Challenges in Beam Intercepting Devices and Targetry technology for CERN's accelerator complex

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Sources, Targets and Interactions Group

10th Anniversary

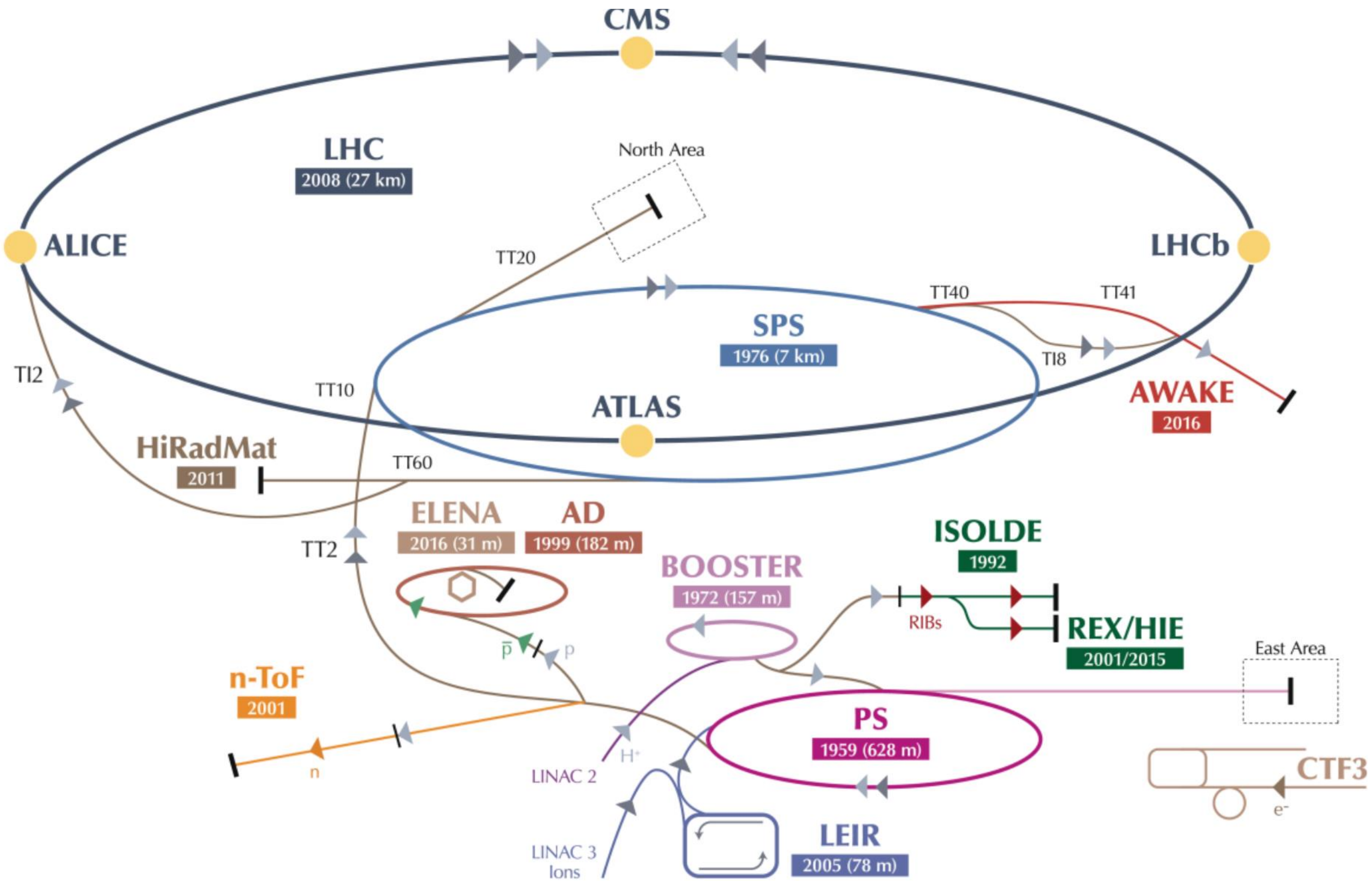
J-PARC Symposium 2019

Disclaimer & acknowledgments

- Only a subset of the different palette of activities will be discussed, focusing on **specific challenges** and **examples on how these are been tackled**
- A. Perillo-Marcone, F.-X. Nuiry, I. Lamas Garcia, S. Gilardoni, D. Carbajo, S. Pianese, A. Lechner, J. Maestre, C. Bahamonde, T. Polzin

Beam Intercepting Devices

Safety function	Beam cleaning & control	Physics
Beam stoppers	**Collimators**	Particle producing targets
Beam dumps	Scrapers	
	Strippers	
	Slits	



~250 devices scattered from the Linac chopper dump (3 MeV) to the LHC main dump (7 TeV)

What type of challenges do we have?

- Devices must be able to withstand **operation** and **accident** scenarios, plus protect delicate equipment
  1. **UHV** requirements (10^{-10} mbar) also in *movable* parts
  2. **High energy densities** (~kJ/cm^3/pulse) as well **power densities** (several MW/cm^3)
  3. **High beam intensity/energy** (~500 MJ for LHC dump)
  4. **High average deposited power** (~250 kW for LIU SPS beam dump or ~350 kW for Beam Dump Facility)
  5. **Physics requirements**, often implying the use of non-structural materials (Pb or Ir)
  6. **Impedance**, especially for colliders
  7. **Radiation damage** on absorbing materials

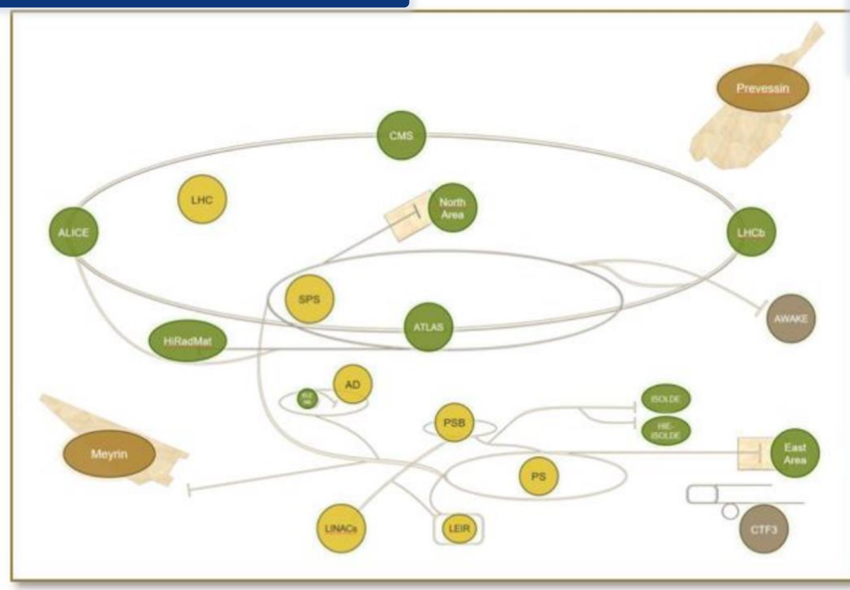
What we are doing for LS2

LIU
(incl. L4 connection)

AWAKE

HL-LHC

Consolidation



DISMAC

ELENA

LHC experiments upgrade

SPS Access

SPS Fire Safety

East Area consolidation

What we are doing for LS2

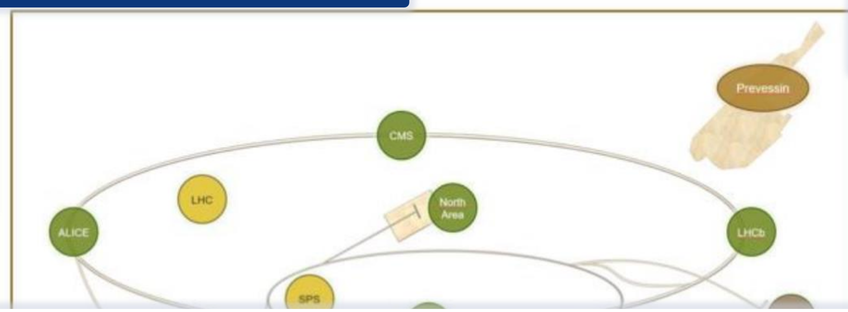
LIU (incl. L4 connection)

AWAKE

HL-LHC (HiLumi HL-LHC PROJECT)

Consolidation

DISMAC

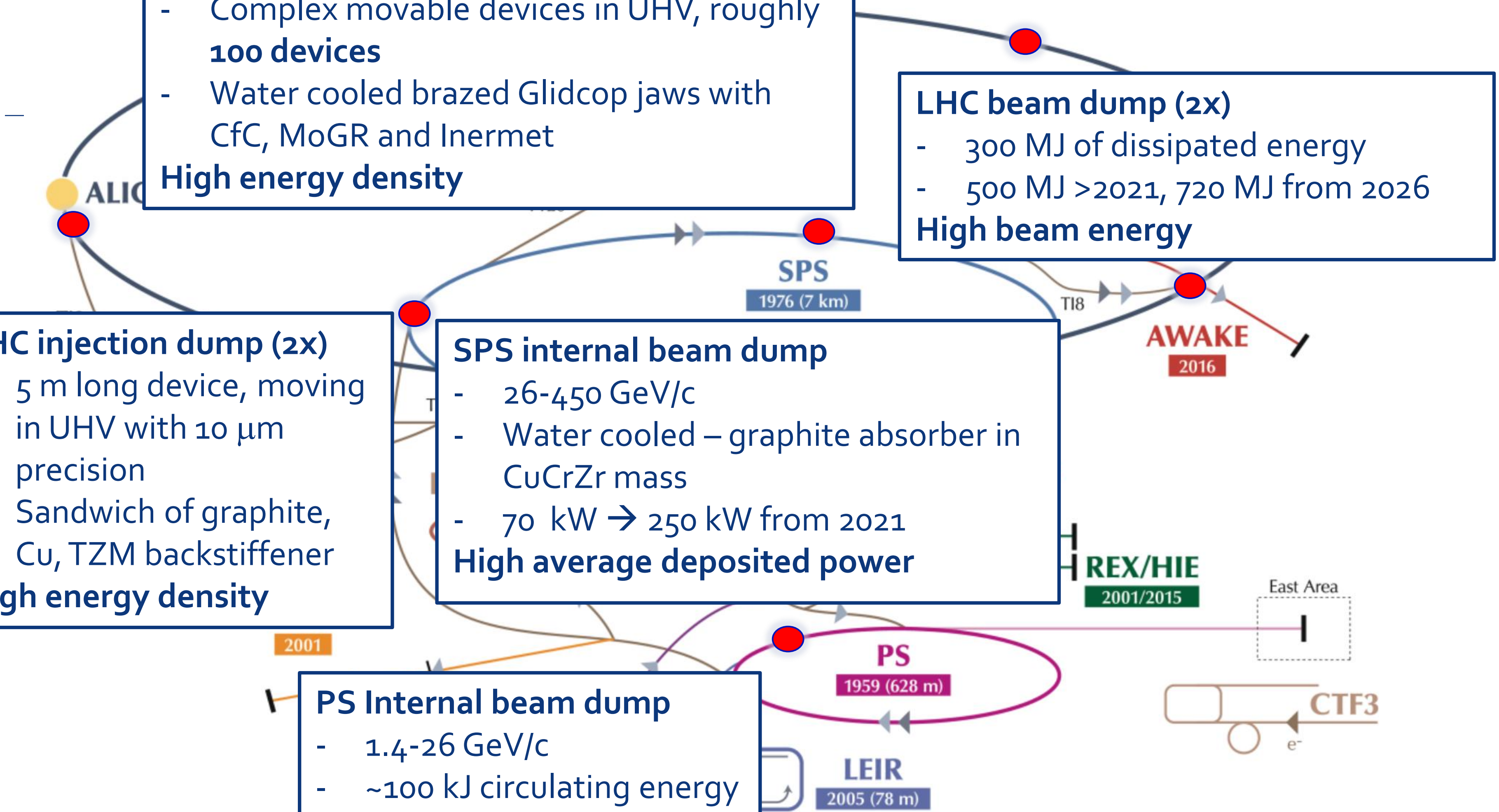


Will be renovating roughly **~70 beam intercepting devices and 2 target areas**, amongst the most challenging of the accelerator complex

SPS Access

SPS Fire Safety

East Area consolidation



LHC collimators

- Complex movable devices in UHV, roughly **100 devices**
- Water cooled brazed Glidcop jaws with CfC, MoGR and Inermet

High energy density

LHC beam dump (2x)

- 300 MJ of dissipated energy
- 500 MJ >2021, 720 MJ from 2026

High beam energy

LHC injection dump (2x)

- 5 m long device, moving in UHV with 10 µm precision
- Sandwich of graphite, Cu, TZM backstiffener

High energy density

SPS internal beam dump

- 26-450 GeV/c
- Water cooled – graphite absorber in CuCrZr mass
- 70 kW → 250 kW from 2021

High average deposited power

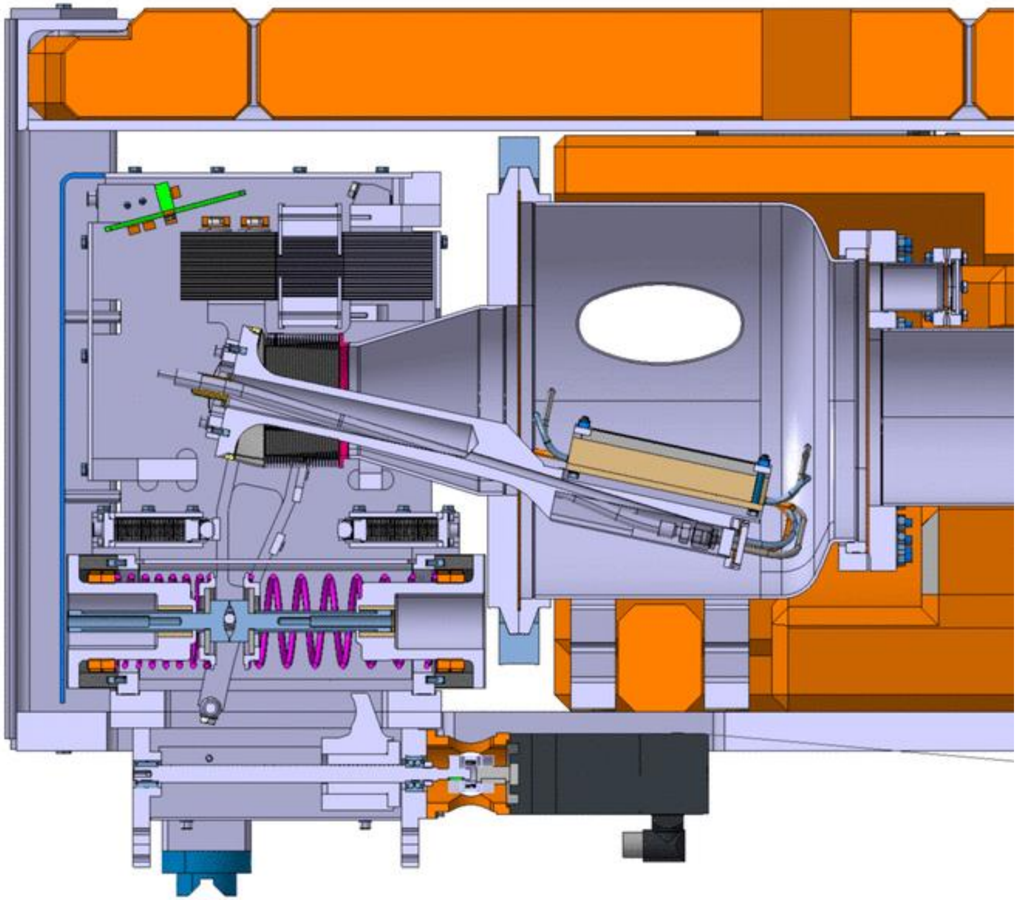
PS Internal beam dump

- 1.4-26 GeV/c
- ~100 kJ circulating energy
- Movable dump in UHV
- Graphite with HIP CuCrZr

