Beam Intercepting Devices

ITHPP visit at CERN

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SY/STI: Sources, Targets and Interactions Group

Sources

Build and operate **all CERN laser**-based particle **sources** and lasers for beam ionization/spectroscopy of short-lived nuclides
→ **~10 laser facilities to operate**
→ **Electron sources for CLIC/AWAKE**

Interactions

Design, produce, operate beam intercepting devices in circular accelerators and transfer lines
→ **More than 250 devices**
→ **LHC collimation systems, dumps, etc…**
→ **Devices for accelerator and personnel safety**

Monte-Carlo Simulations beam-matter interactions
→ **Fluka development and Geant4**

Targets

Design **produce**, operate **all CERN secondary particle** production targets
→ **operation of the ISOLDE/n_TOF facilities and AD-target**
→ **responsible of the use of 75% of CERN protons**

Beam Intercepting Devices

A beam intercepting device is a component that **intercepts accelerated particle beams** for diverse purposes, such as

- ❑ **Production of secondary particles** ("target")
- ❑ **Protection of sensitive equipment** ("collimator")
- ❑ **Safe disposal** ("dump")

What type of challenges need to be faced? (1/3)

- Devices must be able to withstand operation and accident scenarios & protect delicate equipment
- Mostly employed as "last line of defence" against component damage
- Dependable components, whose failure often leads to long period of downtime
- Usually, the most radioactive components in an accelerator complex

What type of challenges need to be faced? (2/3)

- High energy densities (several **kJ/cm^3/pulse**)
- High power densities (**MW/cm^3**)
- High beam kinetic energy (up **700 MJ**)
- High average deposited power (**hundreds of kW**)

CERNCOURIER.COM

FEATURE SYSTEMS ENGINEERING

INTERCEPTING THE BEAMS

From targets to absorbers, beam-intercepting devices are vital to CERN's accelerator complex.

https://cerncourier.com/a/intercepting-the-beams/

What type of challenges need to be faced? (3/3)

- Ultra High Vacuum requirements (10^{-10} mbar)
- Movable parts with extremely high precision and flatness
- Physics requirements (sometimes implying materials with poor structural properties)
- Impedance (especially for colliders)
- Radiation damage and modification of thermo-physical properties

Palette of absorbing materials employed at CERN

Graphitic materials (and CfC)	Aluminium alloys	Titanium & alloys	(Stainless) steels
1-1.8 g/cm^3	2.7 g/cm^3	4.5 g/cm^3	7.5-8 g/cm^3
Low CTE, good thermal conductivity, low ρ, very high service T, exceptional robustness to beam impact	Light structural materials, good thermal conductivity, low T_m, poor properties at high T	Exceptional strength while light, low CTE, low thermal conductivity	"king" of structural materials, low thermal conductivity

Palette of absorbing materials employed at CERN

Reasonably low CTE, relatively good strength

Refractory metal, stable high, ductile, extreme corrosion resistance

Target material for pbars, poor mech. performances, very high ρ

CuCrZr1 & Glidcop®
8.9 g/cm^3

Mo-alloys and TZM
10.2 g/cm^3

Lead
11.3 g/cm^3

Tantalum
16.6 g/cm^3

Tungsten and alloys
18-19.3 g/cm^3

Iridium
22.6 g/cm^3

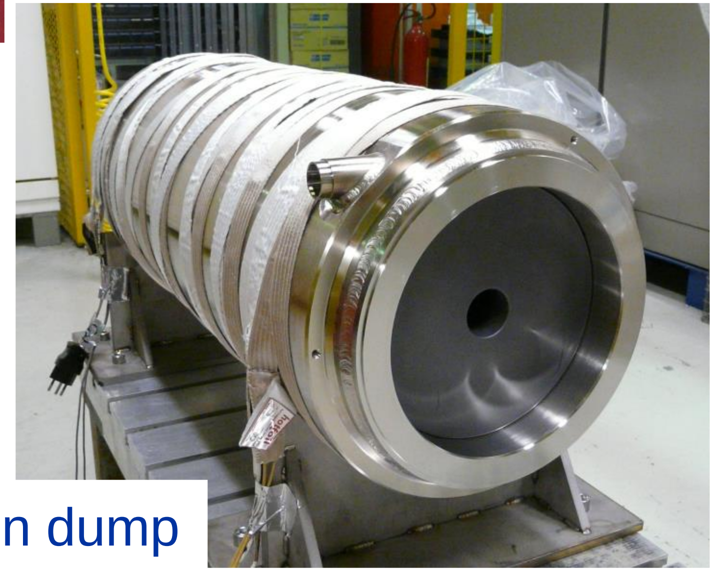
Very good heat conductivity, good strength and stability at high T

