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

AccApp' 17 – Quebec, Canada

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Sources, Targets and Interactions Group

CERN | EN ENGINEERING DEPARTMENT

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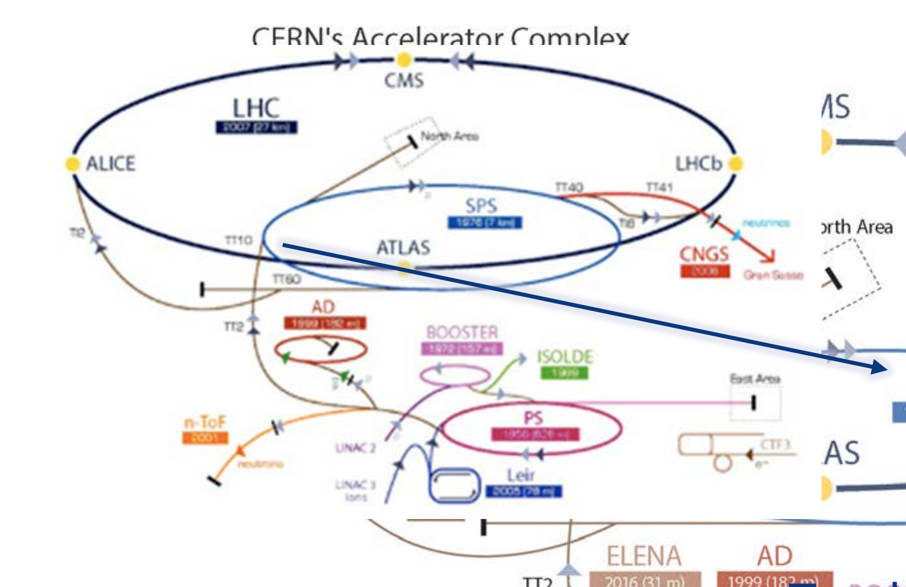
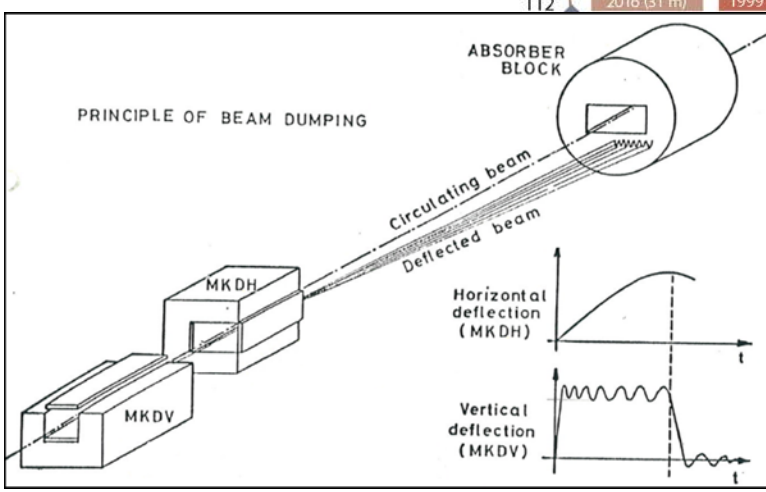
Introduction of the SPS beam dump





Two beam dumps in the SPS:

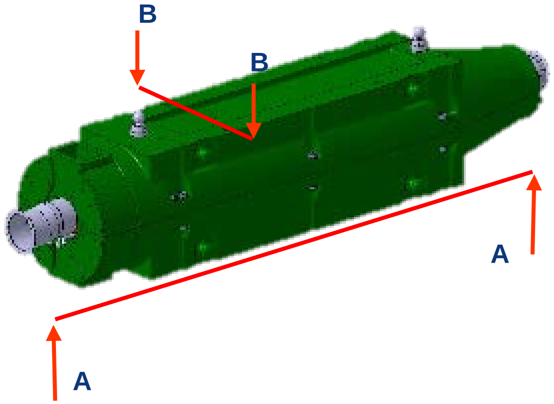
- TIDH (Target Internal Dump Horizontal): low energies, below 28 GeV
- TIDVG (Target Internal Dump Vertical Graphite): high energies, above 105 GeV

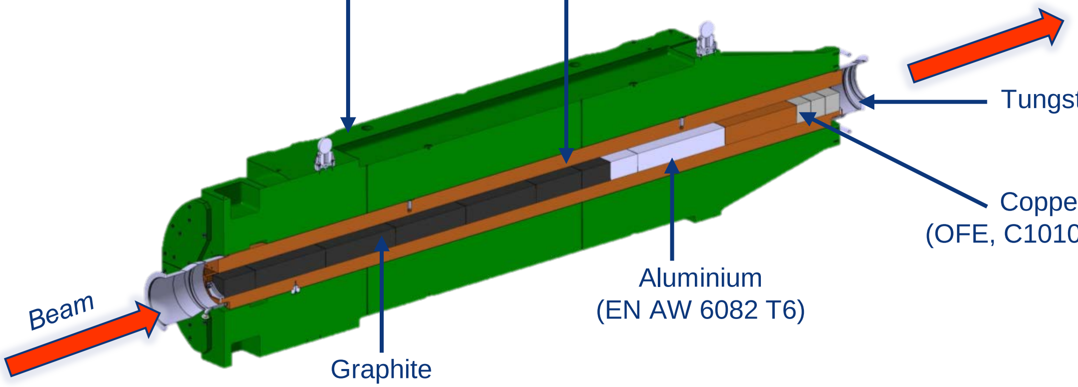
TIDVG

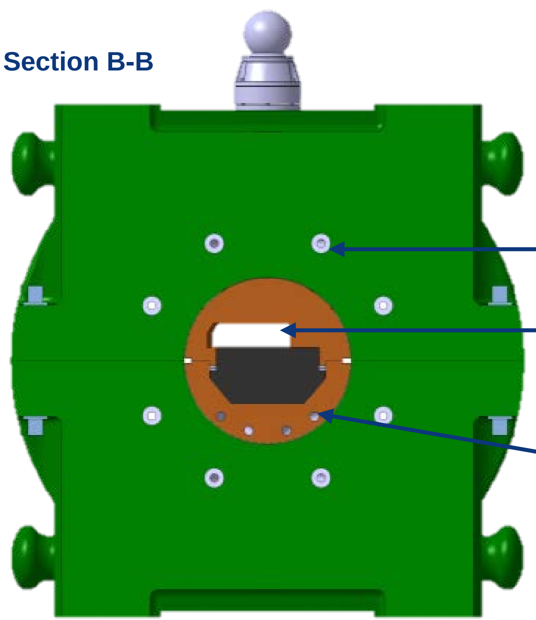
- Total length 4.3 m; 30 cm core diameter
- Internal dump (in UHV)

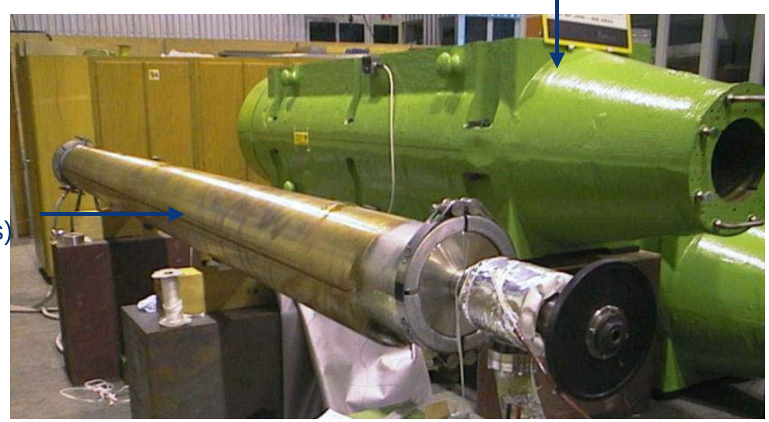
Previous SPS beam dump - Design of TIDVG#3

