Design and construction of beam intercepting devices (including targets) at CERN

F-X. Nuiry
Engineering Department (EN)
Sources Targets and Interactions Group (STI) Group
Targets, Collimator and Dumps (TCD) Section

Acknowledgments

M. Calviani, S. Gilardoni, A. Perillo-Marcone, I. Lamas Garcia, C. Torregrosa, R. Esposito, O. Aberle, T. Polzin, F. Harden, L. Gentini, M. Bergeret, R. Illan, R. Seidenbinder, N. Solieri, A. Lechner, F. Carra, M. Lamont, E. Lopez Sola, E. Fornasiere

Outline

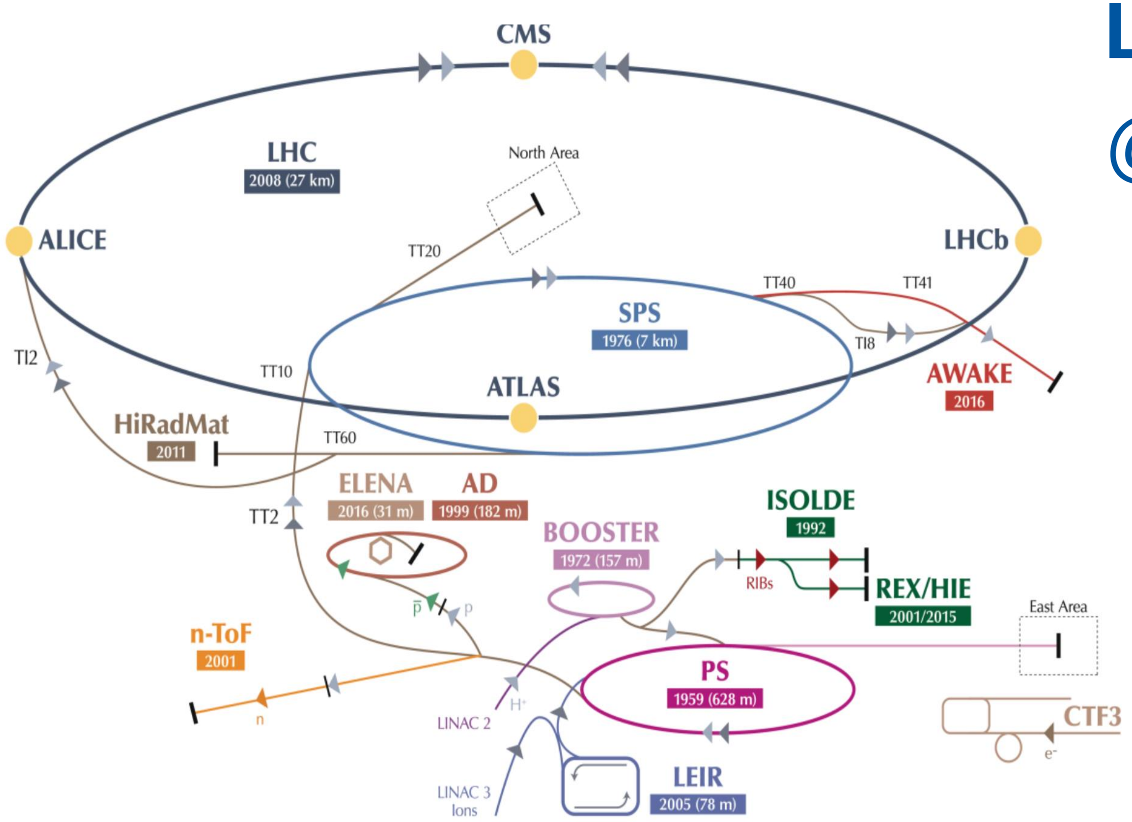
- Overview of BIDs
- Requirements and challenges
- Two examples:

→*Graphite based SPS/LHC collimators and related HiRadMat experiment*

→*AD Target prototype Proton impact test at CERN*

- Conclusions

CERN accelerator complex



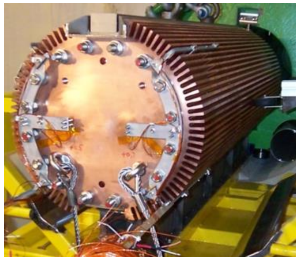
LHC: ongoing Run2

@13 TeV CM

Beam intercepting devices

Safety function

Beam stoppers



Beam dumps

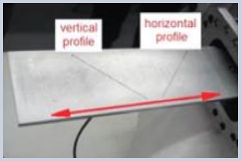
Beam cleaning & control

Collimators

Scrapers

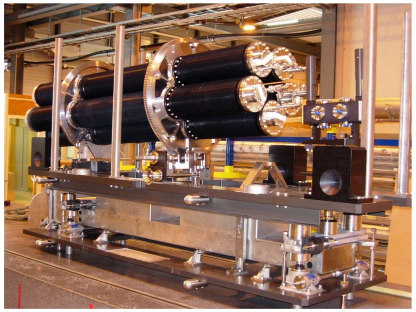
Strippers

Slits

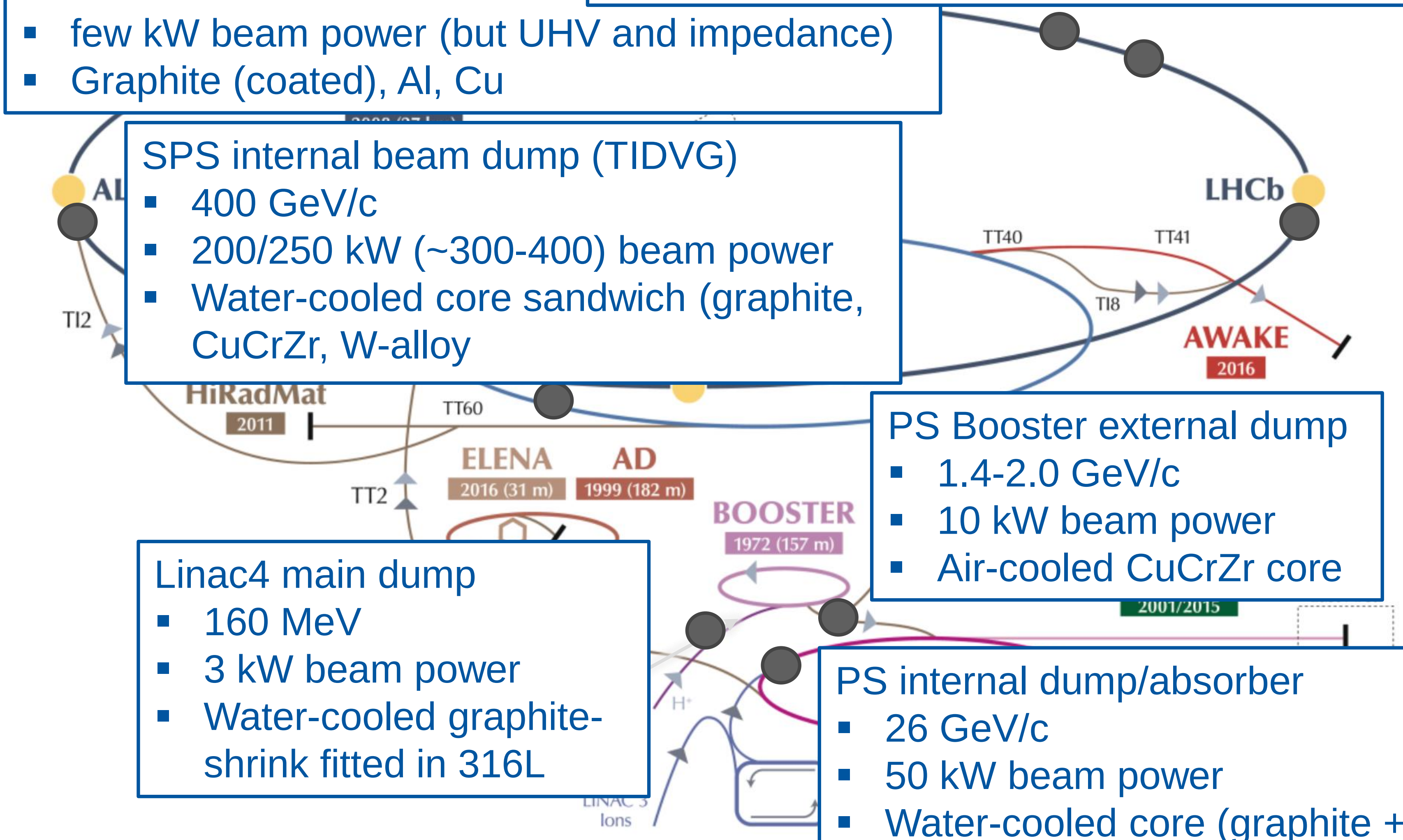


Physics

Targets



Location of mos



LHC external dump (x2) (TDE)
- 7 TeV/c
- 400 MJ beam energy to be dissipated
- Low density graphite (8 meters long), air cooled

LHC injection absorber (x2) (TDI
- 7 TeV/c
- few kW beam power (but UHV and impedance)
- Graphite (coated), Al, Cu

SPS internal beam dump (TIDVG)
- 400 GeV/c
- 200/250 kW (~300-400) beam power
- Water-cooled core sandwich (graphite, CuCrZr, W-alloy

PS Booster external dump
- 1.4-2.0 GeV/c
- 10 kW beam power
- Air-cooled CuCrZr core

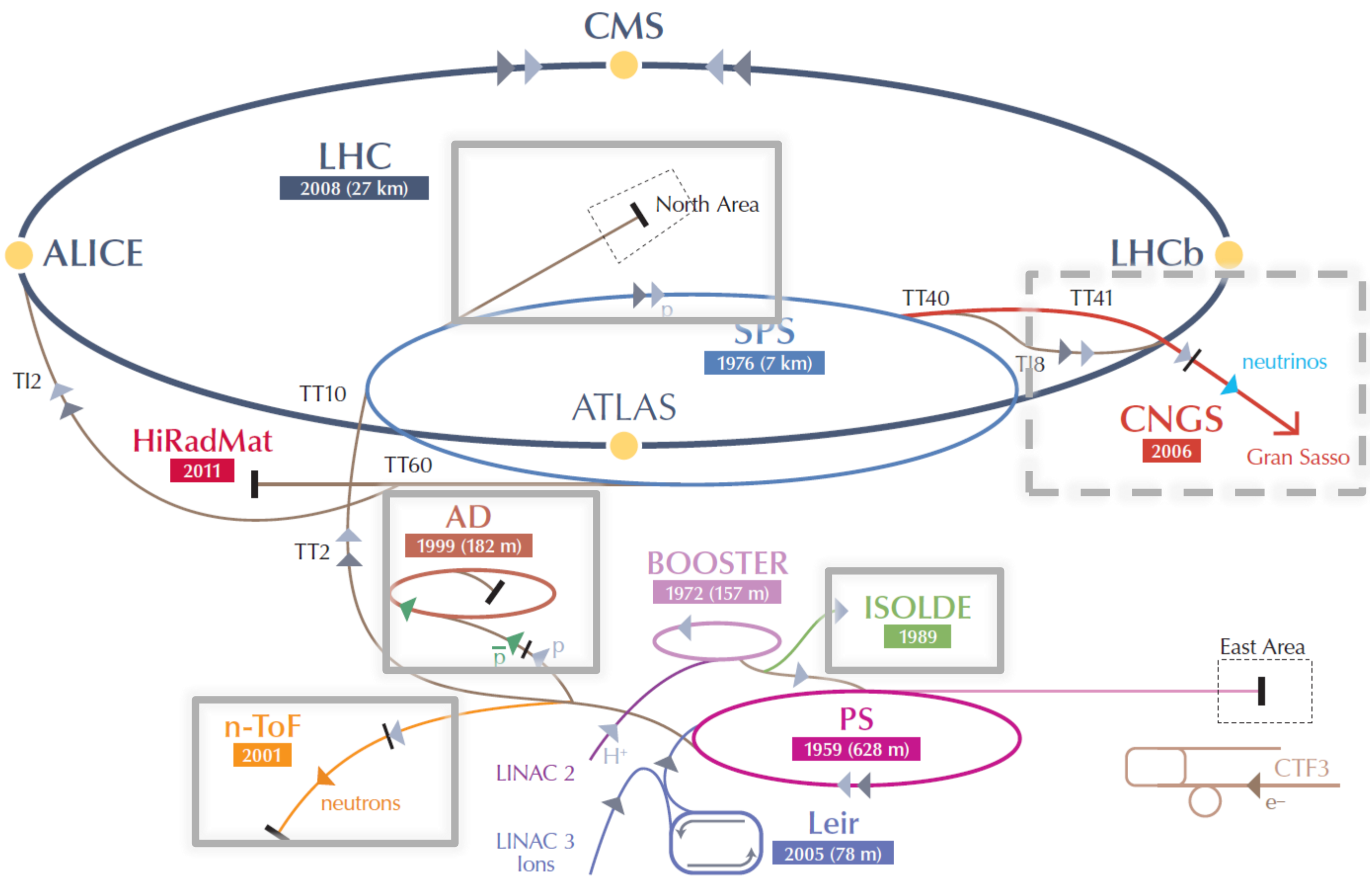
Linac4 main dump
- 160 MeV
- 3 kW beam power
- Water-cooled graphite-shrink fitted in 316L

PS internal dump/absorber
- 26 GeV/c
- 50 kW beam power
- Water-cooled core (graphite + Cu-alloys)

Review of CERN’s fixed target

- CERN has a long and varied history of fixed target experiments, contributing to a diverse program of research
    - Essential part of the lab’s scientific program
- Hadrons physics (COMPASS, NA61...)
- Nuclear physics (ISOLDE)
- Neutron physics (n_TOF)
- Antimatter physics (AD)
- Neutrino physics (WANF, CNGS...)

CERN's accelerator complex



~10^{15} protons/year to LHC

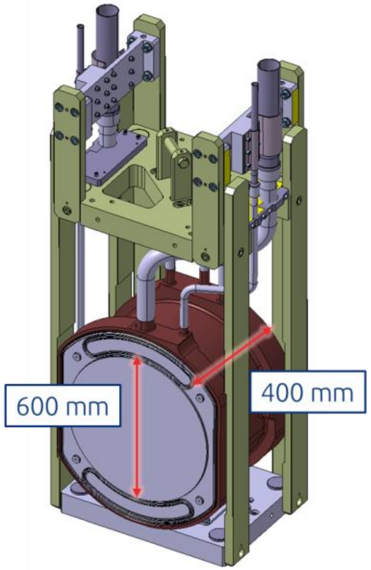
>10^{20} protons/year to fixed targets

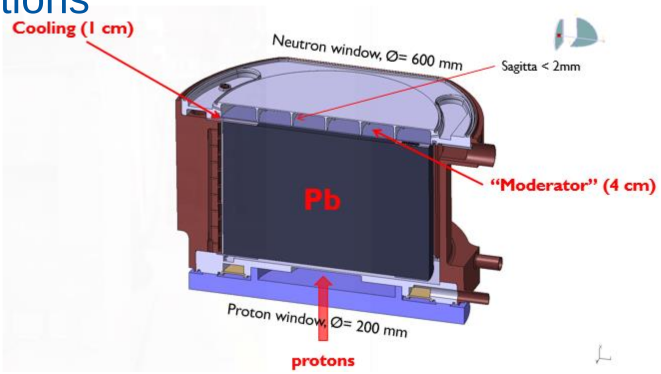
LHC	Large Hadron Collider
SPS	Super Proton Synchrotron
PS	Proton Synchrotron
AD	Antiproton Decelerator
CTF3	Clic Test Facility
CNGS	Cern Neutrinos to Gran Sasso
ISOLDE	Isotope Separator OnLine DEvice
LEIR	Low Energy Ion Ring
LINAC	LINear ACcelerator
n-ToF	Neutrons Time Of Flight
HiRadMat	High-Radiation to Materials

CERN targets, few examples

n_TOF Target

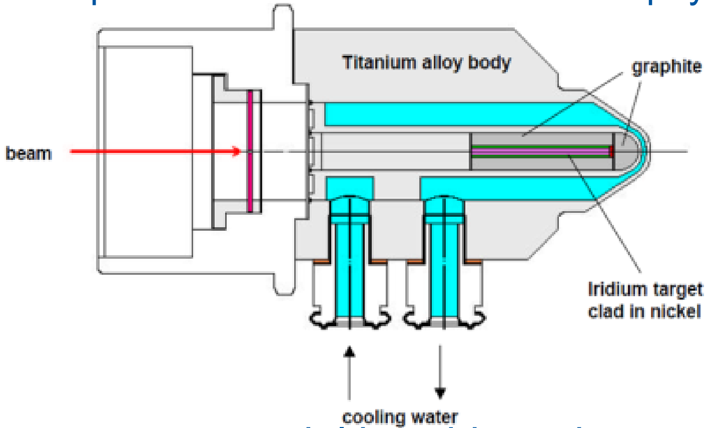
- **20kW** neutron spallation source
- Monolithic lead core
- Target in a AW6082 pressurized vessel
- Water chemistry monitored (ppb O2 content)
- Intensity limitations





AD Target

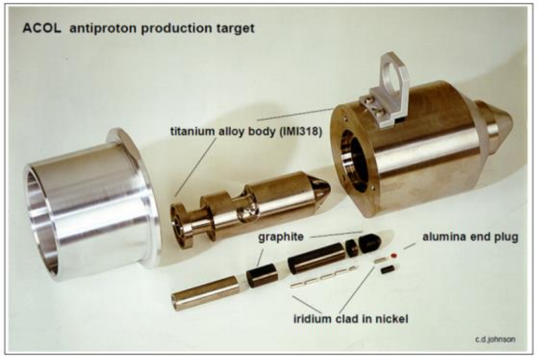
Antiproton production for CERN's antimatter physics



Core material is subjected to extreme thermo-mechanical loads

ΔT > 2000 °C, Tss = 150 °C

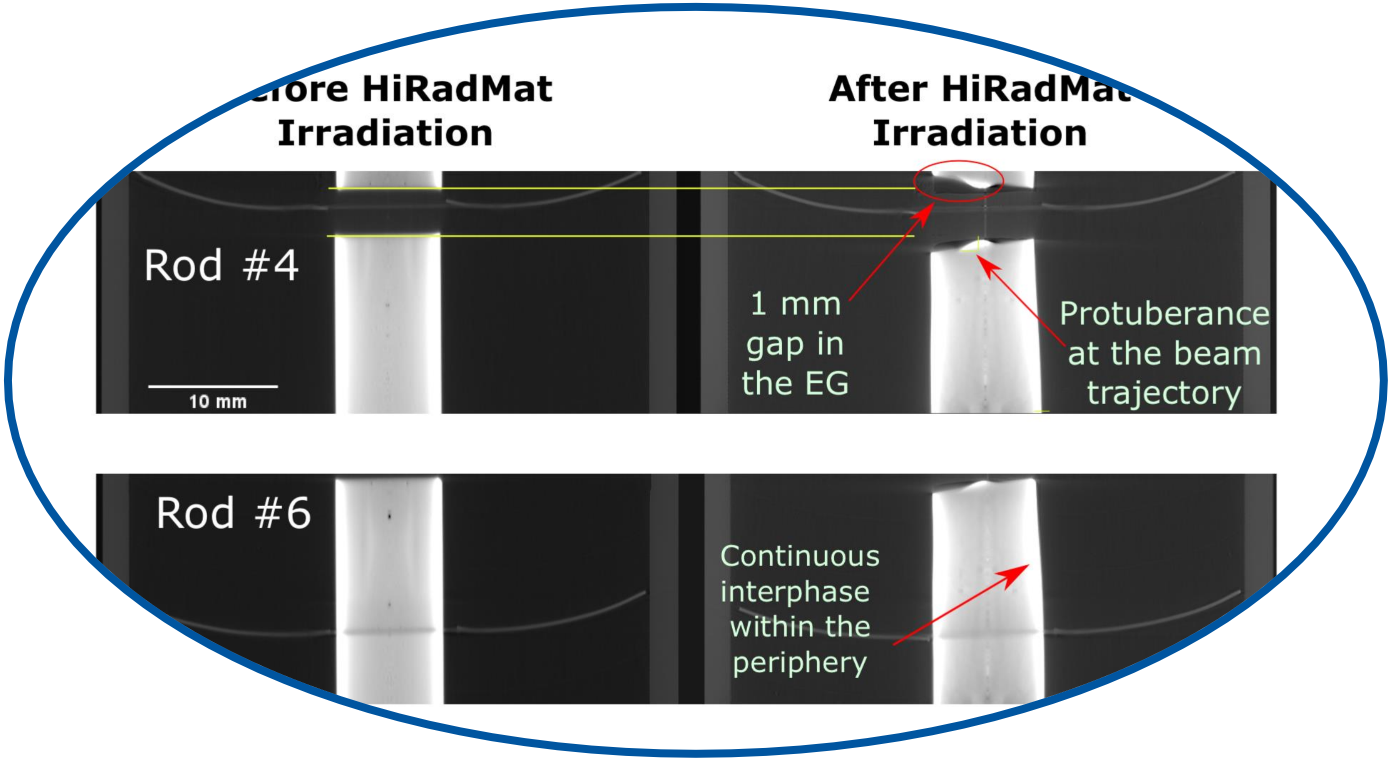
~ 1 DPA/year in the core



Challenges for BIDs

- Must resist to **high energy densities** (kJ/cm^3/pulse)
- High **average power** (dumps/targets) (up to 350 kW)
- Mechanical properties at **high strain rate** and **high temperature**
- Due to the high energies involved, **length** (up to **8 meters**) and **weight (up to 25 ton)** of most equipment is an issue for ALARA, handling …
- **Radiation damage** on the long term will become a critical issue
- **UHV** (10^{-10} mbar)
- **Impedance** (high electrical conductivity)

R&D on materials (beam impacts)



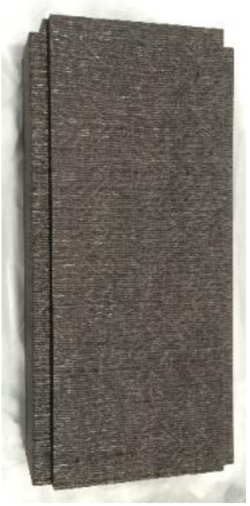
R&D steps of new materials or assemblies

- Identification of **needs** (from low-Z (e.g. flexible graphite at 1.0 g/cm^3) to high Z (e.g. iridium 22 g/cm^3)
- Execution of **mechanical testing** (in-house w/ MME or outside labs) – eventual **dynamic characterizations**
- Development of **new technologies** with external Industrial or University partners
- Beam shock tests at the **HiRadMat facility** for material response knowledge improvement and integral testing (if possible)
- Long-term **radiation damage** tests (critical for targets & absorbers)

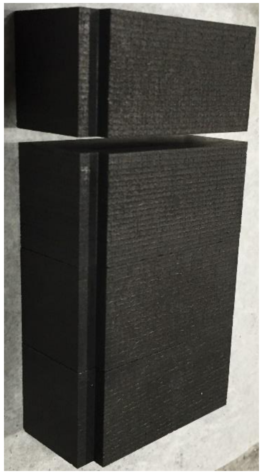
Low density materials

R&D on 3D CC for collimator applications

- 3D Carbon/Carbon composites can be good alternatives to graphite, due to their ability to stop an eventual crack propagation due to their architecture - the material has also a high strain to failure
- **Very high service temperature** (**characterized up to 2750 °C**)
- Materials at least **2 to 3 times higher tensile strength** and **CTE inferior or equal to the graphite one**



Sepcarb® 3D C/C

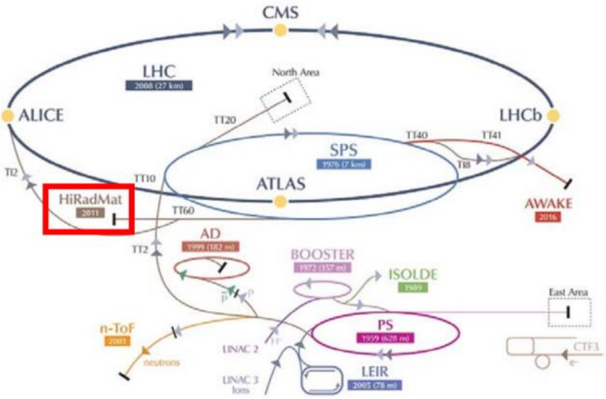


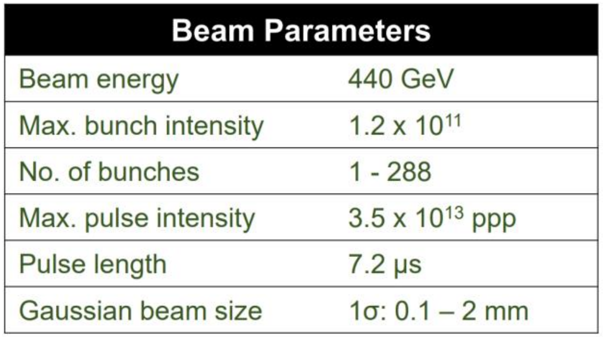
3D C/C A412

	Sigrafine® R7550	Graphite 2123 PT	Sepcarb® 3D C/C	C/C A412
Density [g/cm^3]	1.83	1.84	>1.81	1.7
Thermal Conductivity W. ℃$^{-1}$.m^{-1}	100	112	NDA	-
Coefficient of Thermal Expansion 10^{-6} [℃-1]	4	5.6	2	-
Young's modulus [GPa]	11.5	11.4	NDA	15
Tensile Strength [MPa]	30	35	100	60

