Beam Intercepting Devices at CERN Types, Challenges, Design, R&D and Operation

M. Calviani (SY-STI)

17-18 November 2021

Lecture 2/2

Introduction to this lecture

- We'll review today **examples of beam intercepting devices operated at CERN**, linking to concepts discussed during the 1st lecture
- **Uncomplete set of examples**, but **non-comprehensive example** to understand the **variety of devices** and **challenges** that need to be tackled for successful BIDs operation
- Despite not talking about external labs, collaboration in this field (including operational feedback) is mandatory for success

Targets	1. n_TOF neutron production 2. Beam Dump Facility
Collimators / stoppers	3. LHC & advanced collimation 4. Beam stoppers for inj. complex
Dumps & absorbers	5. SPS beam dump(s) 6. LHC main dump

Particle producing targets

1. n_TOF neutron production

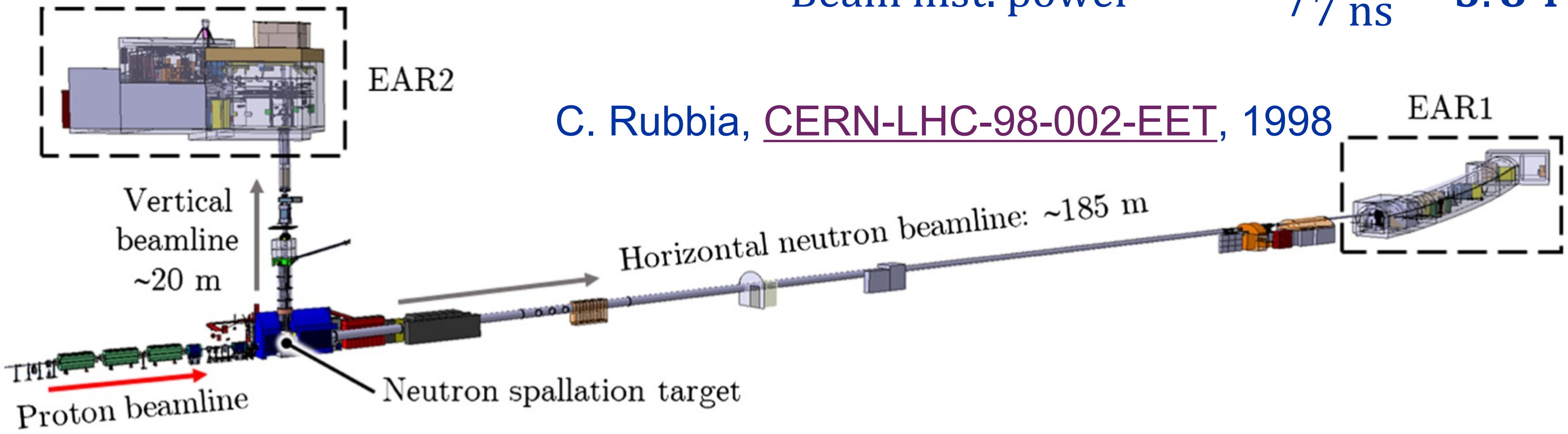
Neutron production at CERN

- n_TOF is a white high-intensity spallation neutron source operating at CERN
- Dedicated to measurement with unmatched S/N ratio for radioactive or low mass samples
- Focus is high intensity per pulse, not average power (limited to around 6 kW)
- Operated with 20 GeV/c proton beam, $8.5 \cdot 10^{12}$ ppp, 7 ns 1σ

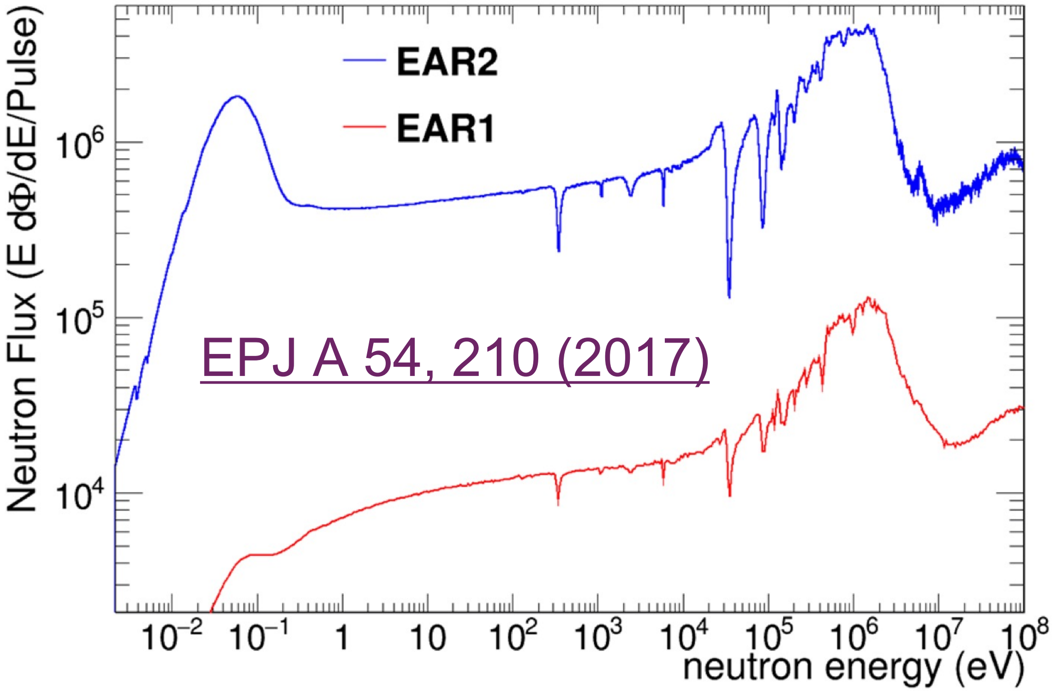
$$\text{Beam kinetic energy} = n_b \times I \times E_b = 1 \times 8.5 \cdot 10^{12} \times 20 = \mathbf{27\ kJ}$$

$$\text{Beam inst. power} = {}^{27\ \text{kJ}}/_{7\ \text{ns}} = \mathbf{3.8\ TW}$$

C. Rubbia, CERN-LHC-98-002-EET, 1998



Neutron production at CERN



EPJ A 54, 210 (2017)

- Facility requires **low-γ background** conditions and **high n/p yield**
- Pb best possible target material, due to:
  - **High elastic neutron cross-section**
  - **(very) Low inelastic neutron cross-section**, reducing reabsorption

n_TOF neutron spallation target

- CERN operated two generations of spallation targets

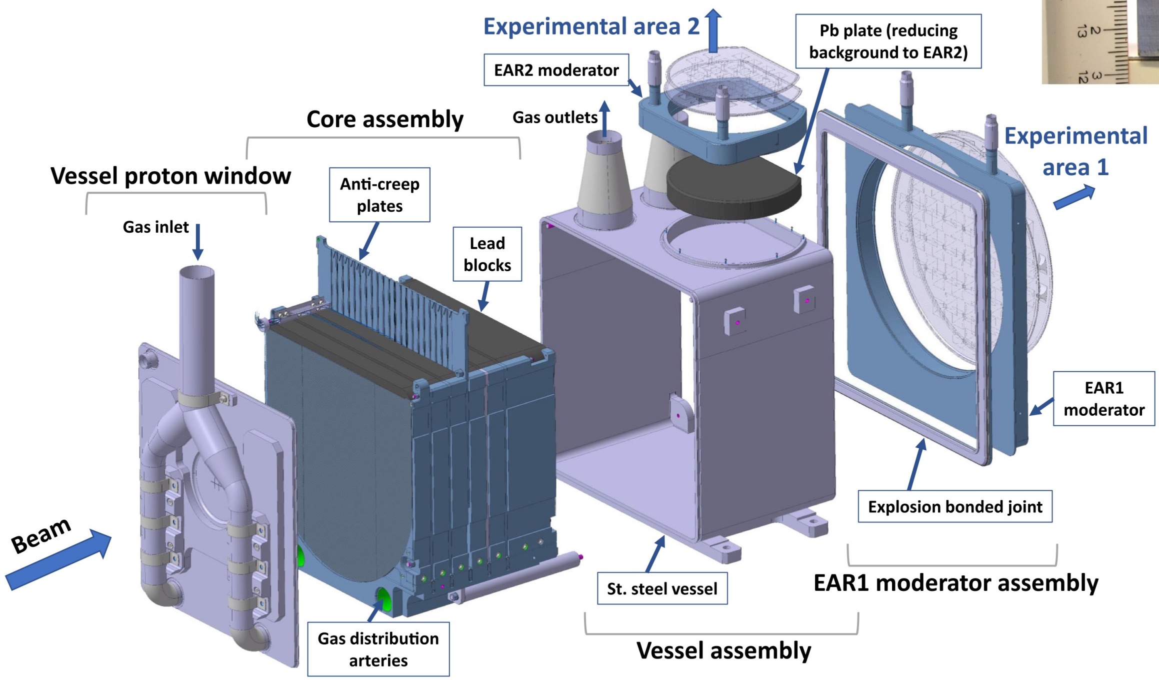
Target #1 (1999-2004)

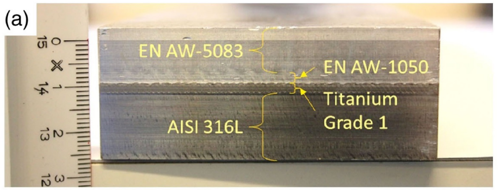
Target #2 (2008-2018)

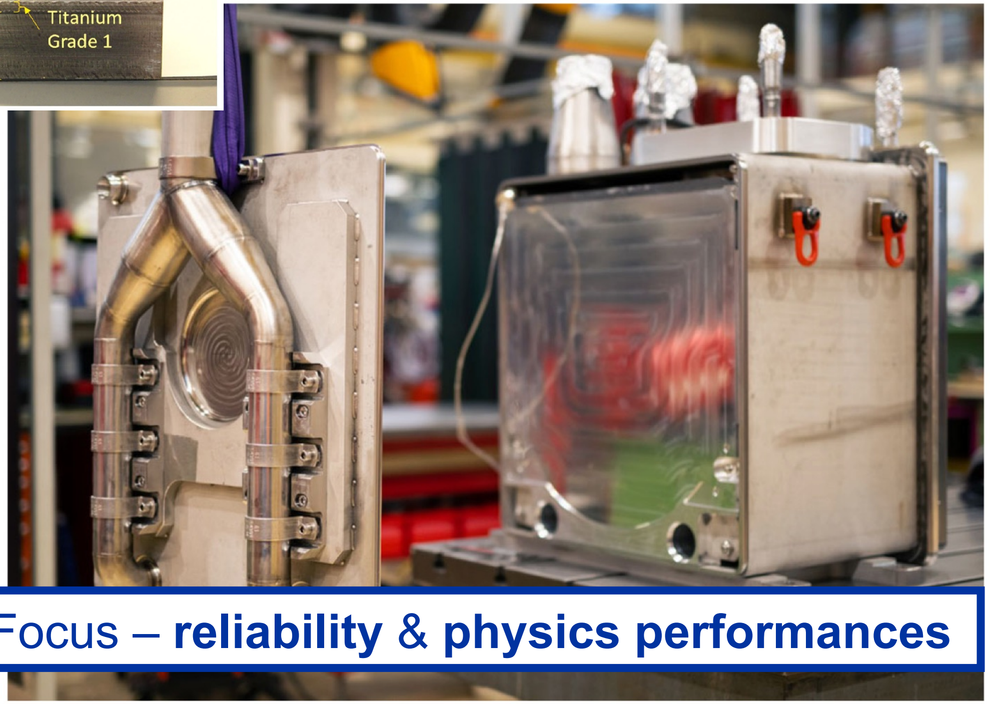
n_TOF neutron spallation target

- 3rd generation spallation target, pure Pb based, N_2-gas cooled, water moderated, operational since July 2021

- Several innovations introduced, including bimetallic transitions & nitrogen gas cooling



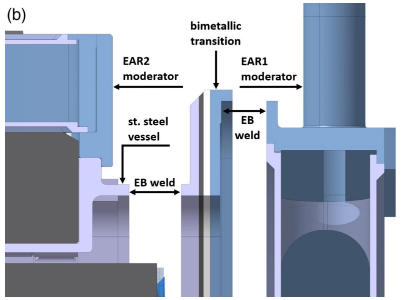




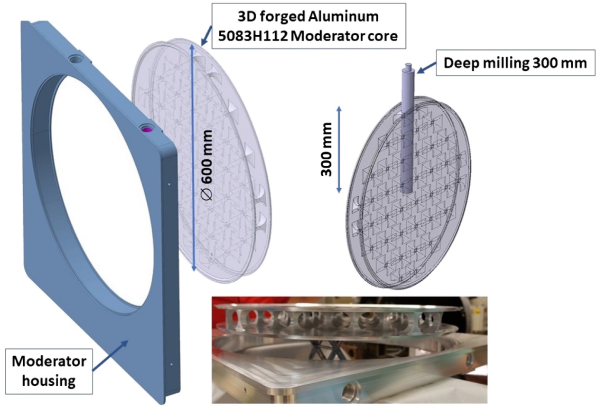
Focus – **reliability** & **physics performances**

Physics/engineering design process

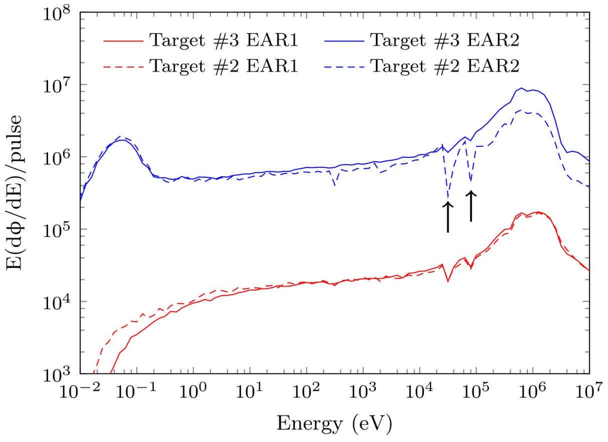
Design and **integration** impacts
(CATIA v5)



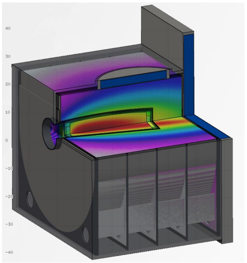
Machinability / reliability / feasibility
(Workshop)



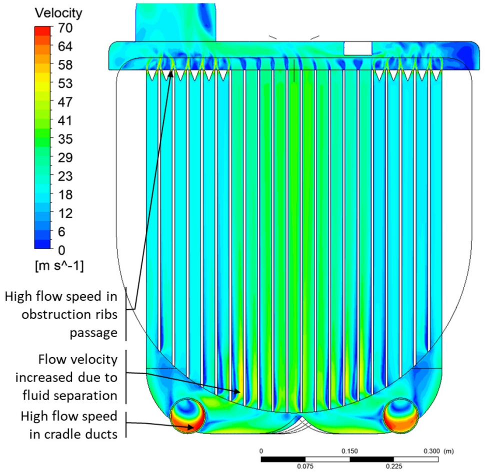
Physics performances
(FLUKA)



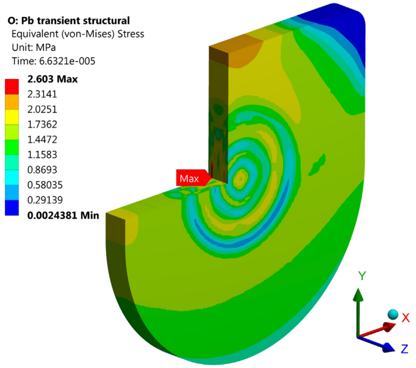
Heat loads
(FLUKA)



Thermal management
(ANSYS CFX)



Mechanical performances
(ANSYS)

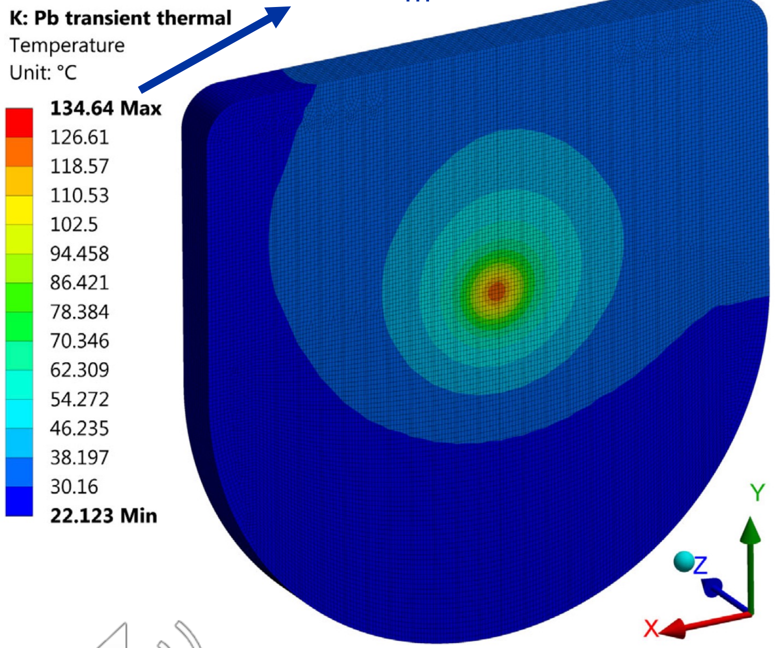


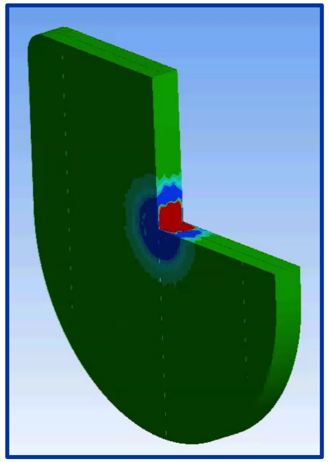
Target (BID) design progression

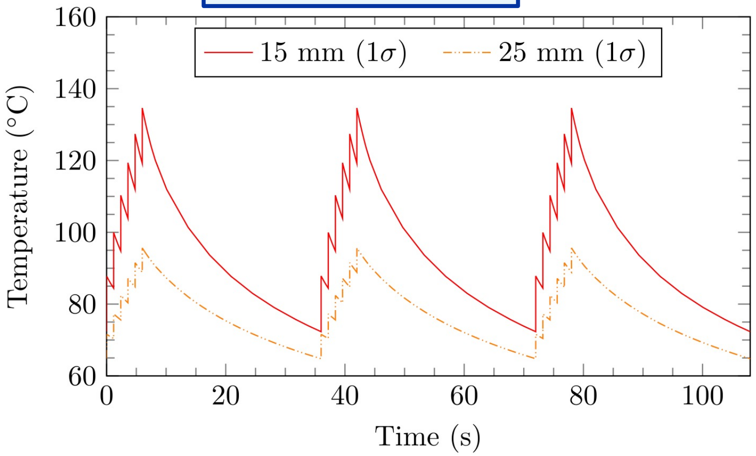
n_TOF neutron spallation target

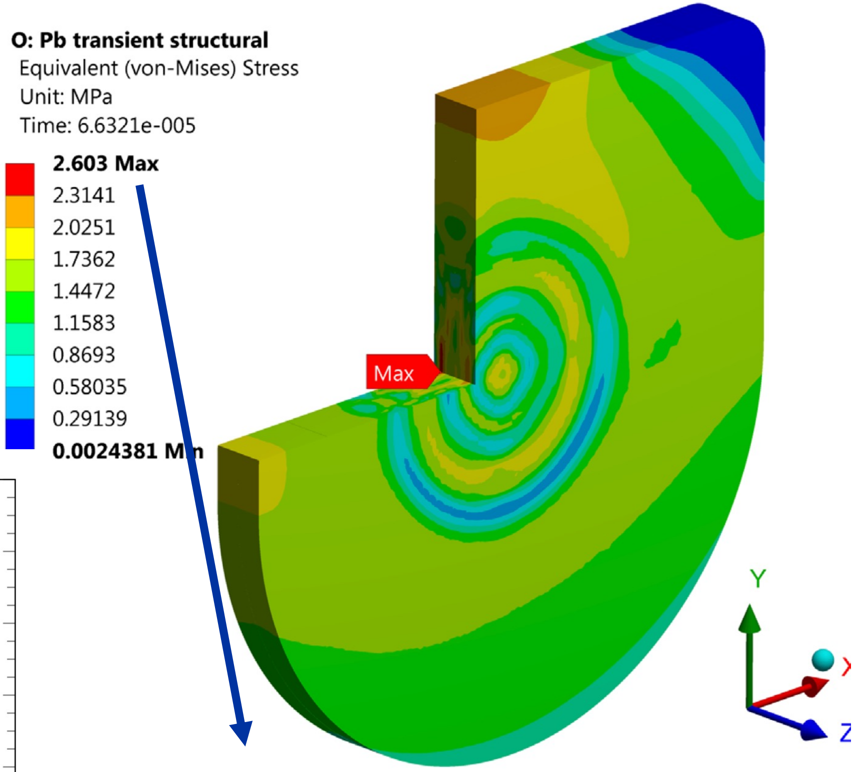
- Pb is a non-structural material, low melting point, very low yielding point

0.7 T_m









2.6 MPa vs. 1 MPa (plastic flow onset)

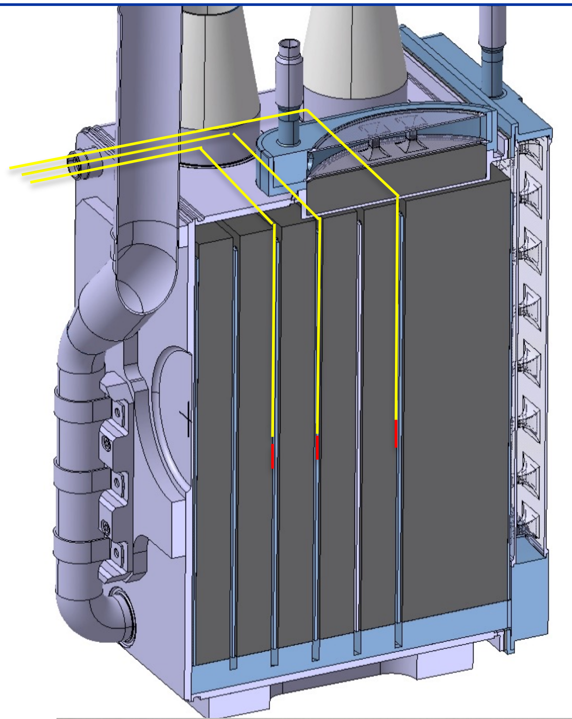
(listen for ±kJ impacting on Pb)

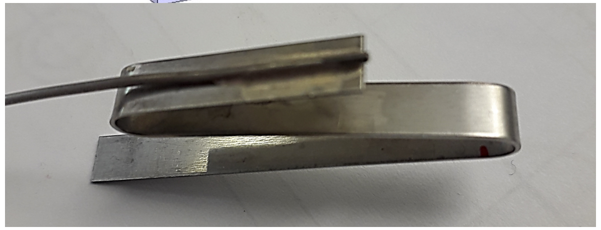
Target monitoring system

6 type-K thermocouples to monitor Pb surface temperature

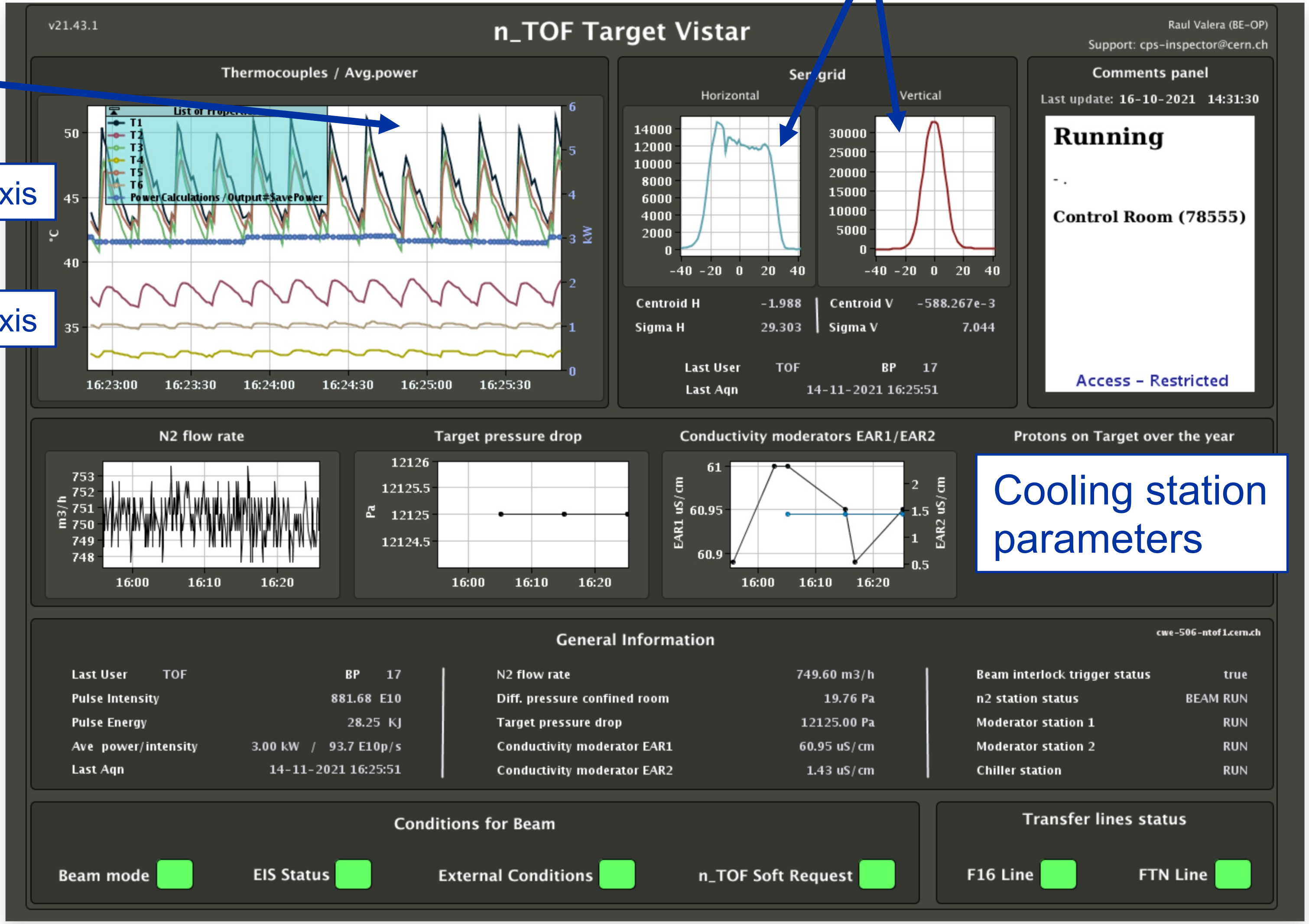
On axis

Off axis





Beam size on target

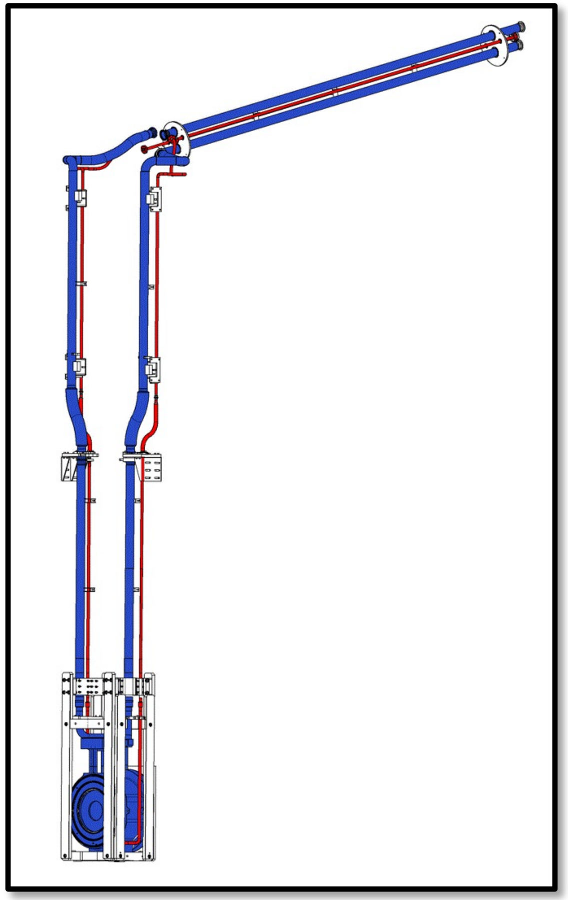


Cooling station parameters

Digression – dismantling and reinstallation

- At CERN facilities are upgraded and devices exchanged in already existing areas – **maximize reuse of existing infrastructure** – n_TOF is an example
- However, challenges are present due to high residual dose rates and potential contamination risks
- E.g., **dismantling of n_TOF Target #2** in order to make space for Target #3
- Maximize use of ALARA processes (remote handling and telemanipulation)

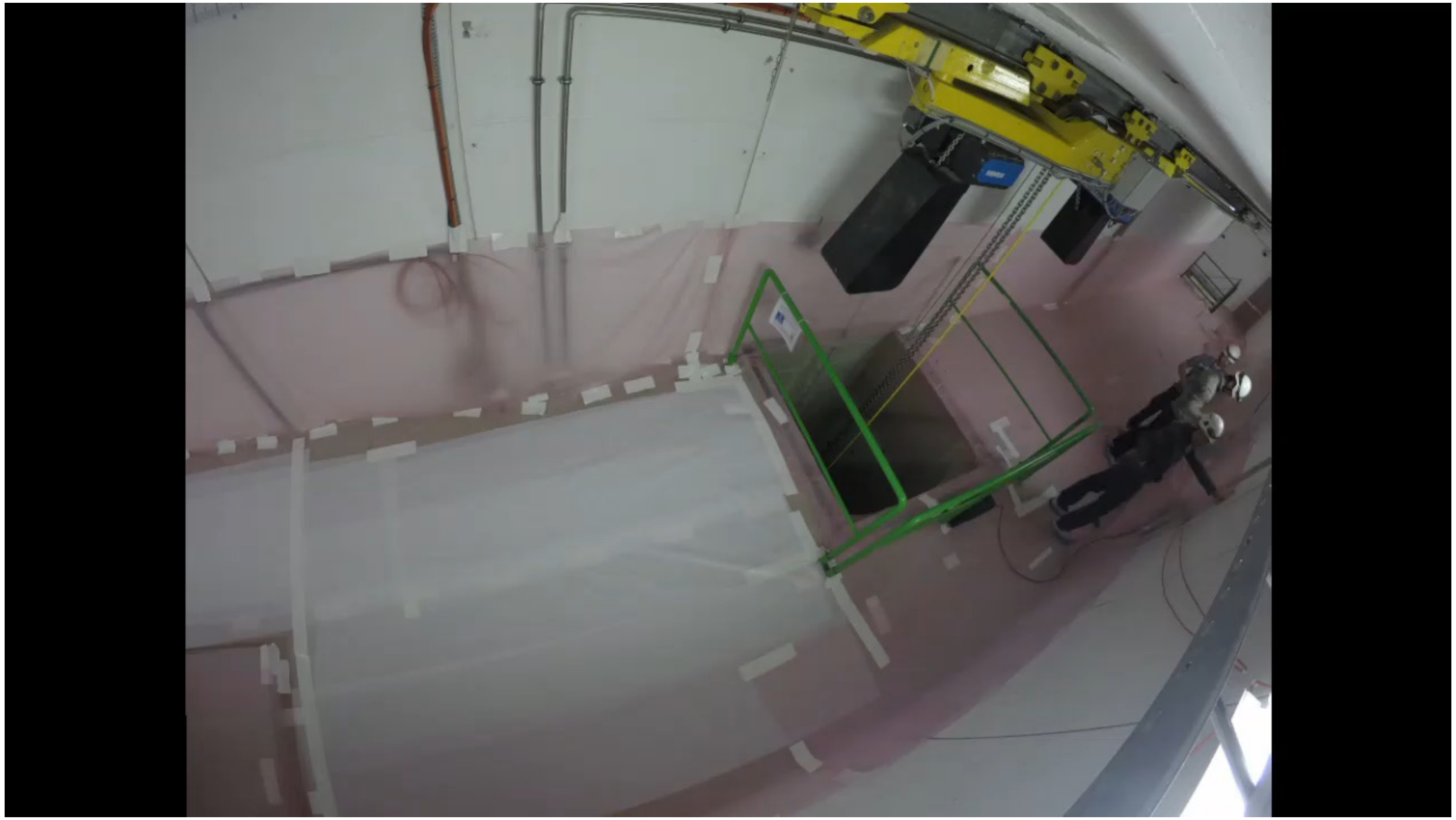
Target #2 cooling & moderator pipes removals

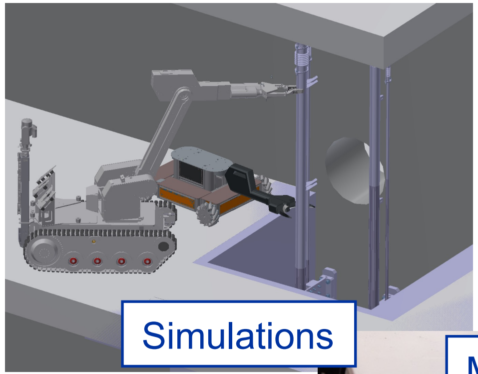




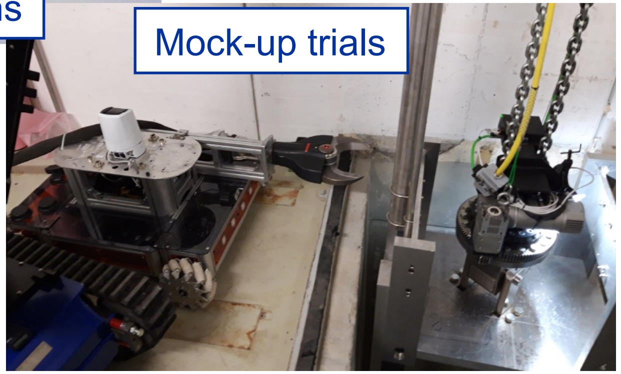
Courtesy: R. Franqueira, J. Martin Ruiz, O. Aberle

Target #2 water pipes cutting (robotics)





Simulations



Mock-up trials

Interventions

Target #2 removal, sampling and packaging

Document lessons learnt for the future!

CERN
CH-1211 Geneva 23
Switzerland

EDMS NO.	REV.	VALIDITY
2424848	0.1	DRAFT

REFERENCE

Date: 2021-02-17

Return of Experience

n_TOF Target #2 Removal - Return of Experience (REX)

ABSTRACT:
This document reports and describes the Return of Experience on the removal of the n_TOF Target #2. It includes the description of the tasks prior to execution, changes in the procedure and lessons learnt on each intervention. A brief radiation report is also included.