Operating during 2014-2016





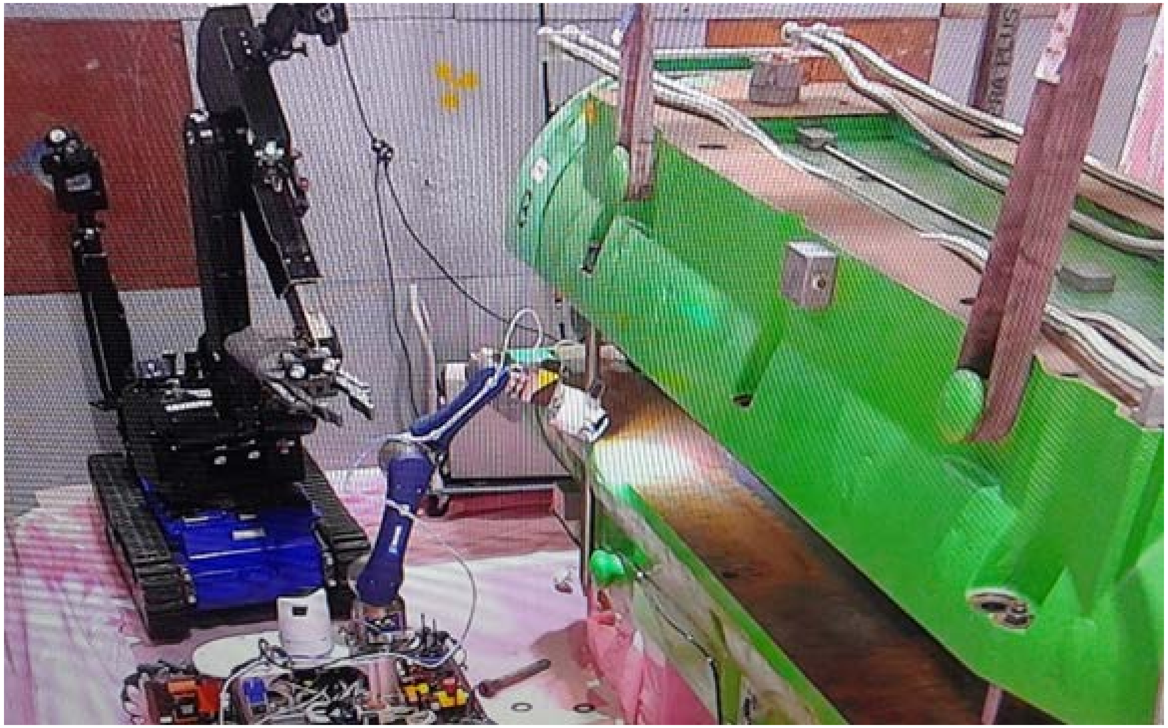




Leak in April 2016

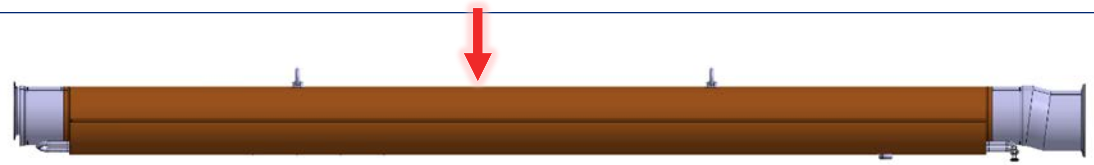
Post-mortem inspection of TIDVG#3

- Vacuum leak test remote inspection (July 2017)
  - Radioactive device: 50mSV/h contact
  - Leak testing was able to identify leak point
  - Vacuum leaks were present on both longitudinal welds around half way along the core



Courtesy of K. Kershaw

Post-mortem inspection of TIDVG#3



History of the SPS beam dump

Device	Modifications/Experience	Date
TIDVG 1	Molten Al	2000-2004
TIDVG 2	Molten Al	2006-2013
TIDVG 3	Gr longer +200 mm Al shorter Vacuum leak in April 2016- NO SPARE! Justified by the fact that a new generation dump was required by 2019-2020	2014-2016

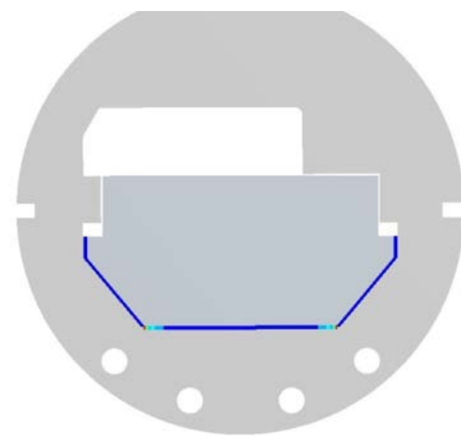
Endoscopy inspection: molten Al in TIDVG 2

After the vacuum leak in April 2016:

- **New design → TIDVG#4** for 2017-2018 operation (previous design: extremely long manufacturing times)

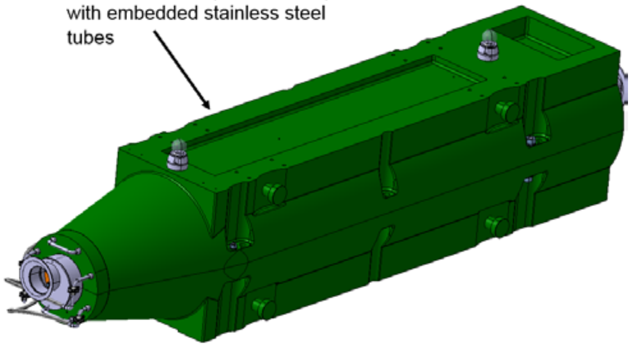
Weak points of TIDVG1,2 and 3:

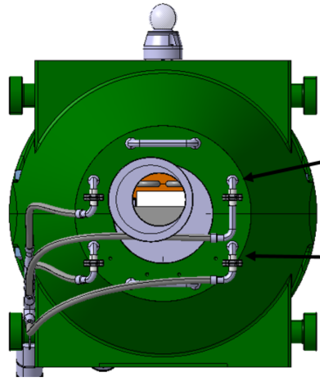
- High outgassing rates
- No proper bake-out possibilities after installation
- No internal instrumentation
- High uncertainty of cooling efficiency

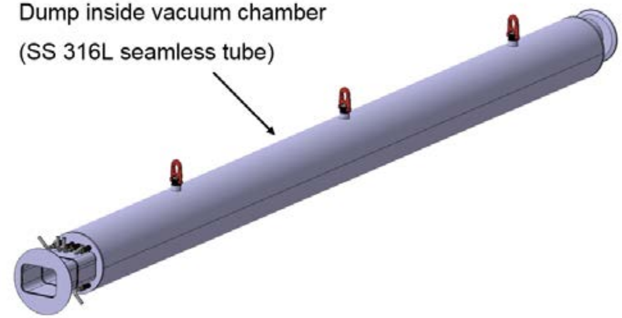


Current SPS beam dump – TIDVG#4

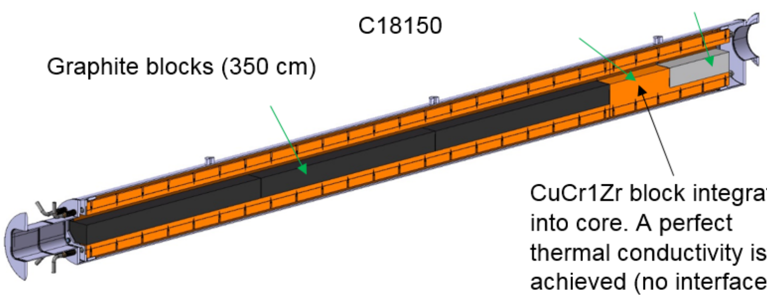
Installation during EYETS 2017 (March)



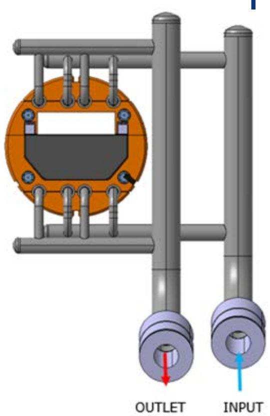


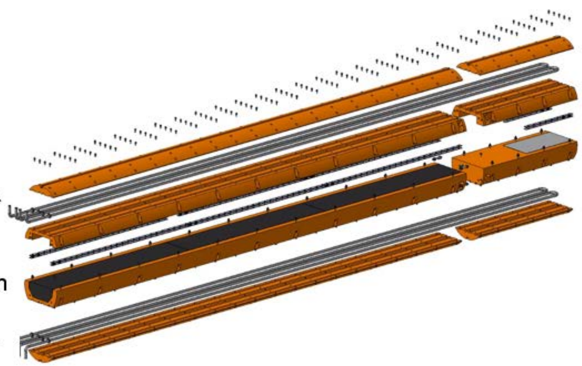


Absorbing blocks



Copper core cooling system:





- Limited time window:
  - Faster manufacturer, materials off-the-shell
  - Use of known technologies. No R&D

- 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. Acceptable delivery times.
  - **UHV compatibility**
  - **Avoid Al** (molten in previous design)
  - Avoid any kind of welds

Component	CERN specifications	Additional treatments applied
Graphite	Homogeneity Isotropic properties Grade with low E and high tensile strength	Degreased Purified in Ar @ T>2000°C Vacuum fired @ 950°C at CERN
Tungsten alloy	Homogeneity	Degreased at CERN Vacuum fired @ 950°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

