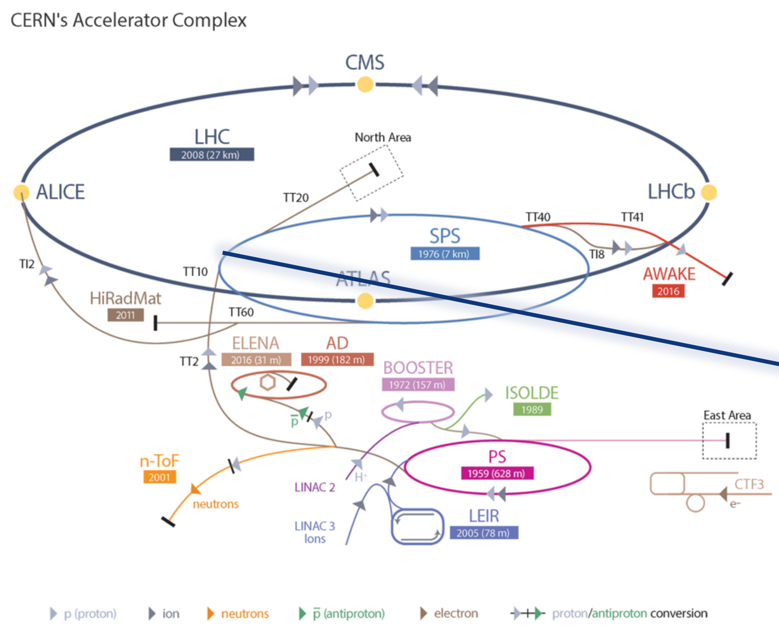
Design, Material Selection and Operational Feedback for the New Design of the High Energy Beam Dump in the CERN SPS

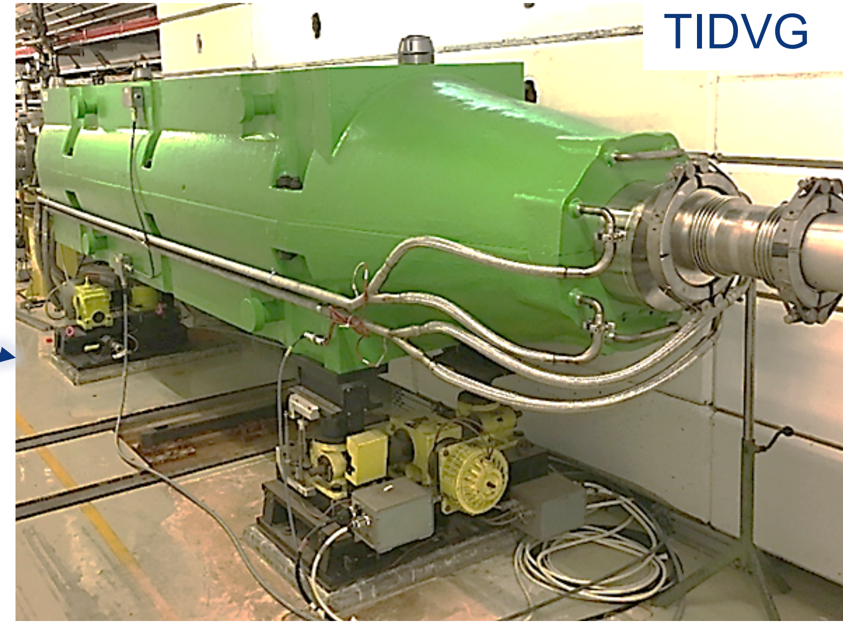
P. Rios-Rodriguez, A. Perillo-Marcone
M. Calviani (CERN)

CERN | EN ENGINEERING DEPARTMENT

Contents

Introduction of the SPS beam dump



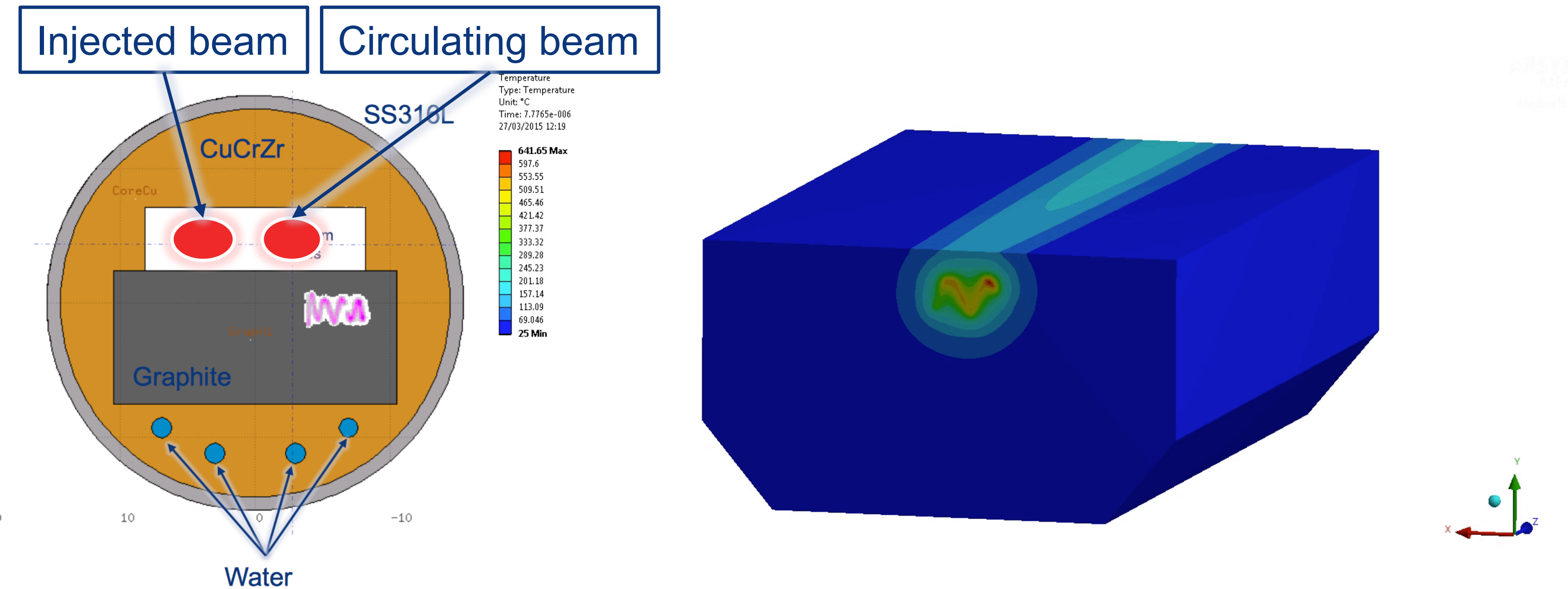


Two beam dumps in the SPS:

- **TIDH** (Target Internal Dump Horizontal): <28 GeV
- **TIDVG** (Target Internal Dump Vertical Graphite): >105 GeV
  - Total length 4.3 m, 30 cm core diameter
  - Internal dump (in UHV)

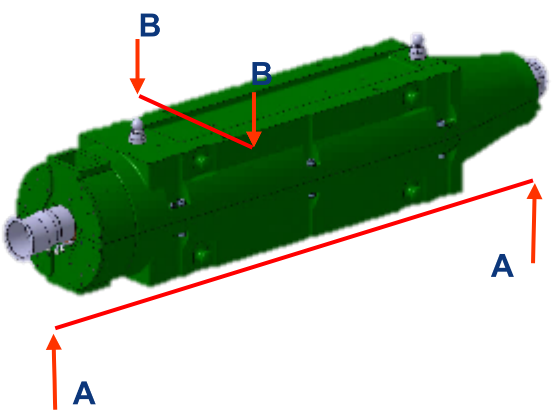
Beam dilution on dump

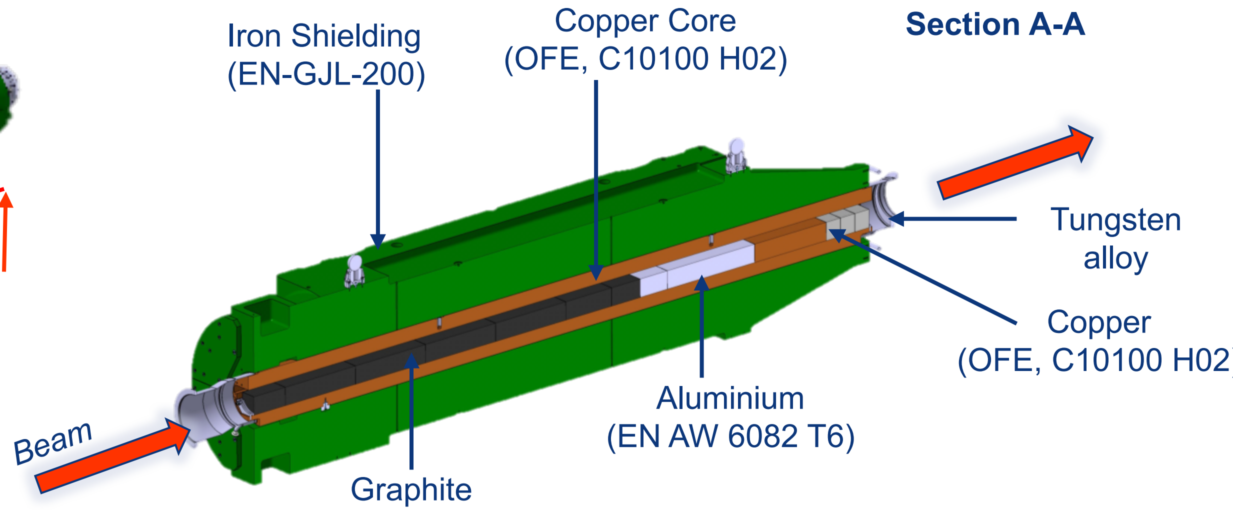
- In order to avoid damaging the dump material, the beam is diluted during ~7.2 μs with dilution/extraction kickers
- Asymmetry in the energy deposition in the dump induced by the position of the dump with respect to the injected beam