DOCUMENT PREPARED BY:	DOCUMENT TO BE CHECKED BY:	DOCUMENT TO BE APPROVED BY:
Rui Franqueira Ximenes SY-STI Oliver Aberle SY-STI Jose Maria Martin Ruiz SY-STI Dennis Boon SY-STI Oscar Fjeld SY-STI	Jean-Louis Grenard EN-HE Jean-Francois Gruber HSE-RP Fabio Pozzi HSE-RP Sylvain Girod BE-EA Mario Di Castro BE-CEM Luca Rosario Buonocore BE-CEM Francesco Dragoni EN-CV Keith Kershaw SY-STI	Marco Calviani SY-STI Simone Gilardoni SY-STI

DOCUMENT SENT FOR INFORMATION TO:
sy-dep-sti-tcd@cern.ch
Brennan Goddard SY
Roberto Losito ATS-DO
Ramon Folch BE-EA
Ans Pardons EN-ACE
Florence Pirotte SY-HDO
Anne Funken SY-HDO

2424848

Task by task procedure | REX

REFERENCE	EDMS NO.	REV.	VALIDITY
	2424848	0.1	DRAFT

Page 27 of 55

330. Drain upper section of pipes from the cooling station

	Estimated	Actual
Local dose rate	10 µSv/hr	
Workforce		
Time needed	?	
Calculated dose		
Responsible	EN-CV	
Involved	EN-EA/ EN-HE/ HSE-RP	

Comments:
Initial pumping/sucking can be done in the cooling station away from the target.
Water needs to be sucked/pumped out at different heights to remove as much water as possible.
Planned Procedure:
1) Pressurise circuit and push water out of circuit using air (should drain 1/2 of circuit)
2) Allow water to settle again and then insert a tube down the pipes to suck out water remaining in the top section (above the main joint). If a tube can't be inserted all the way through the corners in the tube, the tube may be drilled half-way in order to gain access.

Moderator circuit must be drained first to prevent the target's window from breaking and the two circuits mixing. The window will withstand the pressure of the full water column (8.5 m) as long as the pressure is from the cooling to the moderating side (EDMS docs 934369 and 953823).
A manual winch will be needed to recover persons in the case of an emergency.
A mock-up has been made to test this procedure.
This task will be developed further and by EN-CV.

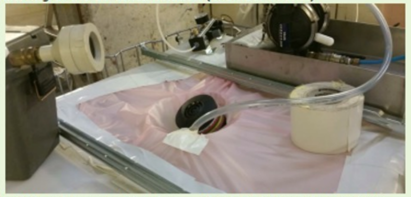
All of the pipes from the cooling station to the target are waste, they will not be reused. They will be removed in a later task.

HSE-RP comments:
Depending on water contamination level (to be verified by RP), the possibility to use the spare cartridge to further filter the water before the target removal and cooling station dismantling should be considered. The possibility to reduce the radiological risks during the intervention should be weighed against the resulting additional waste produced by this action. Expert should provide a recommendation on the benefit of this action. The spare cartridge was partially filled right after its installation with water from the circuit but was never used online.

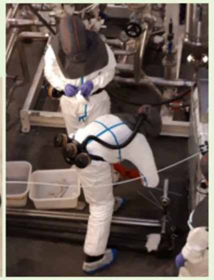
REX
- Full procedure is described in EDMS 2131874. This step corresponds to phase 1 in that document.

Lessons Learnt
- Air contamination detected by the APA and consequent possible internal contamination -> Immediate **STOP** of the works (+https://edms.cern.ch/document/2274303/1.0 Gestion_RP_evenement_de_contamination_atmospherique_a_n_TOF_Septembre_2019.docx)

- Active charcoal filter at the water tank outlet
- Active monitoring of the air contamination (chamber mlonix)



- Appropriate EPI and correct utilization -> Check by intervenient and RP



- Use of full respiratory mask with cartridge ref: 1140 A2B2E2K1HgP3 R D
- Dedicated SAS for collective protective equipment

- Setting up a dedicated SAS for this intervention due to the risk of airborne contamination

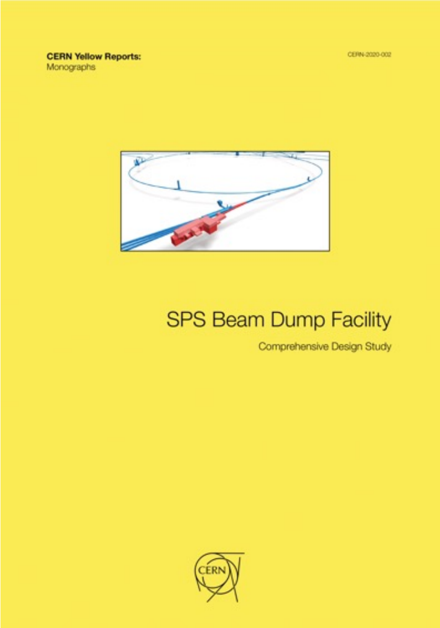
- Relevant notes about how the activity was performed
- Events
- Applied solutions to the events and positive outstanding items
- Suggestions for future interventions

2. Beam Dump Facility

SPS Beam Dump Facility

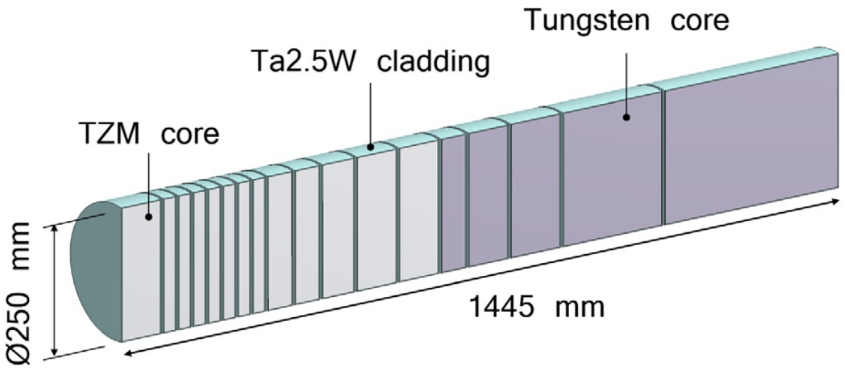
Looking towards the mid-term potential future

- Facility being design at CERN for hidden sector searches
- Requirement: high-Z material (short nuclear inelastic scattering length) & high energy protons & high POT



$$\text{Beam kinetic energy} = I \times E_b = 4 \cdot 10^{13} \times 400 = \mathbf{2.6\ MJ}$$

$$\text{Beam avg. power} = {}^{2.6\ \text{MJ}}/_{7.2\ \text{s}} = \mathbf{360\ kW}$$

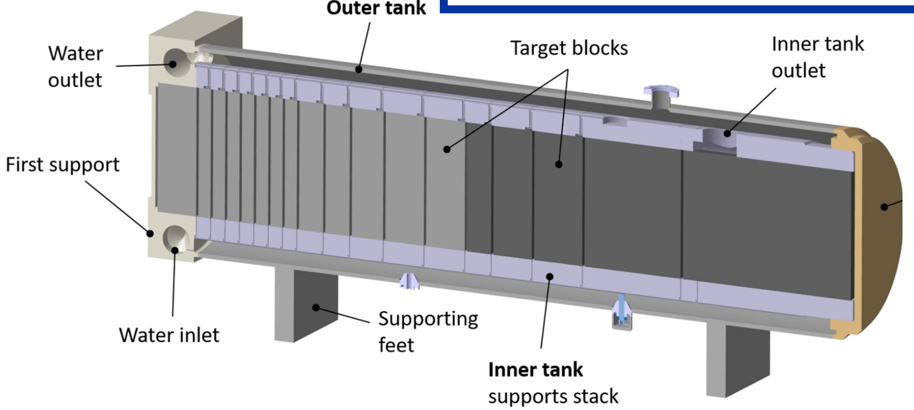


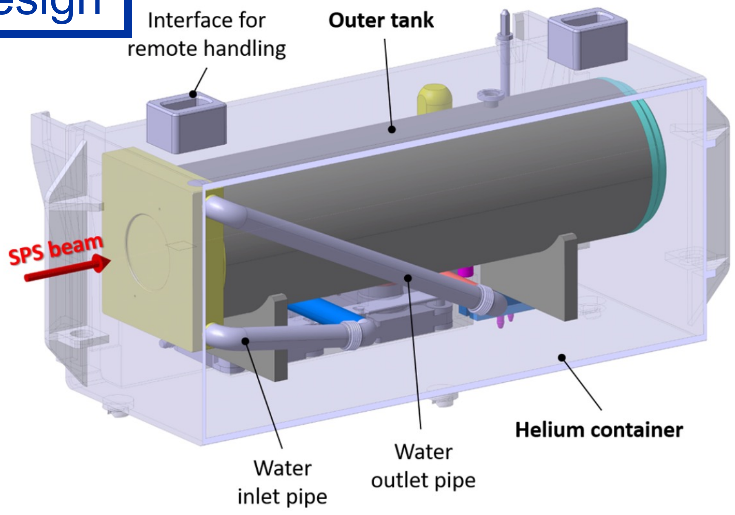
- TZM and W core, water-cooled
- Cladding w/ Ta alloys to avoid corrosion/erosion effects

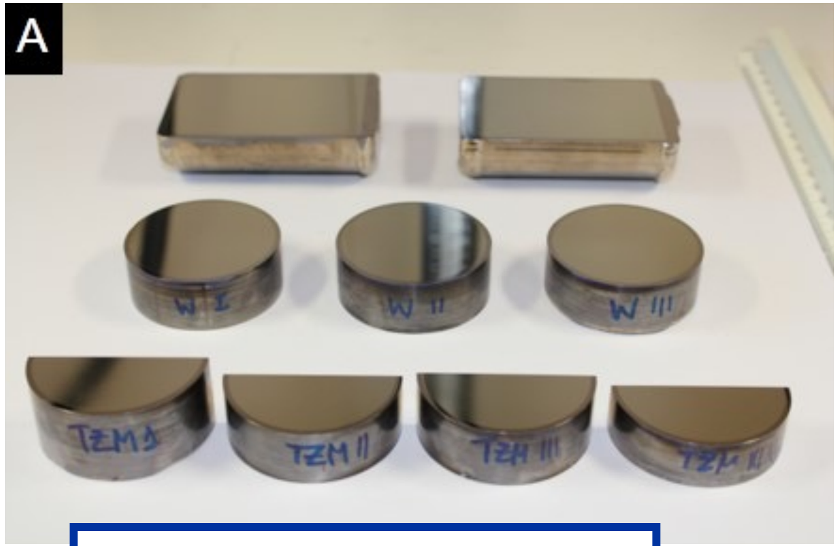
https://doi.org/10.23731/CYRM-2020-002

SPS Beam Dump Facility

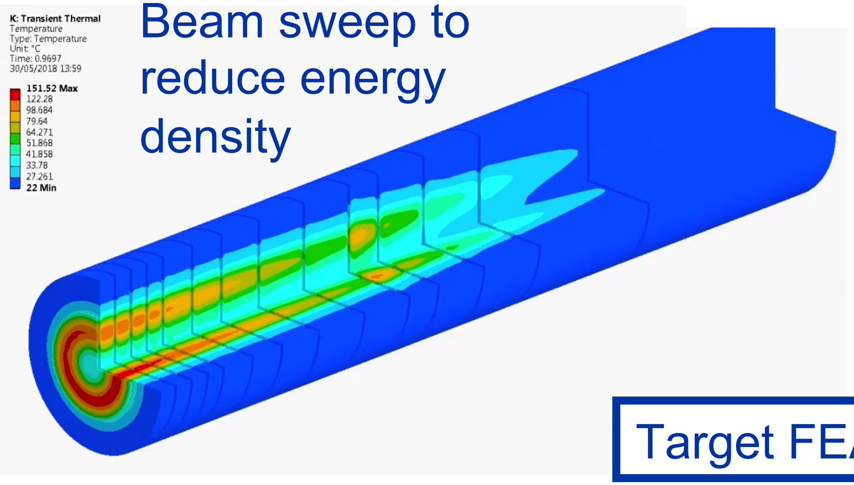
Target mechanical design



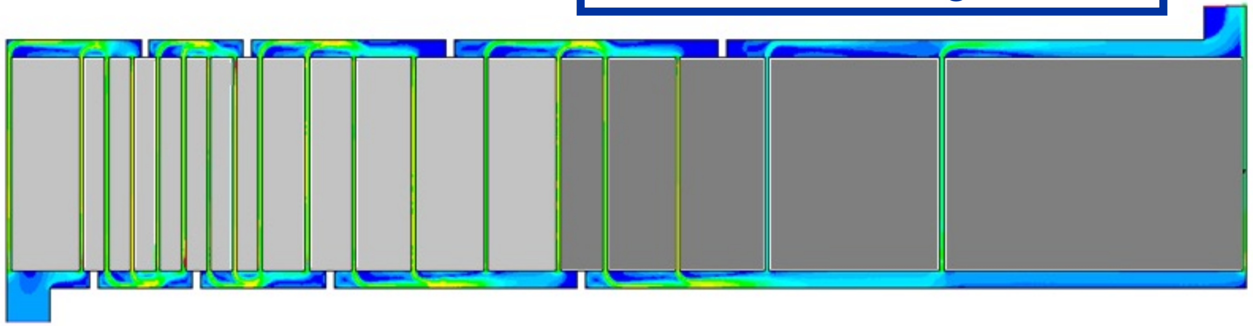




Diffusion bonding via HIP

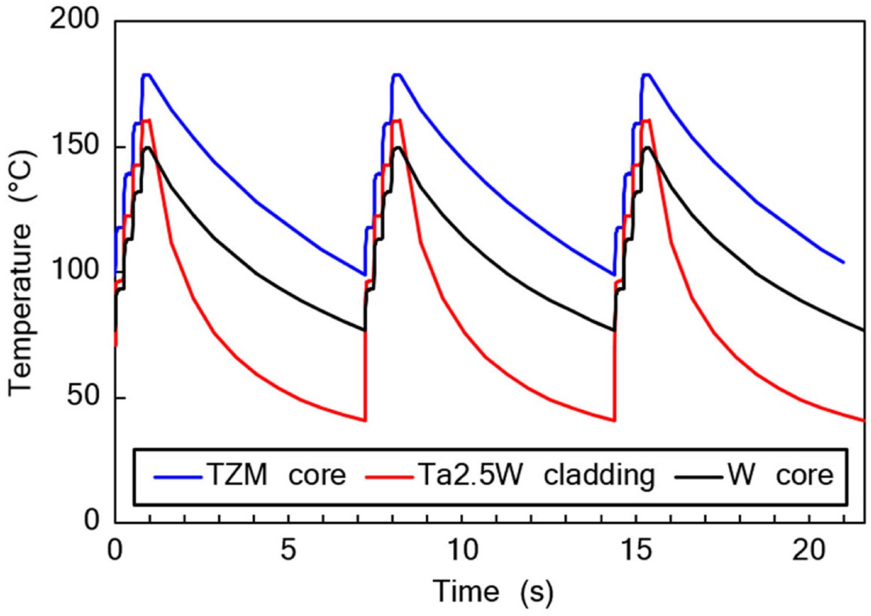


Beam sweep to reduce energy density



Target FEA simulations

SPS Beam Dump Facility



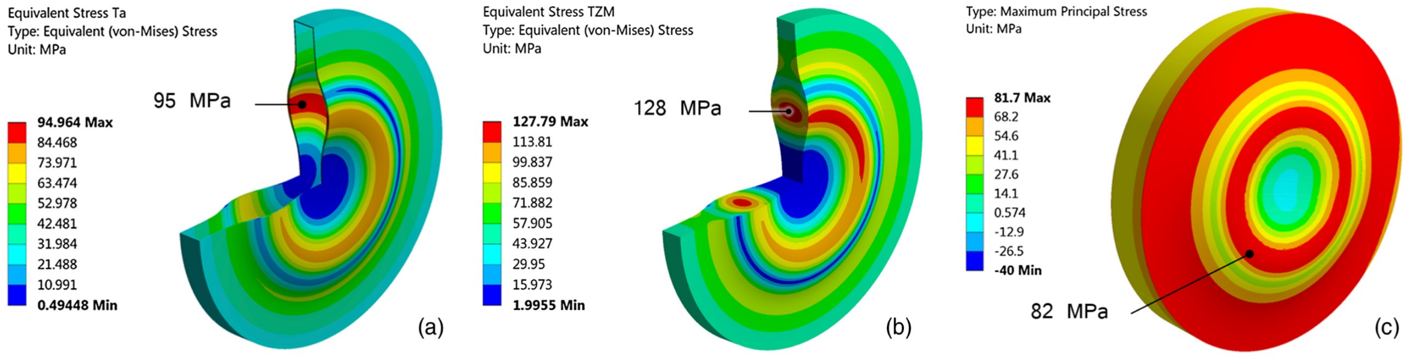


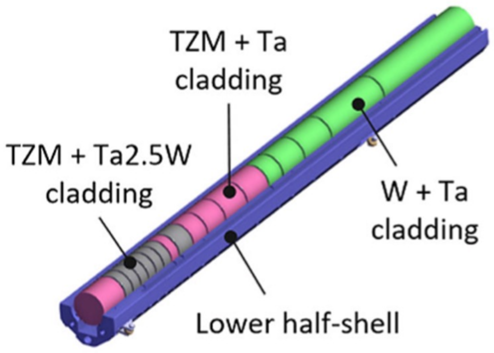
FIG. 5. Von Mises equivalent stress or maximum principal stress distribution after one beam pulse in the most loaded blocks for each target material. (a) Ta2.5W cladding of block no. 4, maximum equivalent stress (95 MPa) reached in the beam impact region at the interface with the block core. (b) TZM core of block no. 4, maximum equivalent stress (130 MPa) found in the core center (mainly due to high compressive stresses) and in the interface with the tantalum cladding. (c) W core of block no. 14, highest value of maximum principal stress reached in the upstream face of the block, following the beam dilution path.

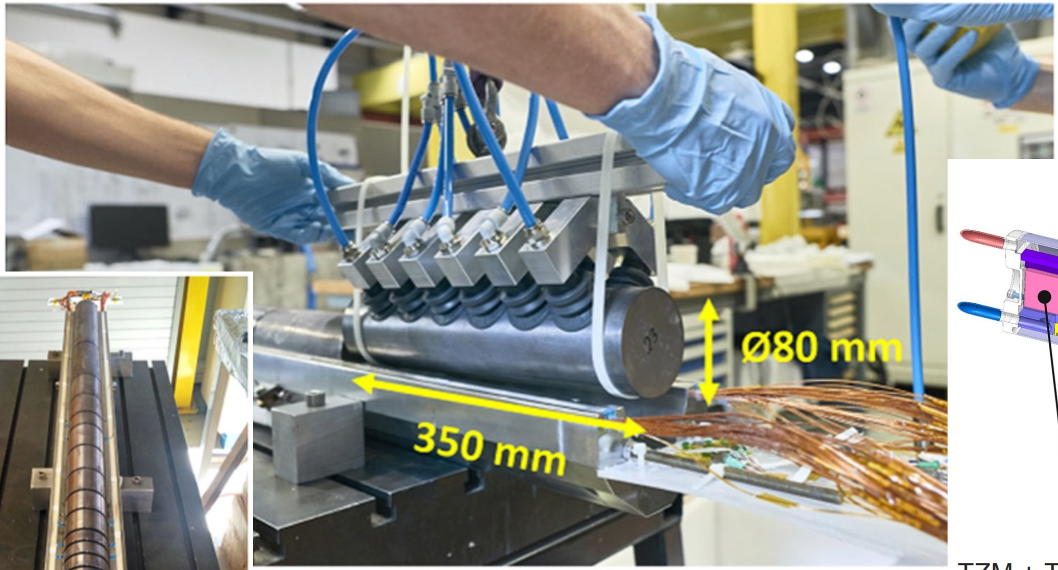
- Cyclic load, high instantaneous energy deposition (hence stress)
- Materials at the limit of reliable operation, considering fatigue + effect of radiation damage ➔ to the innovative nature of the design, **beam test was deemed required**

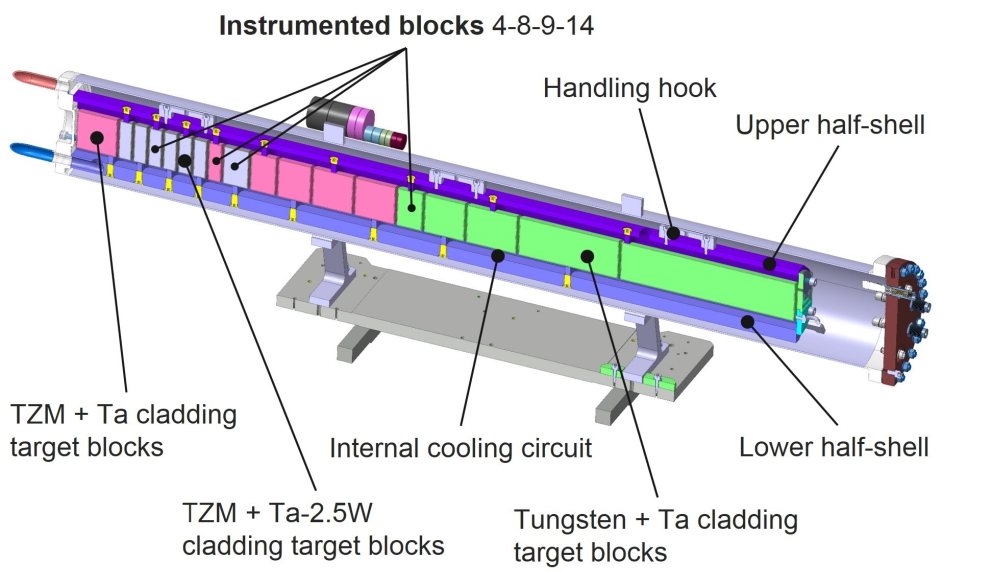
SPS Beam Dump Facility

Beam tests

- A dedicated test bench was built in CERN's North Area
- Prototypic target (same length, reduced target ∅), tested up to 50 kW beam power

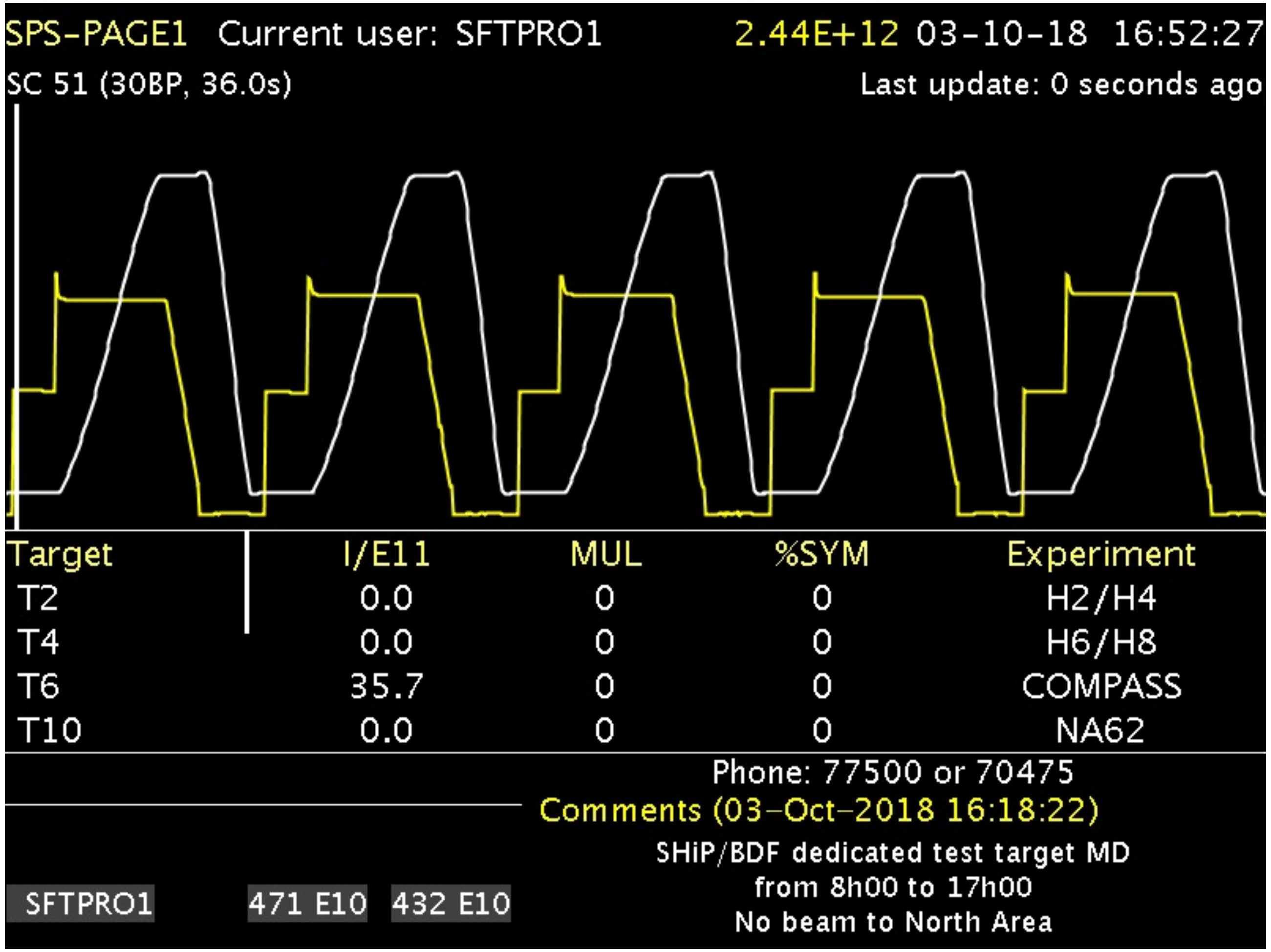


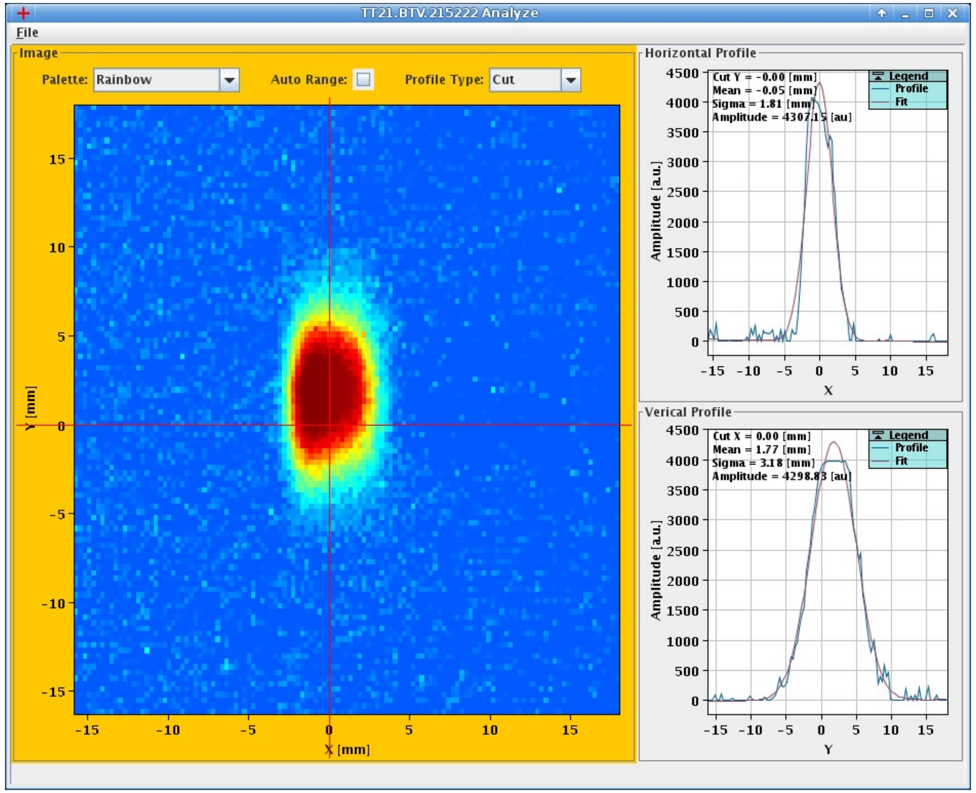




SPS Beam Dump Facility

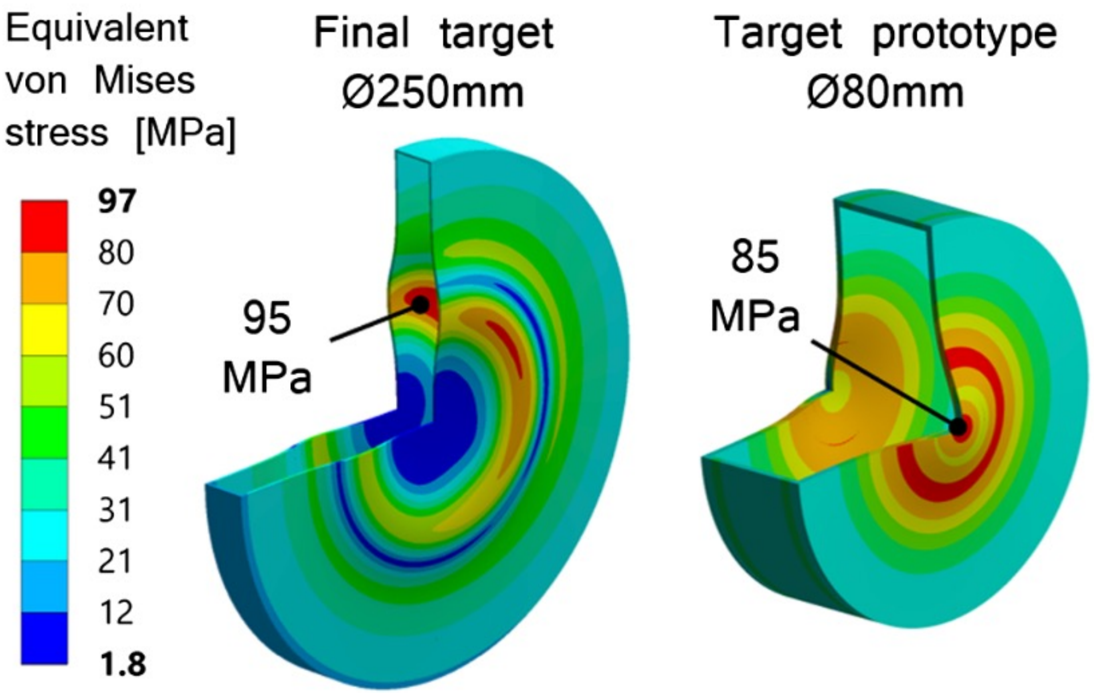
Beam tests / dedicated Machine Development

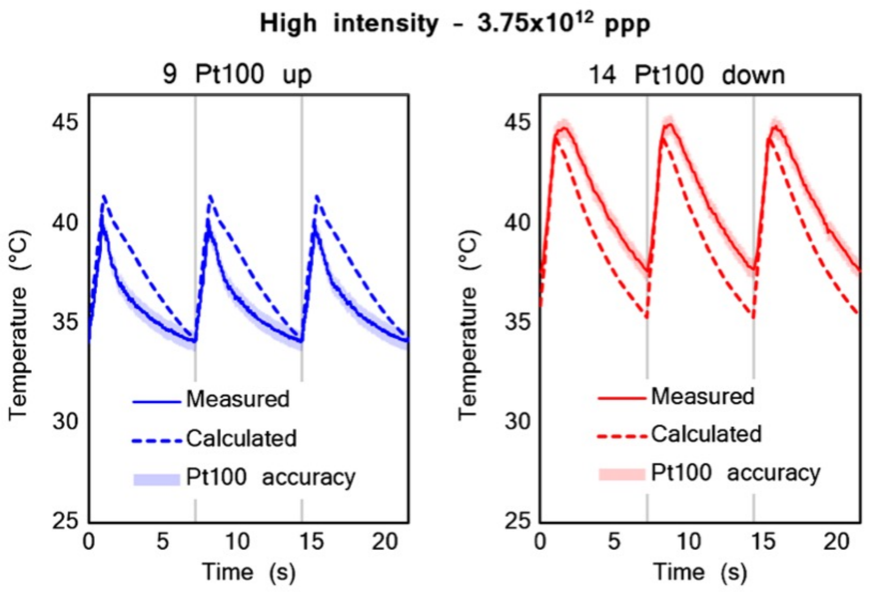


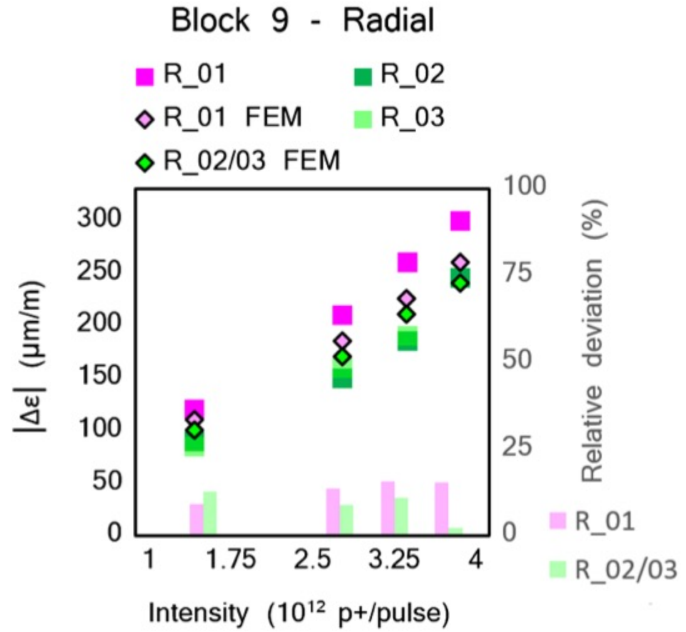


SPS Beam Dump Facility

Beam tests







Excellent agreement between data and simulations results

→ Next steps: **blocks post irradiation examination**

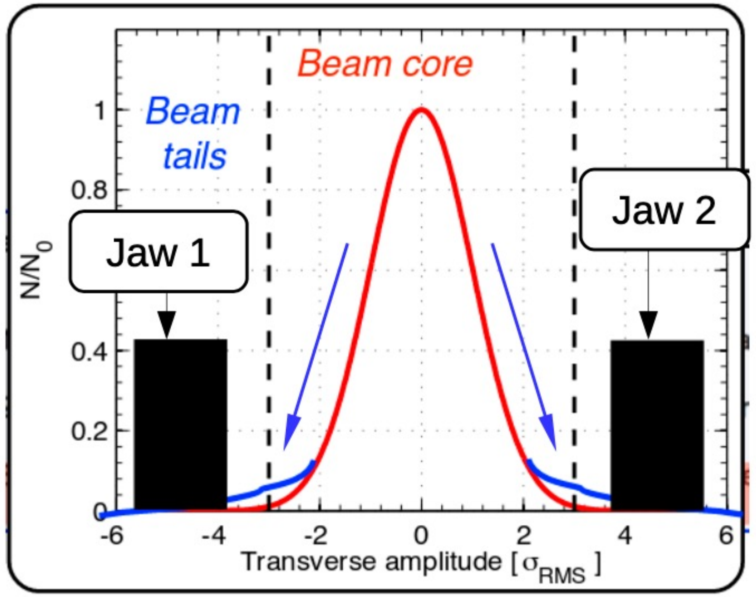
Collimators, scrapers & stoppers

3. LHC & advanced collimation

Large Hadron Collider collimation

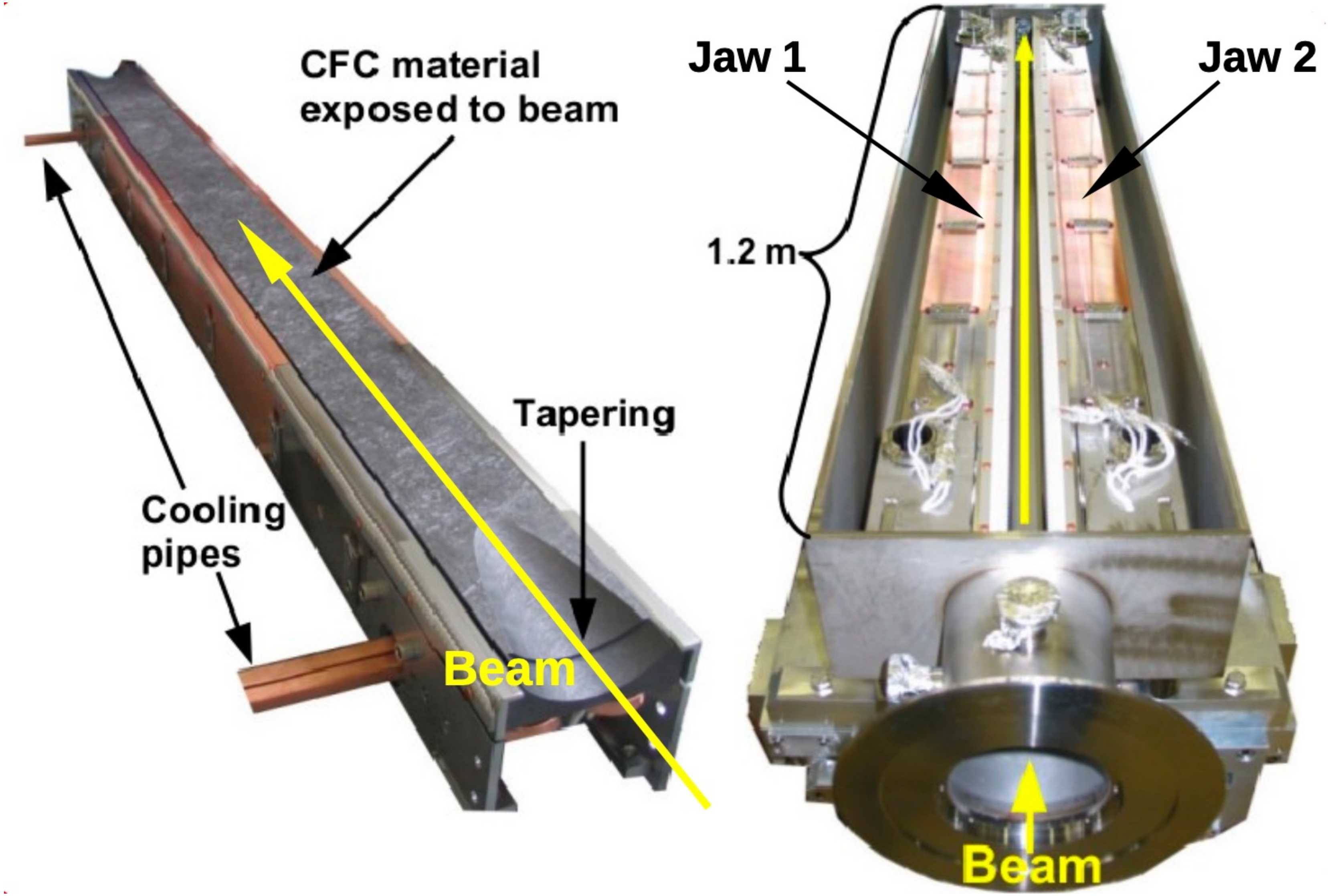
- In a collider, many effects create a beam halo
  - Particle with large betatron amplitudes or momentum offsets tend to populate tails, which would be lost on magnet apertures if nothing would be done

$$x(s) = N\sqrt{\beta_x(s) \cdot \varepsilon} + D(s)\frac{\Delta p}{p}$$



- LHC: losses or around 100 kW typical
- A **robust collimation system** is essential to handle losses (avoid quenches in particular) → **limit transverse beam cross-section**

