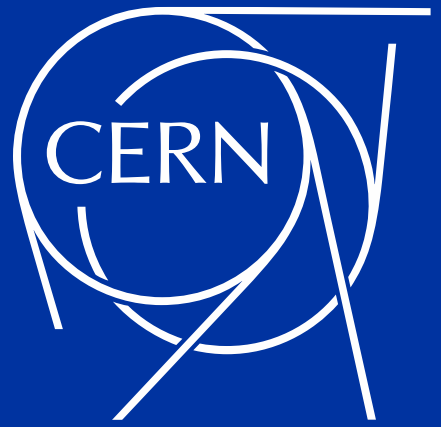


Limitations for LHC beams from TDIS and other STI equipment

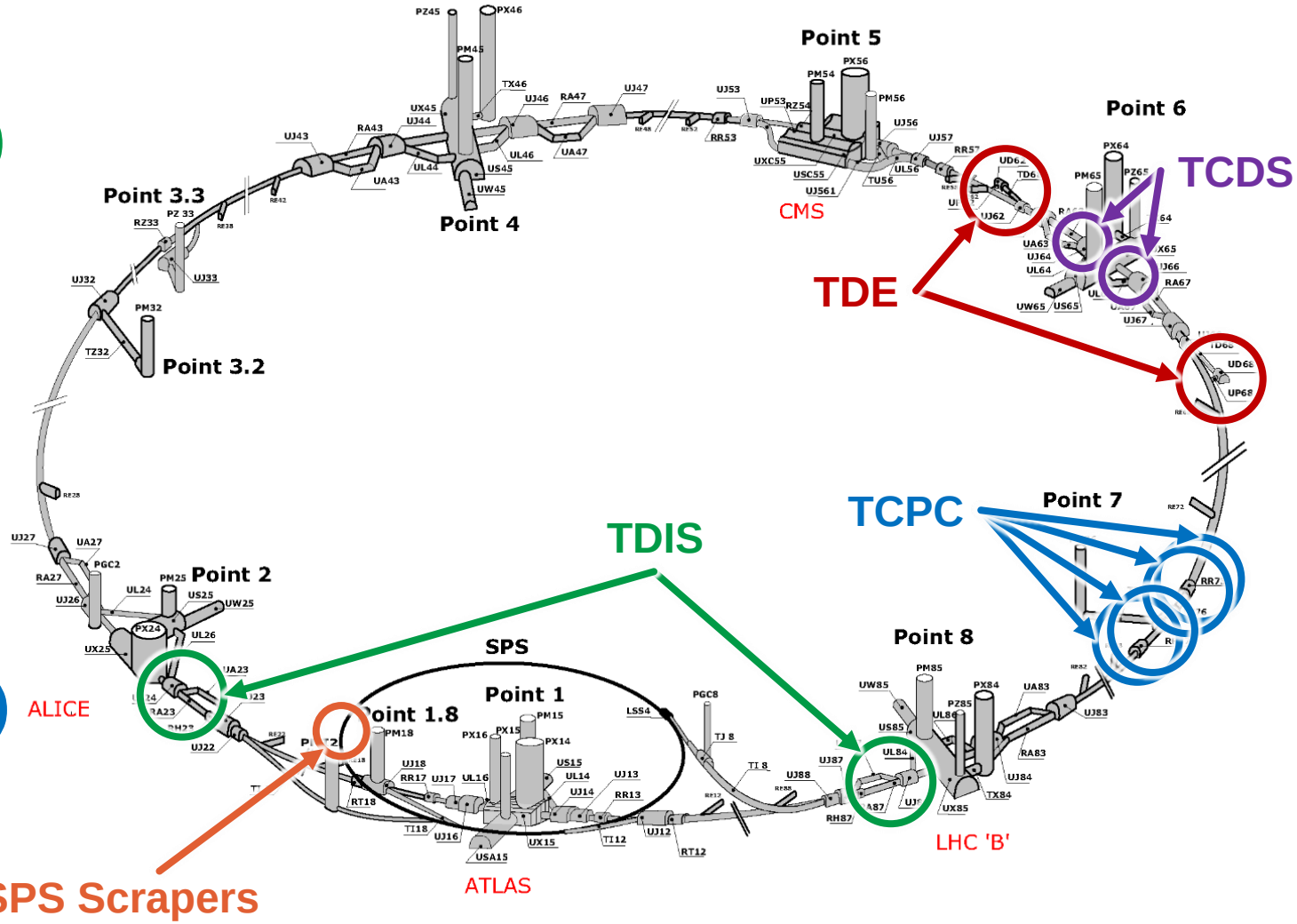
Joint Accelerator Performance Workshop **5th - 7th December 2023, Montreux**

Calum Sharp (SY-STI-TCD) on behalf of SY-STI,

With M. Calviani, A. Perillo-Marcone, R. Franqueira Ximenes, N. Solieri, Q. Demassieux, E. Grenier-Boley, R. Seidenbinder, O. Aberle, D. Grenier, A. Lechner, S. Gilardoni, G. Banks, L. Gross, Christoffer Moelck, K. M. Triantafyllou, C. Vollinger, C. Zannini, B. Salvant, C. Bracco, J. Uythoven, J. Wenninger, L. Gentini, G. Bregliozzi, M. Di Castro, D. Wollmann, E. Matheson among others…

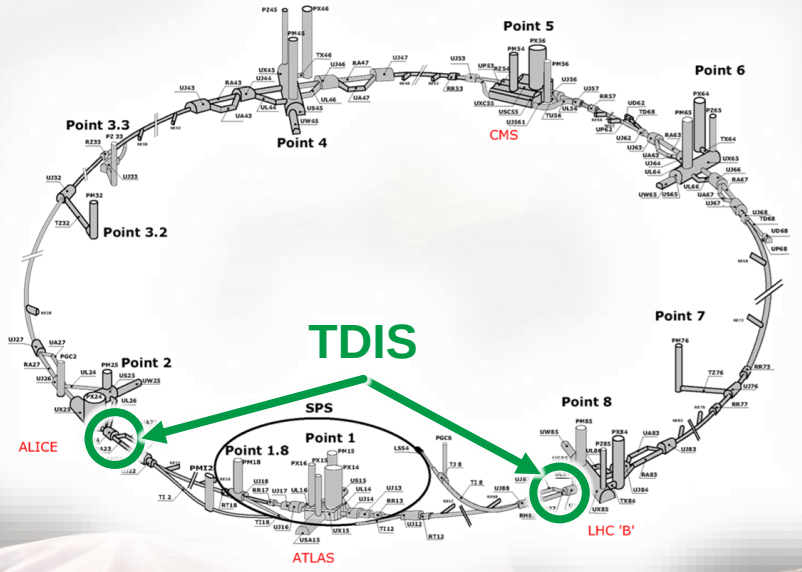
Outline

- **TDIS (injection absorbers)**
  - Bellows vacuum leaks
  - RF screen temperatures
- **TDE (beam dumps)**
  - Spares readiness
  - Cooling limitations
- **TCPC (crystal collimators)**
- **TCDS (septa protection)**
- **SPS Scrapers**



TDIS (injection absorbers)

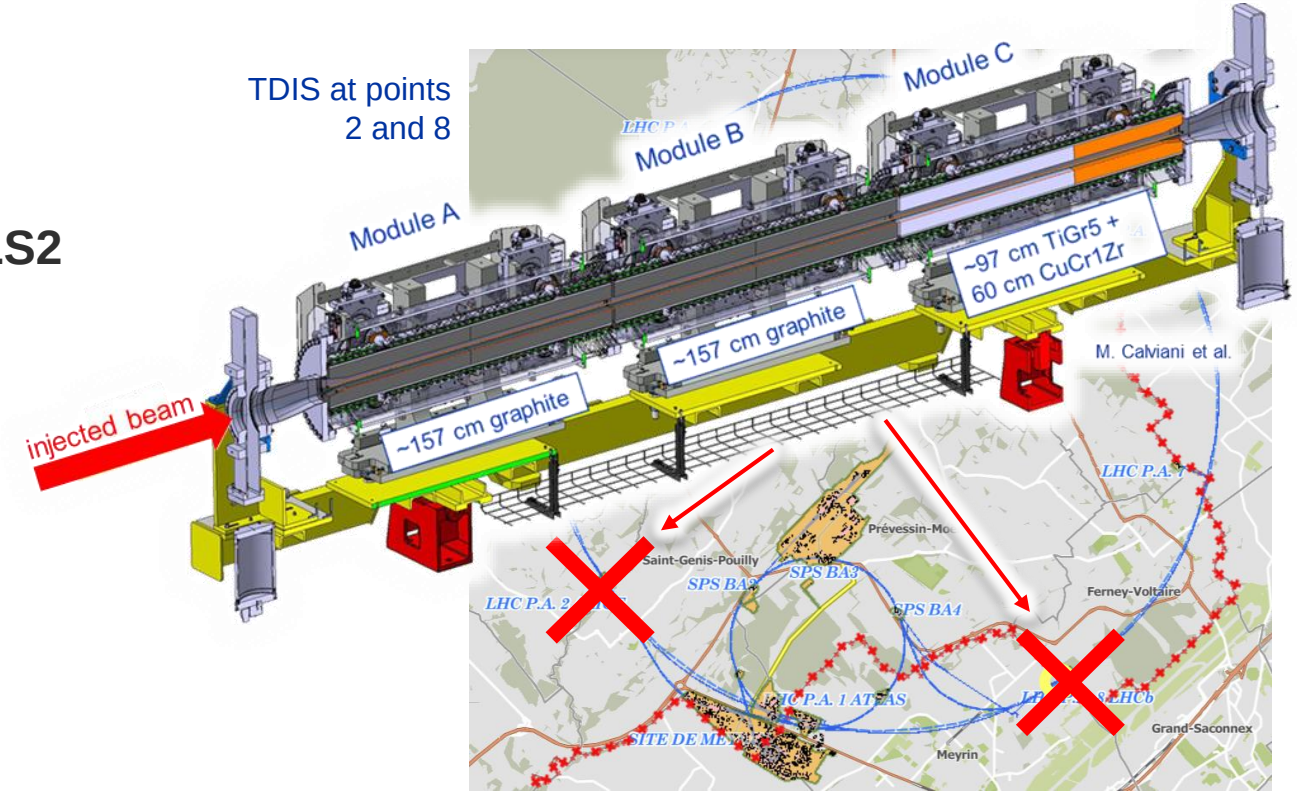
- Bellows vacuum leaks
- RF screen temperatures