Target material for neutron production, very low T_m, almost negligible strength

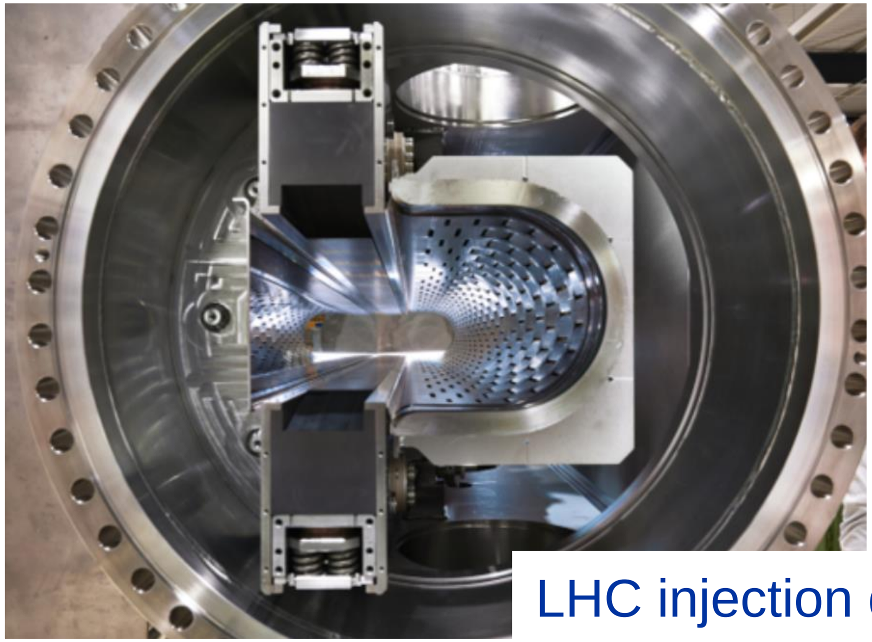
High ρ and related absorption power, alloyed-W has good machinability