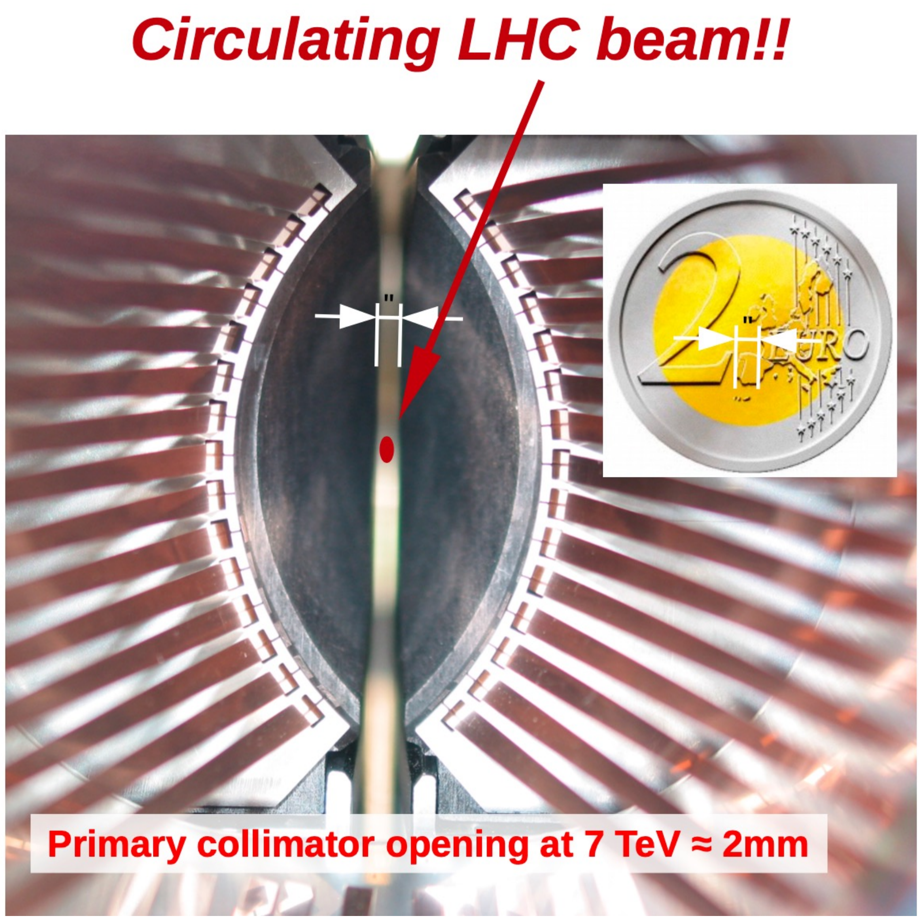
Large Hadron Collider collimation

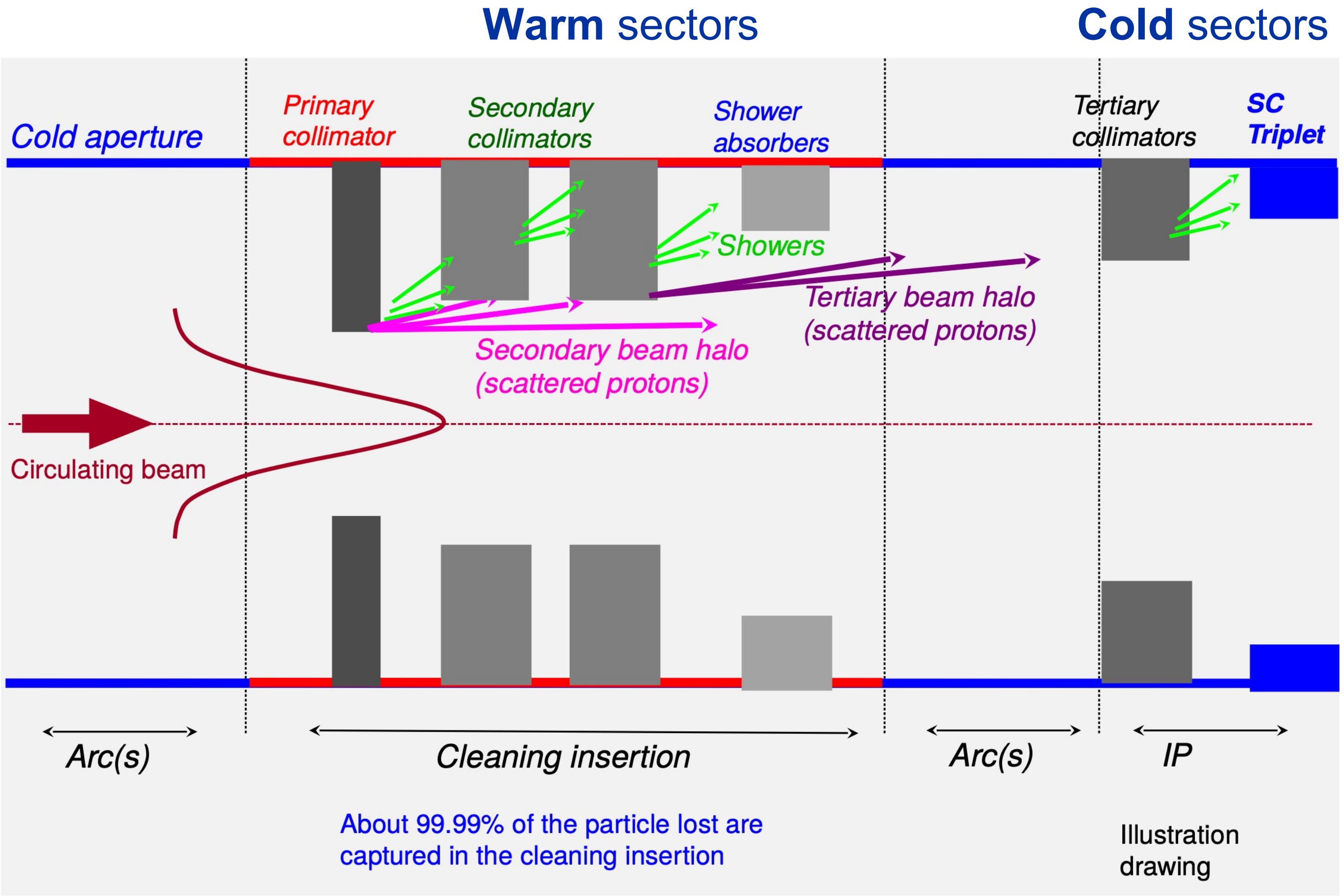


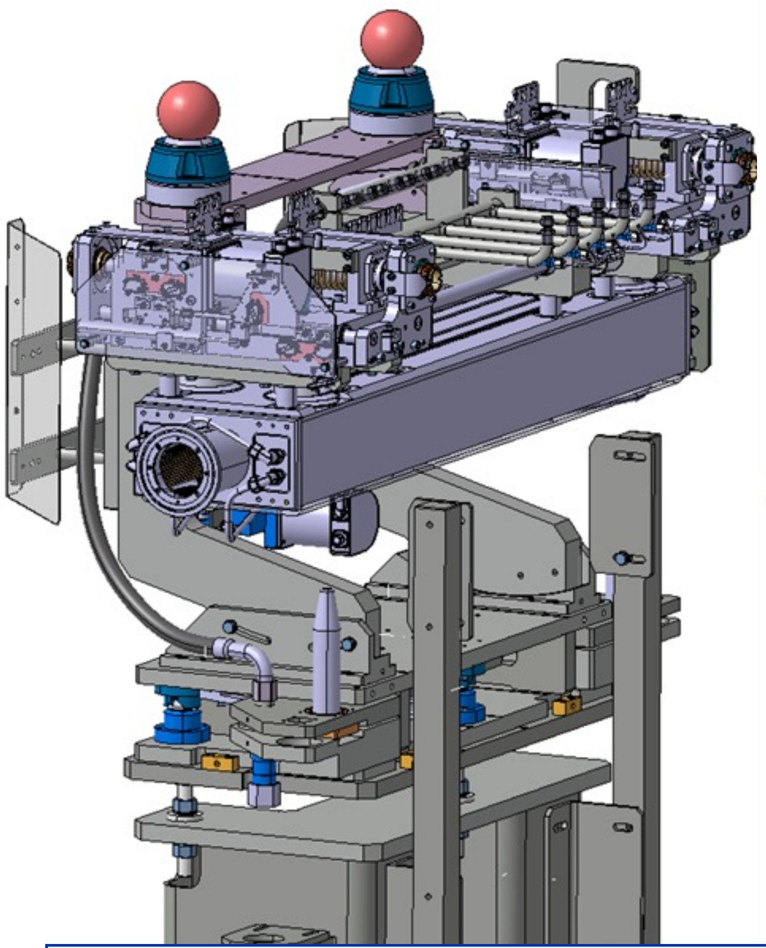
Roles of a collimation system

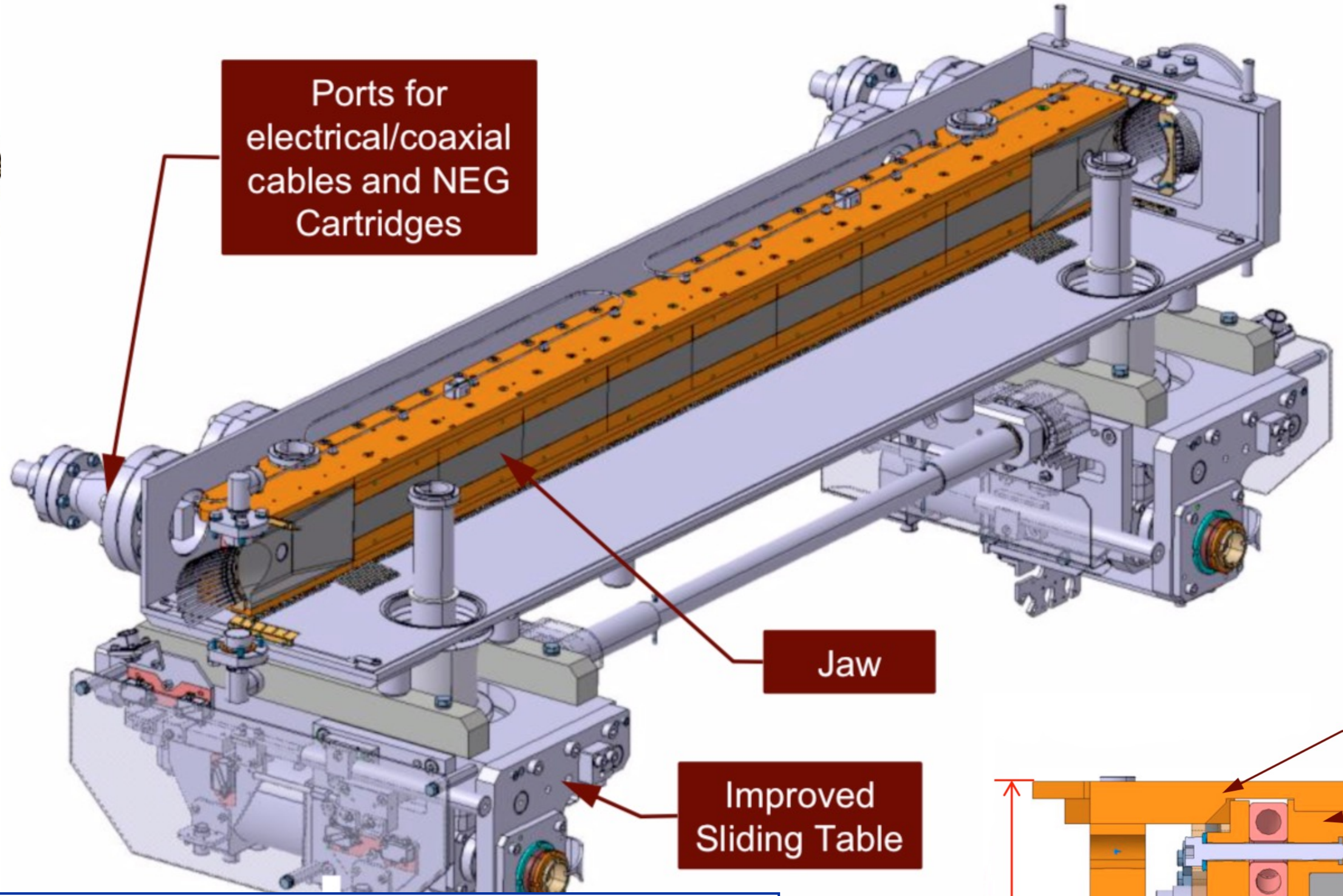
- Quench mitigation for superconducting magnets (mW/cm^3!)
- Protection against long-term radiation damage to magnets (passive masks)
- Concentration of losses/activation in controlled areas
- Cleaning physics debris (for colliders)
- Optimise background in the experiments
- Beam tail/halo scraping, halo diagnostics

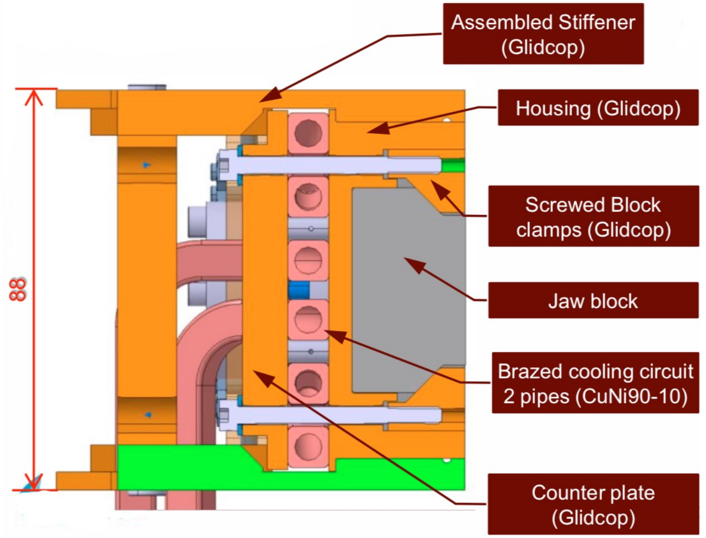
Large Hadron Collider collimation: multi-stage









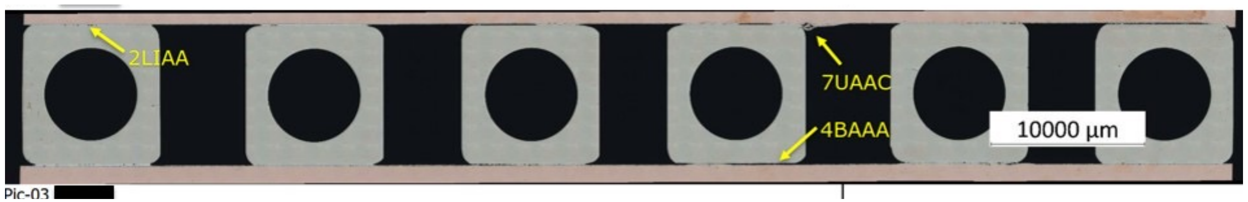


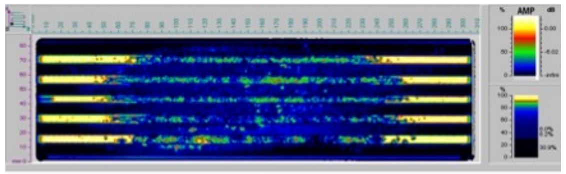
Collimator jaws designed (and tested!) to cope with:

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

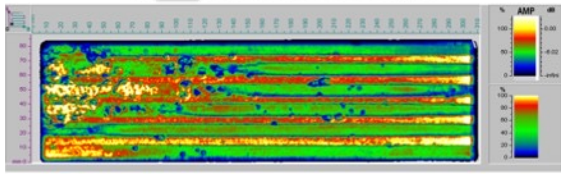
Brazing technology – collimator jaws

- Vacuum brazing (765 ºC)
- Ok for UHV, but could generate some internal leakage
  - Specific surface treatment on Glidcop and CuNi tubes
  - Filler metal: SCP1 (68Ag/27Cu/5Pd), 50 μm sheet
- Variable quality, wetting sometimes difficult
- Very good thermal efficiency

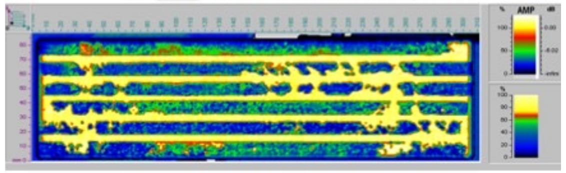




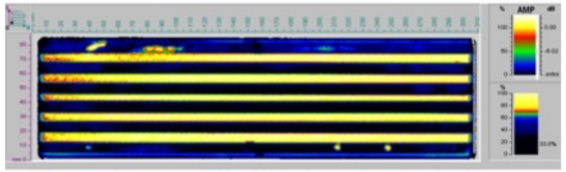
Piece [redacted] brazed interface of **20 mm** Glidcop plate.



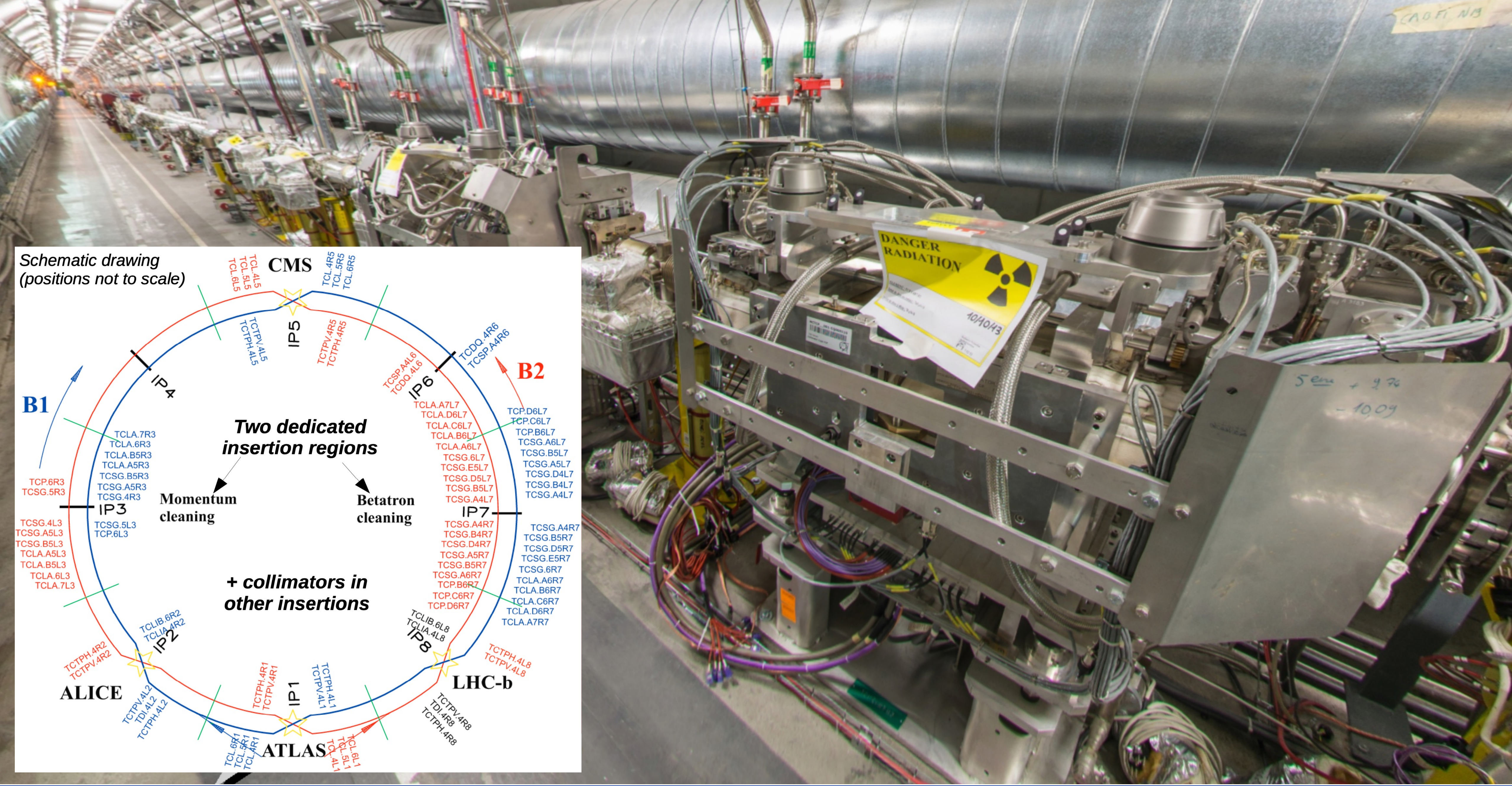
Piece [redacted] brazed interface of **20 mm** Glidcop plate.



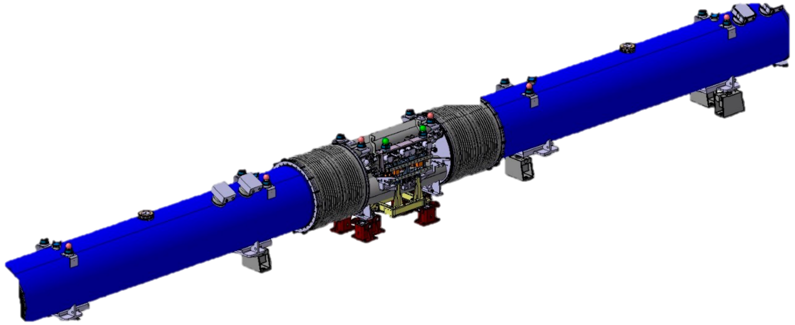
Piece [redacted] brazed interface of **20 mm** Glidcop plate.



Piec[redacted]razed interface of **20 mm** Glidcop plate.

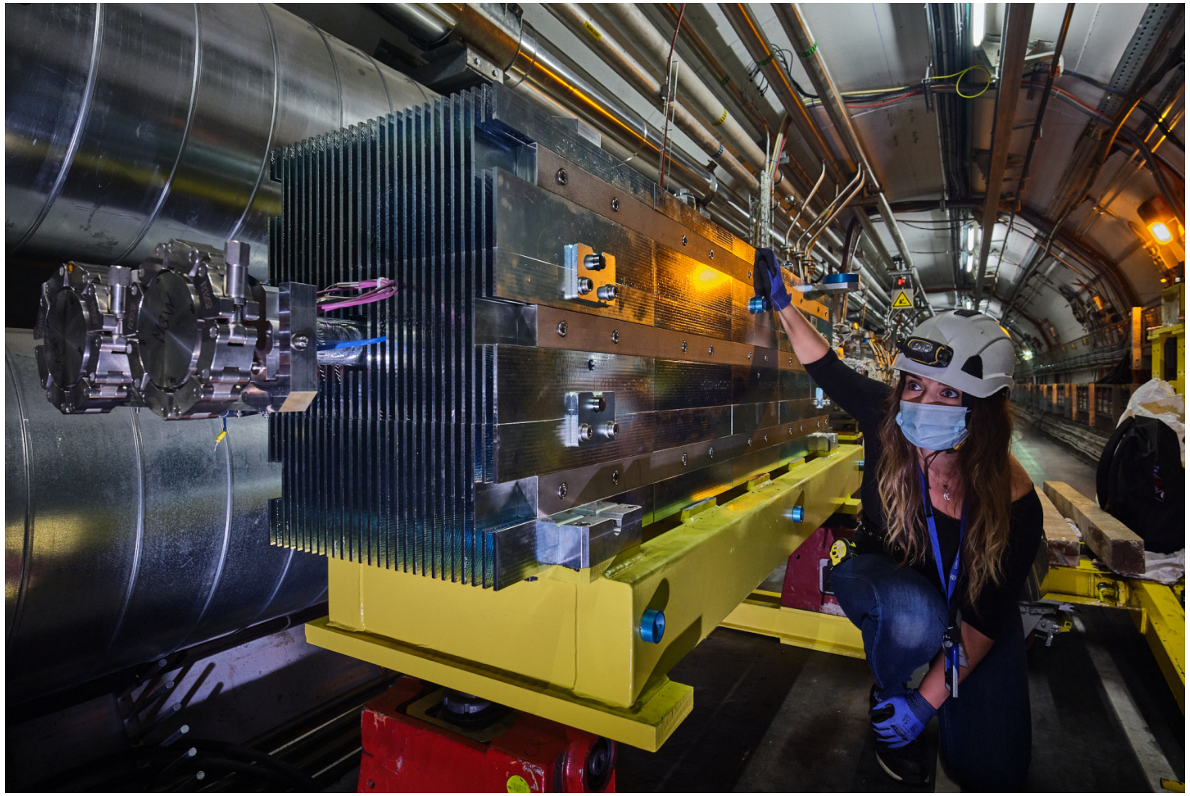

DANGER
RADIATION
10/10/13
Schematic drawing
(positions not to scale)
CMS
TCL.4L5
TCL.5L5
TCL.6L5
TCL.4R5
TCL.5R5
TCL.6R5
IP5
TCTPV.4L5
TCTPH.4L5
TCTPV.4R5
TCTPH.4R5
TCDQ.4R6
TCSP.A4R6
TCSP.A4L6
TCDQ.4L6
IP6
B2
B1
IP4
TCLA.7R3
TCLA.6R3
TCLA.B5R3
TCLA.A5R3
TCSG.B5R3
TCSG.A5R3
TCSG.4R3
TCP.6R3
TCSG.5R3
IP3
TCSG.5L3
TCP.6L3
TCSG.4L3
TCSG.A5L3
TCSG.B5L3
TCLA.A5L3
TCLA.B5L3
TCLA.6L3
TCLA.7L3
Two dedicated
insertion regions
Momentum
cleaning
Betatron
cleaning
TCLA.A7L7
TCLA.D6L7
TCLA.C6L7
TCLA.B6L7
TCLA.A6L7
TCSG.6L7
TCSG.E5L7
TCSG.D5L7
TCSG.B5L7
TCSG.A4L7
TCP.D6L7
TCP.C6L7
TCP.B6L7
TCSG.A6L7
TCSG.B5L7
TCSG.A5L7
TCSG.D4L7
TCSG.B4L7
TCSG.A4L7
IP7
TCSG.A4R7
TCSG.B4R7
TCSG.D4R7
TCSG.A5R7
TCSG.B5R7
TCSG.A6R7
TCP.B6R7
TCP.C6R7
TCP.D6R7
TCSG.A4R7
TCSG.B5R7
TCSG.D5R7
TCSG.E5R7
TCSG.6R7
TCLA.A6R7
TCLA.B6R7
TCLA.C6R7
TCLA.D6R7
TCLA.A7R7
+ collimators in
other insertions
TCLIB.6R2
TCLIA.4R2
IP2
TCTPH.4R2
TCTPV.4R2
ALICE
TCTPV.4L2
TDI.4L2
TCTPH.4L2
TCLIB.6L8
TCLIA.4L8
IP8
TCTPH.4L8
TCTPV.4L8
LHC-b
TCTPV.4R8
TDI.4R8
TCTPH.4R8
TCTPH.4R1
TCTPV.4R1
IP1
TCTPH.4L1
TCTPV.4L1
ATLAS
TCL.6R1
TCL.5R1
TCL.4R1
TCL.6L1
TCL.5L1
TCL.4L1

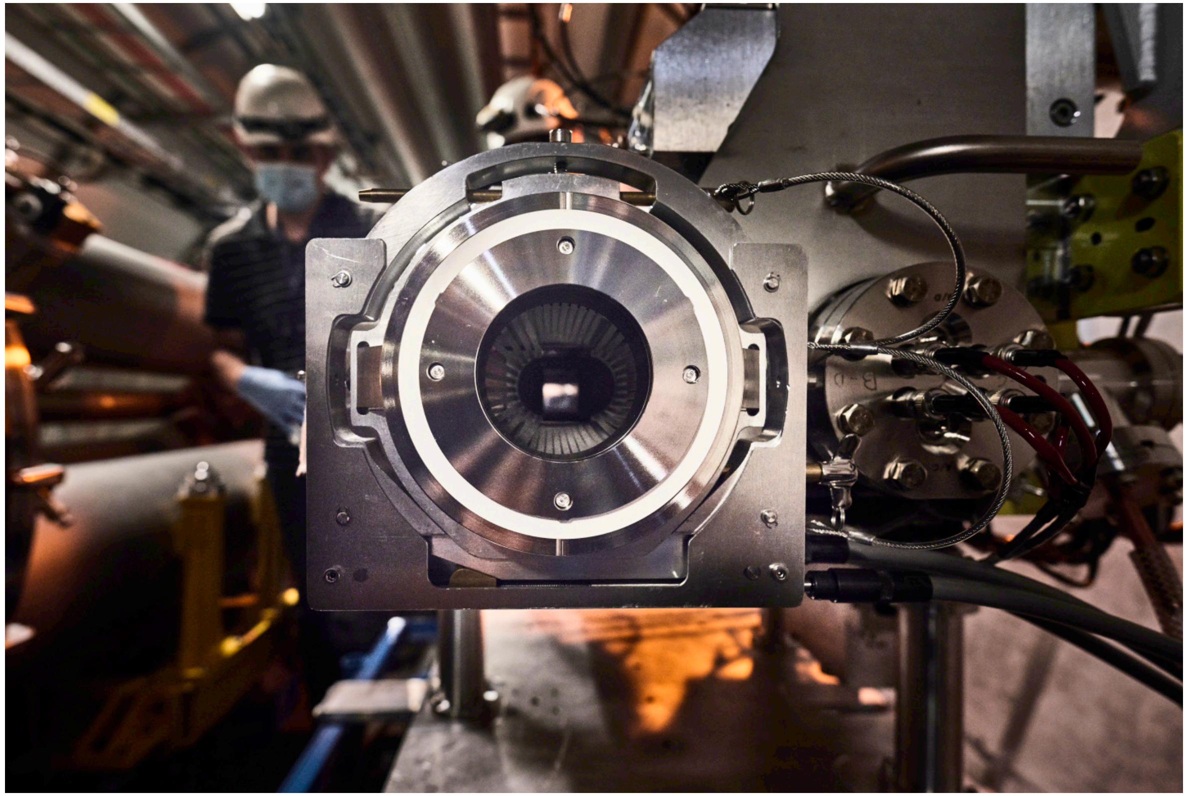
Large Hadron Collider collimation



Passive masks, protecting resistive quads in betatron cleaning insertion

W collimators intercepting particles from interaction region

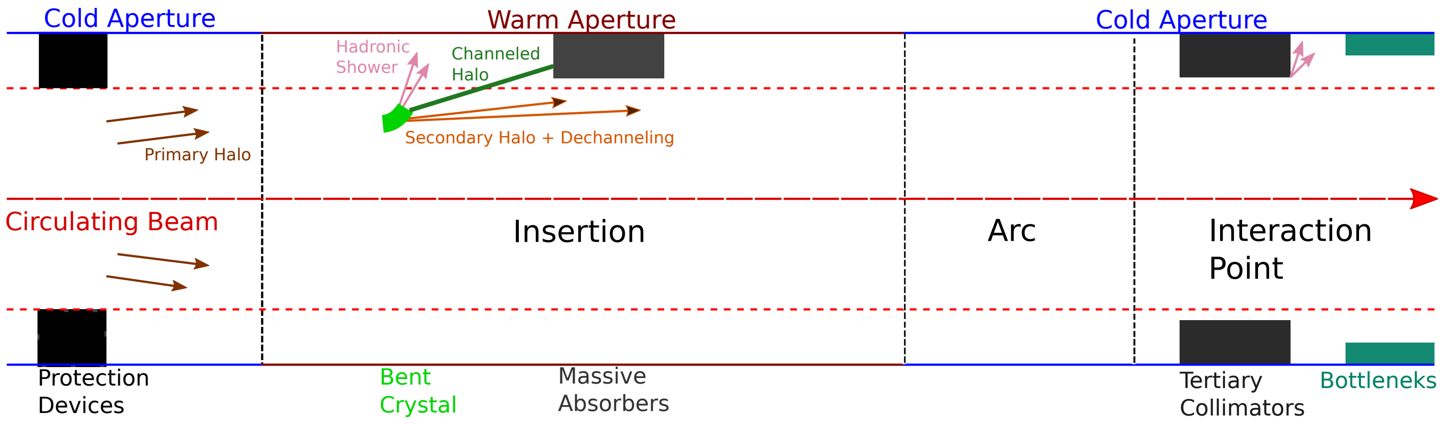


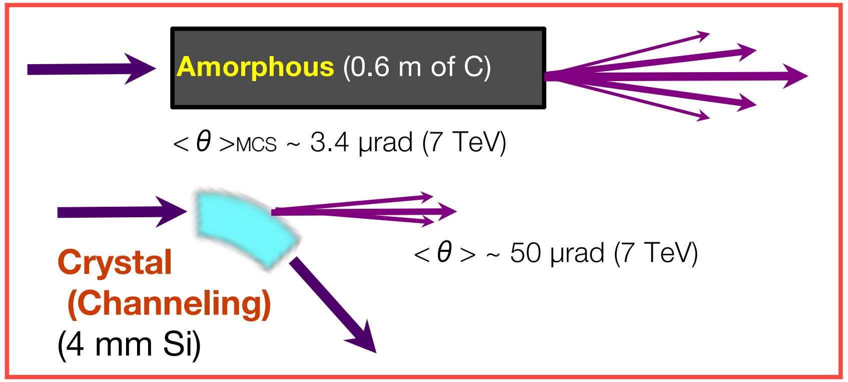


Advanced collimation – bent crystals

- In recent years, attention has been turned to crystal collimation:
  - Primaries are replaced by **bent crystals that steer all halo particles onto a single absorber**