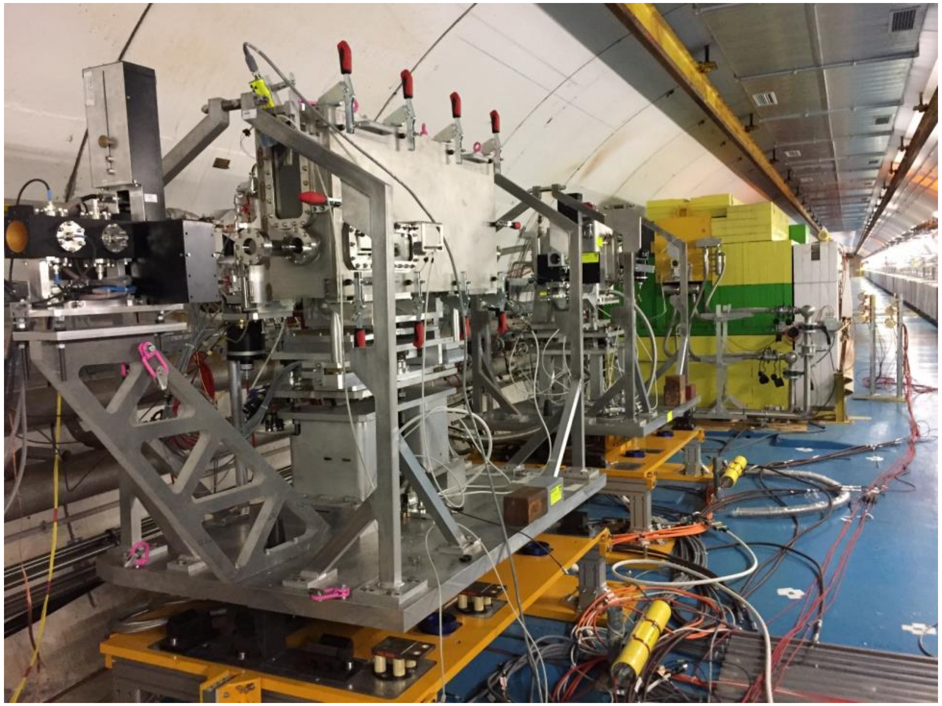
HiRadMat facility

- Facility to conduct single (or multiple) shot experiment using the SPS beam → high intensity and high energy density beams
- Fundamental for design validation & R&D

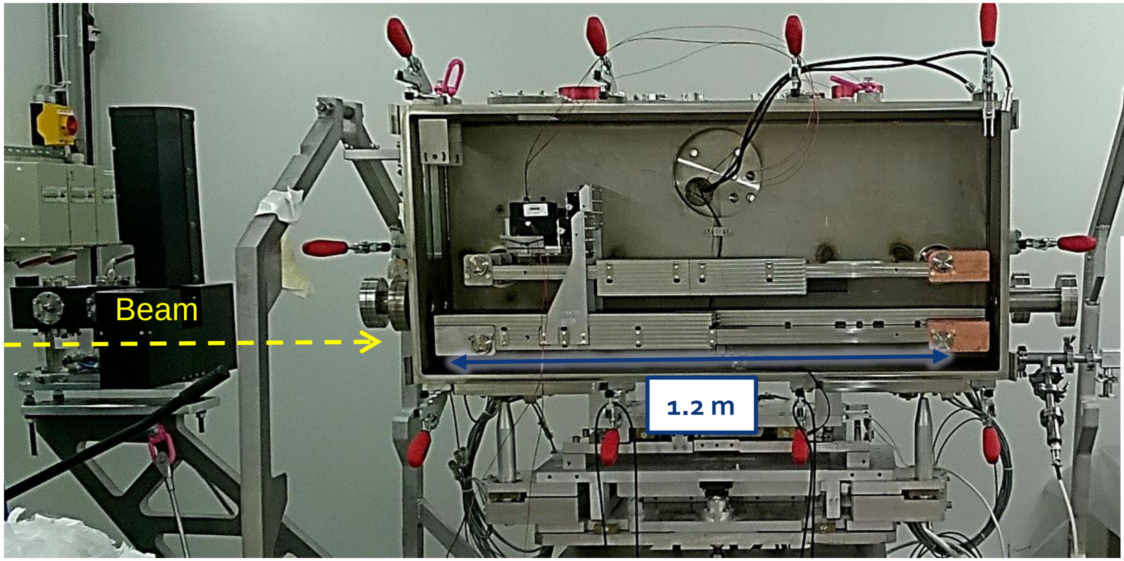




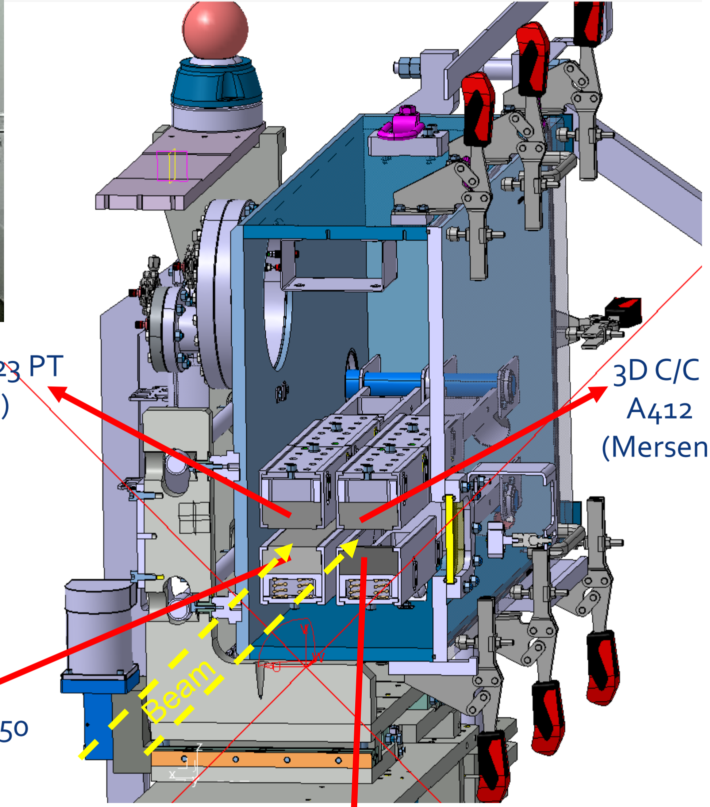
Beam Parameters	
Beam energy	440 GeV
Max. bunch intensity	1.2×10^{11}
No. of bunches	1 - 288
Max. pulse intensity	3.5×10^{13} ppp
Pulse length	7.2 µs
Gaussian beam size	1σ: 0.1 – 2 mm



HiRadMat-28 dynamic tests on graphite and 3D CC



- Multi-purpose tank for collimator like applications, adapted to integral tests (1.2 m long jaws max)
- LDV head measuring displacement
- 4 materials impacted
- 1.12*10^{15} POT cumulated



Graphite 2123 PT
(Mersen)

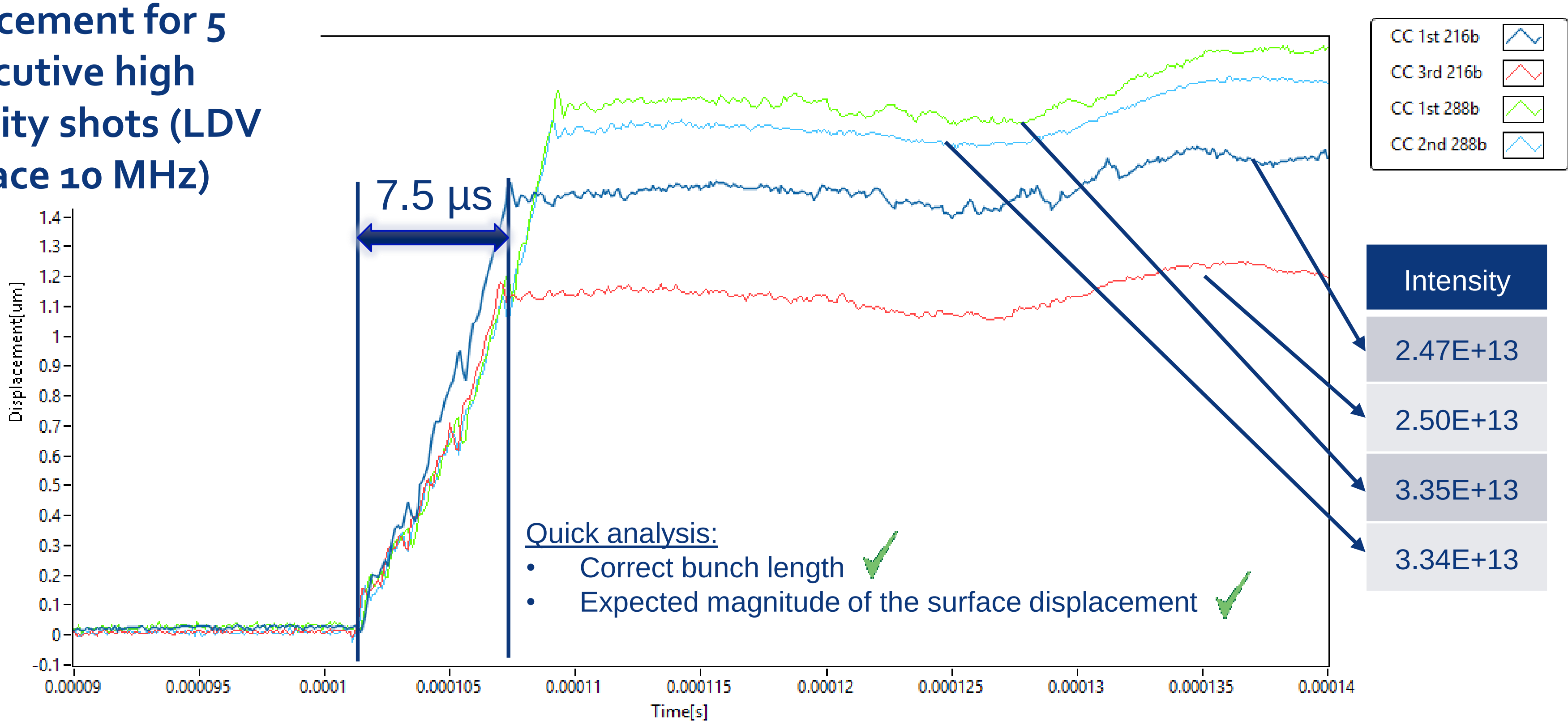
3D C/C
A412
(Mersen)

Graphite Sigrafine® R7550
(SGL)

Sepcarb®
3D C/C
(Airbus Safran Launchers)

HiRadMat-28 dynamic tests on graphite and 3D CC

3D CC (AG) surface displacement for 5 consecutive high intensity shots (LDV interface 10 MHz)



Intensity
2.47E+13
2.50E+13
3.35E+13
3.34E+13

Quick analysis:

- Correct bunch length ✓
- Expected magnitude of the surface displacement ✓

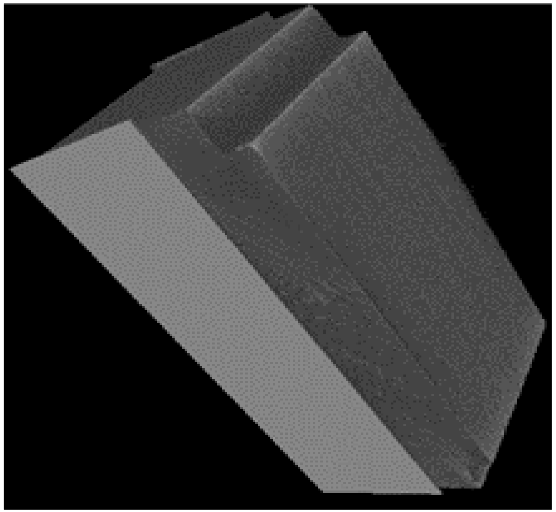
The very similar surface displacement curves over time are an **indicator that no beam induced damage occurs on the material, shot after shot**

The amplitude difference for the 1st and 3rd shots at 216b due to a spot offset in X

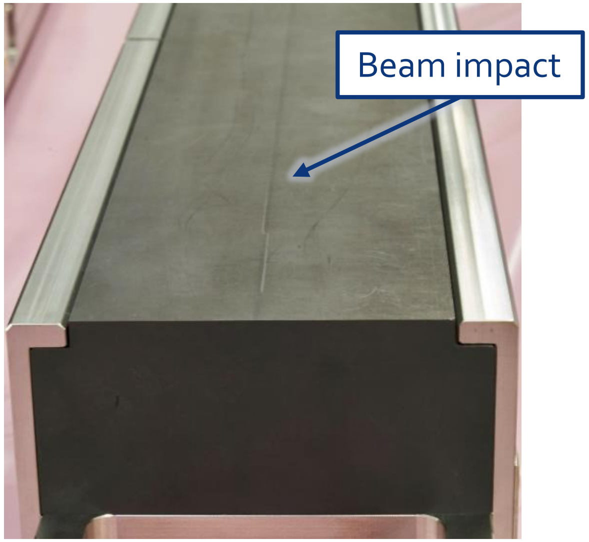
HiRadMat-28 dynamic tests on graphite and 3D CC

- **All materials survived all shots**
- Absorbing blocks already removed from tank
- Post Irradiation Examinations **ongoing** (including metrology, x-ray tomography, etc.)

micro-tomography at ESRF (before and after impacts)

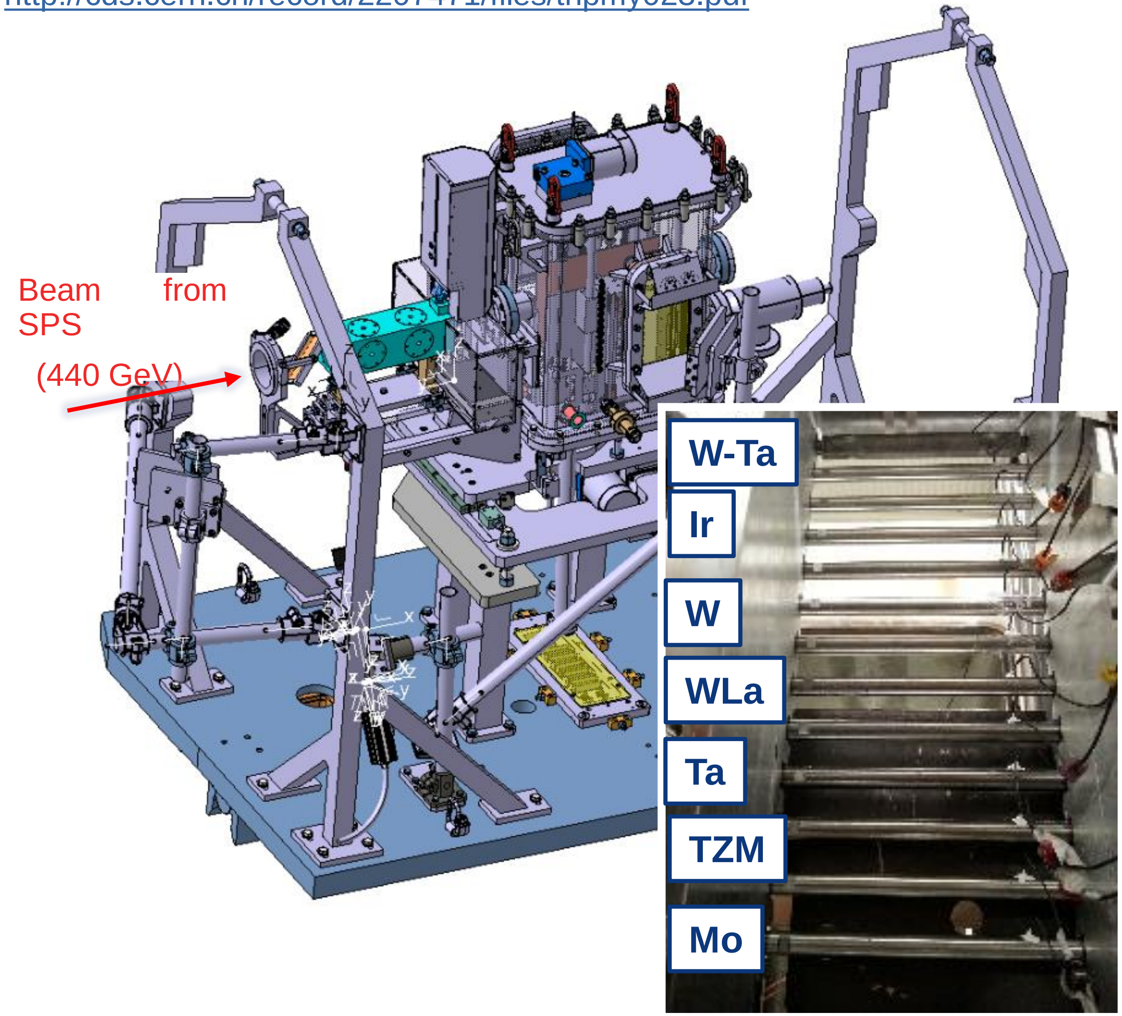


22.5 µm resolution

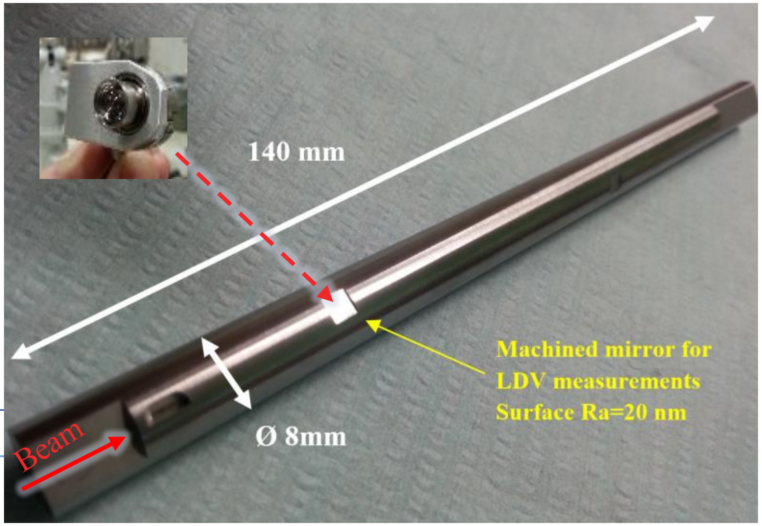


AD Target studies at HiRadMat

http://cds.cern.ch/record/2207471/files/thpmy023.pdf

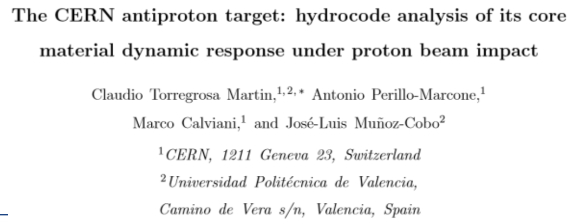


- 13 rods of high-Z materials impacted by 440 GeV/c beam
- Irradiation performed in a **ramped** way to obtain material response at intermediate state before reaching AD-Target conditions



http://cds.cern.ch/record/2064079?ln=en

Targets after the experiment



The CERN antiproton target: hydrocode analysis of its core material dynamic response under proton beam impact

Claudio Torregrosa Martin,[1,2,*] Antonio Perillo-Marcone,[1]
Marco Calviani,[1] and José-Luis Muñoz-Cobo[2]
[1]CERN, 1211 Geneva 23, Switzerland
[2]Universidad Politécnica de Valencia,
Camino de Vera s/n, Valencia, Spain

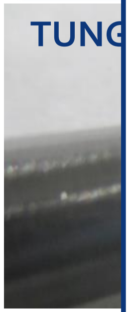
IRIDIUM

Ir tar

Longitudinal cracks in **Iridium** at intermediate intensities.

Detailed experimental results compiled in https://cds.cern.ch/record/2216475?ln=en

TUNG



CERN-EN-2016-004

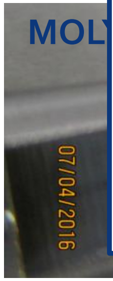
2016-07-04

claudio.torregrosa@cern.ch

The HRMT27 (Rodtarg) Experiment: Design, Operation and First Results

C. Torregrosa, A. Perillo-Marcone, M. Calviani, M. Butcher, D. Horvath, E. Fornasiere, L. Gentini, J. Humbert.
European Organization for the Nuclear Research, Geneva, Switzerland

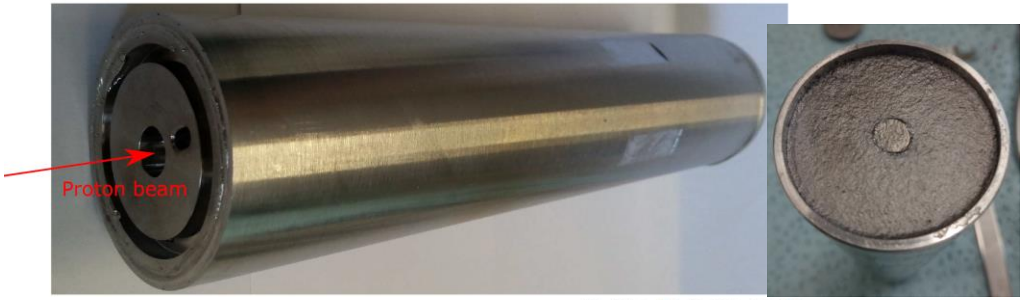
MOL

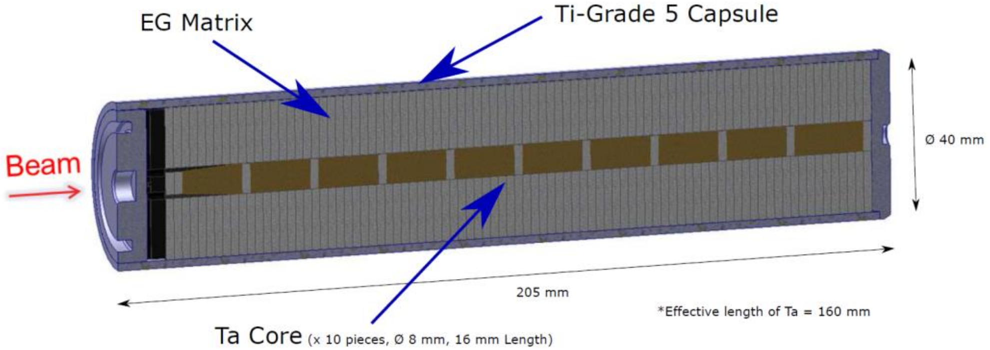


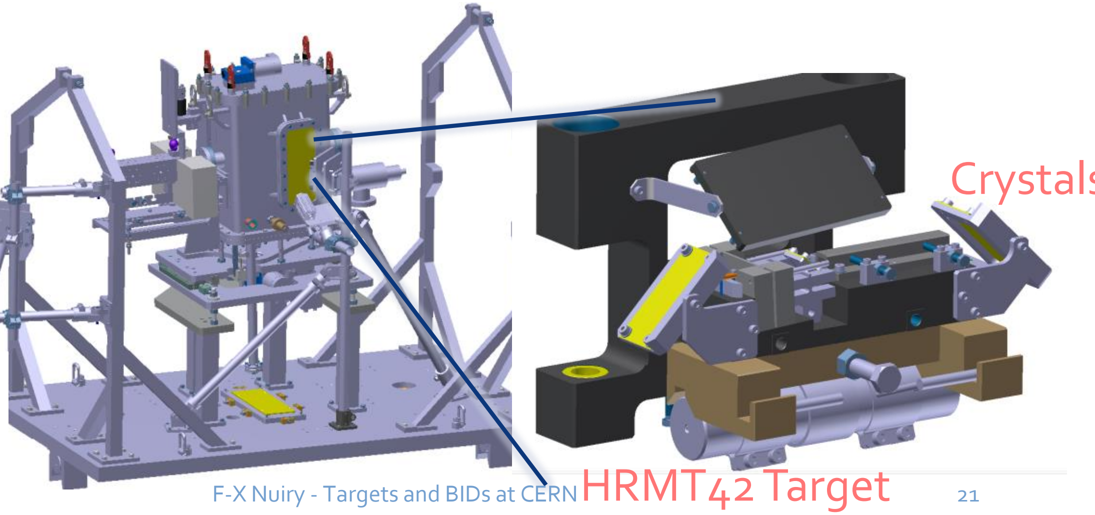
a targets.