TCAPM

Beam stopper

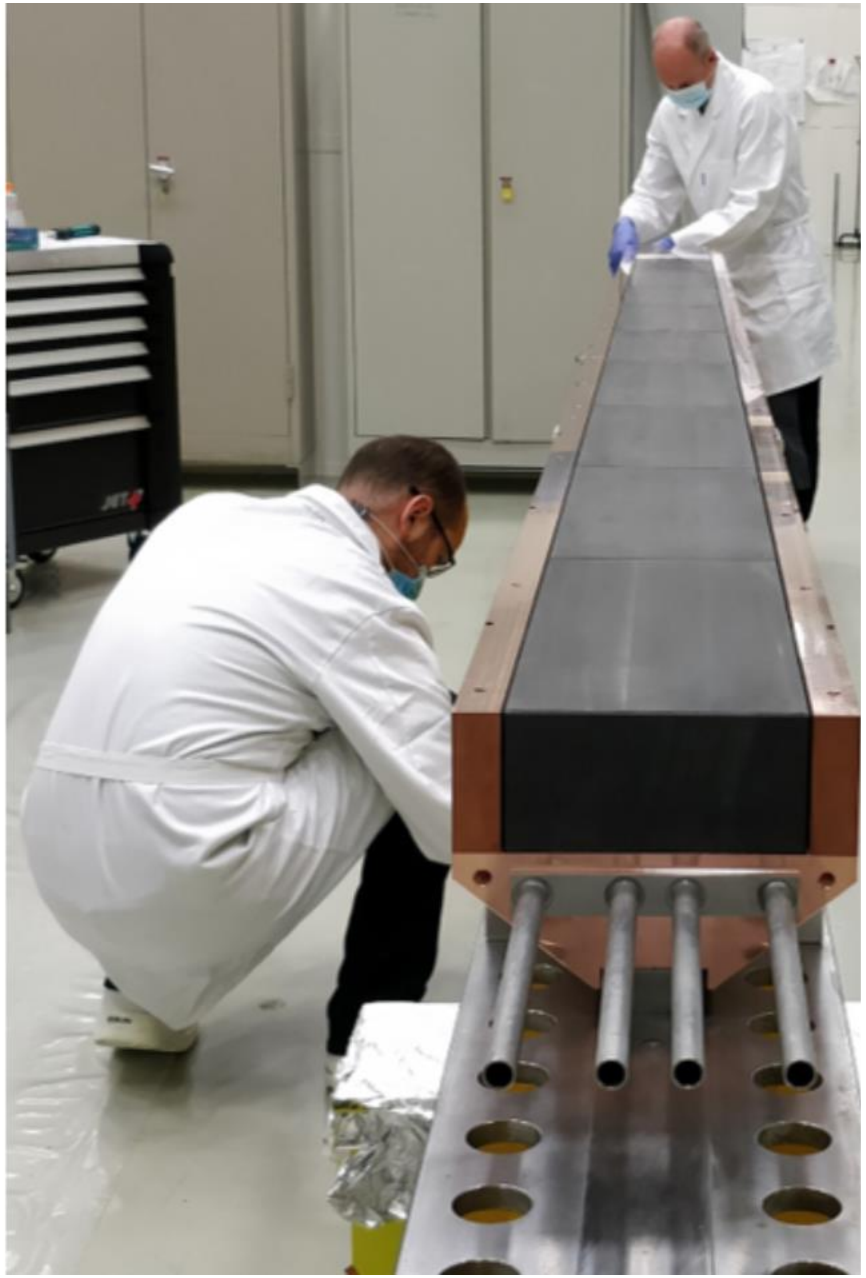


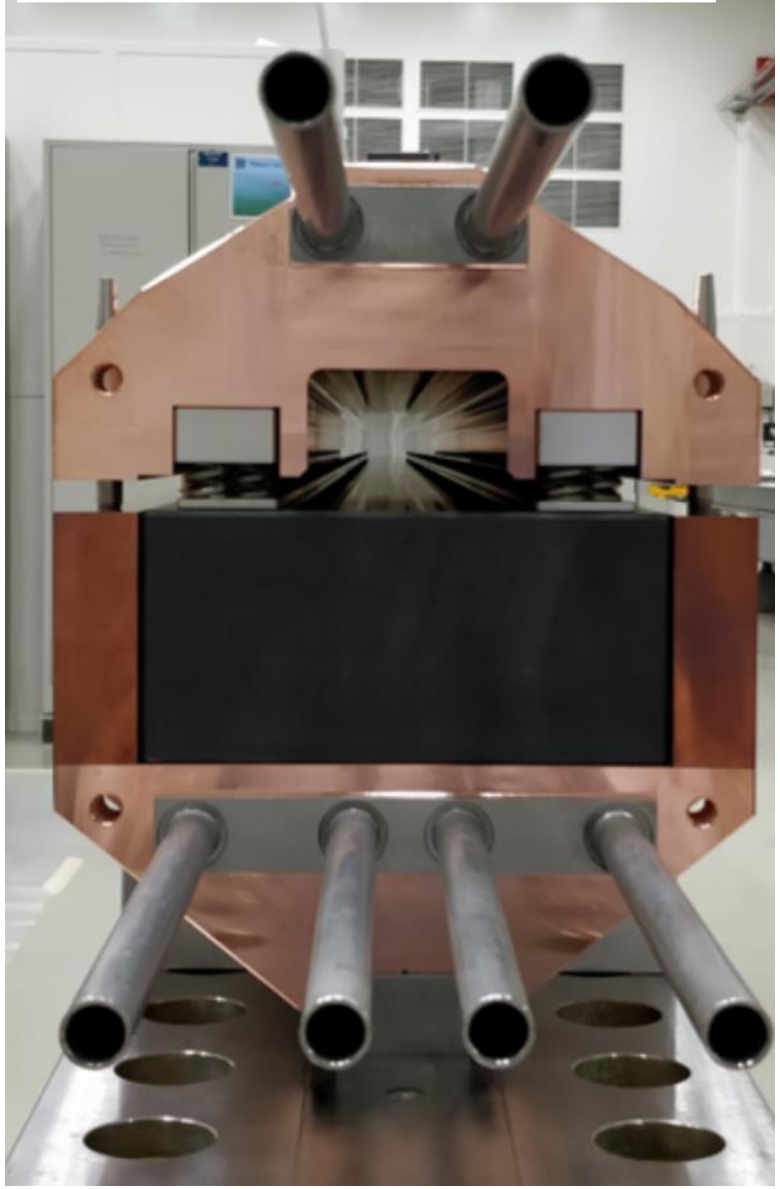
