

- 2024 running with spare TDIS (same type of bellows) **w/ revised operation**
- **Ensure operation for post-2024**
  - A. **Repair** of both leaking and radioactive TDIS (both P2 and P8)
  - B. **Production of new tanks**. **3 in-house + 3 externally**
  - C. **Conditioning of spent** TDI as backup

Bellows understanding & QA

- Fatigue tests of current bellows
- Close work with supplier for new compliant bellows
- Fatigue test of new bellows



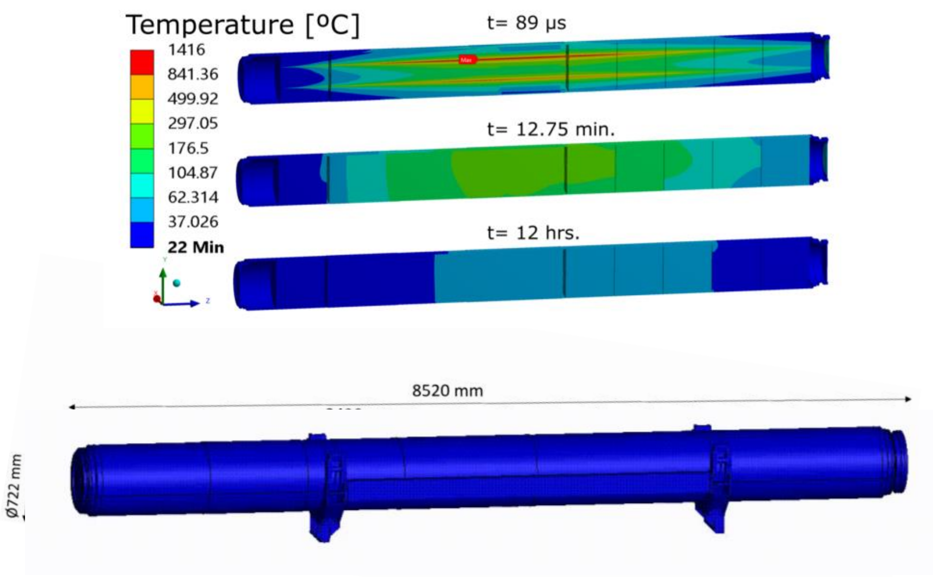


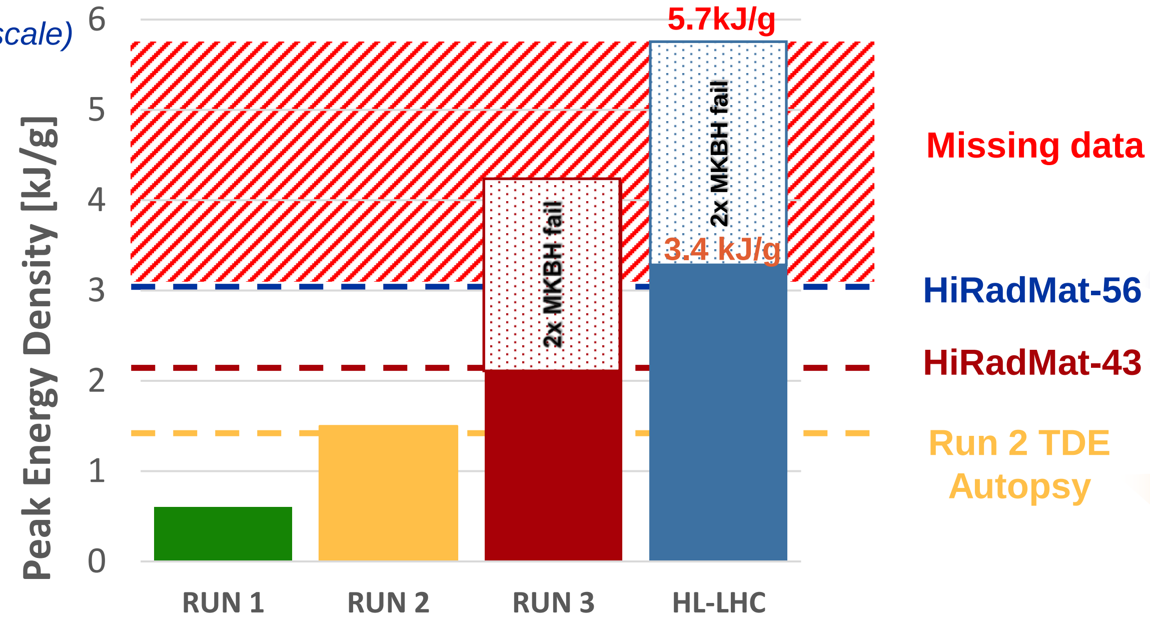
HL LHC-TDE

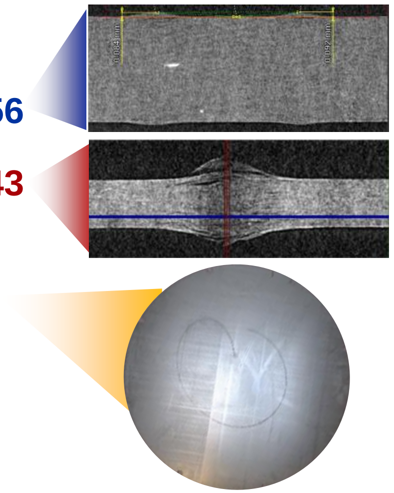
LHC Beam Dumps

Challenges in HL-LHC – Core materials

Detailed modelling & understanding
of the dynamic response of the Run3 LHC-TDEs (not at scale)





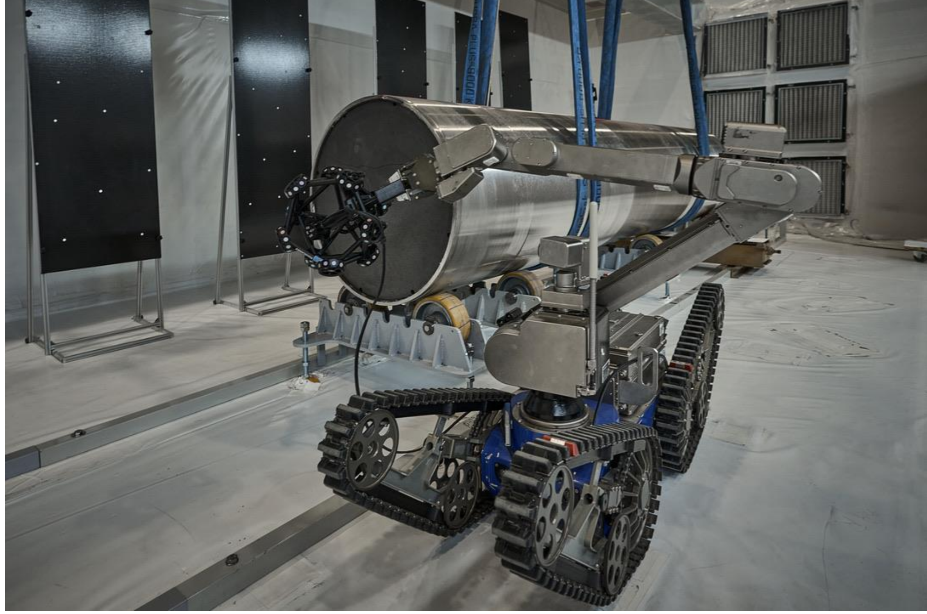


Absorb the LHC beam at any time, energy, or intensity

Stored beam energy set to increase to 710 MJ in **HL – more than 4.5 times than Run 1**

- Peak energy deposition increase in the core beyond tested values (**Failure scenarios** previously not reproducible)
- No information on resistance to **repeated dumps**
- Testing scenarios **not compatible with the HiRadMat facility** as it was **before the upgrade**

Autopsy (& waste disposal)



HiRadMat-HLTDE experiment

HiRadMat facility **upgraded successfully** to deliver LIU beams (up to 288b x $2.3 \cdot 10^{11}$ ppb) in YETS 23-24 thanks to the joint efforts of many groups (BE-EA, SY-STI, TE-VSC, BE-CEM, SY-ABT, BE-OP)

Experiment aims:

Test candidate materials for the HL-LHC beam dump (TDE) core:

- Isostatic Graphite (**IG**) – 5 grades
- Carbon-Fibre-Reinforced Carbon (**CFC**) – 3 grades
- Flexible graphite, **Sigraflex®**