AD target last prototype (scale up)

- Core of 8 mm diameter Ta rods
- Effective Ta length of 160 mm
- Ta core embedded in a matrix made of compressed layers of Expanded Graphite (EG)
- Encapsulated in a 2 mm thickness Ti-6V-4Al e-beam welded container








Scaled Prototype of a Tantalum Target Embedded in Expanded Graphite for Antiproton Production: Design, Manufacturing and Testing under Proton Beam Impacts at HiRadMat

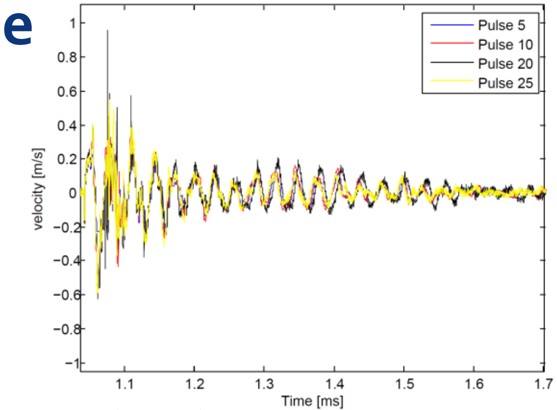
Claudio Torregrosa Martin,[1,2,*] Marco Calviani,[1] Antonio Perillo-Marcone,[1] Romain Ferriere,[1] Nicola Solieri,[1] Mark Butcher,[1] Lucian-Mircea Grec,[1] and Joao Canhoto Espadanal[1]

[1] *CERN, 1211 Geneva 23, Switzerland*
[2] *Universidad Politécnica de Valencia, Camino de Vera s/n, Valencia, Spain*
(Dated: March 28, 2018)

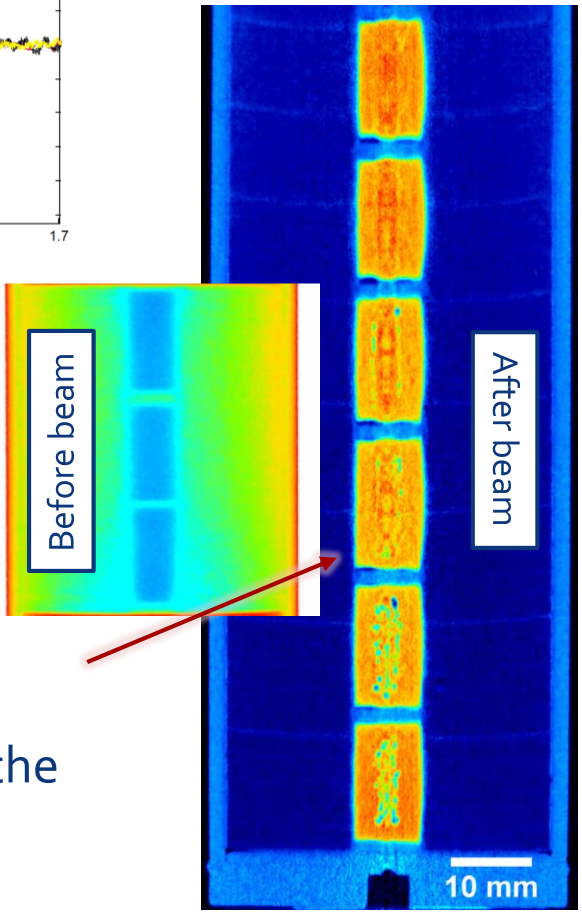
HRMT-42: Online results and first PIEs

Velocity recorded online

- A radial wave of ~28 µs period dominates the response.
- Damped in ~500-600 µs



neutron tomography @ PSI-NEUTRA



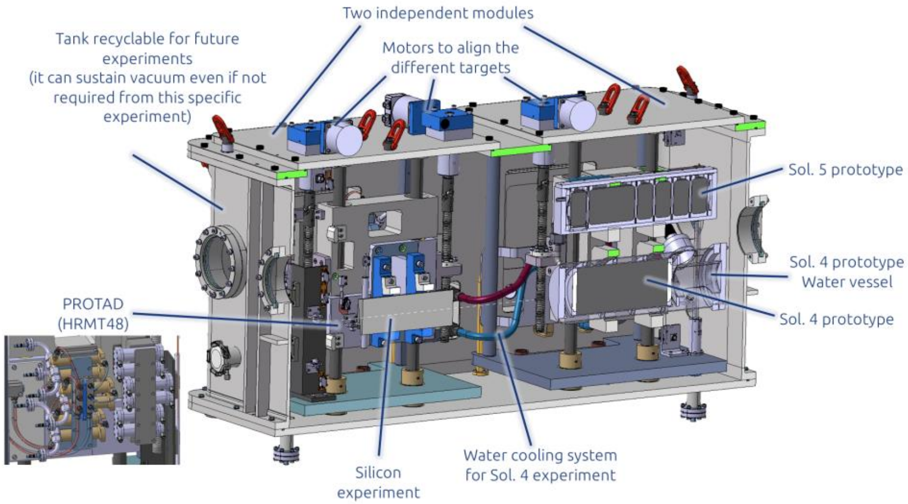
X-ray tomography @ ESRF (FR)

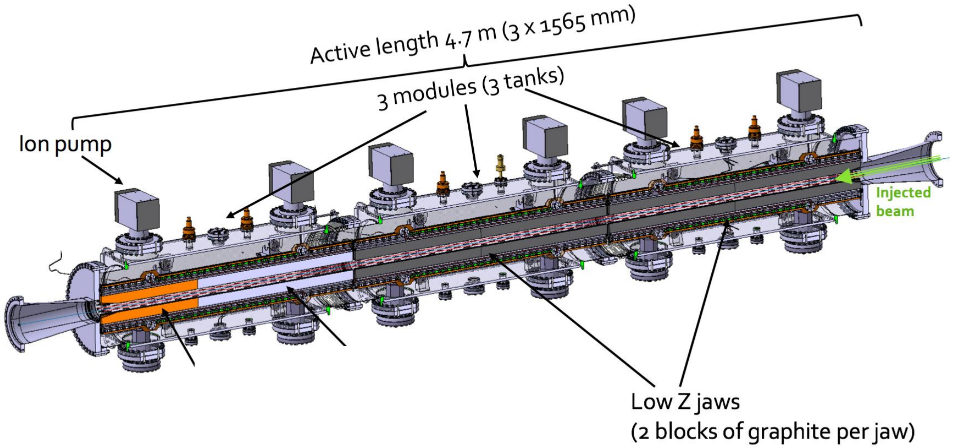
- Significant plastic deformation of the Ta core, formation of voids (spalling*).
- Continuous EG-Ta interface (no gaps) at least in the periphery

**voids formation in Ta in case of high tensile stress in 3 directions*

Some coming HiRadMat experiments in 2018

- Experiment 44: Study of beam impacts on scale 1 LIU collimator (TCDIL proto)
- Experiment 45: Study of beam impacts on scale 1 LHC injection absorber (TDIS proto)
- Experiment 46: n_ToF target prototype designs beam test
- Experiment 48: AD target prototype test
- Experiment 43: BeGrid2: Irradiation on target materials





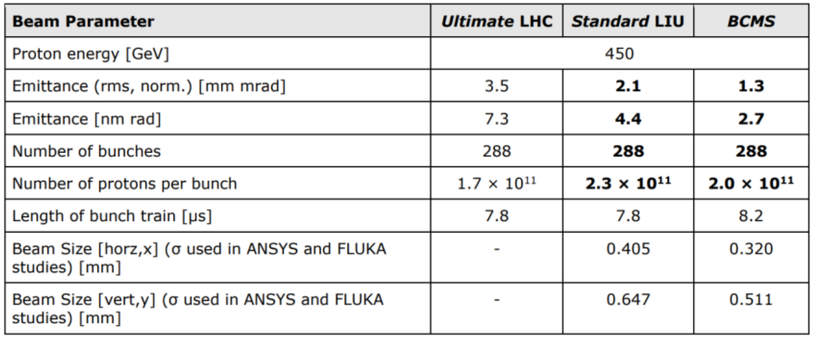
Conclusions

- Short outline of few selected Beam Intercepting Devices across the complex
- Challenges across all fronts, including mechanical properties at high T and strain rates, radiation damage, UHV compatibility, etc.
- Beam impact test output is enhance with well prepared PIE;
- Significant R&D on graphitic materials and high-Z refractory metals (static/dynamic tests + beam impacts)

BACKUP

R&D on 3D CC for collimator applications

- Historically, two types of graphite have been employed at CERN:
  - **Isotropic graphite** (e.g. **SGL 7550**, employed in most BIDs, TDI, TIDVG4, L4 dump, etc.)
  - **2D reinforced CfC** (due to higher electrical conductivity and strength)
- Recently – together with MoGR – the use of a more thermo-mechanical resistant composite was suggested (3D CC)
- Within the LIU TCDIL Project (SPS to LHC transfer line collimators), a choice was made to **explore new materials for collimators** active parts
  - Follow-up of a long-term "wish" to explore 3D CC which started during the **CNGS target development** times



Beam Parameter	***Ultimate LHC***	***Standard LIU***	***BCMS***
Proton energy [GeV]	450		
Emittance (rms, norm.) [mm mrad]	3.5	**2.1**	**1.3**
Emittance [nm rad]	7.3	**4.4**	**2.7**
Number of bunches	288	**288**	**288**
Number of protons per bunch	1.7×10^{11}	$\mathbf{2.3 \times 10^{11}}$	$\mathbf{2.0 \times 10^{11}}$
Length of bunch train [μs]	7.8	7.8	8.2
Beam Size [horz,x] (σ used in ANSYS and FLUKA studies) [mm]	-	0.405	0.320
Beam Size [vert,y] (σ used in ANSYS and FLUKA studies) [mm]	-	0.647	0.511

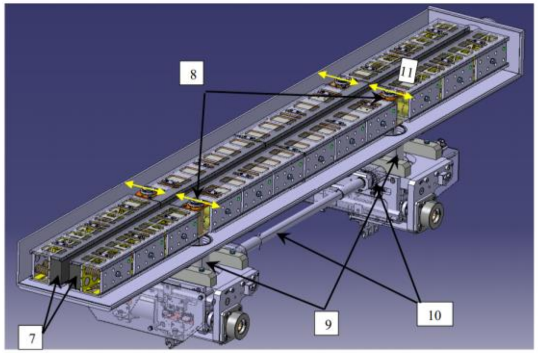


Figure 5: TCDI collimator with jaws and mechanical table units

Item (7): Collimator absorber material (graphite and 3D CC blocks, clamped inside the jaw);
Item (8): Two stainless steel shafts per jaw, linking jaws to mechanical table units;
Item (9): Stainless steel bellows, linking the vacuum vessel to the mechanical table units;
Item (10): Rack-pinion system to prevent excessive jaw misalignment;
Item (11): Jaw advancement per motor step: 5 μm. Jaw stroke: 35 mm (switch 'in' to switch 'out');

HiRadMat-28

Experiment conceived to validate suitable materials for TCDIL, TDI and TPSG/C and check 3D CC ability to withstand operational-like thermal shocks

1. Assess the Integrity of graphite & 3D CC for Run 3 beams. The goal is to reproduce the worst accidental scenario that the TCDI and the TDI can see during their life time.
2. Cross-check simulations

- **Executed in 2016 and 2017**

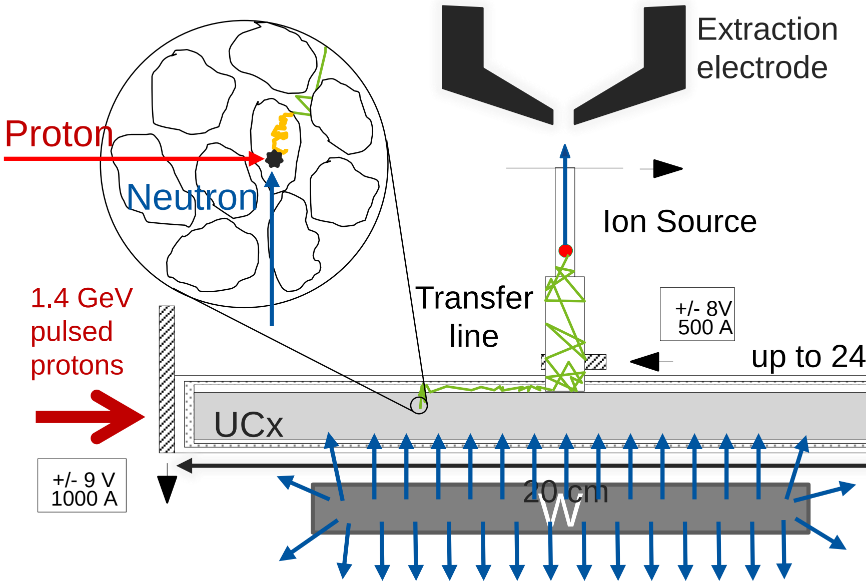
Beam	Intensity	Sig X[mm] × Sig Y[mm]	Max T [°C]	M-C Safety Factor*
Run 3 BCMS	5.76 E13	0.320×0.511	1450	1
HiRadMat requested beam	3.46 E13	0.313×0.313	1342	0.96

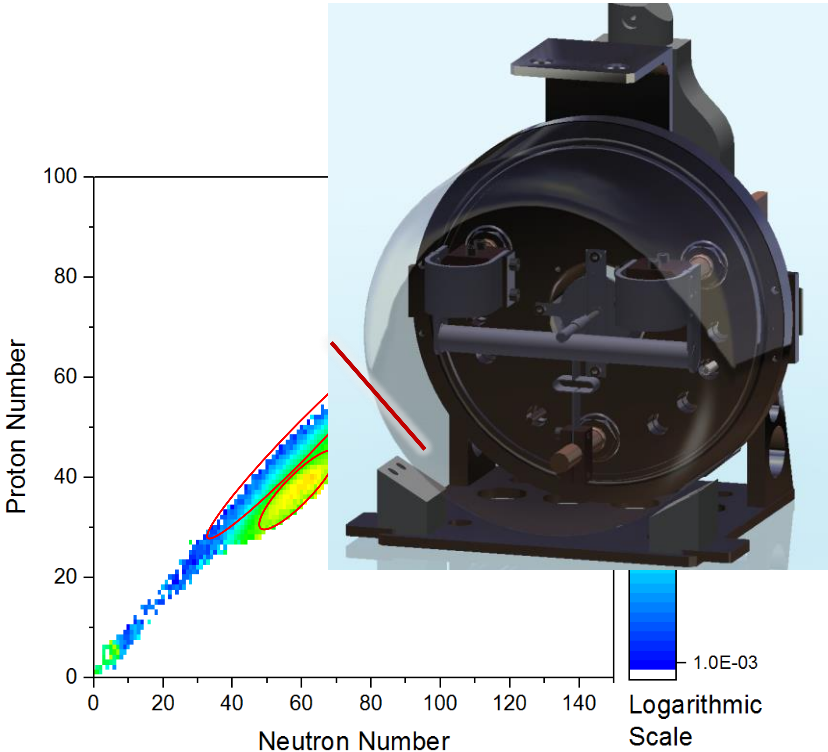
*The Mohr Coulomb safety factors are calculated with a graphite tensile limit 40 MPa which is the value considered by SGL for the R7550 graphite.

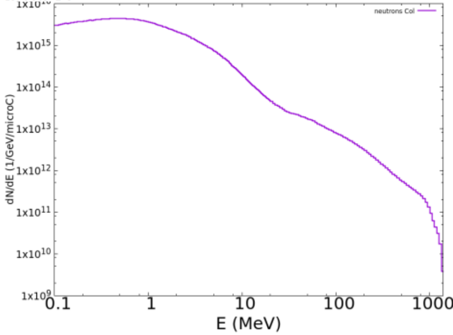
$$F_s = \left[\frac{\sigma_1}{\sigma_{Tensile\ \ limit}} + \frac{\sigma_3}{\sigma_{compressive\ \ limit}}\right]^{-1}$$

ISOL Isotope Separation OnLine

Slide from J.P Ramos, CERN







1. Production
2. Diffusion
3. Effusion
4. Ionization
5. Mass Separation
6. Transport

$$Beam\ Int. =$$

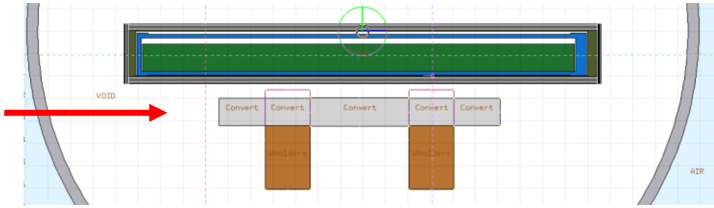
$$\varepsilon =$$

N_t – Nr of exposed atoms [dim]
j – Proton flux [cm^{-2}]
σ – Cross section [mb]
ε – Efficiency [%]

Concept

Slide from J.P Ramos, CERN

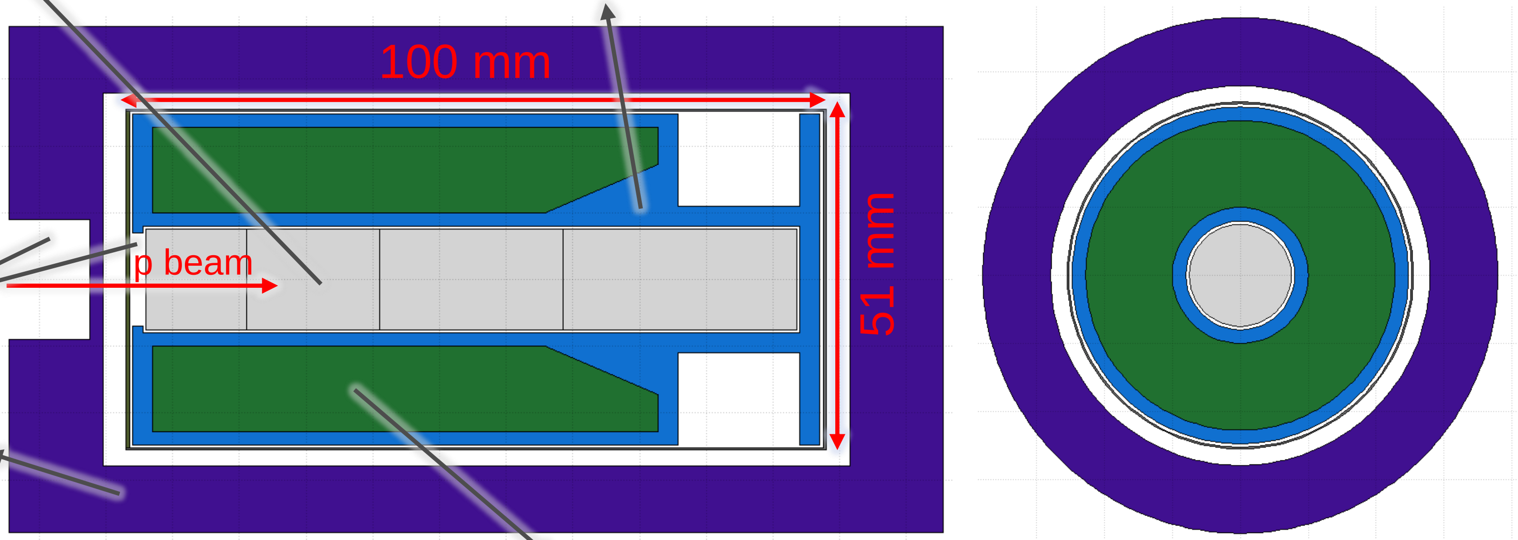
Converter very close to uranium carbide – high neutron flux!



W converter

- Ø15 mm (12 mm - standard)
  - Sliced to mitigate thermal shocks
- Operated at 2000 °C

Graphite container



Avoid proton scattering

Thermal Shielding

- Sigratherm® - “graphite foam”
- 0.2 g/cm^3
- Low thermal conductivity

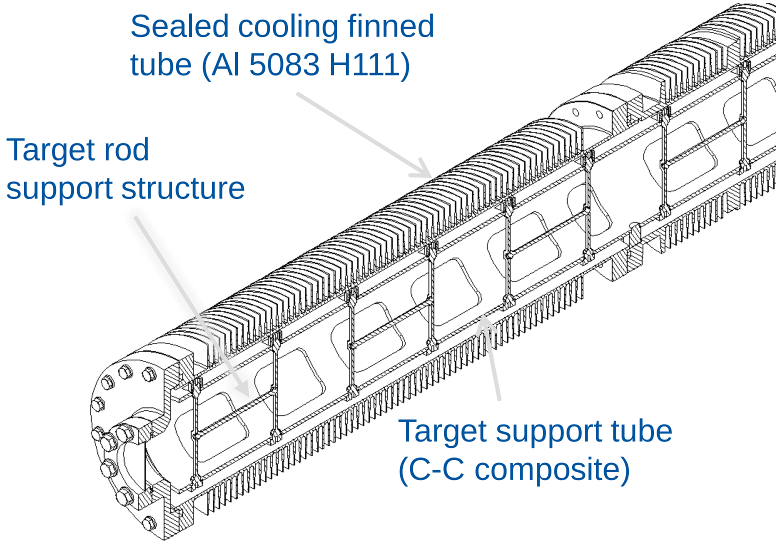
UC$_x$: new procedure has to be made for annular shape

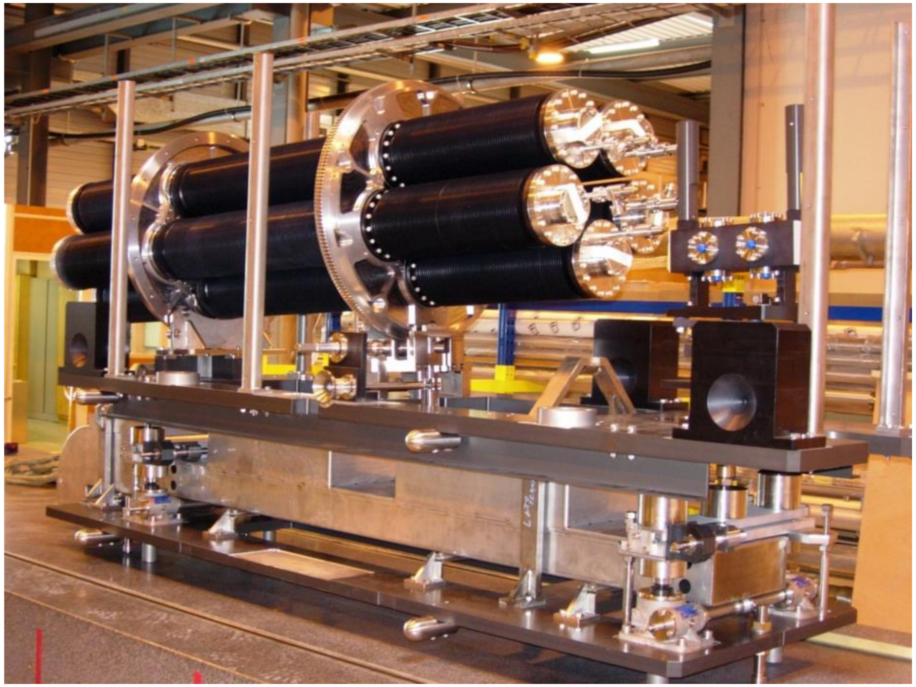
Standard UC$_x$ pellets

Slide from M. Calviani, CERN

CNGS engineering challenges

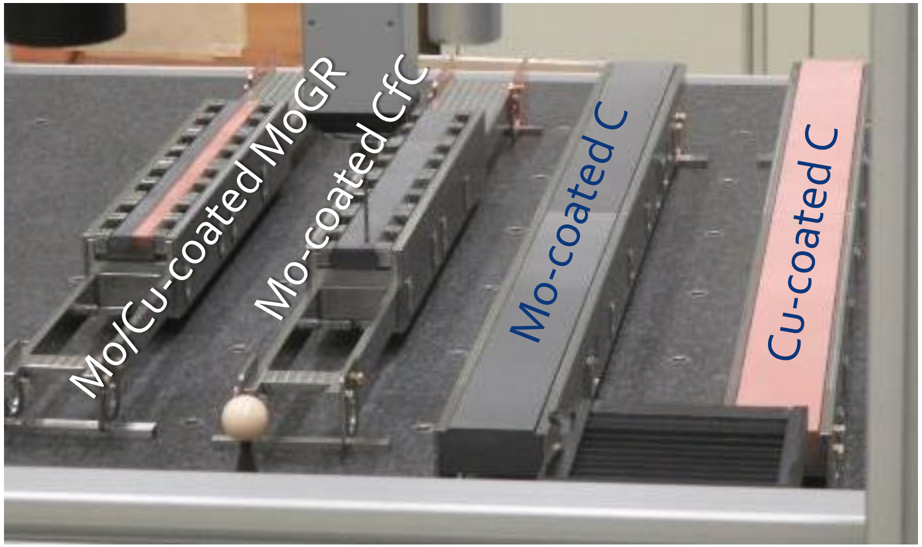
- CNGS target unit conceived as a static sealed system with 0.5 bar of Helium
  - 130 cm long graphite target (~3λ)
  - Radiative-cooled target ~1200 °C
  - Radiation resistance of employed graphite (2020PT, C-C composites, etc.)