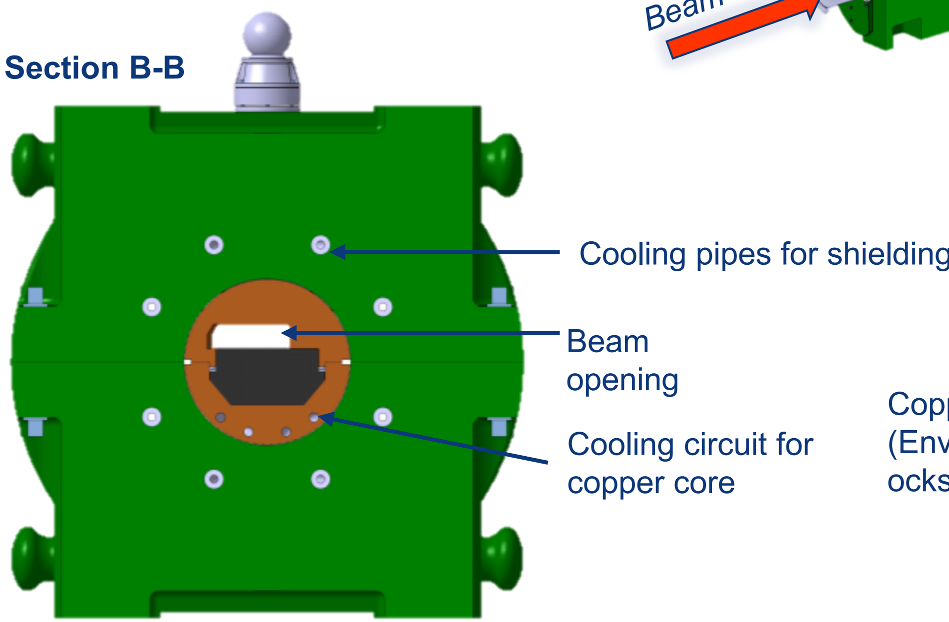


Previous SPS beam dump - TIDVG#3

Operating during 2014-2016





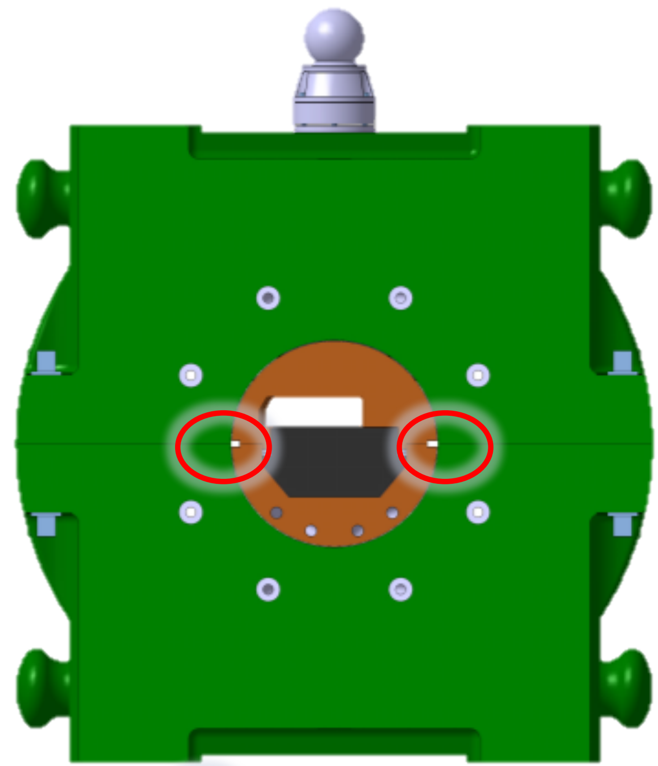


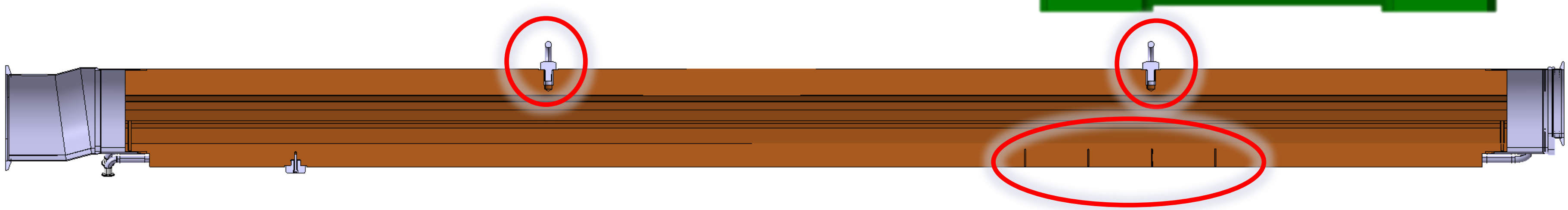
Background for TIDVG#3 inspection

- Leak in the TIDVG sector appeared on April 25th 2016 after a series of dumps at high energy
- Helium spray vacuum leak tests in the tunnel indicated leak in the core inside outer shielding
- Slow increase of vacuum pressure over the rest of the year (10^{-8} mbar → 10^{-6} mbar)
- Replaced with TIDVG#4 before 2017 run
- TIDVG#3 stored in bunker
- Post mortem inspection recommended from beginning of crisis project

Aim of post mortem investigations

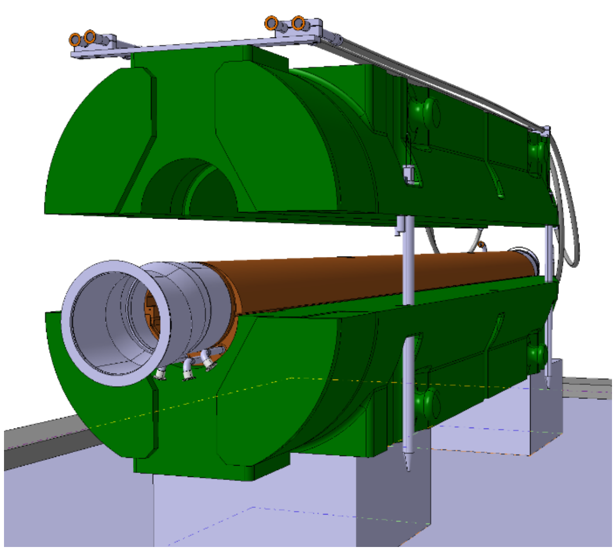
- In general - learn from this failure to improve future designs
- Confirm source of vacuum leak – 3 main possibilities:
  - Core longitudinal electron beam welds
  - Lift point holes at top of core
  - Thermocouple holes at bottom of the core

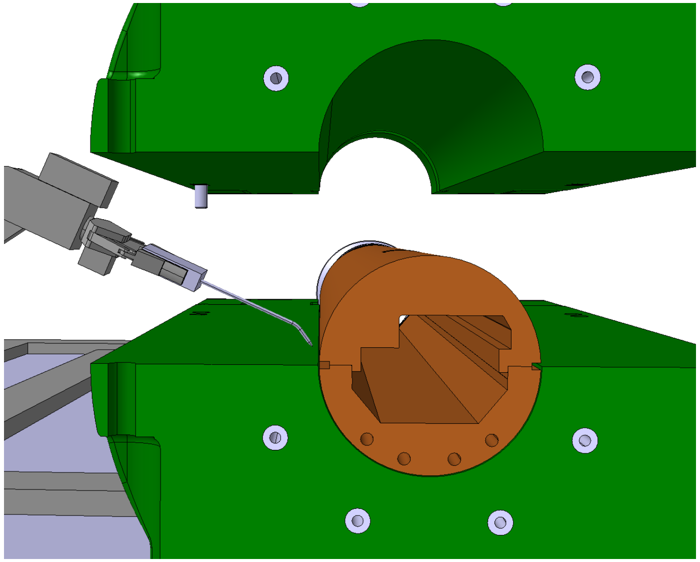




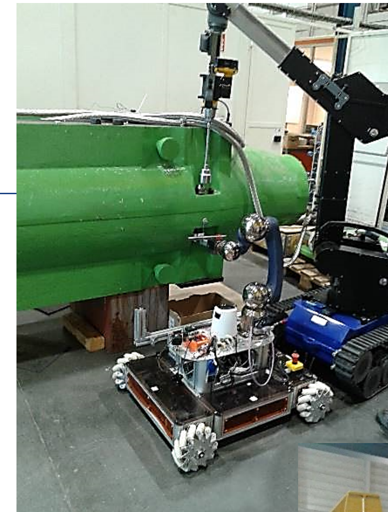
Inspection method

- Remote handling needed as dose rates expected of several tens mSv/h with shielding open
- Initially considered removing core from shielding to inspect whole surface
- However, to simplify handling and reduce risks – lift upper shielding only to access top half of core and longitudinal welds

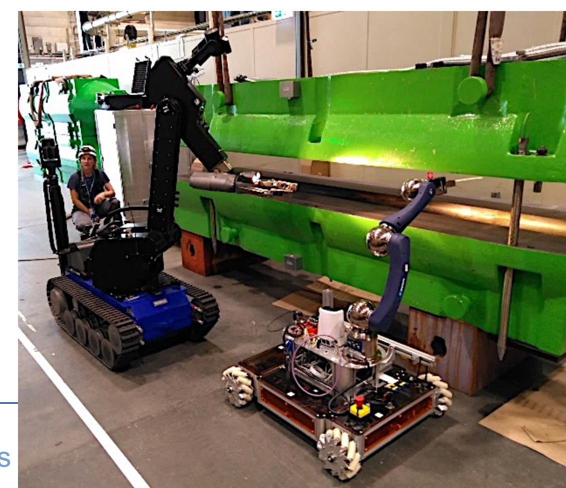




Preparation

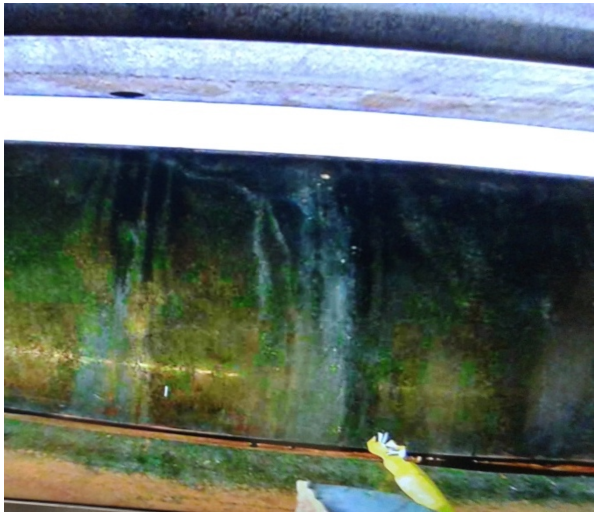


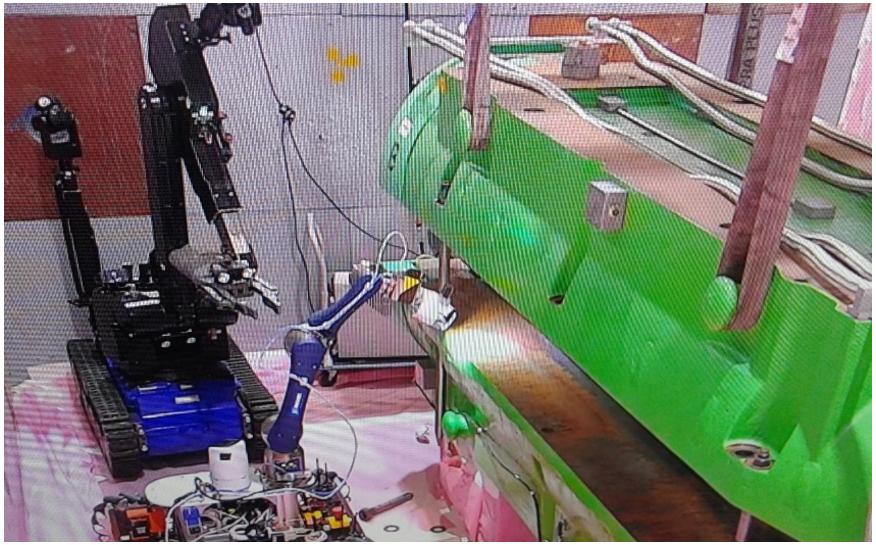
- CATIA sequence to check feasibility and organize with teams
- Prepare work dose planning (consider recovery from problems)
- Mock-up trials on identical shielding to develop techniques for key tasks using mobile robots and crane:
  - Lifting mobile robots
  - Undoing shielding bolts (six M36 threaded bars with nuts)
  - Lifting upper shielding
  - Vacuum leak testing
  - Replacing shielding bolts