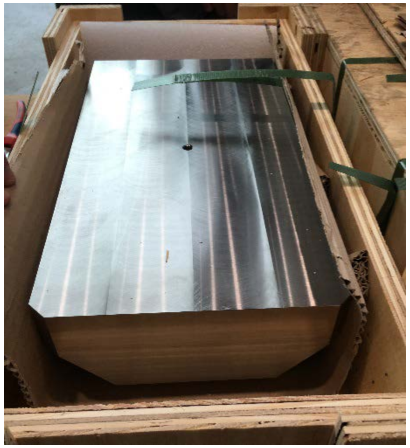
Current SPS beam dump – TIDVG#4

Forging of SS vacuum chamber

SS vacuum chamber

Vacuum firing of the Gr blocks

Tungsten alloy



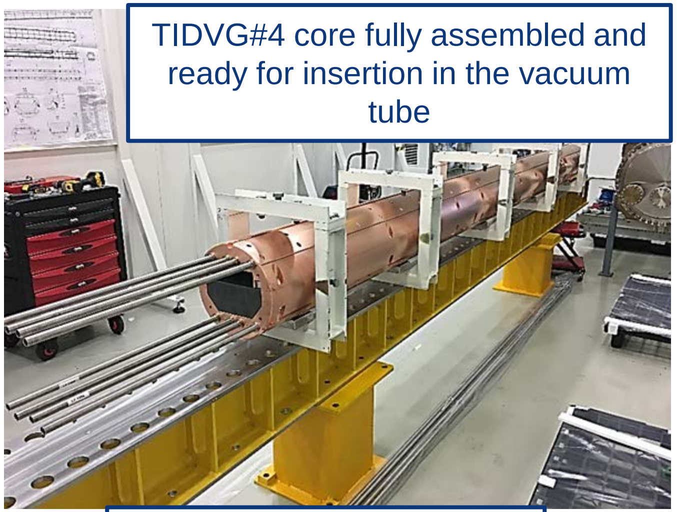
CuCrZr core

Current SPS beam dump – TIDVG#4

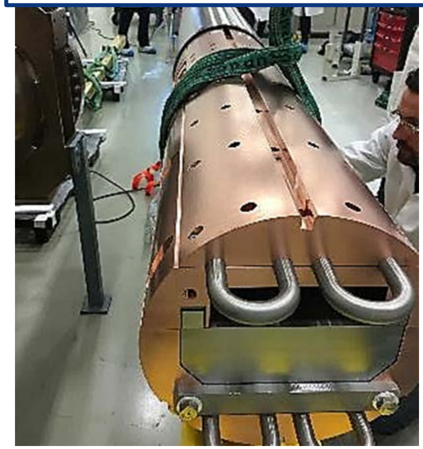
Graphite inside the CuCrZr core

Medium/high-Z absorber

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

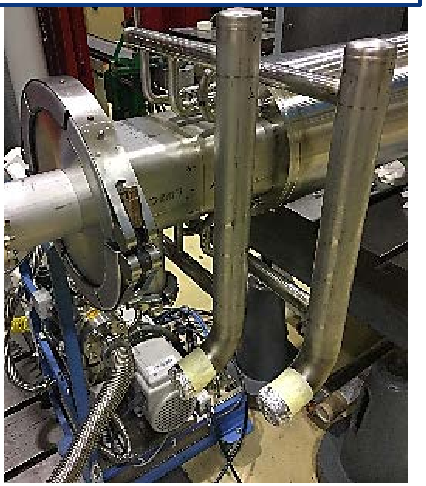


TIDVG#4 core being pulled into the vacuum chamber



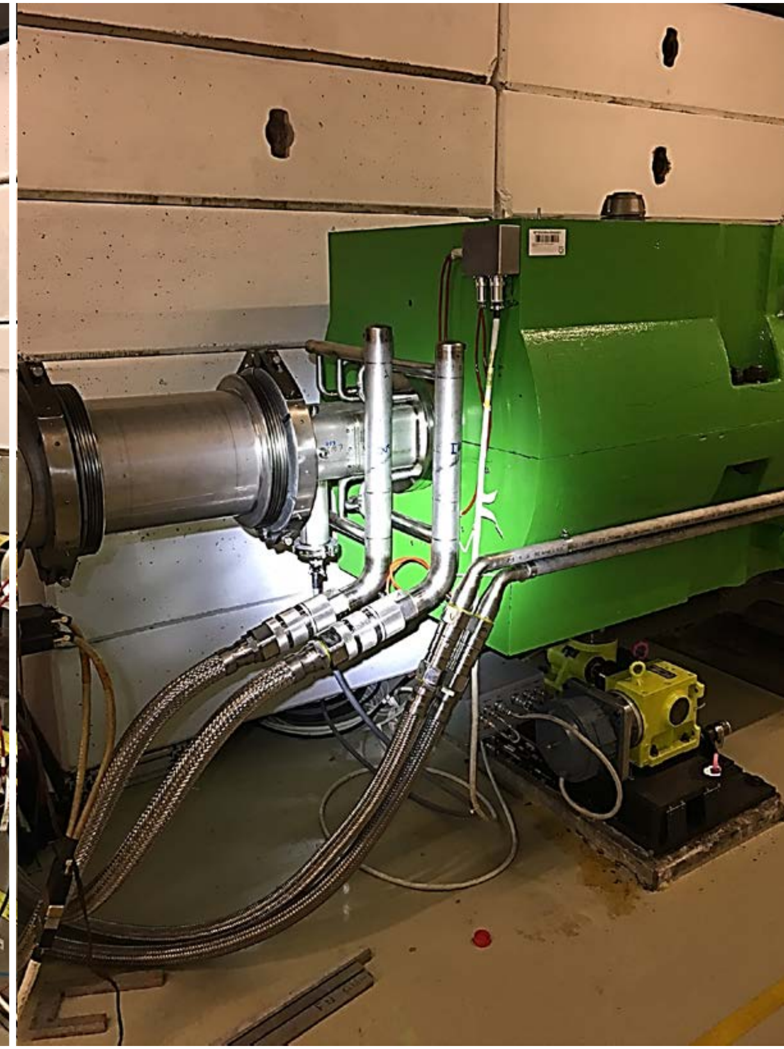
TIDVG#4 core fully inserted (upstream)

Final leak detection (upstream/ water manifolds)



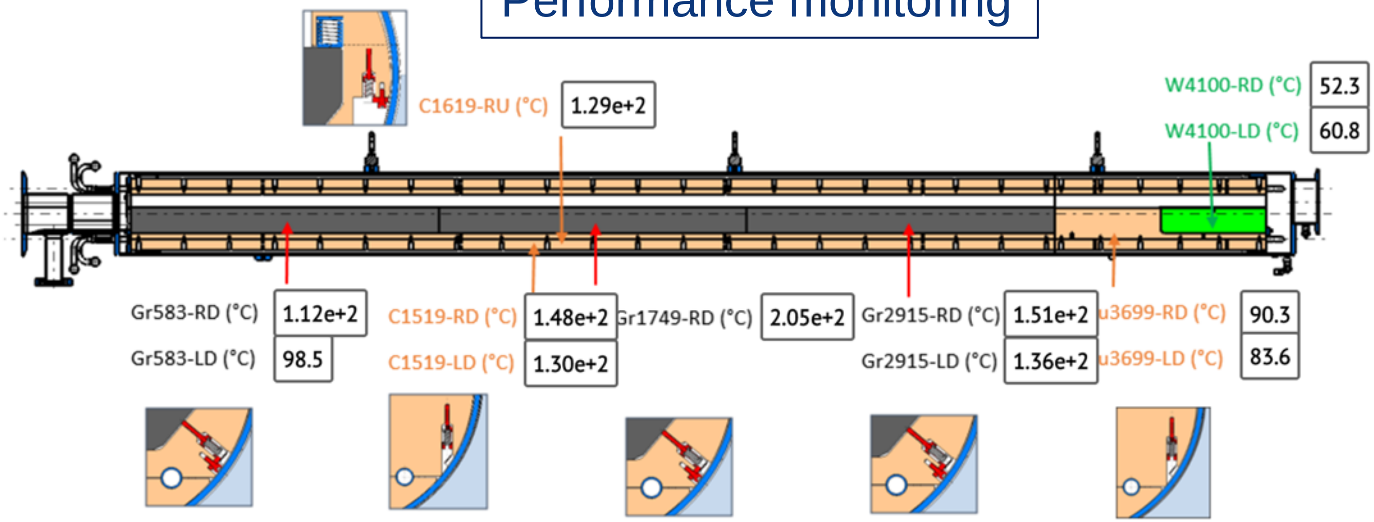
Current TIDVG#4- Installation

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

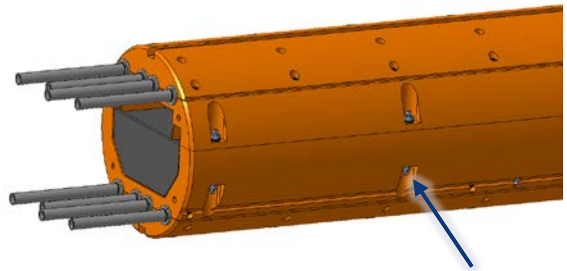
Beam intensity: 7.63e+11 charges

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

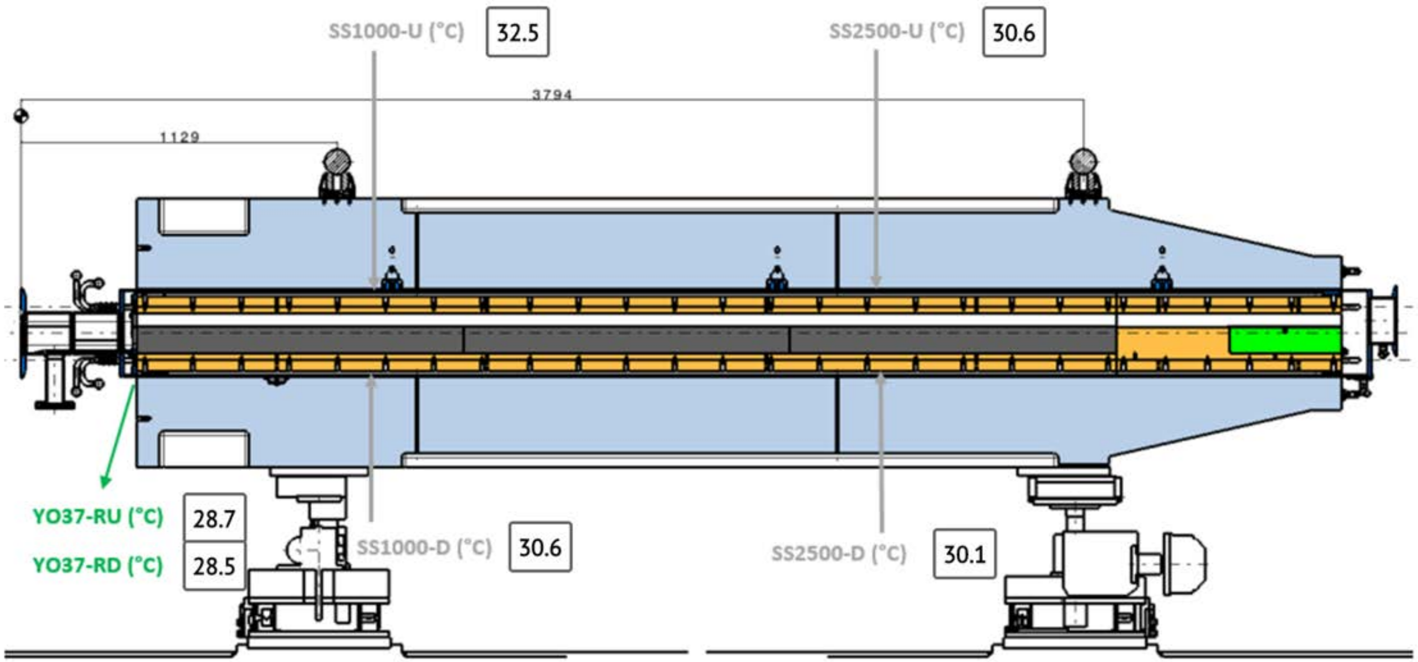
Average beam power over last hour: 1.88e+1 kW