Experiment is a defined **qualification criterion** in two active **Market Surveys**

Aim is to induce:

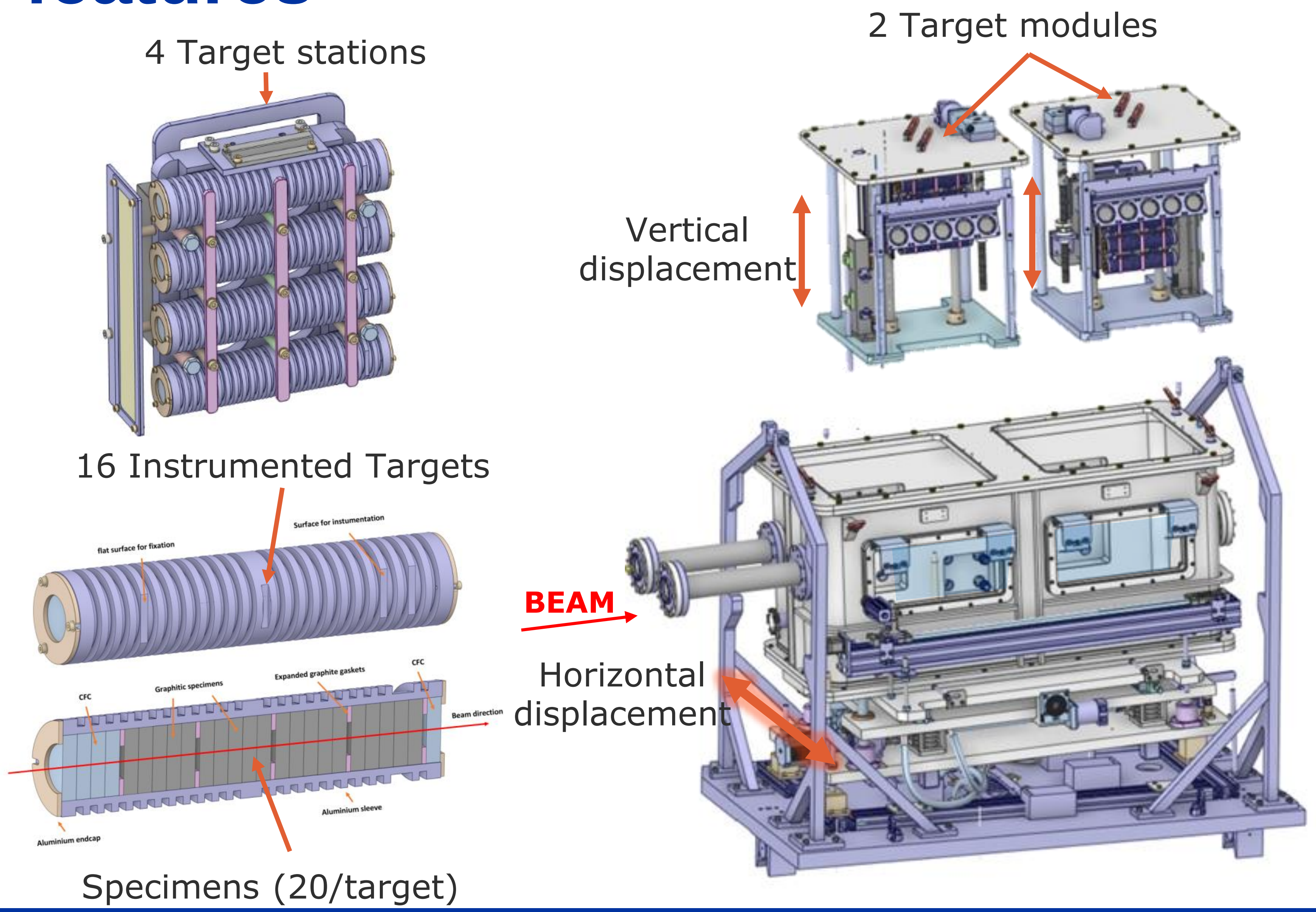
- **Energy density**
- **Thermal shock**
- **Number of impacts**