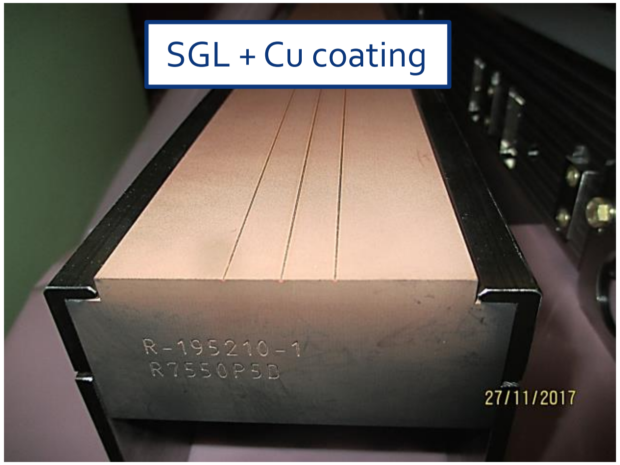
HiRadMat-35

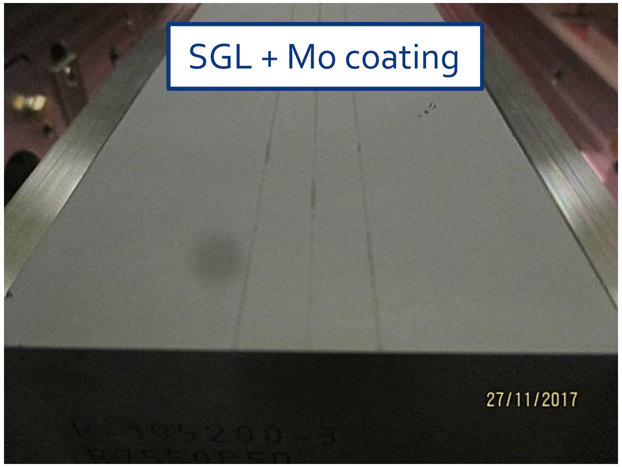
- **SGL Graphite R4550 TDI coating configuration with Cu coating**
- **SGL Graphite R4550 TDI coating configuration with Mo coating**
- *Tatsuno CfC FS140 in a TCPPM/TCSPM configuration with Mo coating*
- *Molybdenum Graphite (MoGr) in a TCPPM/TCSPM configuration with half Cu/half Mo*

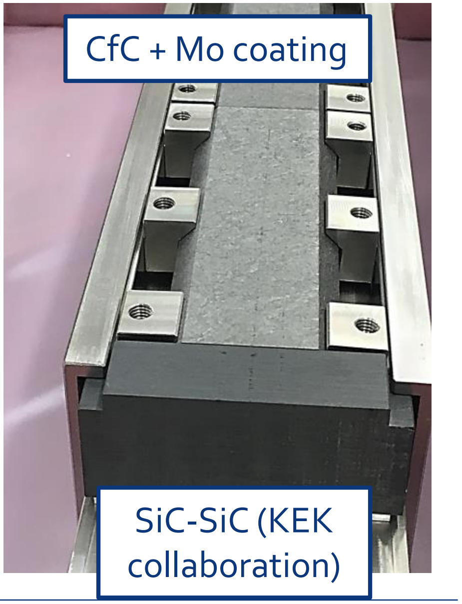


HiRadMat-35

- Experiment successfully executed **August 2017** (>15 shots per jaw at high intensity, with an operationally representative sigma)
- Disassembled few weeks later despite significant residual dose rate (few mSv/h)
- Very minor effect on the coated SGL and CfC jaws coating, especially for the Mo
- PIE and coating adhesion planned


SGL + Cu coating

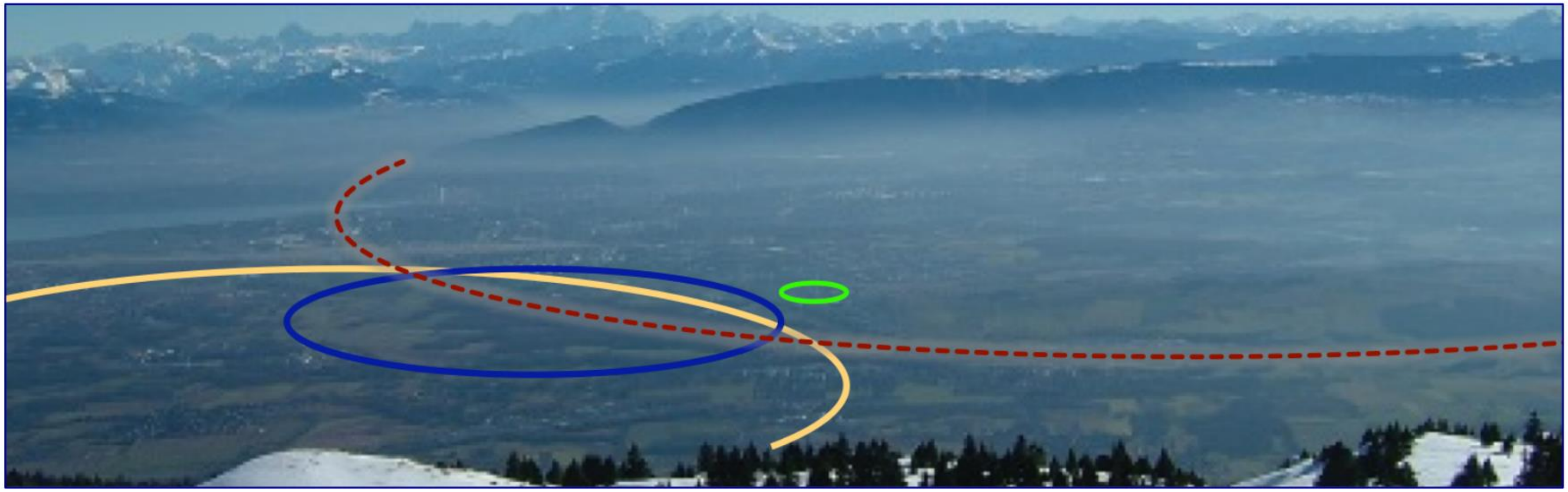

SGL + Mo coating


CfC + Mo coating

SiC-SiC (KEK collaboration)

Looking into the far future…

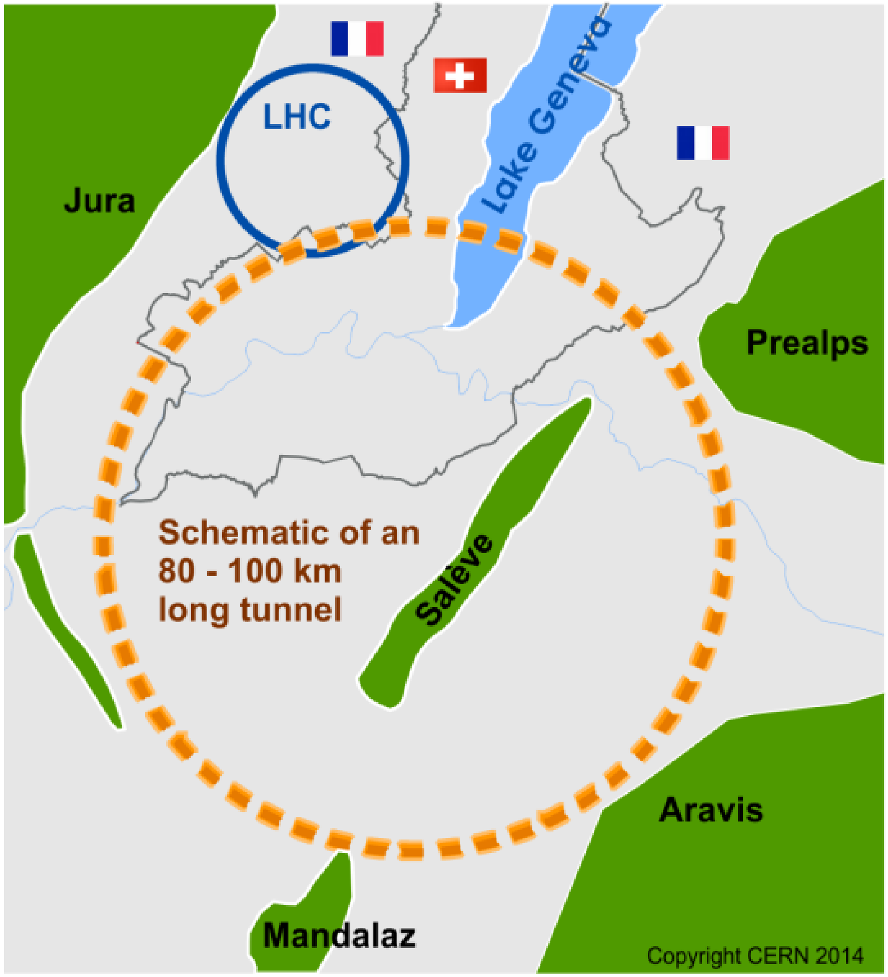
FCC – Future Circular Collider



- Study for a 100 km ring providing collisions at 100 TeV CM
  - Employing injector chain of CERN

FCC

- pp collider (FCC-hh) – sets the boundary conditions
  - 100 km ring, 100 TeV CM, L~2*10^{35} cm^{2}s^{-1}
  - HE-LHC included (~28 TeV)
- e$^+$e$^-$ collider as possible first step
  - 90-350 GeV CM
  - L~1.3*10^{34} at high E

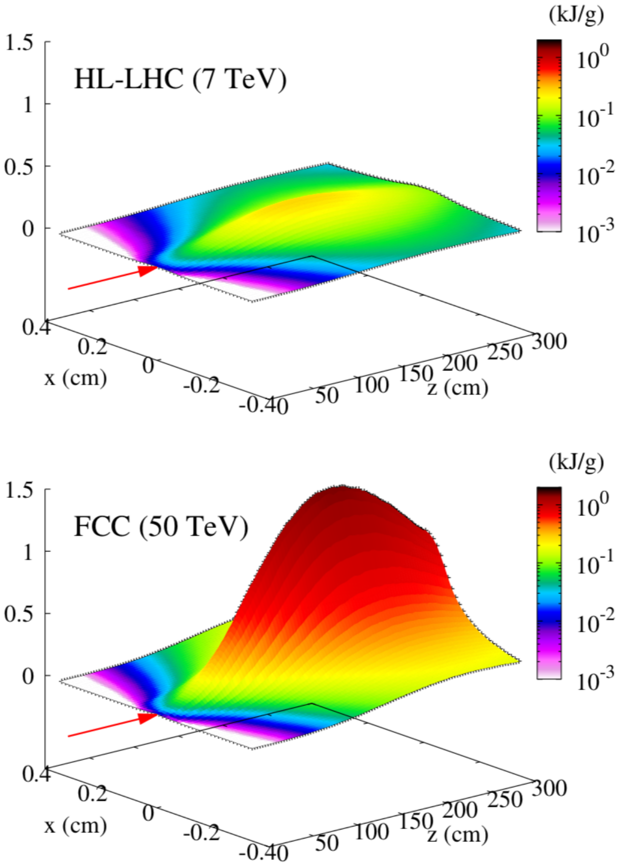


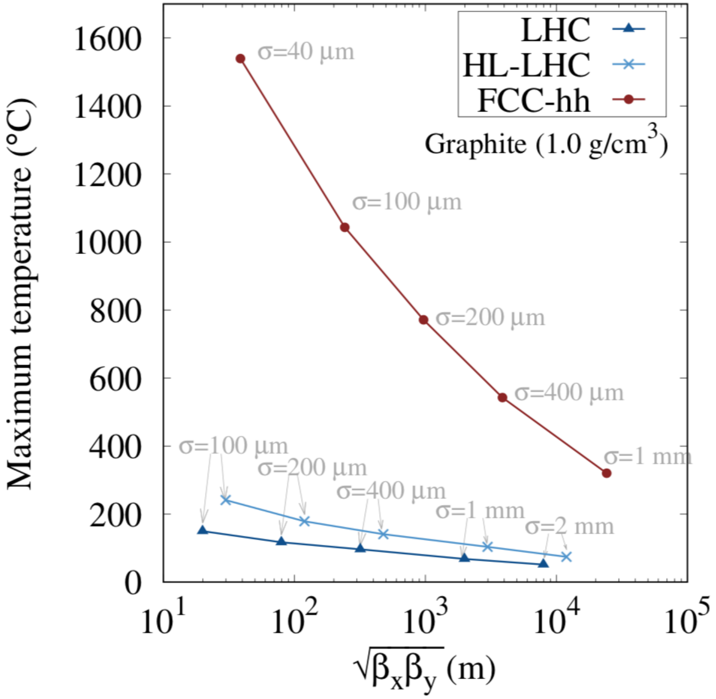
Challenges for FCC-era BIDs

(HL-)LHC vs FCC-hh: single proton bunch on Graphite

	LHC	HL-LHC	FCC
E (TeV)	7	7	50
ϵ_n (μm·rad)	3.75	2.5	2.2
ppb ($\times 10^{11}$)	1.15	2.2	1.0

1 proton bunch,
Graphite (1.0 g/cm^3)





Even with large β:

- ○ **O(few) FCC bunches** can induce **critical stresses**
- ○ **O(tens) FCC bunches** can provoke **phase transition**

(if all on the same spot)

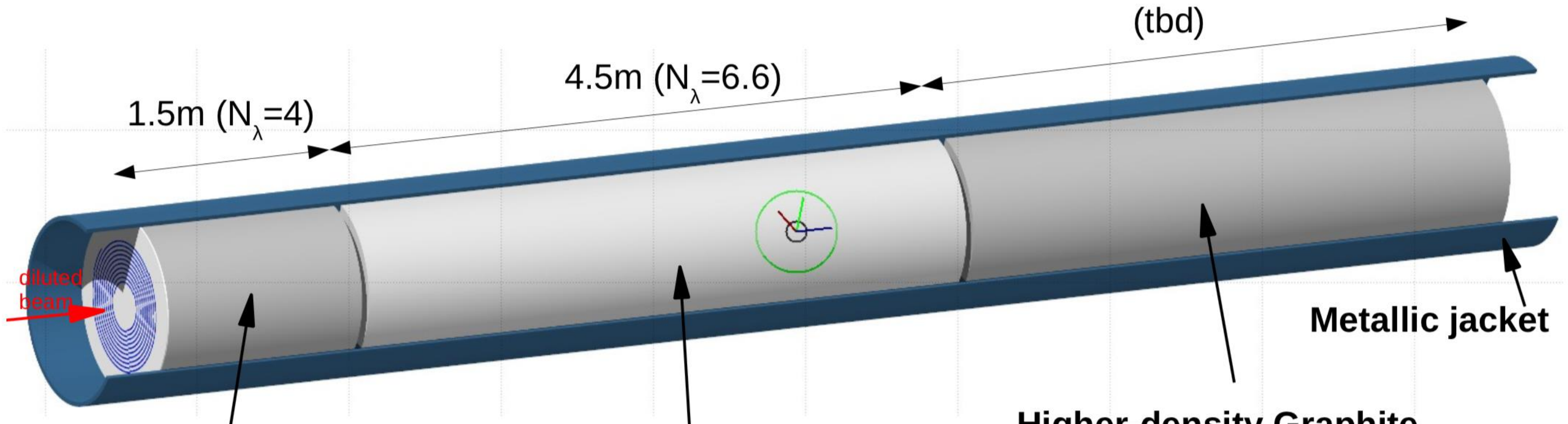
Figures on the left: dose in 3 m long Graphite (1.83 g/cm3) for one nominal proton bunch (σ =400μm) - HL-LHC (top) and FCC (bottom).

Max. energy density/temp. by single bunch → spot size

A. Lechner

Challenges for FCC-era BIDs

FCC-hh dump concept (LHC-like Graphite dump)



Higher-density Graphite segment (1.8 g/cm³)

Higher material density at upstream end gives rise to a steeper shower build-up and hence reduces the overall dump length

Note: the presence of the higher-density graphite has only a small effect on the maximum energy density in the low-density segment if the beam is diluted across the dump face

Low-density Graphite segment (1.0 g/cm³)

Lower material density in the region of the shower maximum reduces the max. energy density and temperature

Higher-density Graphite segment (1.8 g/cm³)
+ possibly other materials (tbd)

Higher material density gives rise to better attenuation of the longitudinal shower tails and hence reduces the dump length

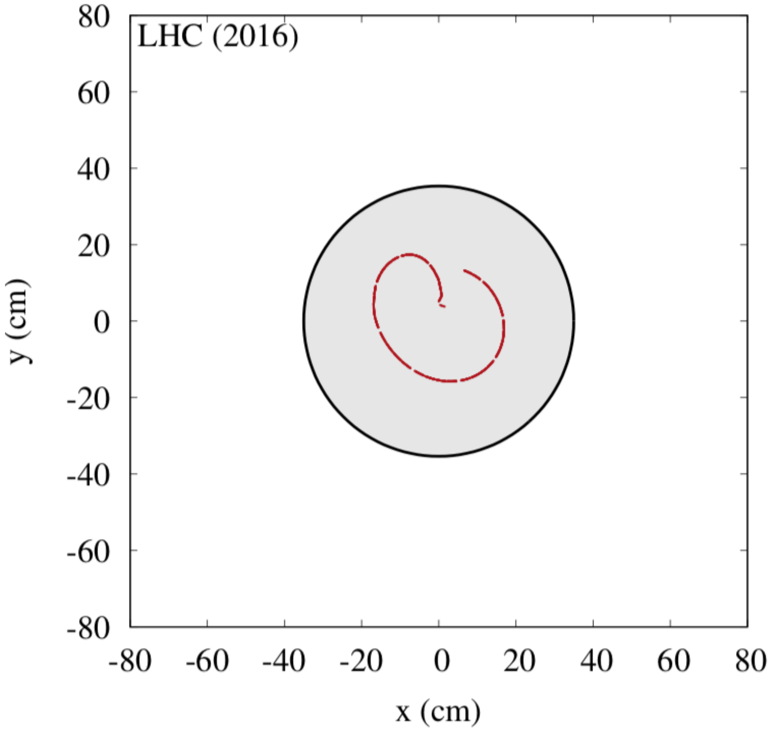
Total core length expected < 10-12m

Core radius depends on sweep pattern (+ a certain margin to jacket)

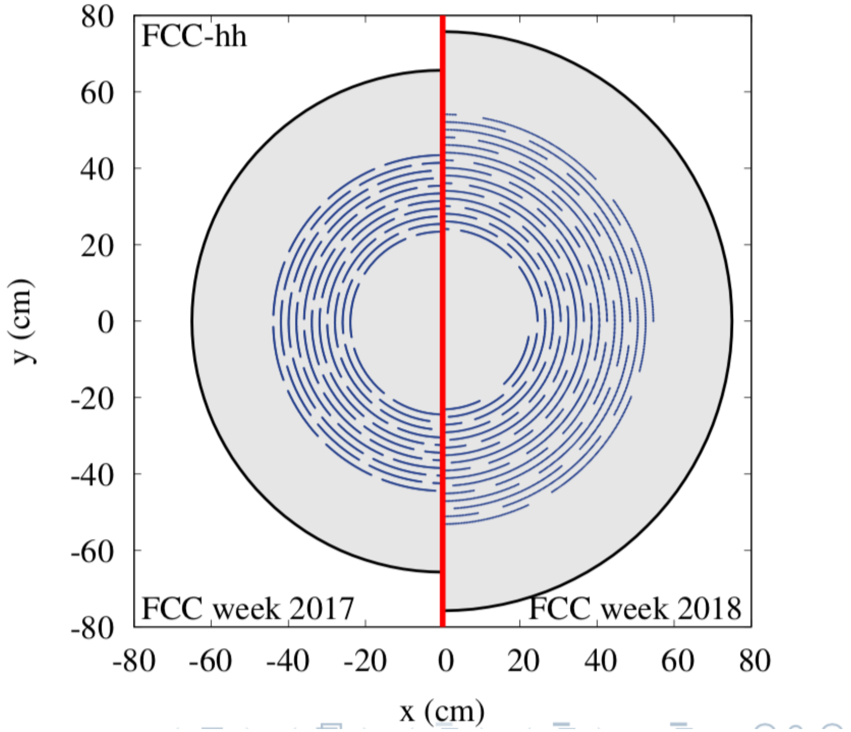
A. Lechner

LHC vs. FCC dump core

LHC (core radius = 35 cm):



FCC-hh (min. core radius 70-80 cm):

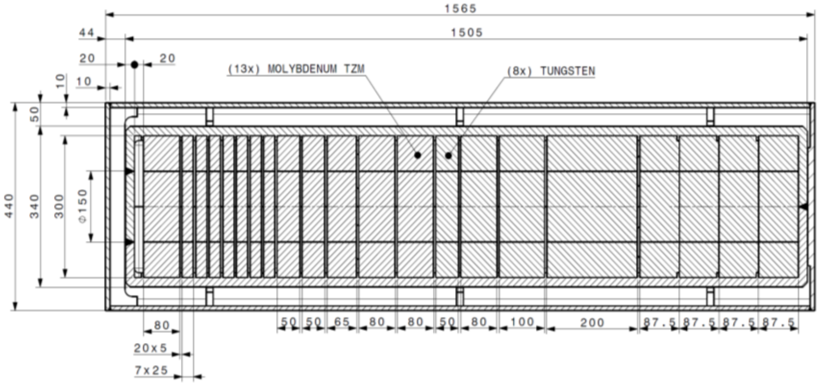


Beam Dump Facility target (I/II)

- High intensity proton beam: **$4*10^{13}$ p^+/pulse, $4*10^{19}$ POT/year**, **355 kW** average beam power **extracted** (CNGS ~500 kW)
- Slow extraction (~1 sec. flat top)
- O(400 GeV) optimal beam momentum
- Dense target/dump to **maximize production** & stop π and K before decay into $\mu+\nu$
- Significant R&D in the next 2 years

BDF target (II/II)

- Target is 250 mm diameter hybrid Ta-cladded TZM+W target,1500 mm long
- **~320 kW** to be dissipated (water cooled, 200 m^3/h)
- Challenges:
  - **Thermal management**
  - **Radiation damage**
  - **Thermal fatigue**
  - **Feasibility**
- Prototype will be built in 2018 and beam tested at 400 GeV/c



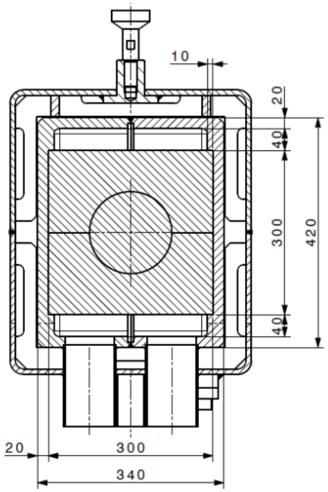
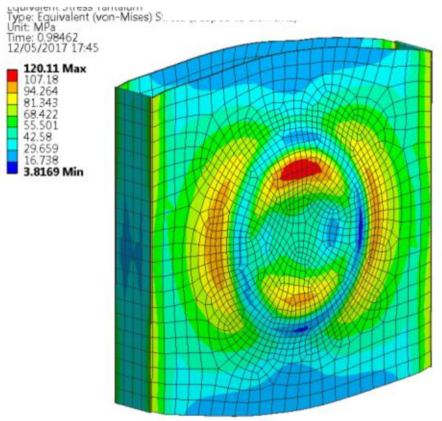
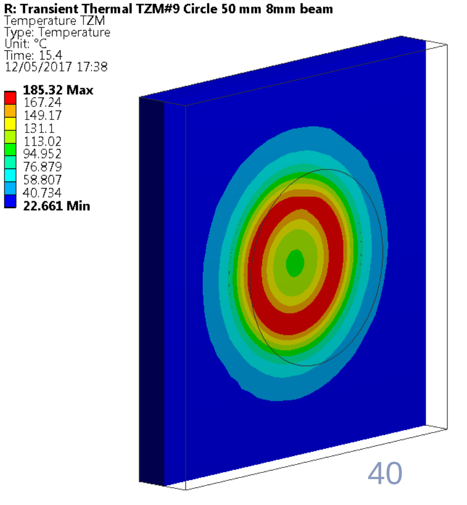


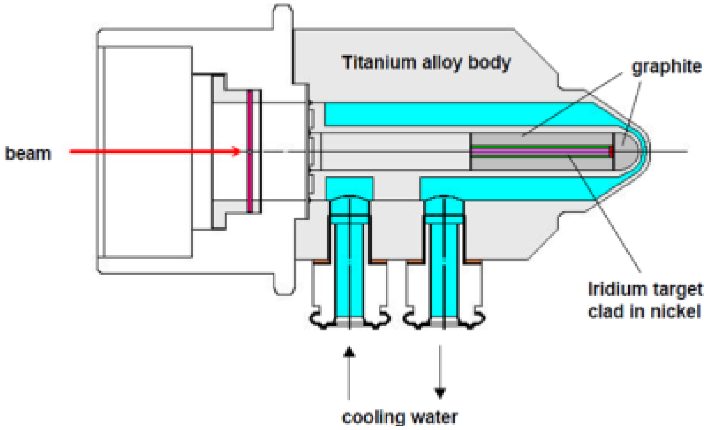
Figure 51: Transversal view of the SHiP target asse



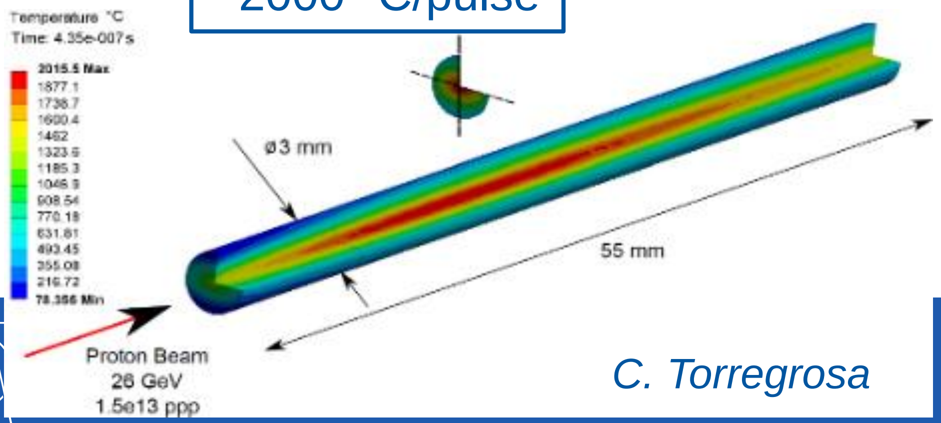


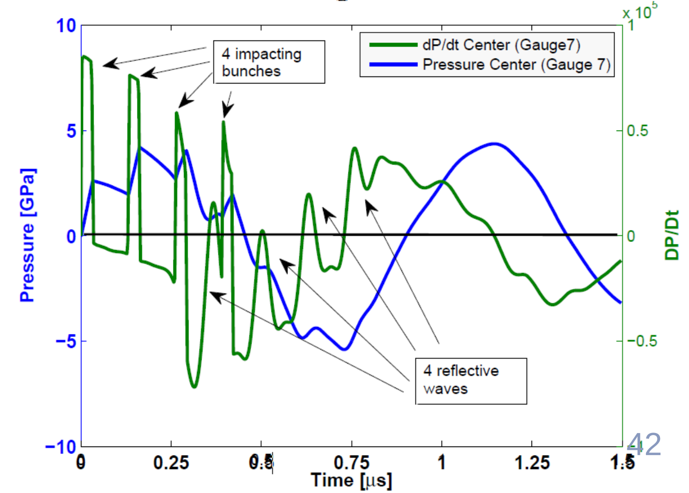
Antiproton target

- AD complex will run until at least 2035 – global consolidation of target area during LS2 (including new target & horns)
    - 26 GeV/c
    - 0.5 mm x 1.0 mm
    - $1.45*10^{13}$ ppp
    - 430 ns pulse length
    - ~1 DPA/y