1. **Improved collimation cleaning (especially for ions)**
2. **Reduce impedance** (less collimators at larger gaps)

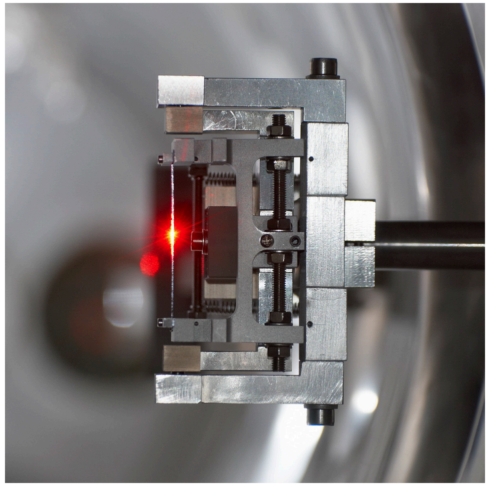


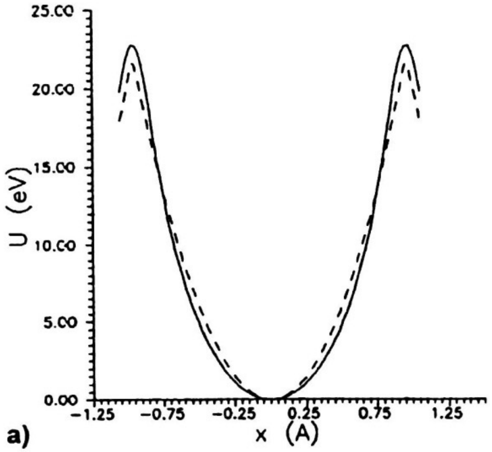


With 50 µrad of bending in 4 mm the crystals produce the effect of an equivalent 310 T field

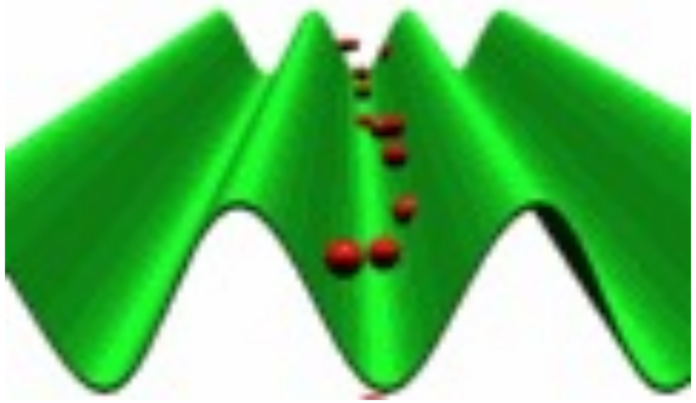
Coherent effects in bent crystals

- The trajectory of a positive particle travelling at a small angle with respect to crystalline planes is strongly **influenced by the repulsive potential** averaged along the atomic planes

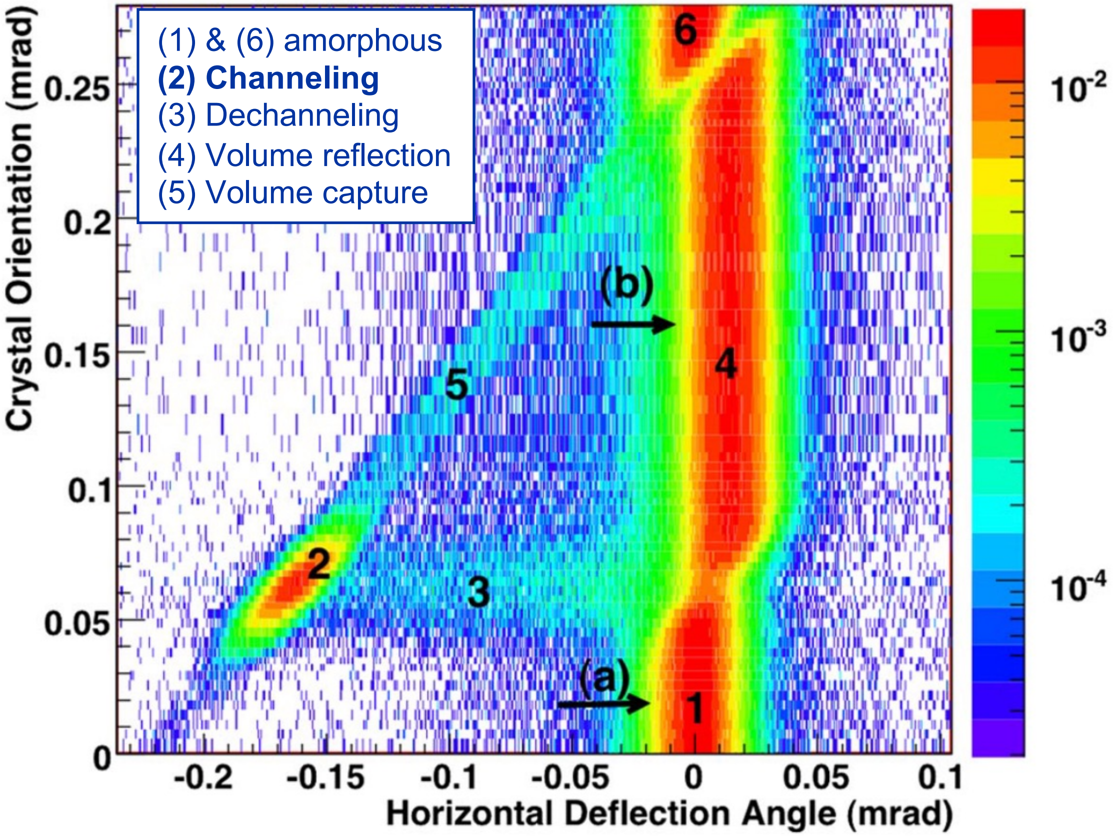


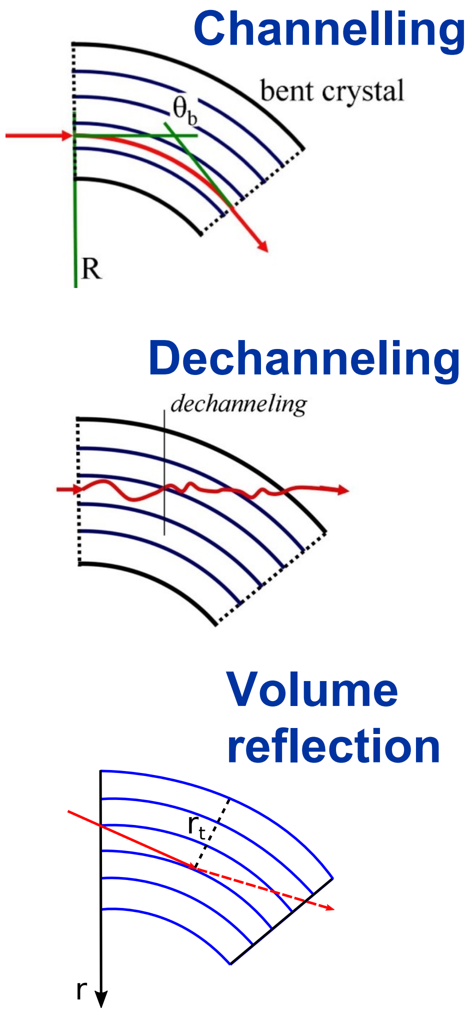


- **Channeling is the result of particle confinement in the potential well** between neighboring crystalline planes

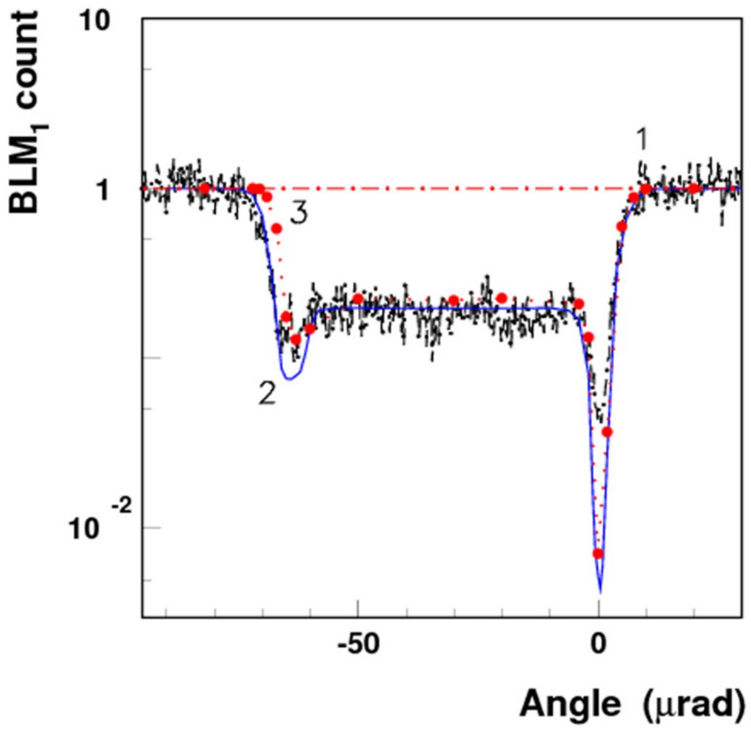


Crystal channelling and collimation in action





Does it work?

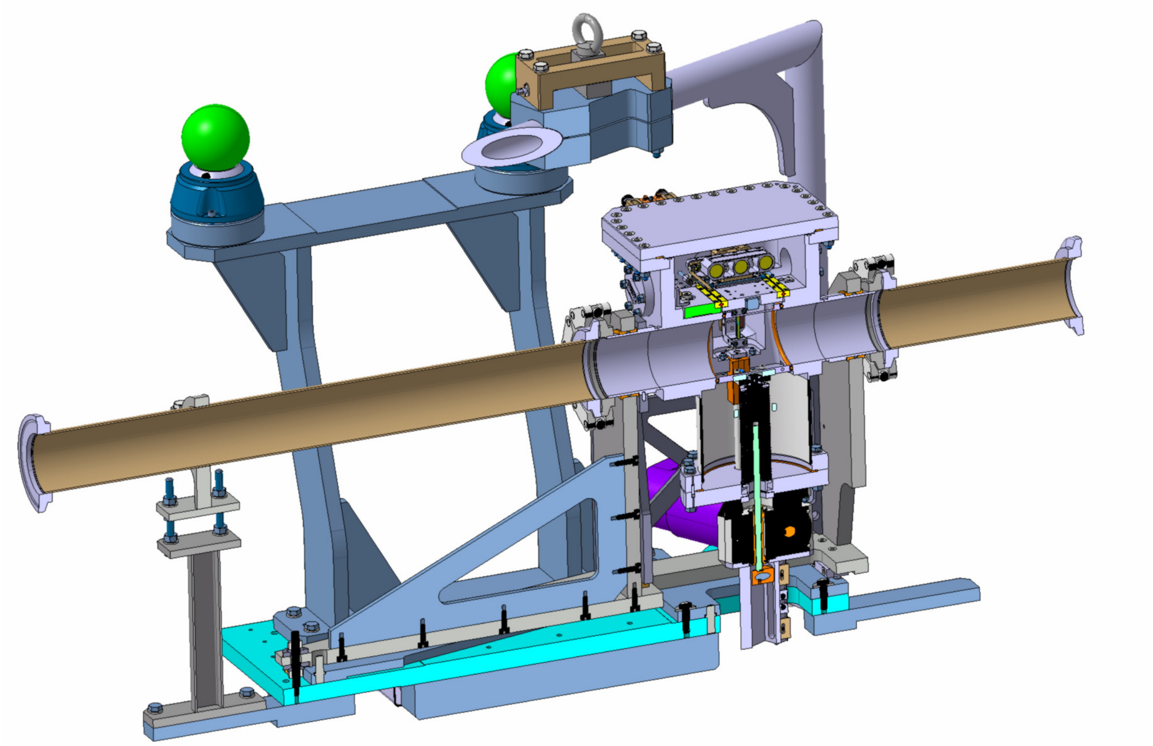


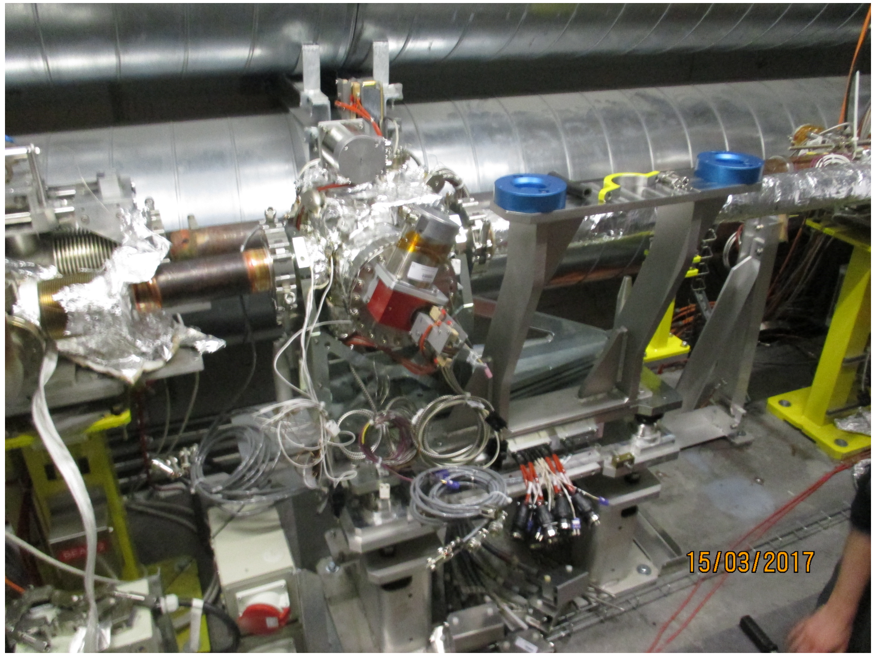
Yes!

W. Scandale, Phys. Rev. Lett. 98.154801
W. Scandale, J. Phys. Lett. B 2016.05.004

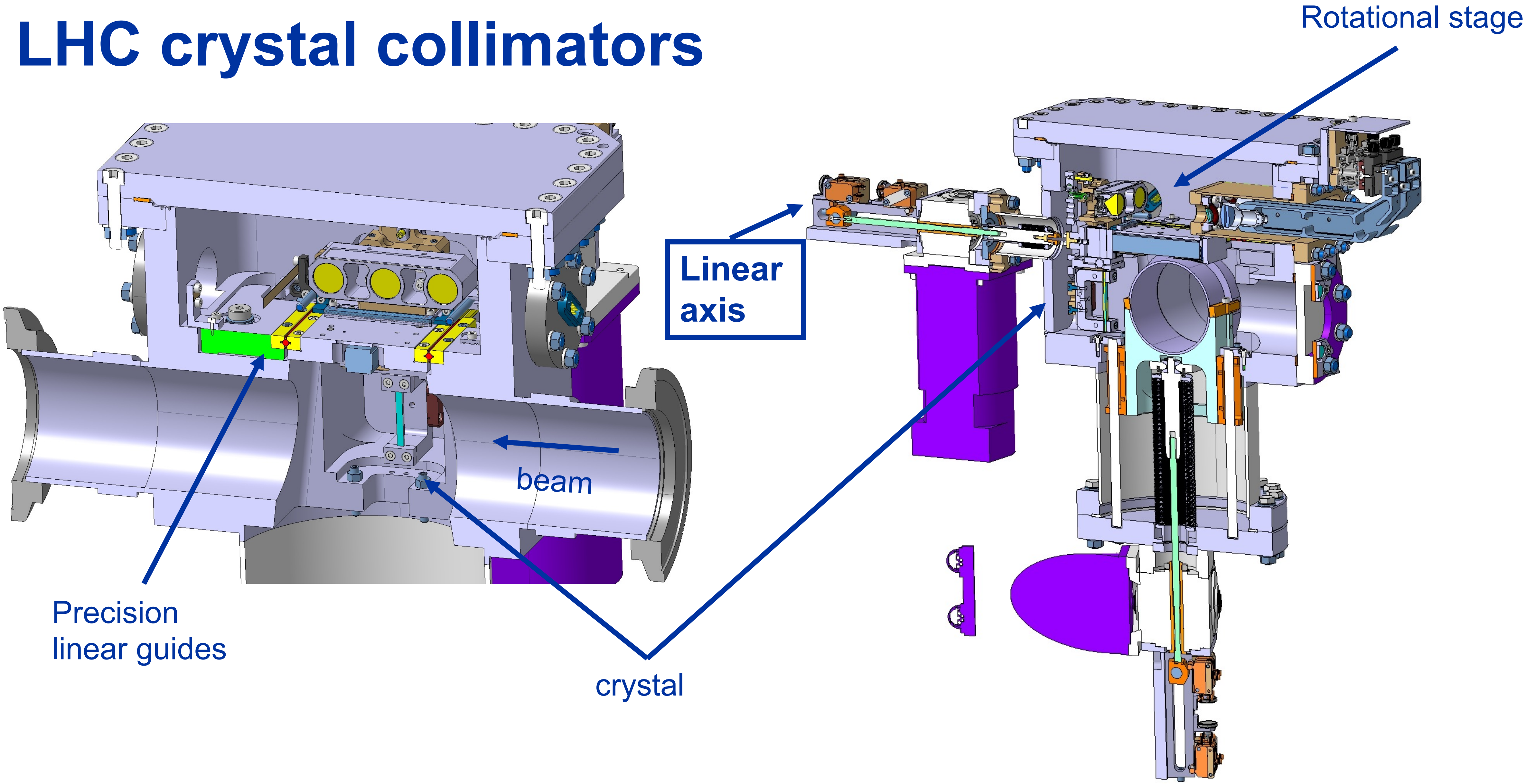
LHC crystal collimators (ion operation)

- A technological challenge, with high-precision angular positioning system (e.g., yaw angular accuracy of **±1 μrad**)
- Operational device for ion operation (impedance considerations)

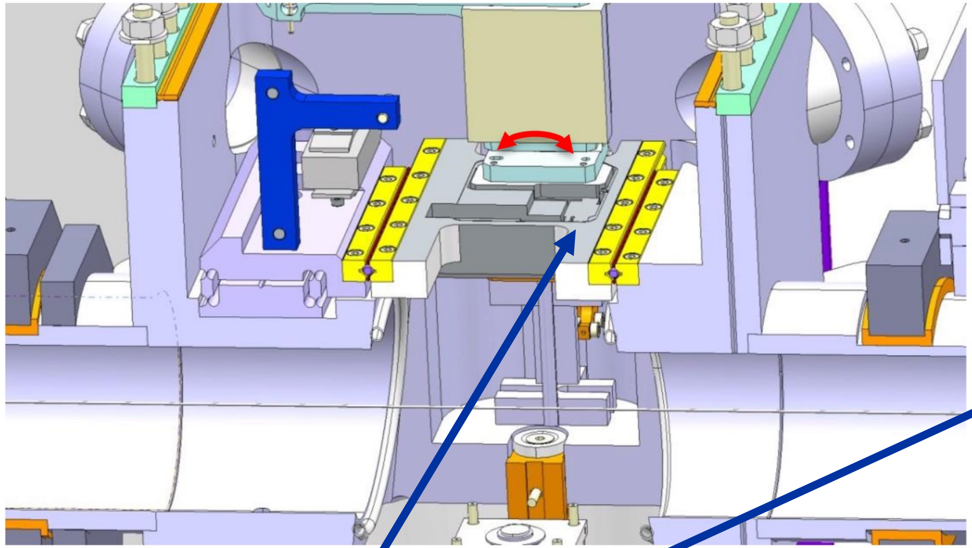


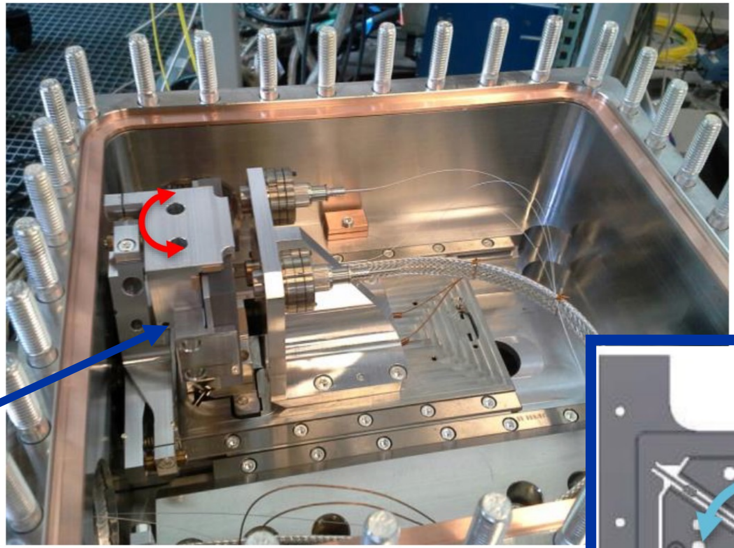


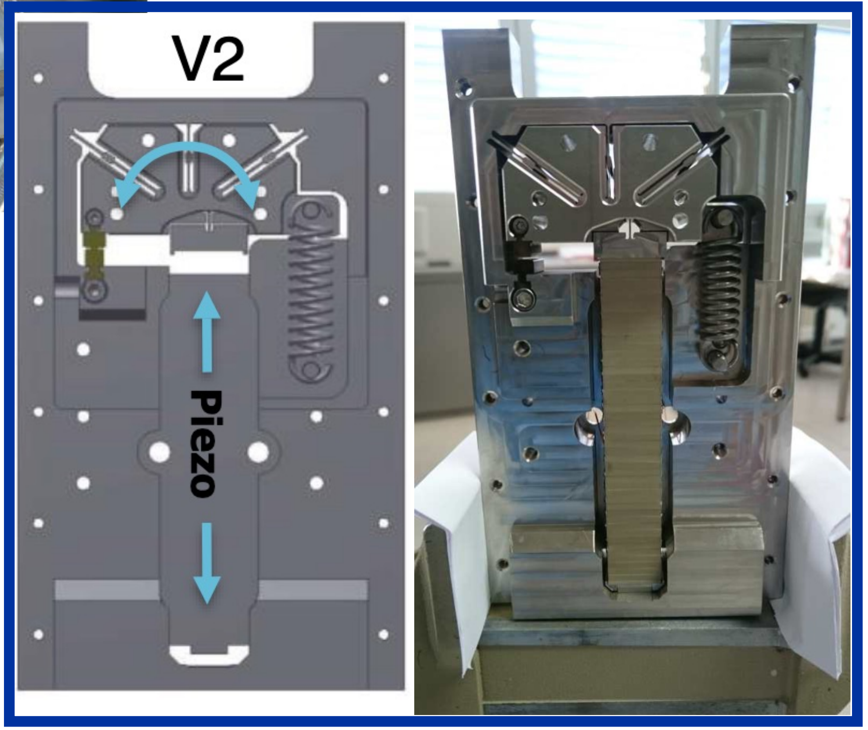
LHC crystal collimators



LHC crystal collimators





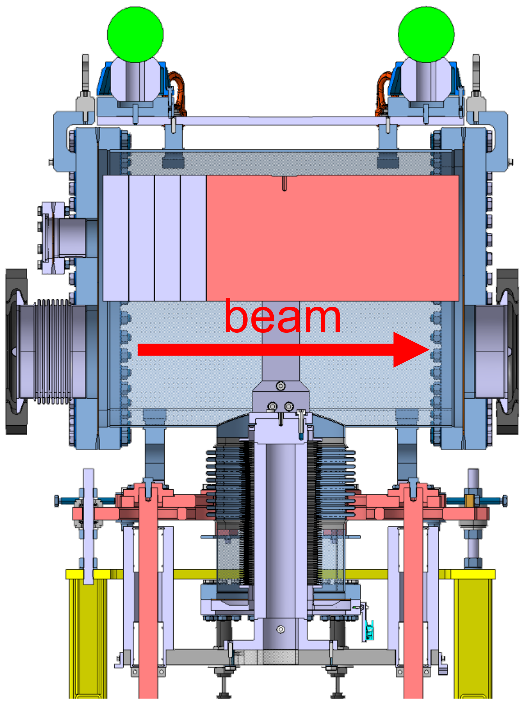


Piezo actuated rotational stage
↑ high force-to-size ratio & immune to magnetic fields
… but ↓ suffers from hysteresis and creep

4. Beam Stoppers

Beam stoppers

- Devices are classified as "critical" elements for personnel safety
- Must protect personnel intervening in the accelerator tunnels from exposure to radiation produced by beam circulation or beam injection

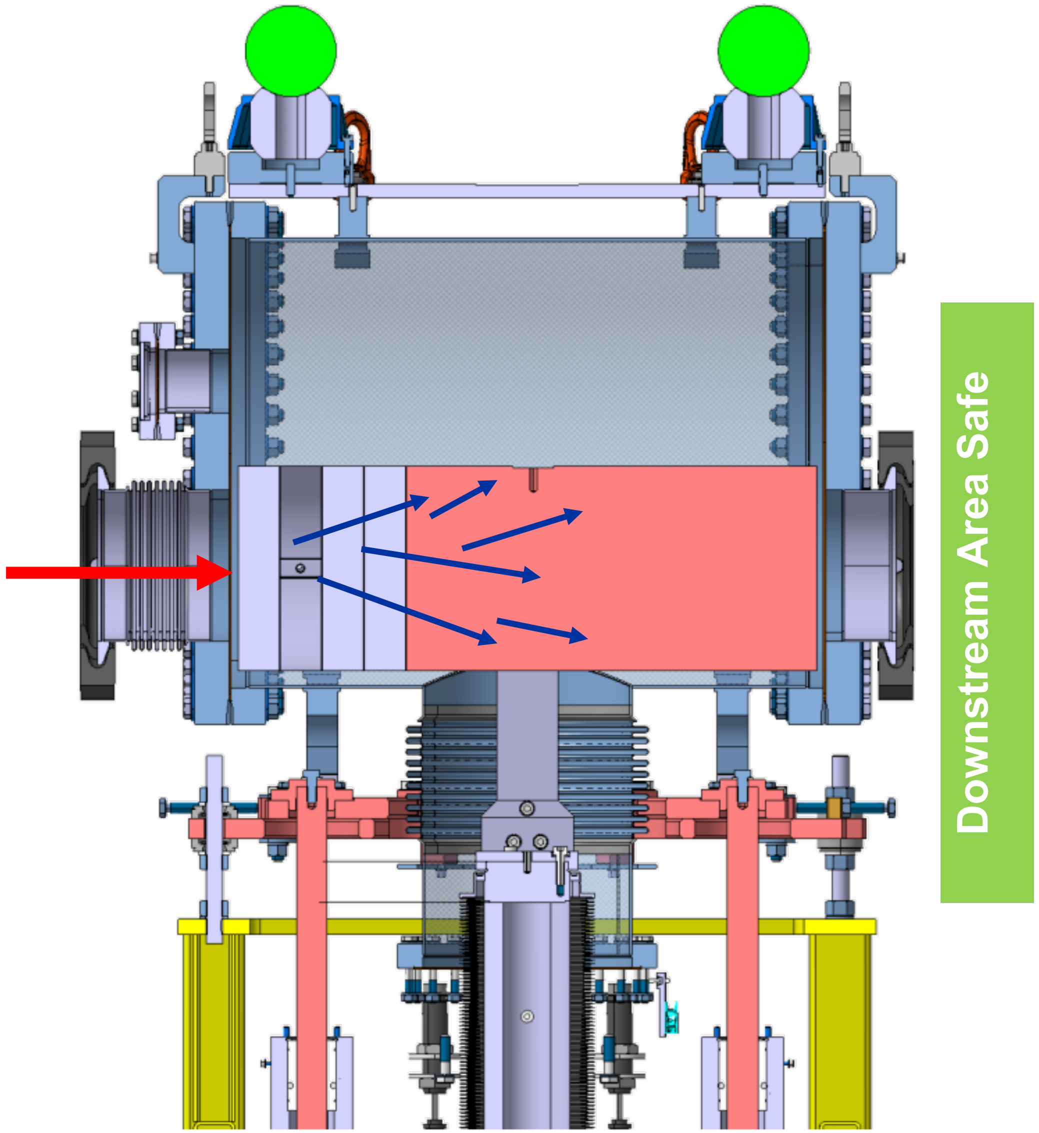


Downstream Area Beam Mode

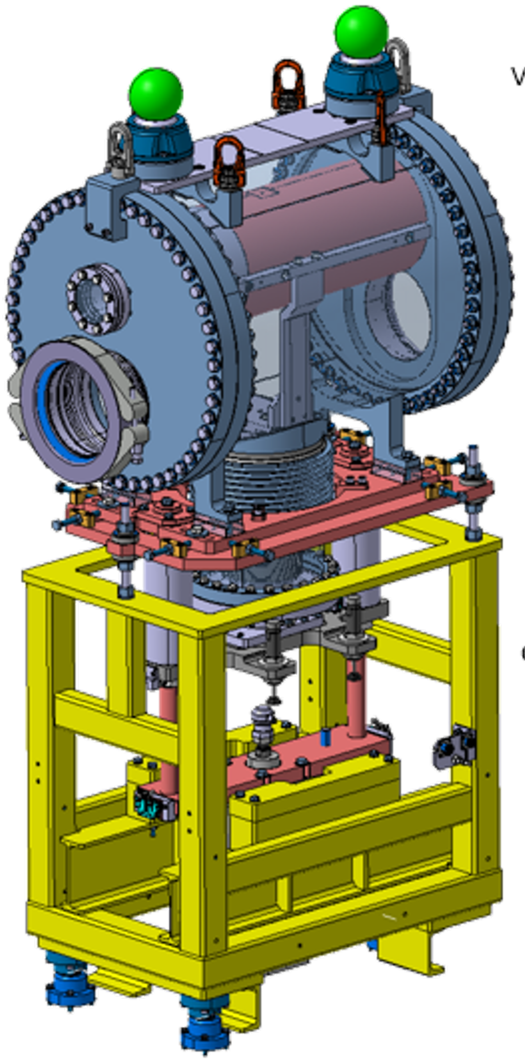
- **Particle absorbing core** that remains **out of the ultra-high vacuum** particle beam line during normal operation of the accelerators
- Beam allowed to pass through undisturbed

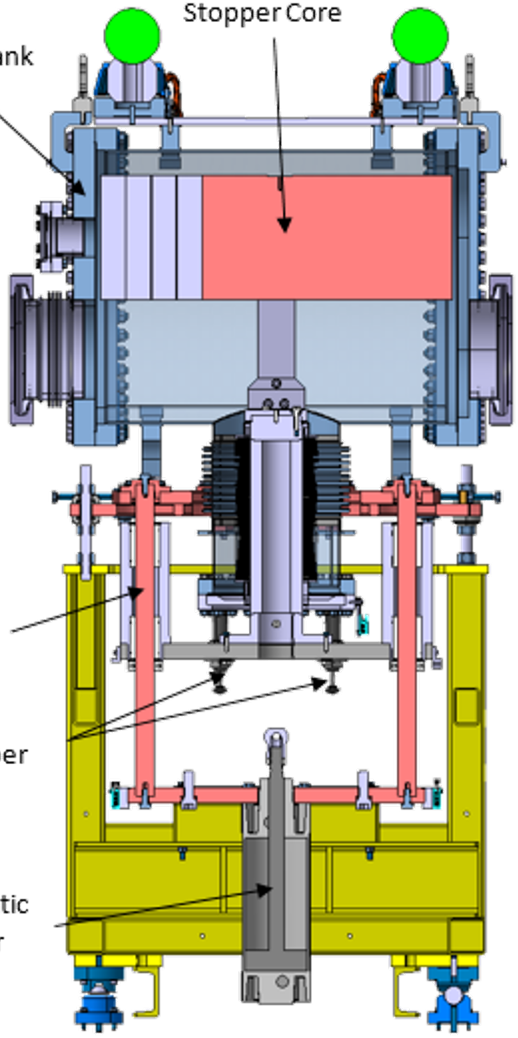
Beam stoppers

- Beam stoppers are put **in-beam** when
  - Access to a downstream experimental facility
  - Forced access to a downstream facility (accidental scenario, few beam pulses could hit the stopper)
  - Power cut or air-pressure failure (fail-safe condition) (few beam pulses likely to hit stopper)
- Core absorption must be enough to contain radiation shower (3.8 λ)
- Must absorb 15 repeated pulses
- 26 GeV/c, 2.3*10^{13} ppp