Representative of HL **nominal** operation and **accidental** scenarios

Experiment key features

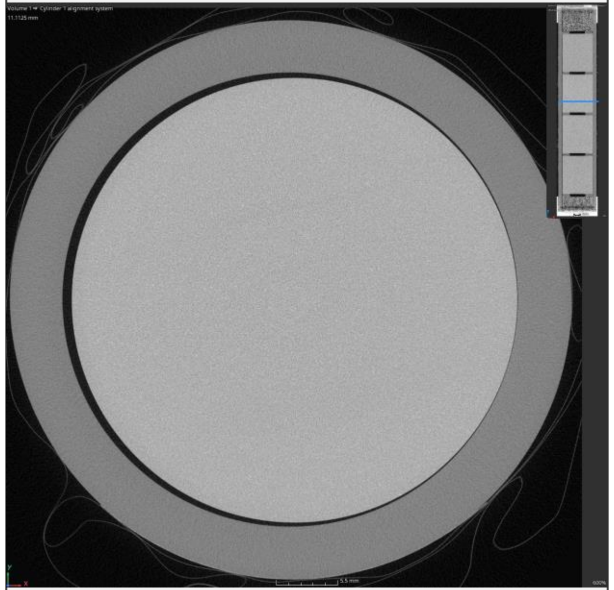
HiRadMat-65-HLTDE

- Multipurpose tank
- Previously used for multiple experiments
- Four target types
- **16 targets** in total
- **August 2024**
- **Over 450 pulses extracted on the targets over 1.5 weeks**



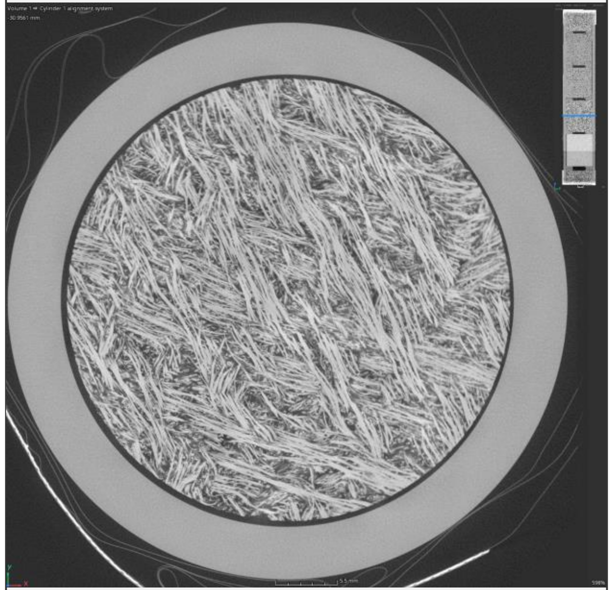
Post-Irradiation Examination Results

ISO GRAPHITE



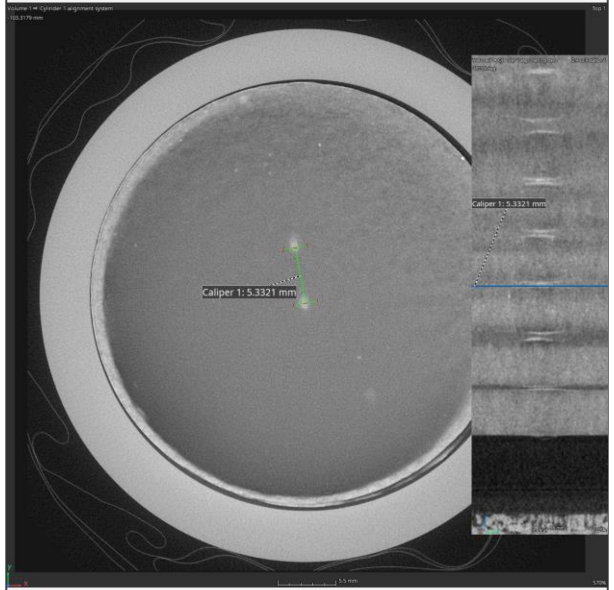
No damage in any grade for **nominal** and **accidental**