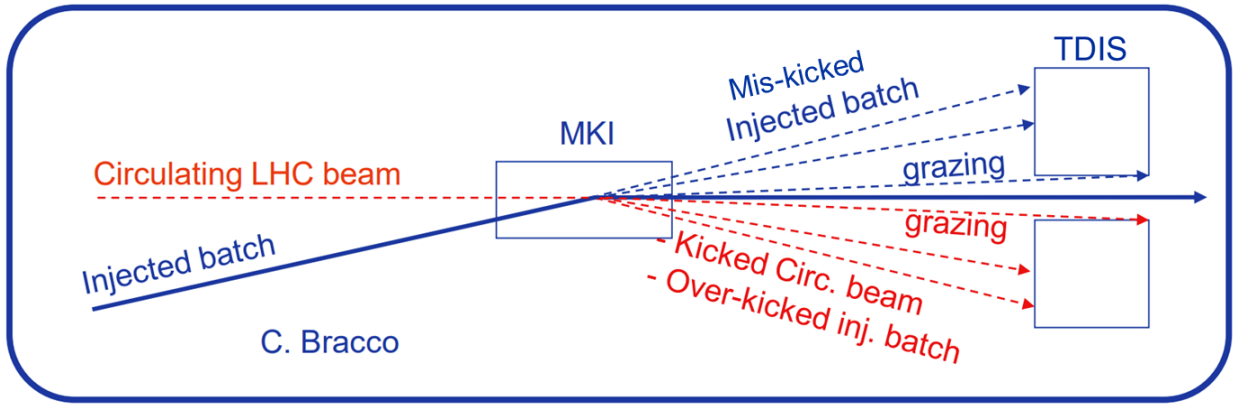


LHC-TDIS

- **Target Dump Injection Segmented installed in LS2**
- **Movable absorber at injection points 2 and 8**
- **Two sets of jaws (upper and lower) divided into three modules: graphite, Ti6Al4V, CuCr1Zr**
- **Inserted close to the beam during injection to protect magnets and equipment downstream in case of misfiring of the injection kickers**

TDIS at points 2 and 8

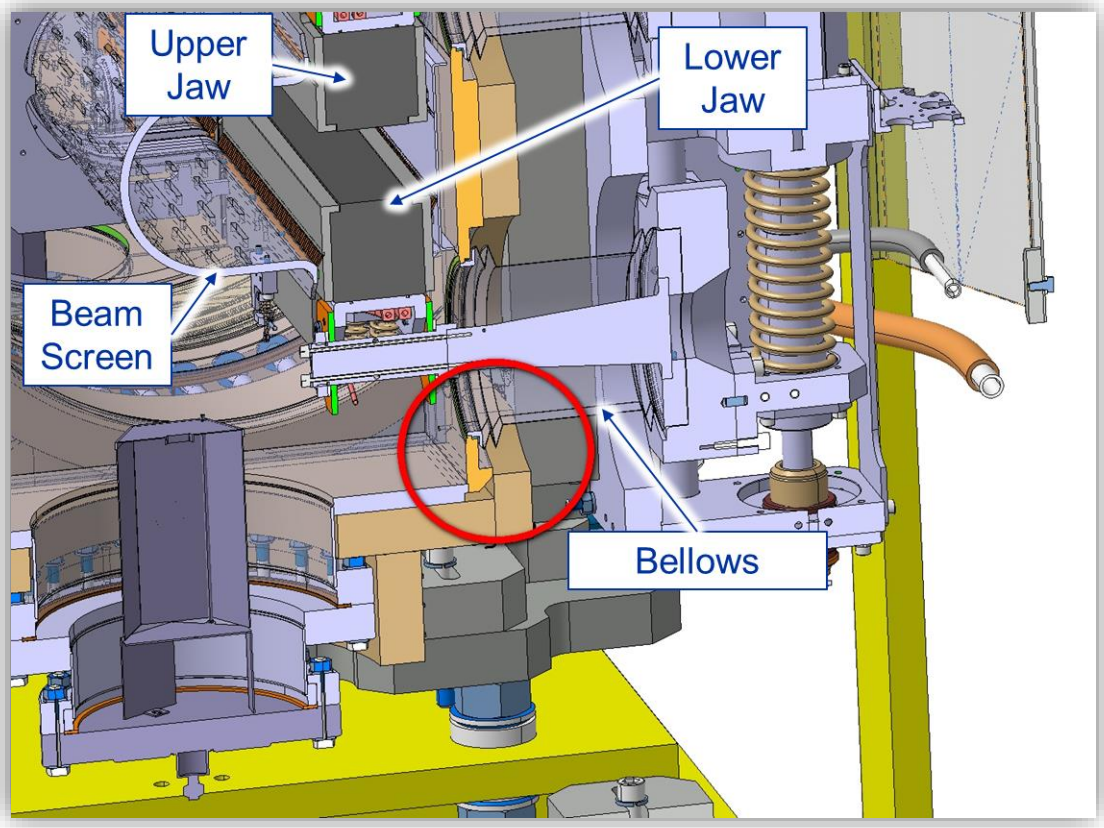




MKI misfiring scenarios

LHC-TDIS: Bellows vacuum leaks

- **Problem located, cause established as a mis-specification of the bellows by CERN, and solution identified**
- **Limitations at the end of 2023 but allowed the safe continuation of the ion run**
- **Replacing with available TDIS spares for 2024 – no modifications possible given the time**
- **Bellows should cope with required cycles in 2024; fatigue tests are underway to gain confidence**
- **But device will remain non-compliant in 2024**
- **No intensity limitations but unnecessary cycles of the TDIS jaws should be avoided; more details at next LMC 13th December**
- **Strategy in place to urgently deliver fully compliant systems as spares by summer 2024 to be installed in YETS 24-25 for operation in 2025**



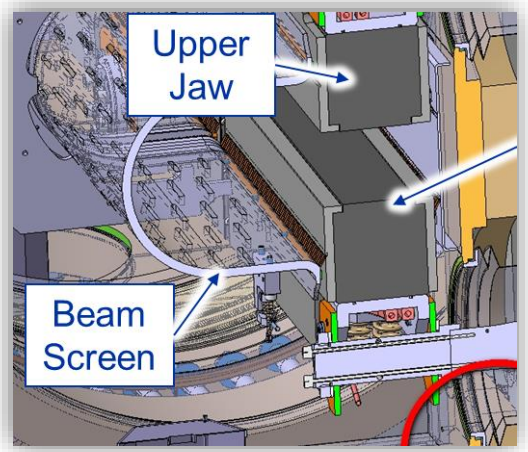
Leak located to jaw actuator bellows

TDIS Repair and Consolidation Project Management Plan LHC-TDIS-MR-0001 EDMS 3002443