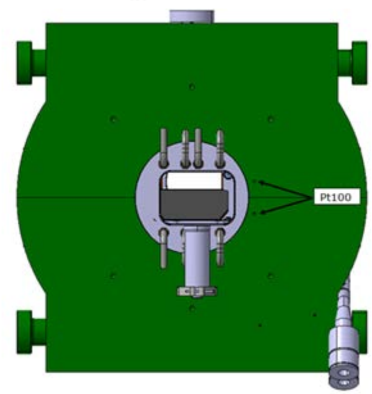
Gr583-RD

14 (-2) PT100 installed in the dump core

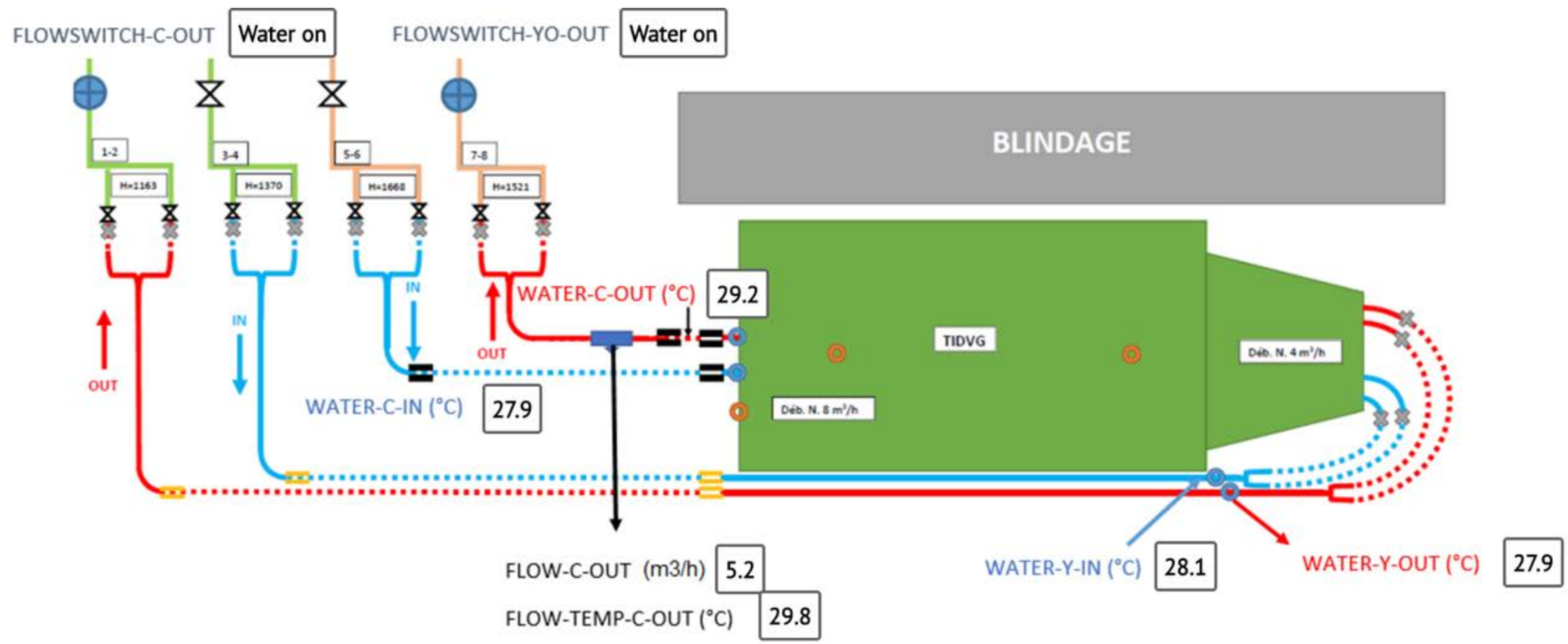
Operational feedback for TIDVG#4



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

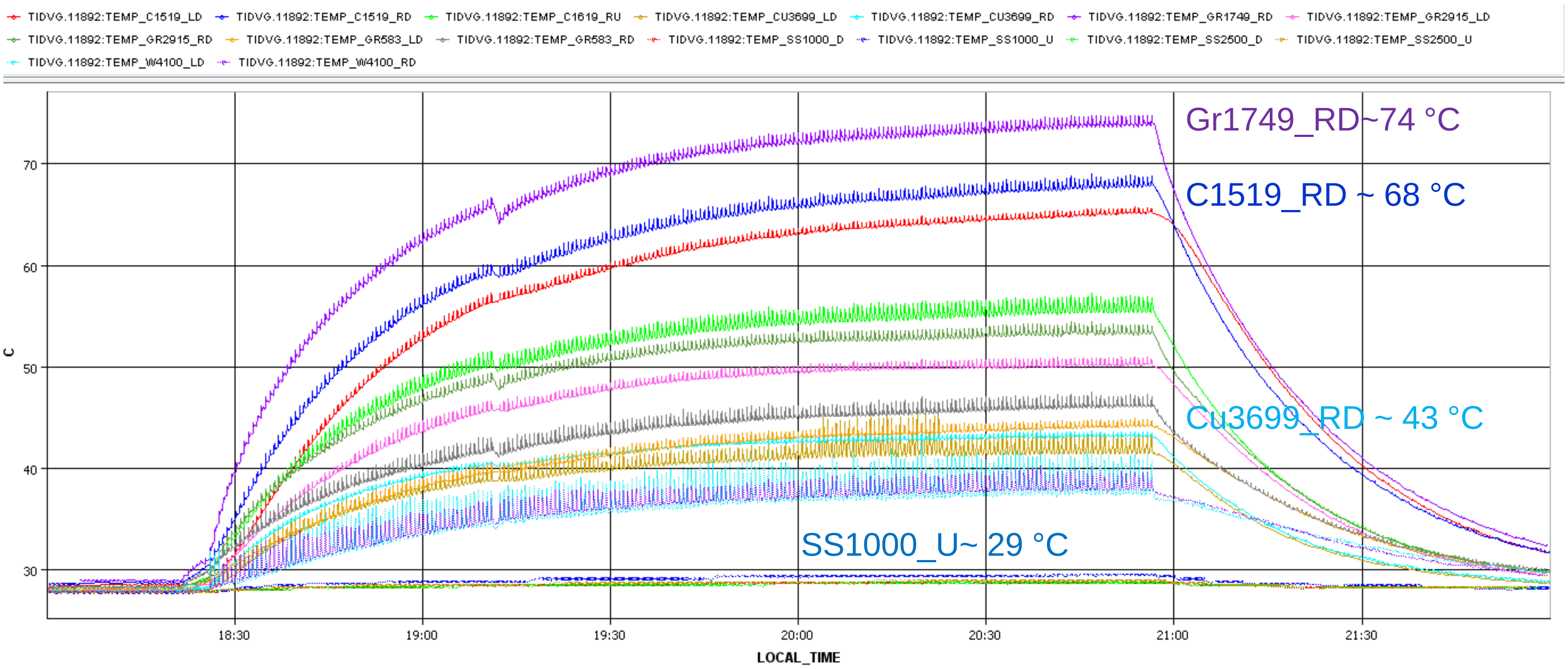
Commissioning beams:

Beam Type	p GeV/c	Bunch Intensity	# Bunches	Total Intensity	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	$9*10^{12}$	4h	16
LHC	440	$1.10*10^{11}$	144	$1.6*10^{13}$	3h	27
LHC	440	$1.10*10^{11}$	288	$3.2 *10^{13}$	1h30	55