CFC



No damage in any grade for **nominal** and **accidental**

Sigraflex

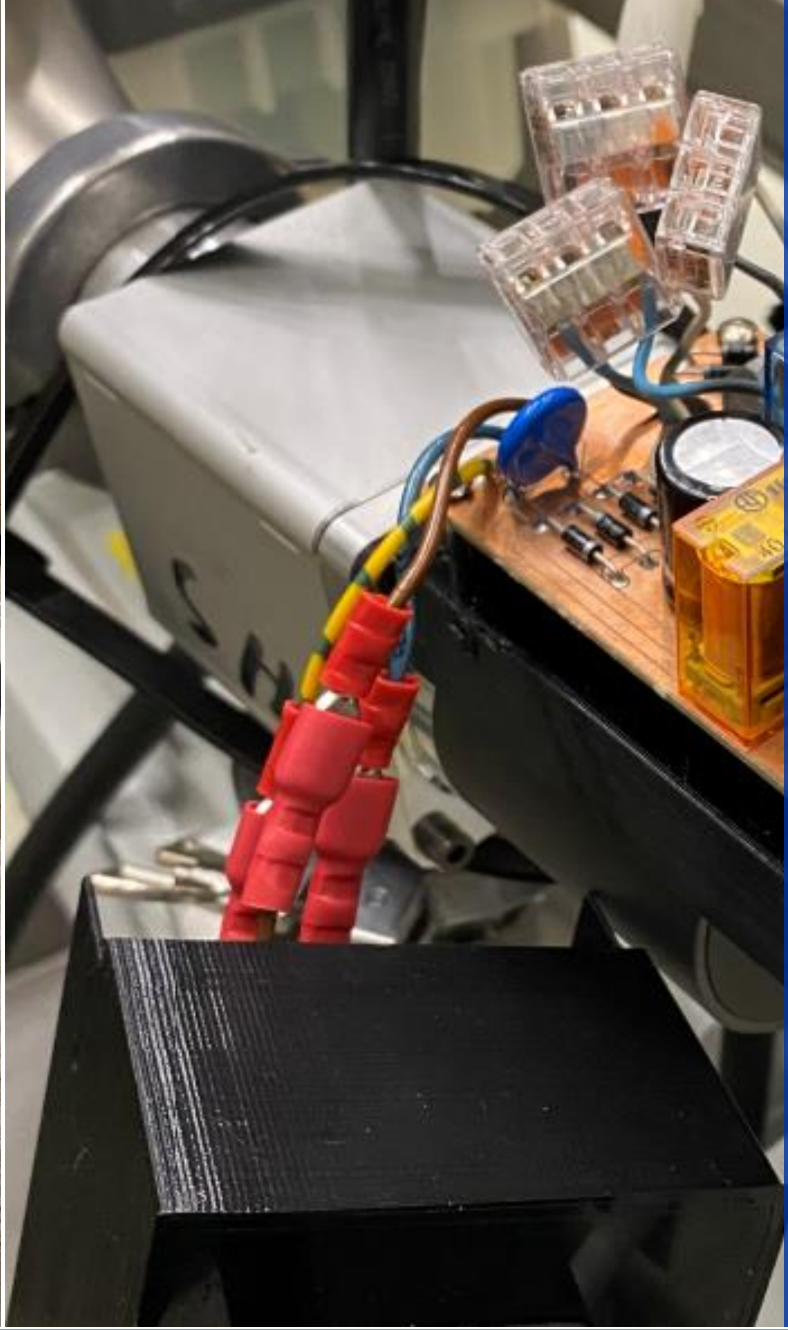


Damage occurred **in all cases**

Key risk of the project – no material fully qualified – averted

Sigraflex **not qualified** for HL operation

Possibility to perform additional material layout optimization in the core



Electro valves

In Secondary Beam Areas

V2 Electrovalve

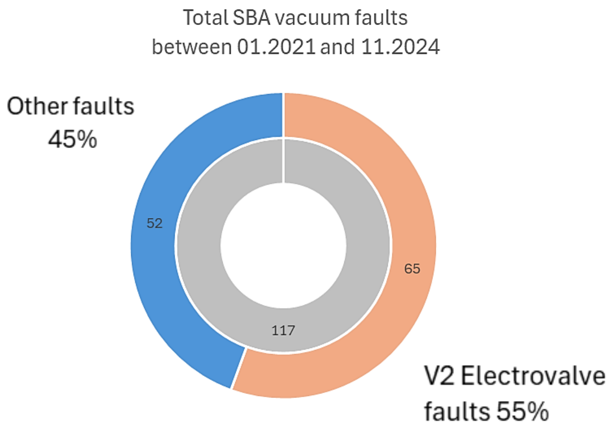
In SBA**, 60 pumping groups** are installed across 7 km of beamlines to ensure primary vacuum between 10^{-2} to $9x10^{-3}$ mbar.