Inspection operation

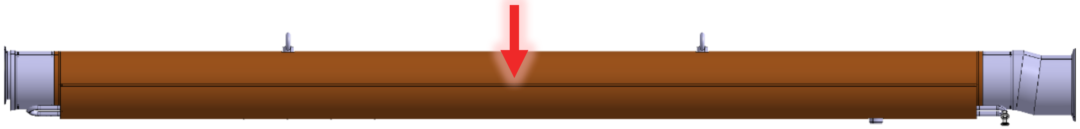
- Operations went well
- Personnel radiation doses less than estimate (102 μSv vs 180 μSv)
- Leak testing was able to identify leak points
- Visual inspection showed weld condition
- Note: shielding opened 3x (1x in WDP)



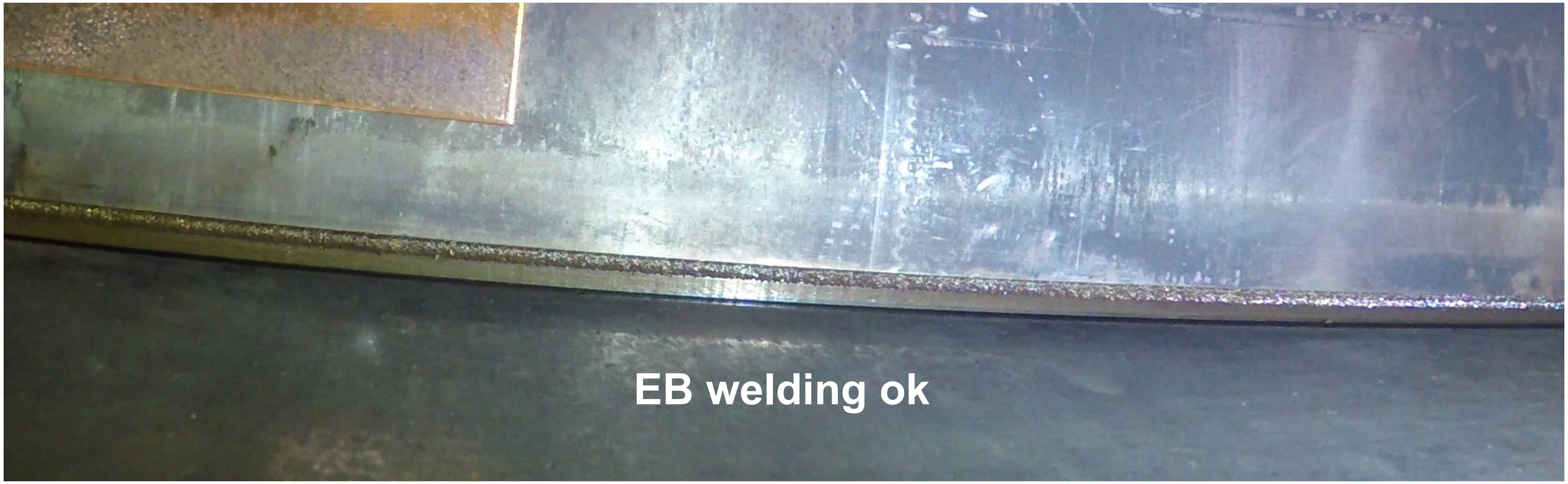


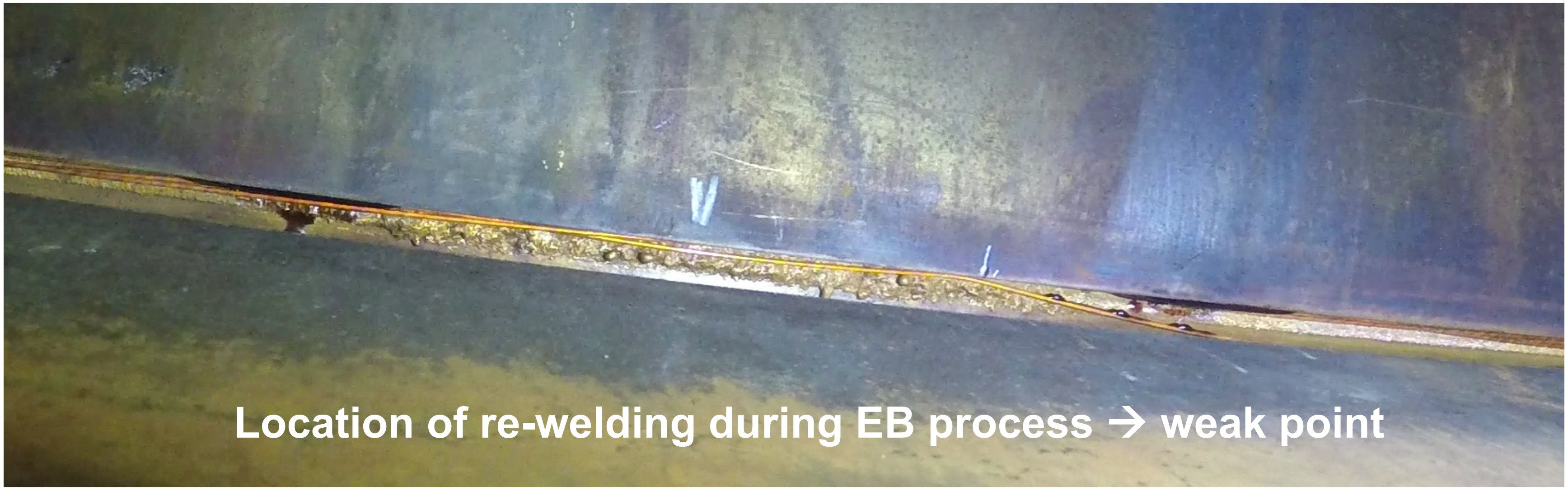
Findings

- Vacuum leaks were present on both longitudinal welds around half way the core
- The electron beam welds in the areas where leaks were found showed evidence of re-work
- Situation worsened by the fatigue (dump bending)



Visual inspection – weld close ups



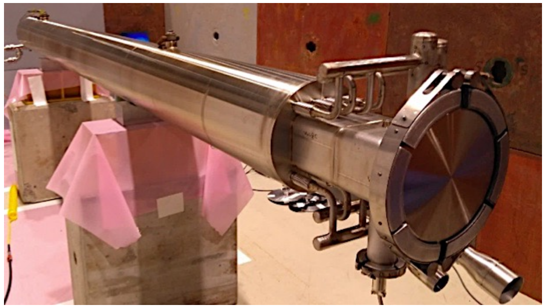


Inspection conclusions

For the TIDVG:

- Longitudinal electron beam welds along the core were identified as the source of the leak
- Positions of the leaks correspond to the areas of some of the weld re-work and the highest tensile stresses

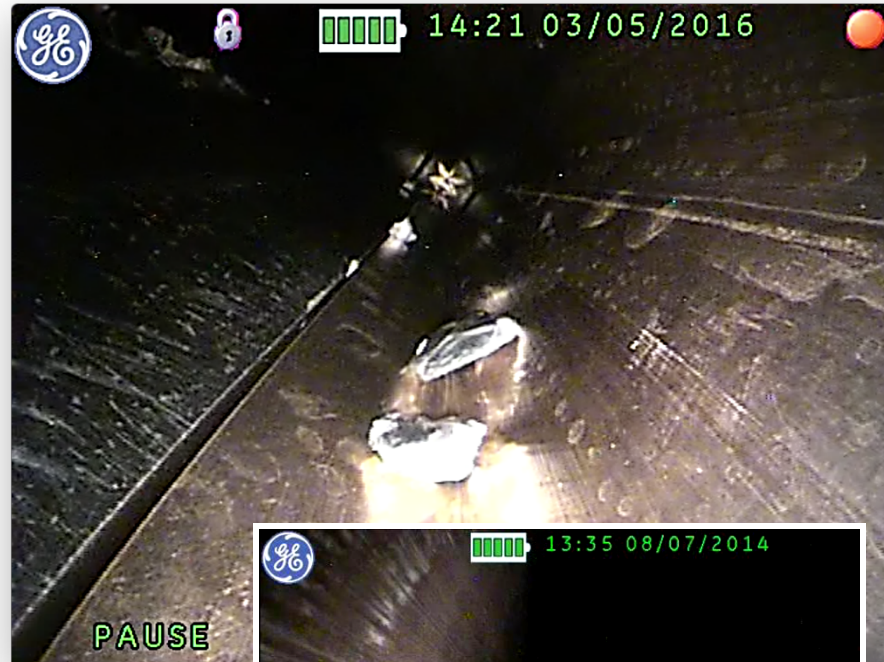
The new TIDVG#4 and #5 use a seamless stainless steel tube to avoid these welds!