Linac4 main dump

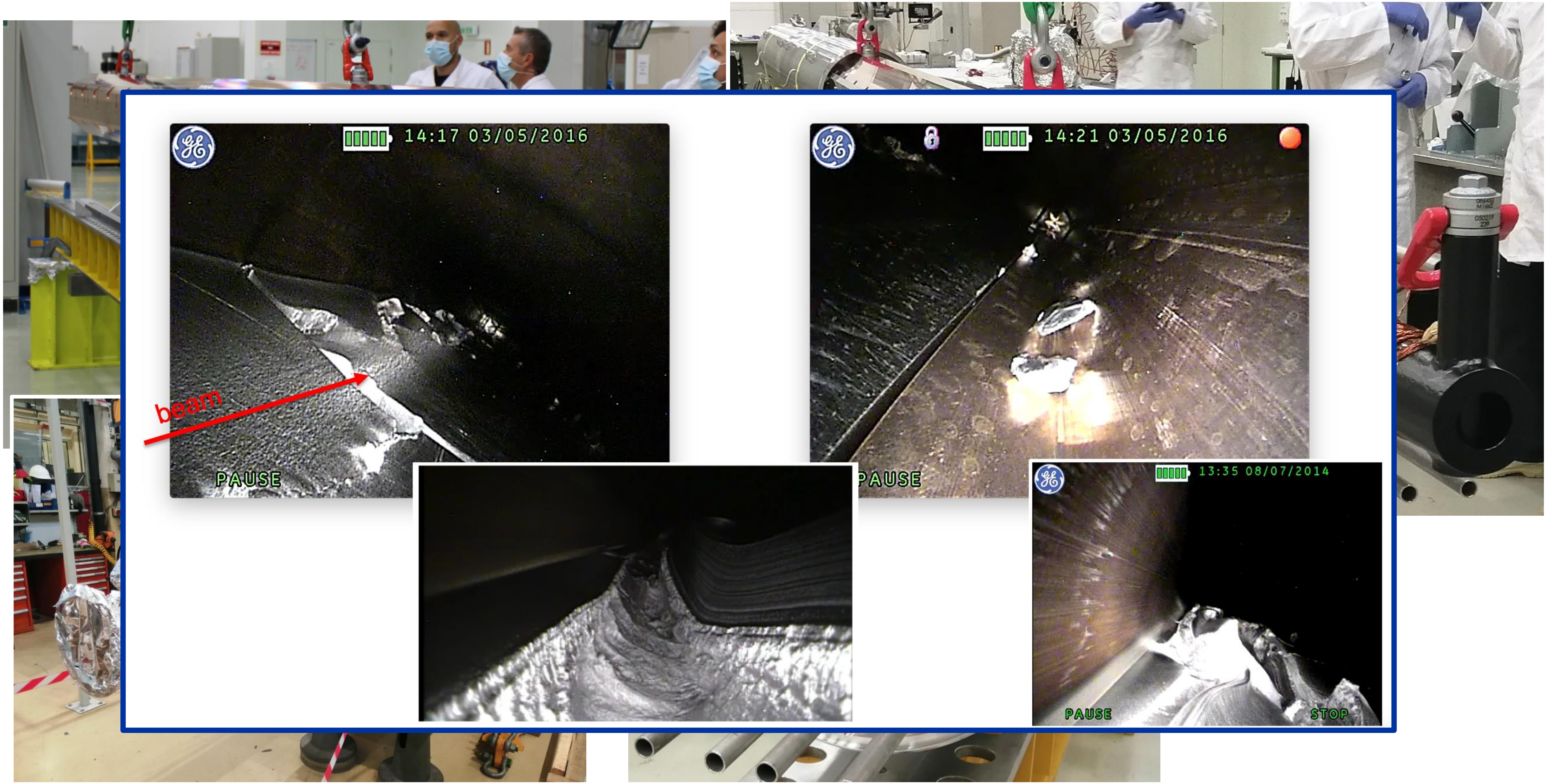


LHC injection dump (TDIS)

SPS beam dump (TIDVG5)