V2 Electrovalve

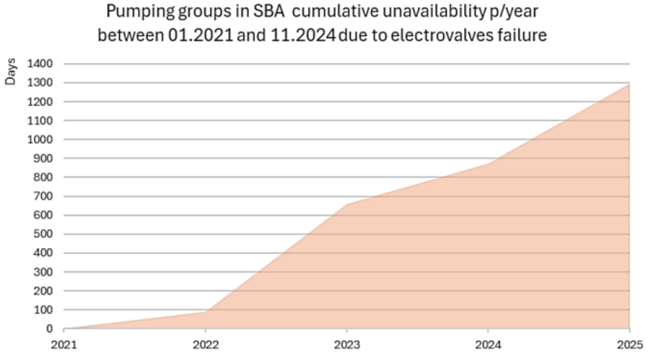
1. Open / Close the pumping group to the beamline
2. Protect pumping group & beamline vacuum in case of pumping group failure
3. Allow quick maintenance of the pumping group

Passive electronics V2 Electrovalves
Not commercially available

Active electronics V2 Electrovalves
Commercially available but **sensitive to radiation**



Registered V2 Electrovalve failure rate since 2021: 17 p/year



Over 1200 days of pumping group operation lost due to faulty V2 Electrovalves since 2021
(Redundancy of pumping groups ensures that the vacuum performance in SBA is maintained)

- Access request incurring in **beam down time**, **personnel exposure and time for maintenance** are the main consequences of the electrovalve failures

Rad-hard electrovalve

Discussion with the Industry to enable in house development of Rad-hard solution

- Collaboration with VAT to allow a complete understanding of the operation of the present V2 electrovalve and use it as a baseline for the new rad-hard version

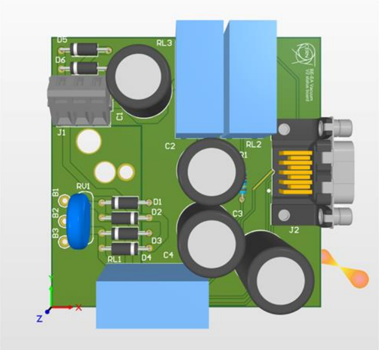
1. SBA requirements: Flange connection ISO-KF40, Coil power supply at 230V, 2 dry contacts for monitoring.
2. Control coil with only passive components. → RC filter (resistor-capacitor circuit)
3. Characterization of RC filter
4. Development of control PCB with only passive components.
5. Optimization of the PCB for integration with the existing V2 Electrovalve base

Constraints

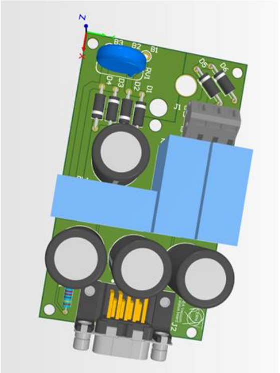
- **Size and Integration** – using an existing commercial electrovalve as base for R&D
- **Thermal management** – electrovalve coil heating and heat dissipation
- **Electric insulation** – from the PCB to the coil

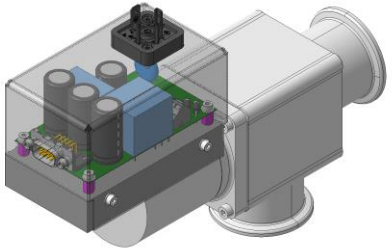
PROOF OF PRINCIPLE, 08.2023

PROTOTYPE 1, 07.2024



PROTOTYPE 2, 10.2024





Rad-hard electrovalve

Offline testing / validation

- **Irradiation** → 138kGy (~50 years). Good working condition, despite slight degradation of polymeric casings.
- **Fatigue** → ~500 cycles) without degradation or failures
- **Temperature** → 45°C (manufacturer Threshold < 70°C)