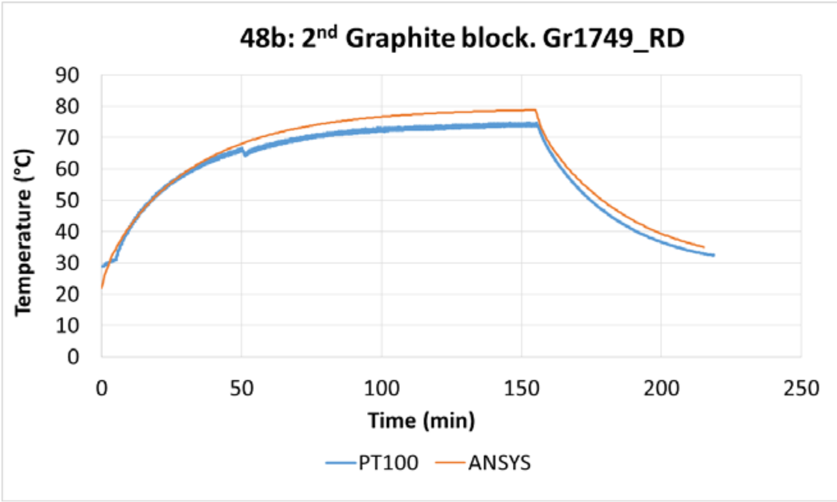
- Dedicated **commissioning beams** have been requested in order to validate the performances of the dump (cross-check with simulations) as well as to condition the graphite
- TIDVG4 is designed for continuous deposited power of **~60 kW** continuously