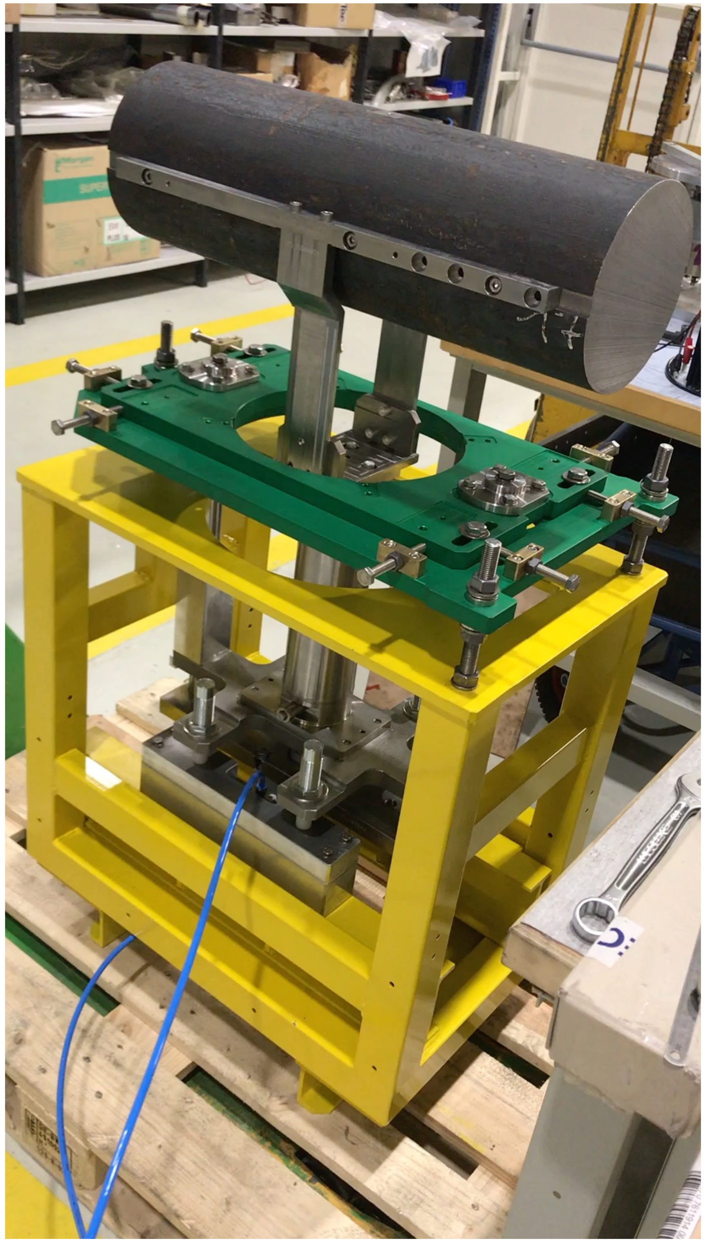


Beam stoppers mechanical design - c

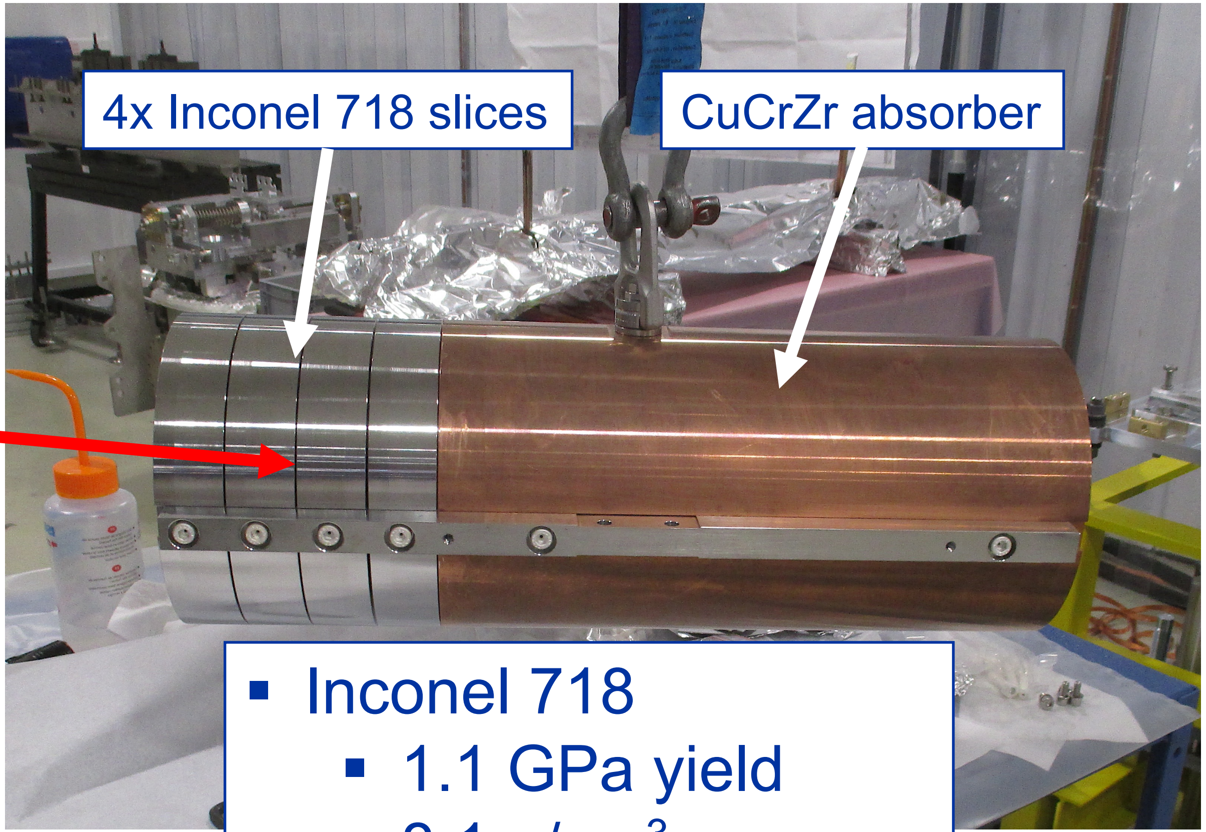




- Pneumatic actu
- Flange-to-flang
- >10k cycles
- Actuation time
- Flexibility to ins complex techni plug-in system
- Commercial ma withstand up to nearby)



Beam stoppers mechanical design - core



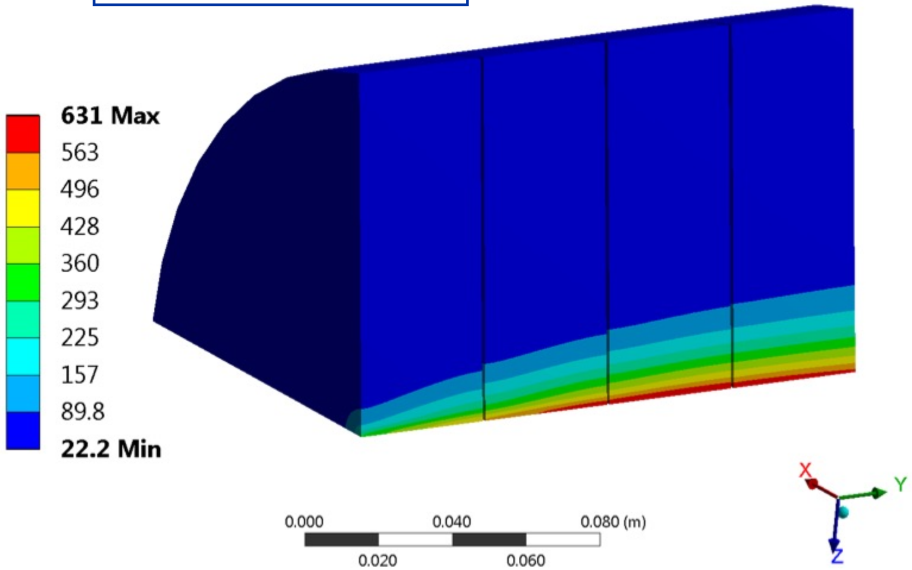
- Inconel 718
  - 1.1 GPa yield
  - 8.1 g/cm^3
  - service T <650 ºC

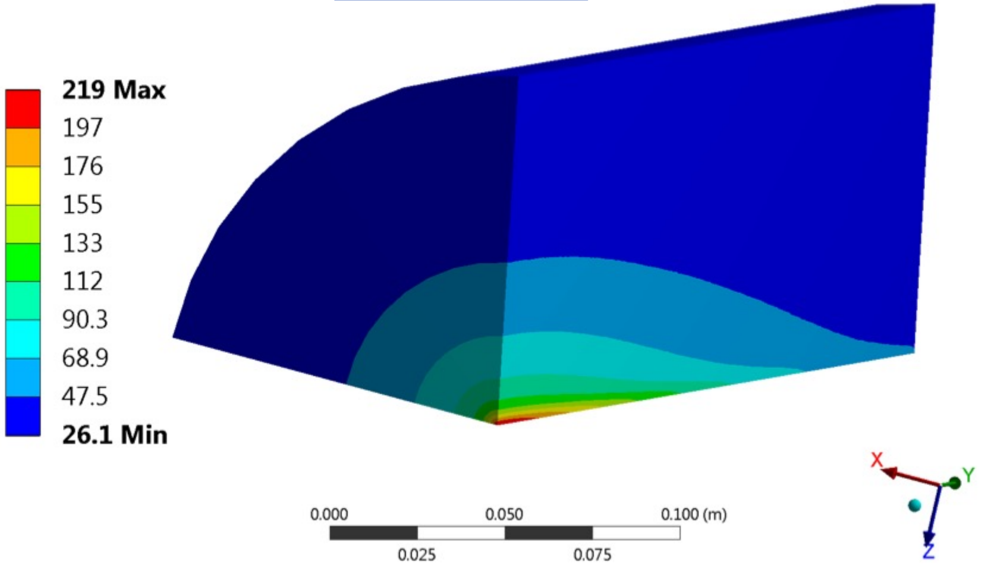
- Length: (4*50+364) mm
- Diameter: 200 mm
- Weight: 156 kg

Inconel 718

CuCrZr

Temperature (ºC)

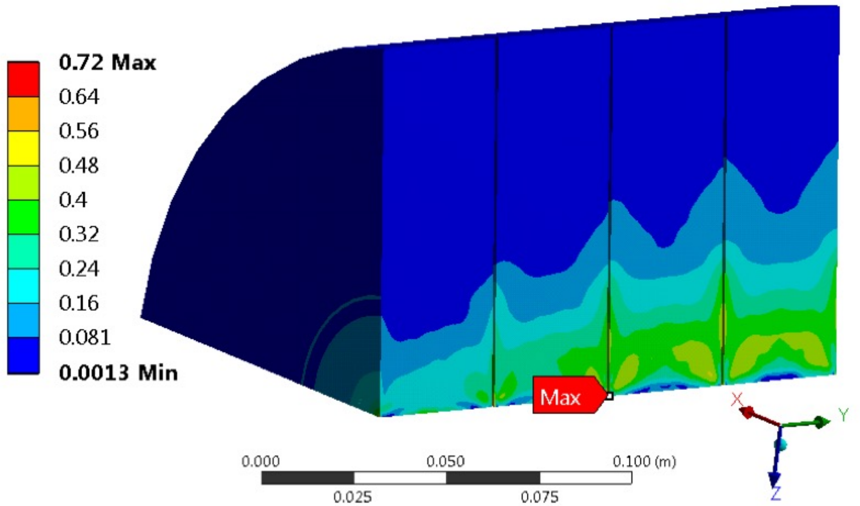


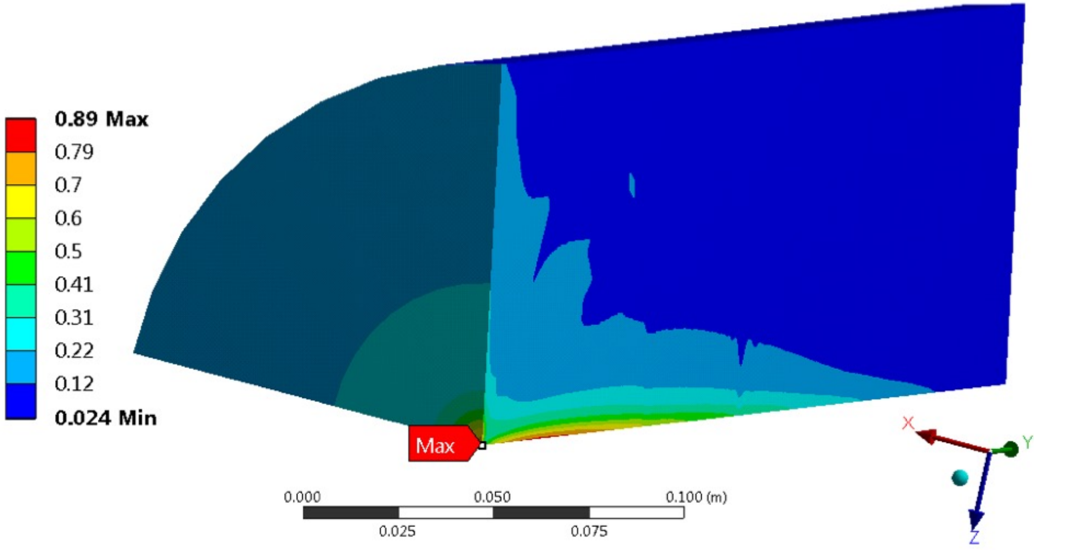


Equivalent Von-Mises stress

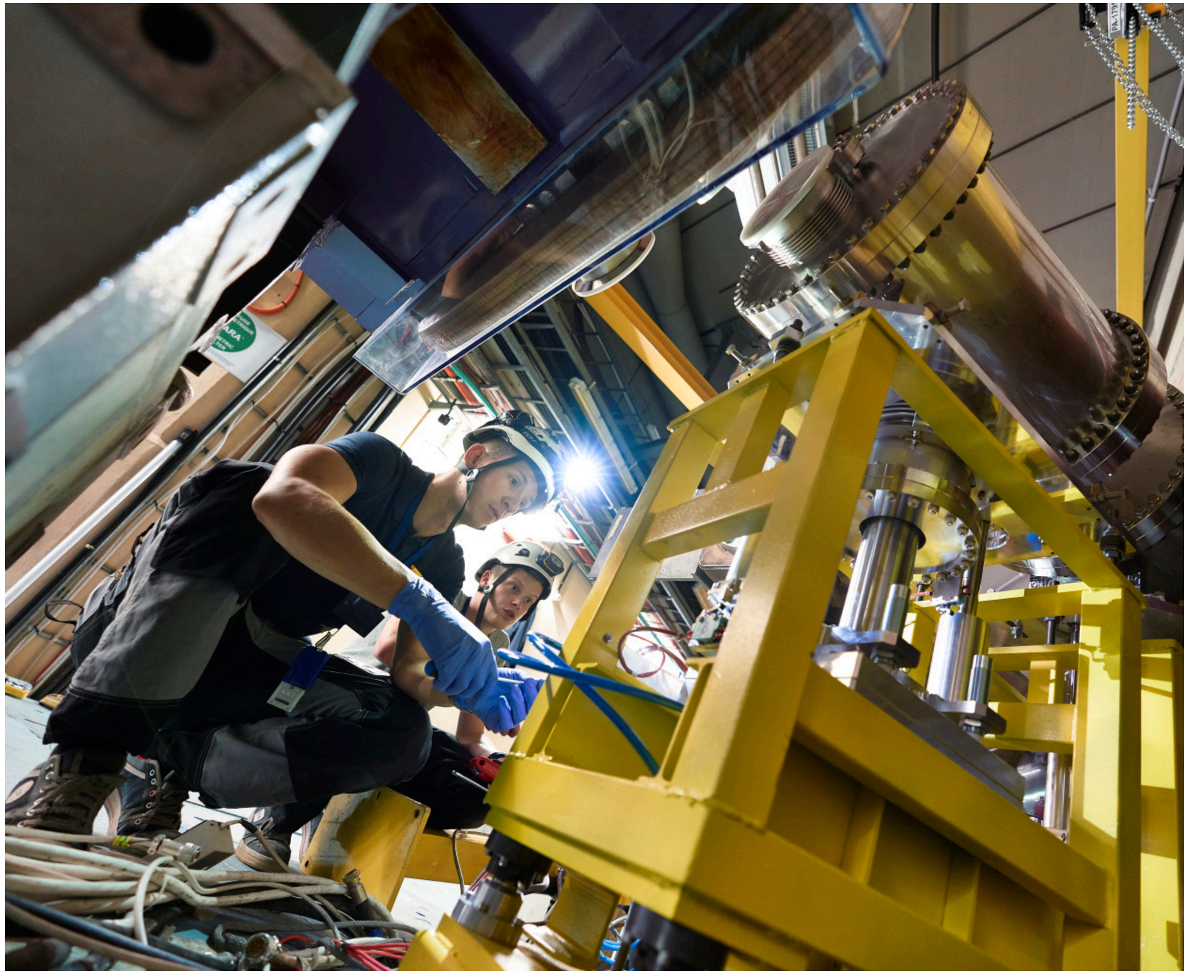
$$\sigma_{eqv} / \sigma_y(T)$$

T dependent yield strength





Long Shutdown 2 installation
PS Booster



Beam dumps and absorbers

5. SPS Beam Dumps

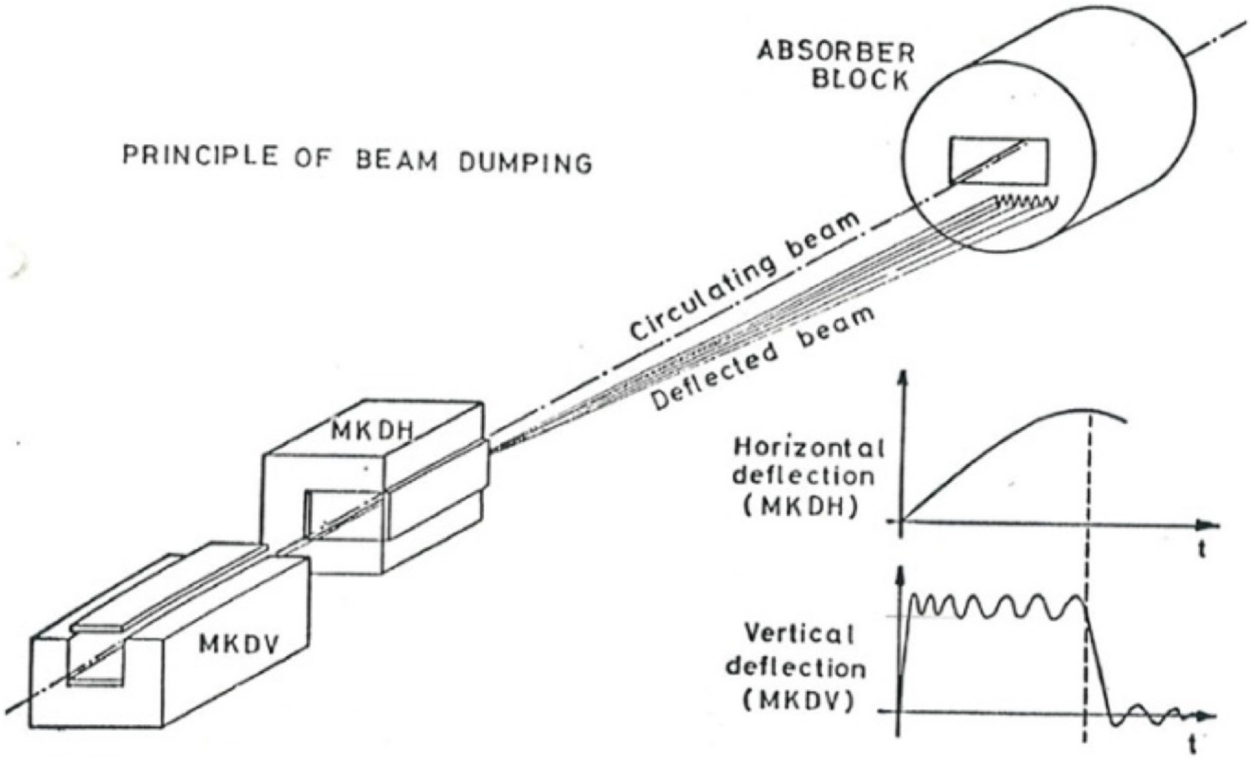
Internal vs. external dumps

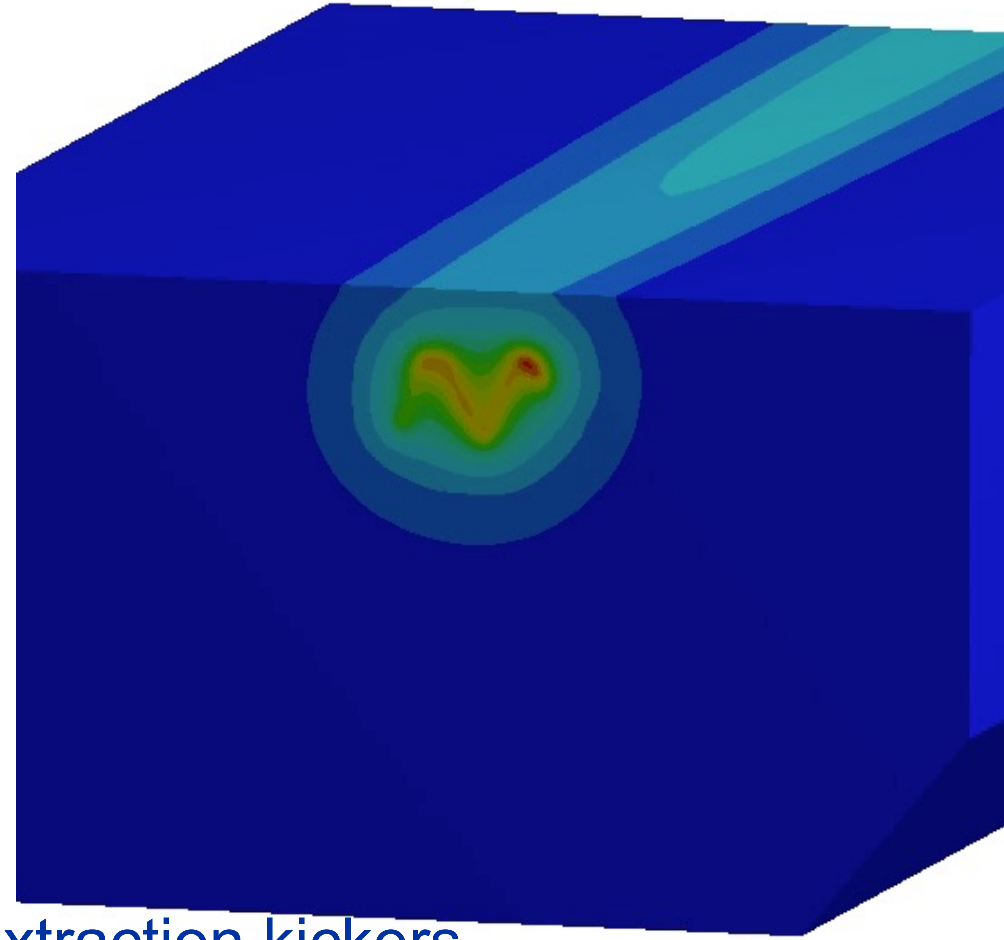
- Dumps are designed to withstand **all potential beam scenarios**, **safety devices** for machine components
- They can be located **internally** or **externally** to the machine vacuum depending on the geometry and external requirements
- Internal dumps have the extra challenge of having to comply with the strict UHV requirements despite the high T
- External dumps usually requires dedicated caverns or line components

SPS Internal Beam Bump
History, challenges and technology

- Due to the specific design of the SPS, the dump is **internal**
- Heavily used in the machine (not only during exceptional case), to allow flexibility and setting up beams
- Reliability is a key parameter for operation

SPS beam dumping





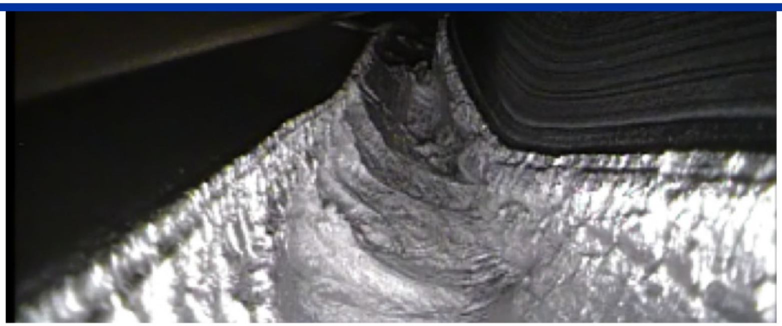
- Beam is diluted during 7.2 μs with dilution and extraction kickers
- Asymmetry in the energy deposition results in asymmetric stress distribution

SPS Internal Beam Bump
History, challenges and technology

- Historically (up to 2000), SPS dumps were including only **aluminium** as absorber
- From 2000 onwards ("millennium" dump) – due to the higher intensities – **graphite** was introduced, keeping Al for the downstream part – earlier generation were Ti-coated
- It was a good idea, but…

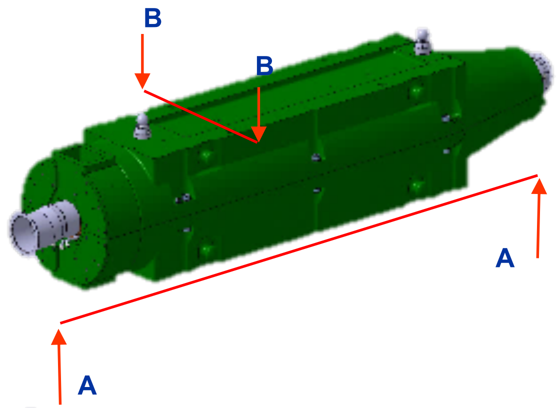
What happens with insufficient cooling?

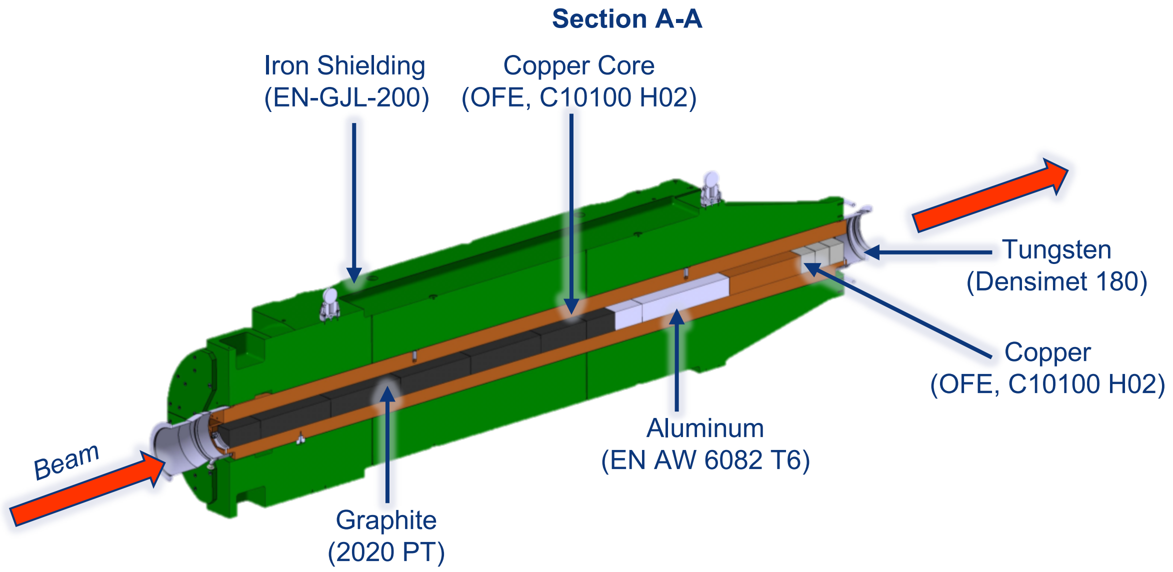
- Molten aluminium coming from insufficient cooling
- Lesson learnt: **complete removal of Al and focus on improving thermal contact with Cu sink**

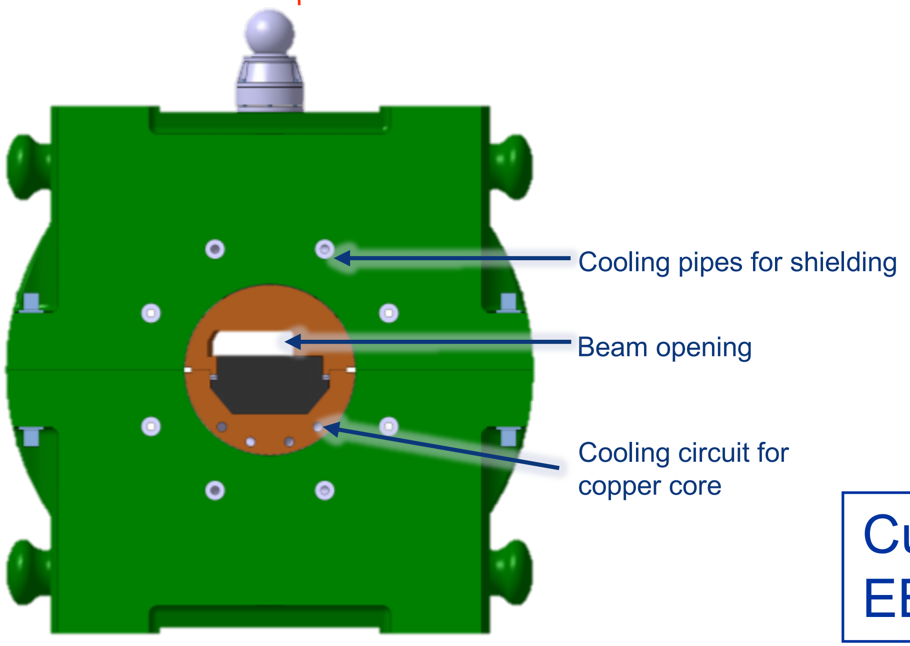


Third generation dump

< 2016



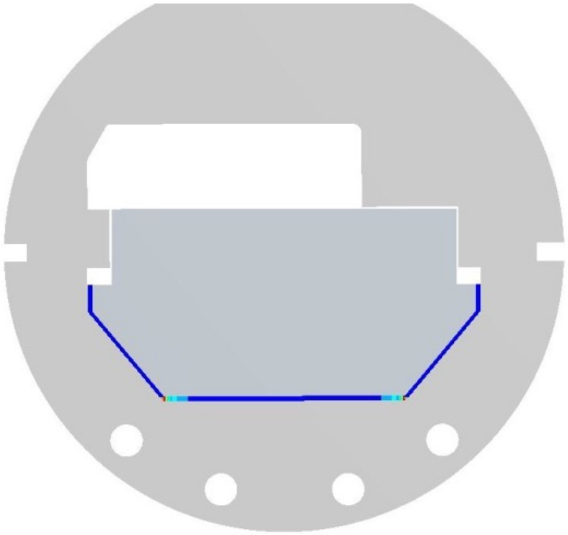




Cu-OFE 3D forged core
EB welded half shells

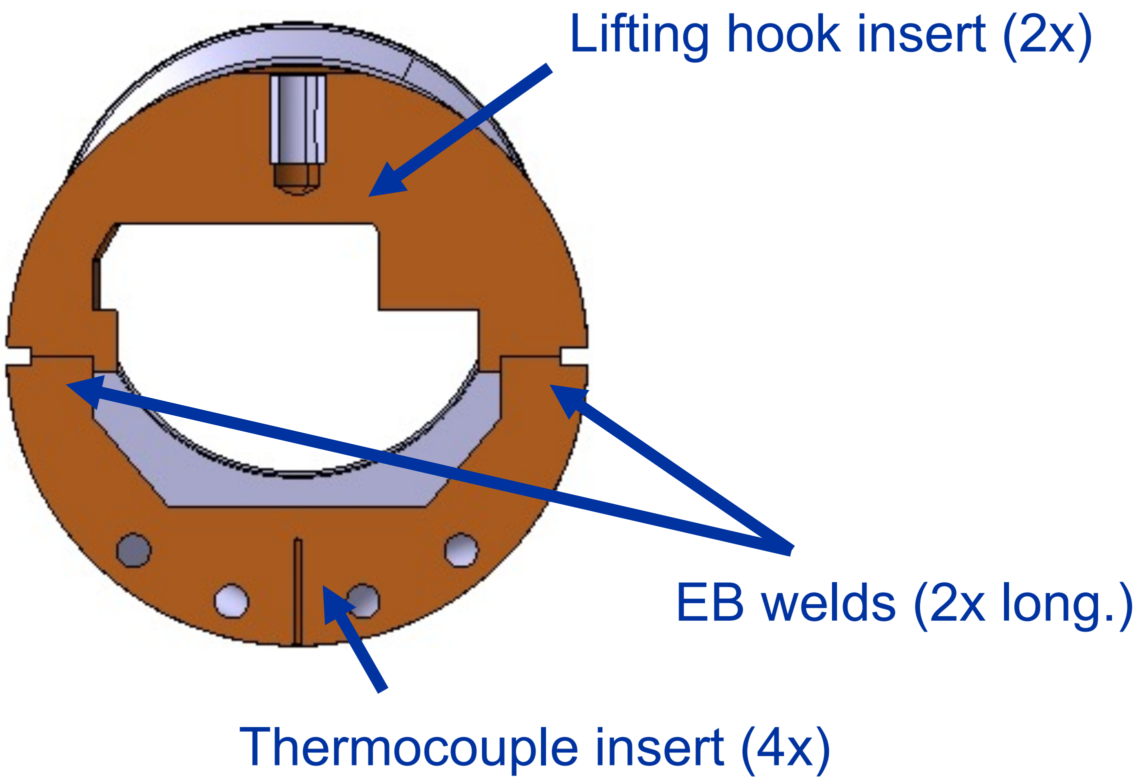
Issues with previous designs

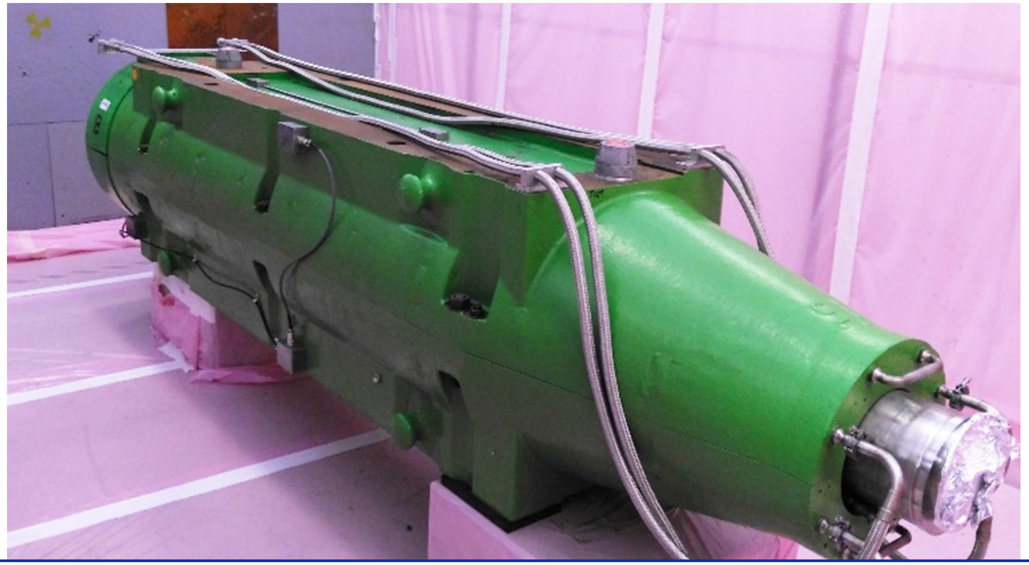
- Limited internal instrumentation (blind during operation)
- Unpredictable contacts between absorbing blocks and Cu core
- Extremely long manufacturing time of 3D forged Cu-OFE
- Aluminium as beam absorbing materials
- Vacuum leaks at EB welds due to asymmetric energy deposition