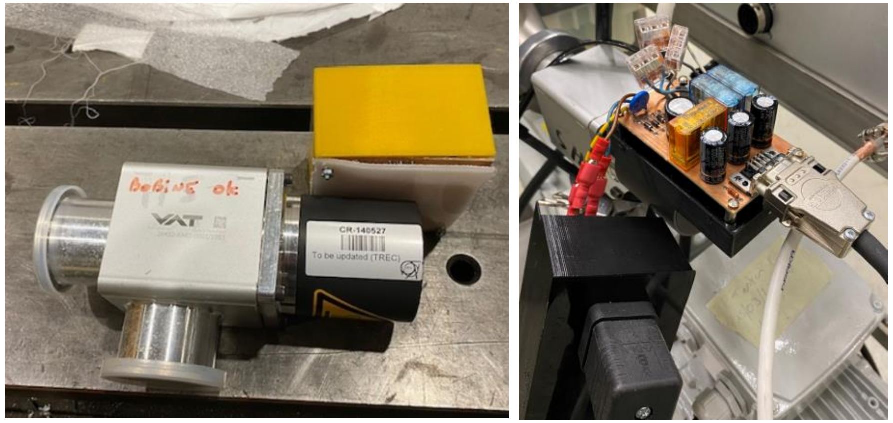
Operational Trial

- 1st rad-hard electrovalve installed in 08.2024 in T8 EAST AREA complex.
- **Past** → 17 faults since 2021 (**1 fault /1.5 months**)
- **Present** → **0 faults after 4 months** of operation

Plan / large-scale deployment

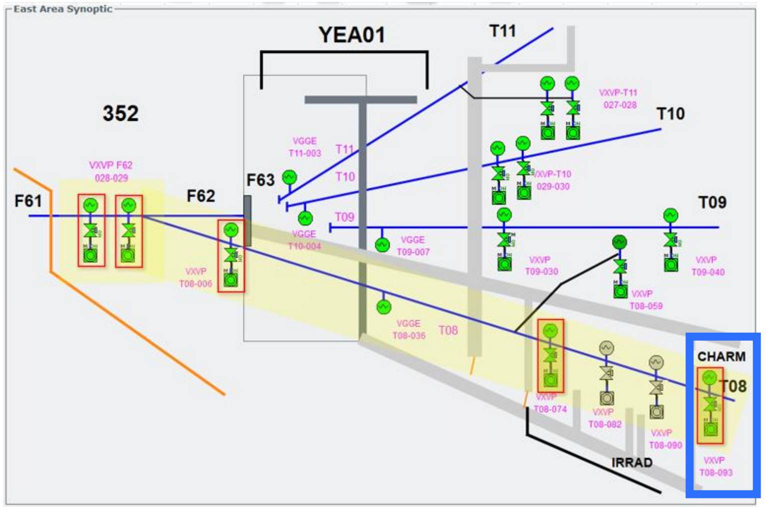
- Large-scale validation until LS3
- → 30 rad-hard V2 electrovalves to be deployed during Q1-2025 in SBA

Rad-hard electrovalve setup for irradiation tests



Thermal analysis of the electrovalve using a FLIR camera

Trial with new electrovalve in the EA



Summary | Best practises

SPS-Scraper

- New design following **brainstorming and functional analysis**
- **Discussions OP on** its operation mode and revision of **functional specification**
- **Design & process review** with everyone onboard (and making it a standard practice)
- Cycling **testing**
- **Prototype** tested **in the machine** during 2025

TDIS

- **Project management plan and operation risk mitigation**
- **Review** device **mode of operation with OP**
- **QA** of bellows **via test-bench**, **CERN experts** and close work with **suppliers**

BGI

- **Use of CERN-wide experts** support of the ATS EMC lab and other groups
- **Review panel**

LHC-TDE

- **Detailed modelling/understanding**
- **Full-fledged material test & qualification for MS** with beam conditions in accident-like scenarios
- **Use of CERN's beam testing facilities**
- **Post-irradiation examination**

SBA Electro-valves

- R2E mitigation via design with passive elements
- **System monitoring** to identify issues
- **Collaboration with supplier** to achieve requirement.
- **Testing**: cyclic, irradiation, temperature

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