UHV and movable devices

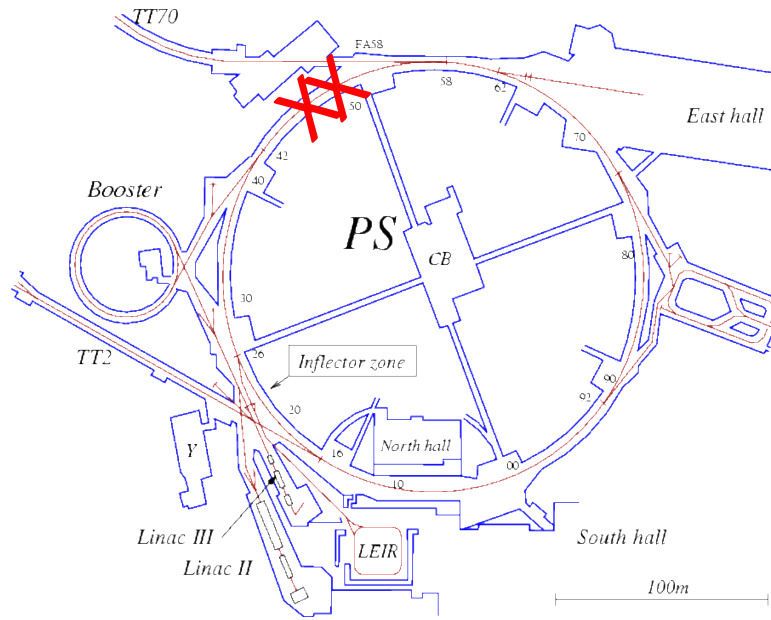
Some examples

Challenge: UHV and movable parts

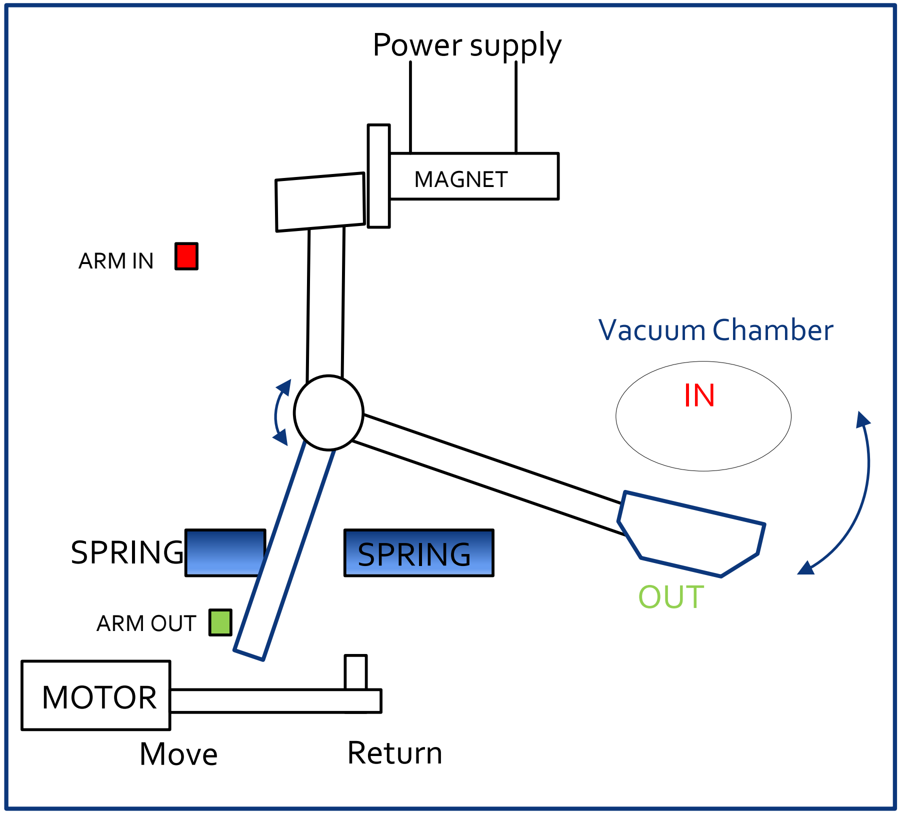


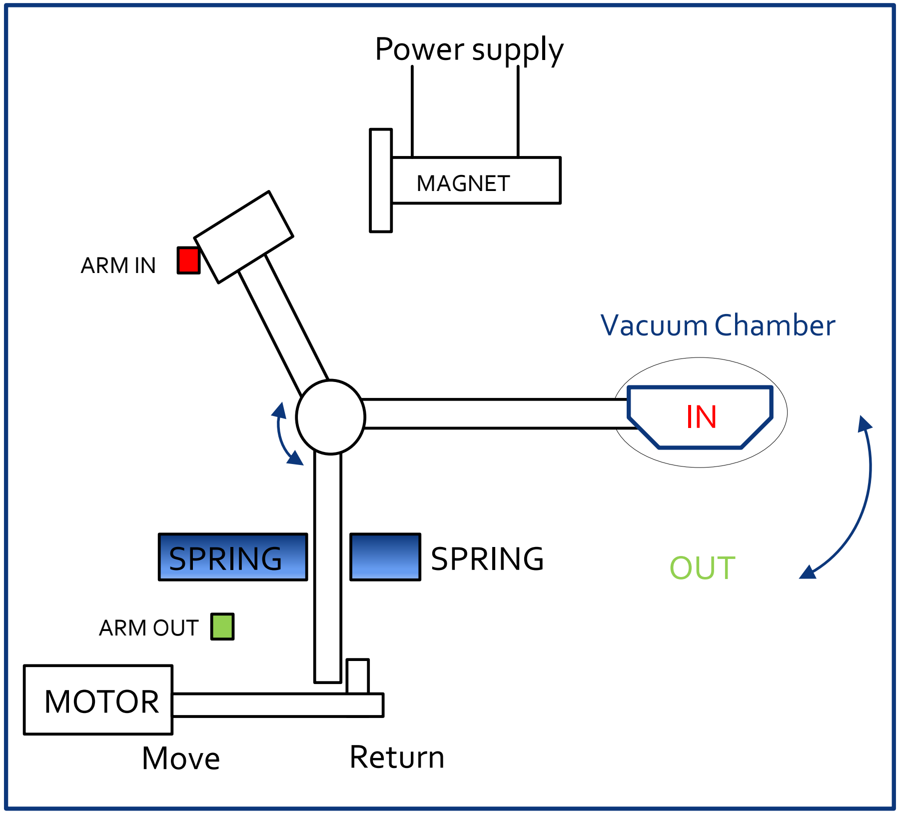
PS Internal Dump

- Main dump(s) of the CERN's Proton Synchrotron
- Beam up to 200 kJ, could have to cope with 80 kW
- Due to PS configuration, the dump are **movable devices in UHV**



- Cycle time ~300 ms
- Revolution time of PS 2.1 μs
- Dump is shaving/scraping the beam over the cycle time, ~150k revolutions
- Dump mass ~10 kg





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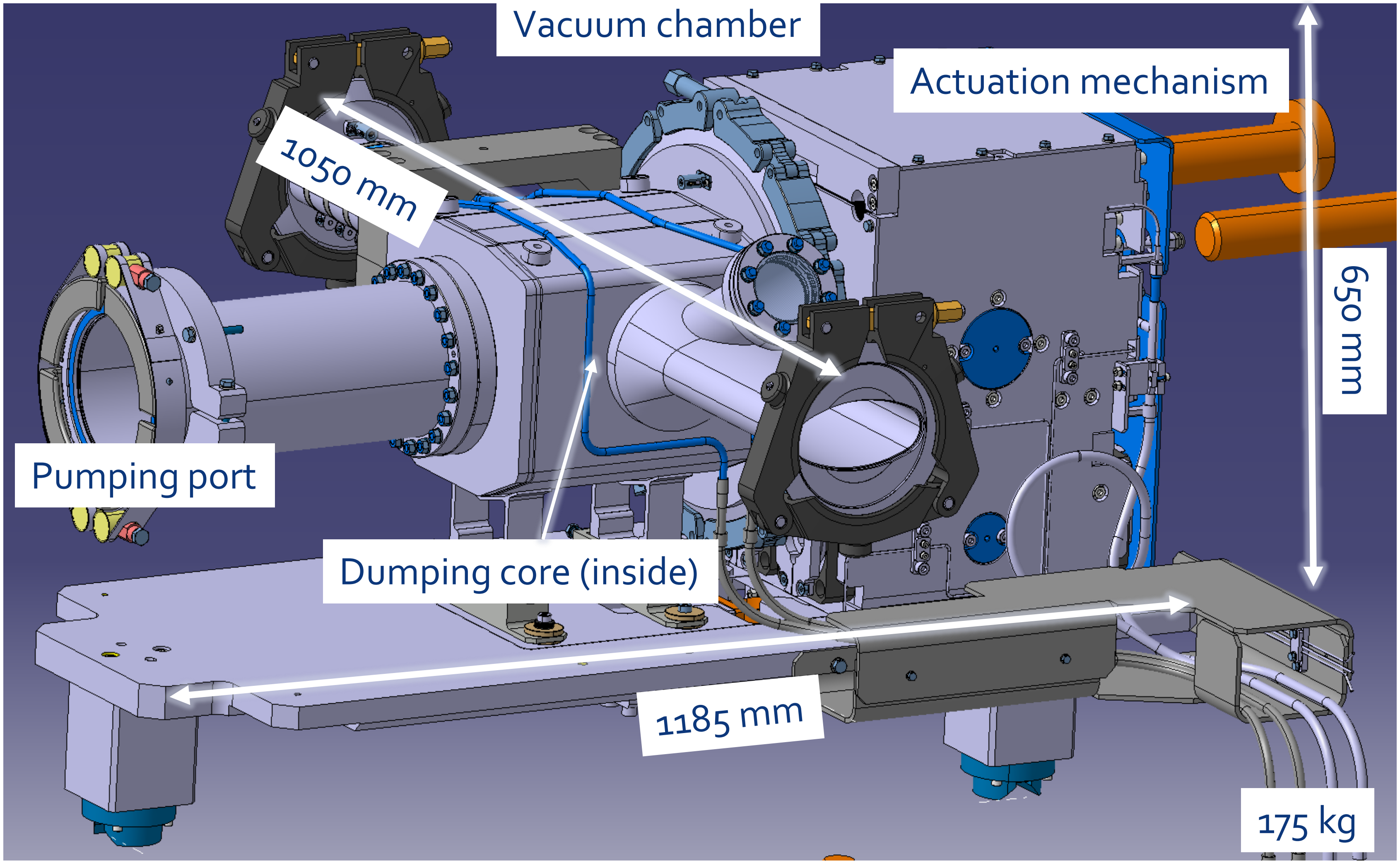
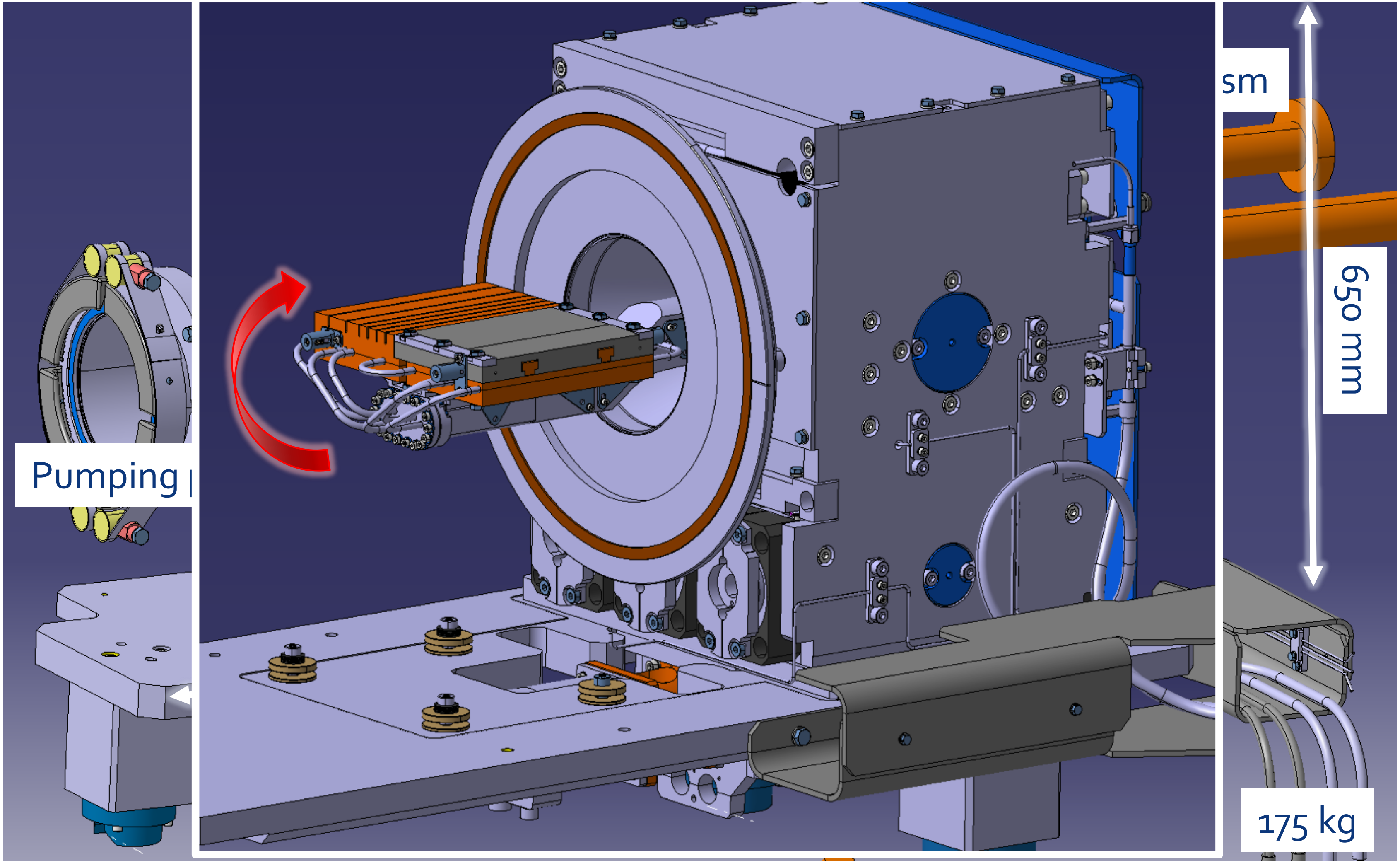
Design of the dump assembly

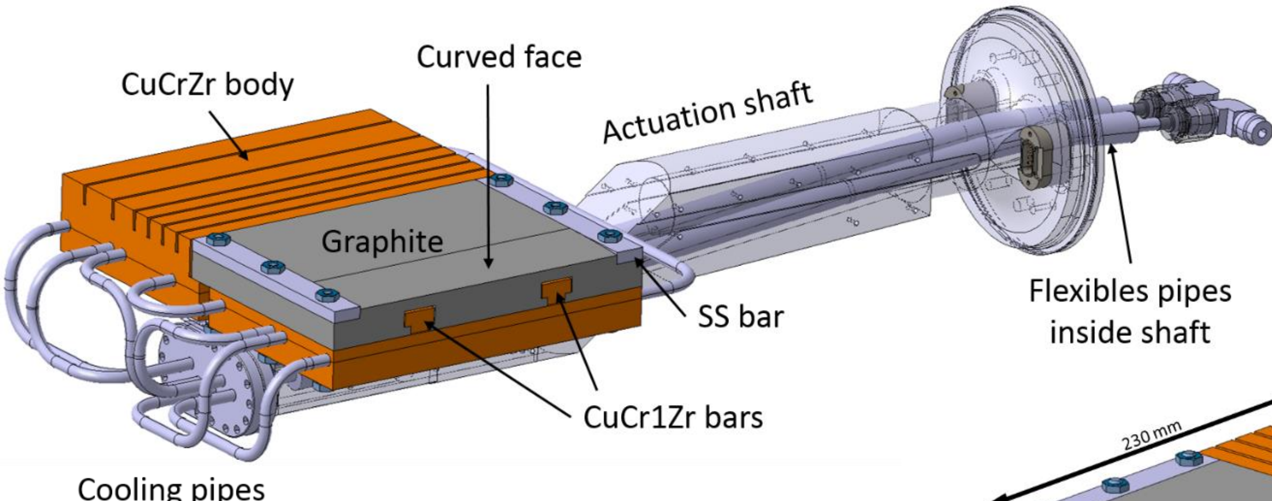


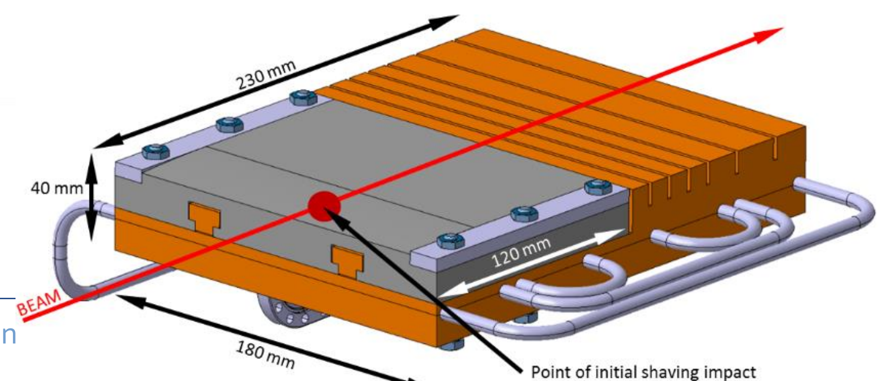
Design of the dump assembly



But how is the core built?