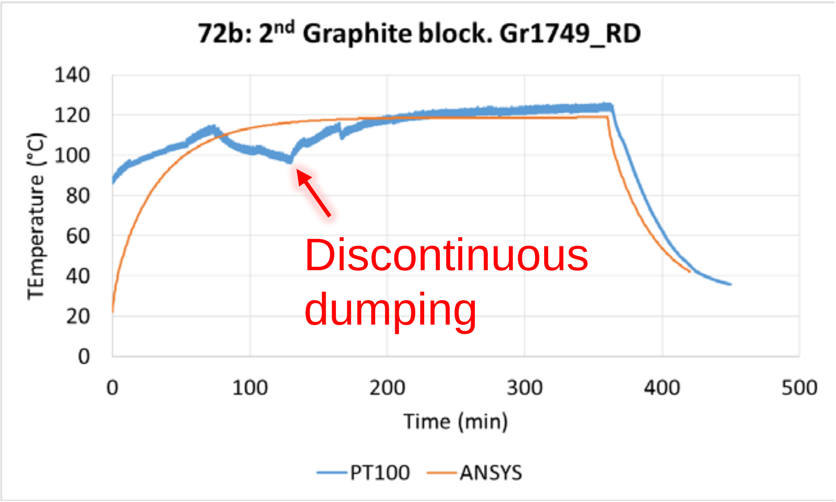
Operational feedback for TIDVG#4

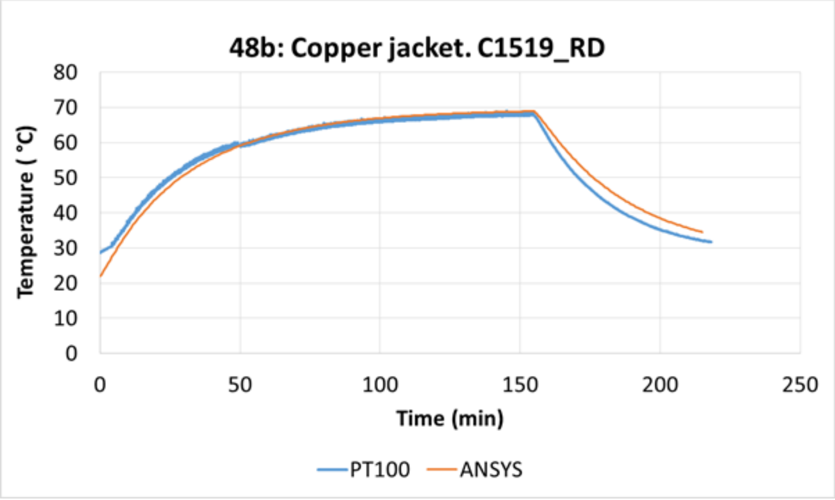
Behavior under 48b beam

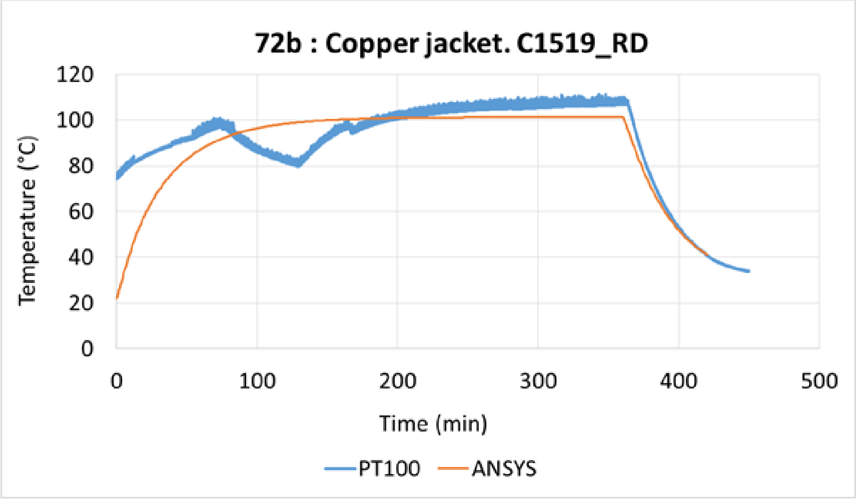


Operational feedback for TIDVG#4

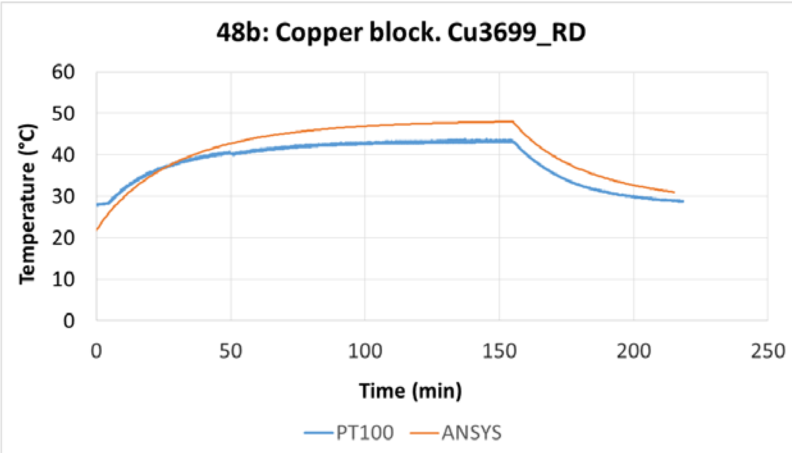


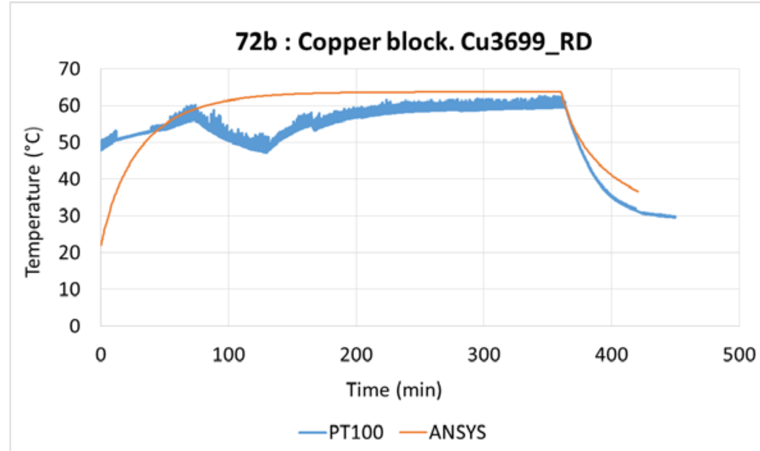




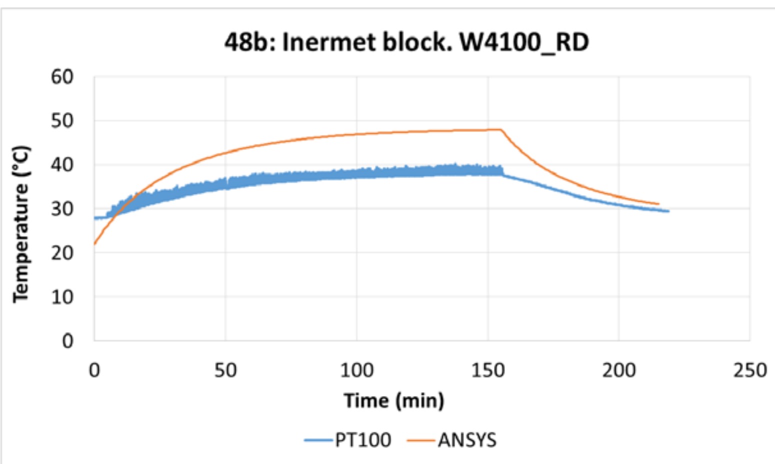


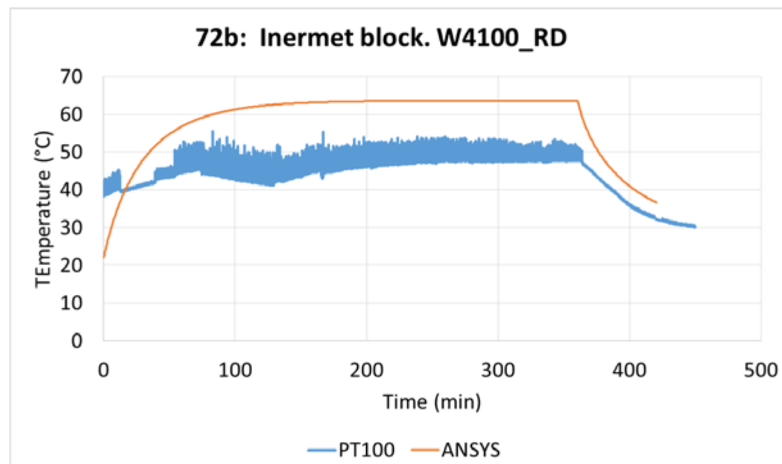
Operational feedback for TIDVG#4





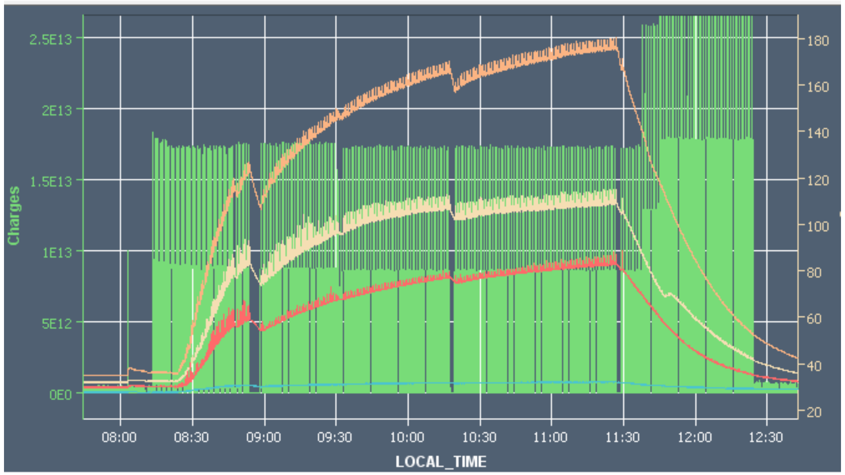
Good agreement (within ~25%)





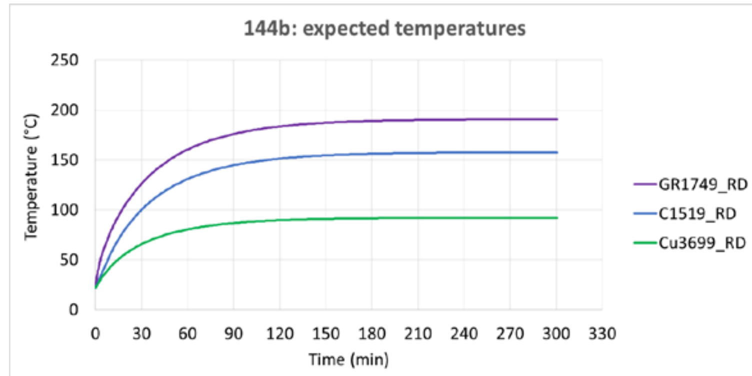
Operational feedback for TIDVG#4

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

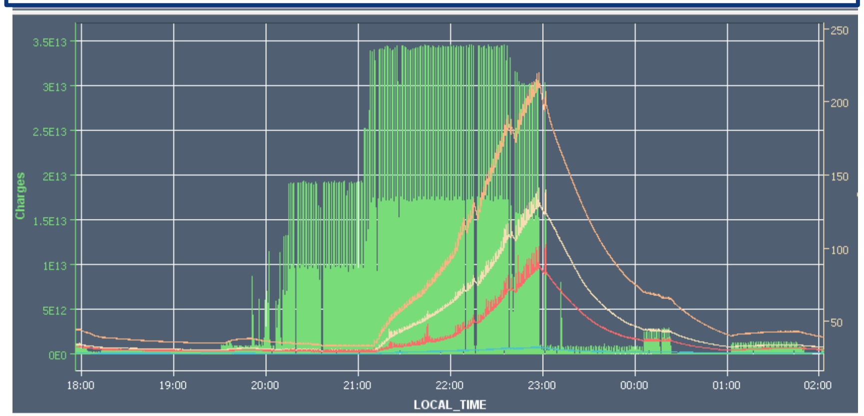


Temp. (°C)

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

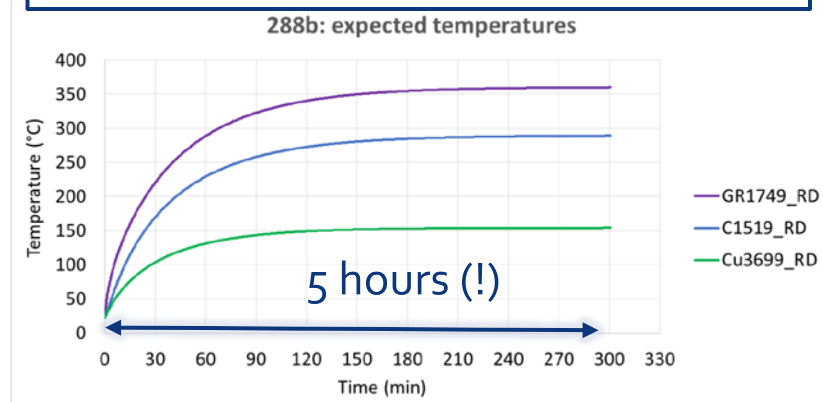


288 bunches (1h30– 55 kW deposited)



Temp. (°C)

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



Conclusions

- 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)

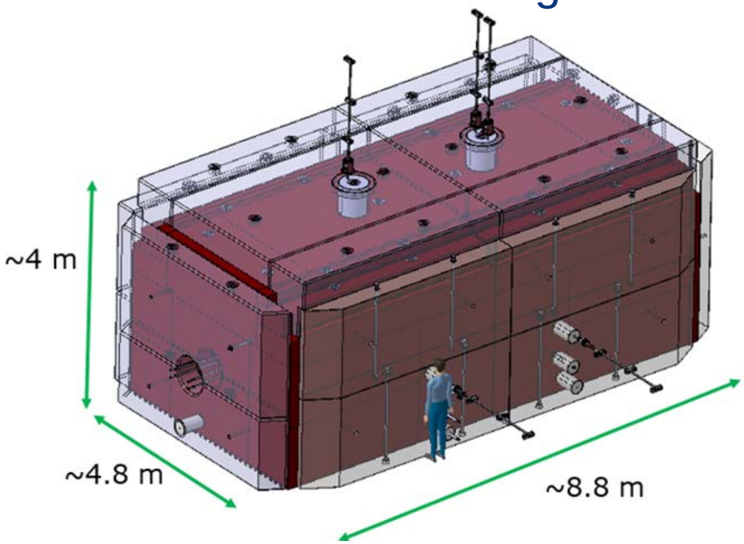
Thank you for your attention.

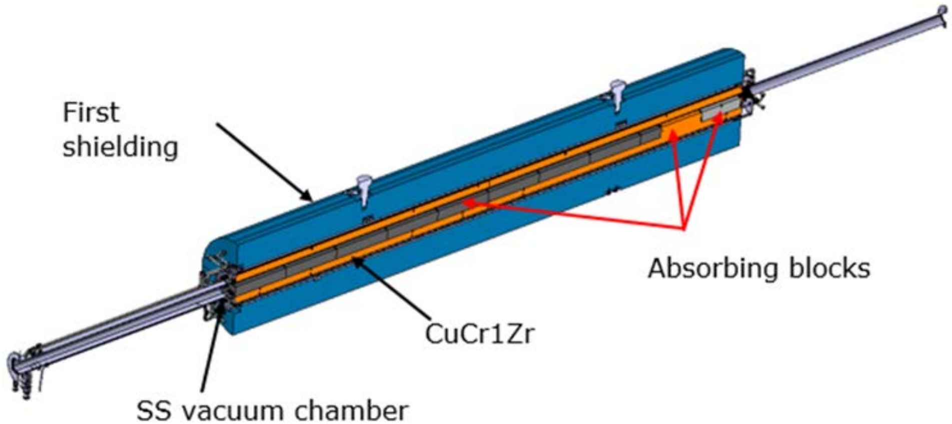
Do you have any questions?