~2000 °C/pulse

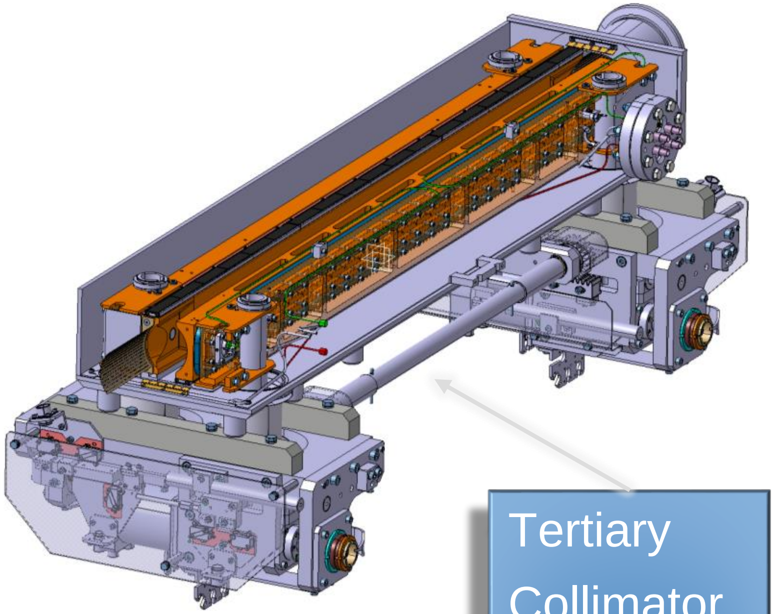




C. Torregrosa

Competences and technologies involved in the manufacturing of LHC collimators

- Manufacturing Engineering
- High Precision Dry Machining
- Surface Treatments
- UHV Cleaning
- Vacuum Brazing
- EBW and TIG welding
- UHV leak testing and outgassing
- Assembly of UHV components in precise mechanisms
- 3D metrology and assembly adjustments



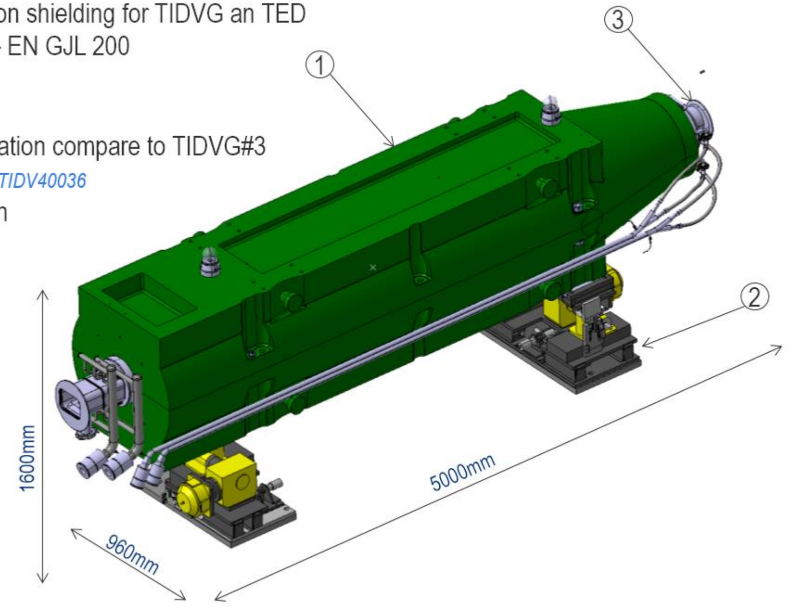
Tertiary Collimator (TCTP)

TIDVG (SPS internal dump)

1- TIDVG Yoke *SPSTIDV40049*
- Identical Iron shielding for TIDVG an TED
- Cast Iron – EN GJL 200
- Mass 19t

2- Foot Assembly
- No modification compare to TIDVG#3

3- TIDVG#4 Core *SPSTIDV40036*
- New design
- Mass 2t



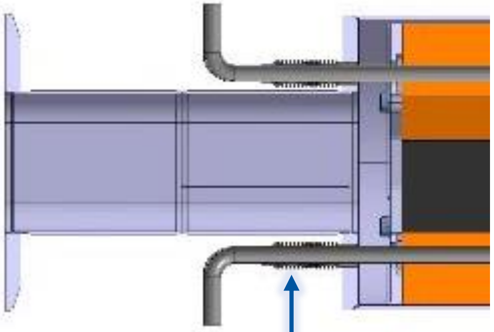
- Device essential for the operation of the accelerator complex
- New SPS internal dump (innovative design) constructed in ~8 months following a failure in 2016, operational since March 2017
- Completely new design – “prototype” for new dump for LS2 (LIU)

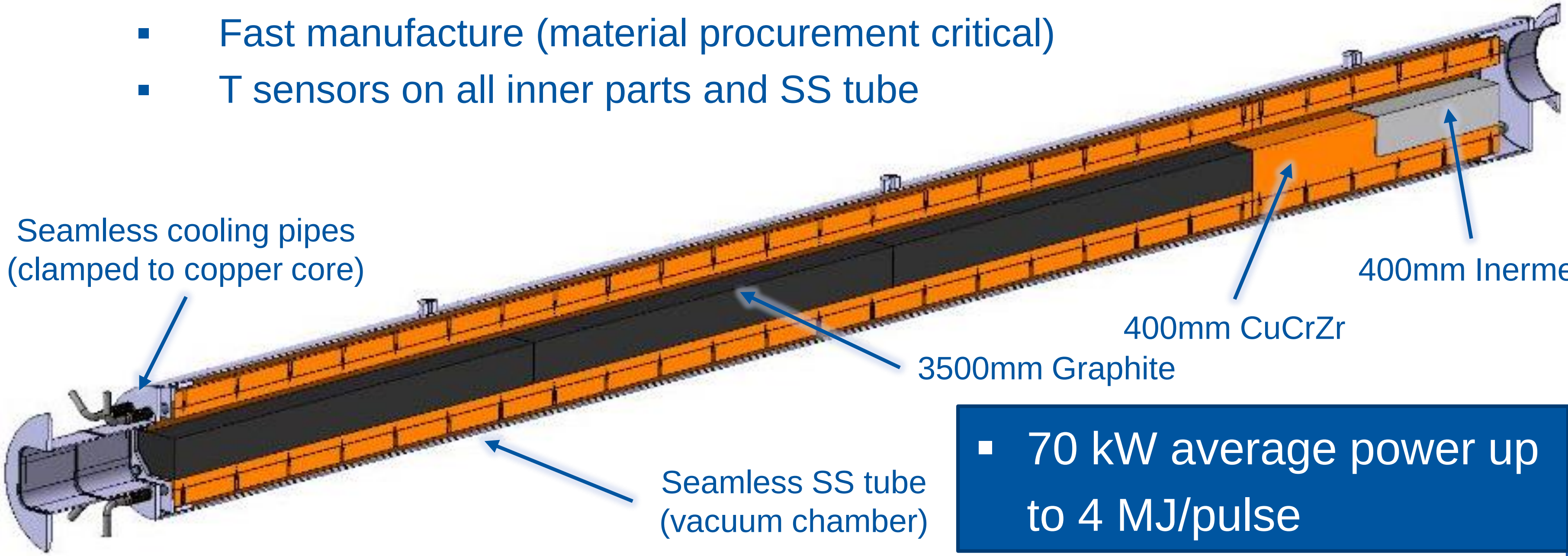
Example of what happened to a previous generation (TIDVG#2)

- ‘”Tsunami-effect” in the Al core (molten due to beam impact)

TIDVG#4 (for 2017-2018 operation)

- Main features:
  - No aluminum
  - CuCrZr as absorbing block (integrated with core)
  - Better springs (more reliable thermal contact pressure)
  - Seamless SS vacuum chamber around dump (minimum risk of leaks)
  - Fast manufacture (material procurement critical)
  - T sensors on all inner parts and SS tube

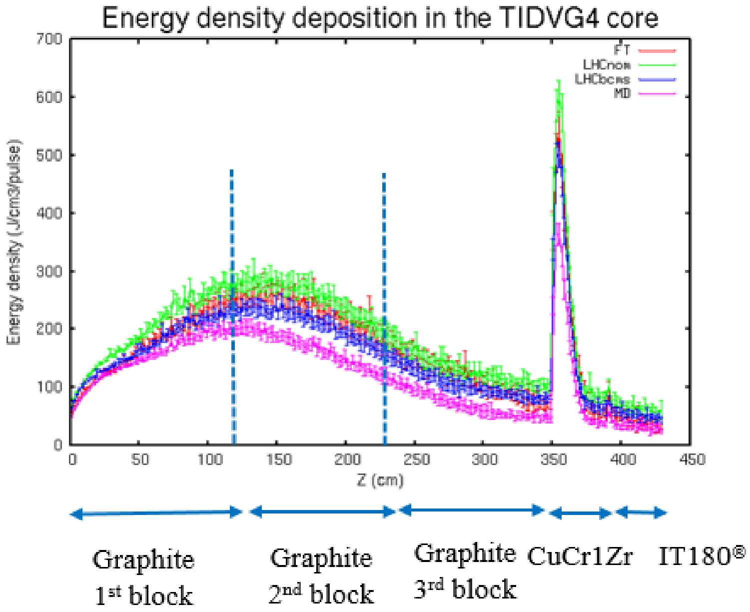


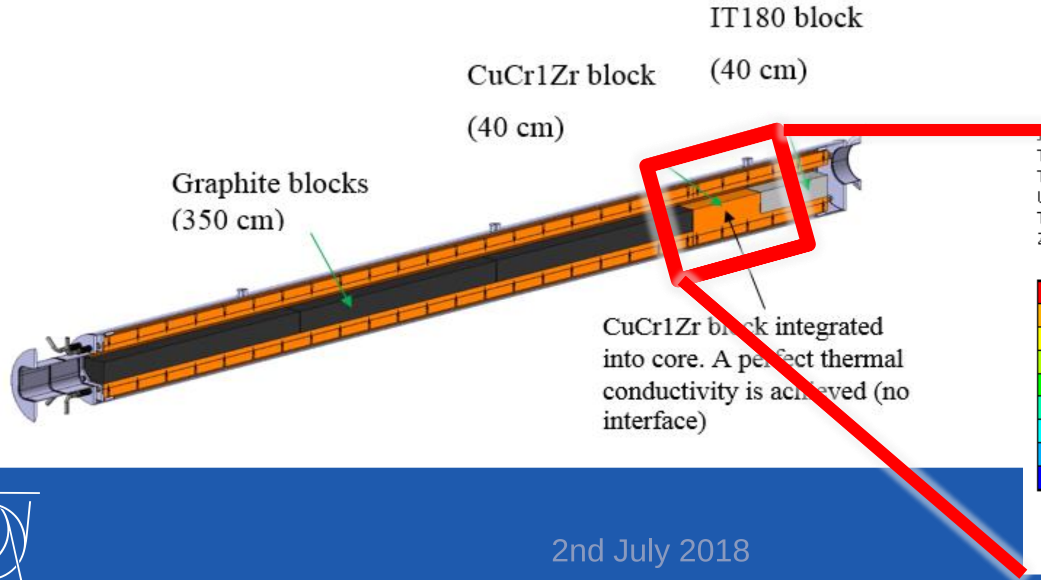


- 70 kW average power up to 4 MJ/pulse

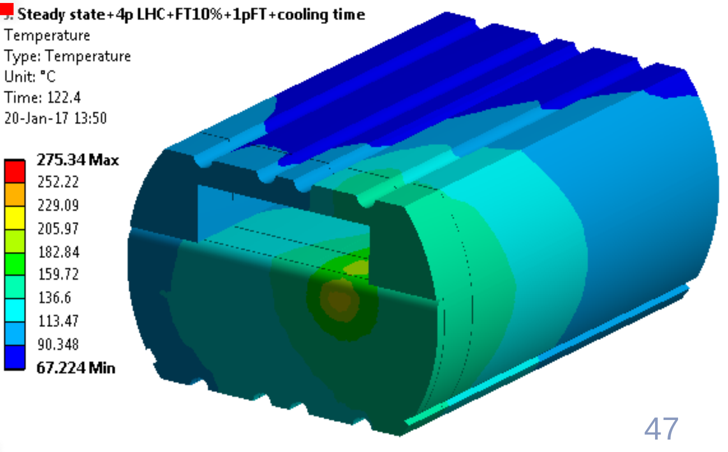
Beam parameters for TIDVG

Beams	E [GeV]	Bunch intensity [p+/bunch]	# of bunches	Total intensity [p+/pulse]
LHC (25 ns)	450	$1.5 \cdot 10^{11}$	288	$4.32 \cdot 10^{13}$
FT	400	$1.4 \cdot 10^{10}$	4200	$5.88 \cdot 10^{13}$
FT 10%	400	$1.4 \cdot 10^{9}$	4200	$5.88 \cdot 10^{12}$
LHC (BCMS)	450	$1.2 \cdot 10^{11}$	288	$3.45 \cdot 10^{13}$





CuCr1Zr block integrated into core. A perfect thermal conductivity is achieved (no interface)

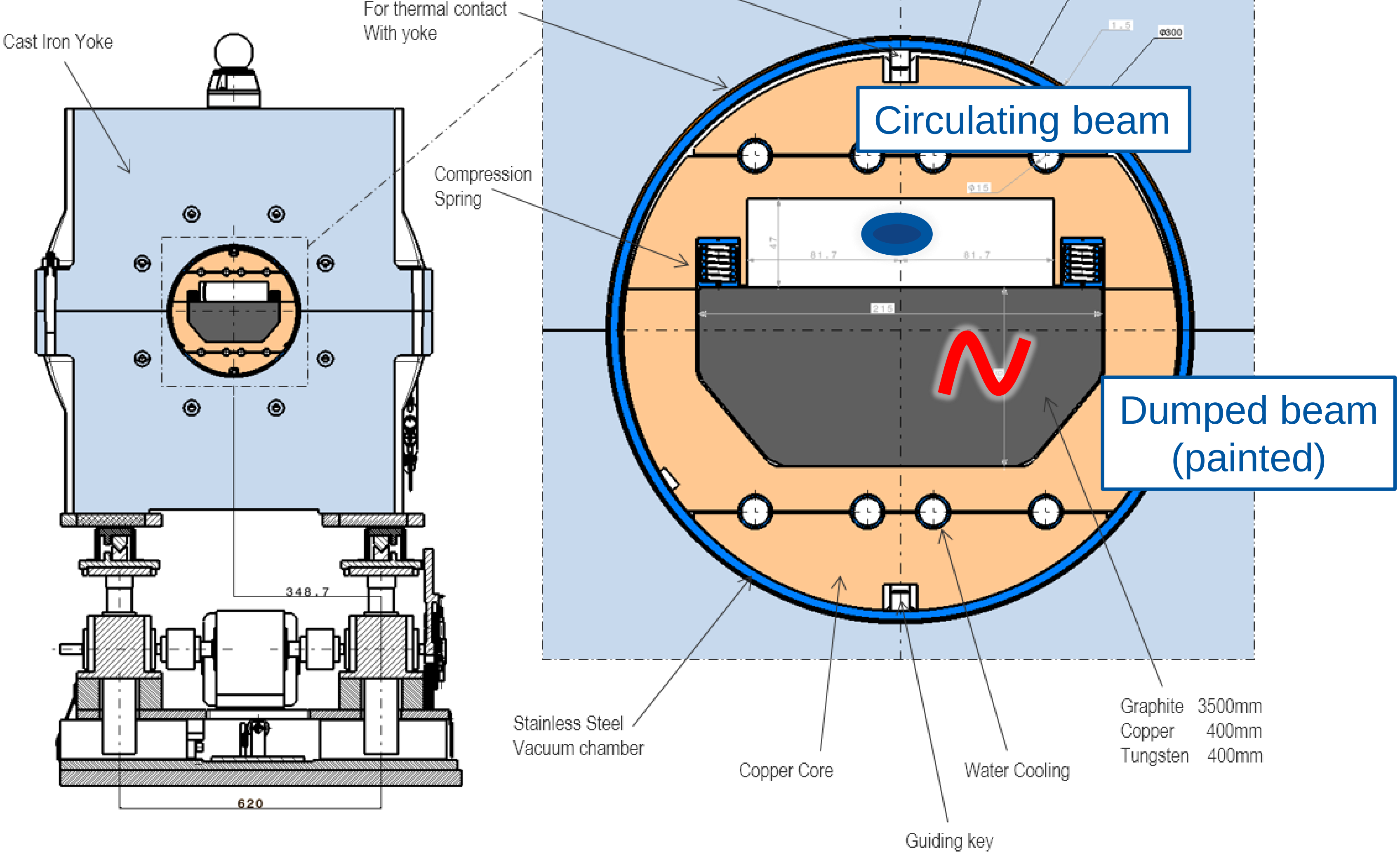


Window: 163.4 x 47 mm

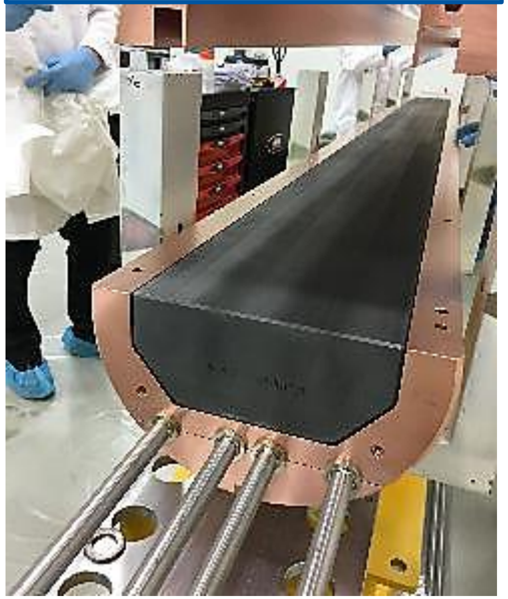
The copper rests in the stainless tube.

Position and Orientation is guaranteed by the keys.

The top gap is 4mm

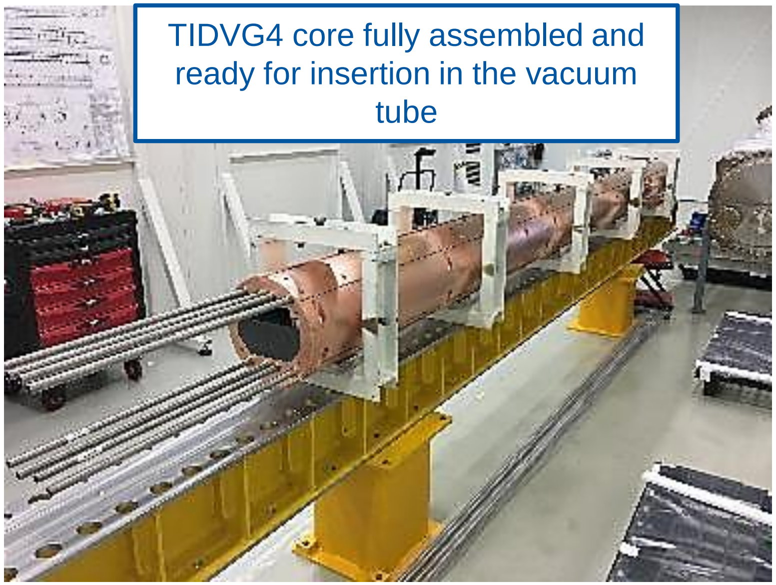


Graphite	3500mm
Copper	400mm
Tungsten	400mm

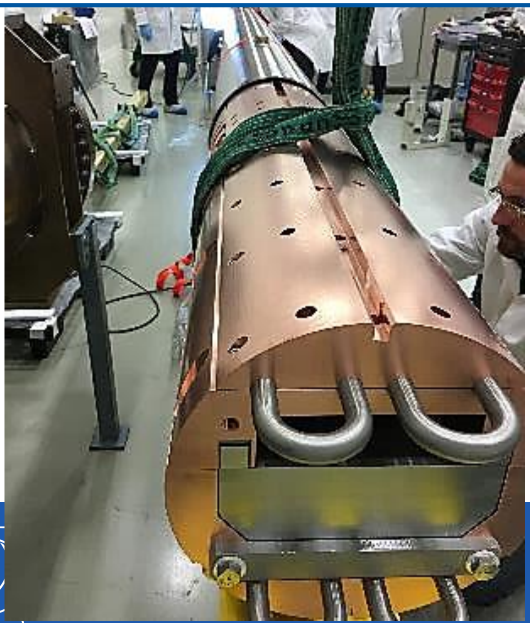


Graphite inside the CuCrZr core

Medium/high-Z absorber

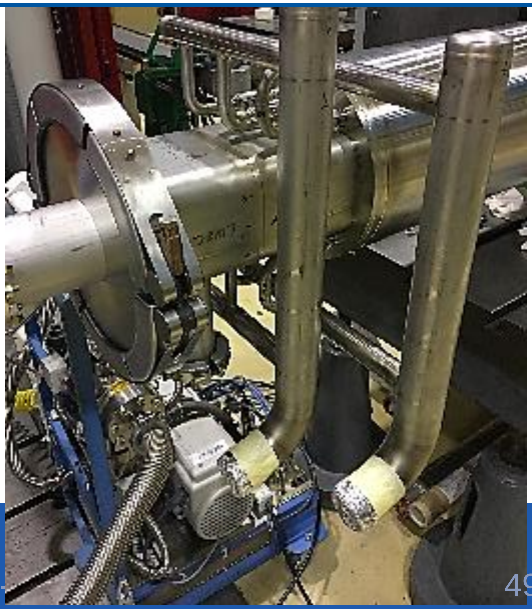


TIDVG4 core fully assembled and ready for insertion in the vacuum tube



TIDVG4 core being pulled into the vacuum chamber

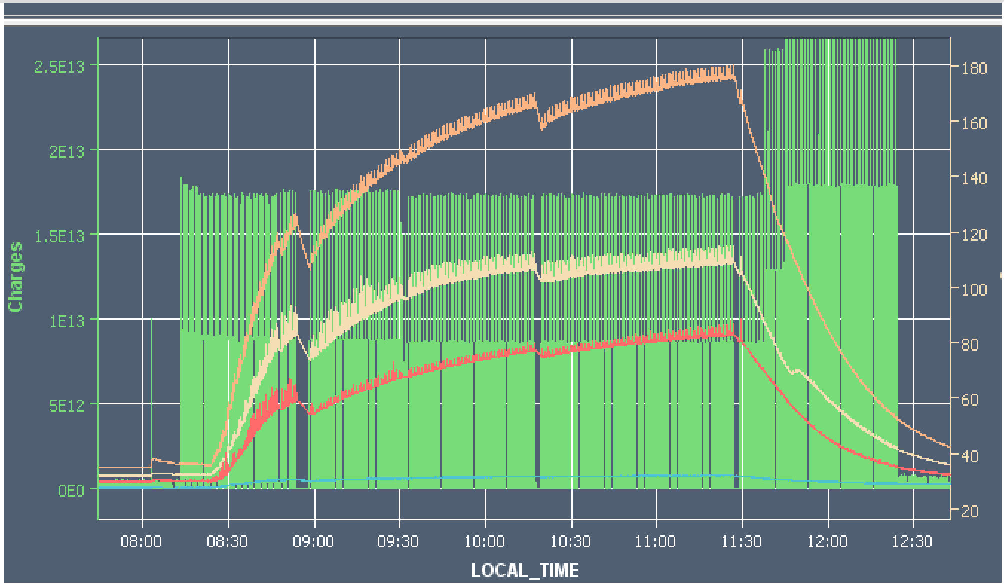
TIDVG4 core fully inserted (upstream)