- Old generation was based on a water cooled Cu-OFE block
- Graphite (SGL7550) is required now to cope with higher beam intensities (and higher power) as well as CuCrZr owing to higher strength
- Only solution to remove the heat was based on **diffusion bonding by hot-isostatic pressing (HIP) between CuCrZr and 316L tubes**





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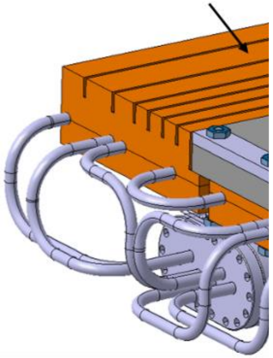
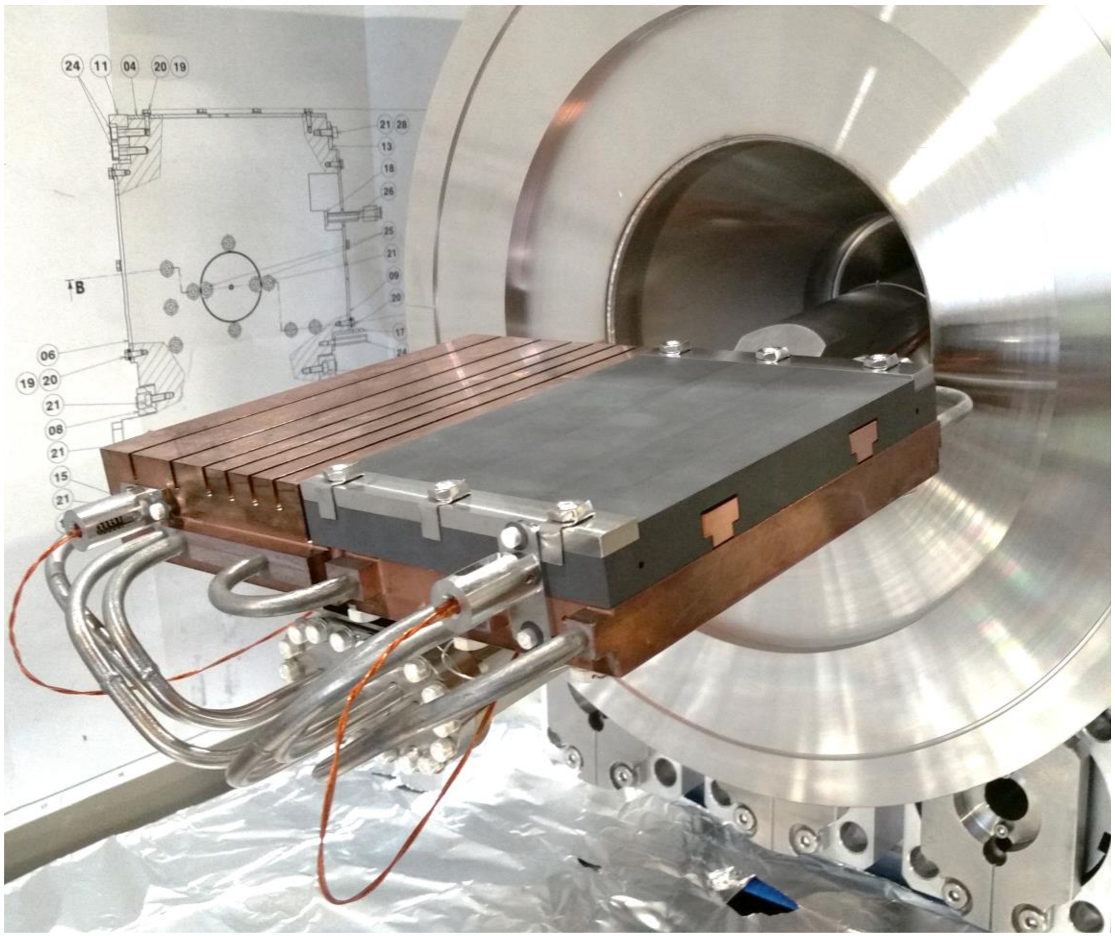
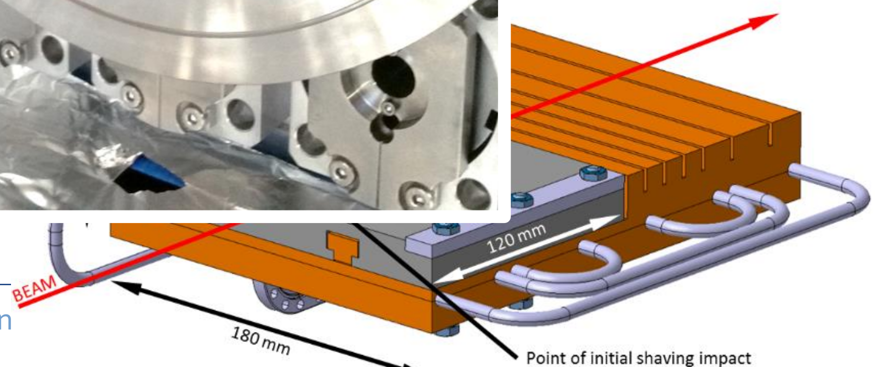
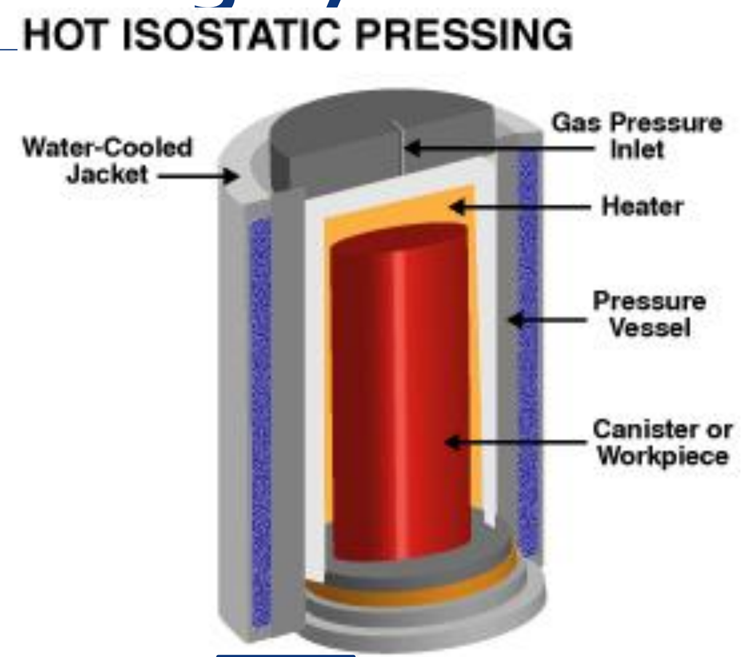


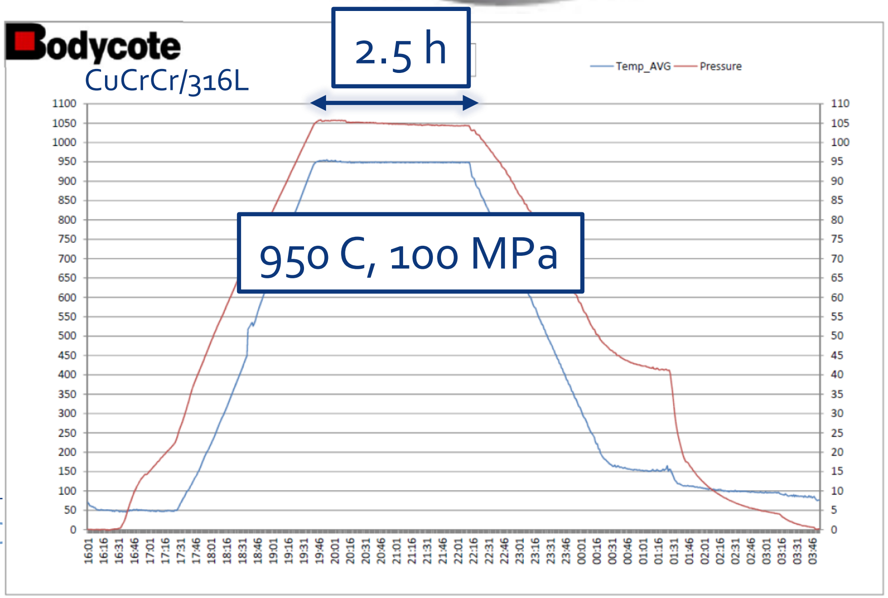




Intermezzo: diffusion bonding by HIP

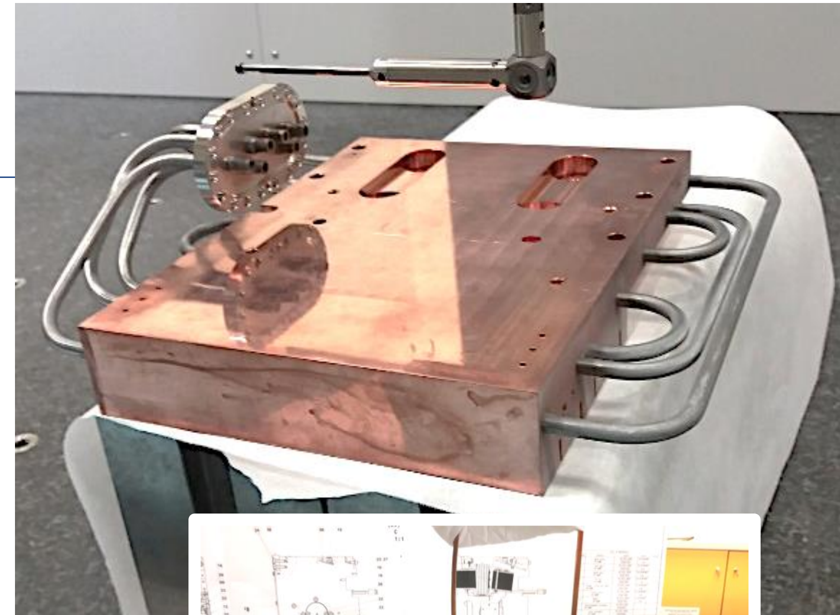
- Hot Isostatic Pressing (HIP)
  - **Maximum thermal efficiency** (diffusion bonding all around the tube – perfect TCC)
  - Compatible with UHV
  - Versatile – different geometries possible
  - Reproducible
  - Sensitivity to tolerances but manageable *once known*

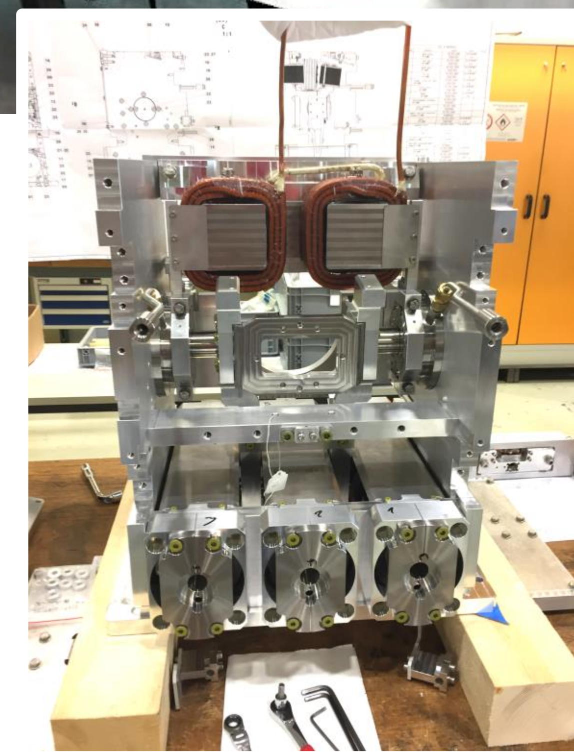




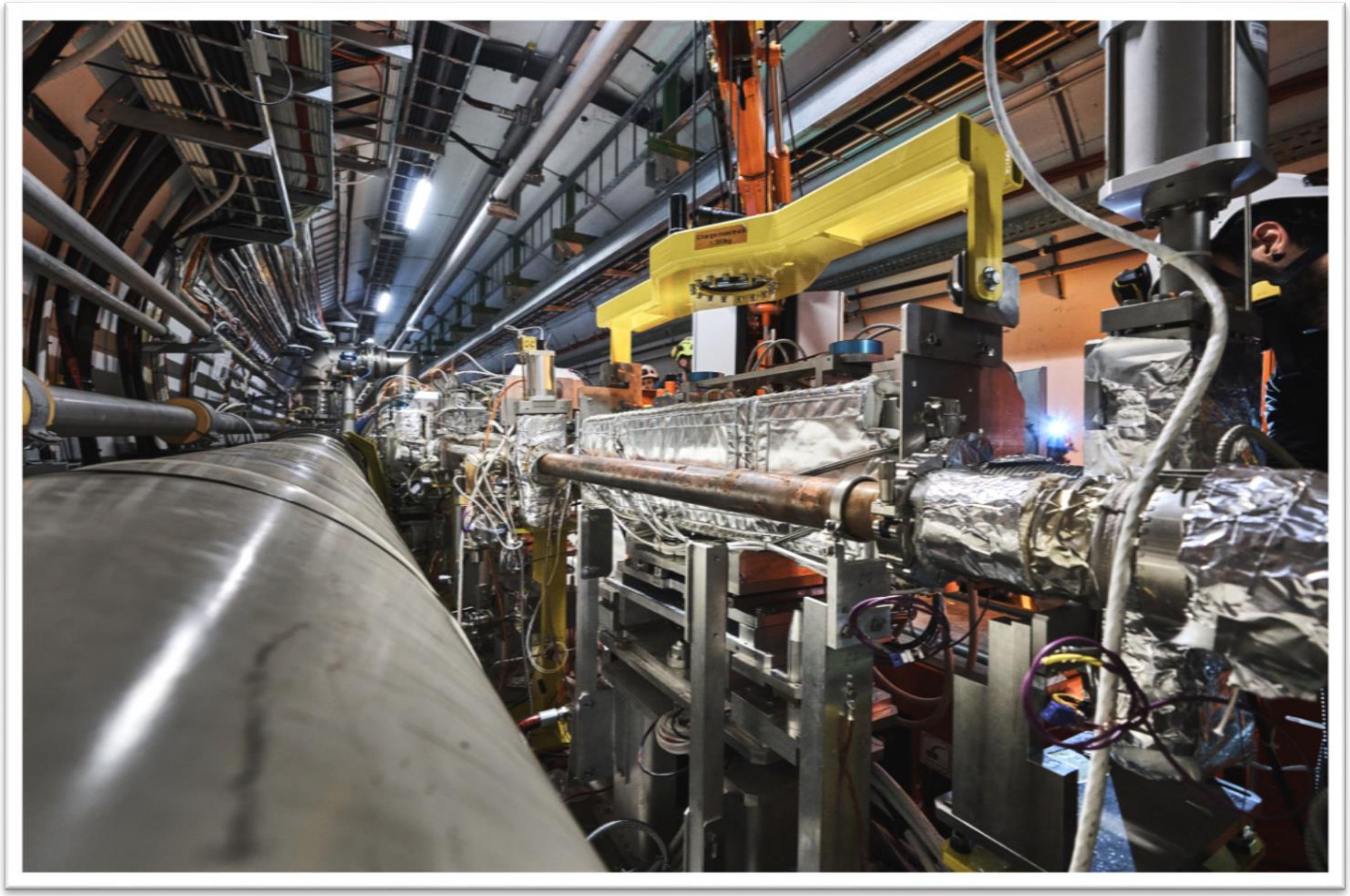
Challenges & status

- Prototype dump successfully run **for 1.5 M cycles**
  - ~10 years operation
- **Final dump** being assembled, together with the final HIP runs for the different cores (3x)
- Attention to material compatibility with UHV is critical
- **All on track for installation in the PS in April 2020**



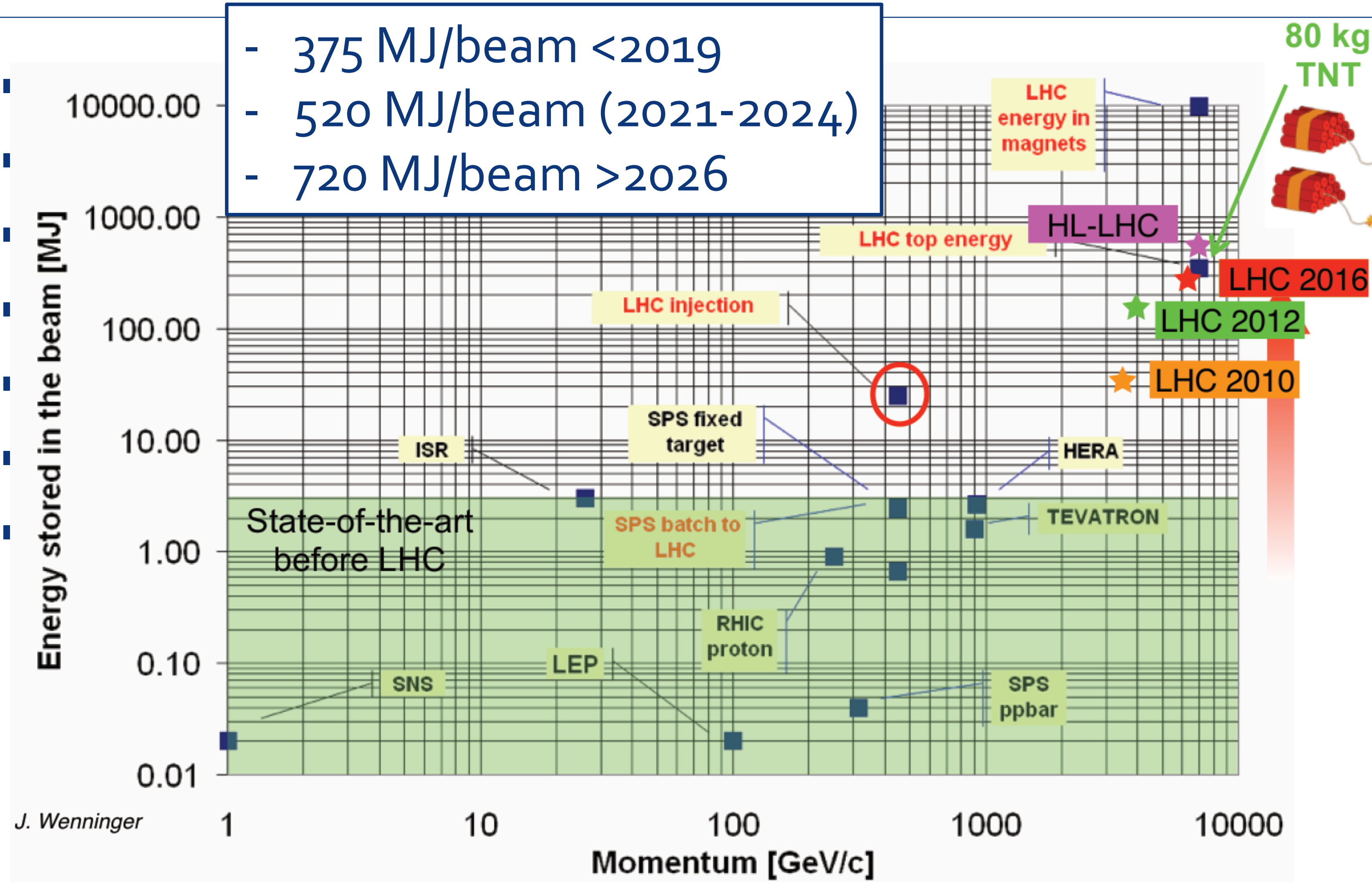


Challenge: High energy density



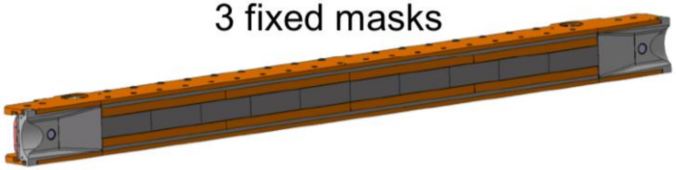
Roles of the collimation system

- 375 MJ/beam <2019
- 520 MJ/beam (2021-2024)
- 720 MJ/beam >2026

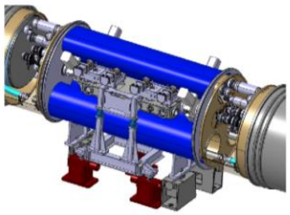


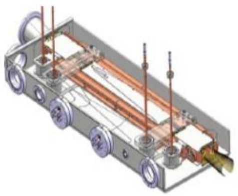
Collimation HL-LHC upgrade baseline

Completely new layouts
Novel robust material: CuCD
IR1+IR5, per beam:
- 4 tertiary collimators (TCTs)
- 3 physics debris collimators
- 3 fixed masks