For the remote investigation:

- Mock-up work ensured full development of operating methods, tools, hardware and efficient collaboration between different teams
- Remote vacuum leak testing allowed leaks to be pinpointed
- Remote visual inspection identified areas of weld re-work
- Careful operation and reliability of commercial and in-house robots ensured no major problems with remote operations

Ex. what happened to a previous TIDVG#2



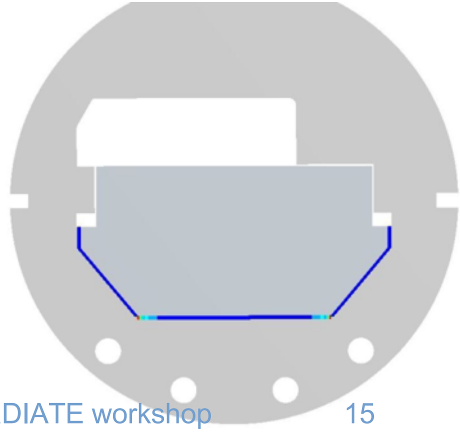
- Molten Al due to beam impact
- Affected area much larger than beam size
- Culprit was the thermal contact conductance between Al and the heat sink

History of the SPS beam dump

Device	Modifications/Experience	Date
TIDVG 1	Molten Al + Ti (outgassing!)	2000-2004
TIDVG 2	Molten Al (outgassing!)	2006-2013
TIDVG 3	Longer Gr (+200 mm), shorter Al Vacuum leak in April 2016- NO SPARE!	2014-2016

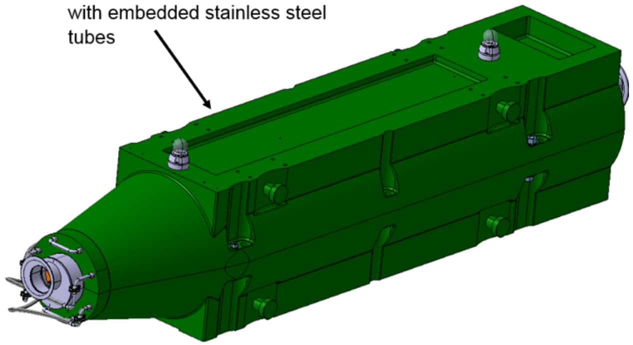
- After the vacuum leak in April 2016:
- **New design** → **TIDVG#4** for 2017-2018 operation (previous design: extremely long manufacturing times)

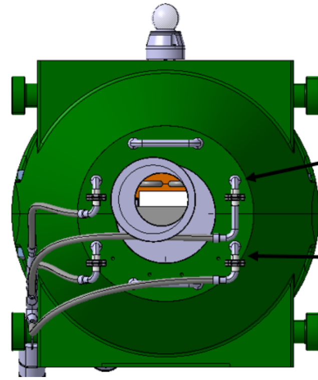
- Weak points of TIDVG1, 2 and 3:
  - High outgassing rates
  - No proper bake-out possibilities after installation
  - No internal instrumentation
  - High uncertainty of cooling efficiency

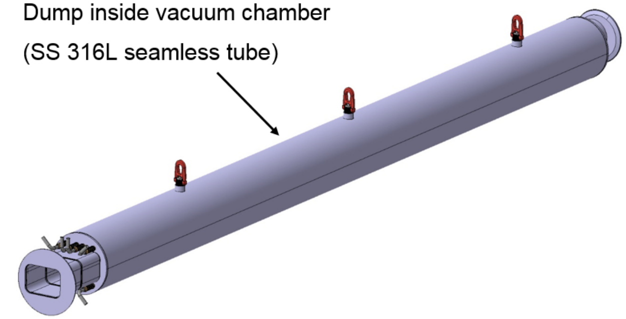


Current SPS beam dump – TIDVG#4

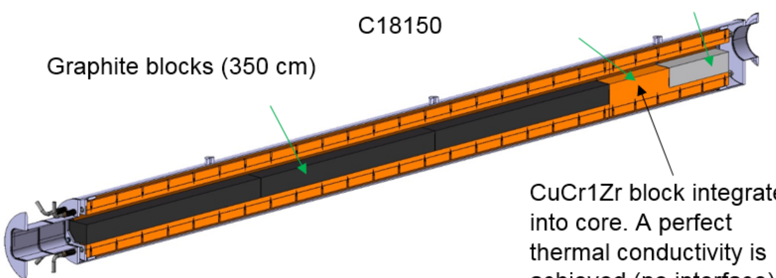
Installation during EYETS 2017 (March)



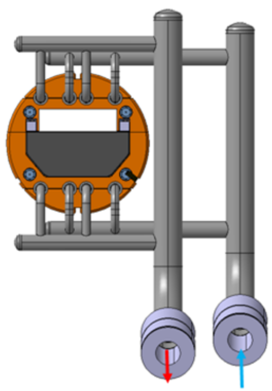


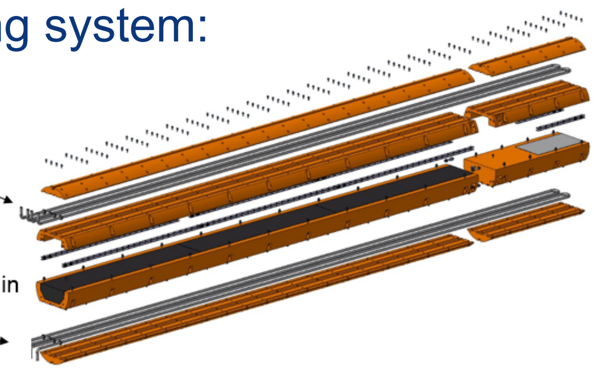


Absorbing blocks



Copper core cooling system:





- Limited time window:
  - Faster manufacturer, COTS materials
  - Use of known technologies. No R&D
  - 0.2 MPa (27 kN/m)

- T sensors on all the parts (18 in total)
- T sensors for the water +1 flow meter
- Copper core made of CuCrZr

Material selection for TIDVG#4

- General material requirements for the SPS beam dump design:
  - **Good thermal and mechanical properties**
    - High power to be dissipated and high stresses due to the beam impact
  - Materials available in needed quantities, sizes and easy to machine + delivery
  - **UHV compatibility** including avoid all welds
  - **Avoid Al** (molten in previous design)

Component	CERN specifications	Additional treatments applied
Graphite	Homogeneity Isotropic properties Grade with low E and high tensile strength	Degreased Purified in Ar @ T>2000^{o}C Vacuum fired @ 950^{o}C at CERN
Tungsten alloy	Homogeneity	Degreased at CERN Vacuum fired @ 950^{o}C at CERN
CuCrZr	Homogeneity / 3D forged	Degreased at CERN
Tube for vacuum chamber	Homogeneity + small grain size 3D forged 316L as per CERN spec. Seamless	Degreased at CERN

Current SPS beam dump – TIDVG#4

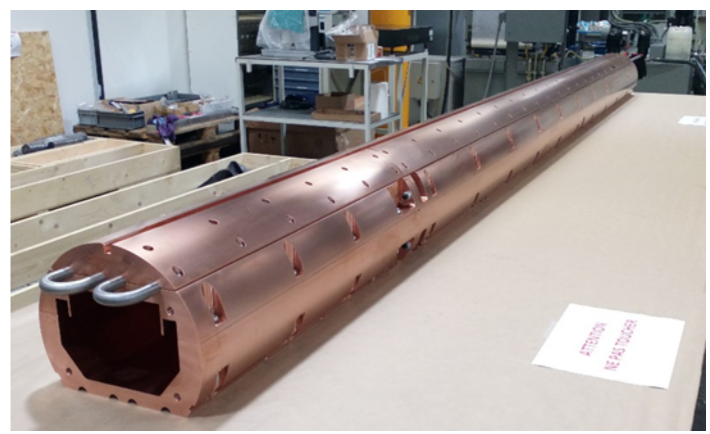
Forging of SS vacuum chamber

SS vacuum chamber

Vacuum firing of the Gr blocks

Tungsten alloy

CuCrZr core

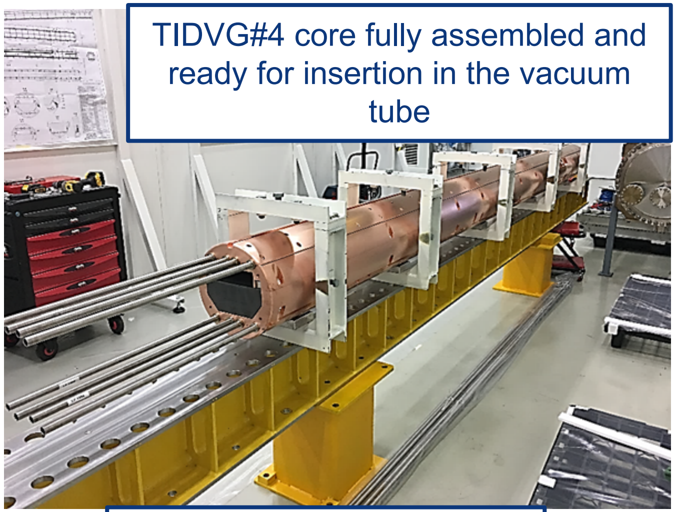


Current SPS beam dump – TIDVG#4

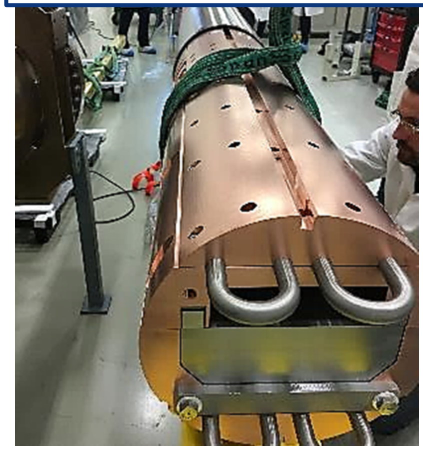
Graphite inside the CuCrZr core

Medium/high-Z absorber

TIDVG#4 core fully assembled and ready for insertion in the vacuum tube

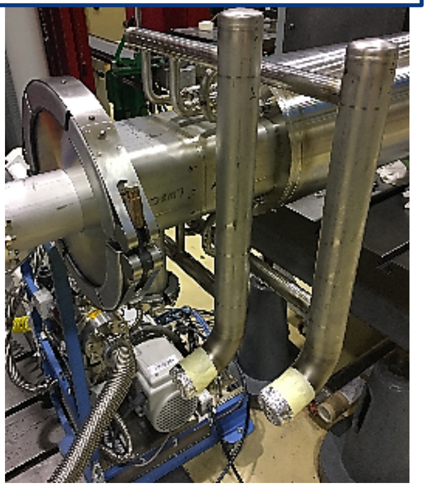


TIDVG#4 core being pulled into the vacuum chamber



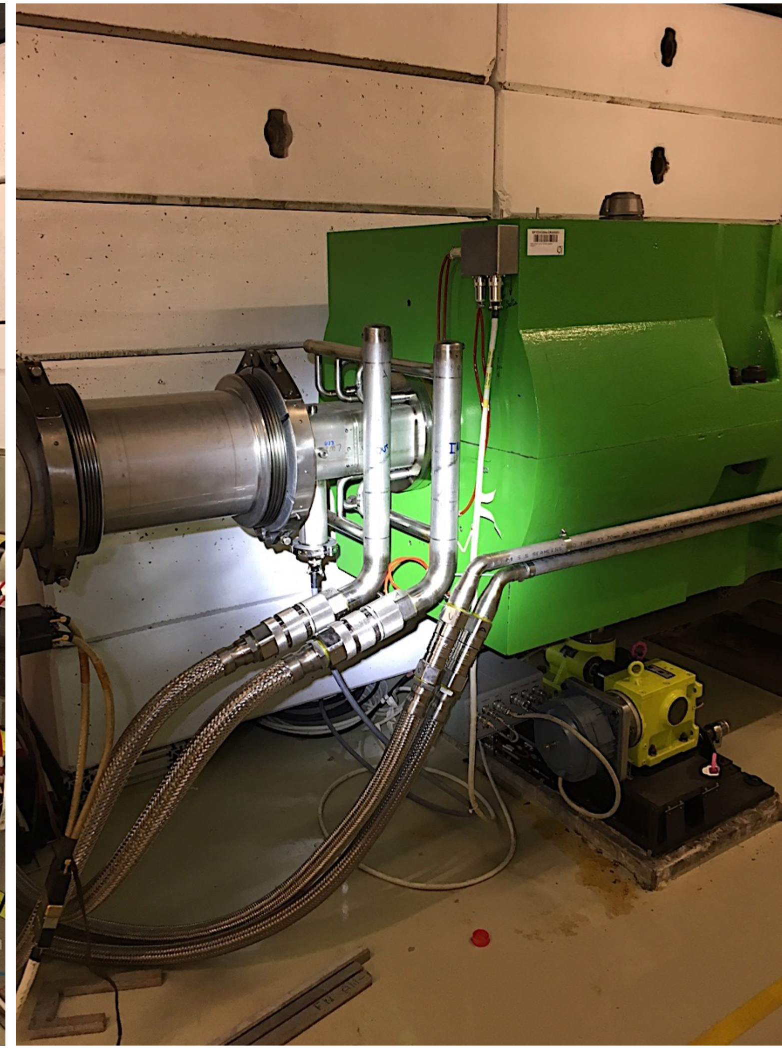
TIDVG#4 core fully inserted (upstream)