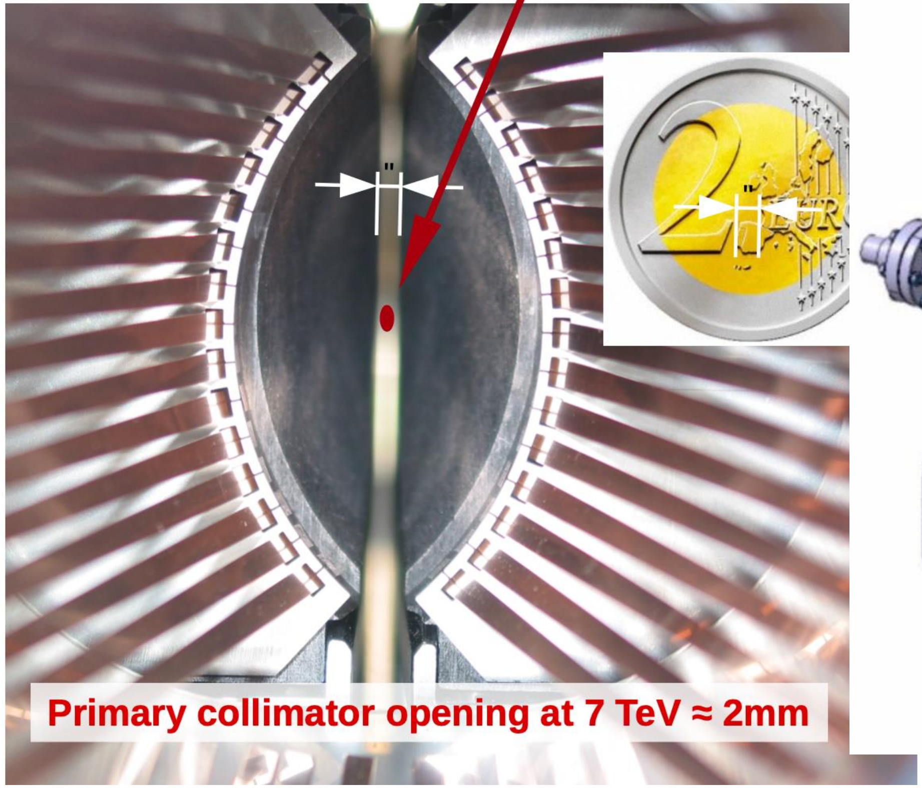


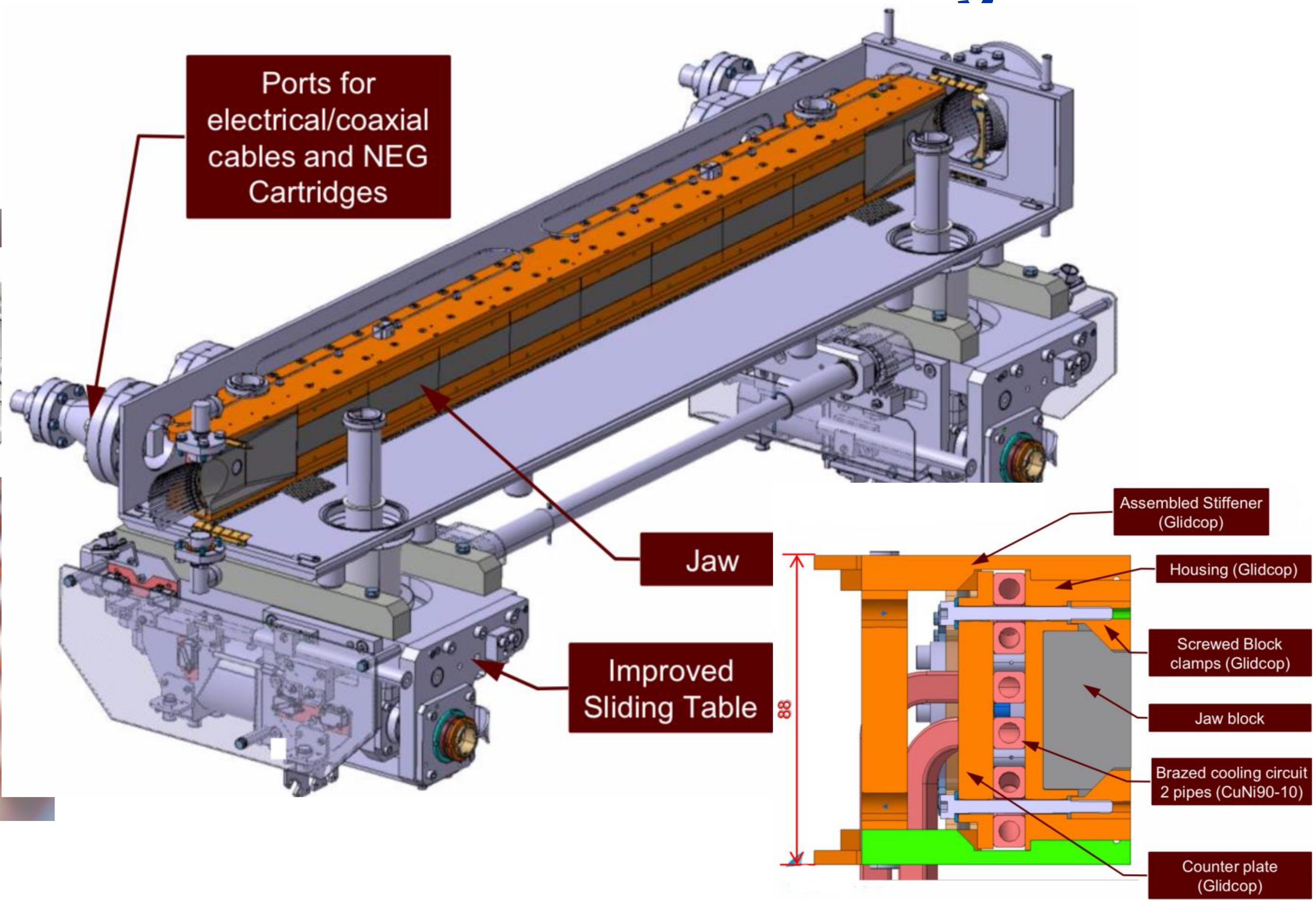



14:17 03/05/2016
beam
PAUSE
14:21 03/05/2016
PAUSE
13:35 08/07/2014
PAUSE
STOP

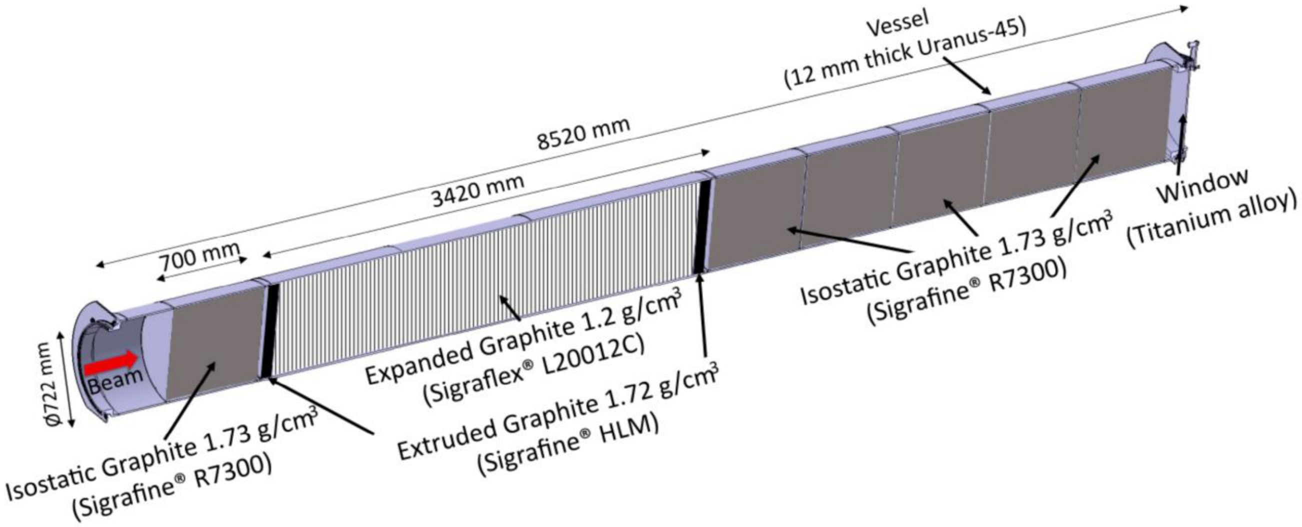
Large Hadron Collider collimation: multi-stage

Circulating LHC beam!!





LHC external beam dump



1.2% nominal Run3 max intensity