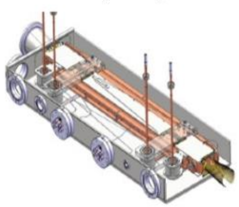


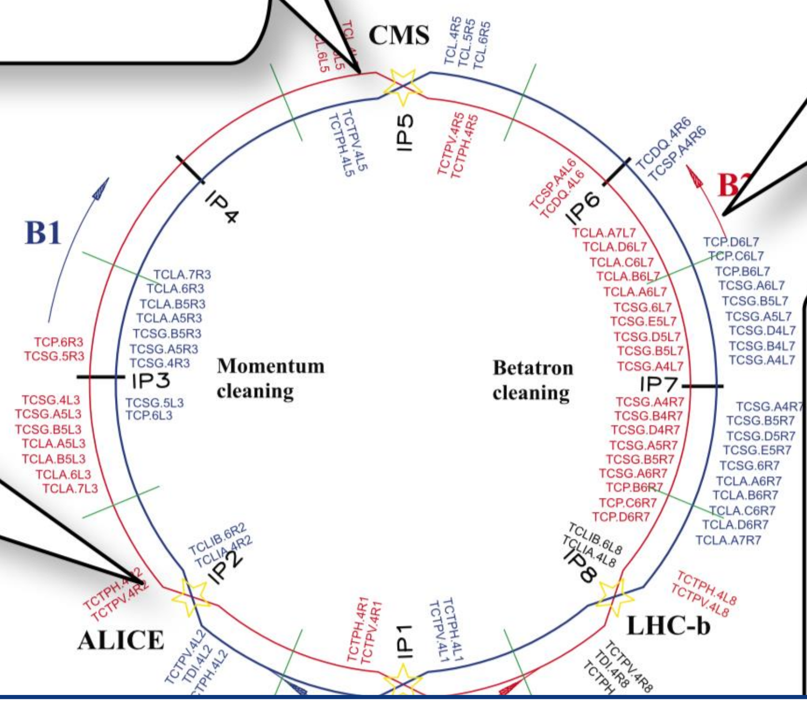
Cleaning: DS coll. + 11T dipoles, 1 unit per beam



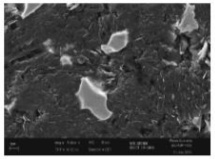


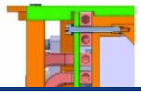
Ion physics: dispersion suppressor (DS) collimation

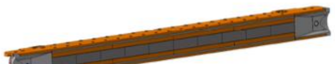




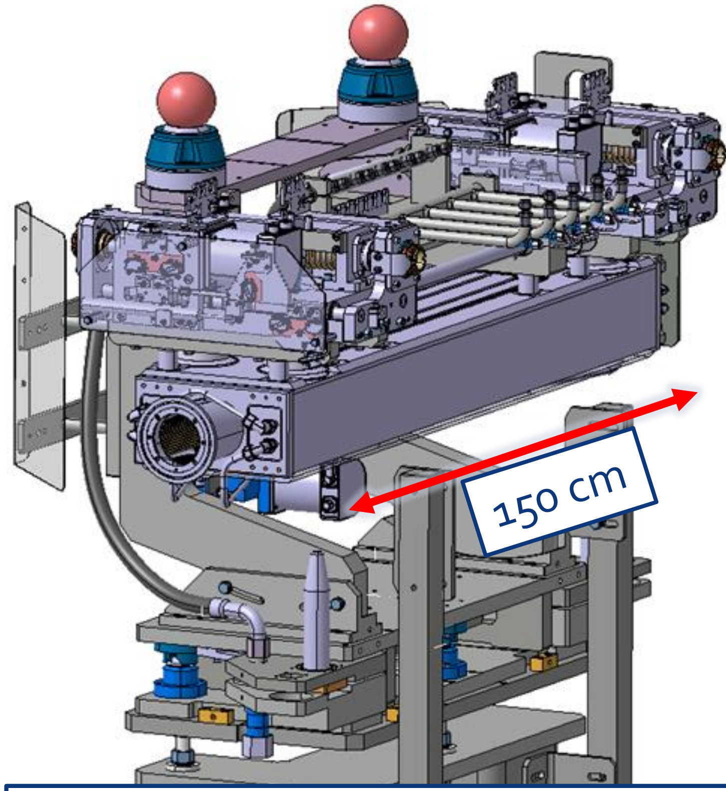
9 low-impedance, high robustness secondary collimators: coated MoGr

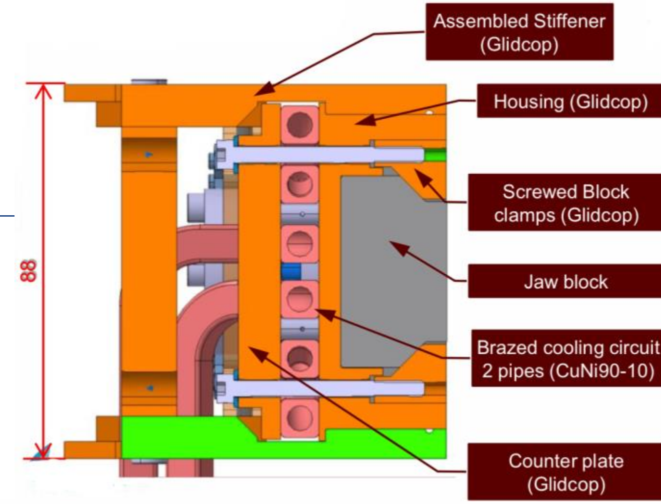


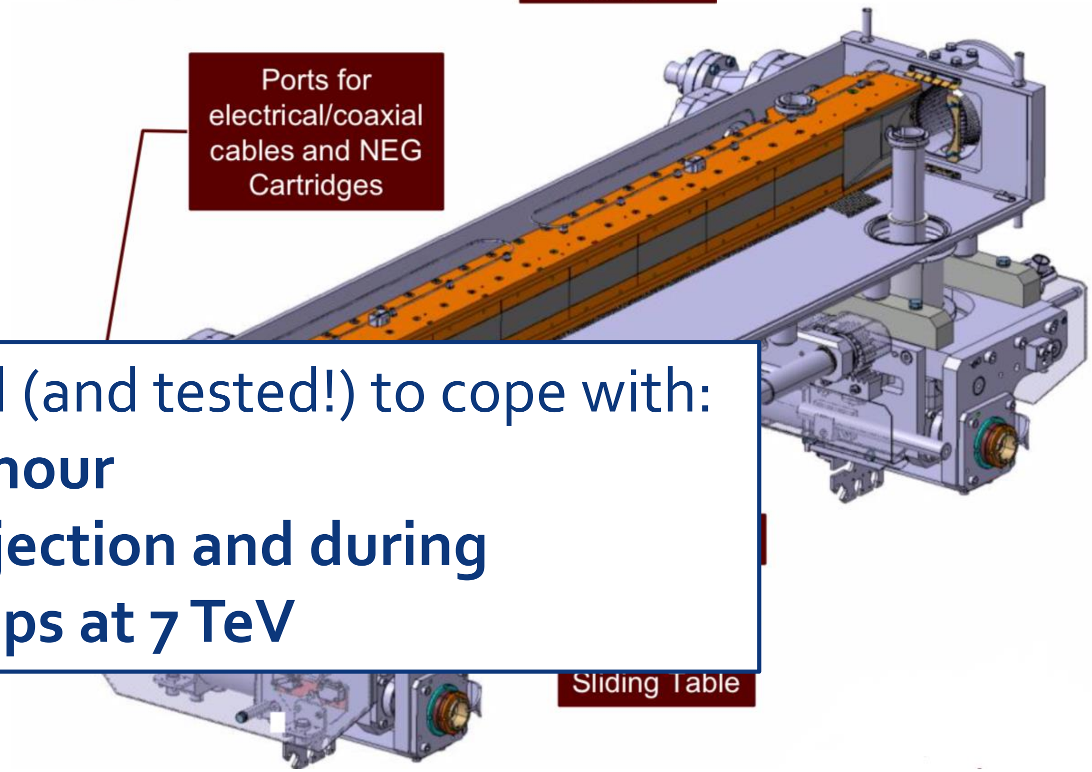




~20 new collimators being built for CERN LS2 (2019-2020)
… while ~40 foreseen for LS3





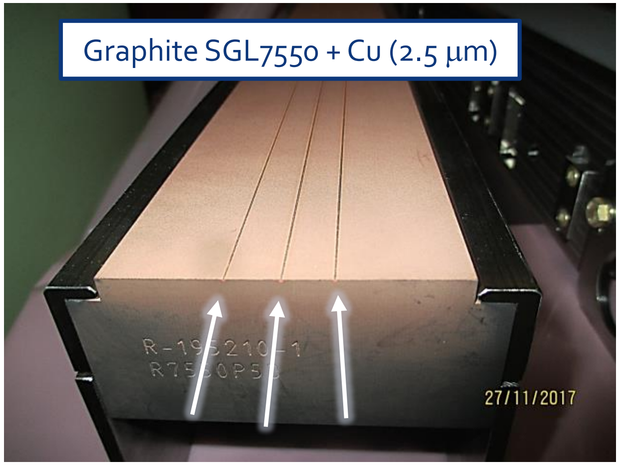


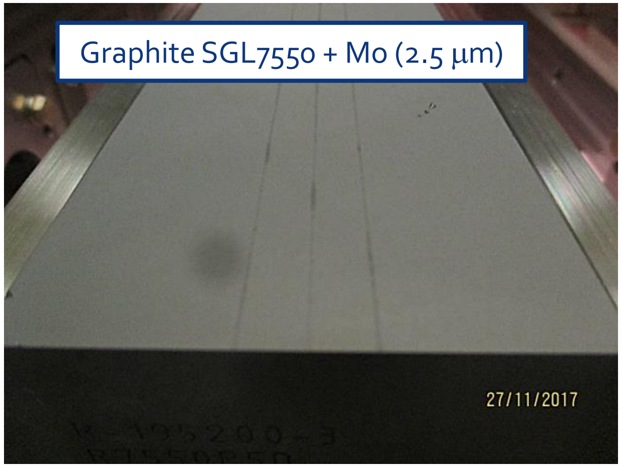
Each collimator jaw designed (and tested!) to cope with:

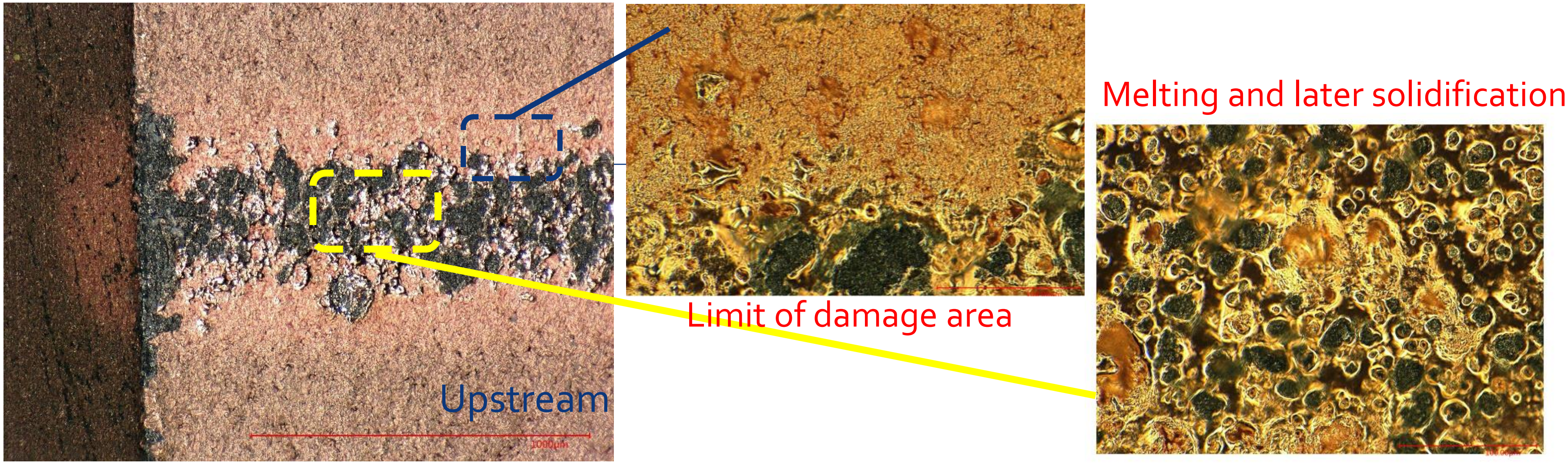
- **10 kW steady losses of 1 hour**
- **Direct beam impact at injection and during asynchronous beam dumps at 7 TeV**

Beam test of coating on collimators jaws

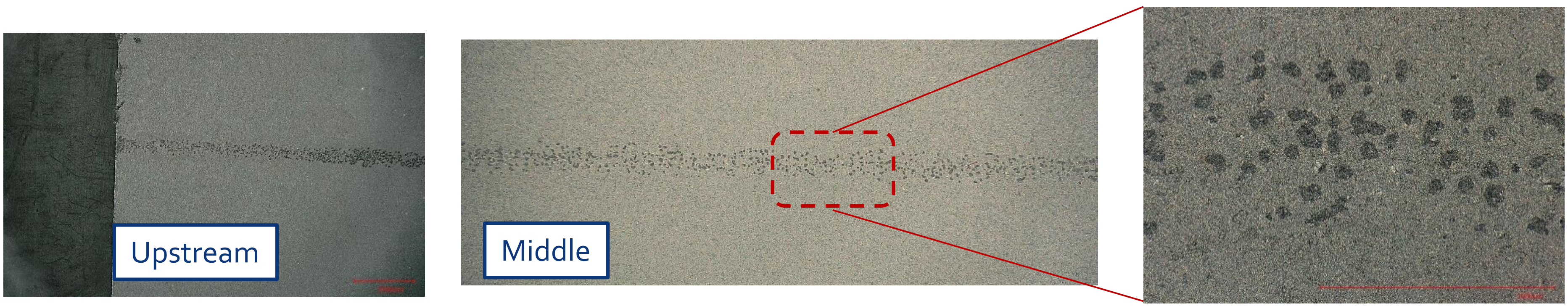
- HiRadMat test of **Cu and Mo coated graphite jaws** to understand **coating adherence under beam impact scenarios**
  - Same energy density as for a potential similar impact in the LHC
- Extensive campaign of simulations vs. experimental results







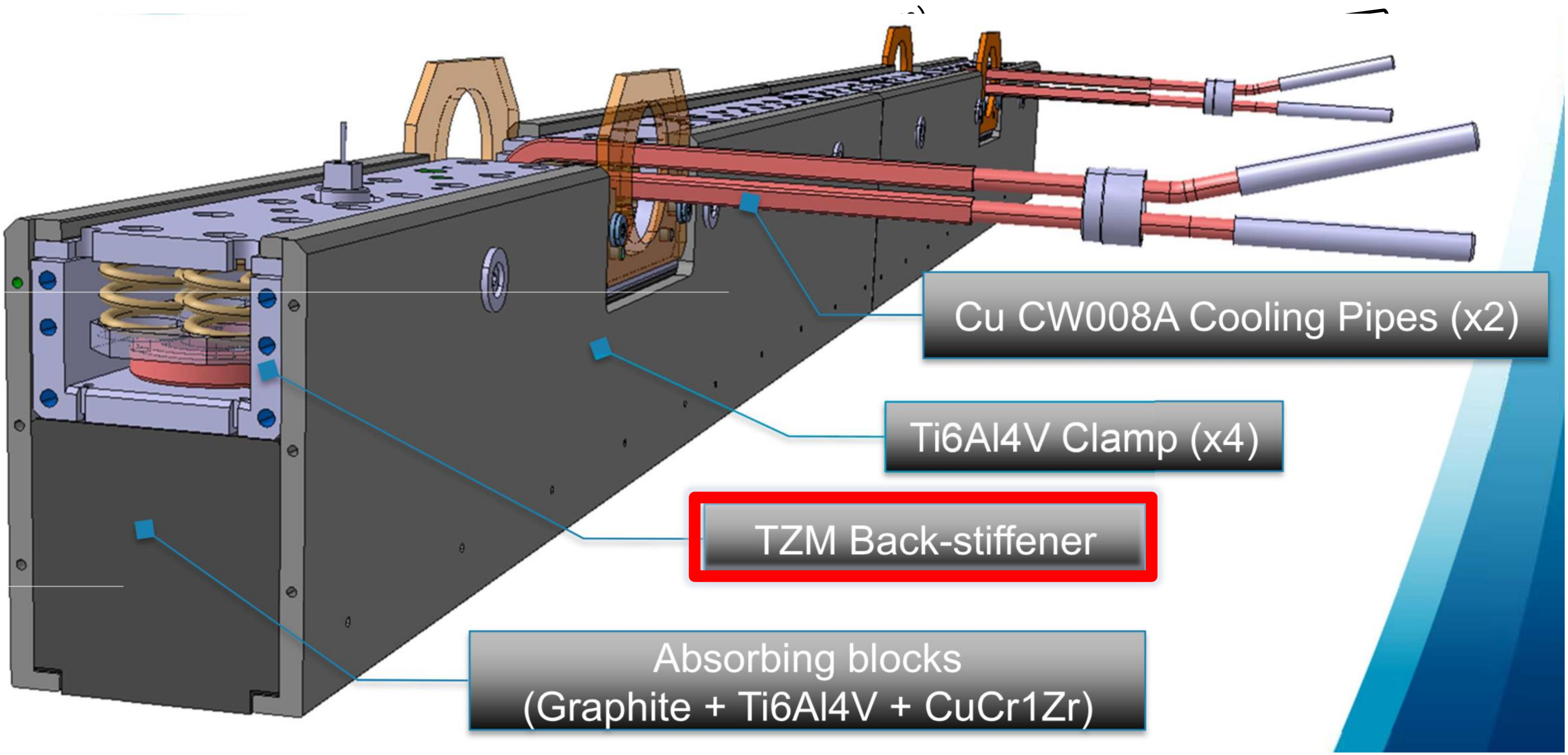
Surface damage detail in Cu coating: grazing impact