Final leak detection (upstream/ water manifolds)



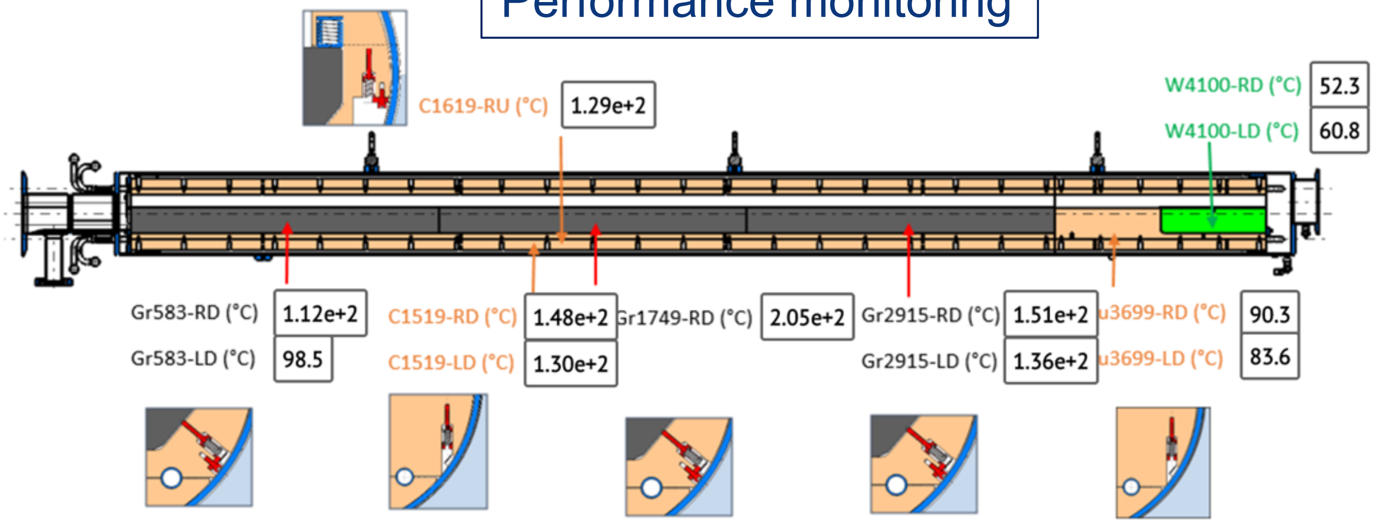
Current TIDVG#4 Installation

Installation during EYETS 2017 (March)



Operational feedback for TIDVG#4

Performance monitoring



P-VACUUM-VGHB11860 (mbar)	7.00e-8
P-VACUUM-VGHB11879 (mbar)	1.90e-7
P-VACUUM-VGHB11931 (mbar)	1.10e-8
P-VACUUM-VGHB11936 (mbar)	1.60e-9
P-VACUUM-VGHB11952 (mbar)	6.00e-9
P-VACUUM- VGHB11959 (mbar)	1.80e-8

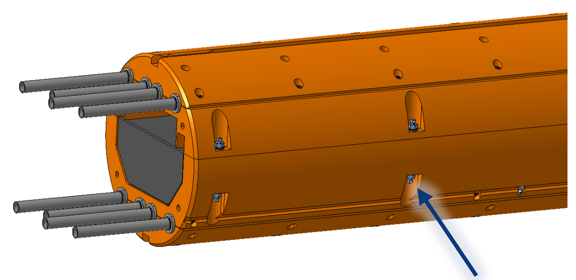
Beam intensity: 7.63e+11 charges

Beam energy: 4.00e+2 GeV

Average beam power over last 10 mins: 4.27e+1 kW

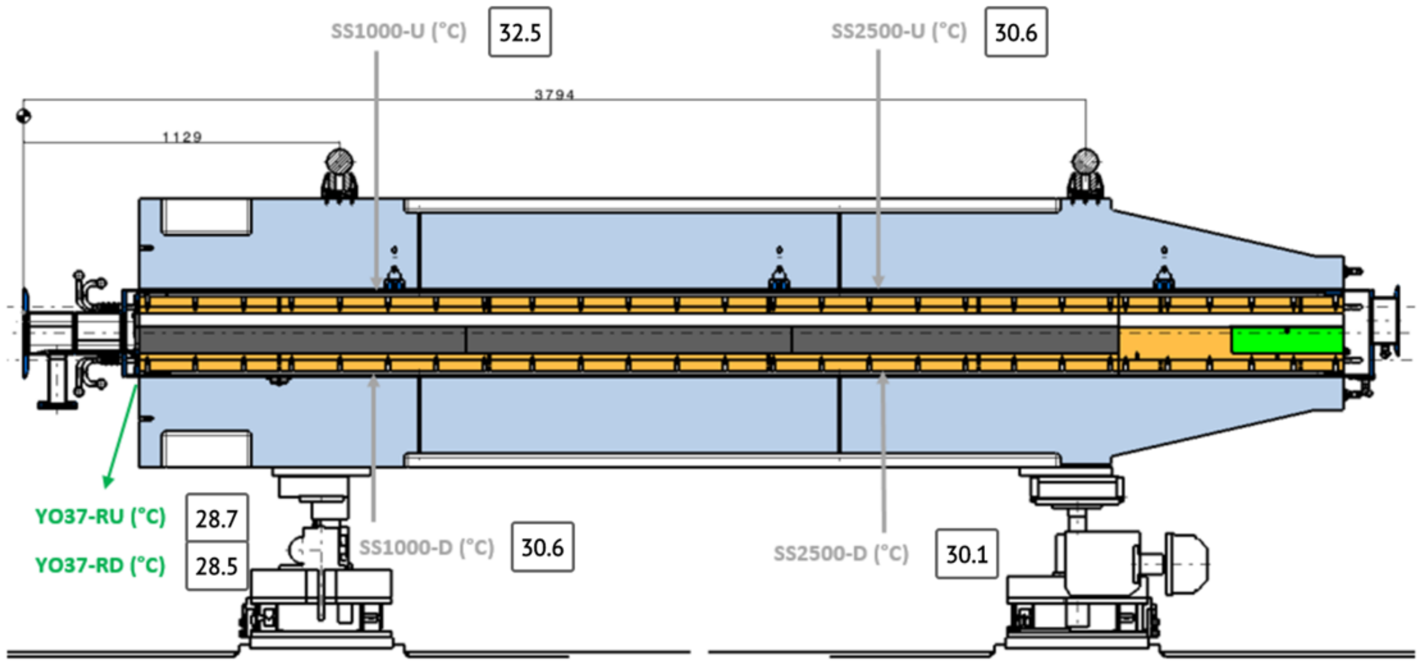
Average beam power over last 10 SC: 4.83e+1 kW

Average beam power over last hour: 1.88e+1 kW

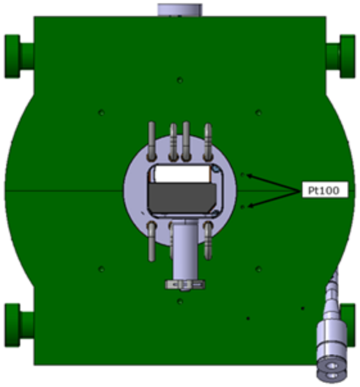


14 PT100 installed in the dump core
(2 PT100 were damaged during assembly)

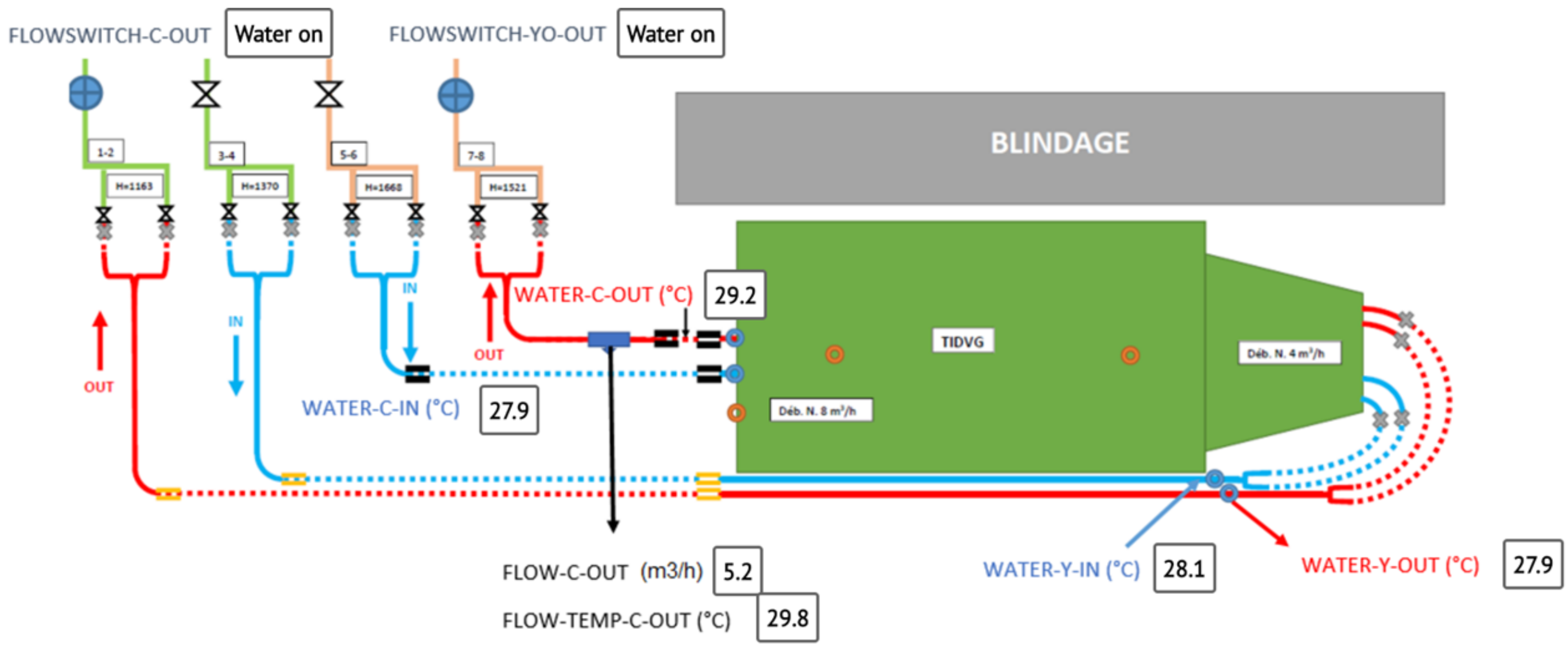
Operational feedback for TIDVG#4



4 PT100 on the SS vacuum chamber
2 PT100 on the shielding



Operational feedback for TIDVG#4



Sensors located in the water:

- 2 flow-switches
- 4 PT100 in the water
- 1 water flow sensor (water flow and outlet T)

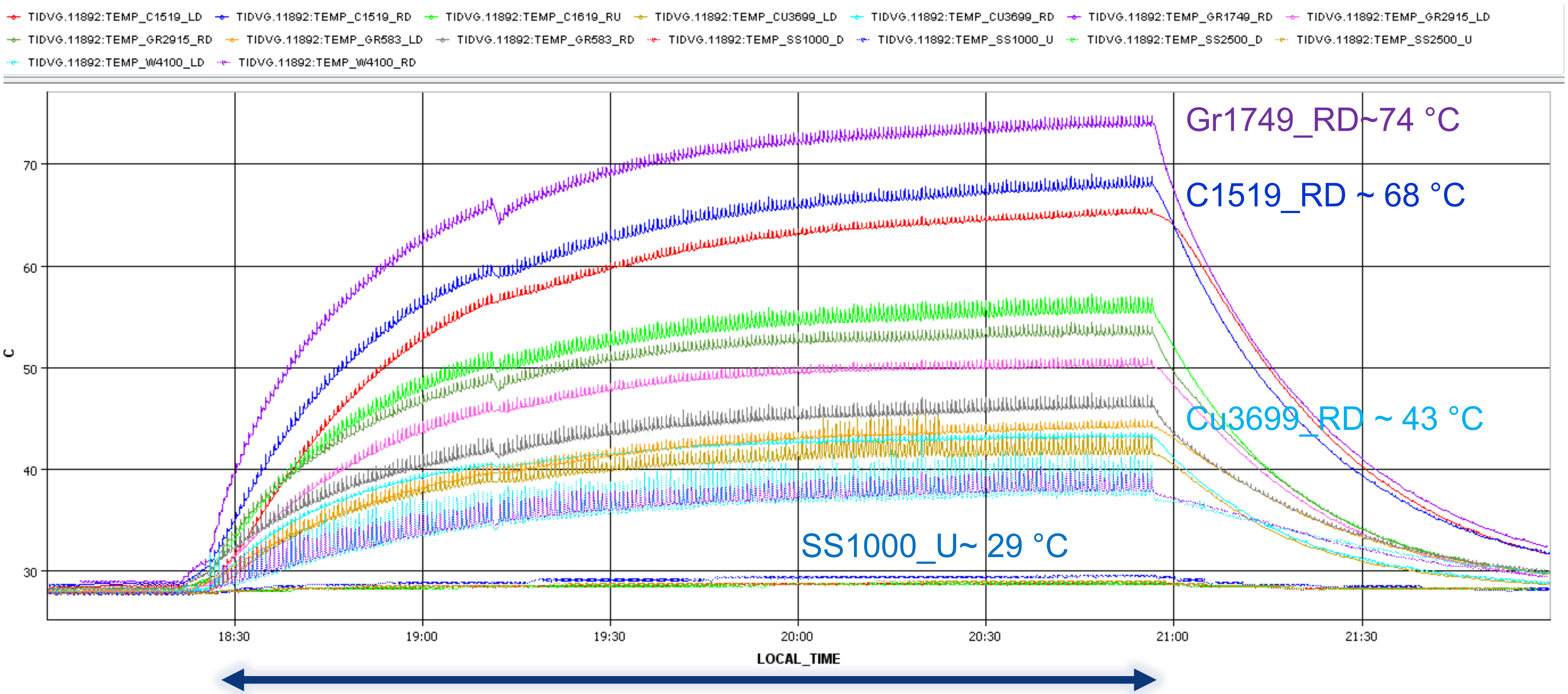
Operational feedback for TIDVG#4

Beam Type	p GeV/c	Bunch Intensity (protons)	# Bunches	Total Intensity (protons)	Continuous beam dump	Average power (kW)
LHC	440	$1.10*10^{11}$	48	$5.3*10^{12}$	2h30	9
LHC	440	$1.25*10^{11}$	72	$9.0*10^{12}$	4h00	16
LHC	440	$1.10*10^{11}$	144	$1.6*10^{13}$	3h00	27
LHC	440	$1.10*10^{11}$	288	$3.2*10^{13}$	1h30	55

- Dedicated **commissioning beams** have been requested in order to validate the performances of the dump (cross-check with simulations) as well as to condition the graphite
- TIDVG4 is designed for continuous deposited power of **~60 kW**