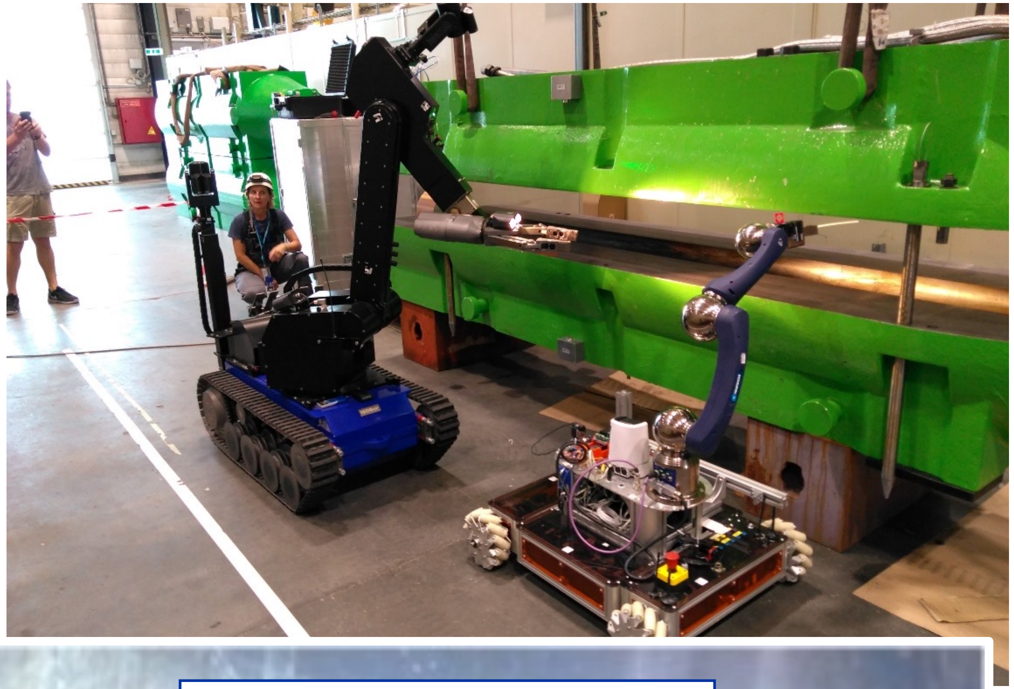
Intermezzo: importance of PIE

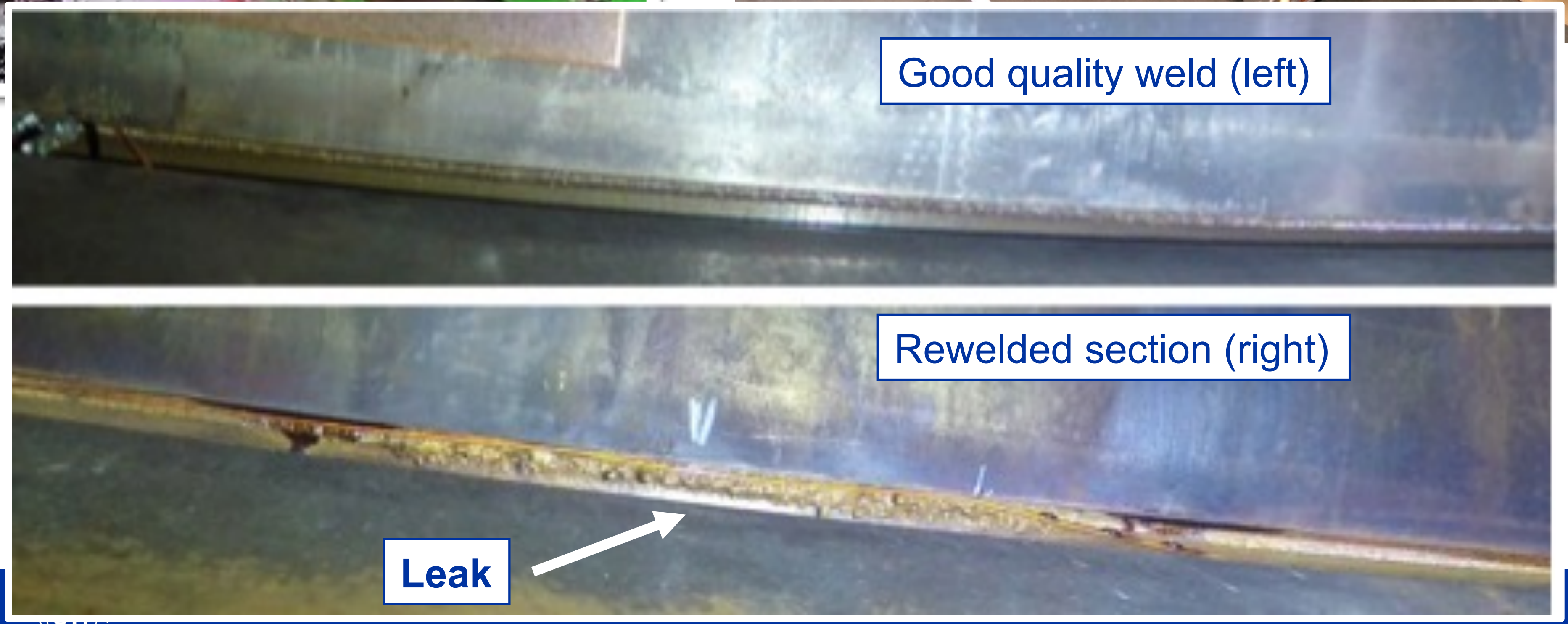
- Third generation dump was inspected post-mortem at CERN in order to confirm position of leak and correct in fourth generation dump





Few mSv/h with shielding close
±50 mSv/h core open
➔ Robotic means employed to inspect

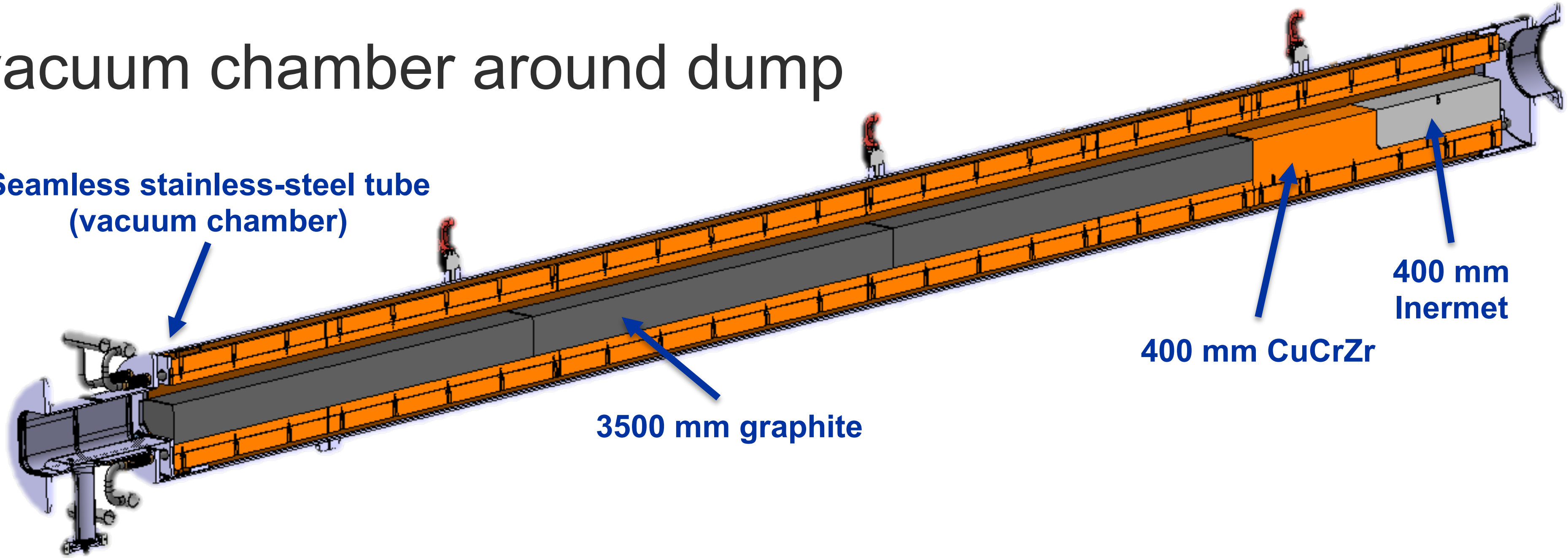



Good quality weld (left)
Rewelded section (right)
Leak

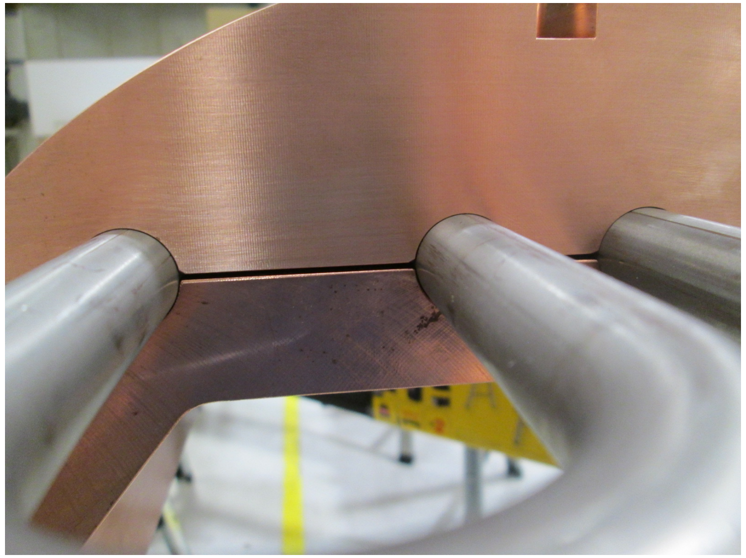
Fourth generation dump (2017-2018)

- Eradication of aluminium
- CuCrZr as absorber (integrated with heat sink)
- Better springs to improve TCC
- Seamless SS vacuum chamber around dump
- T sensors

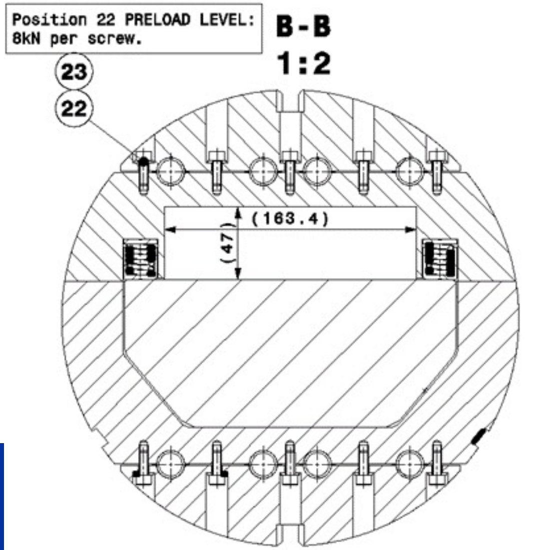
P_{dep}=60 kW
E_{beam}=4.2 MJ

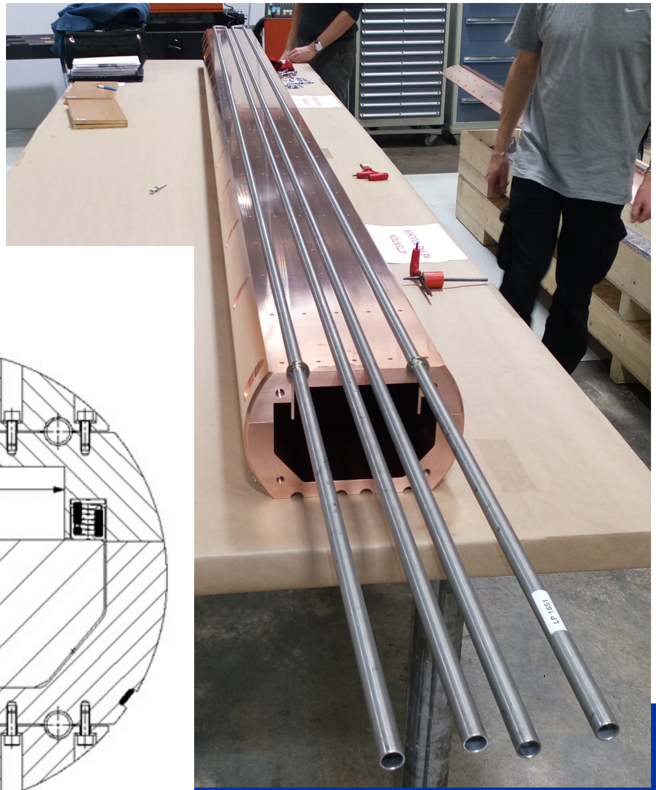


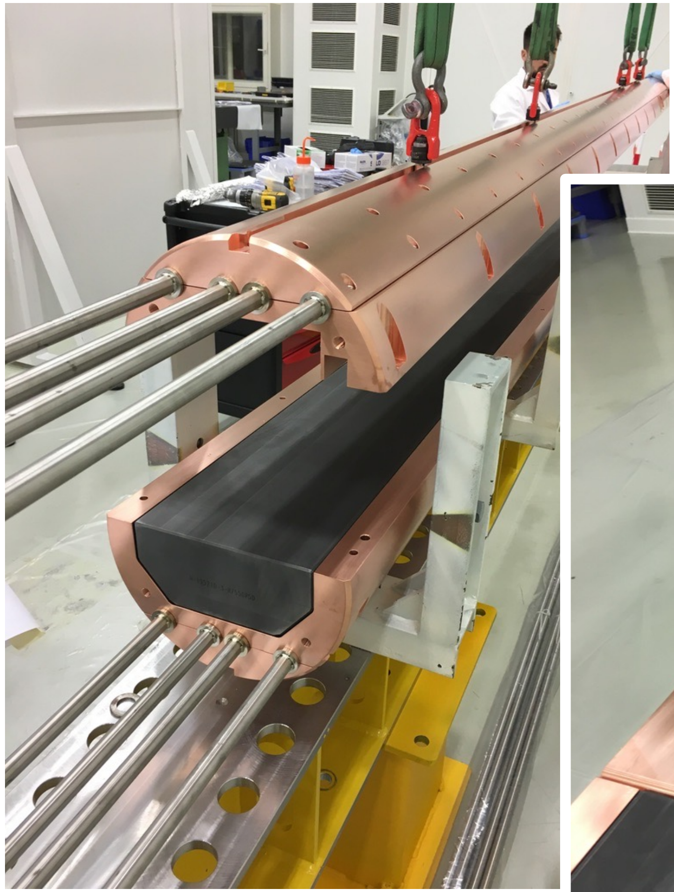
Mechanical clamping

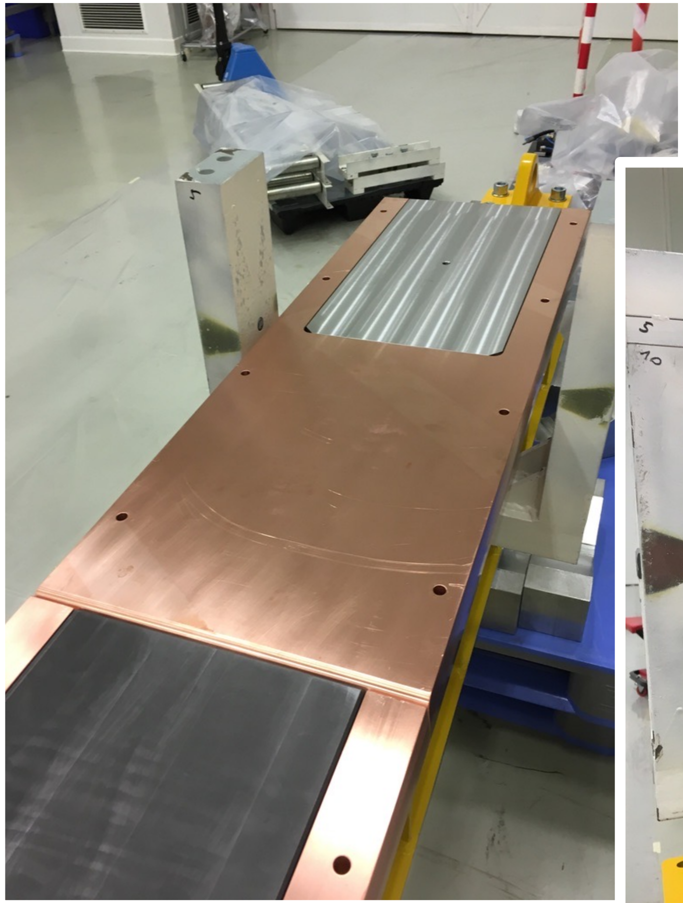


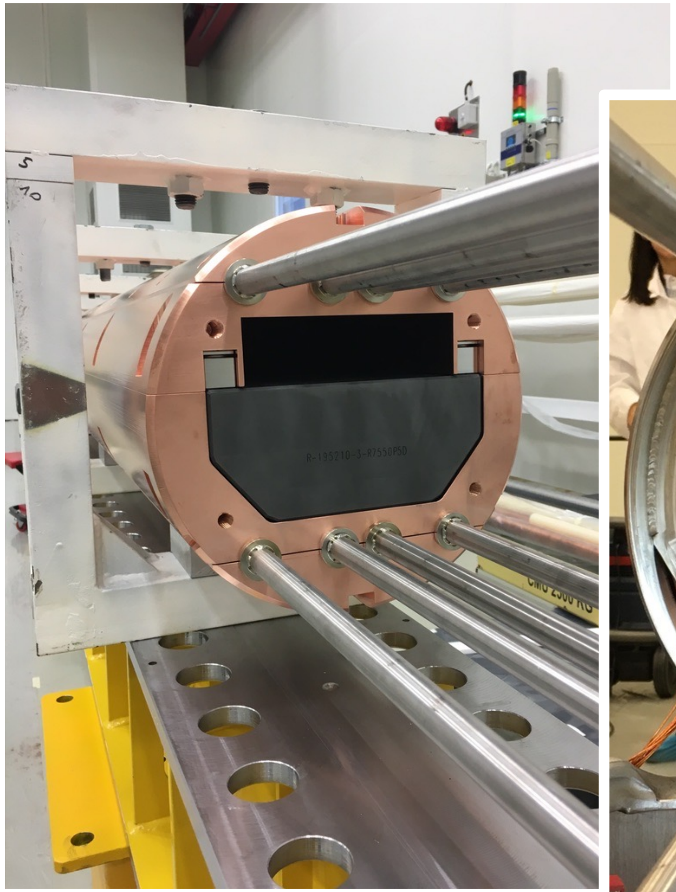
- Due to the short time available for design and construction, mechanical clamping was chosen to dissipate heat from CuCrZr to stainless steel tubes
- UHV compatible, high precision machining required, but thermal contact difficult to estimate

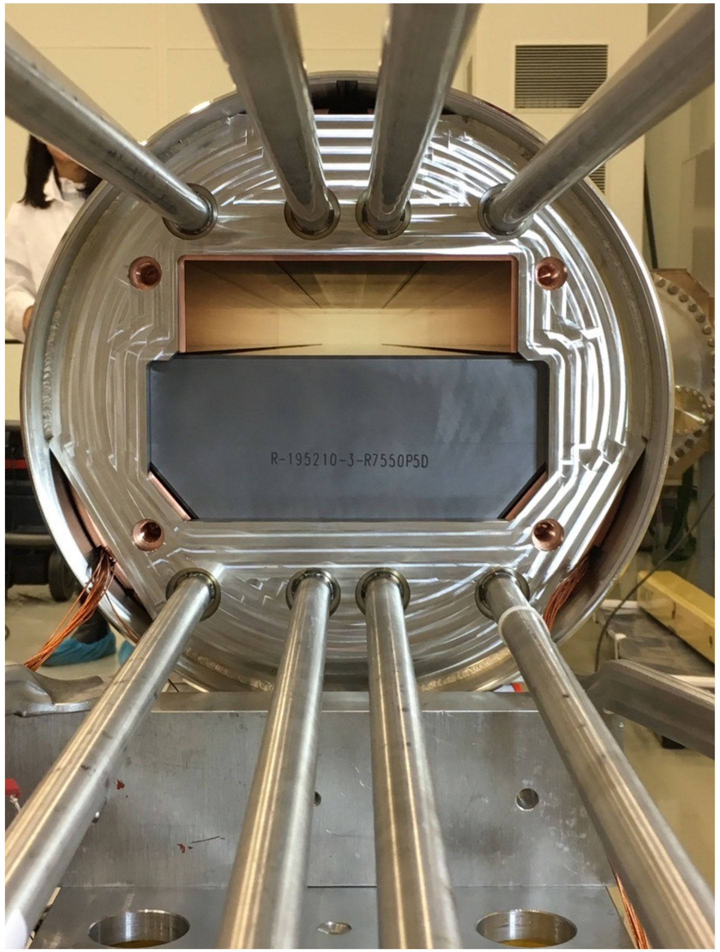











R-195210-3-R7550P5D

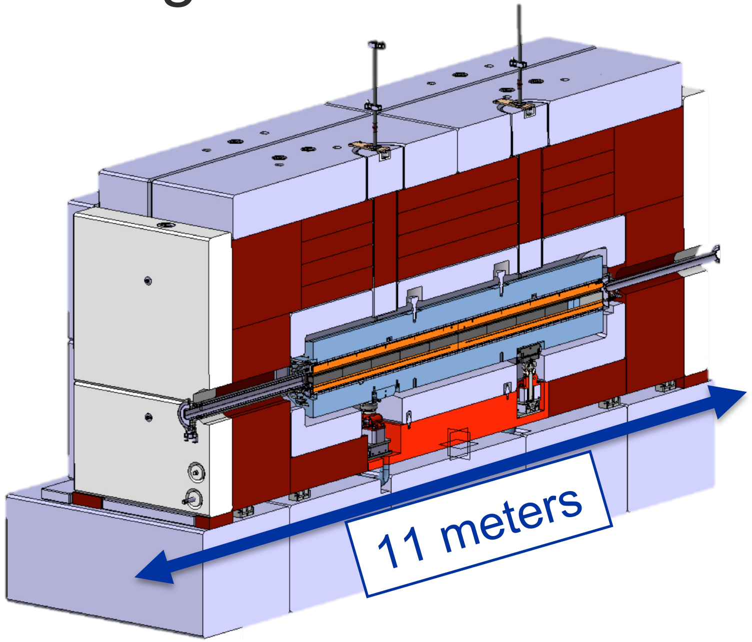
Fifth generation dump (→ 2021)
LHC injectors upgrade

- Incremental upgrades were not possible anymore → **revolutionary design**

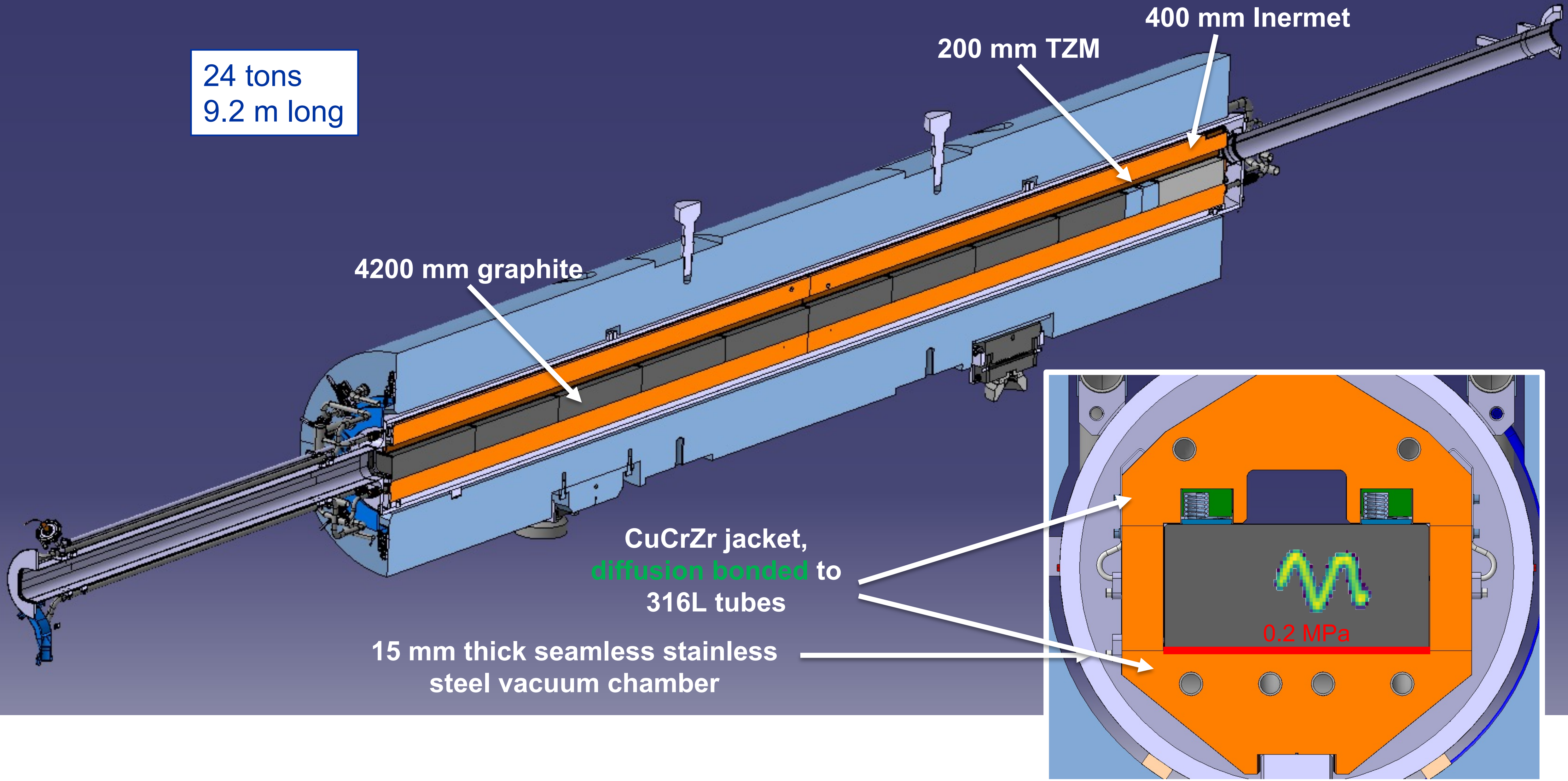
1. Need to cope with higher beam power (70 kW → 260 kW)
2. Need to comply with strict radiation protection regulations

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

Parameter	Unit	HL-LHC Standard Low Energy	HL-LHC Standard High Energy	LIU-SPS 80b Low Energy	LIU-SPS 80b High Energy	HL-LHC BCMS Low Energy	HL-LHC BCMS High Energy
Energy	GeV	26	450	26	450	26	450
Brightness	e13 p+/μm	3.92	3.70	4.35	4.11	4.93	4.67
Stored energy / pulse	MJ/pulse	0.30	5.04	0.34	5.60	0.30	5.04
Pulse period	s	21.6		21.6		28.8	
Max. dumps / hour		167		167		125	
Average power	kW	14.3	233.6	15.9	259.6	10.7	175.2
Consecutive dumps		>1h(1, 2)		>1h(1, 2)		>1h(1, 2)	

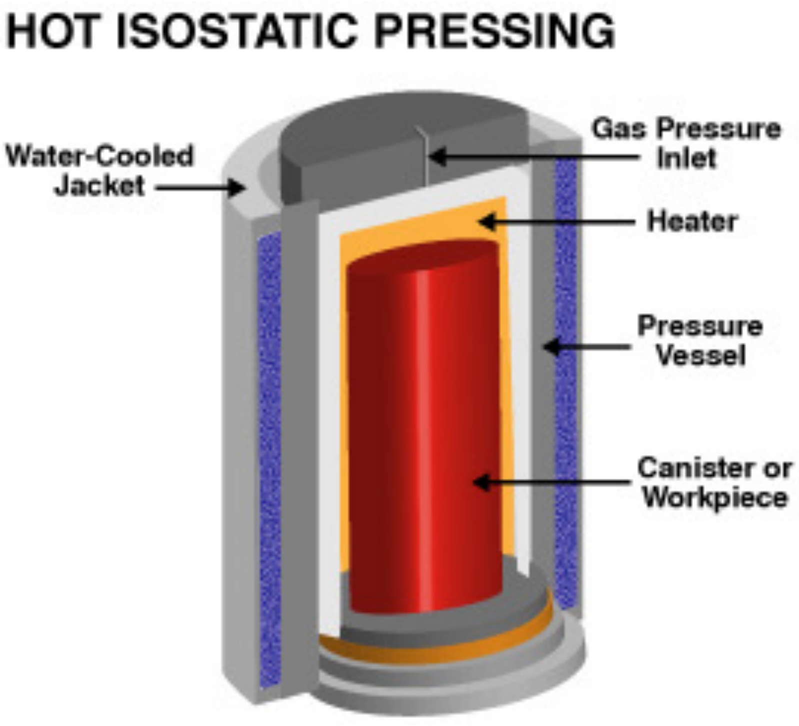


~520 t cast iron
90 t concrete
50 t marble

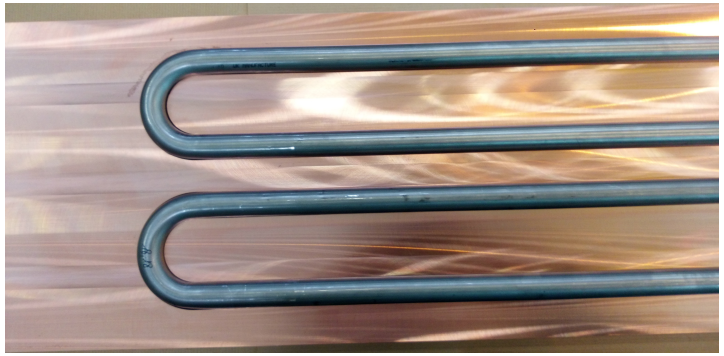

24 tons
9.2 m long
400 mm Inermet
200 mm TZM
4200 mm graphite
CuCrZr jacket, diffusion bonded to 316L tubes
15 mm thick seamless stainless steel vacuum chamber
0.2 MPa

Diffusion bonding via HIP

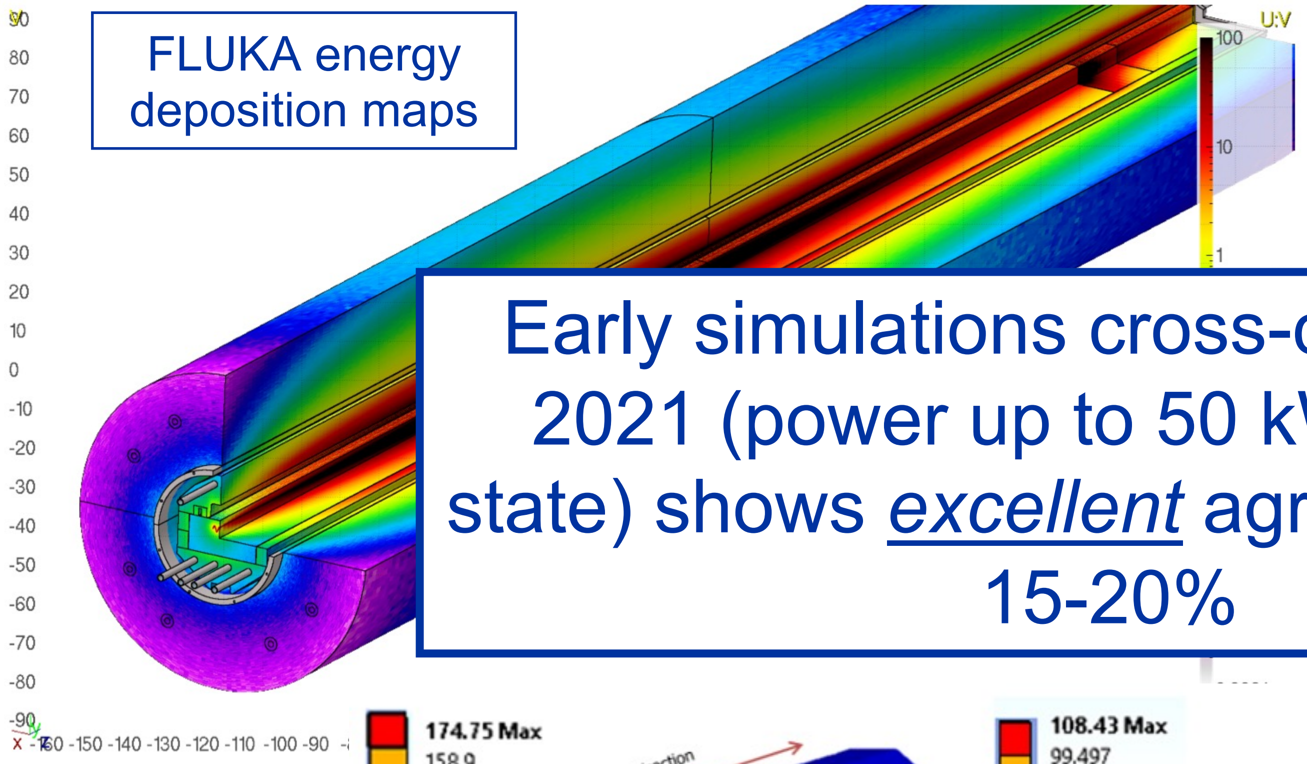
- Material densification technique
- Enclosures often of large size (operate under high pressure of inert gas and can reach high temperatures)
- Treatment of parts containing residual defects, giving them improved mechanical properties (foundry, powder metallurgy)...
- Allows to obtain a diffusion welding = perfect contact
- Compatible with UHV
- Different geometries possible
- Reproducible procedure

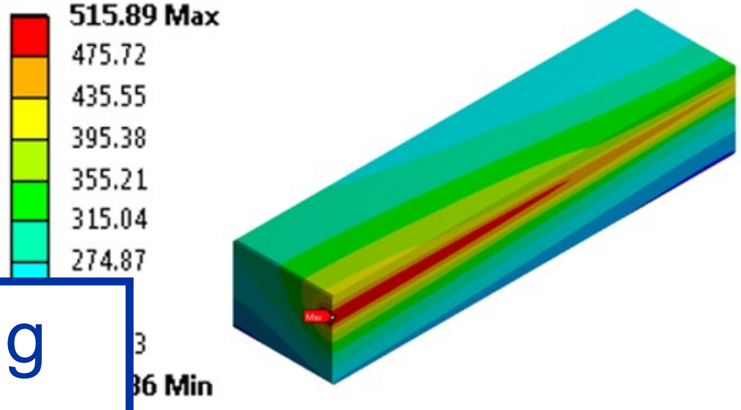


Custom development for CuCrZr diffusion to 316LN

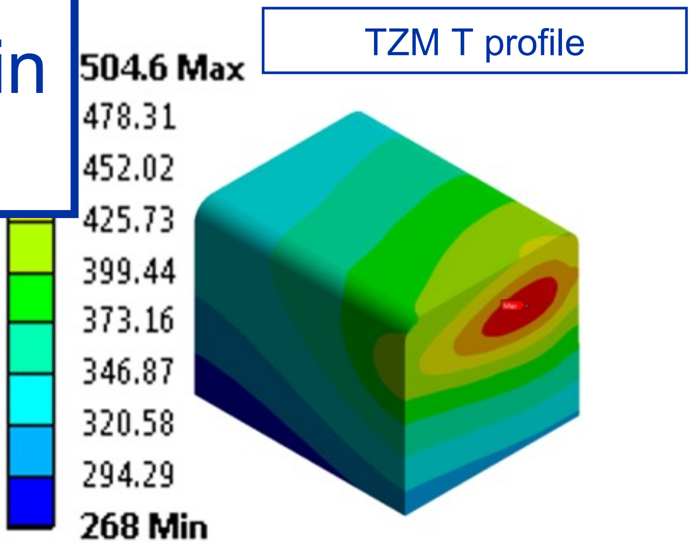


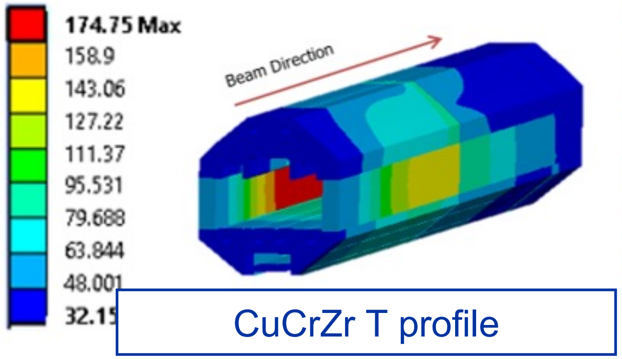
Multiphysics simulations for the core

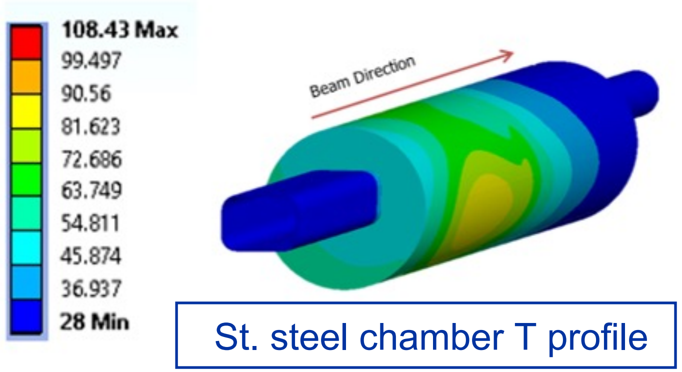




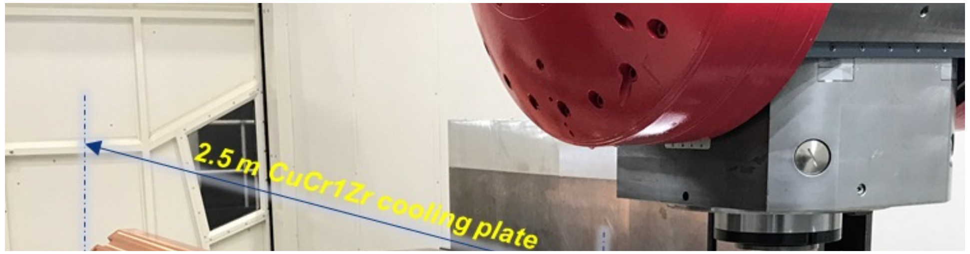
Early simulations cross-check during 2021 (power up to 50 kW in steady state) shows *excellent* agreement within 15-20%