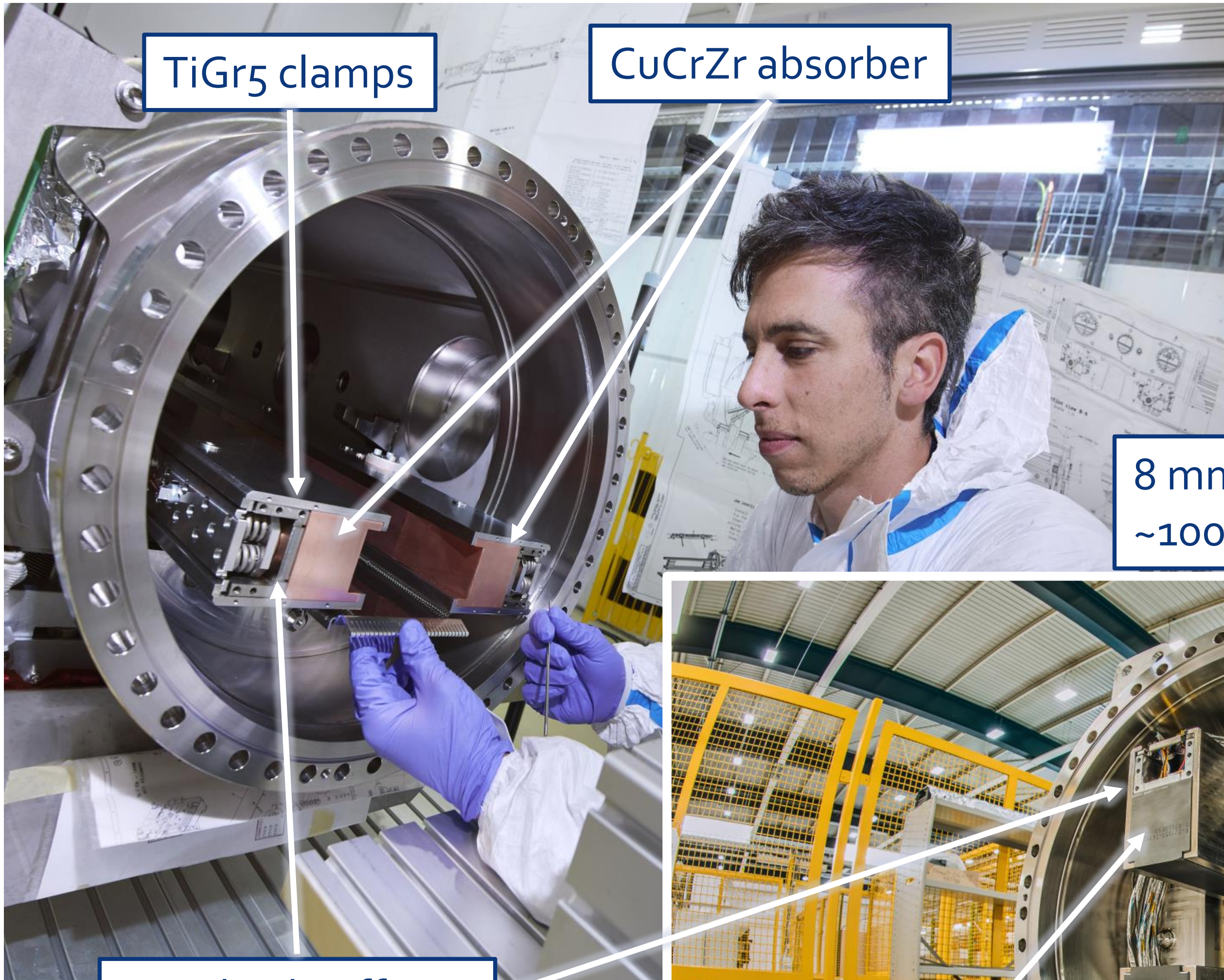
Surface damage detail in Mo coating: tilted impact

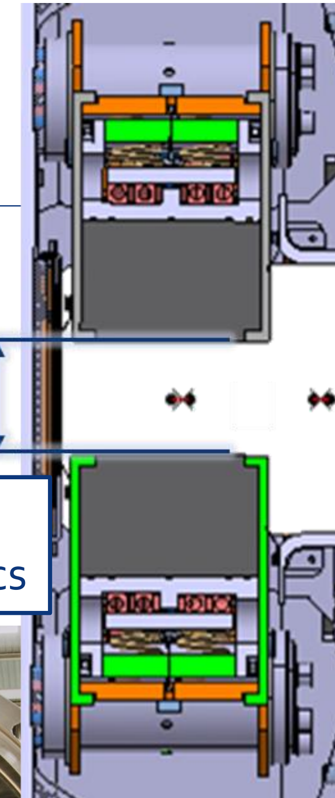
- Microscopic analysis confirms Cu coating **melting as predicted by simulations**
- **Mo coating not melting**, as predicted, but appearing to have spallation damage

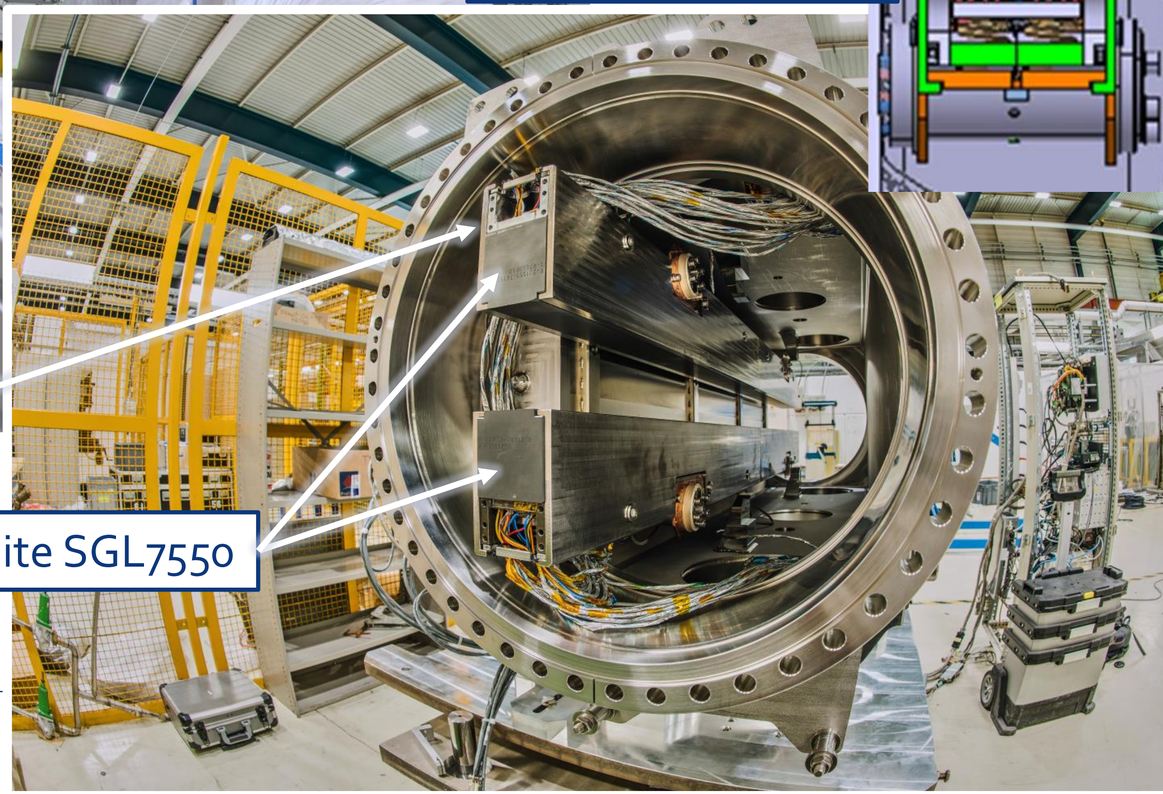
LHC Injection Beam Dump, currently being constructed



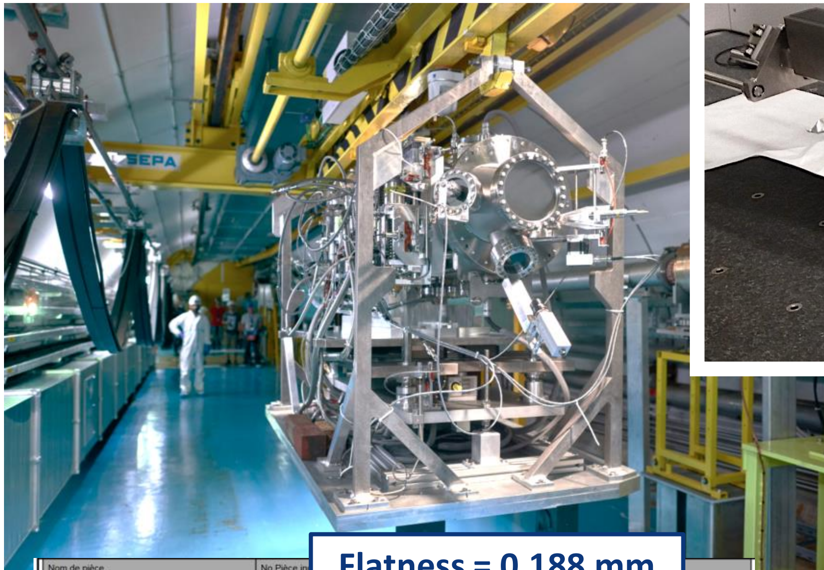
~200 µm flatness of absorbing blocks over the entire length

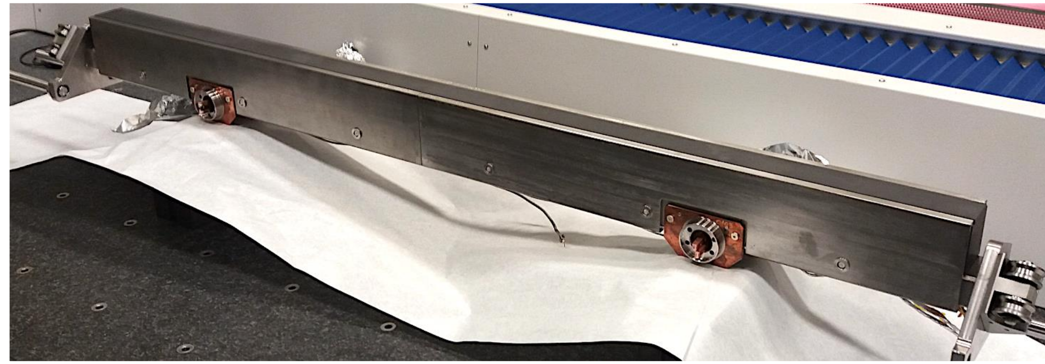

TiGr5 clamps
CuCrZr absorber
TZM backstiffener


Gap
8 mm @injection
~100 mm @physics

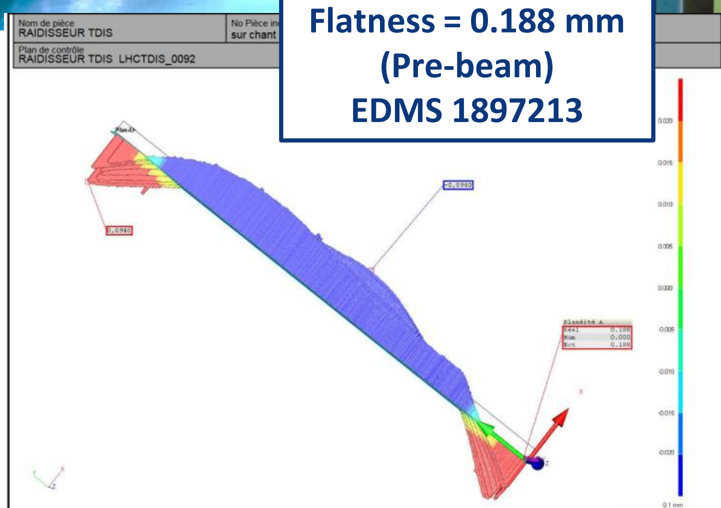

Graphite SGL7550

Validation of jaw resistance at HiRadMat

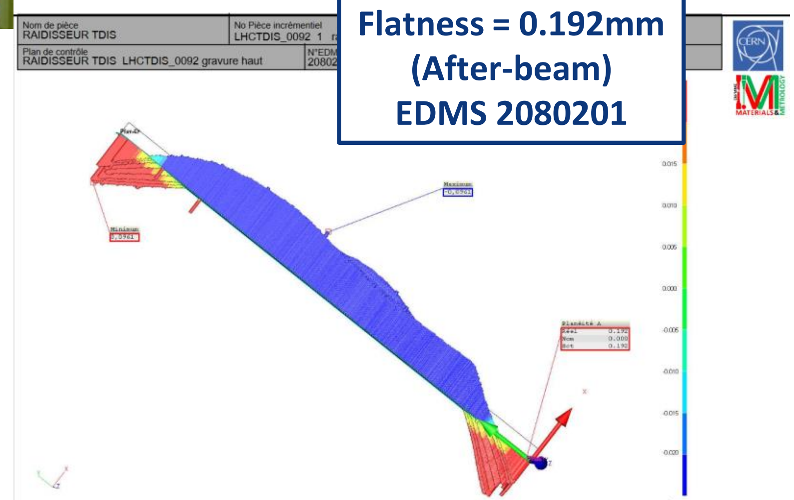




Dose rate ~500 uSv/h at contact

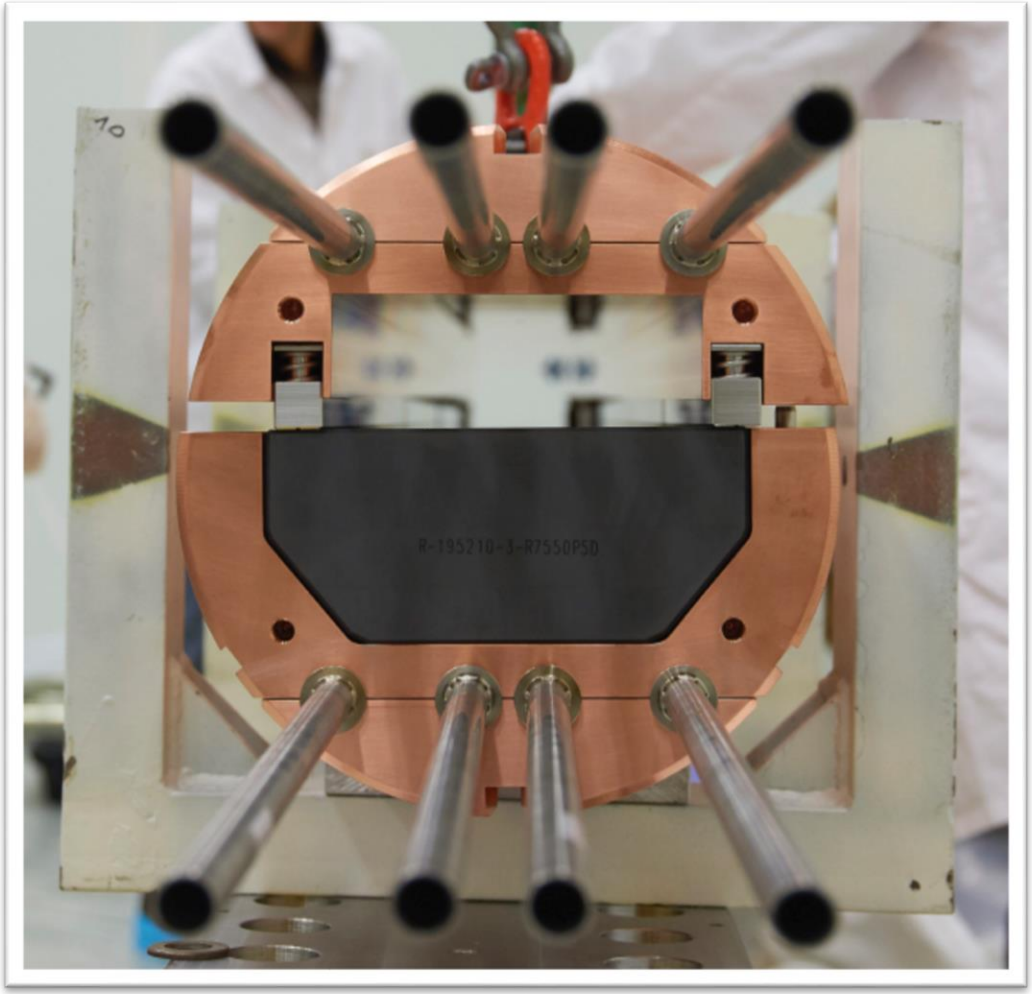


Flatness = 0.188 mm
(Pre-beam)
EDMS 1897213



Flatness = 0.192mm
(After-beam)
EDMS 2080201

Challenge: High average deposited power



SPS internal beam dump

- Due to the specific design of the SPS, the dump is **internal** in UHV
- Heavily used in the machine, to allow flexibility and setting up beams – should **not** be a showstopper for operation and has to be reliable for all beams scenarios