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

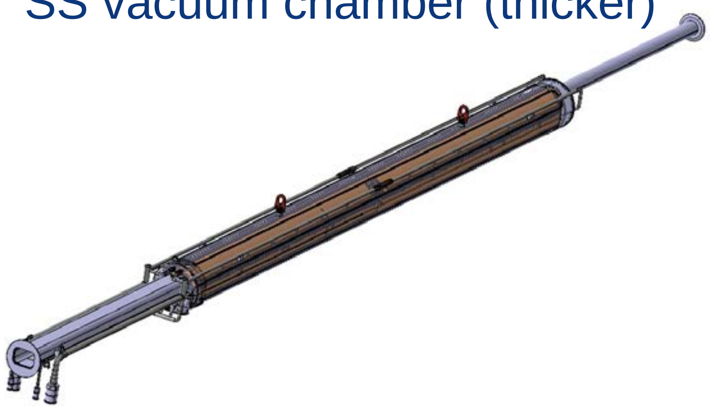
Future SPS beam dump (TIDVG#5)

External shielding

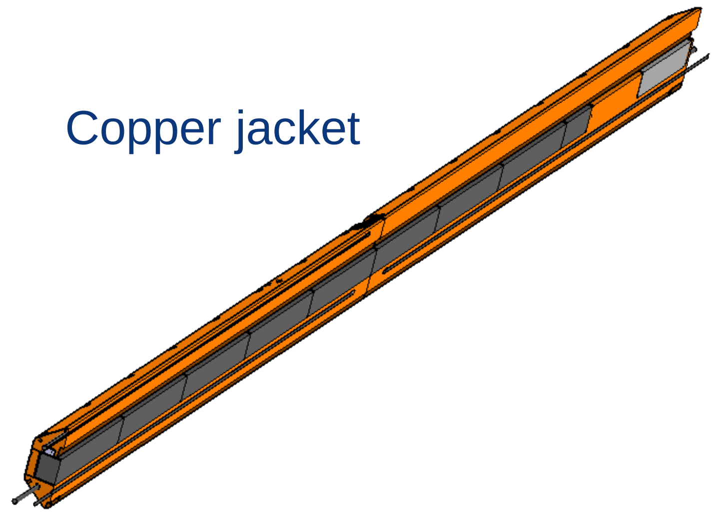




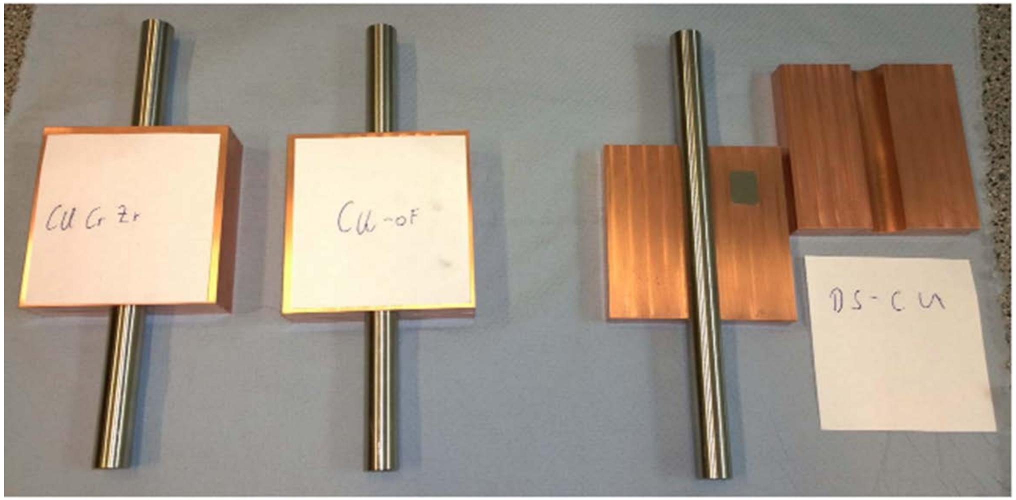
SS vacuum chamber (thicker)



Copper jacket



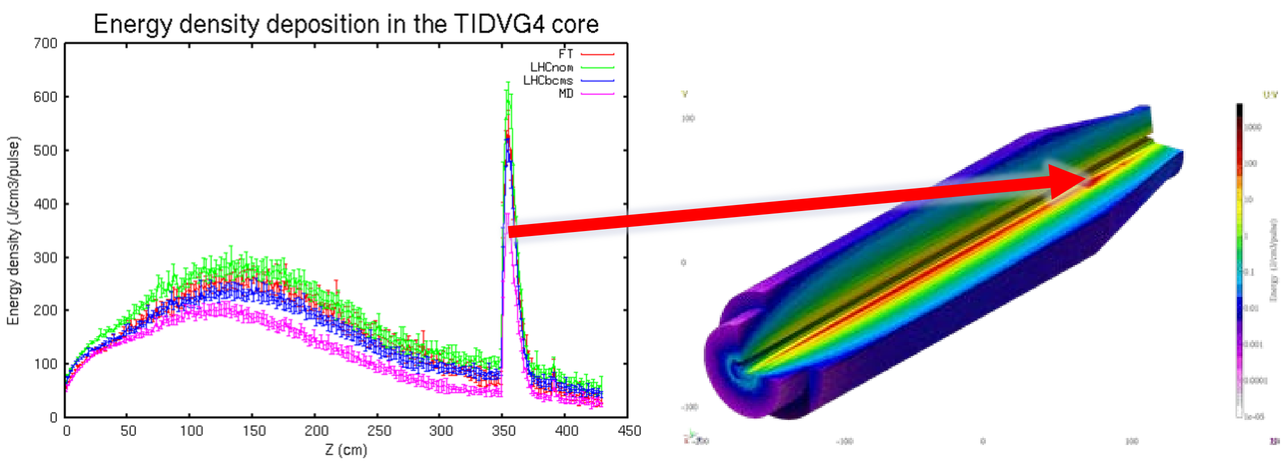
Future SPS beam dump: Prototypes



Hiping cuprous materials around SS pipes (Fraunhofer):
The contact between the tubes is made by diffusion bonding, like welded. Perfect contact.

Thermomechanical simulations

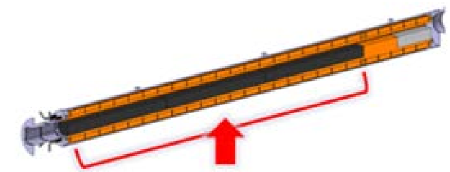
Beam Type	p GeV/c	I p^+/bunch	Bunches	Total I p+	Cycle length s	Time of continuous beam
FT (achieved)	400	$1.40*10^{10}$	4200 (5 ns)	$5.88*10^{13}$	70.0	-
LHC (25 ns)	450	$1.50*10^{11}$	288 (25 ns)	$4.32*10^{13}$	40.8	-



Maximum power deposited on the dump~76kW

CuCrZr absorbing part sees the peak of energy deposition

Thermo-mechanical analysi

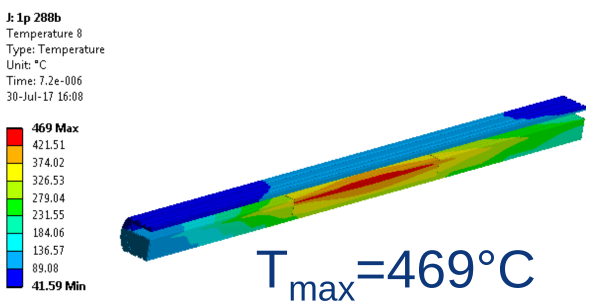


Thermal

Graphite blocks & Cu core:

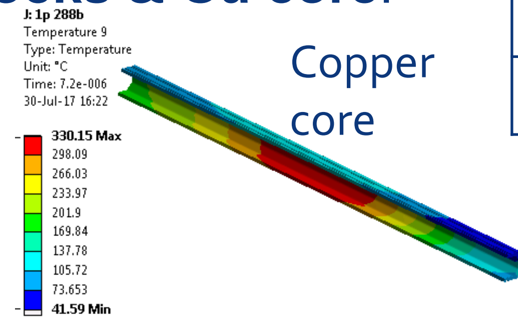
$T_{service\ Gr}$=2000°C
$T_{service\ CuCrZr}$=400°C