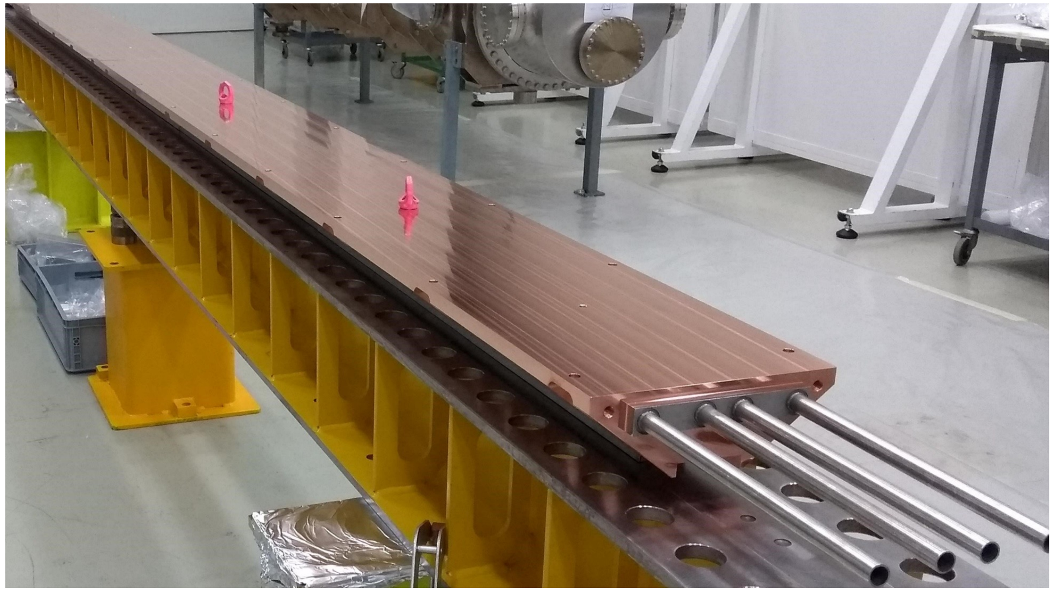


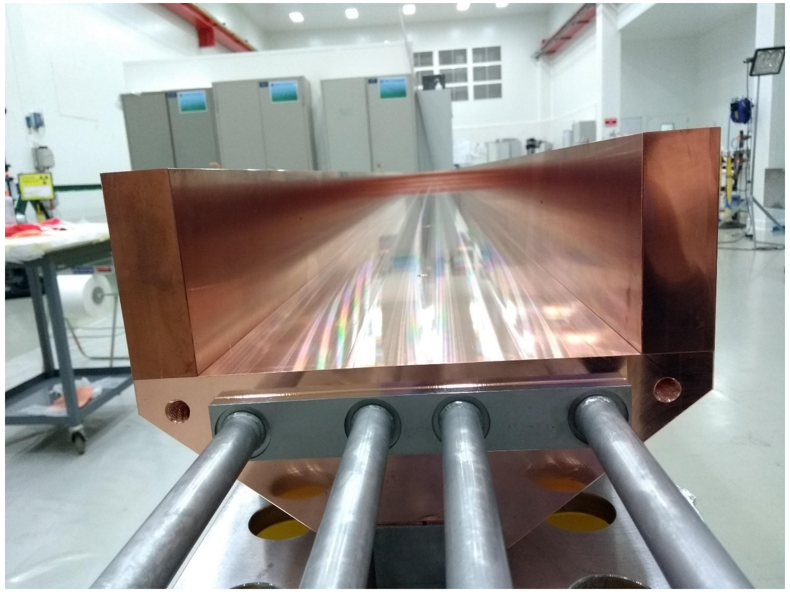




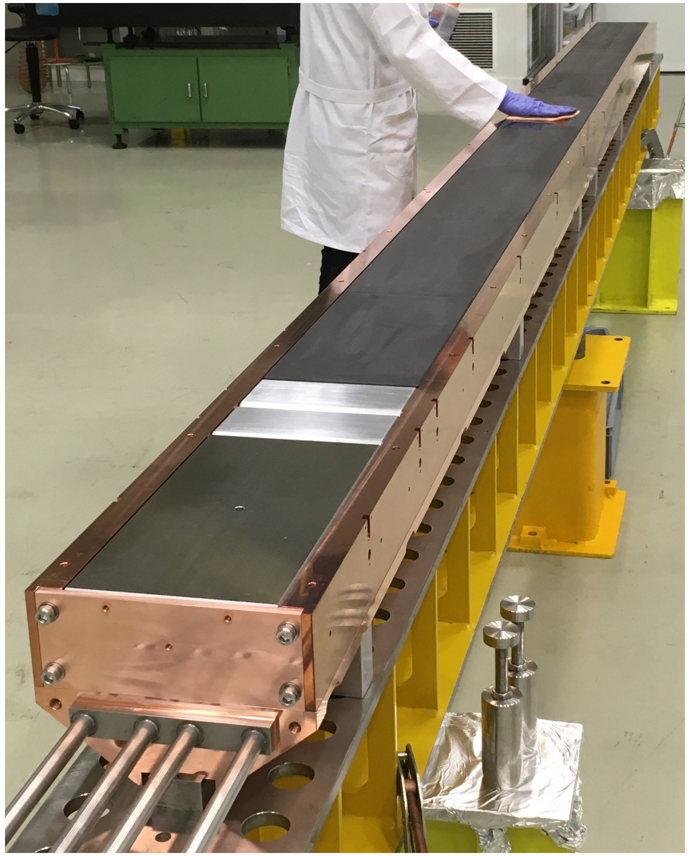
Fifth generation dump – assembly & installation

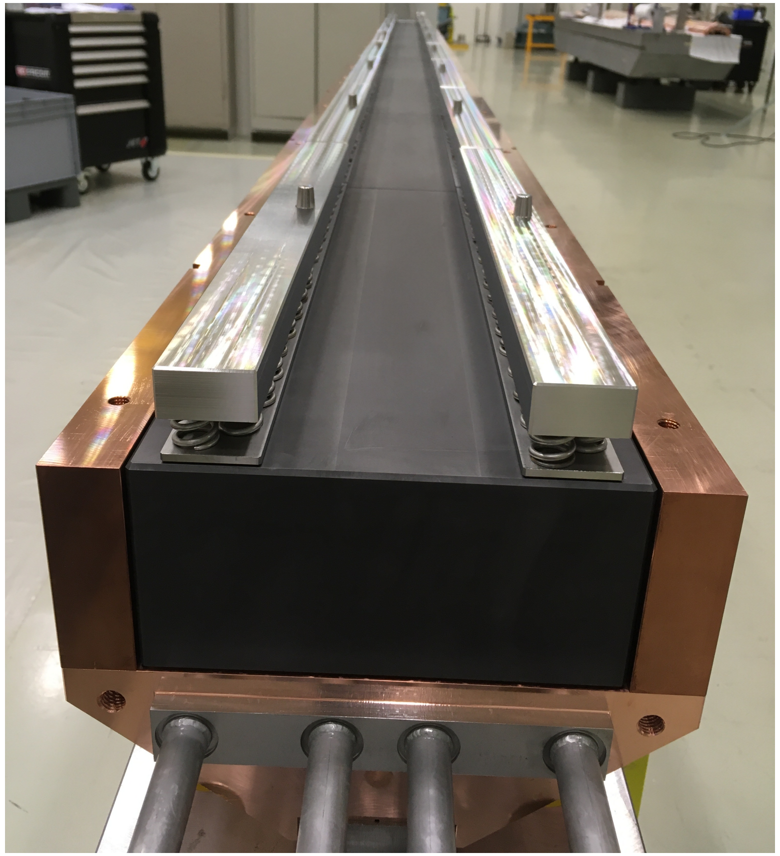




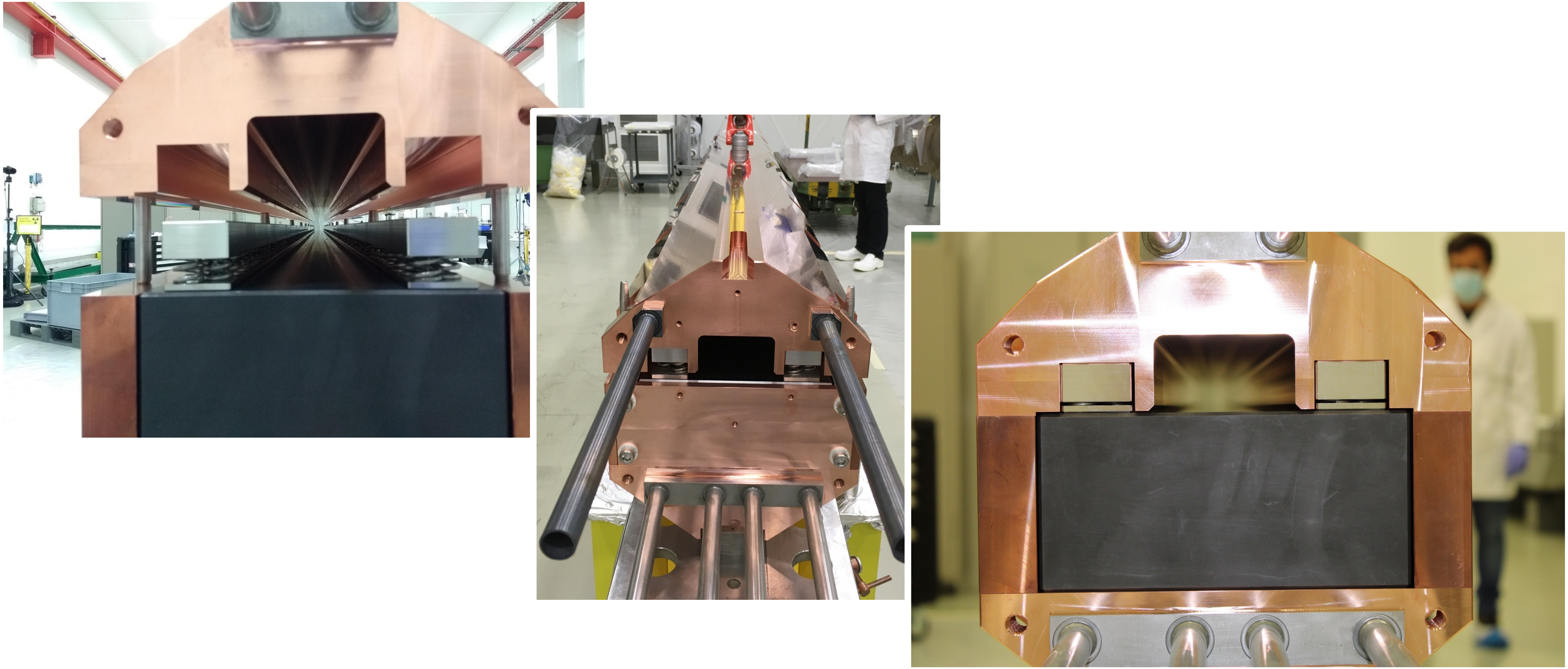


Fifth generation dump – assembly & installation

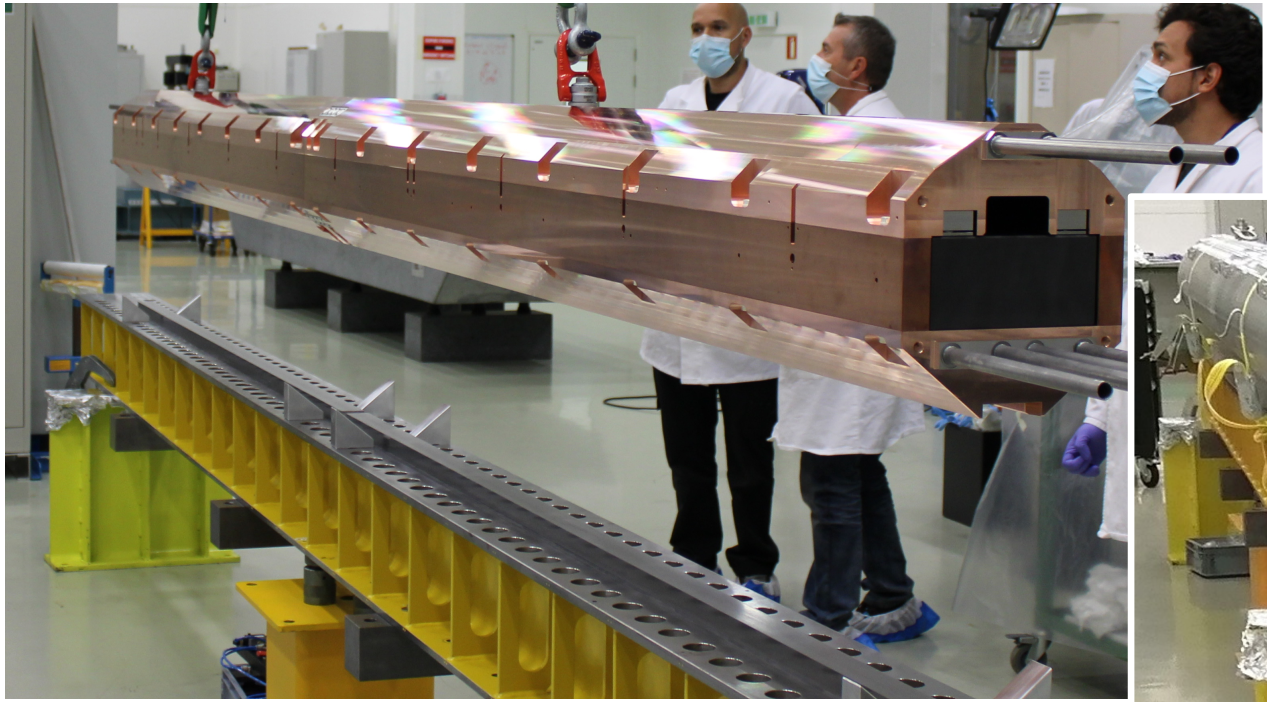


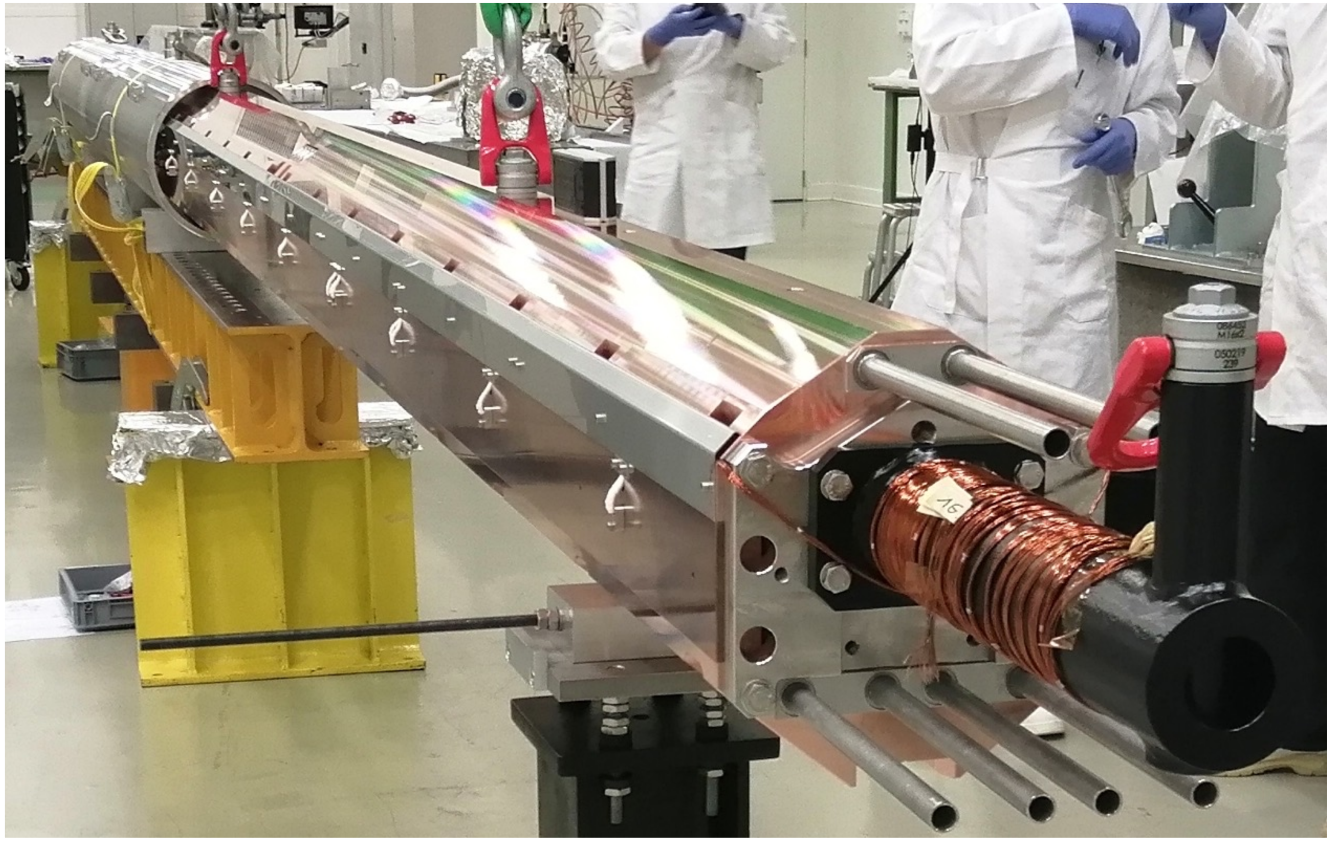


Fifth generation dump – assembly & installation



Fifth generation dump – assembly & installation

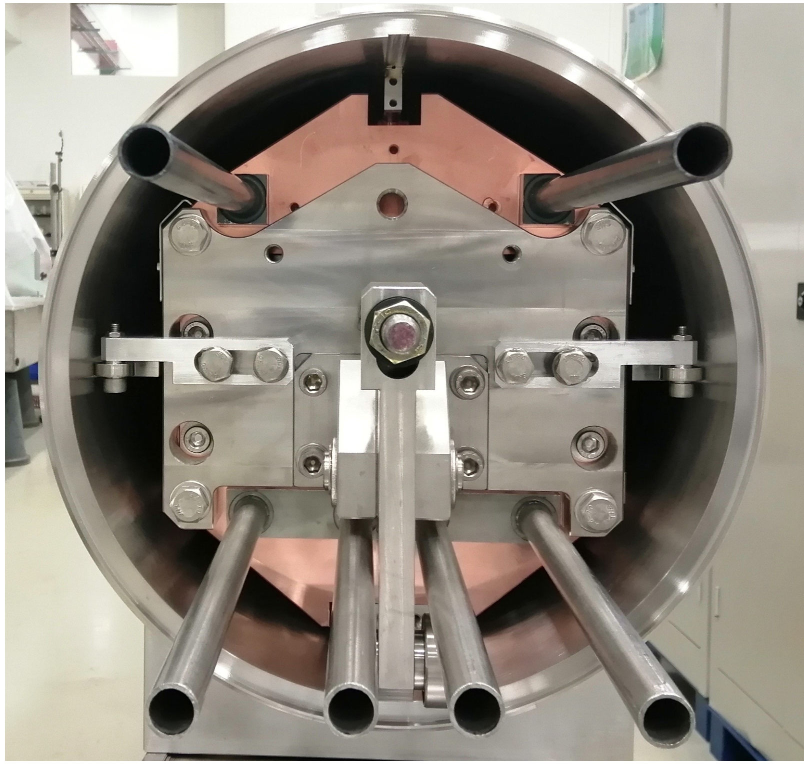


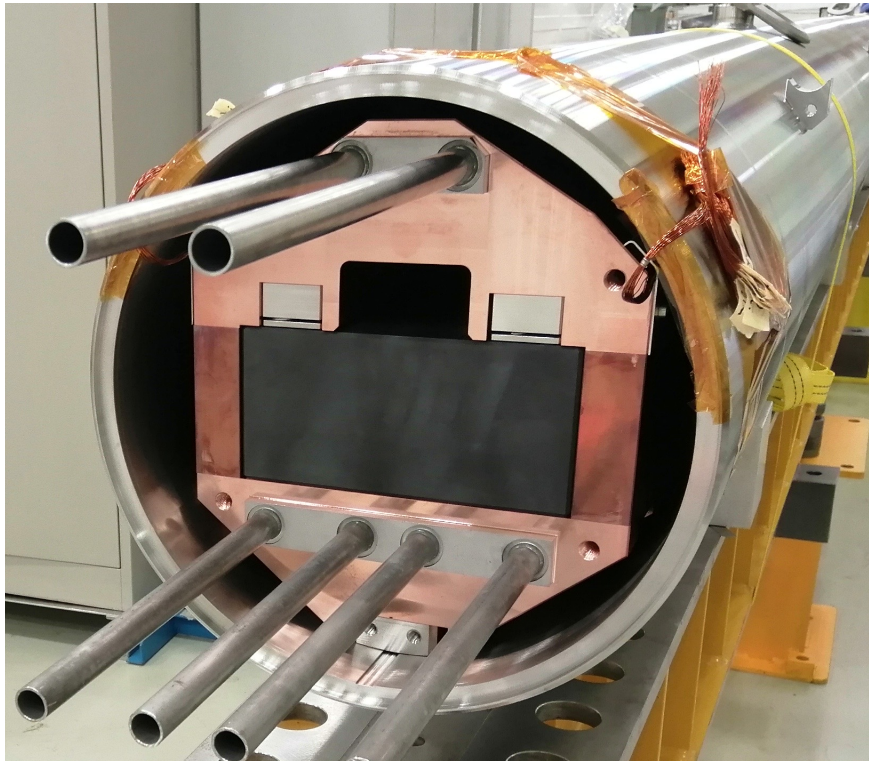


Fifth generation dump – assembly & installation

(a)

(b)



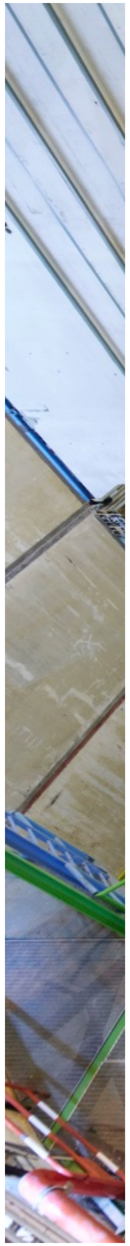


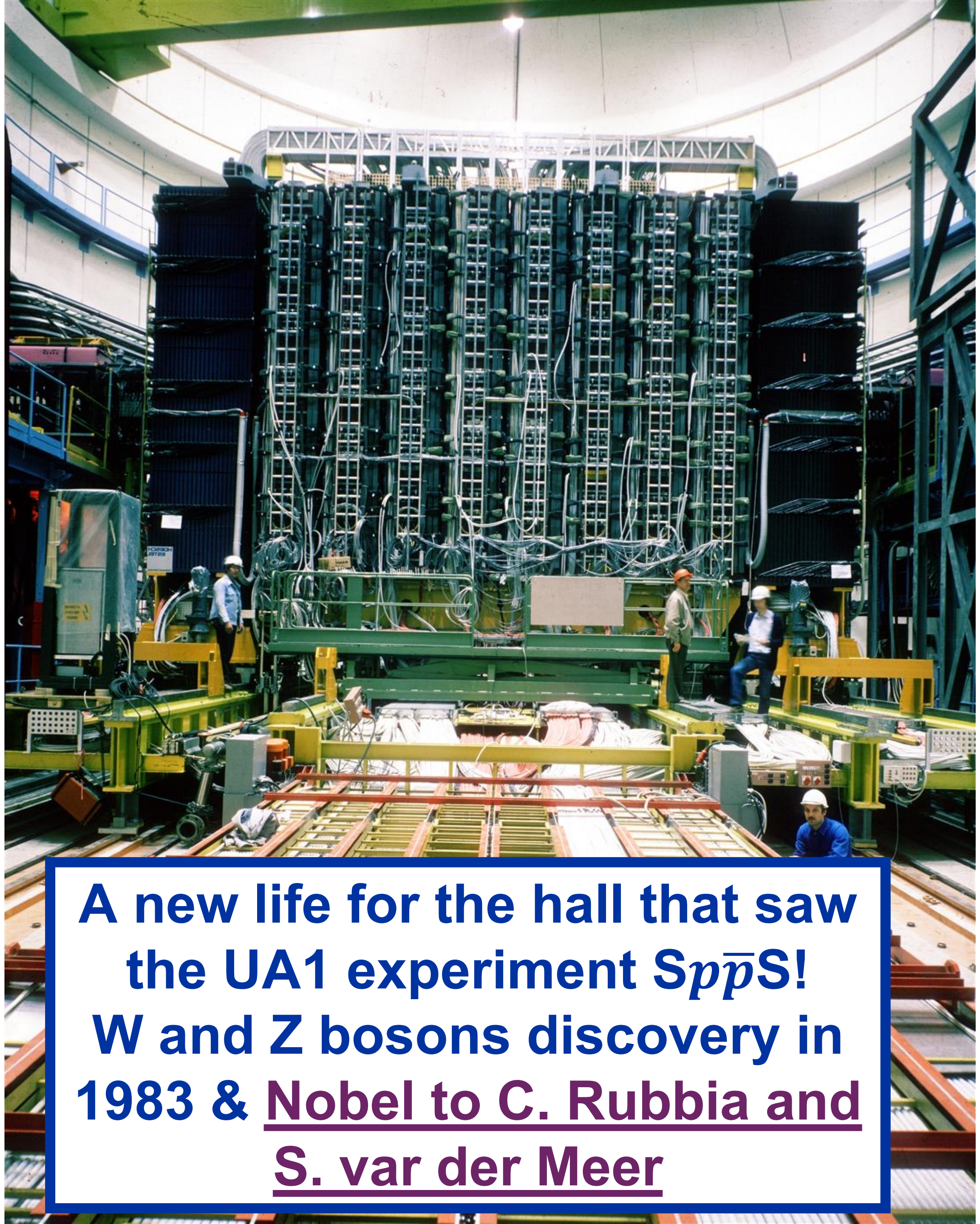
Construction of seamless vacuum chamber from forging

Fifth generation dump – assembly & installation

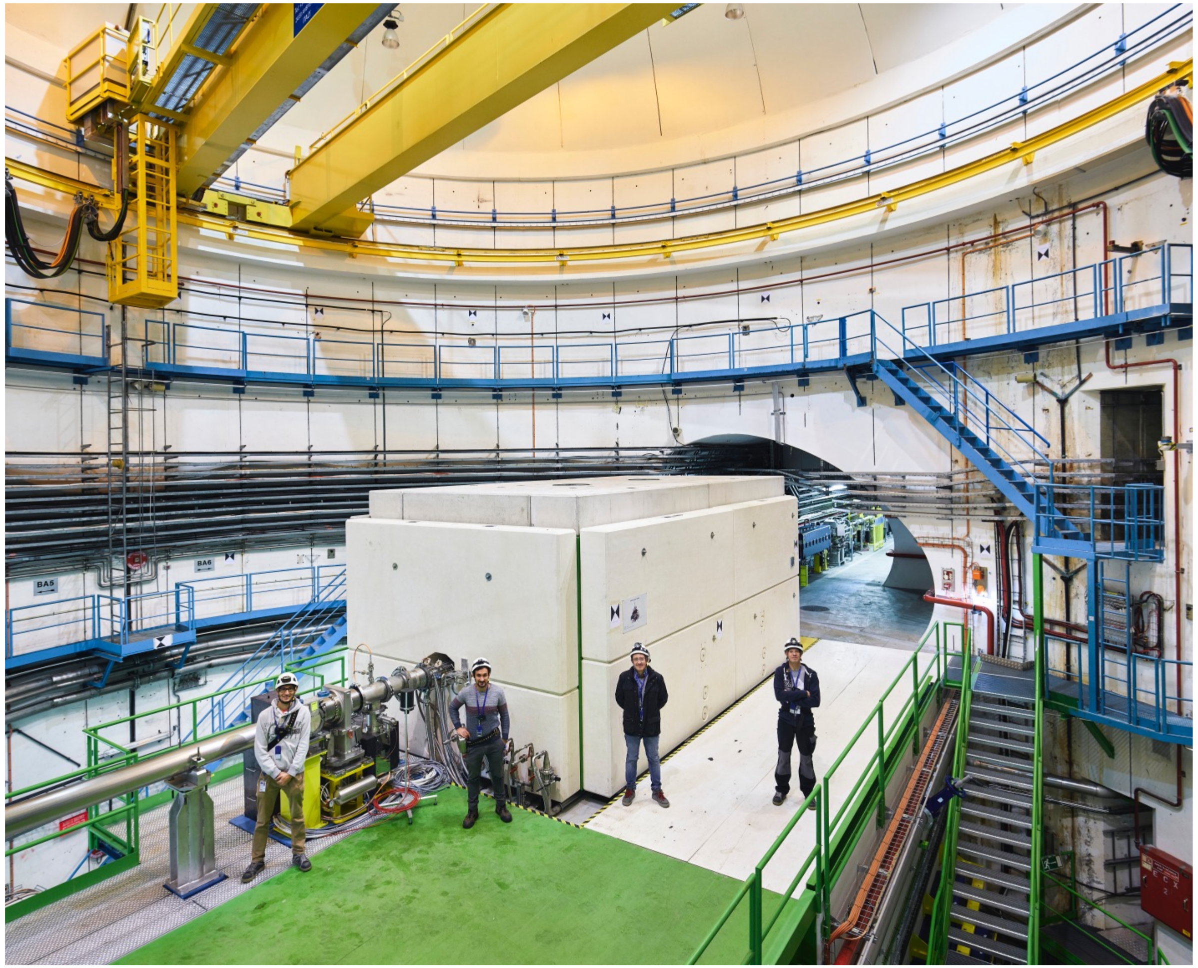
Welding of cooling channels and beam pipe

Installation of external shielding and final welding of yoke cooling





A new life for the hall that saw the UA1 experiment $Sp\bar{p}S$!
W and Z bosons discovery in 1983 & Nobel to C. Rubbia and S. var der Meer



Successful installation of dump in readapted caverns in SPS LSS5

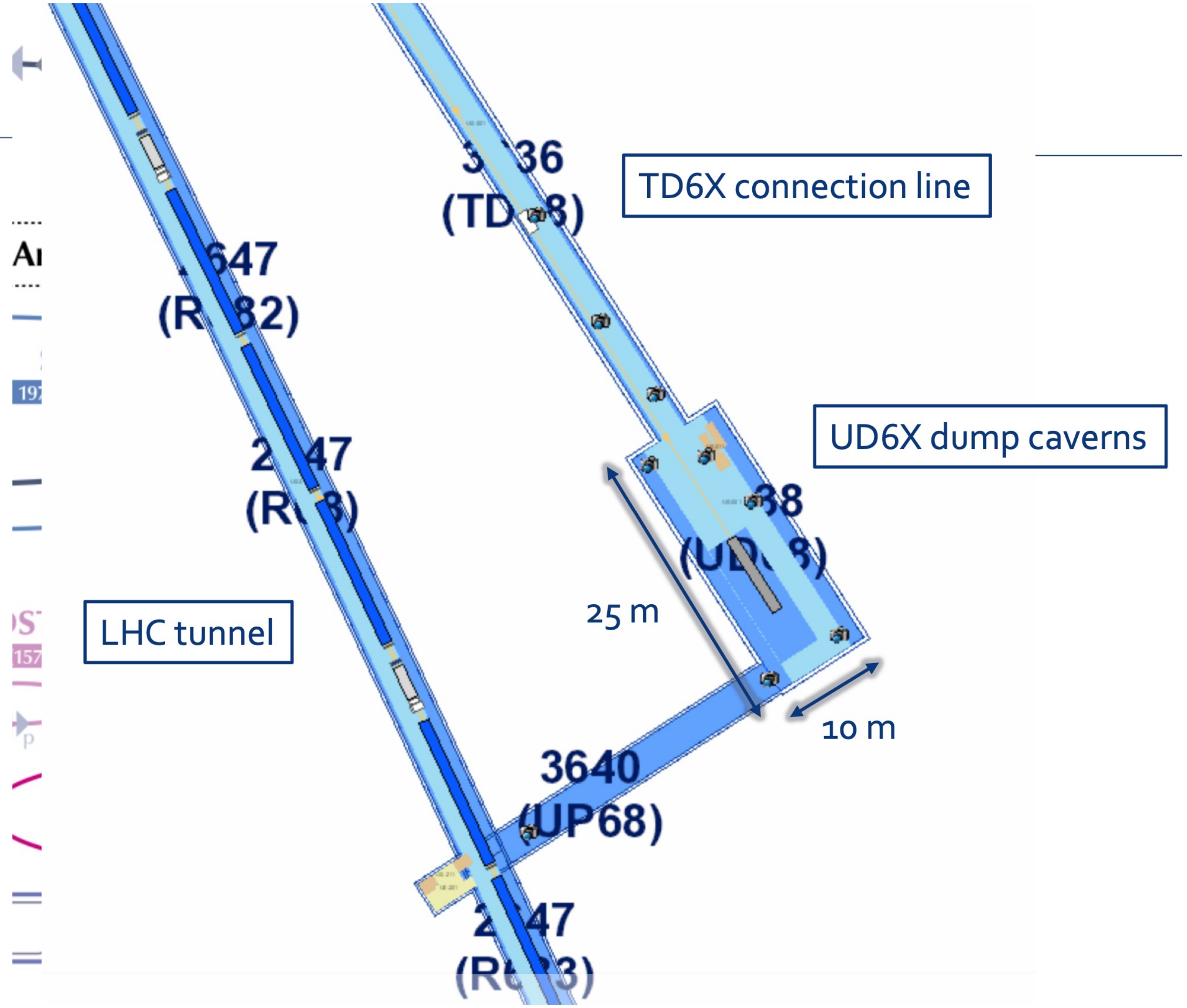
6. LHC main dump

Large Hadron Collider beam dump

- LHC beam kinetic energy reaching **several hundreds of MJ**
  - **This energy is sufficient to melt more than 2.5 tons of Cu**
- How do we safely dispose of these beams without damaging equipment?