- Up to 2018 at its 4th generation (TIDVG4)
  - **70 kW** (max) dissipated power
  - **4.2 MJ** beam energy
- For LHC Injector Upgrade (LIU) Project → 5th generation is being built
  - **250 kW** dissipated power
  - **5.3 MJ** beam energy

SPS internal beam dump

- Due to the specific design of the SPS, the dump is **internal** in UHV
- Heavily used in the machine, to allow flexibility and setting up beams – should **not** be a showstopper for operation and has to be reliable for all beams scenarios

Challenges:

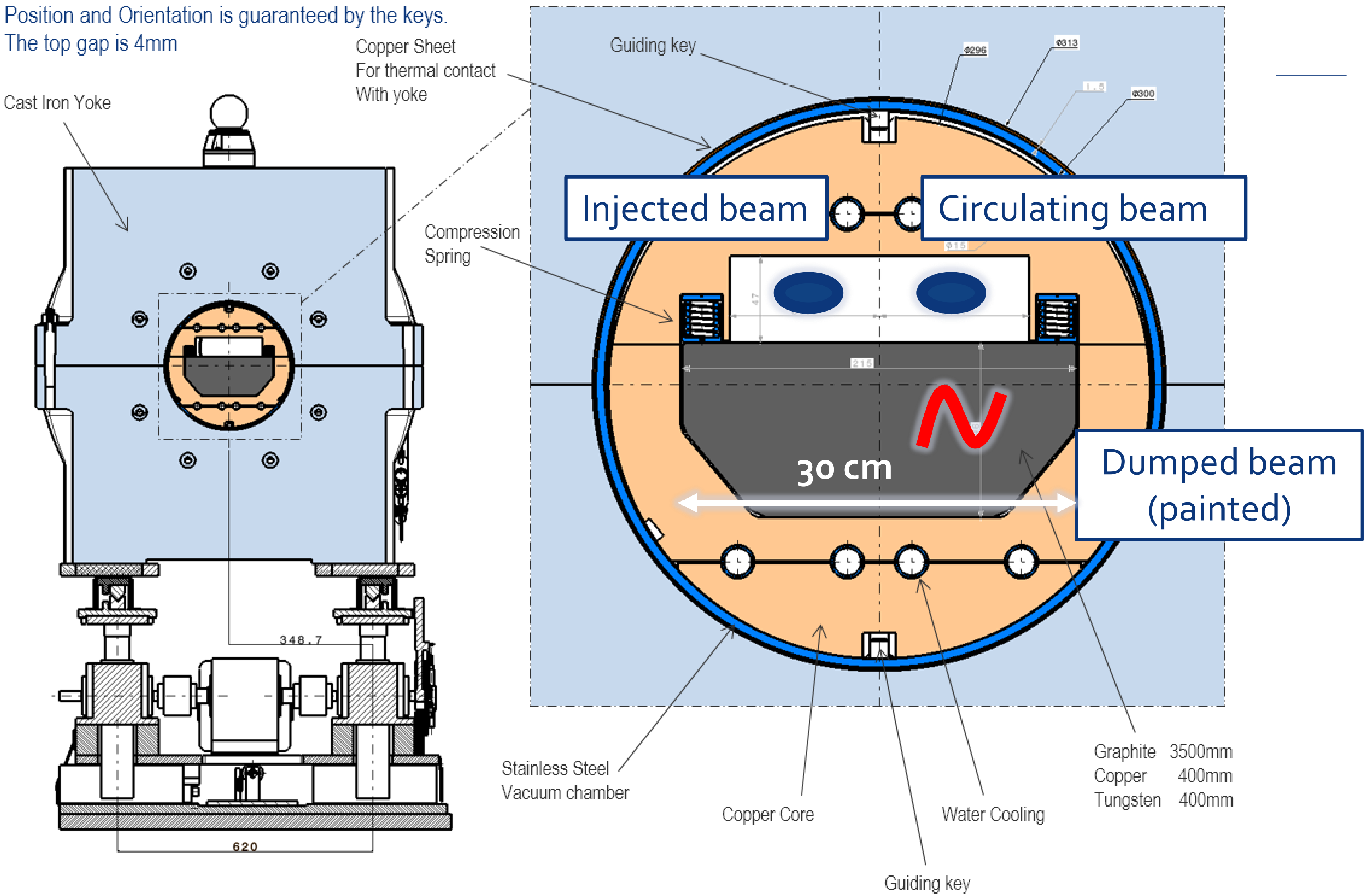
- Materials with high robustness against beam impact
- UHV compatibility
- Good cooling power and thermal contact with absorbing materials
- Limited space longitudinally
- High residual dose rate
- Reliability on the long-term

  - **250 kW** dissipated power
  - **5.3 MJ** beam energy

What could happen with insufficient cooling?

Endoscopy results from a previous generation internal dump, which operated until 2012
→ Complete removal of Al and focus on thermal contact with Cu sink

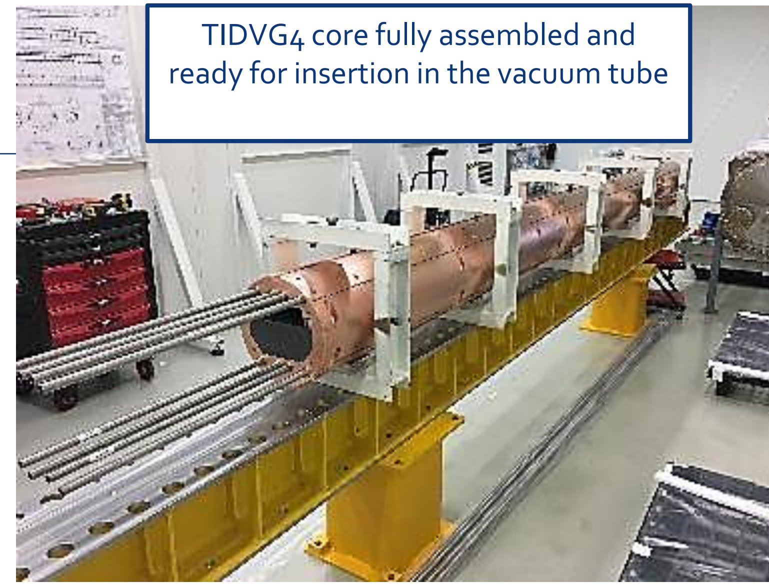
Window: 163.4 x 47 mm
The copper rests in the stainless tube.
Position and Orientation is guaranteed by the keys.
The top gap is 4mm



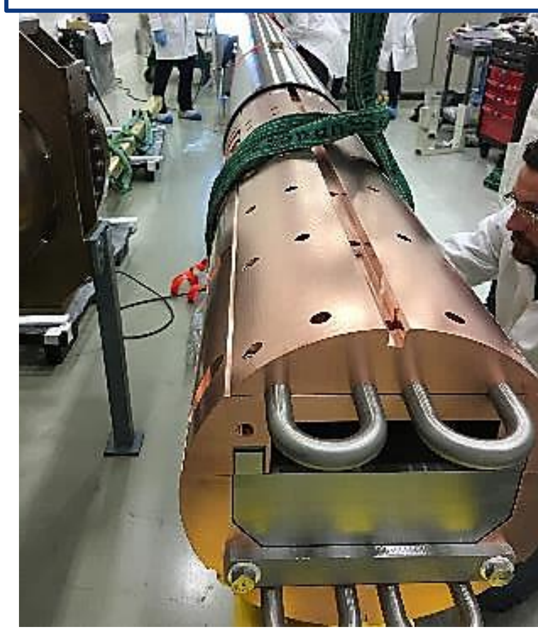
Graphite inside the CuCrZr core

Medium/high-Z absorber

TIDVG4 core fully assembled and ready for insertion in the vacuum tube



TIDVG4 core being pulled into the vacuum chamber



TIDVG4 core fully inserted (upstream)

Final leak detection (upstream w/ water manifolds)

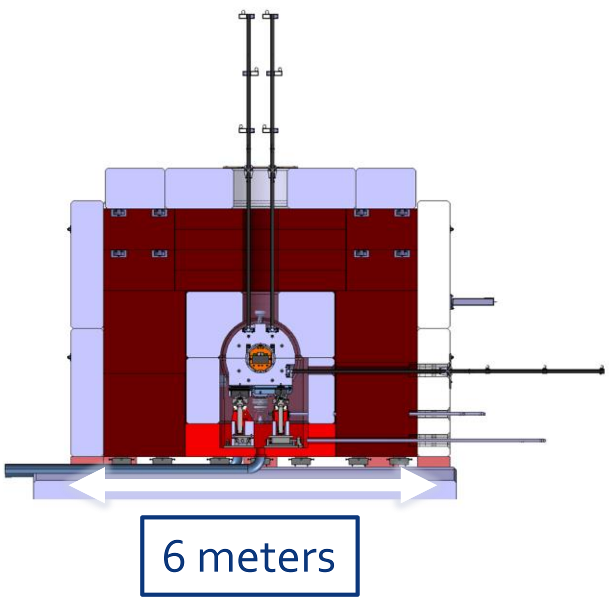
But with the LHC Injector Upgrade Project…

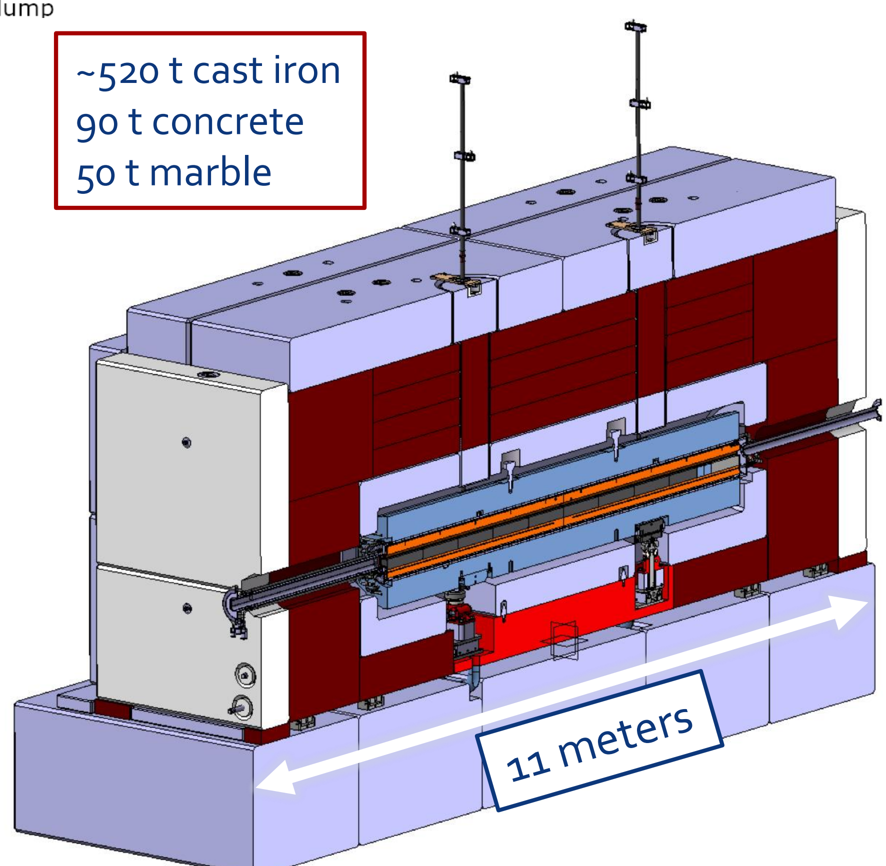
…the current dump will not be sufficient:

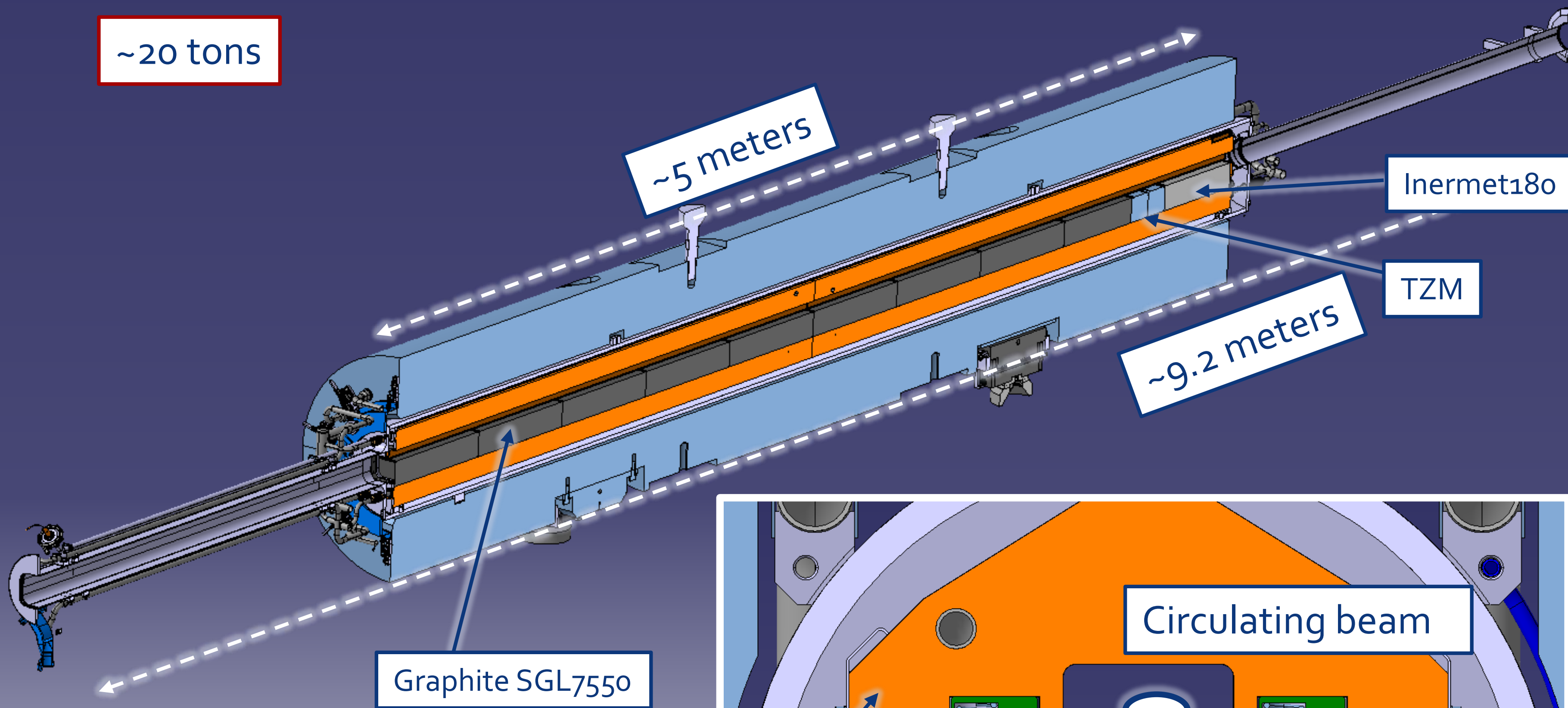
1. Need to cope with **higher beam power** (and deposited)
2. Need to comply with **strict radiation protection** rules

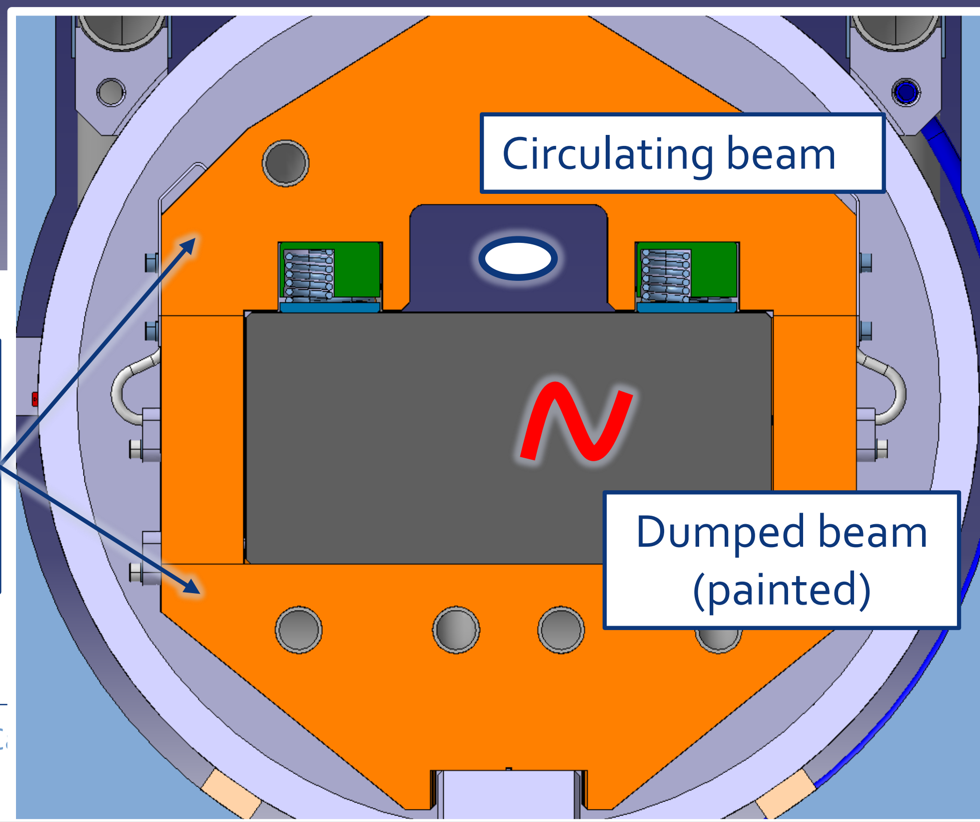
Table 3: HL-LHC beam load parameters for internal dump