More details available from LMC #474

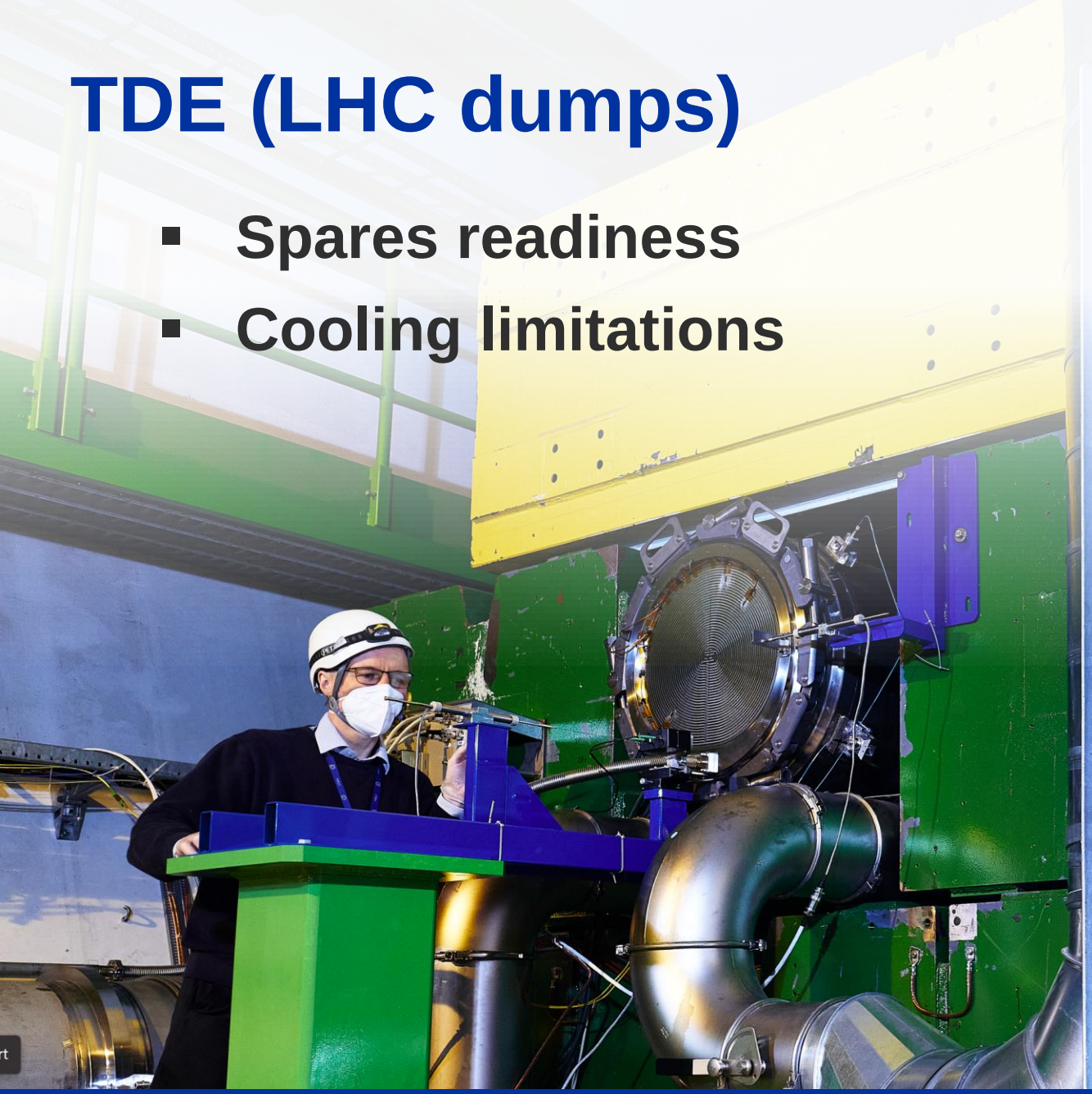
LHC-TDIS: RF screen temperatures

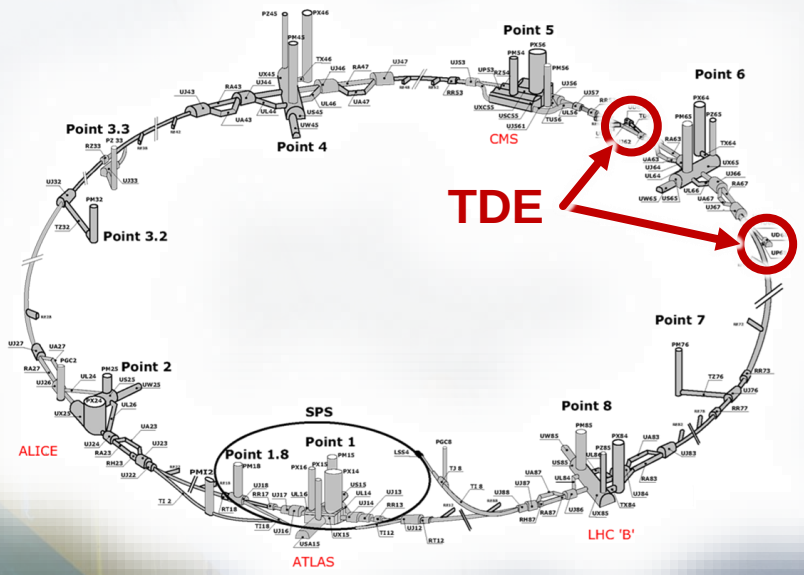
- Unexplained high temperature signals in the RF screen PT100s causing interlocks and limiting LHC filling
- Task force ongoing in parallel with bellows activity to explain temperature signals in RF screen PT100s
- Established that if it is real heating then it is likely to be a localised effect, but mechanism not yet understood
- Impedance measurements in progress on removed device
- Could also be influenced directly by electromagnetic interference
- Upgraded shielded instrumentation on RF screen foreseen for 2025 TDIS
- **RF screen temperature interlock at 150 °C must remain until cause is understood and, in any case, until spares are available in summer 2024 – STI currently evaluating possibility of increasing towards O(200 °C)**
- **Strategy for avoiding this during filling is to be defined, in terms of temporary retraction or delay, accounting for risk of additional cycles of the bellows**



TDE (LHC dumps)

- Spares readiness
- Cooling limitations





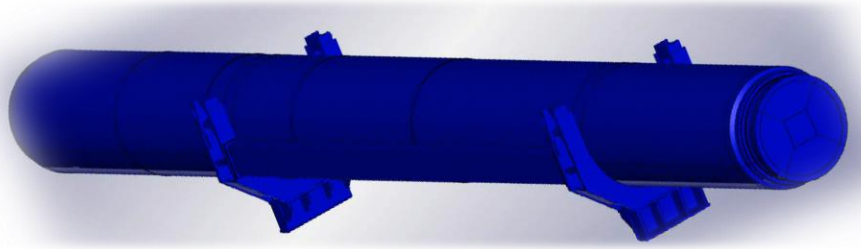
LHC-TDE: Run 3 spare readiness

- **Spares produced with minor upgrades**
  - Increased robustness
  - Ability to recover material for HL dump if required
- **Fully manufactured and assembled in-house – improved quality control and lessons learnt for HL**
- **Now ready to be moved to Point 6 during the YETS**

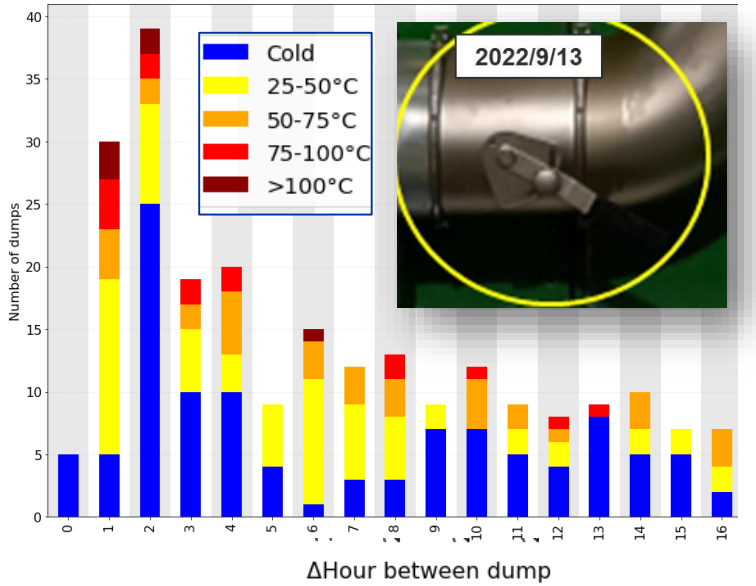




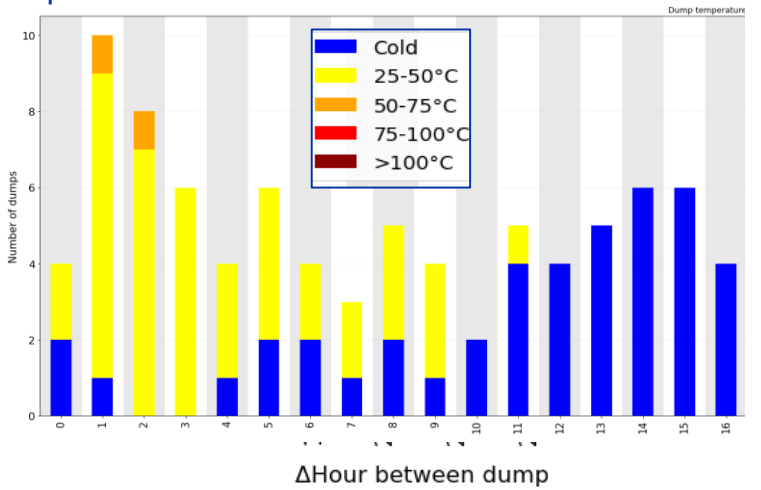

LHC-TDE: Cooling limitations



- **Both dumps' cooling systems now operating in nominal condition**
- **Question of potential operational limitations persists**
- **Temperature response to real operational conditions estimated by:**
  - Regression directly from the operational data (present case)
  - Neural network and/or physics-informed neural network model (work in progress)
  - Thermo-mechanical (FEM & CFD) calibrated with operational data (work in progress)
- **Worst dumping intervals and sequences seen so far in Run 2 & 3 would still be acceptable at full Run 3 intensity**
- **Can potentially accept sustained nominal Run 3 dumping every ~6 hours but high steady-state temperatures (preliminary result)**
- **Dump is behaving well – no operational limitations foreseen for Run 3, although work to better understand behaviour continues**