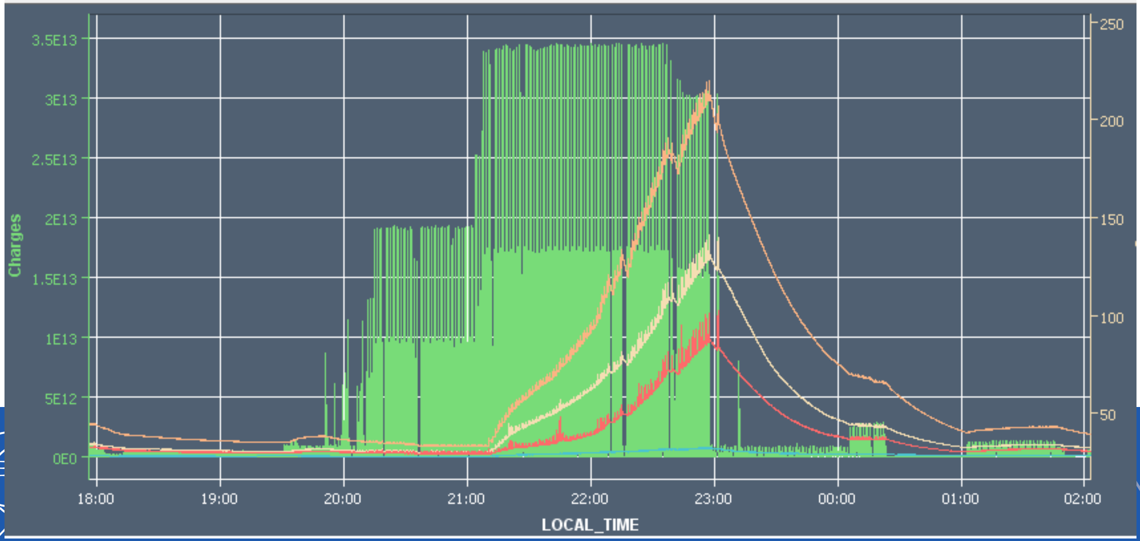
Final leak detection (upstream w/ water manifolds)

TIDVG4 in the SPS tunnel

~Steady state at **144** bunches (25 kW deposited)



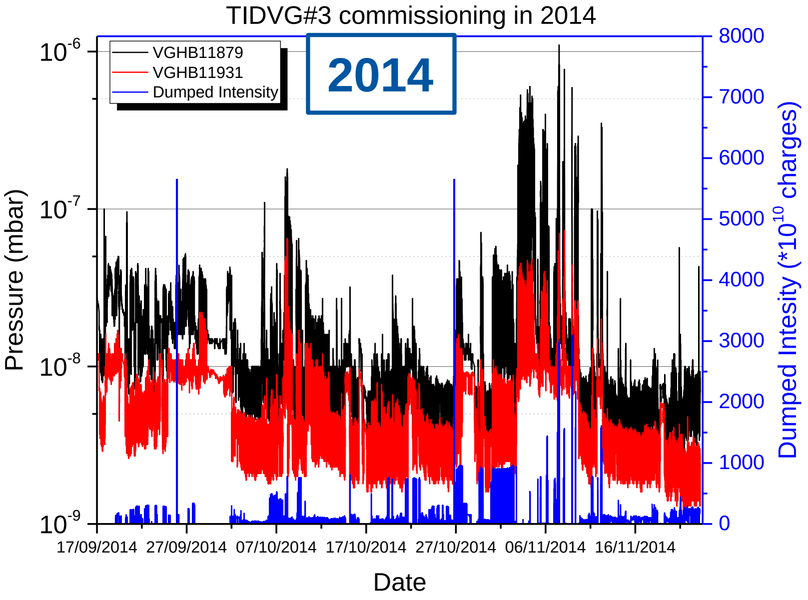
288 bunches (1h30 hours at full power – 55 kW deposited)

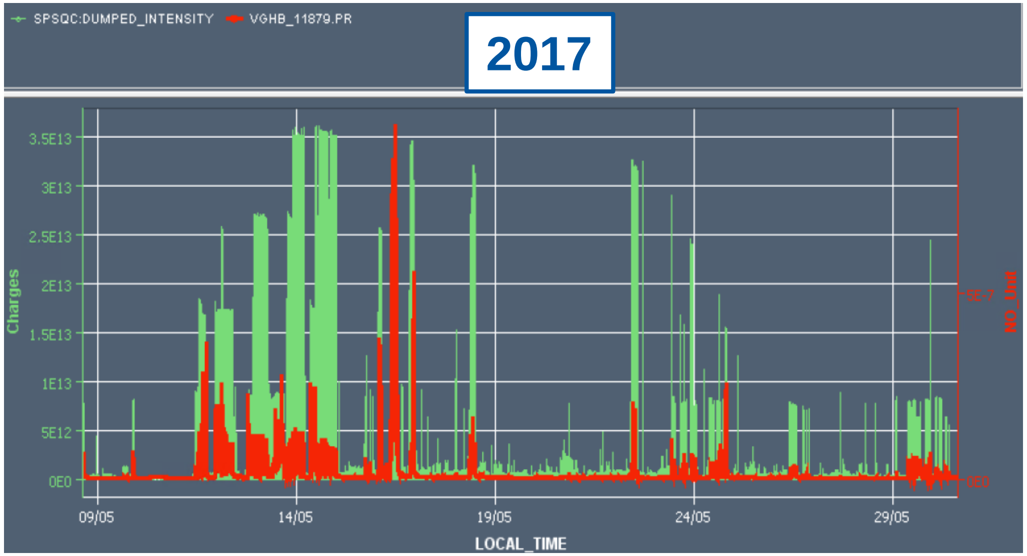


- Operation of the dump successfully so far
- Reach up to almost nominal power at **~55 kW** average beam power
- CuCrZr temperature!

UHV and outgassing

- Outgassing at high T is a problem for BIDs operating in UHV due to limits in neighboring sectors (i.e. septa, kickers, etc.)
- Can be “cured” with proper treatment and precautions during assembly and absorber handling

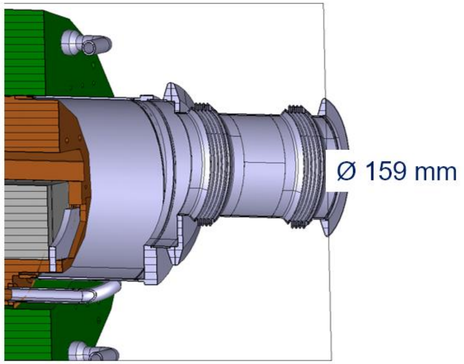




Impedance for TIDVG

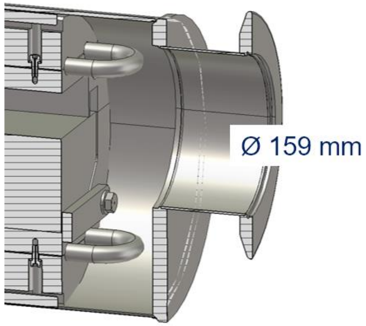
TIDVG #3

- Two-Step transition to DN159

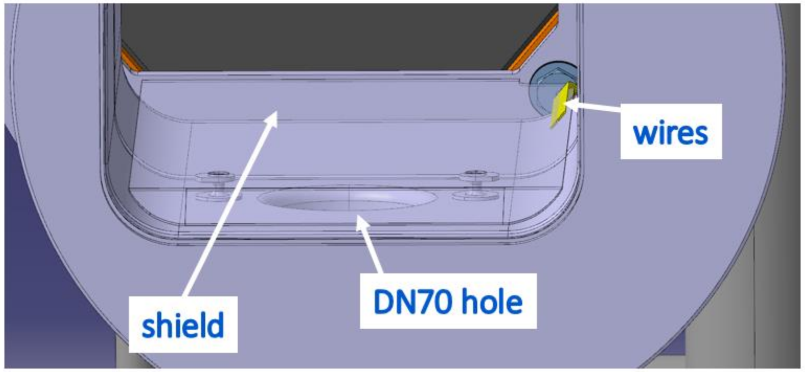


TIDVG #4

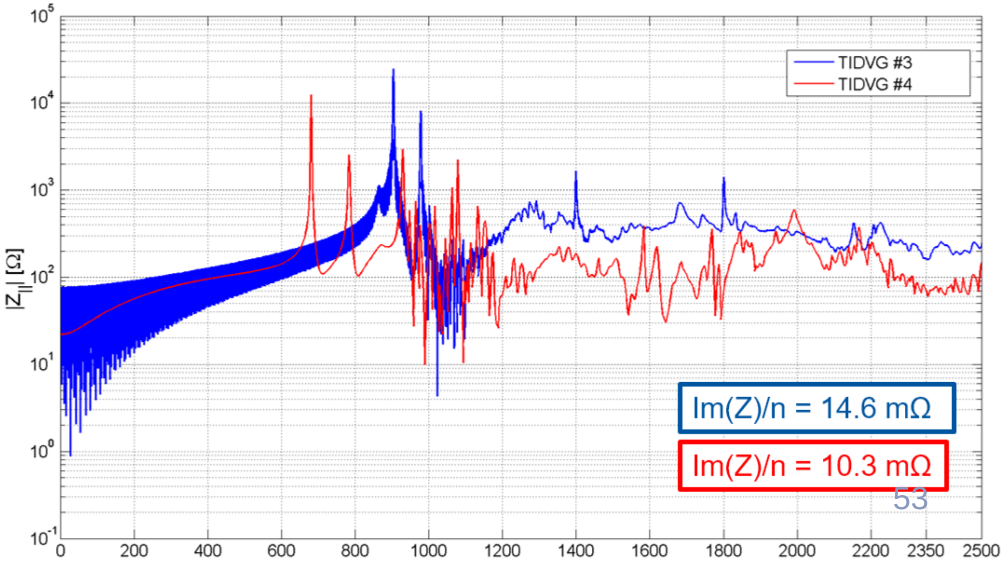
- One-Step transition



- Impedance reduction is critical for achieving high intensity beams with low emittances



Wake Field Simulation Results



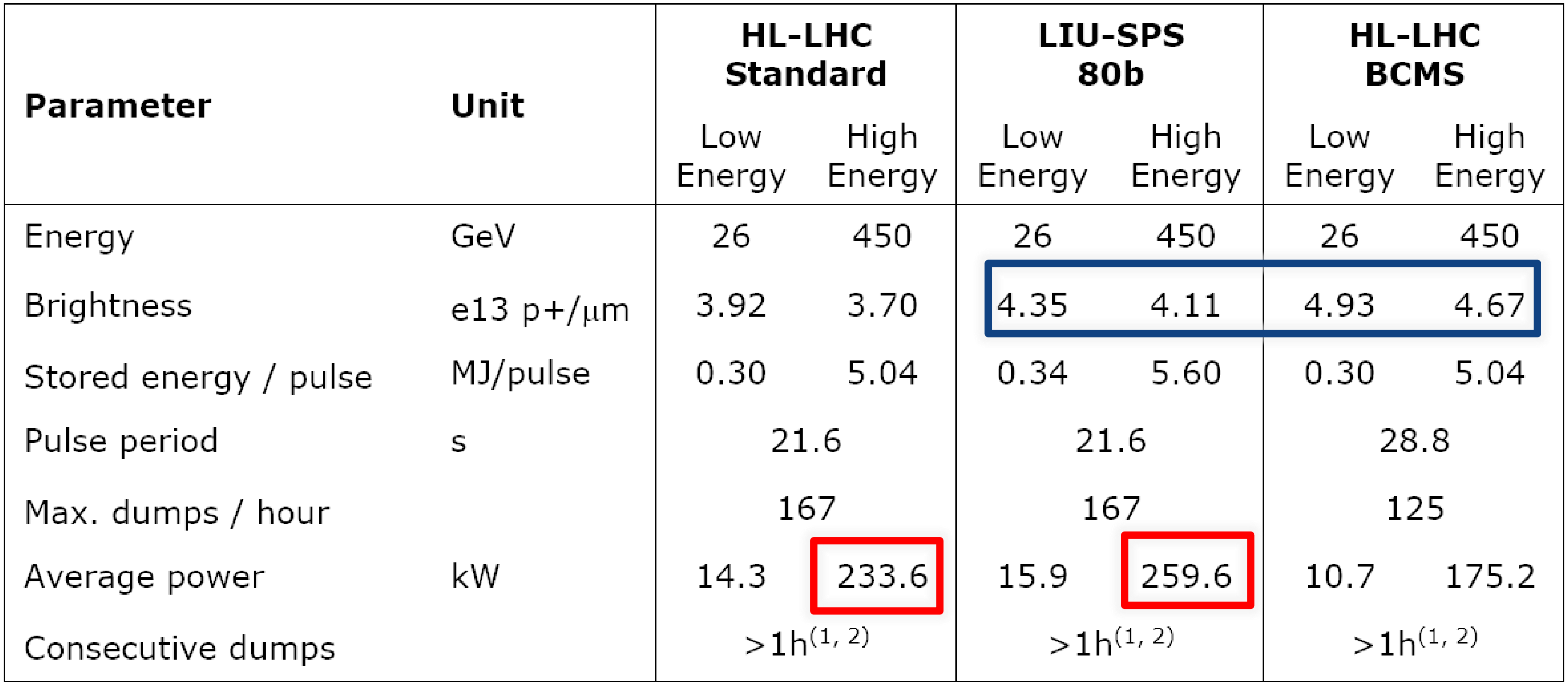
Im(Z)/n = 14.6 mΩ

Im(Z)/n = 10.3 mΩ

TIDVG5 beam loads (I/II)

We are currently designing an upgraded version for LIU Project

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



Parameter	Unit	HL-LHC Standard		LIU-SPS 80b		HL-LHC BCMS	
		Low Energy	High Energy	Low Energy	High Energy	Low Energy	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)	

TIDVG5 beam loads (II/II)

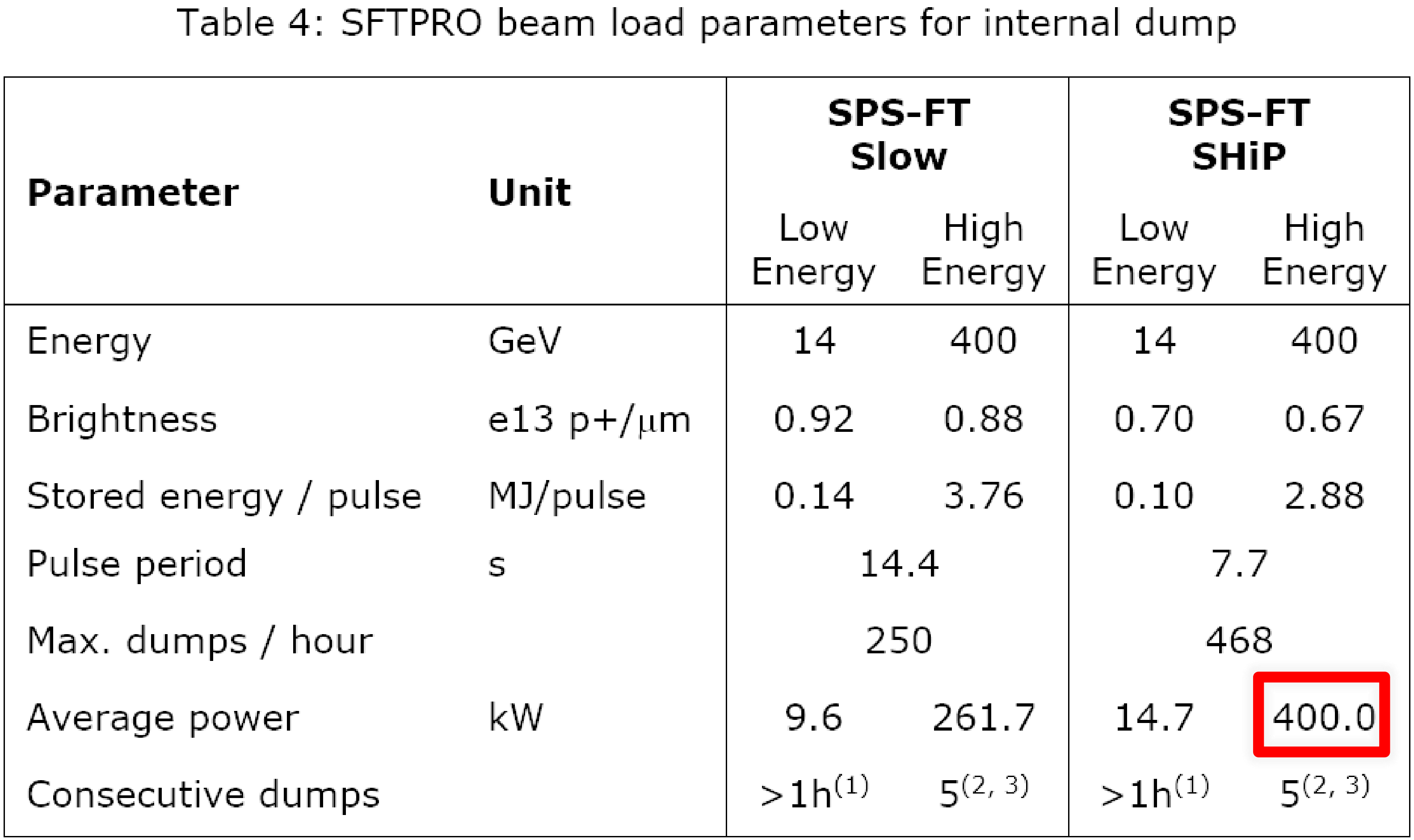
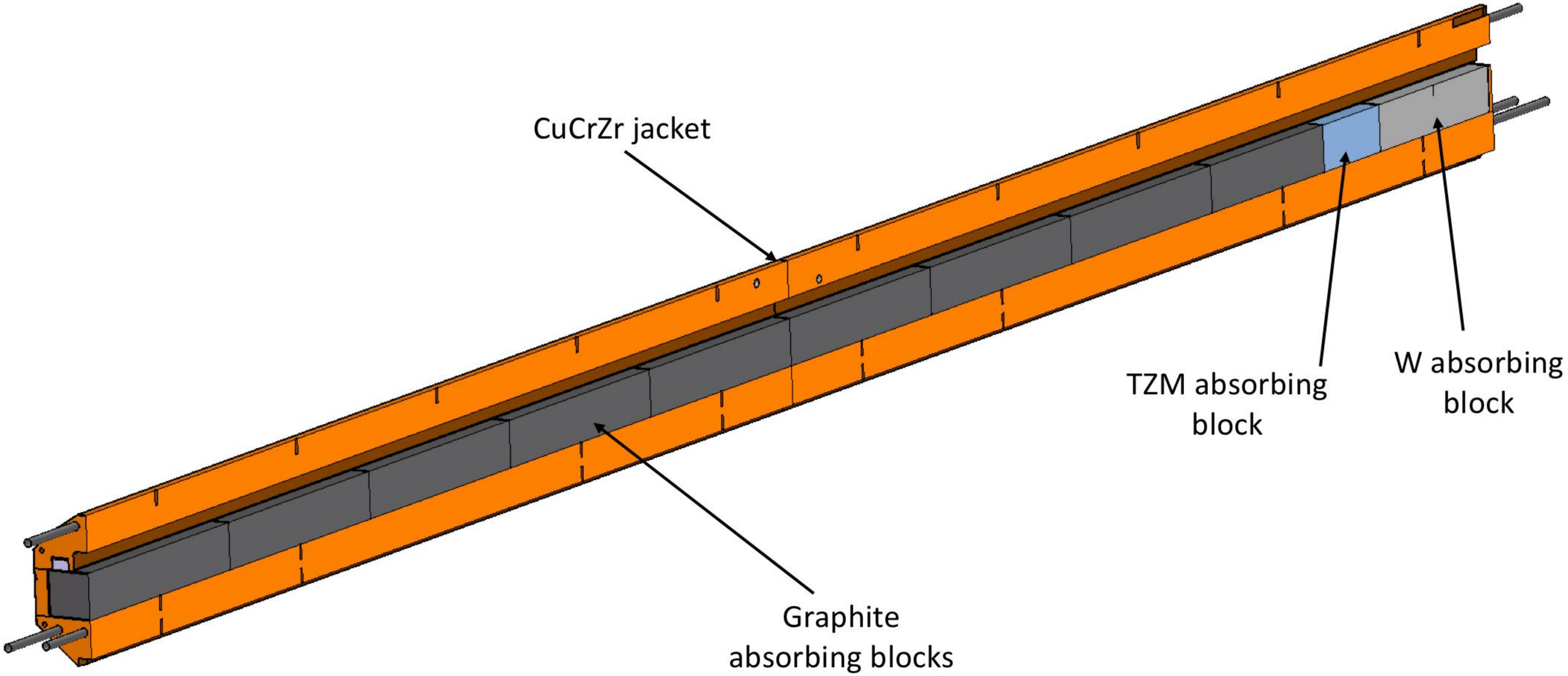


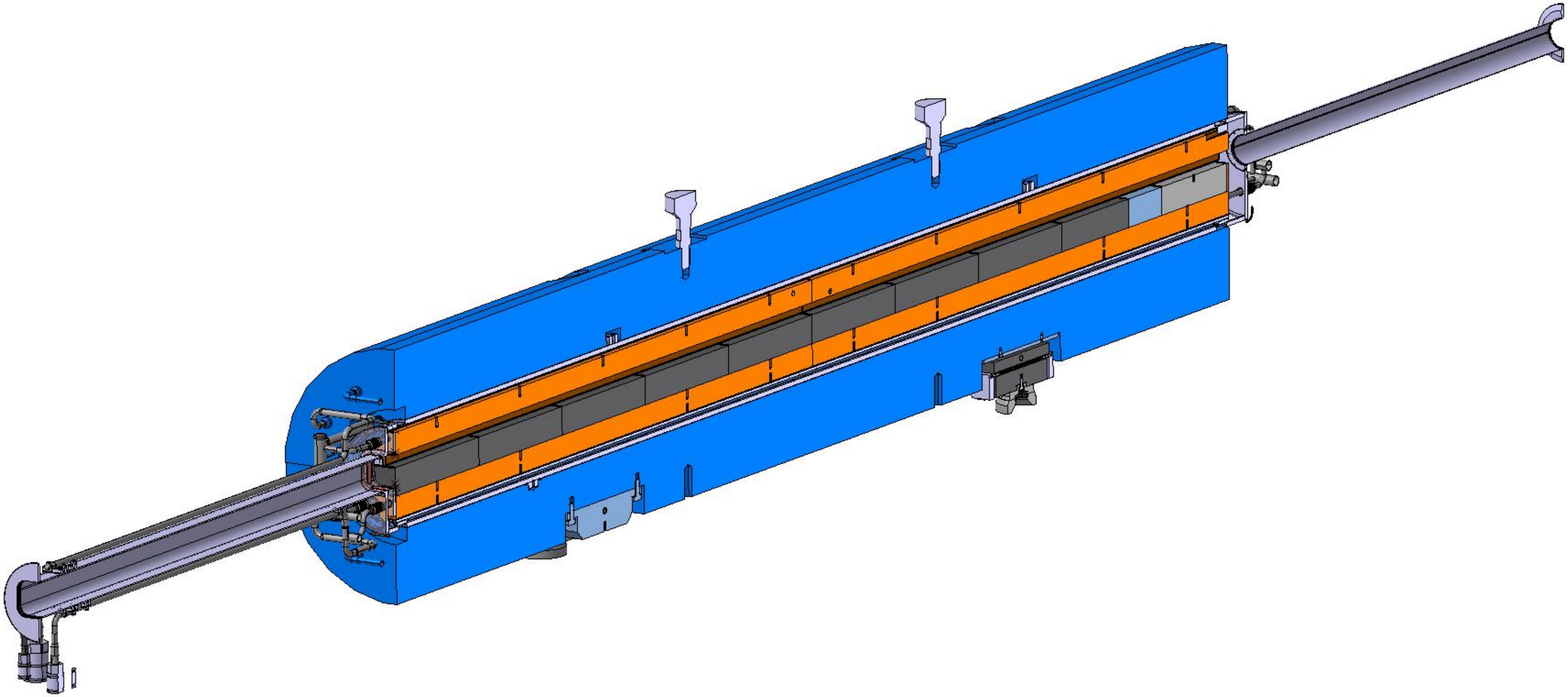
Table 4: SFTPRO beam load parameters for internal dump

Parameter	**Unit**	**SPS-FT Slow**		**SPS-FT SHiP**	
		Low Energy	High Energy	Low Energy	High Energy
Energy	GeV	14	400	14	400
Brightness	e13 p+/μm	0.92	0.88	0.70	0.67
Stored energy / pulse	MJ/pulse	0.14	3.76	0.10	2.88
Pulse period	s	14.4		7.7	
Max. dumps / hour		250		468	
Average power	kW	9.6	261.7	14.7	400.0
Consecutive dumps		>1h$^{(1)}$	5$^{(2, 3)}$	>1h$^{(1)}$	5$^{(2, 3)}$