6.09×10^{12} p⁺
6.6 MJ

55.2% nominal Run3 max intensity
2.73×10^{14} p⁺
297.6 MJ

Could **melt rougly 2 t of Cu**

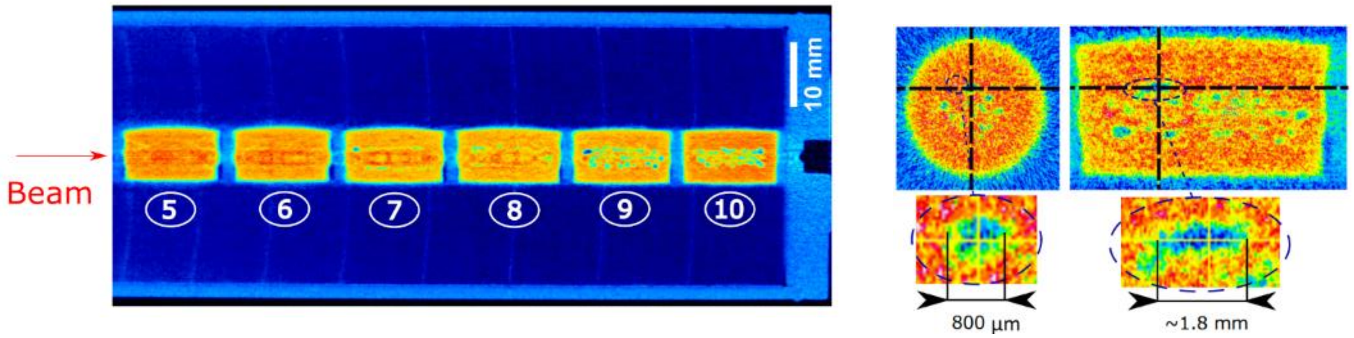
Beam impact experimental testing and validation

- Validation of design often include the possibility of **testing components or integral devices under beam impact**
- Sometimes devices and materials operate at the extreme – **uncharted territory of temperature and stress** (where EOS are not available)
- Existing material constitutive models at extreme conditions are limited and mostly drawn from military research (e.g. Ta, Ir, W).
- **Dedicated tests allows for numerical vs. experimental cross-check**