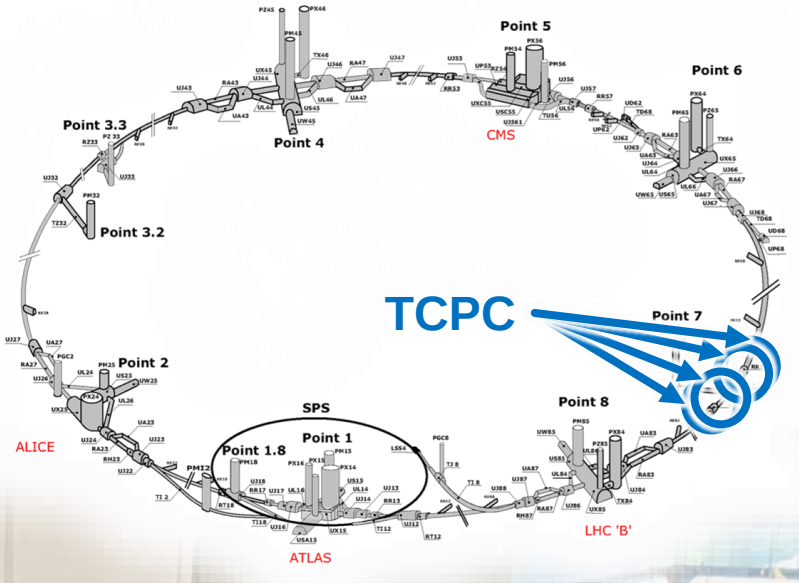
UD68 in 2022: Inefficient cooling evident due to partial valve closure.

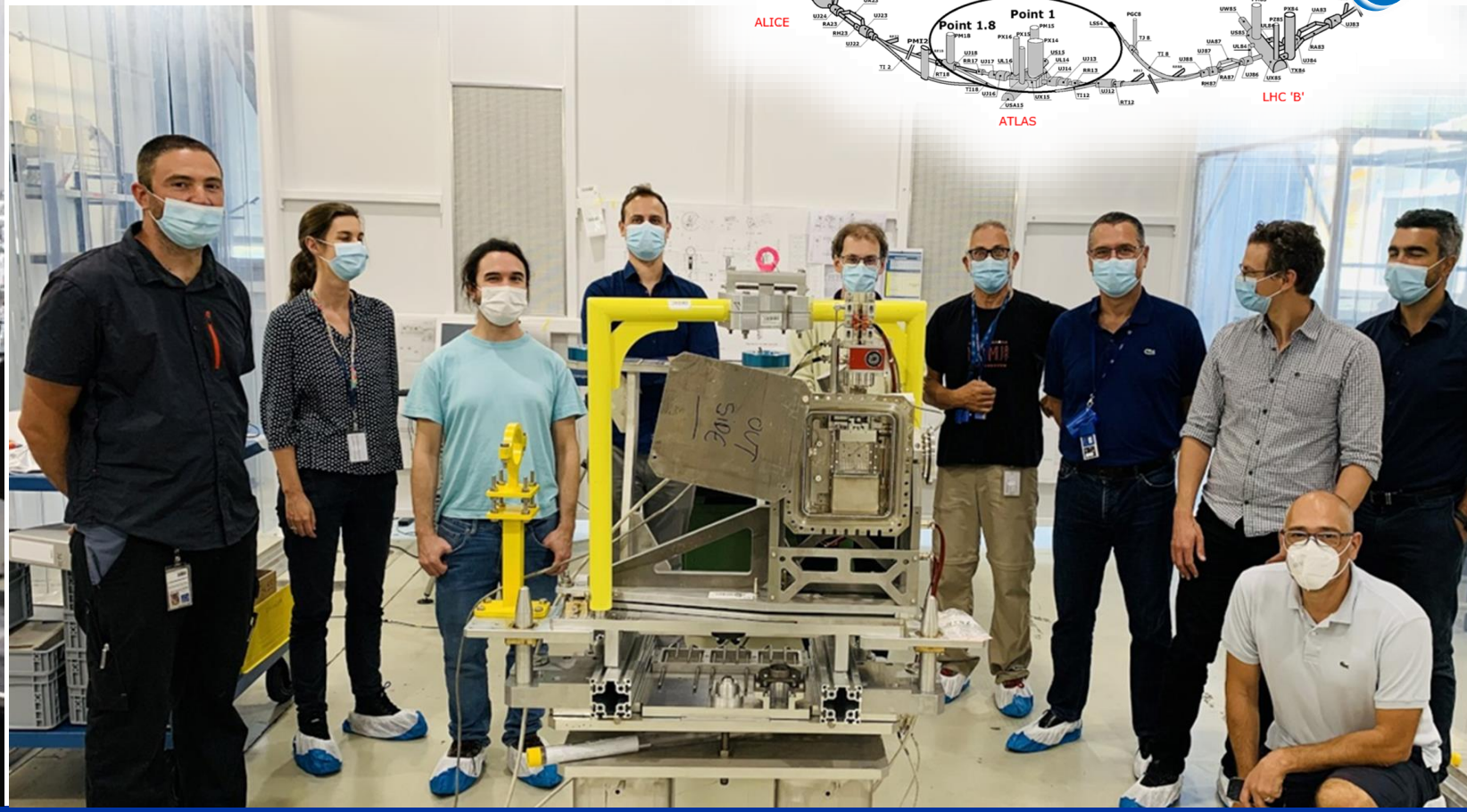


UD68 in 2023: Cooling problems now resolved. Nominal cooling operation. Full cooldown <~10 hr.

More details available from LMC #470

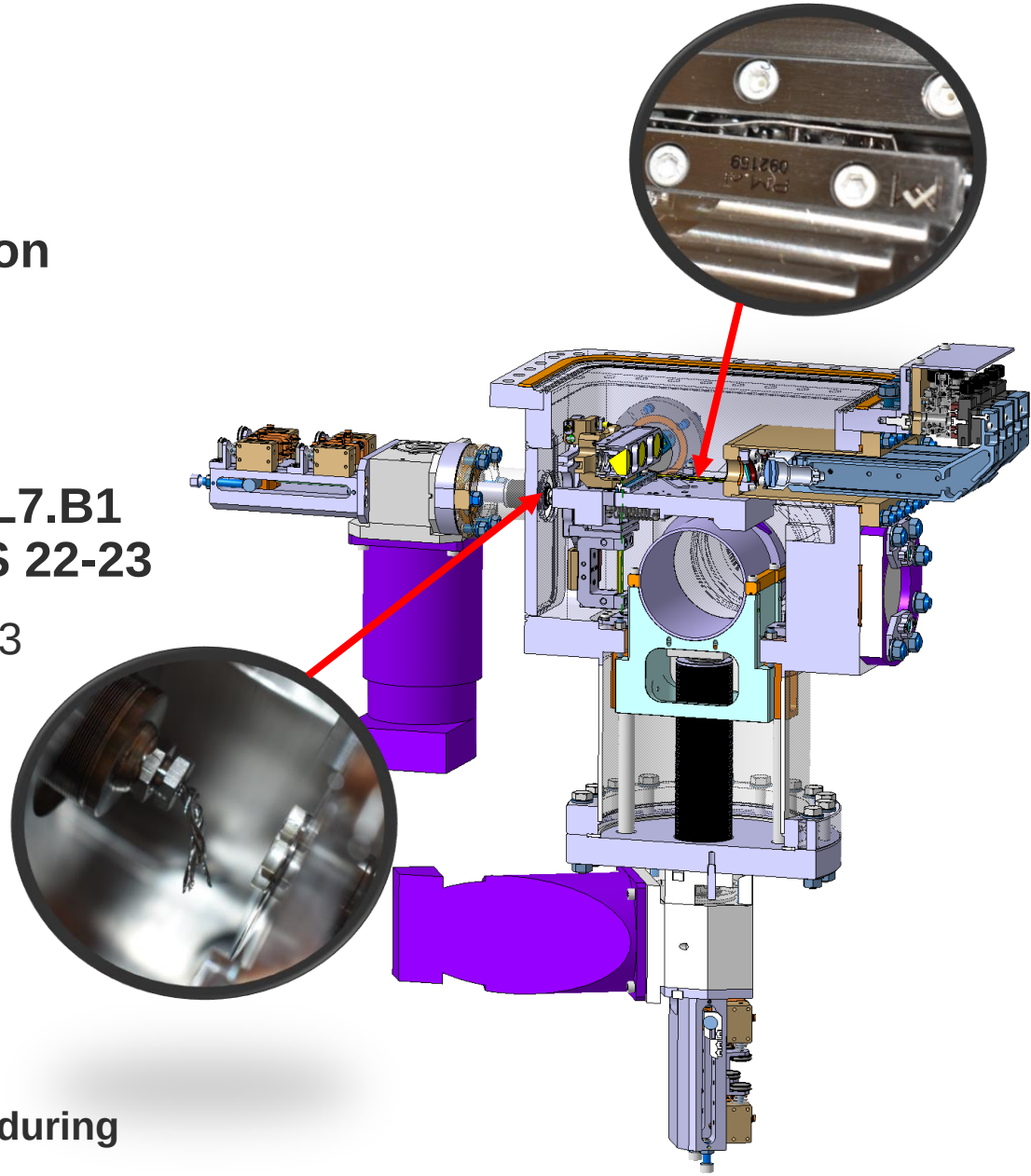
TCPC (crystal collimators)