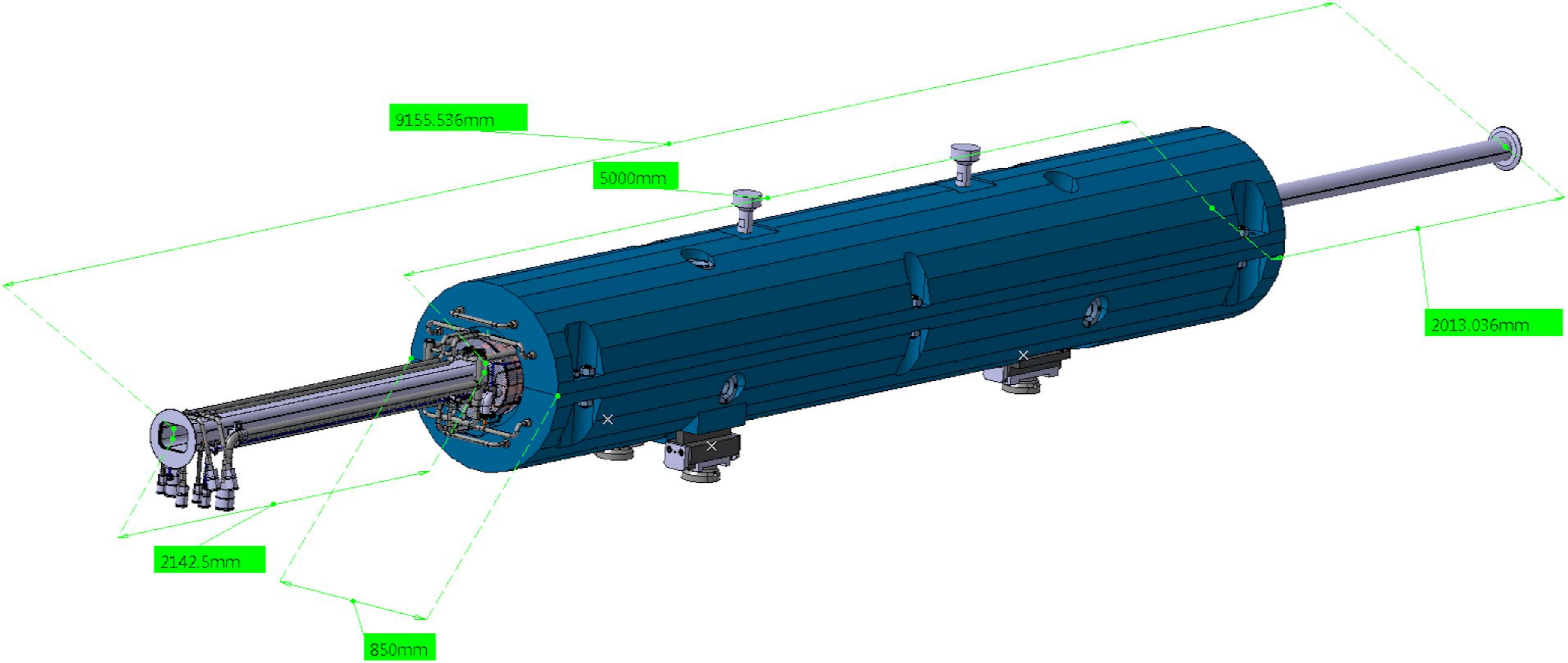
TIDVG5


CuCrZr jacket
TZM absorbing block
W absorbing block
Graphite absorbing blocks

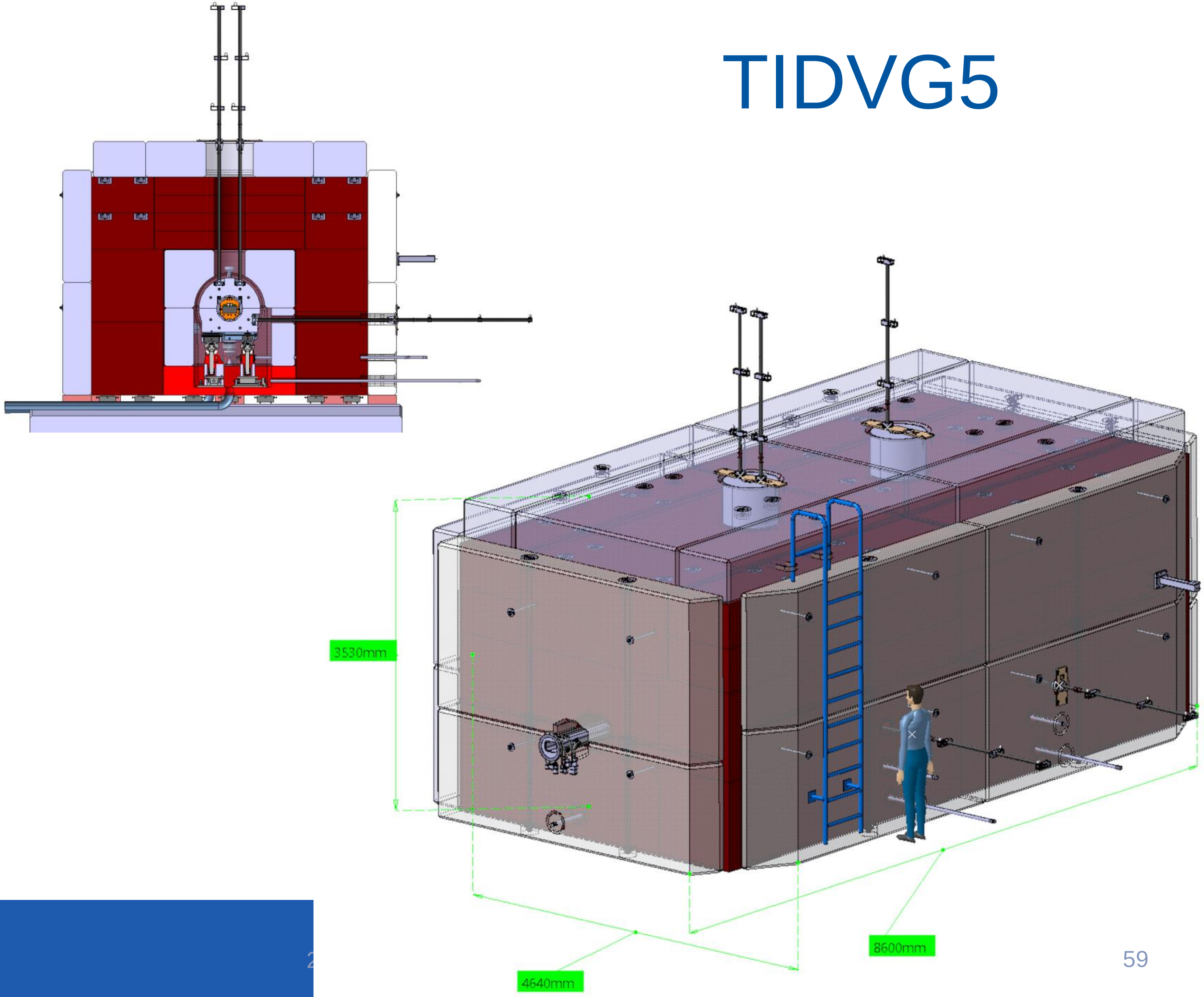
TIDVG5



TIDVG5



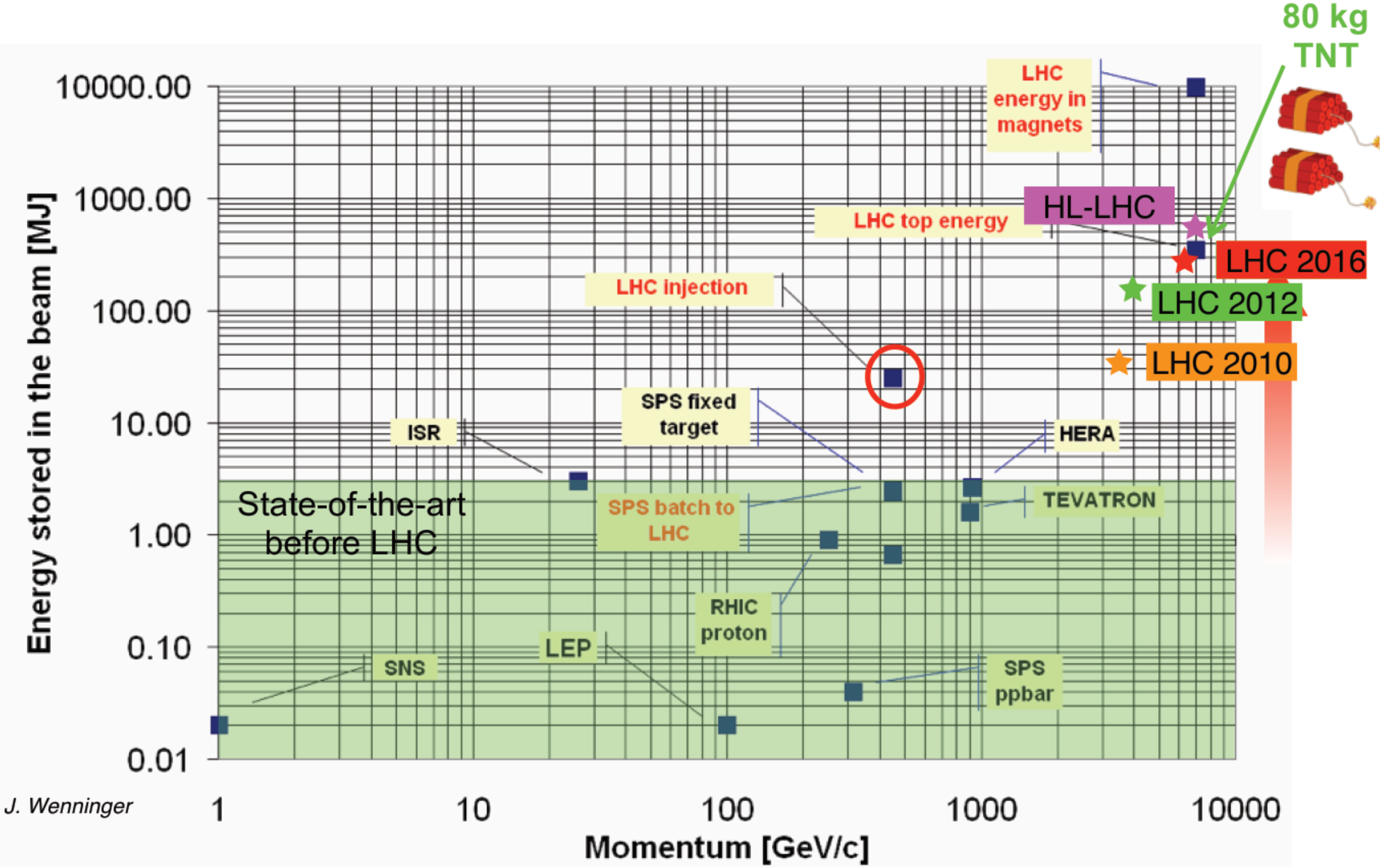
TIDVG5



Roles of collimation systems

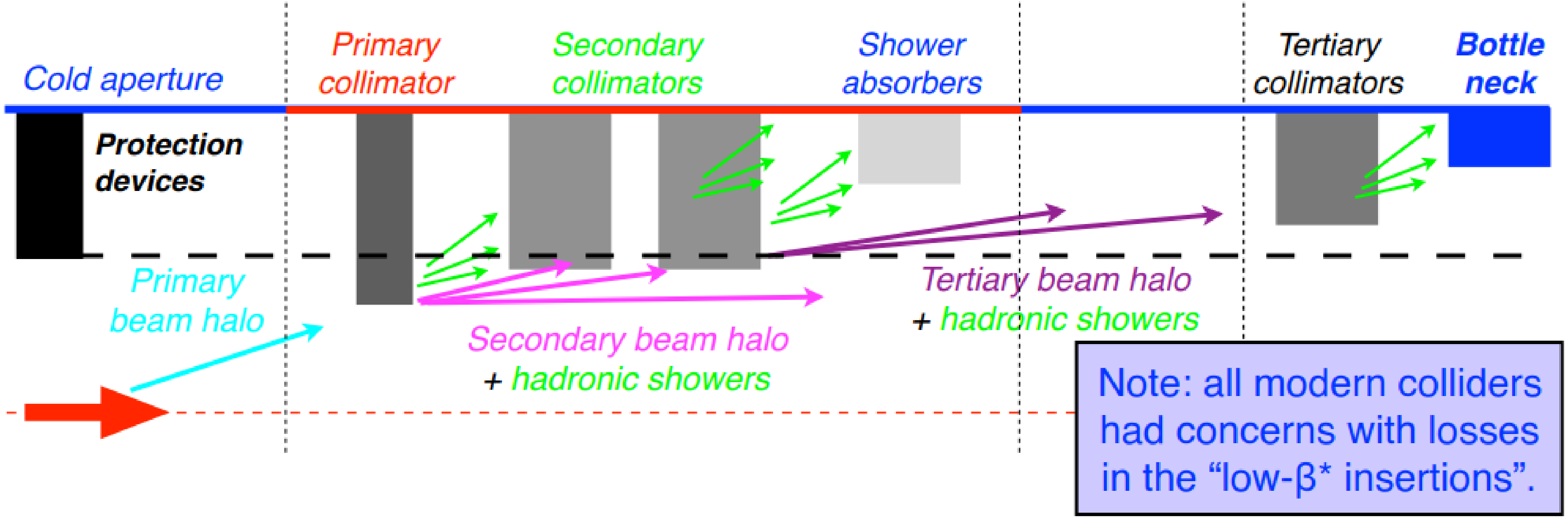
- **Halo cleaning** vs. quench limits (SC machines)
- Passive **machine protection**
- **Concentration of losses/activation** in controlled areas
- **Reduction total** dose on accelerator equipment
- **Cleaning physics debris** (for colliders)
- Optimise **background** in the experiments
- Beam tail/halo **scraping**, **halo diagnostics**

Stored energy challenges



J. Wenninger

Multi-stage cleaning



Note: all modern colliders had concerns with losses in the "low-β* insertions".

Optimum performance relies on respecting a *hierarchy*.

Tight tolerance to respect hierarchy with small spot size!
Typical: ~200 microns at 7 TeV.

The (small) machine aperture sets the scale.

Typical values: ~10 sigma aperture
Collimators to be set at about **6 beam sigmas.**

S. Redaelli

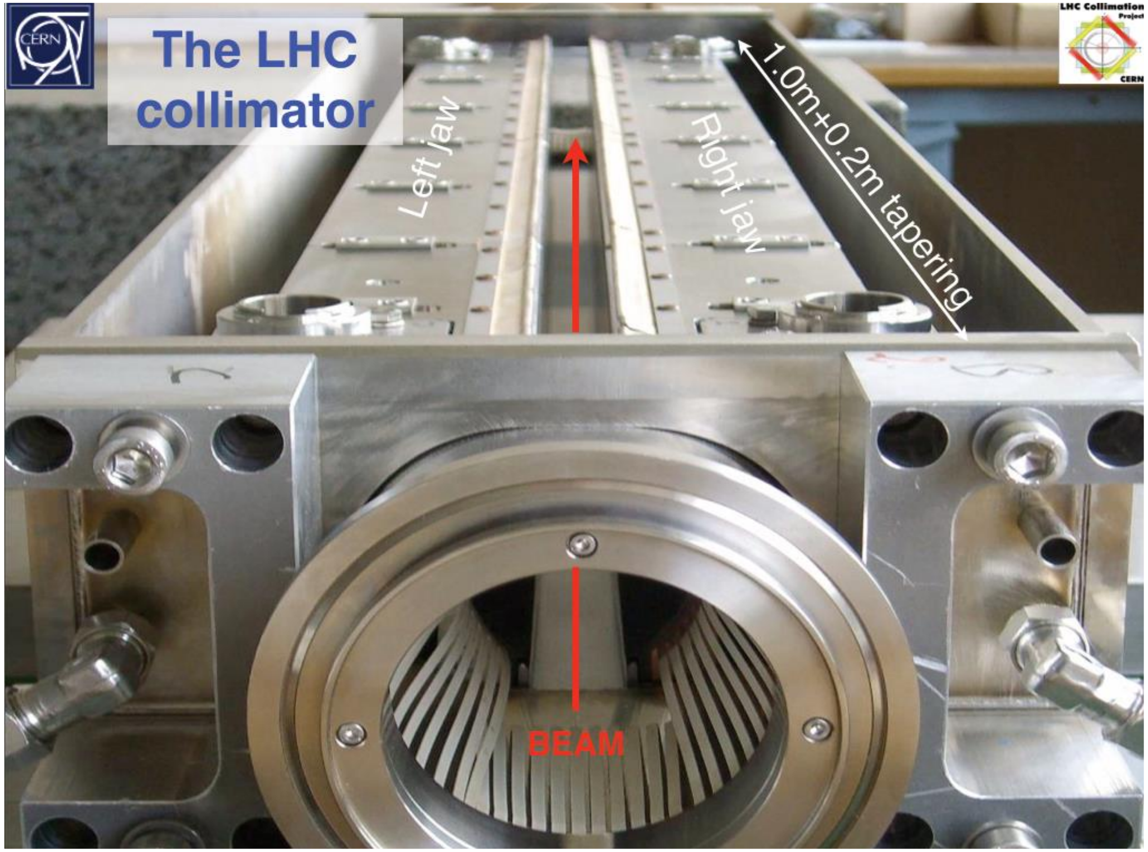
Run-II collimation system

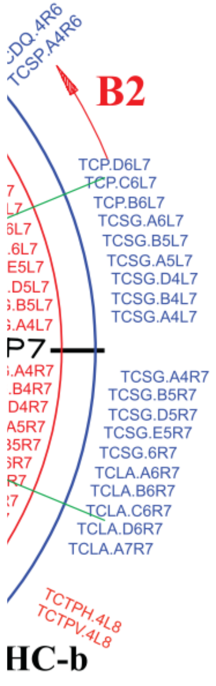
Dedicate
(IR7) an
cleaning

Cleaning
in all exp

Physics
in the hig

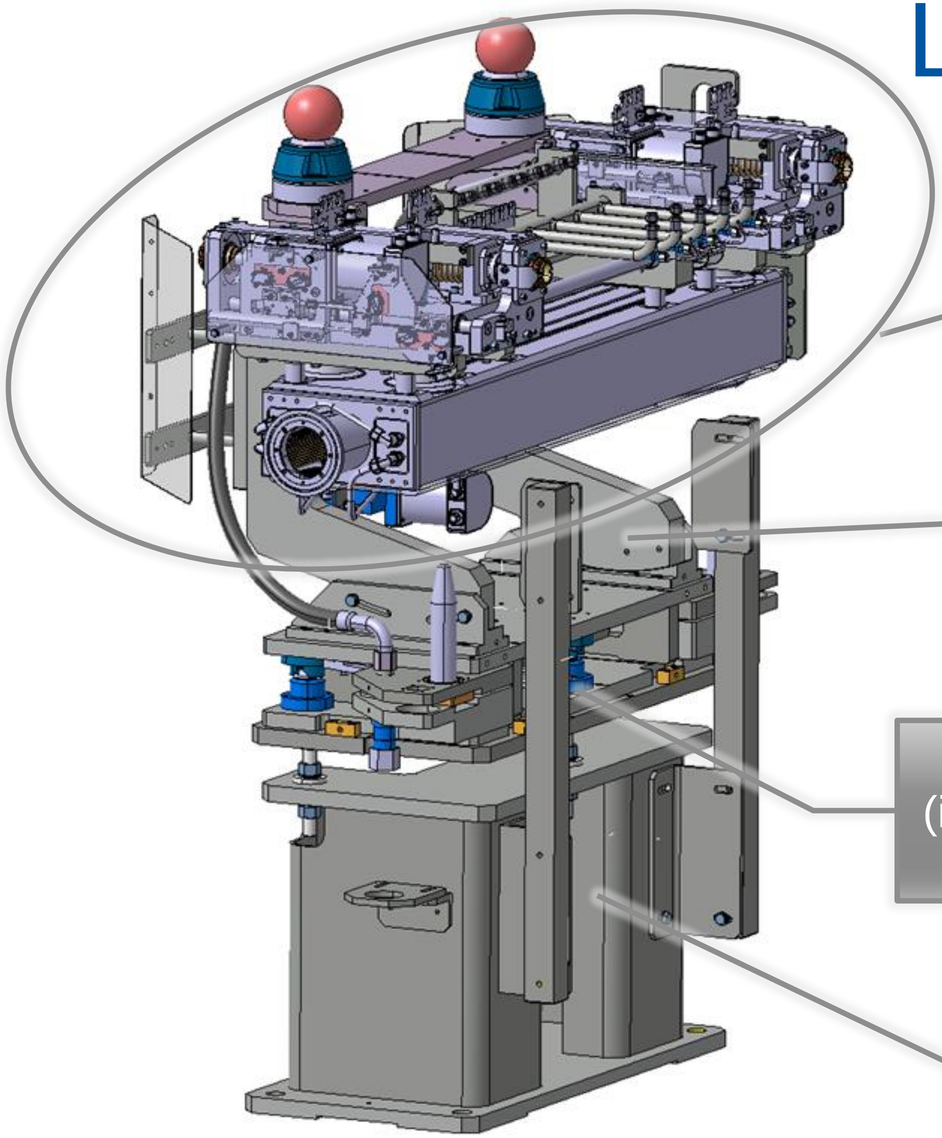
**Total of
collima
(108 [wa**





S. Redaelli

LHC collimators



Collimator assembly

Adjustable (Horizontal) Stand

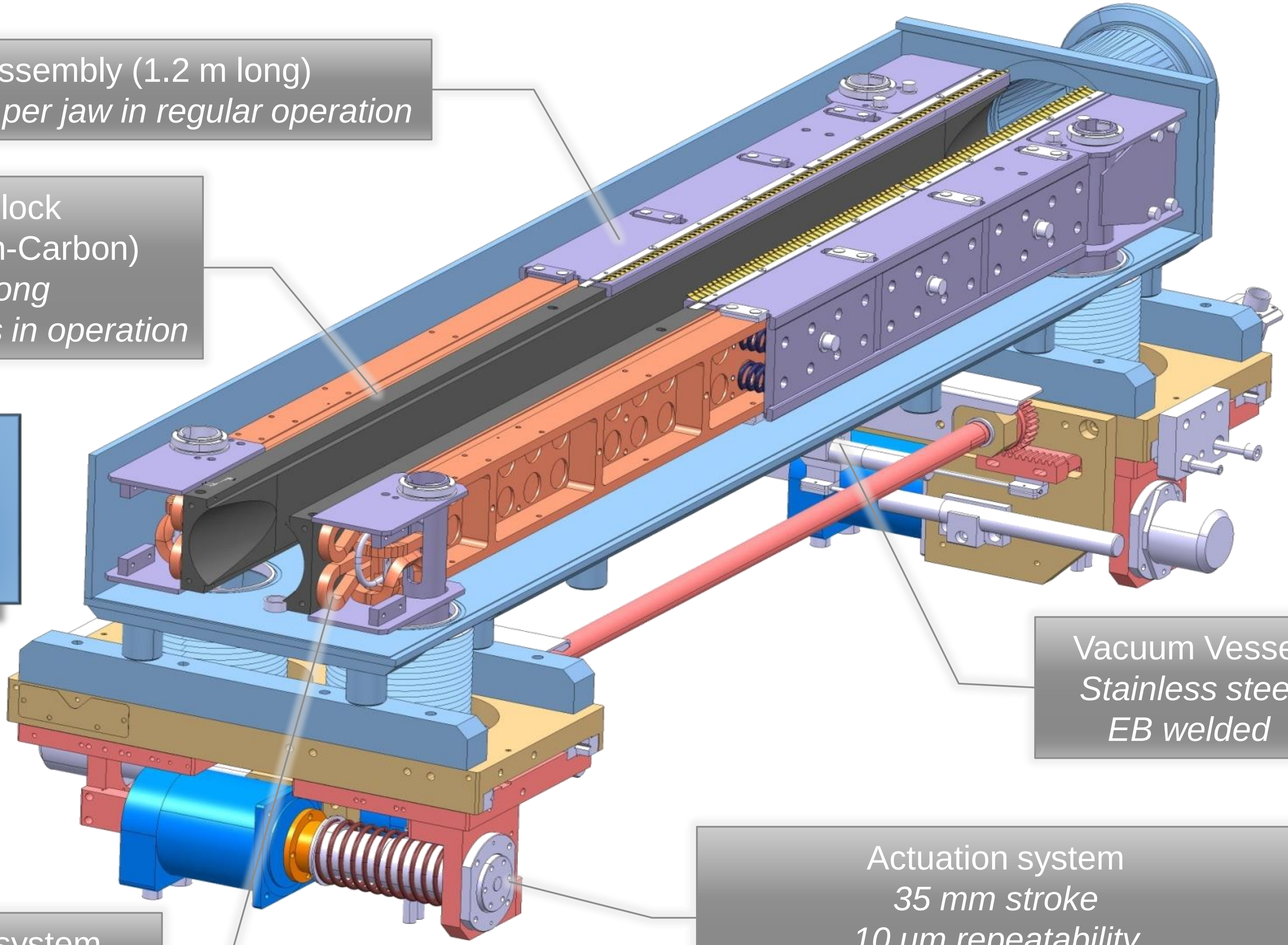
(Al Alloy)

Plug-in system (integrates mechanical, hydraulic and electrical quick connections)

Fixed Support

(Stainless Steel)

Secondary Collimator (TCSG)