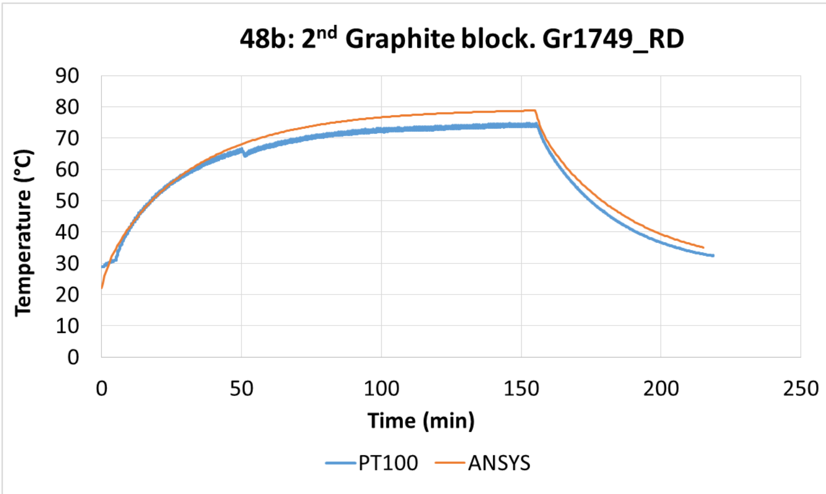
Operational feedback for TIDVG#4

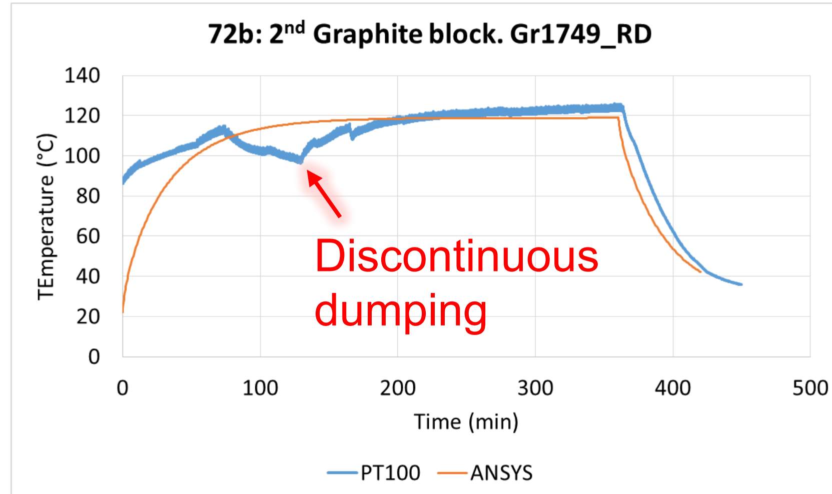
Behavior under 48b beam

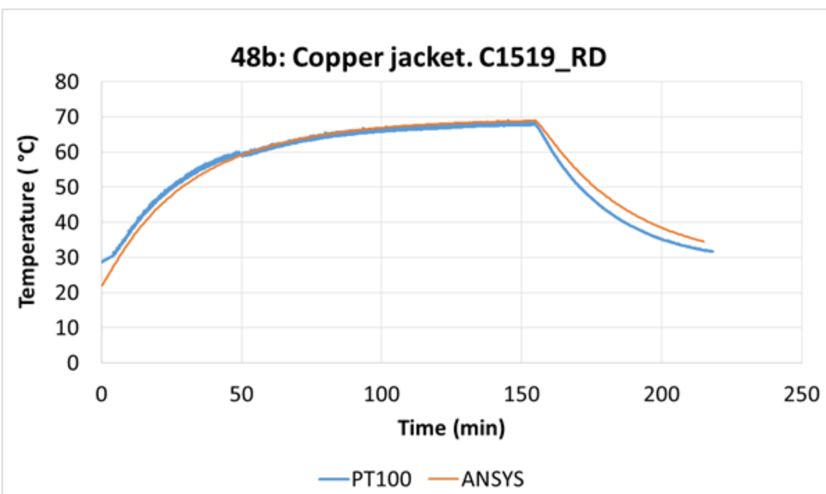


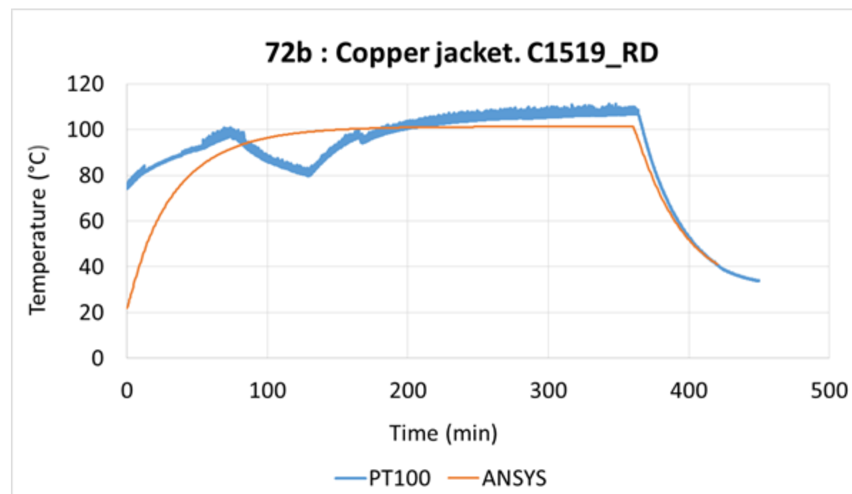
2h30 hours of continuous dumping

Operational feedback for TIDVG#4

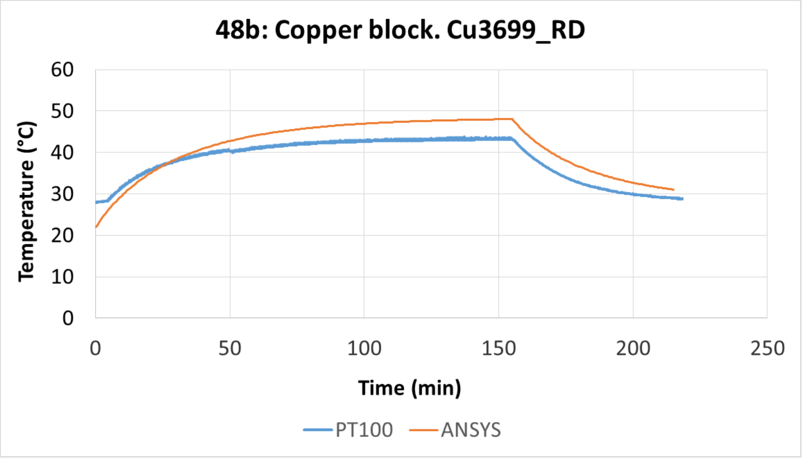


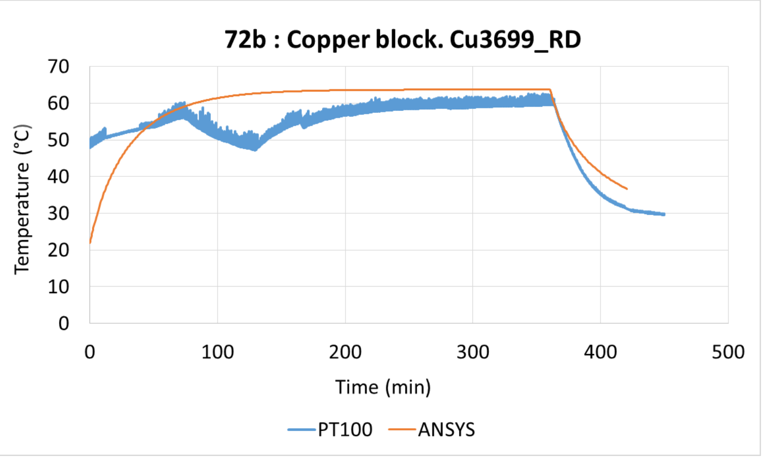




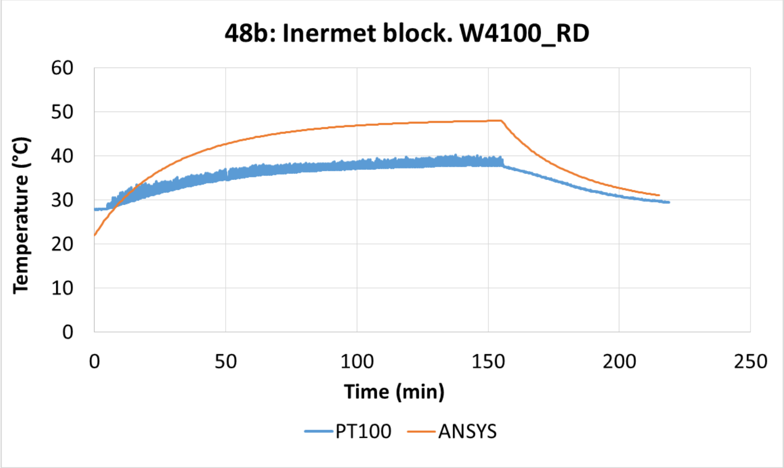


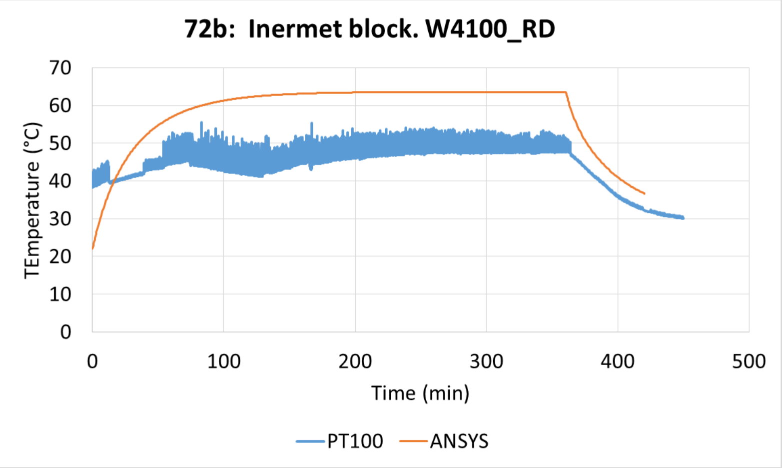
Operational feedback for TIDVG#4





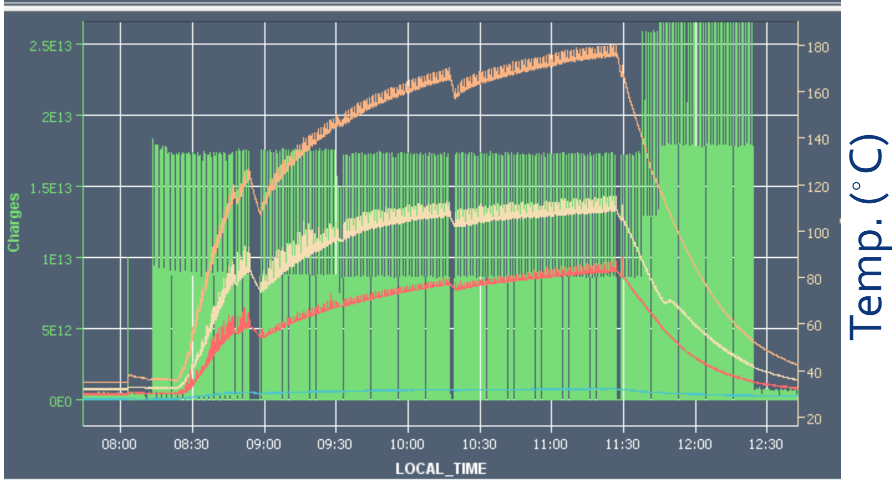
Good agreement (within ~25%)



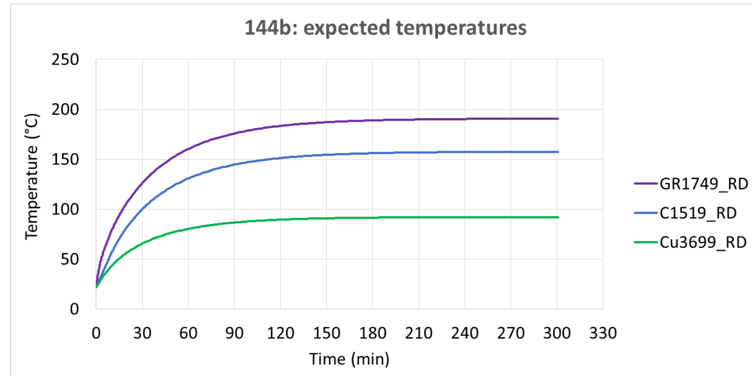


Operational feedback for TIDVG#4

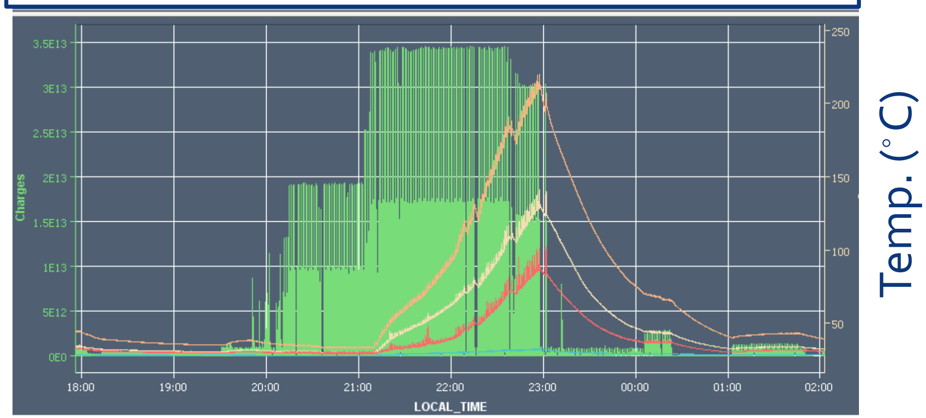
~Steady state at **144** bunches (27 kW deposited)



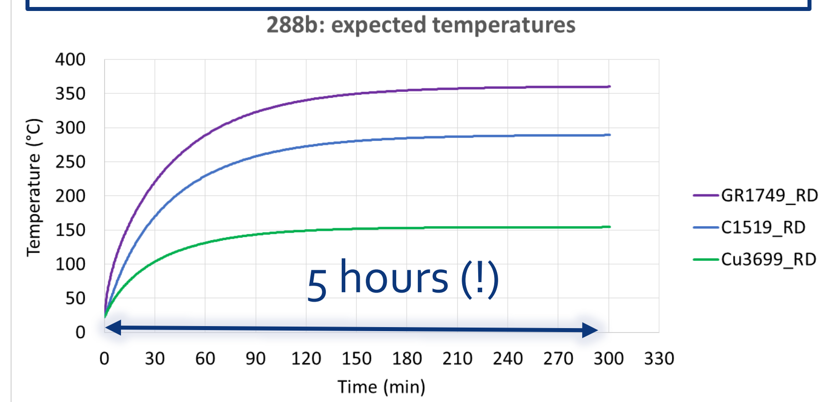
Simulation for **27 kW**
(**144** bunches x $1.1*10^{11}$
$I_{total}=1.6*10^{13}$)



288 bunches (1h30– 55 kW deposited)