TCPC (crystal collimators)

- **4 TCPCs upgrade in LHC IR7 for lead ions collimation**
  - 2 verticals TCPCs installed YETS 21-22
  - 2 horizontals TCPCs installed YETS 22-23
- **Failure of linear stage motion system of TCPCH.A4L7.B1 after 9 cycles during commissioning at end of YETS 22-23**
  - Urgent removal of the defective unit during the YETS 22-23
  - Corrective actions implemented in high priority
    - Exchange of defective parts (cable, rails, bearings)
    - Motion test with motor current monitoring
    - TCPC re-installed in the machine during TS1 (06/23)
  - Root cause analysis
    - Fatigue testing on a spare unit (1000 cycles)
    - **No fatigue observed, root cause is probably initial defect during bearing insertion – assembly procedure improved**

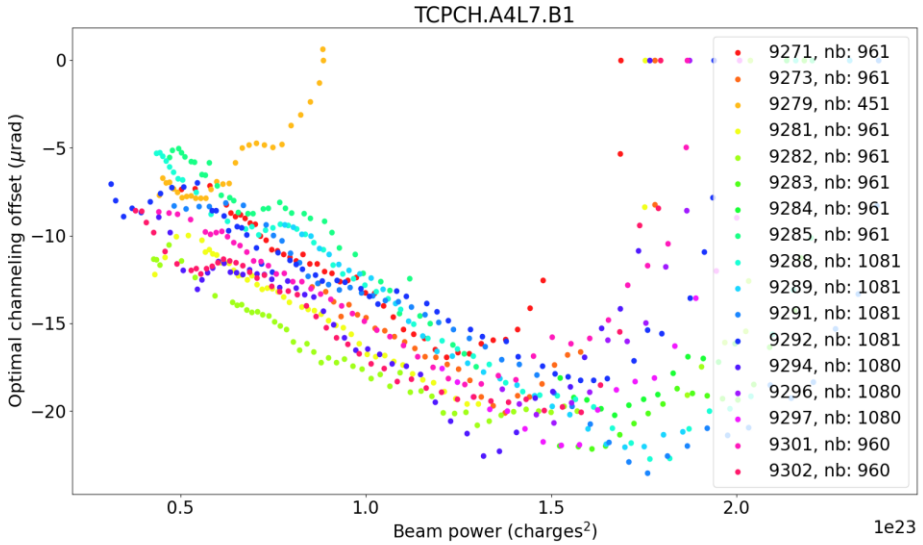


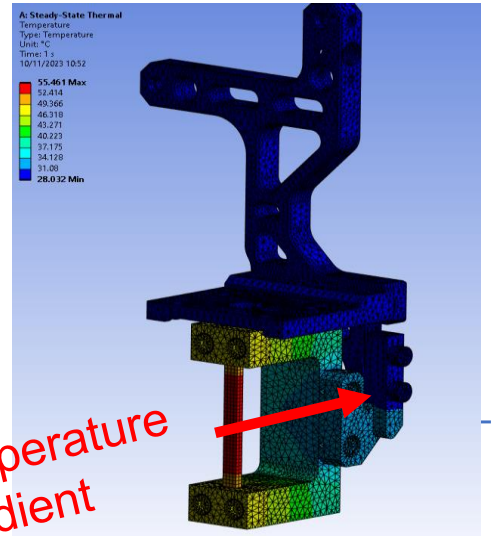
Particular thanks to Quentin Demassieux

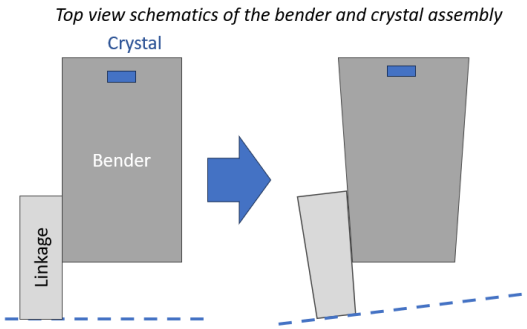
TCPC (crystal collimators)

D. Mirarchi

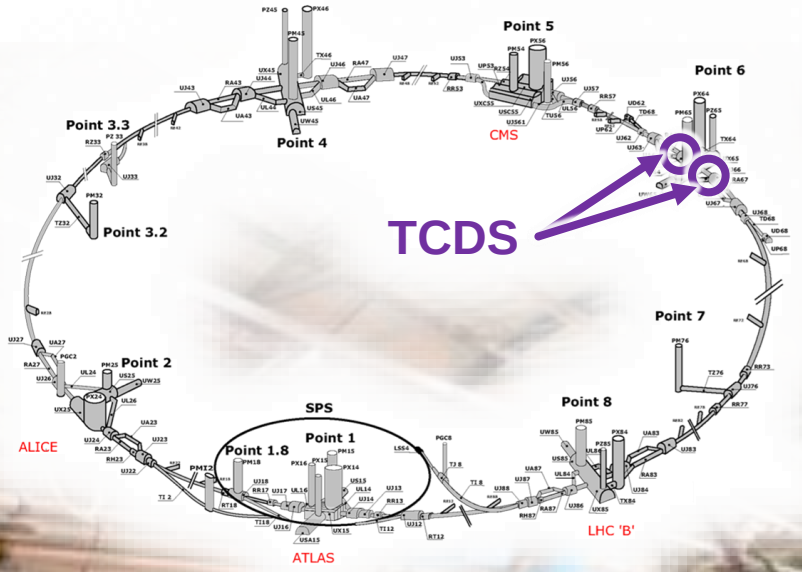
- **First stable ion beams with crystal collimation on 26/09/23**
- **Observation of an “offset” for crystal channelling angle during operation**
  - Offset appears to be correlated with beam intensity
  - There is also clear correlation of offset with readout of temperature probes (Pt100) in the tank
  - However, readout of the Pt100 is not reliable. Measured temperature increase during ramp-up would require 100-450 W of deposited power, while IWG predicts a 6W maximum power deposition
- **First hypothesis: localised heating with uneven mechanical deformation**
- **Impact for future operation to be addressed & need to plan ASAP for any LS3 upgrades**







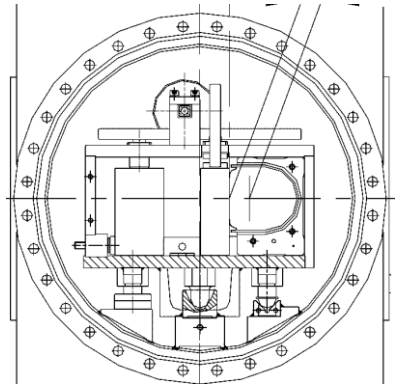
TCDS (septa protection)

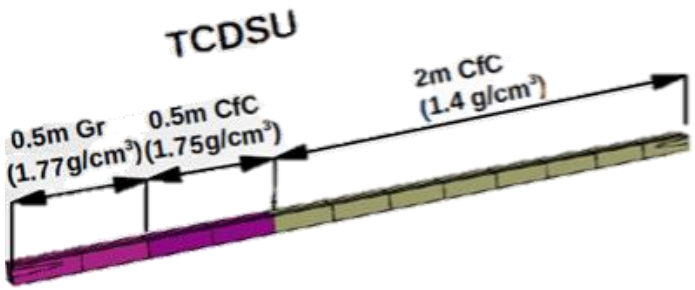


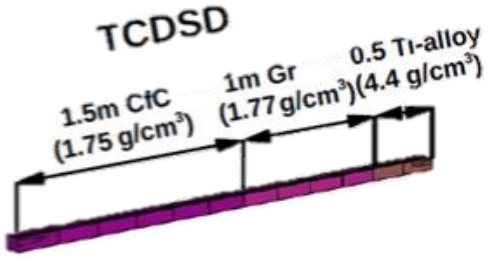
TCDS (septa protection)

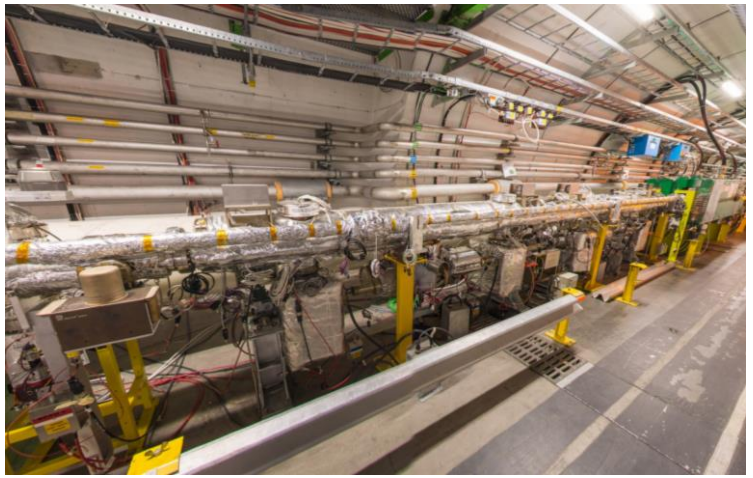
- SY-STI providing support to SY-ABT
- Pre LS3 limitations remain as they are now
- Strategy for HL-LHC upgrades is being defined for LS3