Jaw Assembly (1.2 m long)
Up to 15 kW per jaw in regular operation

Jaw Block
(2D Carbon-Carbon)
1 m long
40 µm flatness in operation

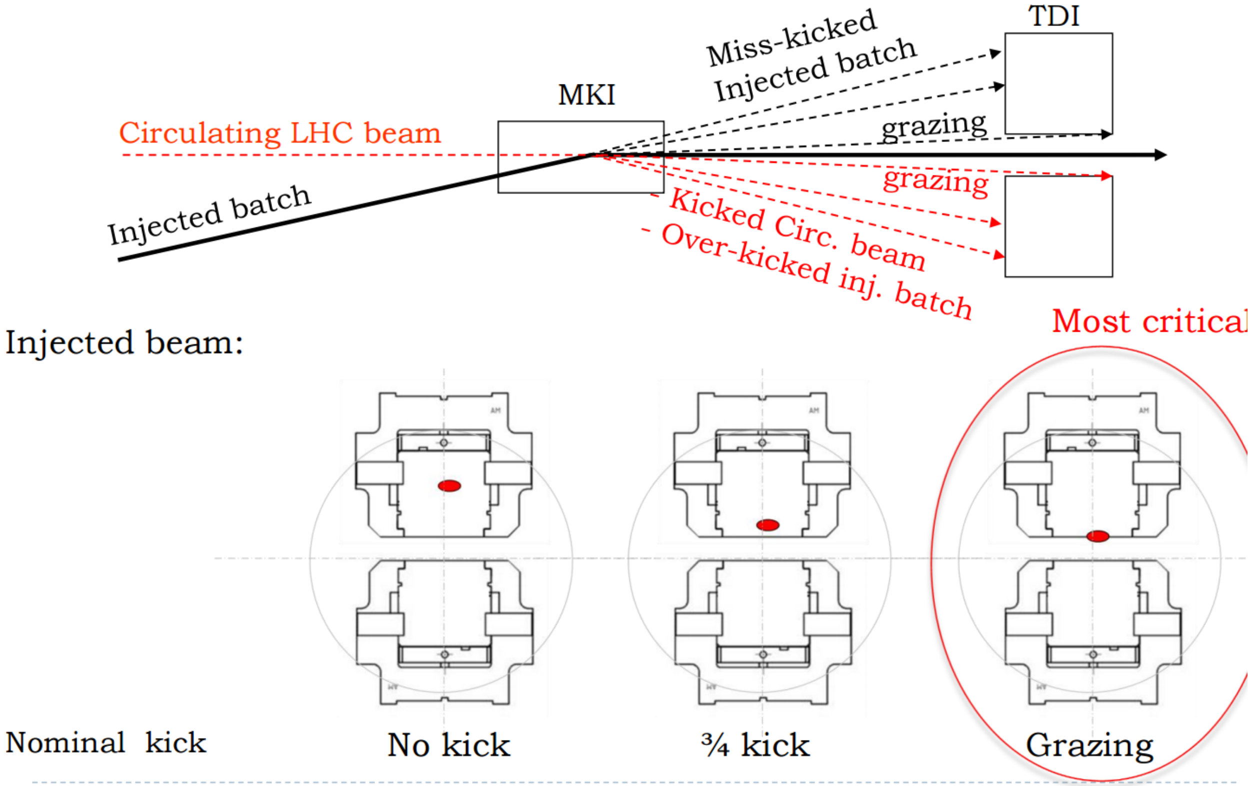
Vacuum Vessel
Stainless steel
EB welded

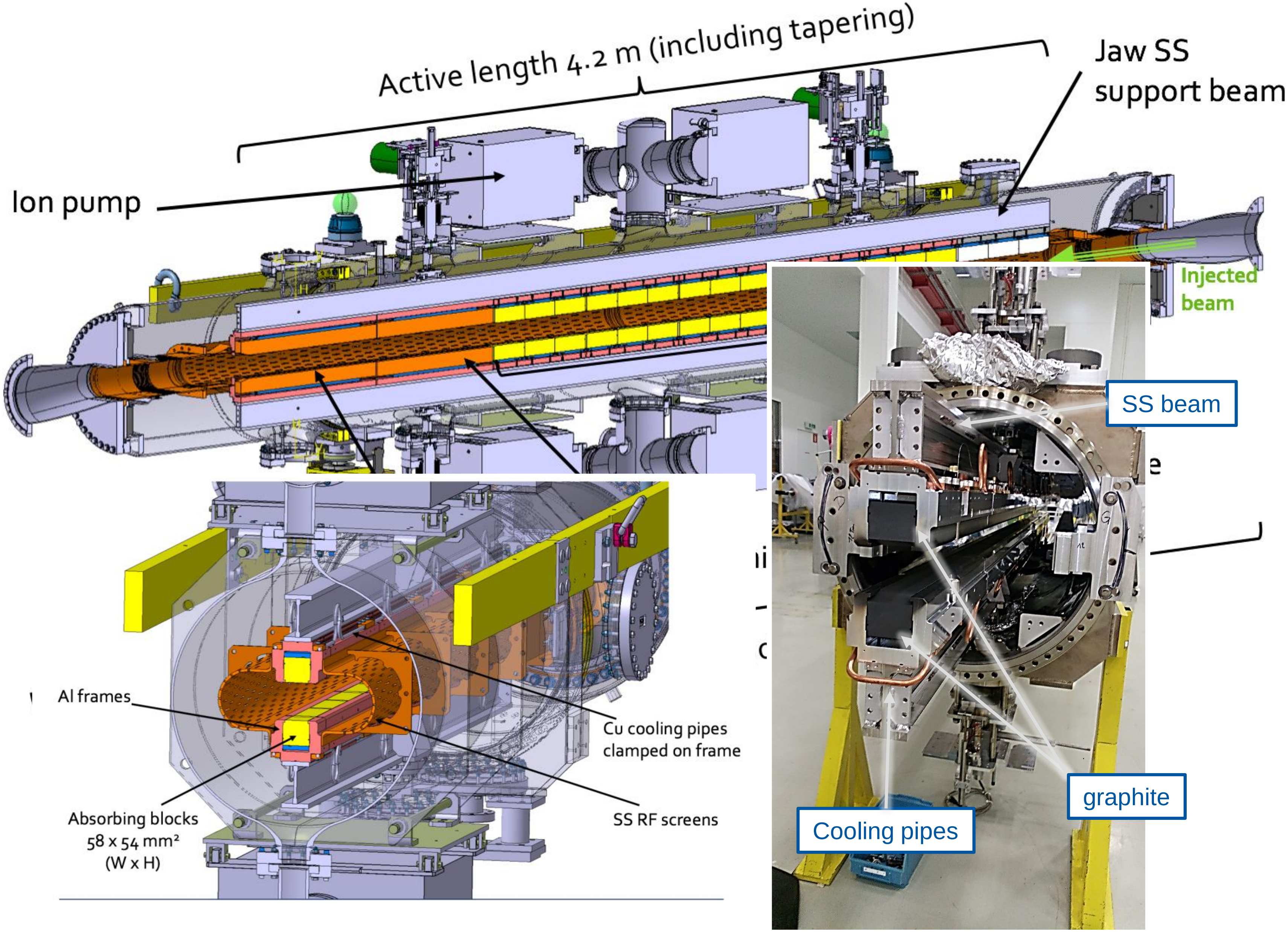
Actuation system
35 mm stroke
10 um repeatability
High radiation compliant

Jaw Cooling system
Cu-Ni Pipes

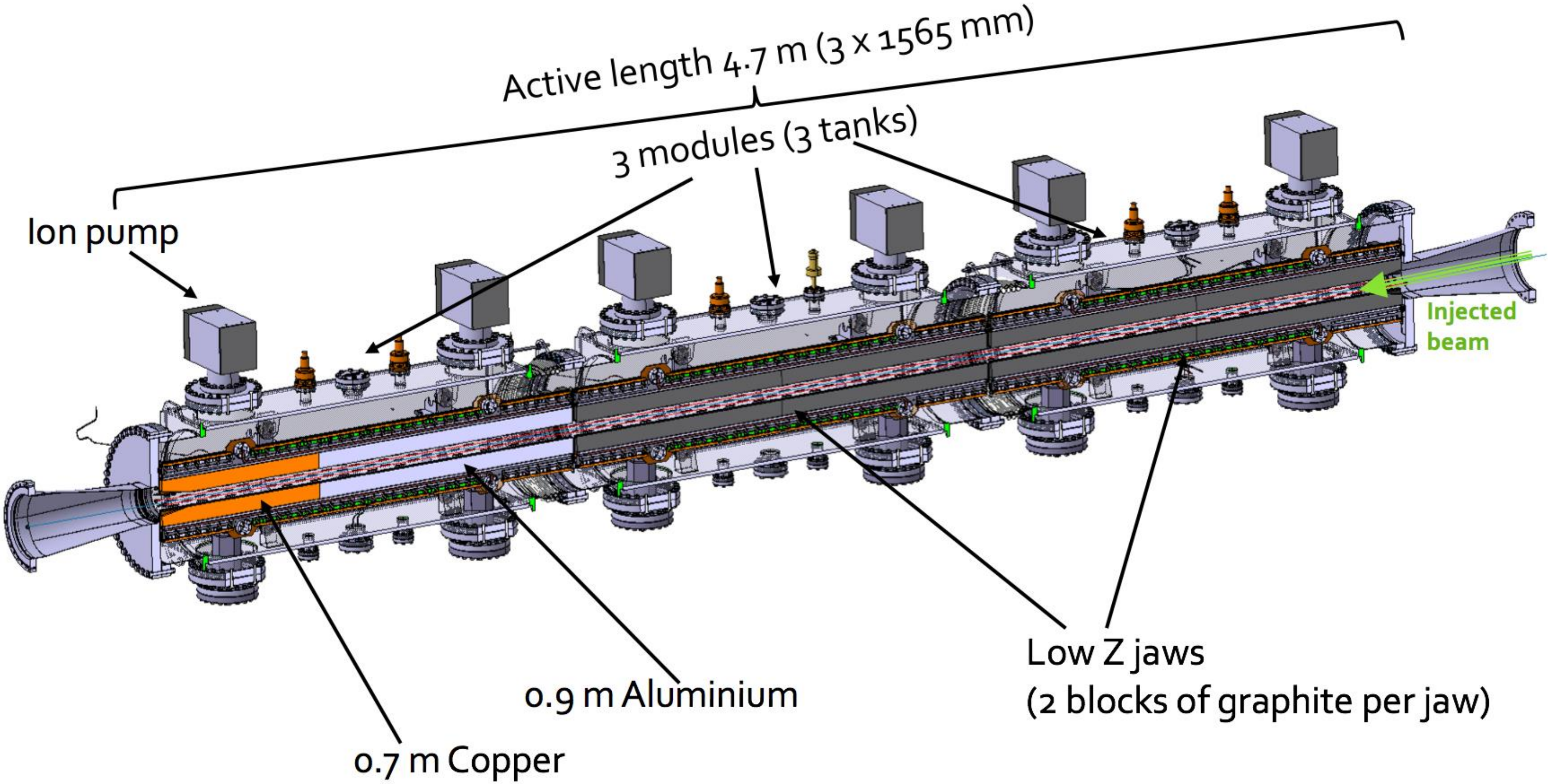
LHC injection absorber

- Located and the end of the injection line from SPS to LHC
- Must absorb mis-injected beam before it could damage SC quadrupoles and experiment (ALICE/LHCb)

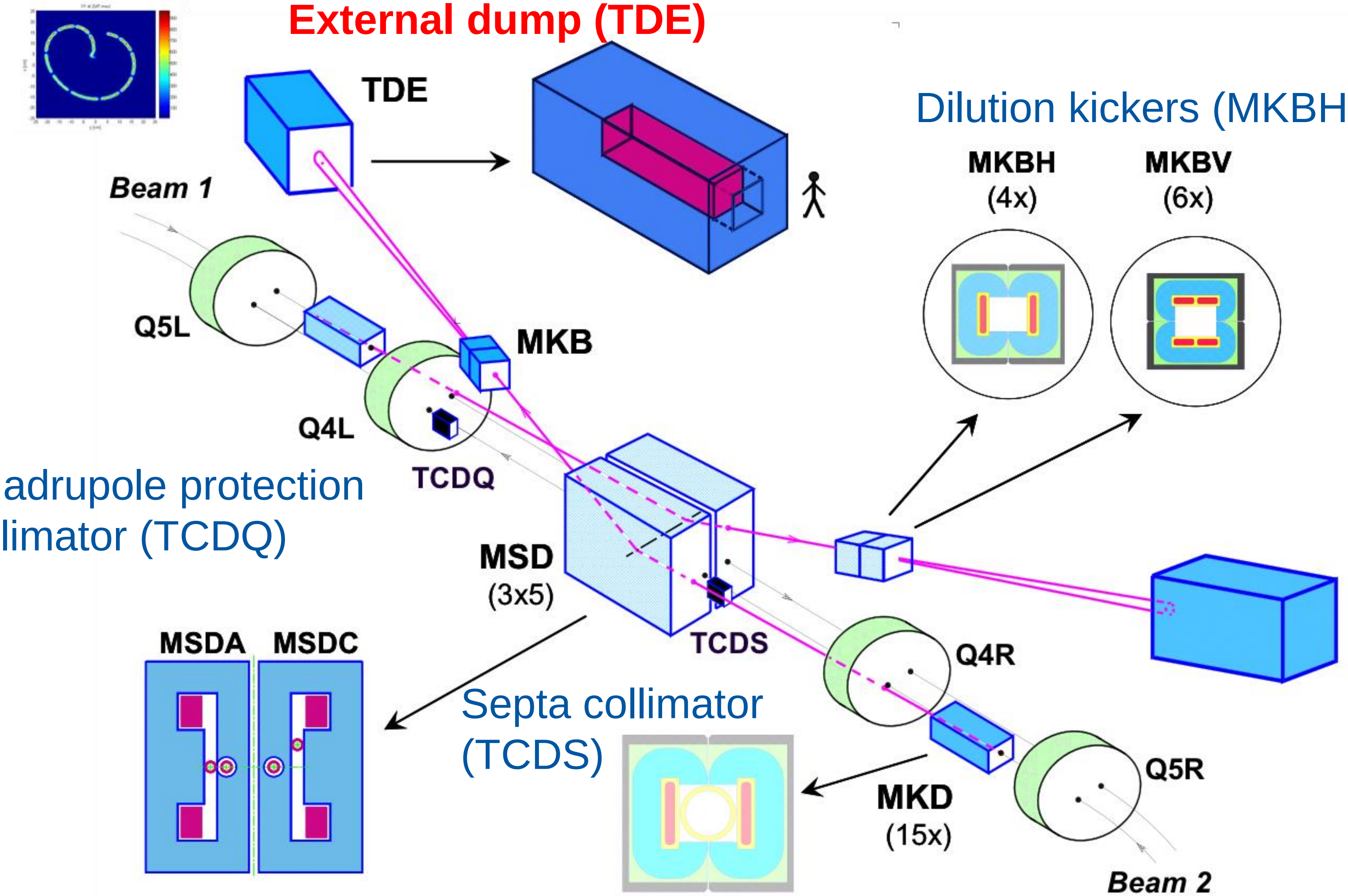



Active length 4.2 m (including tapering)
Jaw SS support beam
Ion pump
Injected beam
Al frames
Cu cooling pipes clamped on frame
Absorbing blocks 58 x 54 mm² (W x H)
SS RF screens
SS beam
graphite
Cooling pipes

TDIS upgrade for the HL-LHC Project (currently under construction)



LHC beam dump system (LBDS)



External dump (TDE)

Dilution kickers (MKBH/V)

Quadrupole protection collimator (TCDQ)

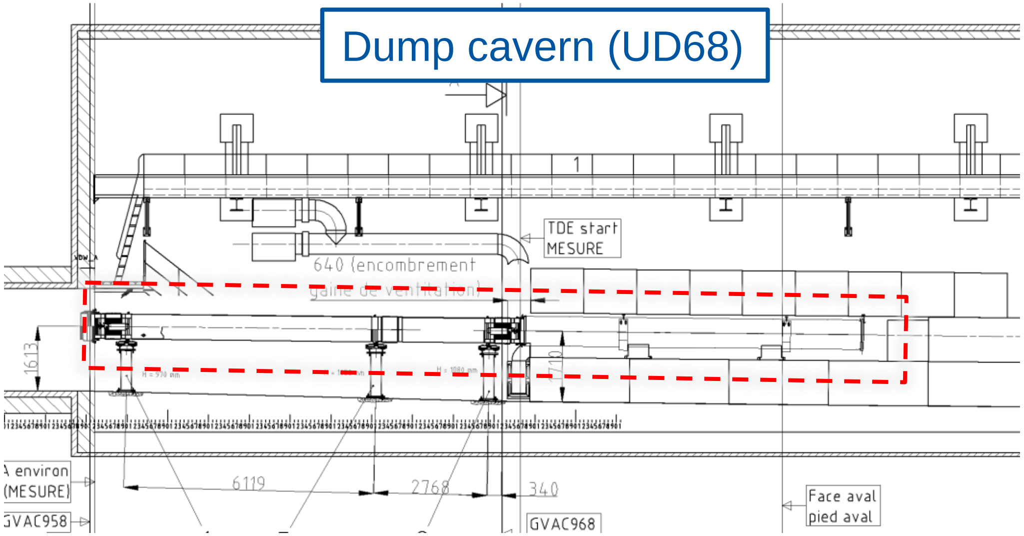
Septa collimator (TCDS)

Extraction septa (MSD)

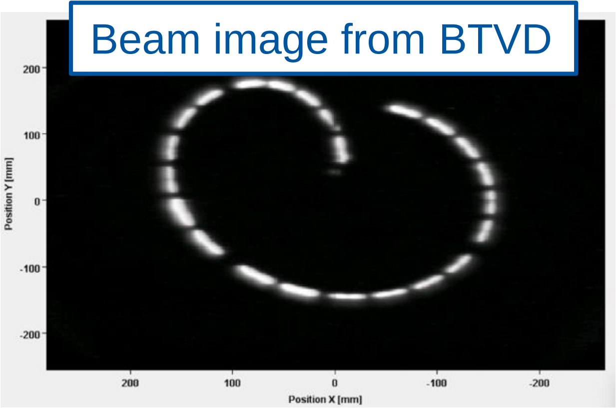
Extraction kickers (MKD)

LHC dump area design

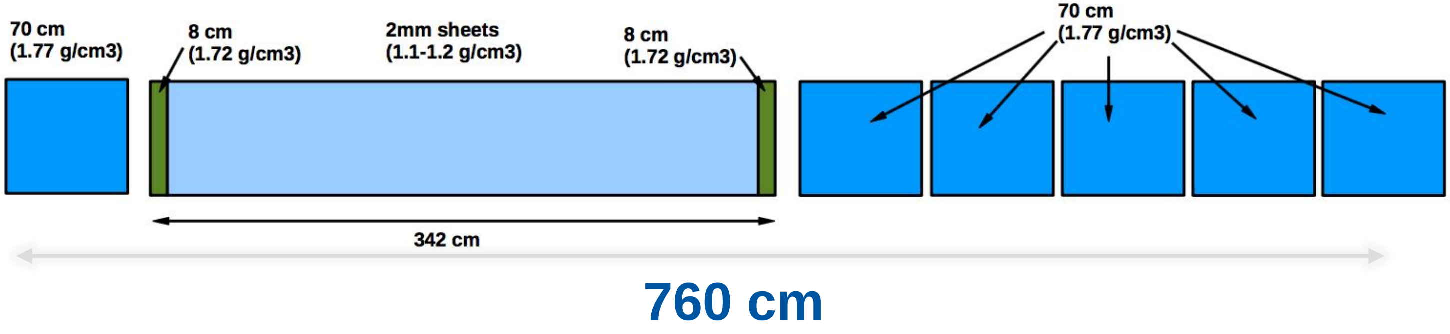
- Dumps installed in dedicated caverns at the end of a 900 m long extraction cavern
- Graphite core installed in a nitrogen volume at ~1.2 bar overpressure to avoid graphite oxidation
- Beam parameters: 7 TeV, 3.8×10^{14} p/pulse, **~400 MJ/pulse (600 MJ/pulse** w/ HL-LHC**)**, diluted


Dump cavern (UD68)

LHC dump core desig


Beam image from BTVD

High and low-density segments:


70 cm (1.77 g/cm3)

8 cm (1.72 g/cm3)

2mm sheets (1.1-1.2 g/cm3)

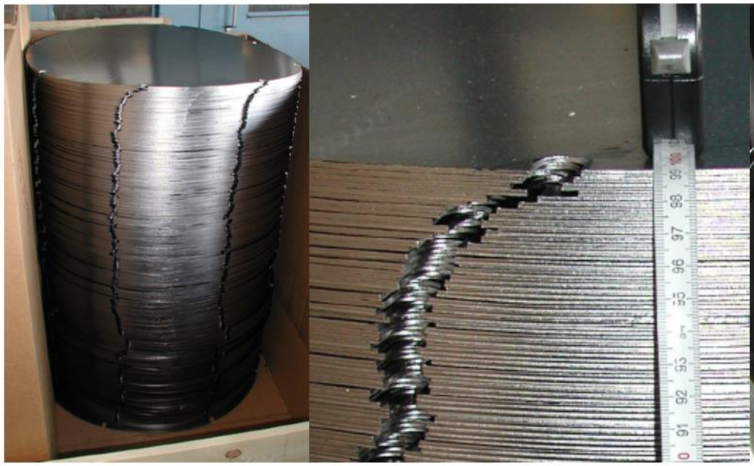
8 cm (1.72 g/cm3)

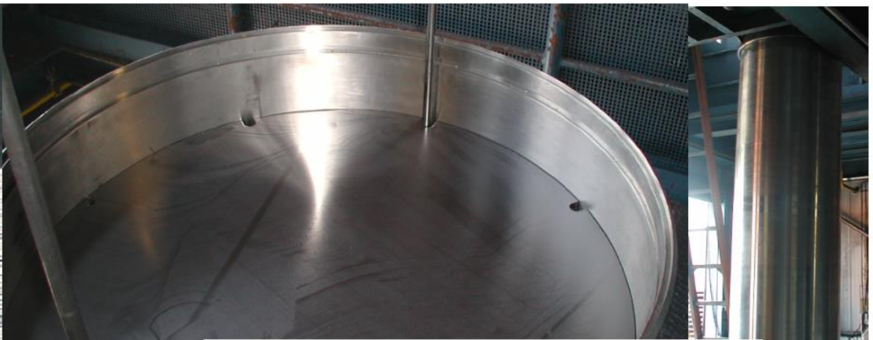
70 cm (1.77 g/cm3)

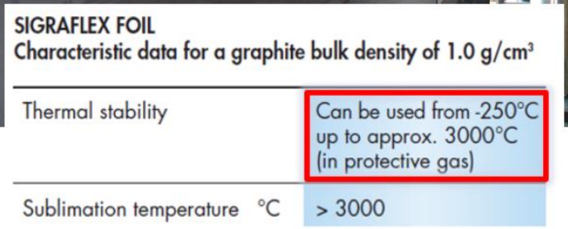
342 cm

760 cm

Low-density flexible Graphite sheets:






SIGRAFLEX FOIL

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

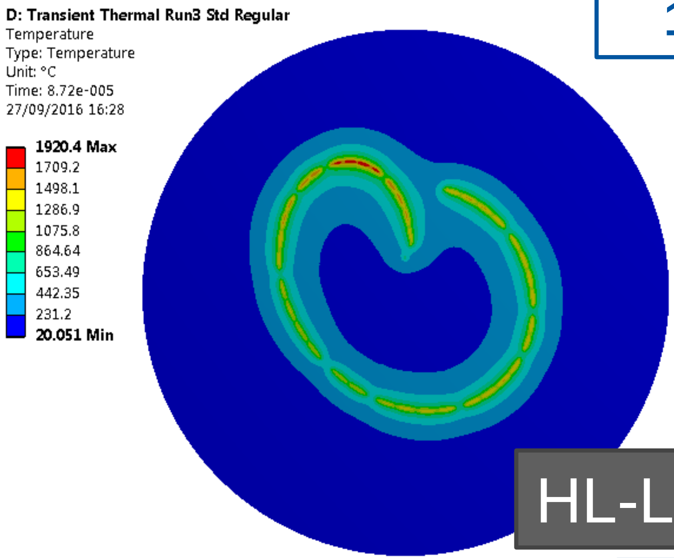
Thermal stability		Can be used from -250°C up to approx. 3000°C (in protective gas)
Sublimation temperature	°C	> 3000

HL-LHC performances

Sigraflex – 1.2 g/cm^3

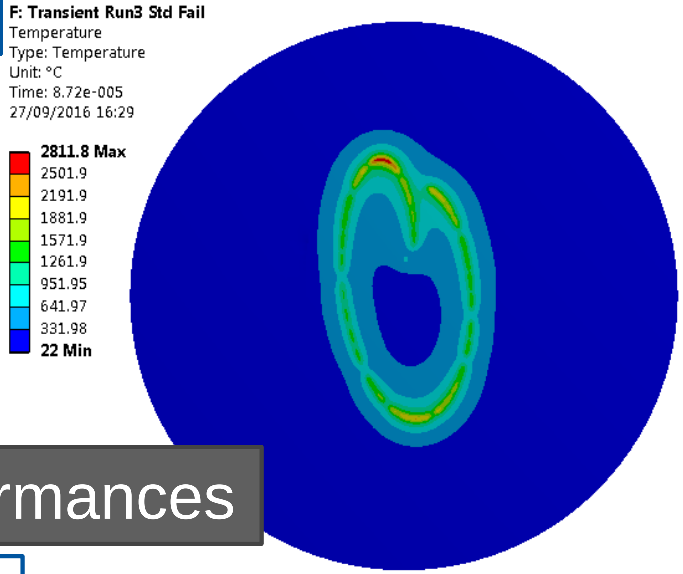
Regular Sweep

Max Temp = **1920°C**



2H kicker failure

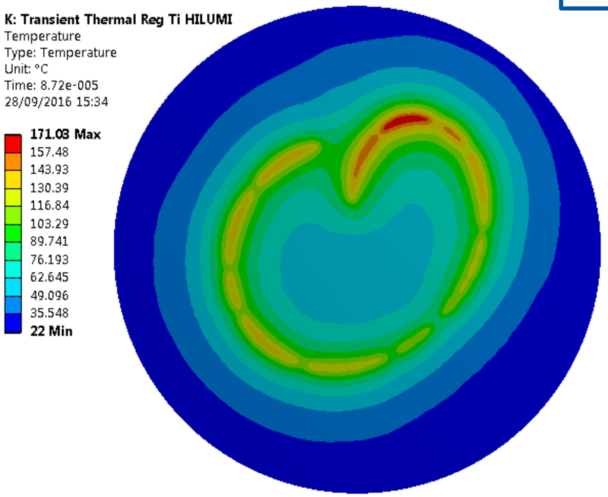
Max Temp = **2810°C!**



Titanium downstream window

Regular Sweep

Max Temp = **170°C**



2H kicker failure

Max Temp = **250°C**