Parameter	Unit	HL-LHC Standard Low	HL-LHC Standard High	LIU-80 Low
Energy				
Brightness				
Stored energy				
Pulse period				
Max. dumps / h				
Average power				
Consecutive du				

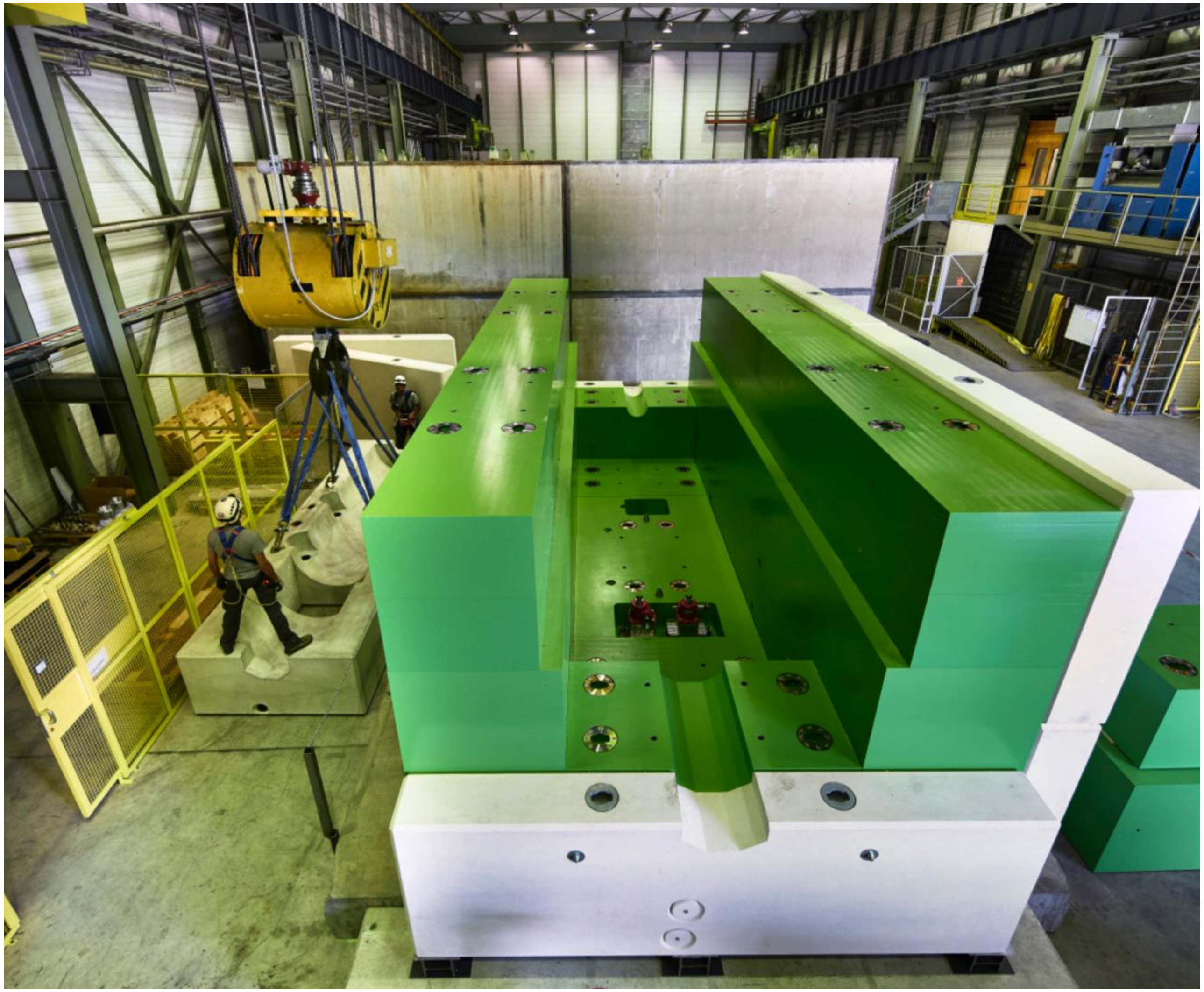





~20 tons
~5 meters
Inermet180
TZM
~9.2 meters
Graphite SGL7550

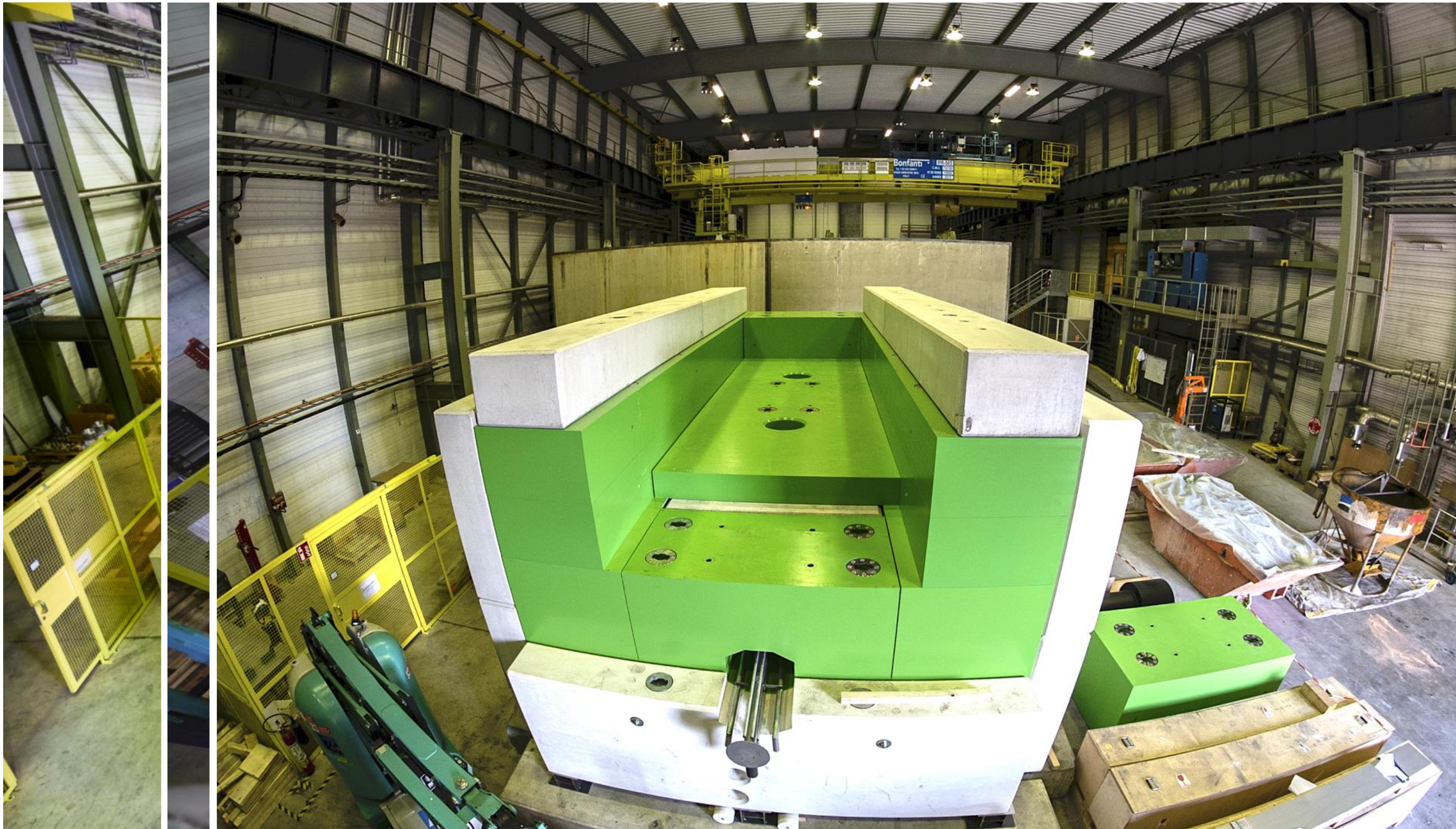

Circulating beam
CuCrZr jacket, HIPed to 316L tubes (water cooling)
Dumped beam (painted)

… to reality!



… to reality!

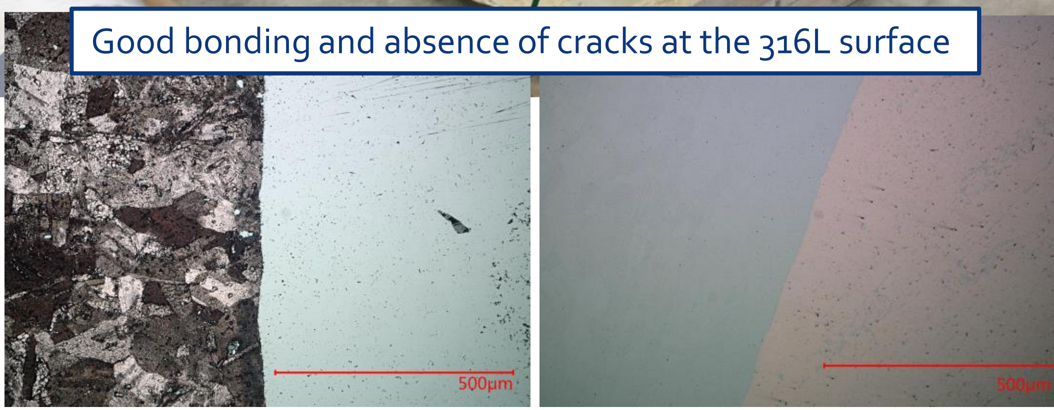
… to reality!



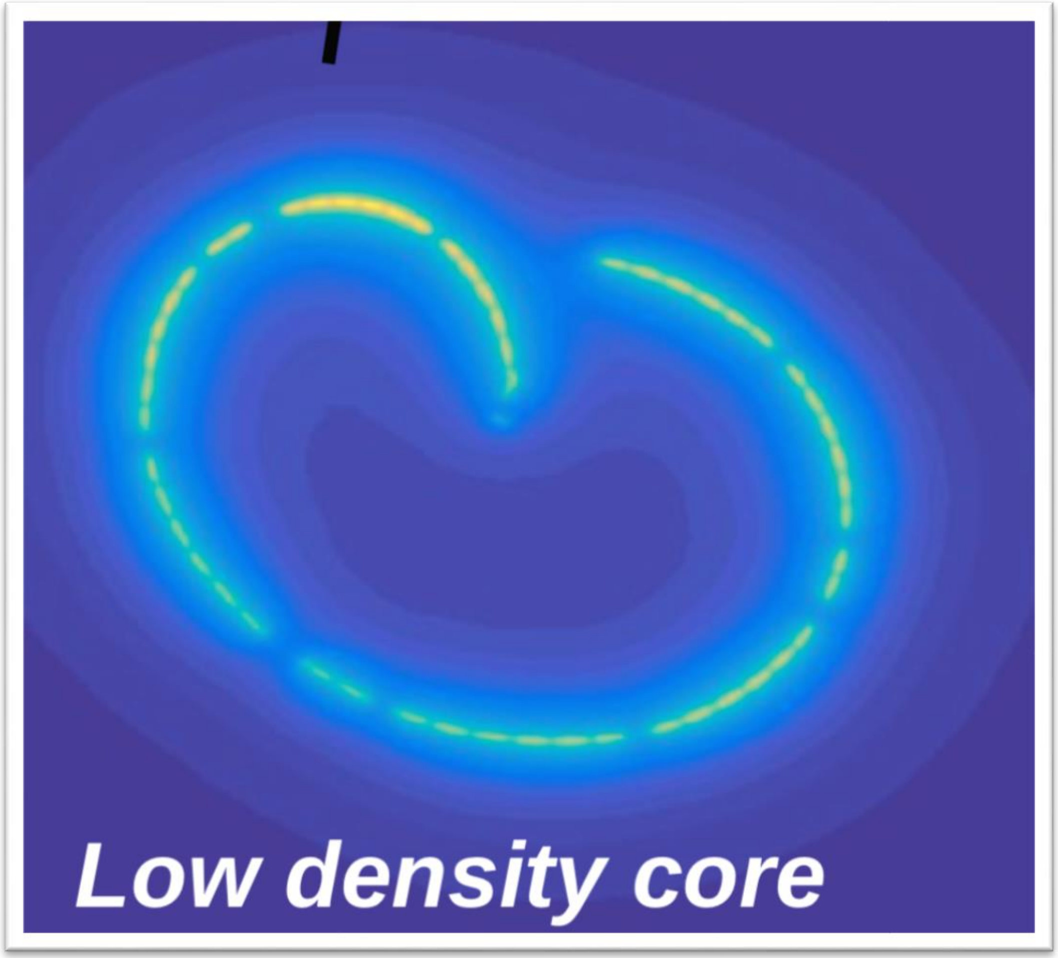
Core being design with HIP technology

All items on track for production and installation of the new dump in SPS during summer 2020

Good bonding and absence of cracks at the 316L surface

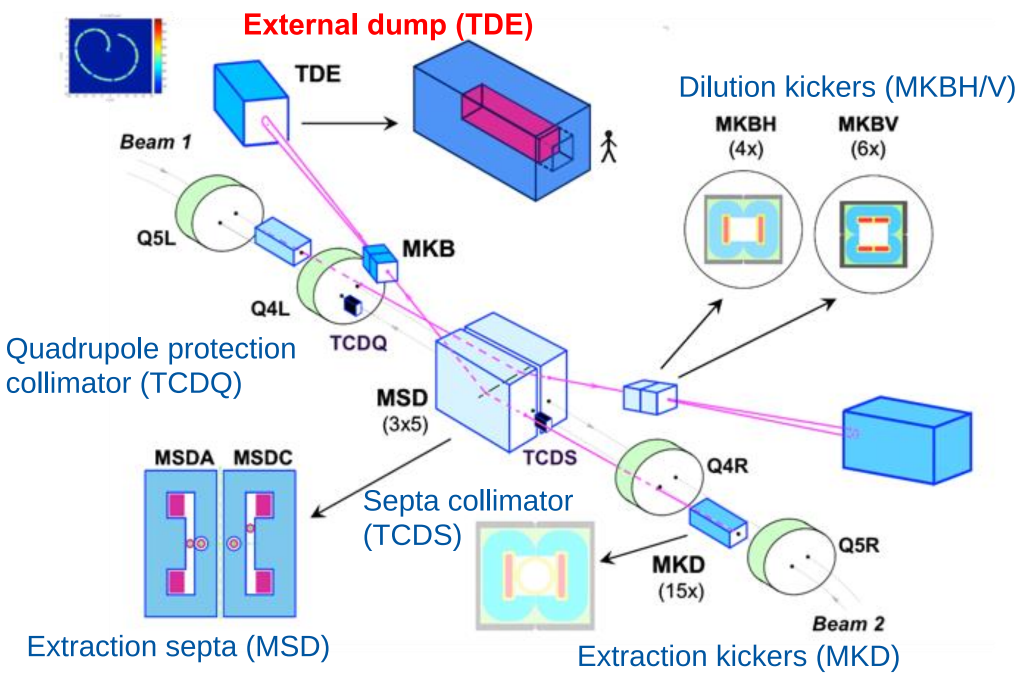


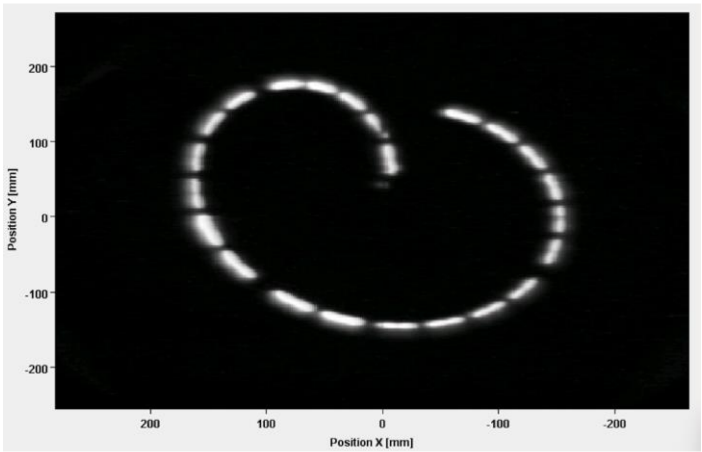
Challenge: High beam energy



LHC external beam dump

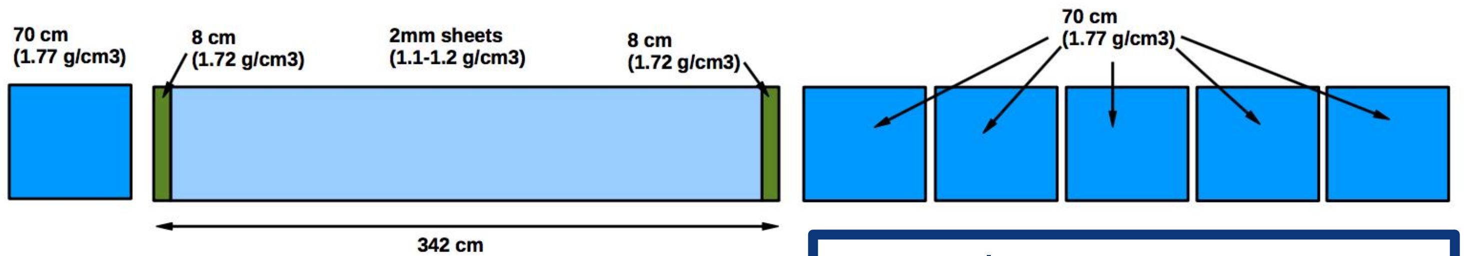
- Circulating beams in the LHC have a kinetic energy of around **300 MJ/beam** (until 2018) → the LBDS is taking care of its extraction from the ring
- **Beam diluted** over the extraction time of **84 μs**