Filling scheme	Bunch intensity limitation
BCMS / hybrids:	1.8×10^{11} p/b
Pure 8b4e:	2.3×10^{11} p/b
24b(7e):	~2.1×10^{11} p/b (**preliminary result**) *Not pursued further as pre-LS3 experiment limitations and LS3 upgrade plans supersede.*









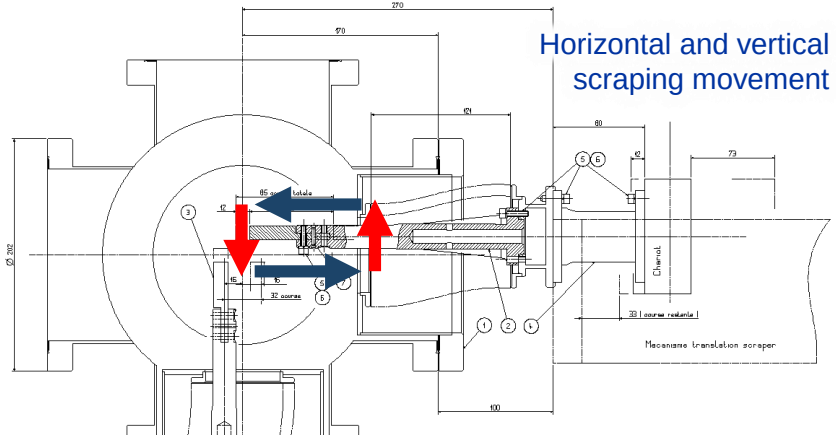
See C. Sharp JAPW 2022 and S. Fartoukh Chamonix 2023

SPS Scraper


Point 5
Point 6
Point 3.3
Point 4
CMS
Point 3.2
SPS Scrapers
Point 7
Point 2
SPS
Point 8
Point 1
ALICE
Point 1.8
LHC 'B'
ATLAS

SPS Scraper

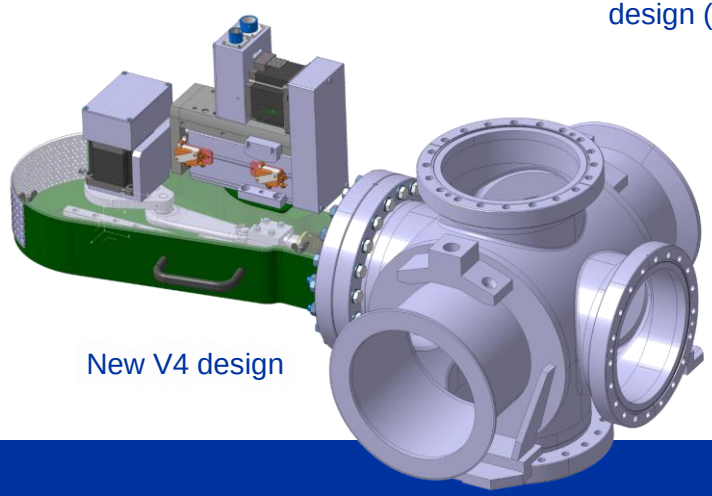
- Used to scrape transverse tails of the beam with horizontal and vertical movement cycle
- Historic design with minor upgrades through V1-V3
- Recurring step losses in stepper motors in early 2023
- Mechanisms are at the mechanical limits with some wear issues but no major damage
- Post-mortem highlighted challenging operational conditions for both mechanics and control
- Cause is still not clear, and investigations are ongoing with BE-CEM during YETS 2023/24
- But no showstoppers foreseen for 2024 operation
- Spares with minor upgrades are prepared if necessary
- Re-designed next generation V4 device being developed for installation in YETS 2024/25 or LS3



V1 (historic) – BA5

V2 (LS1) – BA1

V3 – ALARA design (2018)

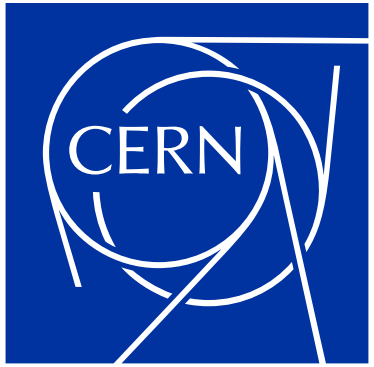


New V4 design

Particular thanks to Edouard Grenier-Boley

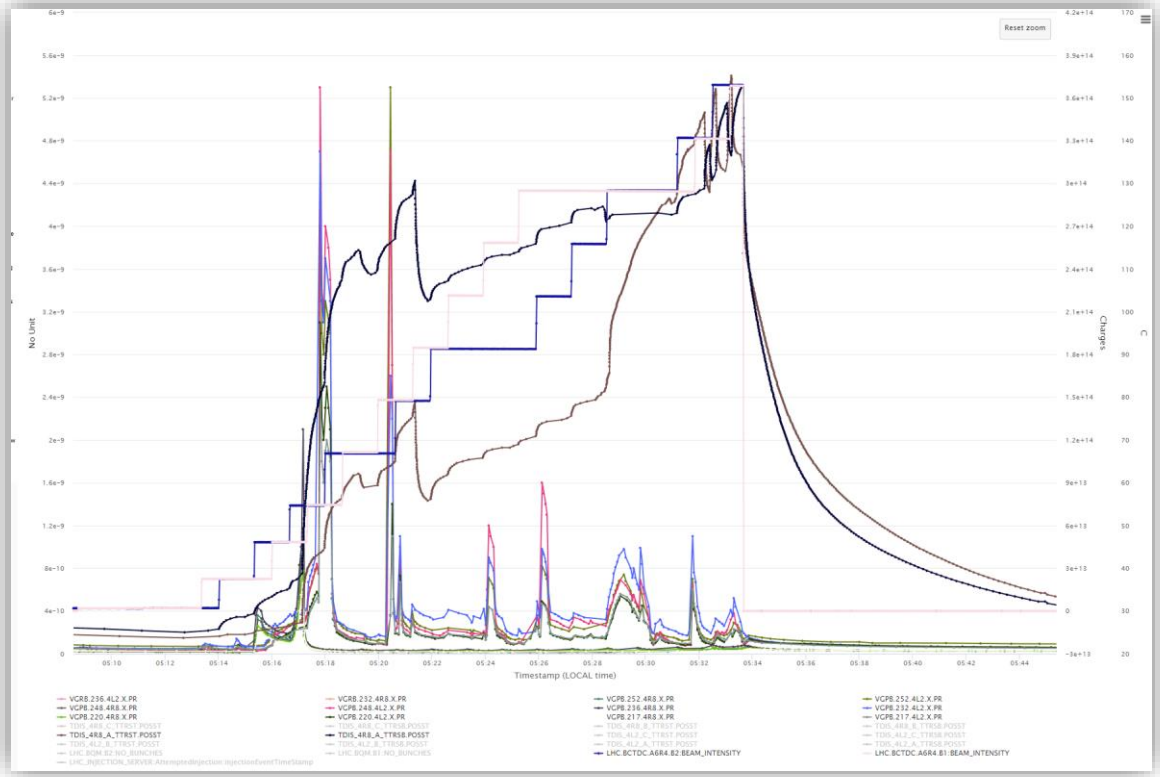
Summary

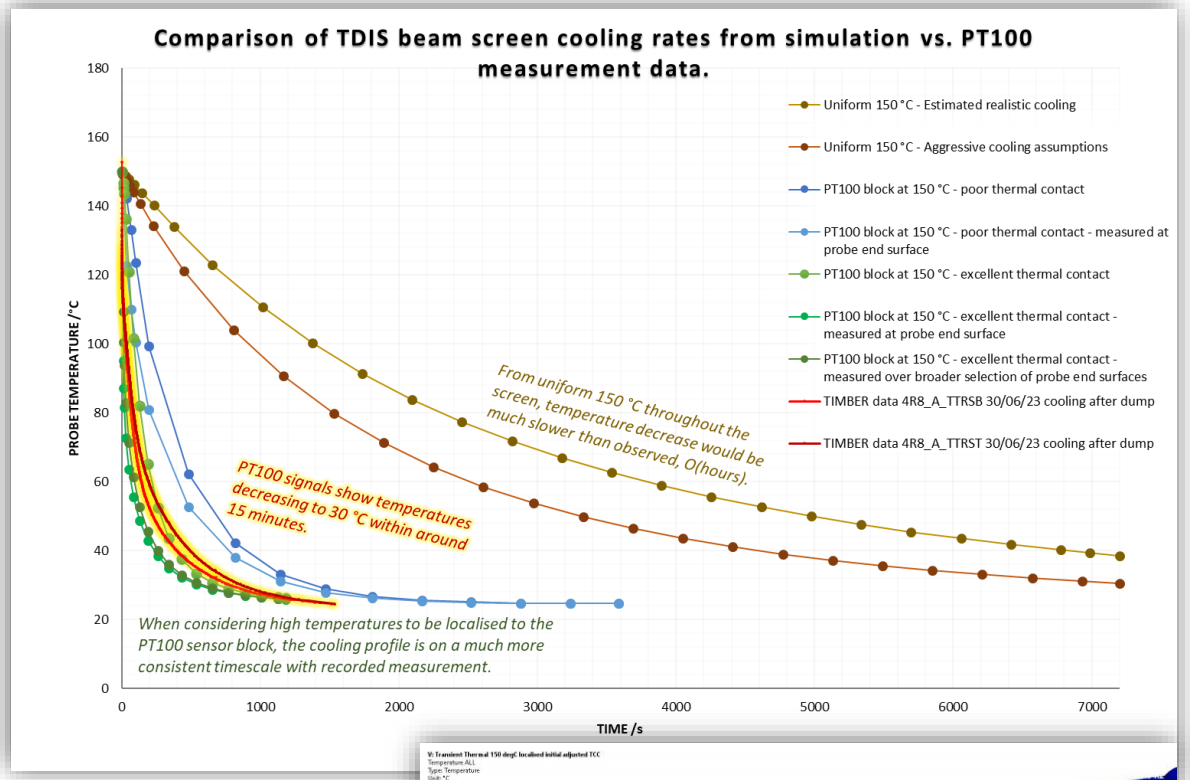
TDIS	➢ **Unnecessary jaw movement cycles to be avoided to minimise bellows risk.** ➢ **150 °C RF screen temperature interlock should remain while investigations are ongoing and at least until spares are available in summer 2024; filling implications TBD.**
TDE	➢ **Operational spares are ready.** ➢ **No operational limitations foreseen for Run 3 operation.**
TCPC	➢ **Movement problem was an isolated event; no issues foreseen in 2024.** ➢ **Ion channelling angle drift under investigation**
TCDS	➢ **No change to bunch intensity limitations; okay for 1.8×10^{11} p/bunch BCMS & hybrids.**
SPS Scraper	➢ **Movement issue mechanics and control under further investigation.** ➢ **Situation is improved, spares are prepared, and full re-design is in progress.**