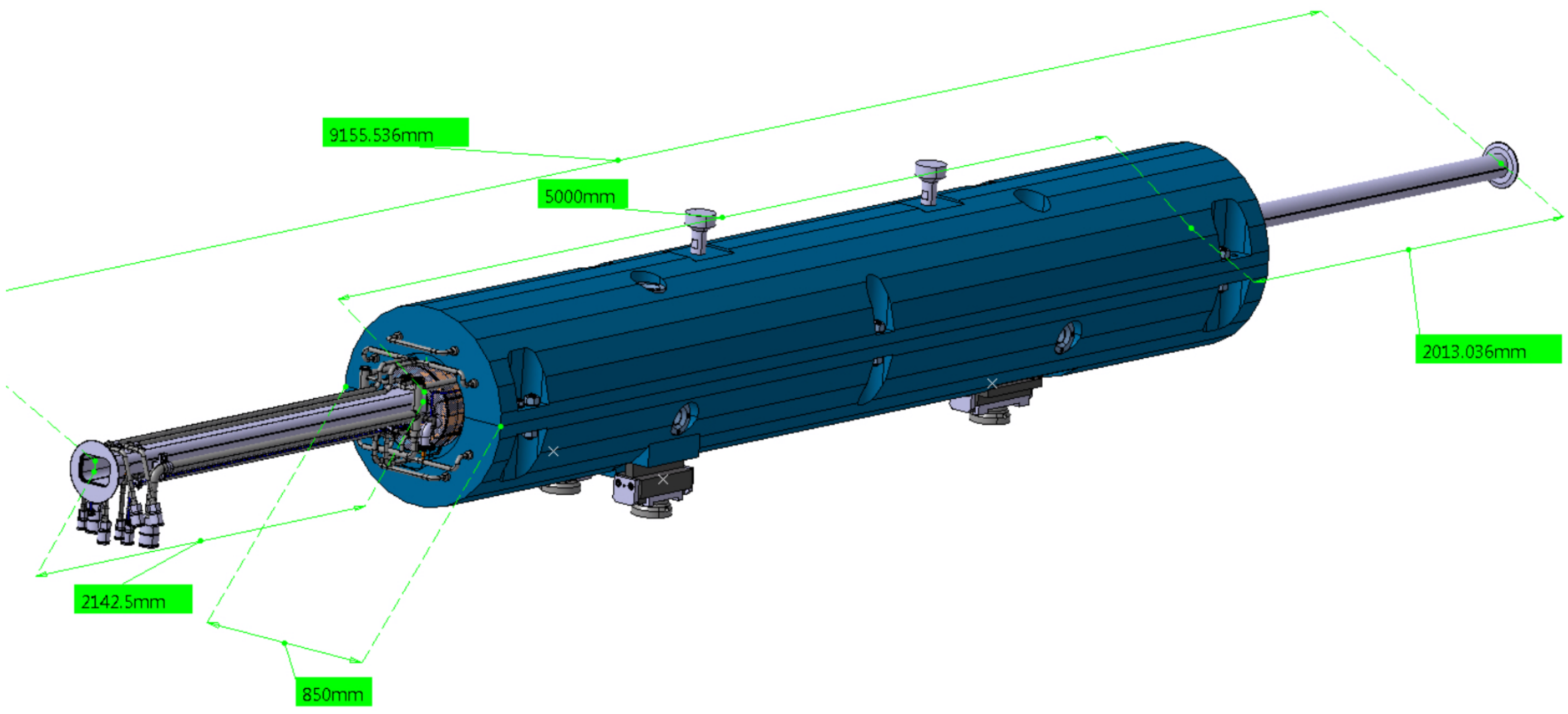


Simulation for **56 kW**
(**288** bunches x $1.1*10^{11}$)

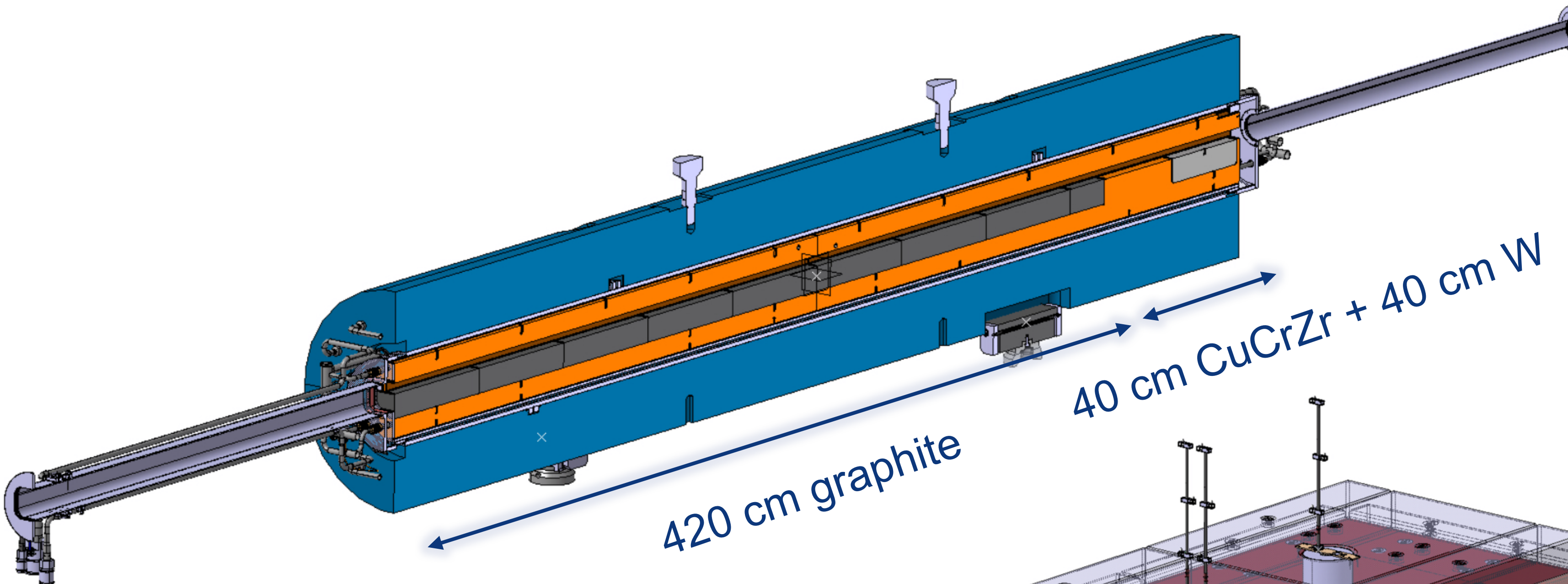


Future SPS beam dump (TIDVG#5)

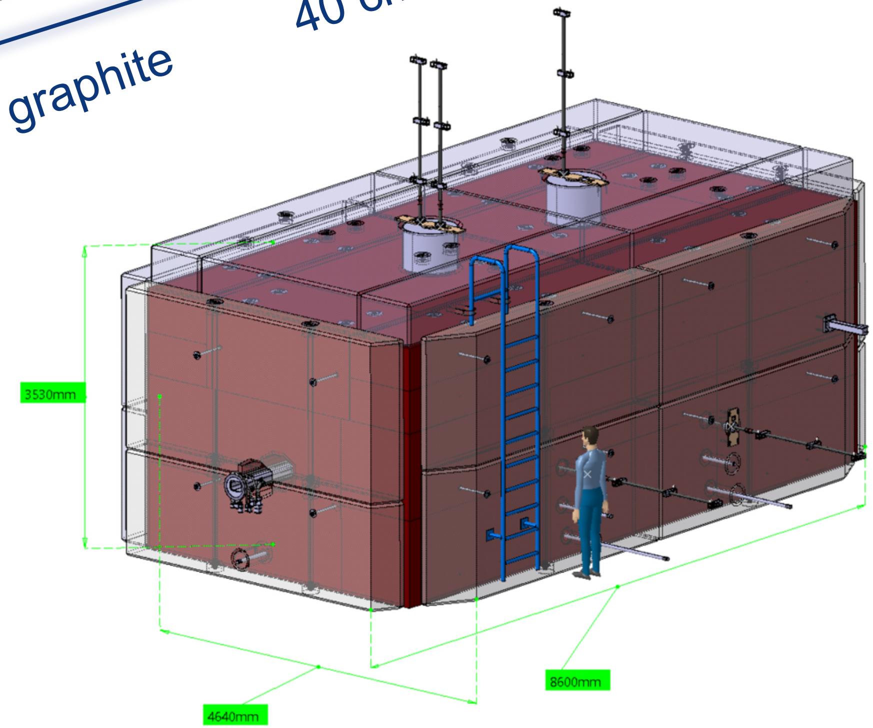
- TIDVG5 must be capable of dissipating **~200 kW** average deposited power
- To be installed in SPS by 2020 (during LS2)



Future SPS beam dump (TIDVG#5)

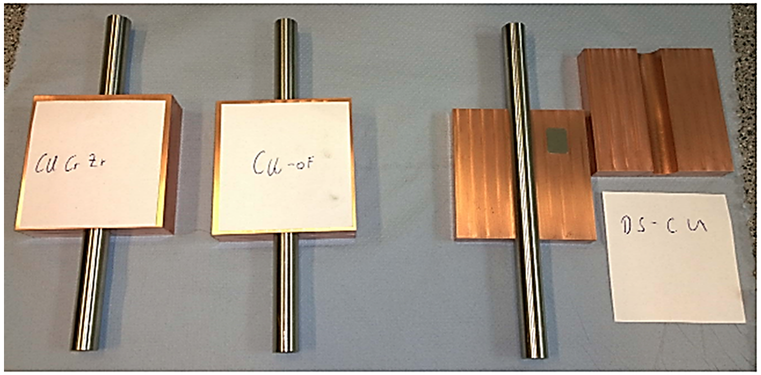


- A ventilated large shielding assembly will surround the dump core

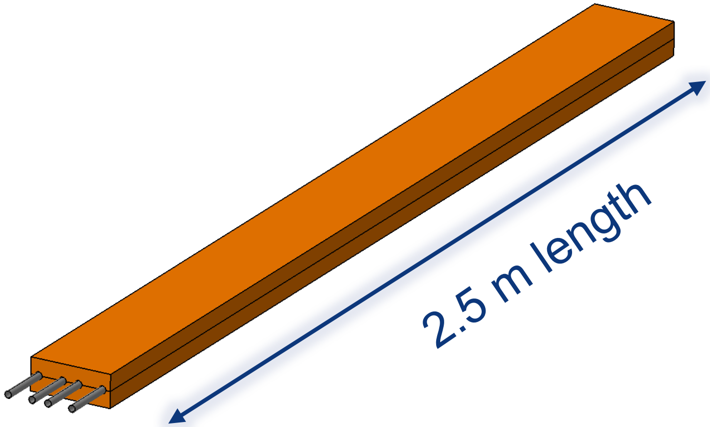


Future SPS beam dump: prototypes

HIP of cuprous materials around SS pipes (Fraunhofer): the contact between the tubes is made by diffusion bonding, i.e. perfect contact.



On-going prototyping activities:



- Real length prototype
- Cooling performance will be tested
- CuCrZr material characterization will be performed after HIP and thermal treatments
- Study of the interface CuCrZr-SS tube

M. Calviani 22/09

Conclusions

- TIDVGs are critical components of the CERN’s accelerator complex
- TIDVG#4 successfully installed and operational according to the project schedule
- Good vacuum performance with a fast conditioning observed
- Good thermal performance (tested for high power beams)
- Longitudinal electron beam welds along the core were identified as the source of the TIDVG#3 leak and must be avoided for future designs (using a seamless vacuum chamber)
- Lessons learnt for TIDVG#5 design (installation in 2020)

Thank you for your attention.

Do you have any questions?

Acknowledgements: J. A. Briz, K. Cornelis, R. Esposito, S. Gilardoni, B. Goddard, J.L. Grenard, D. Grenier, M. Grieco, J. Humbert, V. Kain, F. Leaux, S. De Man, C. Pasquino, J. R. Poujol, S. Sgobba, D. Steyaert, F. M. Velotti, V. Vlachoudis