Steady-state combined LHC

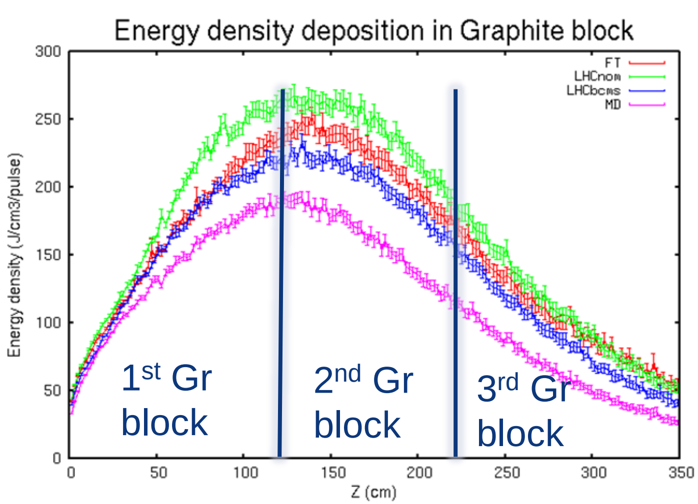


T_{max}=469°C

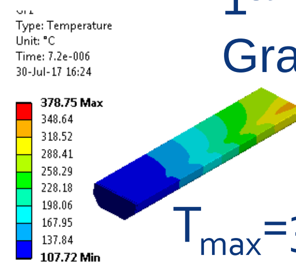
Copper core



T_{max}=155°C

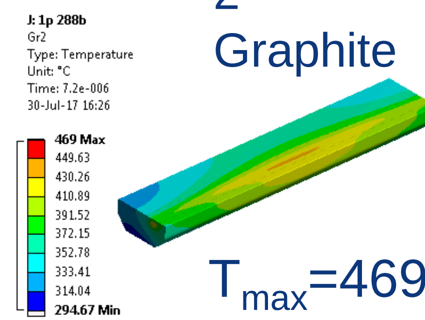


1st Graphite



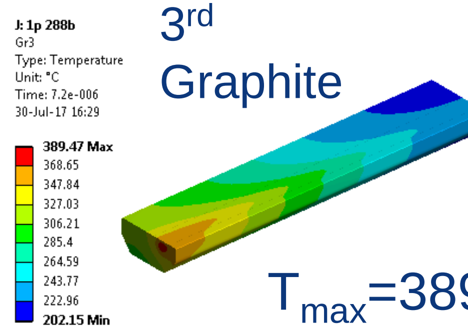
T_{max}=379°C

2nd Graphite



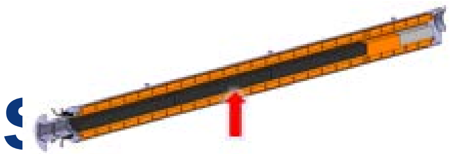
T_{max}=469°C

3rd Graphite



T_{max}=389.5°C

Thermo-mechanical analysis

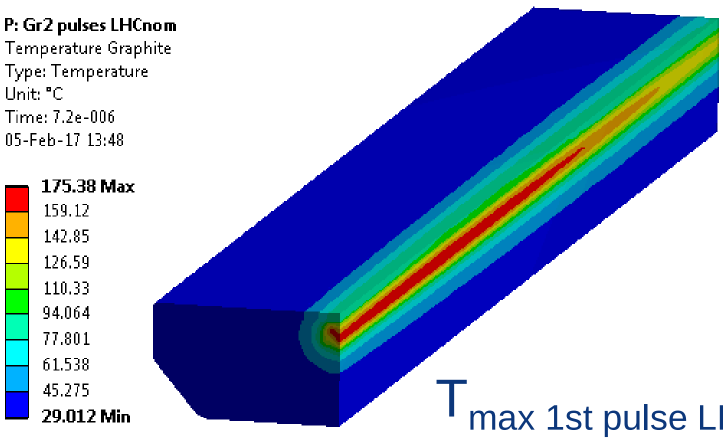


2nd Graphite block:

$T_{service\ Gr}$=2000°C
Tensile strength=60 MPa

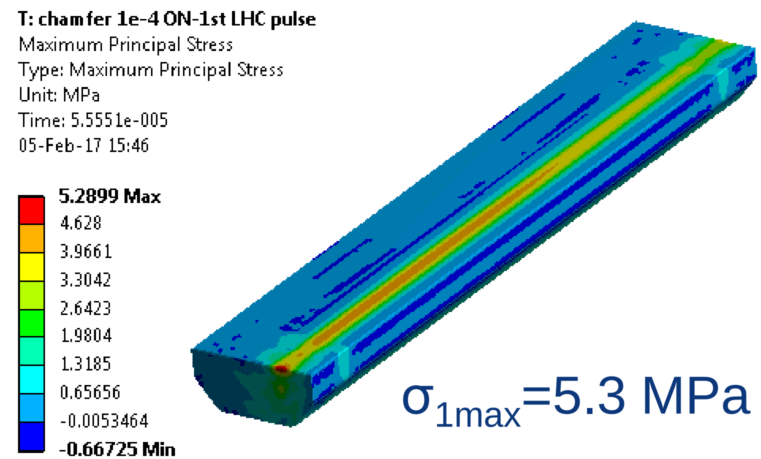
1st pulse of LHC

Thermal

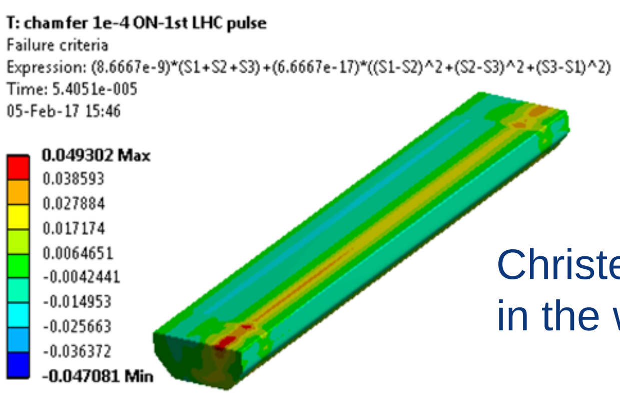


$T_{max\ 1st\ pulse\ LHC}$ =175°C

Structural



σ_{1max}=5.3 MPa



Christensen failure criterion for Graphite
in the worst case (combined LHC + FT10%)– OK ✓

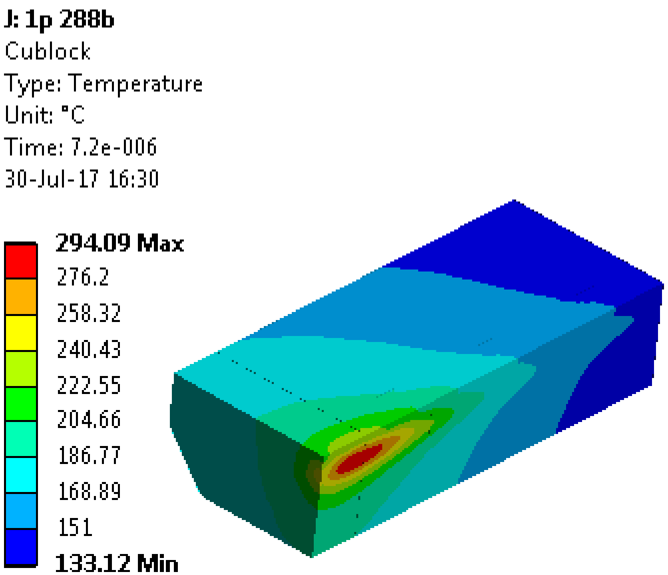
Thermo-mechanical analysis

Thermal

CuCrZr absorbing part:

$T_{service\ CuCrZr}$=400°C
Yield strength=280 MPa

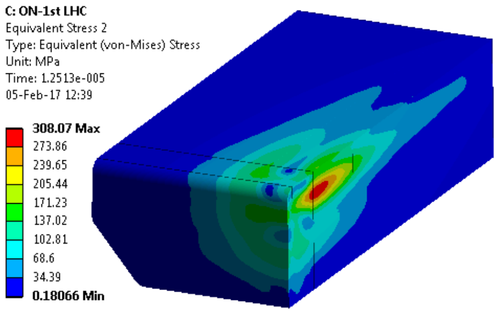
Steady-state LHC

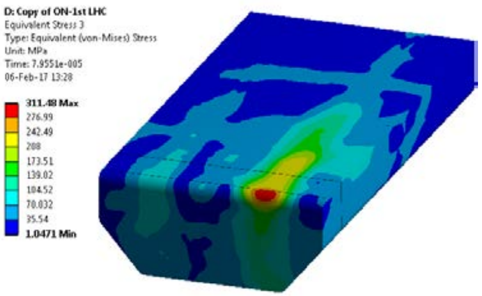


T_{max}=294°C ✓

Structural

1st pulse LHC





σ_{vmax}=311.5 MPa

Thermo-mechanical analysis

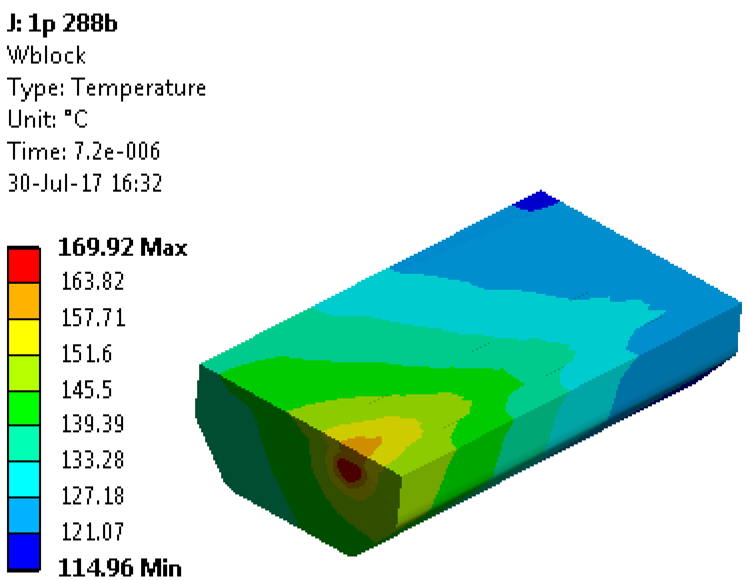
Thermal

Inermet block: Structural

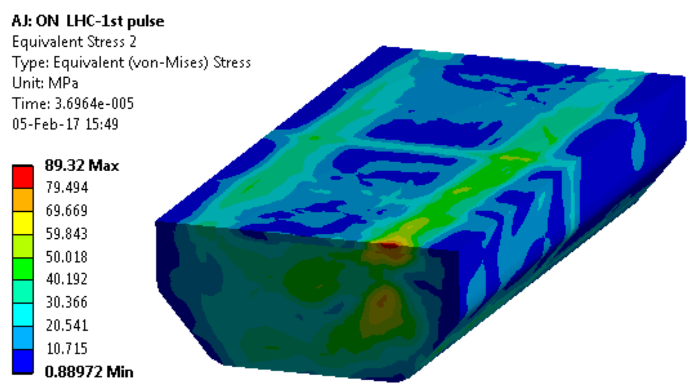
$T_{service\ IT180}$=800°C
Yield strength=500 MPa

Steady-state LHC + 10% FT

1^{st} pulse LHC



T_{max}=167°C ✓



σ_{vmax}=89 MPa ✓

Maximum temperatures TIDVG#4

	Maximum Temperatures (°C) after steady-state of LHC
Graphite blocks	469
Copper jacket	330
CuCrZr absorbing block	294
Inermet block	170