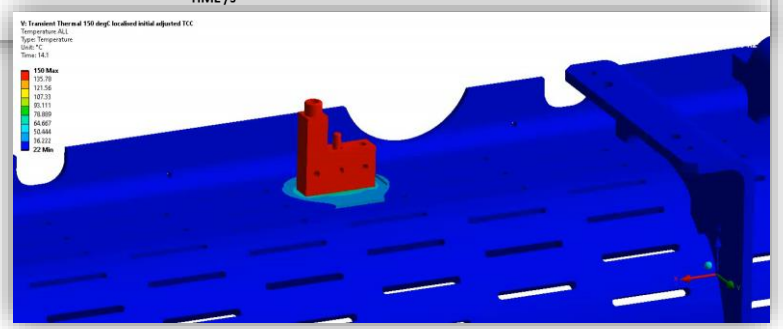


home.cern

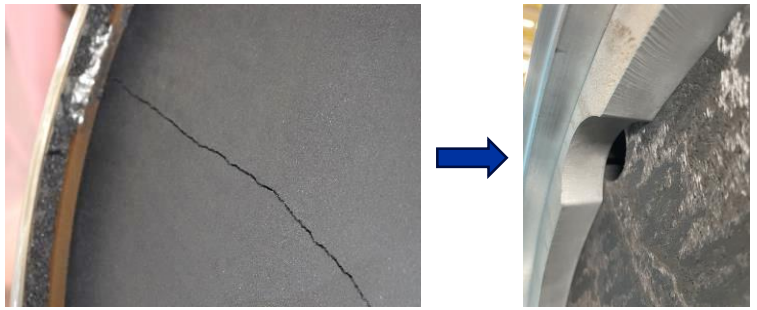
LHC-TDIS: RF screen temperatures



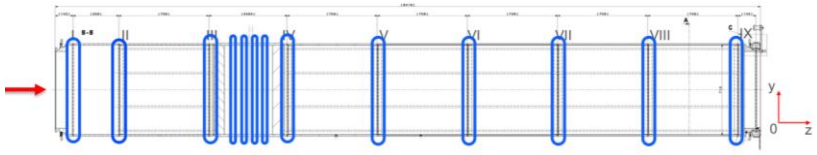




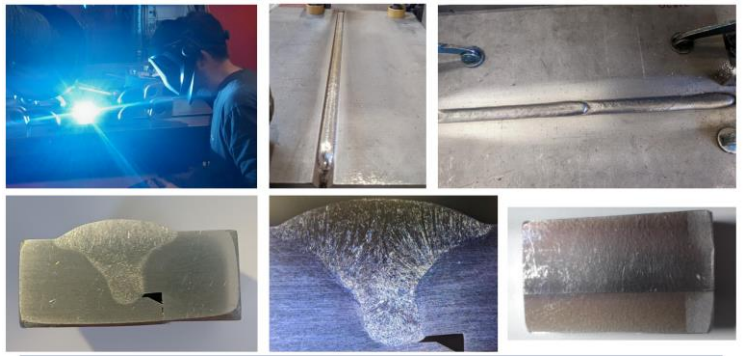
LHC-TDE – Run 3 spare readiness



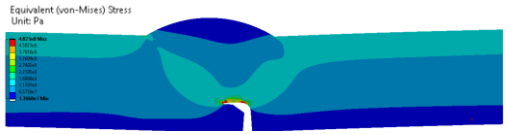
- Design Approach → Carbon copy of operational dumps with minor upgrades:
  - **Increased reliability**
    - + Integration of lessons learnt from RUN 2 TDE Autopsy
    - + Upgrade to advanced Carbon-Fibre-Composites for better resistance to crack initiation and propagation
    - + Improved retaining ring design



  - **In-depth weld assessment:**
    - + Increase in weld penetration depth for increased fatigue resistance
    - + Weld standardisation → only circumferential welds
    - + In-depth weld qualification for current and upgraded weld design



  - **Design optimised for dismantling**
    - + Easier disassembly in case of use
    - + Easier material recovery in case they are not employed



In collaboration with EN-MME

LHC-TDE Cooling limitations

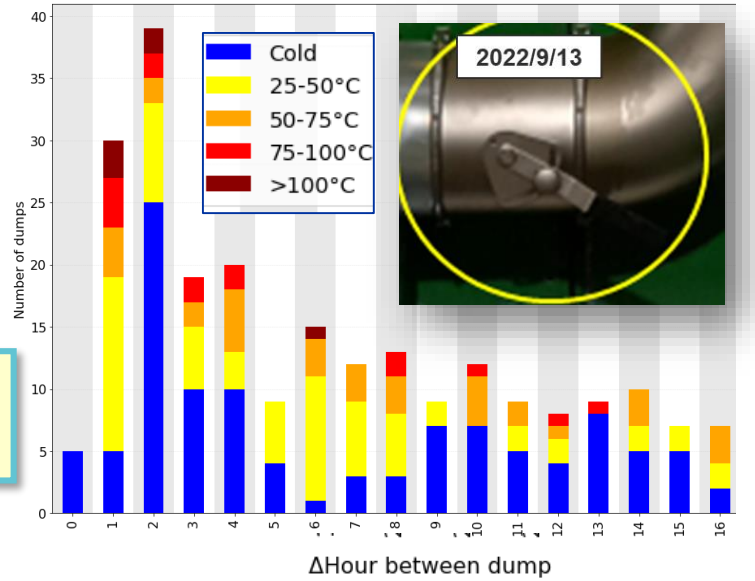
Presented at LMC#470

- **Concerns** raised during **2022** in **UD68**, where cooling back to room temperature was taking longer than expected (> 8h), leading to **temperature build-up under closely-spaced consecutive dumps**.
- ✓ **Issue found during TS in 2022.** → **Duct valve partially closed** → **Solved**

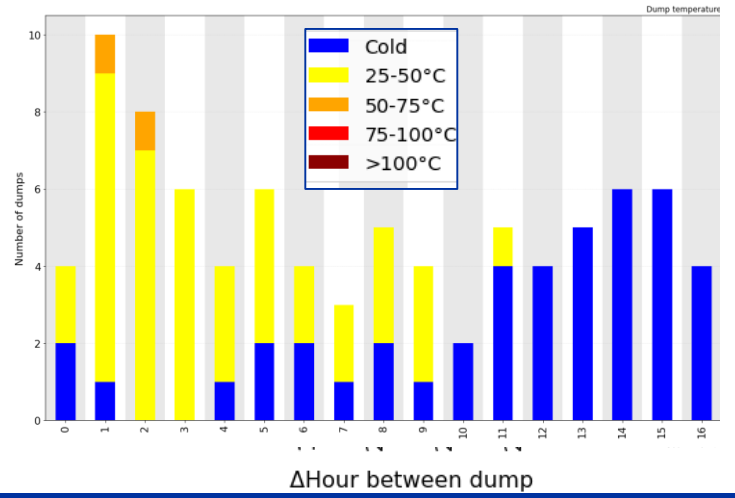
Yet, question persists: What (if-any) operational scenario will be bound by cooling limitations of the dumps?