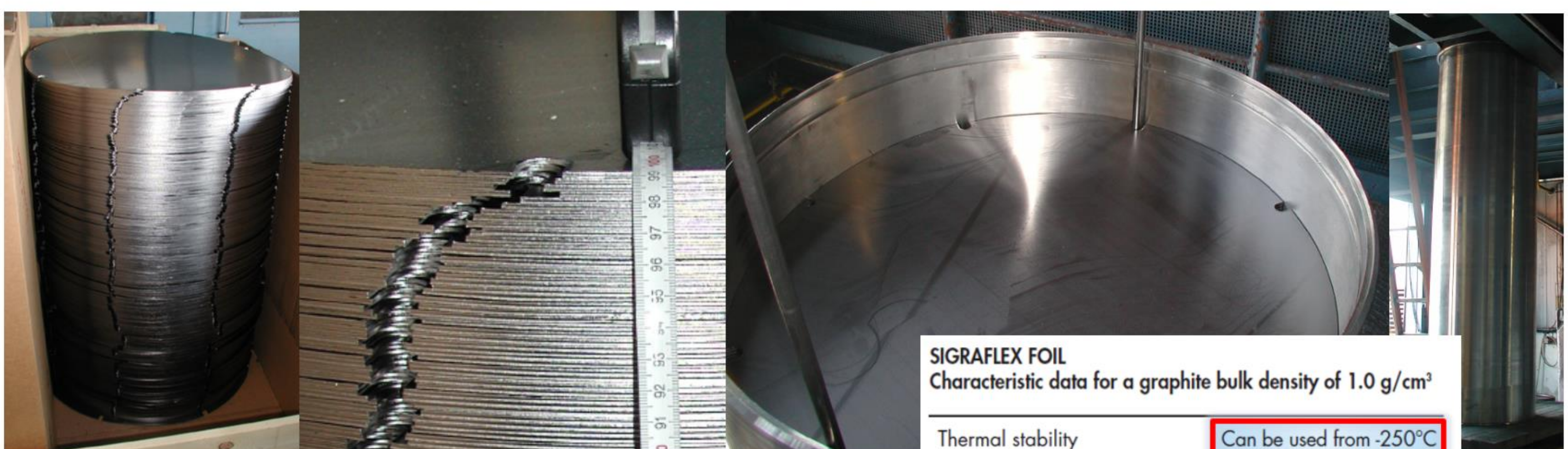
LHC external beam dump

High and low-density segments:



Currently:
- **240 MJ** deposited in graphite
- **20 MJ** in the 318L shell

Low-density flexible Graphite sheets:

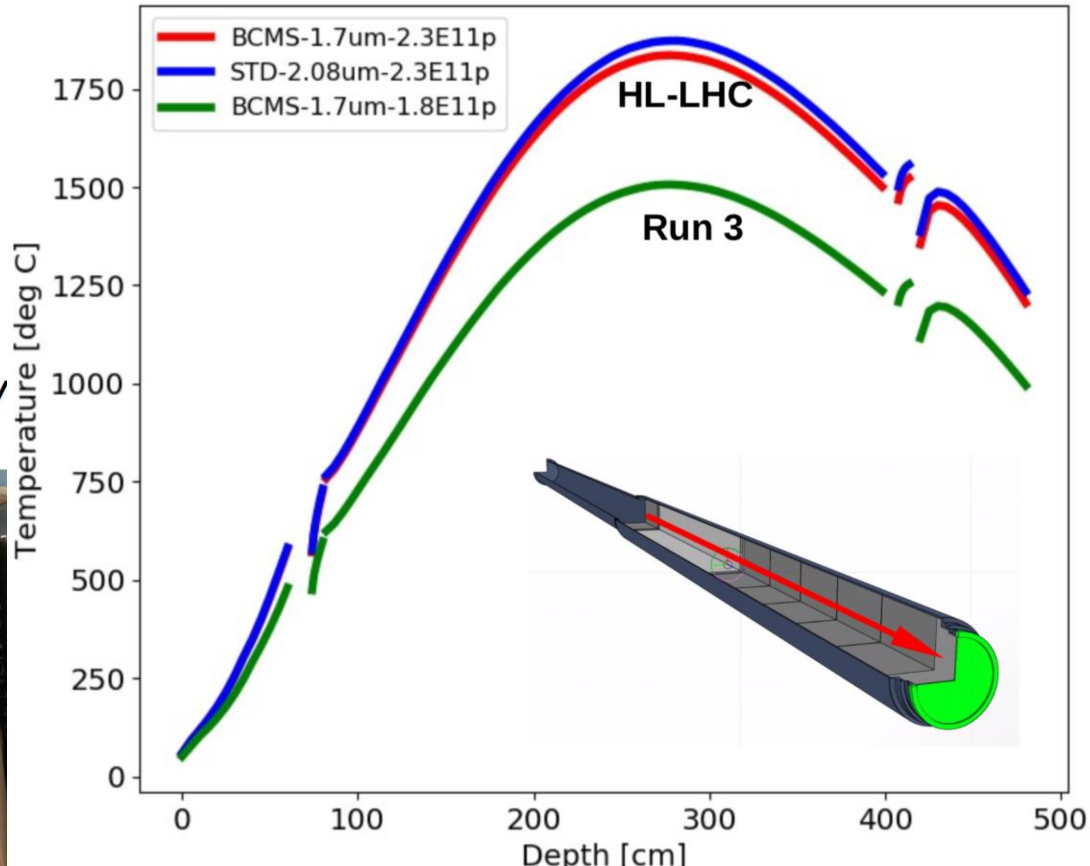


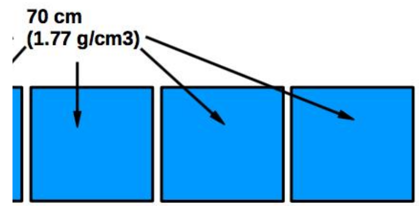
SIGRAFLEX FOIL
Characteristic data for a graphite bulk density of 1.0 g/cm³

Thermal stability		Can be used from -250°C up to approx. 3000°C (in protective gas)
Sublimation temperature	°C	> 3000

LHC external beam dump

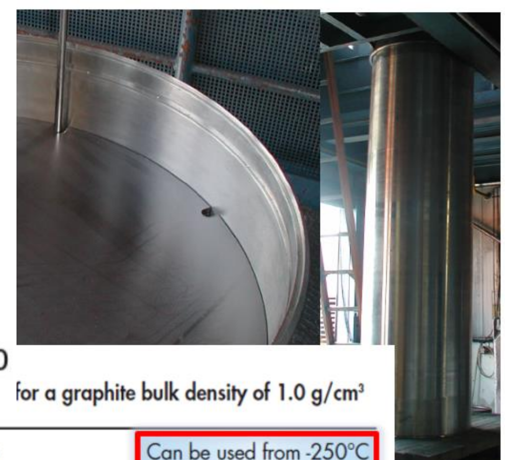
High and low-density segments:





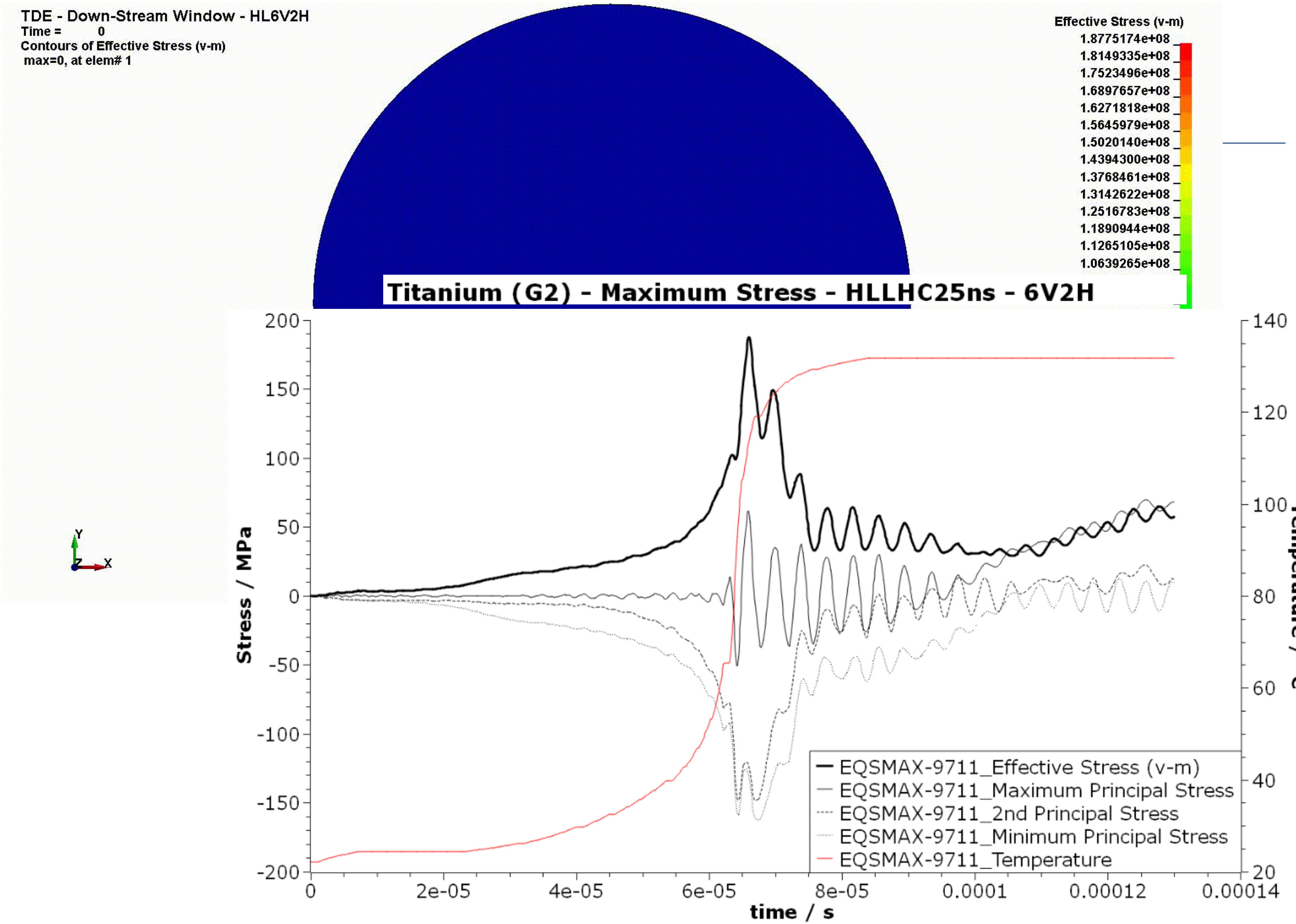
Low

eposited in graphite
he 318L shell



for a graphite bulk density of 1.0 g/cm³

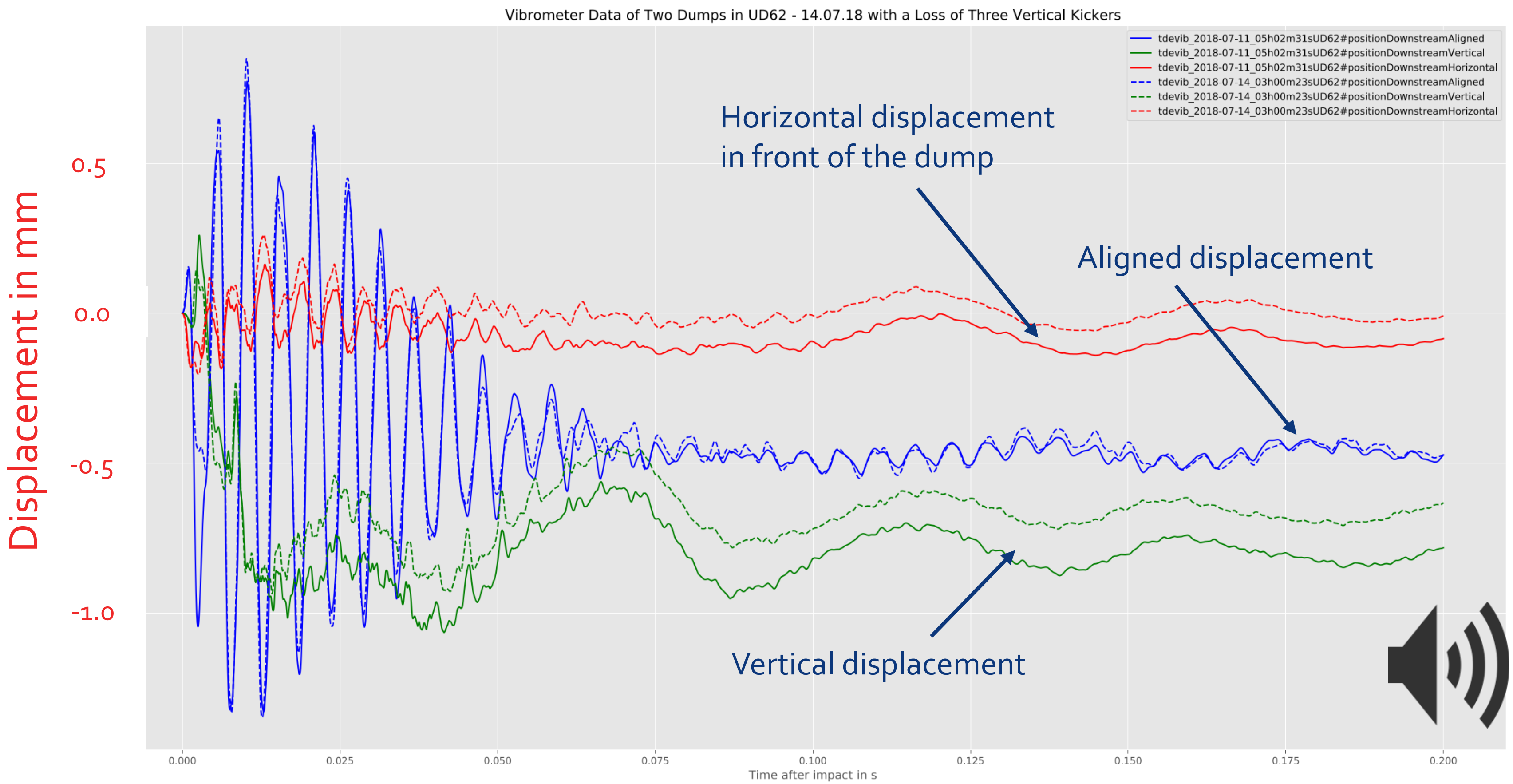
Thermal stability		Can be used from -250°C up to approx. 3000°C (in protective gas)
Sublimation temperature	°C	> 3000



TDE - Down-Stream Window - HL6V2H
Time = 0
Contours of Effective Stress (v-m)
max=0, at elem# 1
Effective Stress (v-m)
1.8775174e+08
1.8149335e+08
1.7523496e+08
1.6897657e+08
1.6271818e+08
1.5645979e+08
1.5020140e+08
1.4394300e+08
1.3768461e+08
1.3142622e+08
1.2516783e+08
1.1890944e+08
1.1265105e+08
1.0639265e+08
Y
Z
X
Titanium (G2) - Maximum Stress - HLLHC25ns - 6V2H
Stress / MPa
200
150
100
50
0
-50
-100
-150
-200
Temperature / °C
140
120
100
80
60
40
20
time / s
0
2e-05
4e-05
6e-05
8e-05
0.0001
0.00012
0.00014
EQSMAX-9711_Effective Stress (v-m)
EQSMAX-9711_Maximum Principal Stress
EQSMAX-9711_2nd Principal Stress
EQSMAX-9711_Minimum Principal Stress
EQSMAX-9711_Temperature

Recent information and future plans

- Over the course of the last 2 years, several N2 leaks occurred in the nitrogen line close to the dump → dump was then instrumented



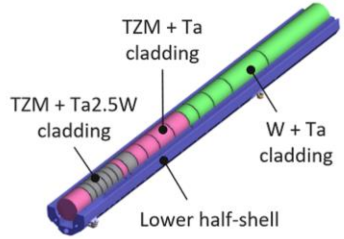
Future plans on LHC beam dump

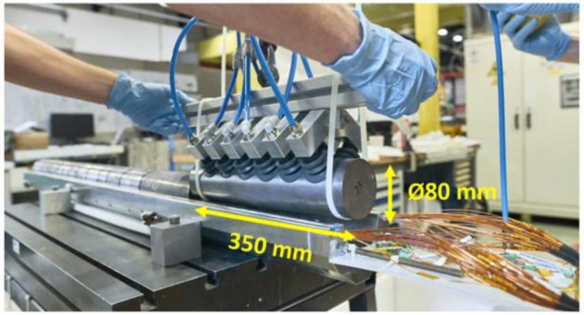
- Several upgrade plans are foreseen during LS2, to reduce dose to personnel during interventions to fix the leaks
  - Including **upgrade of the downstream dump** window (TiGr2 to **TiGr5**) and improved **instrumentation**

1. **Optimize the graphite core configuration** for HL-LHC, since temperature up to 2000 °C for regular operation might not be acceptable for the core *(cyanide formation, sublimation, etc.)*
2. **Sudden thermal expansion** of the 318L (**60 °C in 84 μs**, due to 20 MJ, 80 MJ/m^3) might be responsible for the **significant vibrations** and **permanent displacement** of the dump

Conclusions

- **Beam intercepting devices** and **Targetry technologies** at CERN are being upgraded due to **LIU** and **HL-LHC Project requirements**
- Several other topics **not discussed**, including pbar target, neutron targets, ISOLDE as well as future project such as Beam Dump Facility & FCC
- All activities are requiring **significant technological development** and **material R&D**
- Collaboration such as RaDIATE on radiation damage (including J-PARC!) providing an excellent platform for developments





Thanks!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