	Run 1 (2009–2013)	Run 2 (2015–2018)	Run 3 (2022–2024)	HL-LHC (2027–)
E_{prot} (TeV)	4	6.5	6.8	7
Δt_b (ns)	50	25	25	25
N_b	1380	2556	2748	2760
I_b (p)	1.7×10^{11}	1.2×10^{11}	1.8×10^{11}	2.2×10^{11}
E_{beam} (MJ)	150	320	539	680
ε_n (µm rad)	≈ 2.5	≈ 2	1.8–2.5	2.5

Large Hadron Collider beam dump



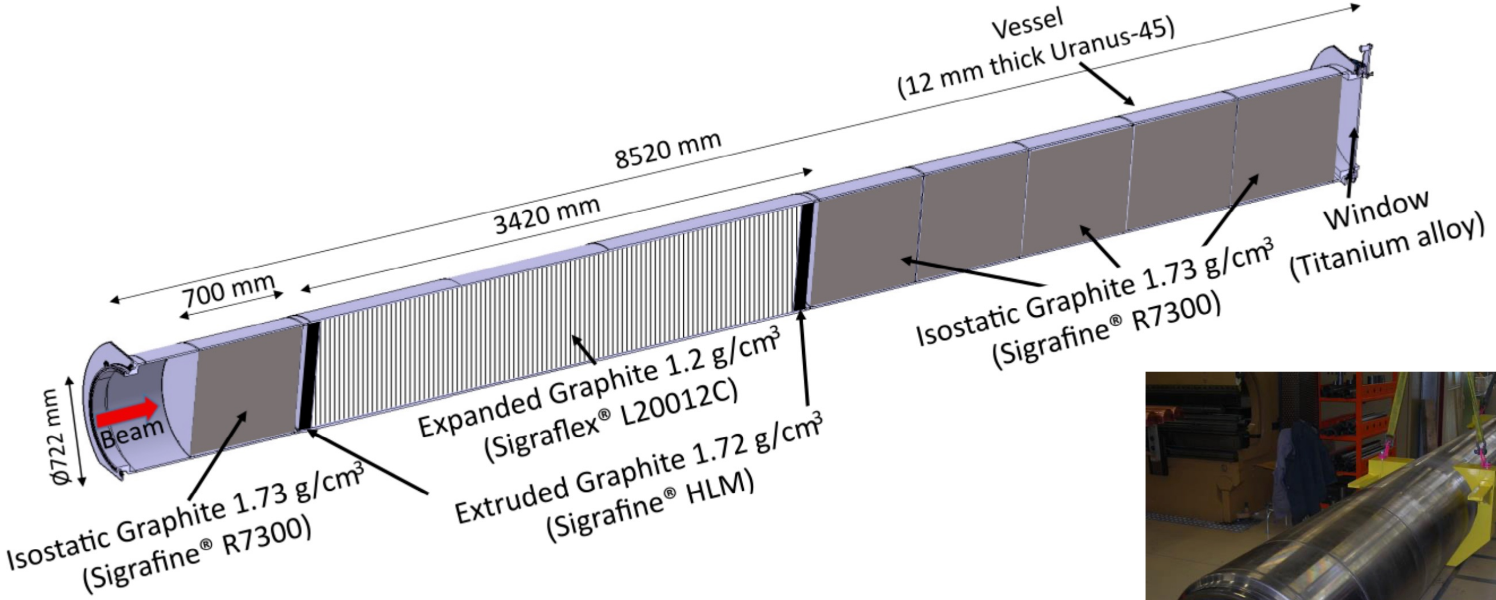
LHC beam dump block

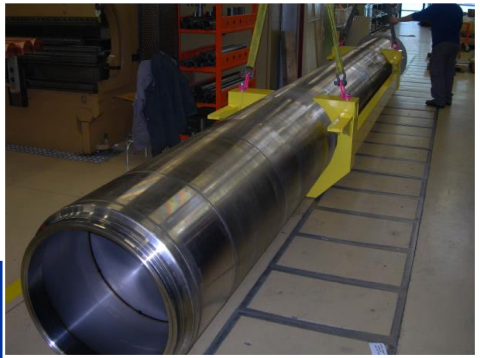
- The LHC TDE (Target Dump External) is a beam dump constituted by a **graphite (low and high density) absorber** of roughly **8.5 m length** and **700 mm diameter**

- It is installed inside a **12 mm thick tube of 318LN duplex stainless-steel (1.4462)** alloy and **filled with nitrogen gas** slightly above atmospheric pressure

$$\lambda \approx 15$$

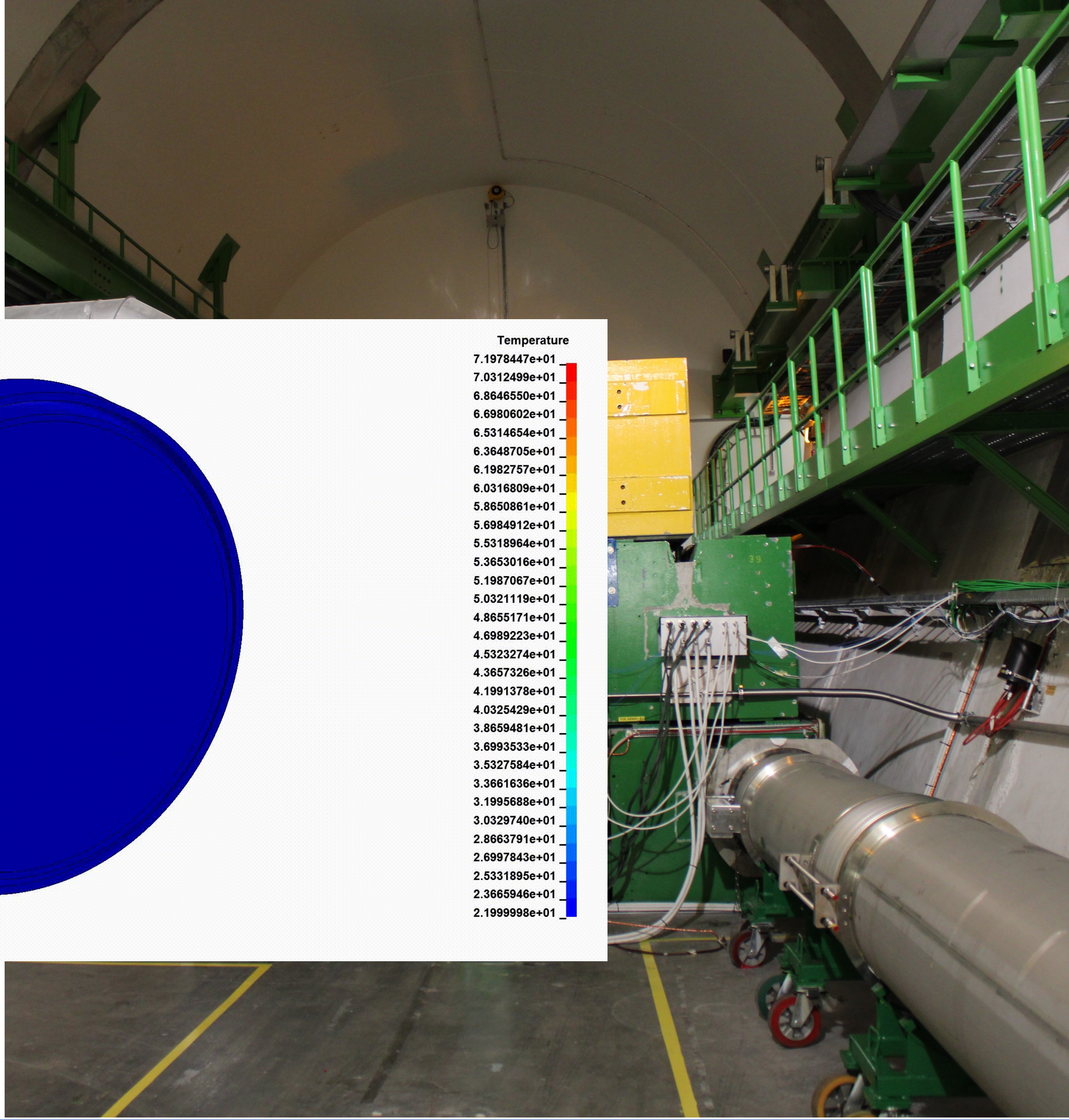
>99.9999% of 6.5 TeV have an inelastic collision in the core

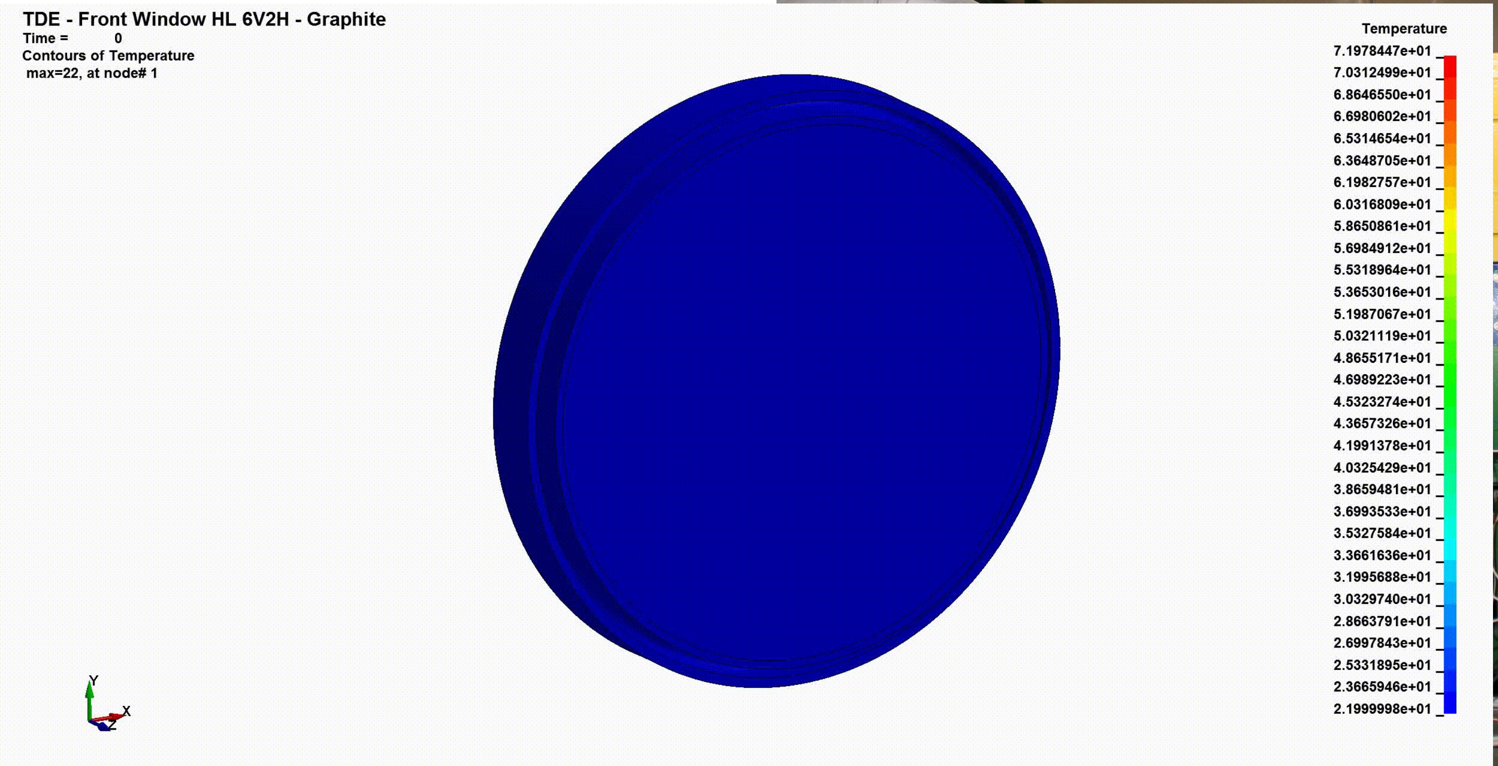




LHC beam dump block

- Two assemblies are installed in the LHC, 1x for
- The dump a inside **shiel** **caverns lo** **the TD62 a** tunnels on e
- Device esse of the LHC allowing the safe disposal of the beam

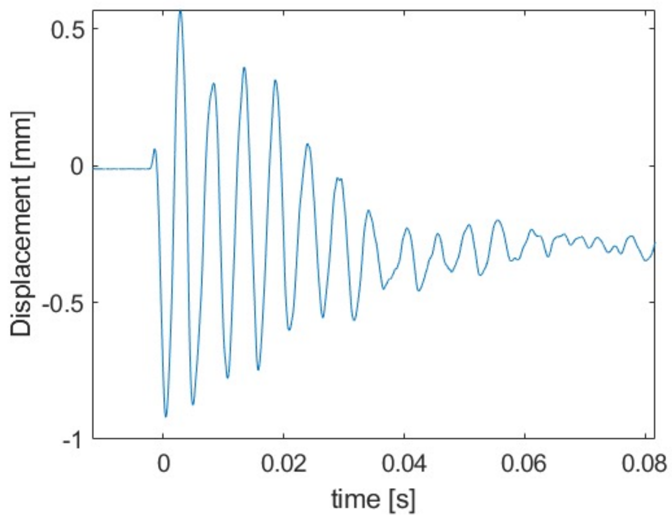




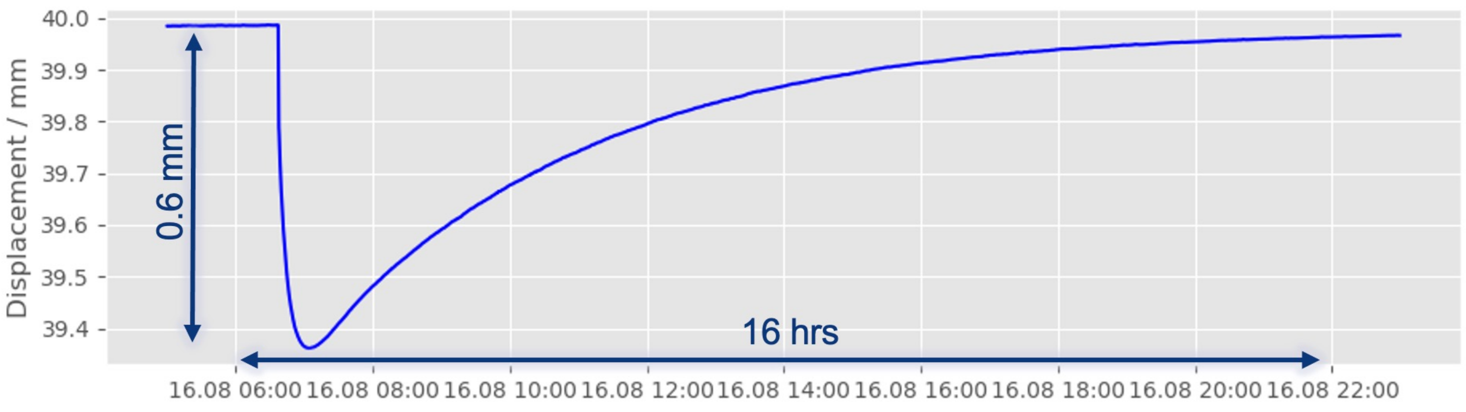
What the challenges?

- In the last few years, we noticed **several operational challenges** (N_2 leaks, massive movements, etc.)
- What do we saw with instrumentation?

Time scale of 100 ms



Time scale of >10 hours (!)



What the challenges?

	Fraction of beam energy	Energy deposition (MJ)
Dump:		
Graphite	73.6%	397
Shell	4.2%	23
Windows, flanges etc.	0.04%	0.2
Total	77.9%	420
Environment:		
Shielding	17.4%	94
Air	0.015%	0.08
Cavern	0.12%	0.6
Molasse, rock, etc.	0.04%	0.2
Total	17.6%	95

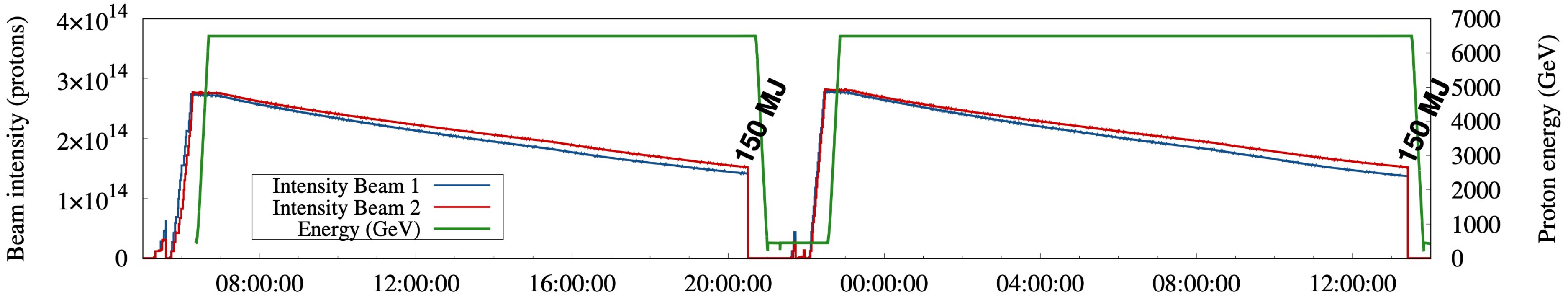
- 539 MJ stored energy
- 420 MJ deposited in dump block
- 397 MJ in graphite
- **23 MJ in the st. steel shell**

Dumped energy

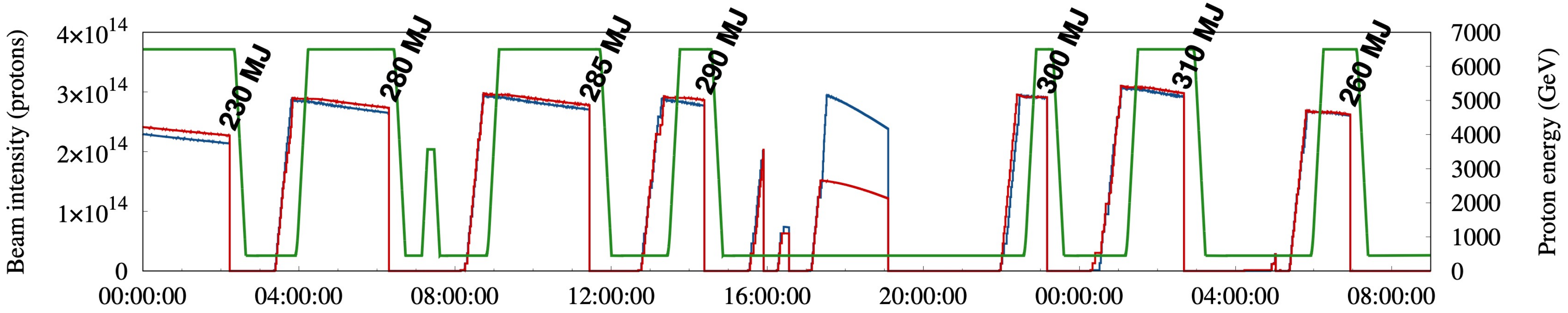
±200 GJ were dumped so far (60 GJ in Run 1 and 140 GJ in Run 2)

Dumped energy = ***proton energy*** *×* ***beam intensity*** *at the moment of beam extraction*

Good day:

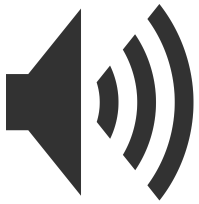


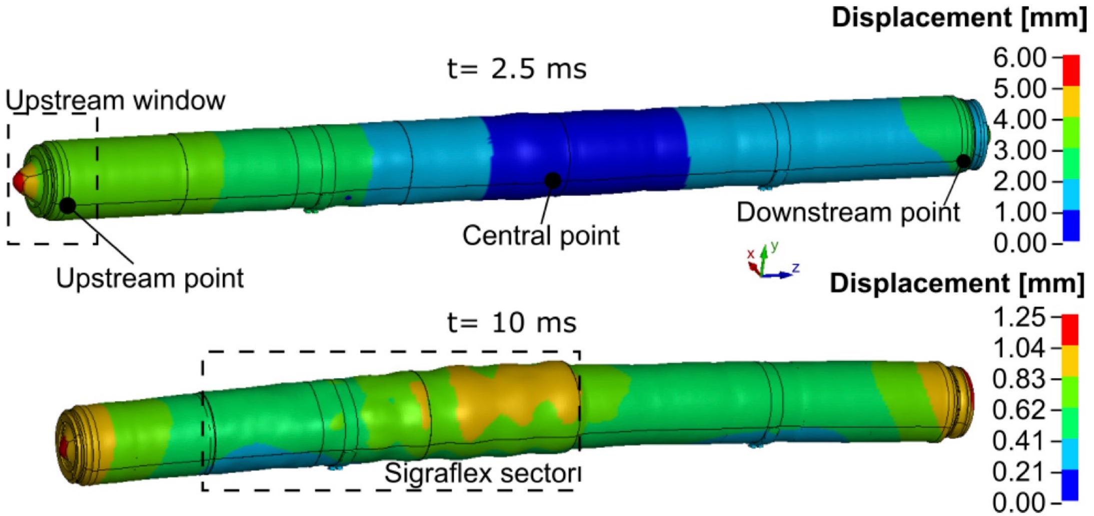
Bad day:

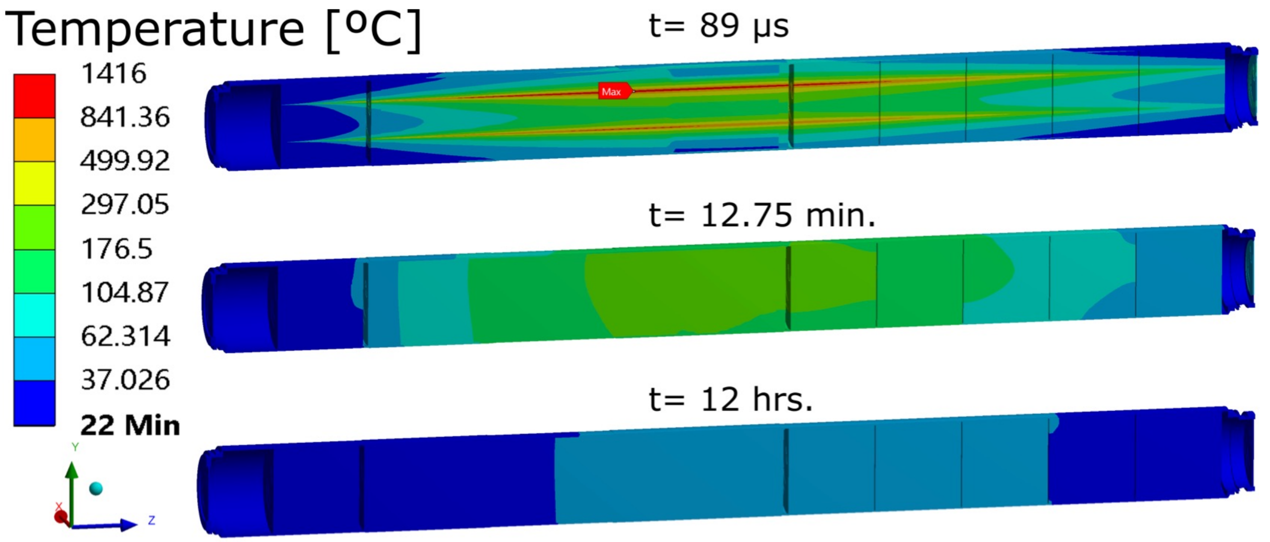


120 MJ

(4.5x smaller than in Run3)

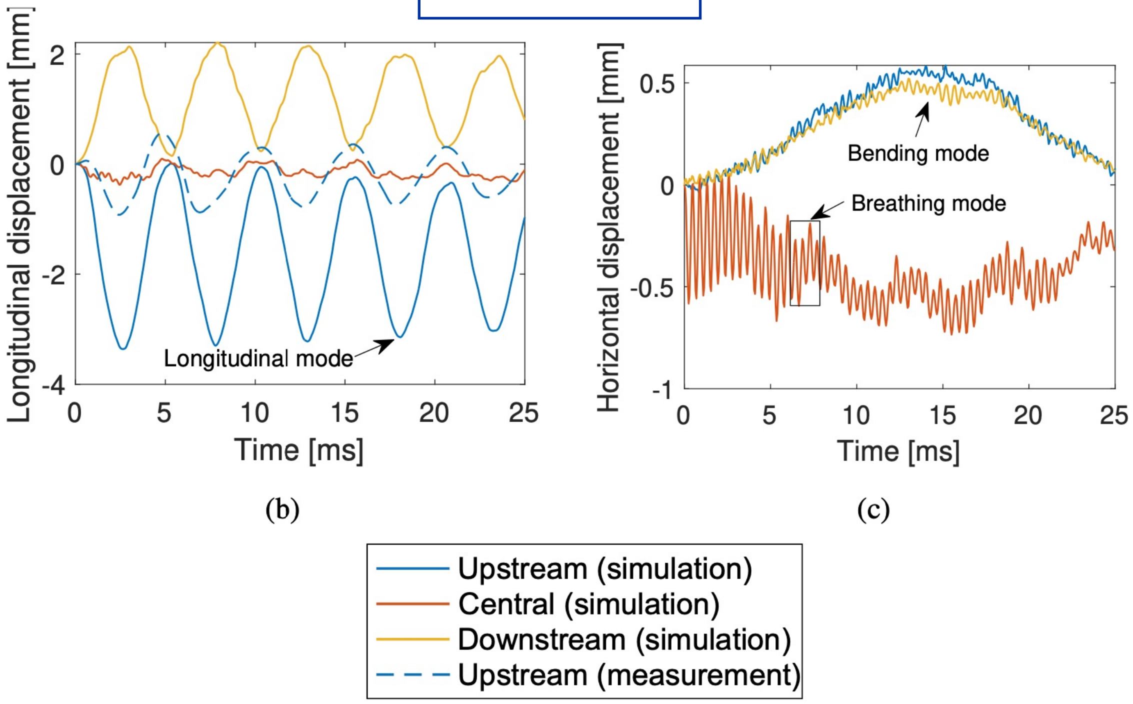




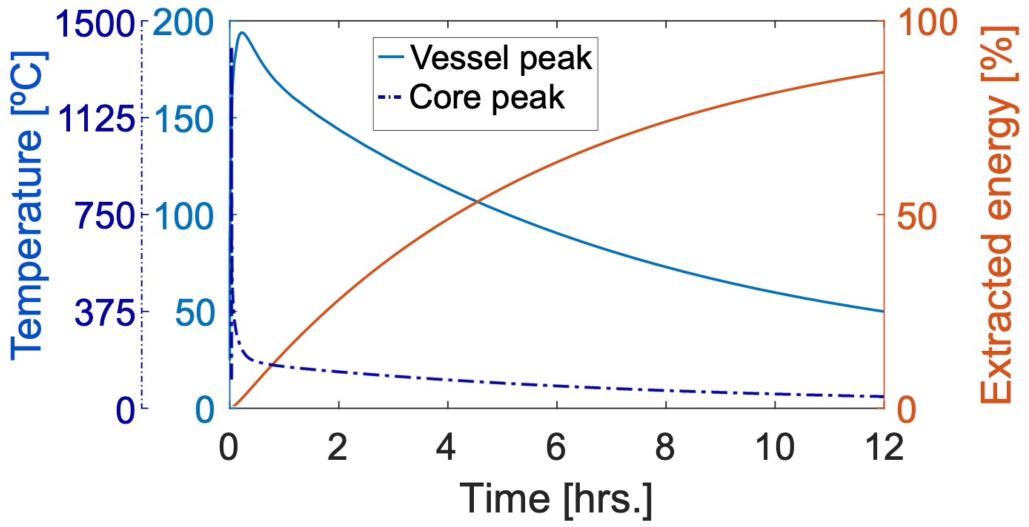


Fast effect

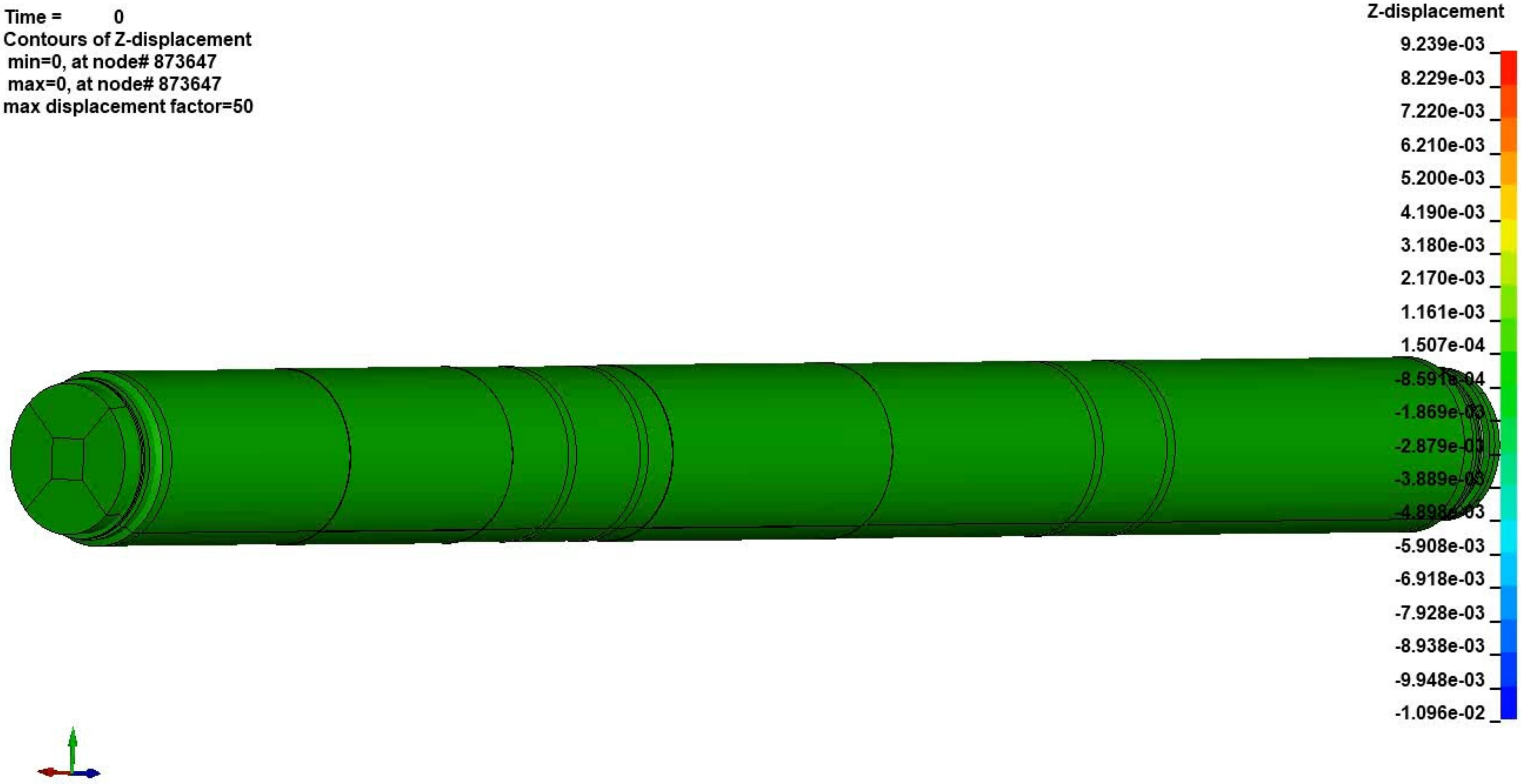
Slow effect



(b) (c)



(b)

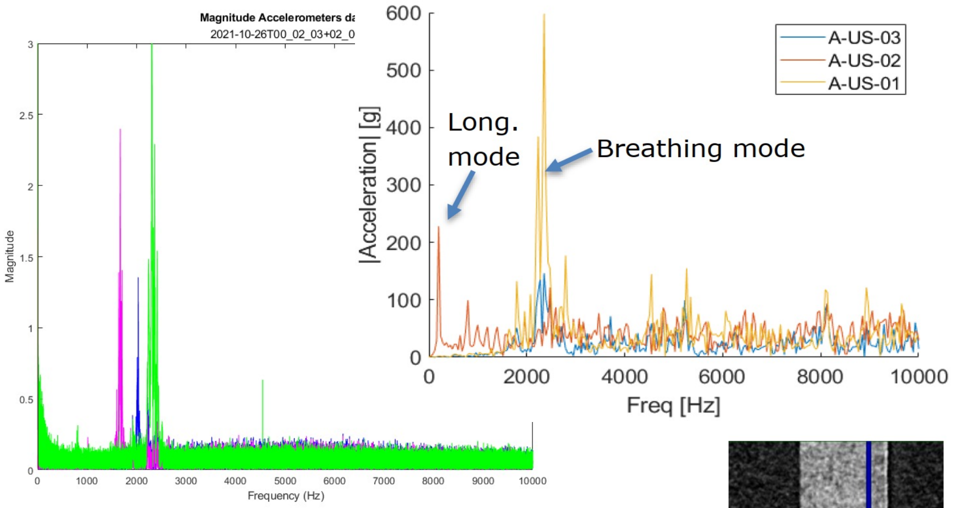

Time = 0
Contours of Z-displacement
min=0, at node# 873647
max=0, at node# 873647
max displacement factor=50
Z-displacement
9.239e-03
8.229e-03
7.220e-03
6.210e-03
5.200e-03
4.190e-03
3.180e-03
2.170e-03
1.161e-03
1.507e-04
-8.591e-04
-1.869e-03
-2.879e-03
-3.889e-03
-4.898e-03
-5.908e-03
-6.918e-03
-7.928e-03
-8.938e-03
-9.948e-03
-1.096e-02

Modification for operation >2022

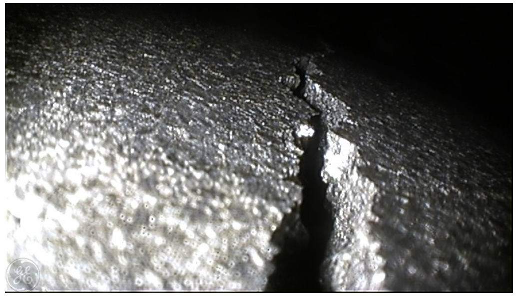
- We cannot remove the physical origin of the vibration – must work on **mitigating the effects** of vibration

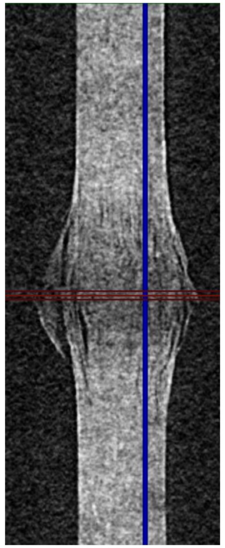
- Dumps currently **installed on steel cables** in order to compensate fast and slow movements and physically separate from vacuum line

Next challenges for LHC beam dump



- Simulations cross-checks
  - Profited from LHC beam test during November 2021
- Material behaviour under irradiation
  - Behaviour of low-density graphite





- Behaviour of radioactive dumps
  - Autopsy of one of the dump which has been removed from the LHC during LS2

Lots of work ahead from 2022 transitioning from 320 MJ to 539 MJ

Where to find additional information for BIDs

- High Power Targetry Workshop (HPTW)
- International Workshop on Spallation Materials Technology (IWSMT)
- International Workshop on Neutrino Beams and Instrumentation (NBI)
- International Collaboration on Advance Neutron Sources (ICANS)
- RaDIATE Collaboration
- HiRadMat Facility

Conclusions

- **Just scratched the surface of operational devices under operation at CERN**
- A vast operational and project expertise exists also in other facilities around the world (ORNL, FNAL, KEK, RAL/ISIS, etc.)
- Large challenges ahead in the field of BIDs, including material development, radiation design, innovative design and production technologies

THANKS, marco.calviani@cern.ch

home.cern

Production of vacuum chamber

Cast SS 304L block → Forging → Pre-machining → Fine machining → Inserting dump core → Welding of upstream-downstream chambers → UHV testing → Bake-out (ready for installation)

Production of CuCrZr heat sink

Cast block of CuCr1Zr → 3D Forging → Solution annealing + Ageing → Machining groves for cooling pipes → Assembly for HIP → HIP → Ultrasound Testing → Machining (remove cladding) → Solution annealing + Ageing → Final machining

Competences and technologies involved in the manufacturing of LHC Collimators

- Manufacturing engineering
- High Precision dry/clean machining
- Surface treatments
- UHV cleaning, leak testing and outgassing
- Vacuum brazing
- Electron beam & TIG welding
- Assembly of UHV components in precise mechanisms
- 3D metrology and assembly adjustment