- ➢ **Limitations** are defined by setting a *material and/or thermo-mechanical criteria x safety coefficient*
  - E.g. Material mechanical limit (such as yield, UTS, fatigue, etc), or maximum acceptable operational temperature
  - **Vessel Duplex steel**, between 280 and 450°C is subjected to thermal ageing embrittlement → **~250 °C limit (directly probed with the sensors)**
- ➢ **Estimation of operational conditions via different methods:**
  - Regression directly from the operational data (present case)
  - NN and/or Physics Informed-NN (work in progress)
  - Thermo-mechanical (FEM & CFD) calibrated with operational data (work in progress)

UD68 in 2022: Inefficient cooling very noticeable



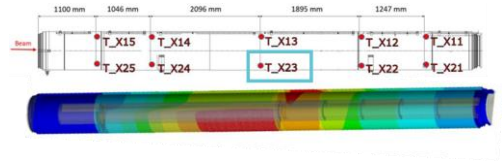
UD68 in 2023: <10 hours cool-down, dump not fully cooled. However acceptable temperature.

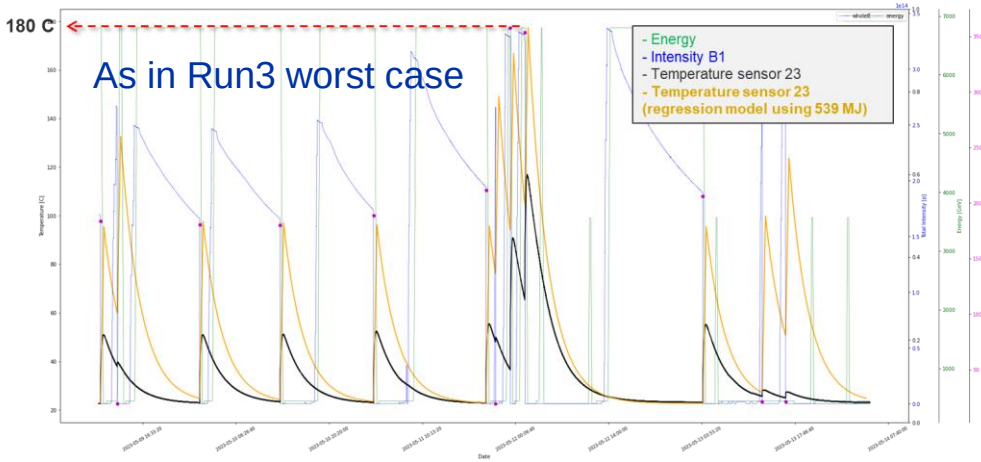


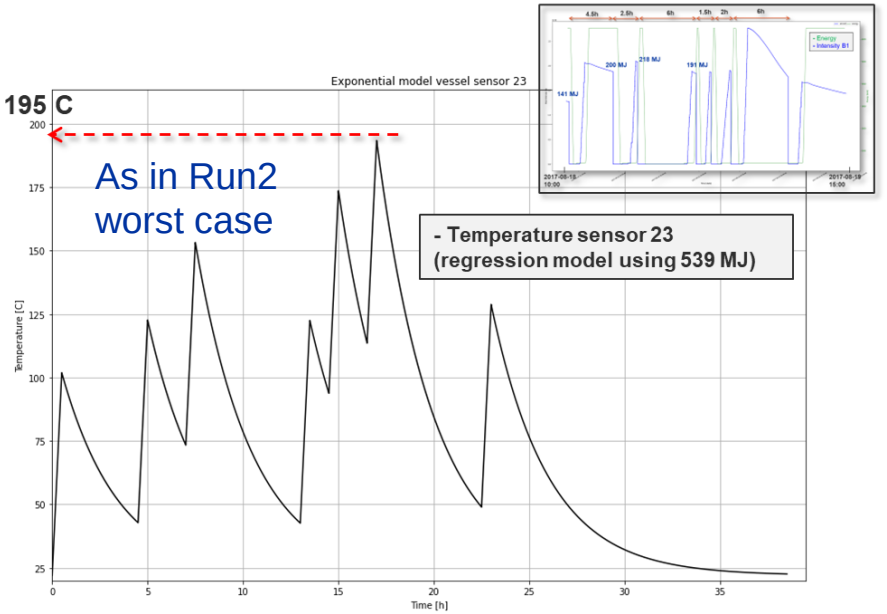
LHC-TDE Cooling limitations

Regression directly from the operational data

- **What would happen with Run 3 and Run 2 worst examples at Run 3 nominal conditions ?** → Temperature below limit
- **How many dumps at maximum intensity and shortest dump intervals can we accept ?** → 2 to 3 dump events at run 3 nominal conditions, spaced <1h
- **What is the acceptable intensity to dump continuously at the shortest dump intervals ?** → Around 140 MJ, considering 45 minutes between dump triggers. But dumps will have a high temperature “steady-state”
- **What is the acceptable shortest dump intervals to dump continuously at Run 3 maximum intensity?** → 4-6 hours should be acceptable (preliminary!) but dumps will have a high temperature “steady-state”

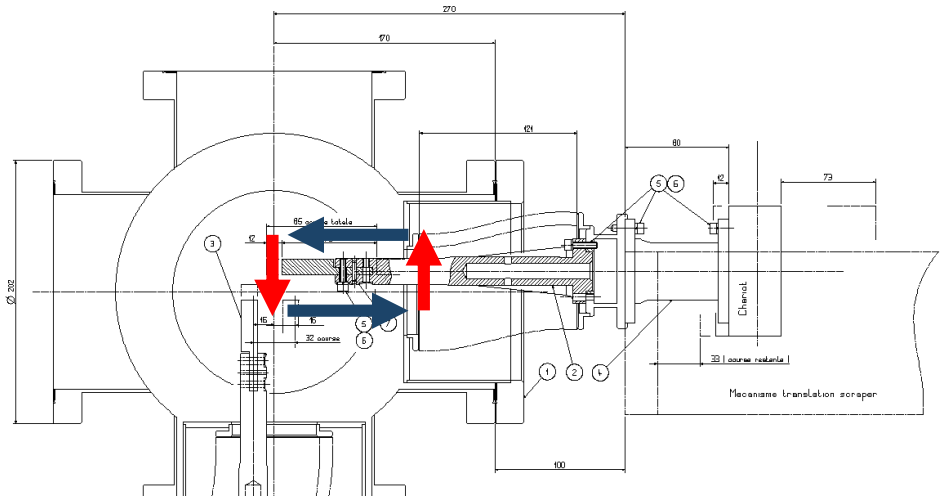






Actual and historic Scraper system

- Scraper is used to cut the tail of the beam to obtain a clean beam for LHC injections:
- It has 2 motorizations, (horizontal and vertical) 1 for vertical scraping.
- Each motorization has a “slow axe (45mm/s)” for scraping position and a “fast axe (80mm/s)” for scraping.



V1 (historic) – BA5

V2 (LS1) – BA1

V3 – ALARA design (2018)

- Historic design for **beam instrumentation** from ISR (pre-history…).
- Minor design upgrade executed between V1 to V3
- Mechanism never redesigned for the real cycling use. No data on initial number of cycling.
- Some motorization changed with spare due to mechanical failures during 2015 and 2018.

Challenge and future V4 scraper

During 2023 operation recurrent step lost are observed on slow axes (Both scraper). **Around 2 mm offset error after 40 scraper cycles.**

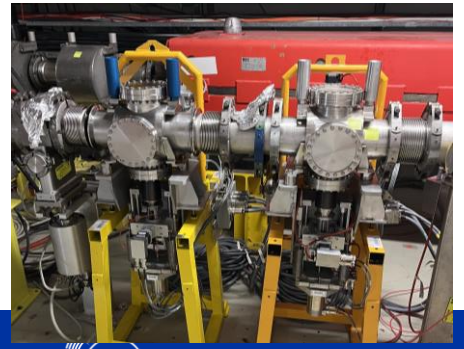
Small improvement by changing spring return and modification of the control cycle (speed and position).

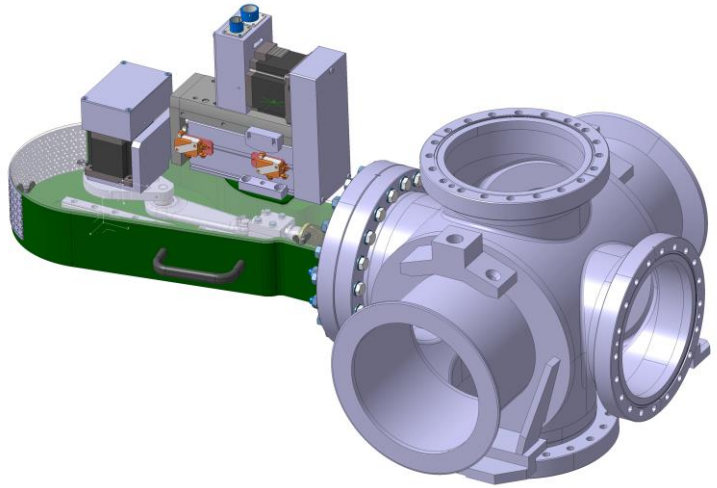
Exchange of the BSHV.11771 during TS1 that present also I high risk of vacuum leak.

After TS1 come back to normal operation

After post-mortem analysis no damage clearly shown why step loses occurred in the beginning of 2023 operation. And also, from control system.

-> Some expertise will be done during YETS 23-24





New design base on new functional specification. (EDMS SPS-BSHV-ES-0001)

Functional analysis done by STI to correctly establish the need. (EDMS 2757827)

New prototype design based on scraping cycle of 100ms and 2,000,000 cycles (instead of actual 1.2 sec and 100,000cycles)

Particular thanks to Edouard Grenier-Boley