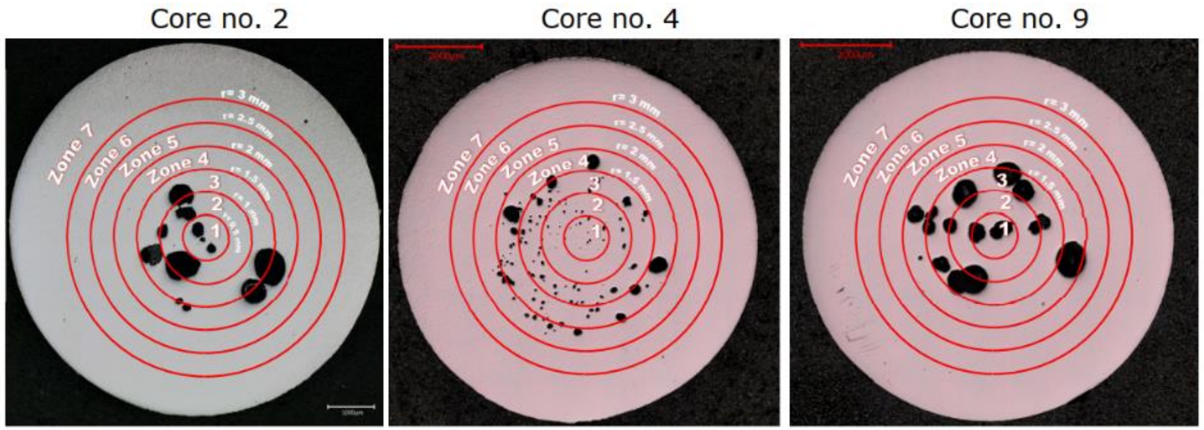
Ta-irradiated sample (±7 kJ/cm3)

Phys. Rev. Accel. Beams 21, 073001 (2018)
European Journal of Mechanics / A Solids 85 (2021) 104149

- Neutron Tomography @PSI (NEUTRA)



- Target opening and slicing cores at CERN

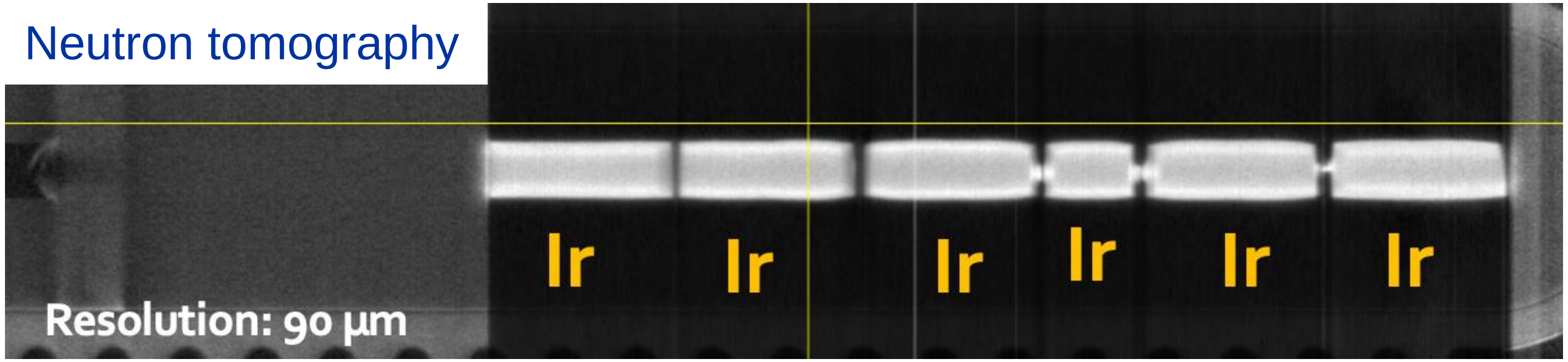


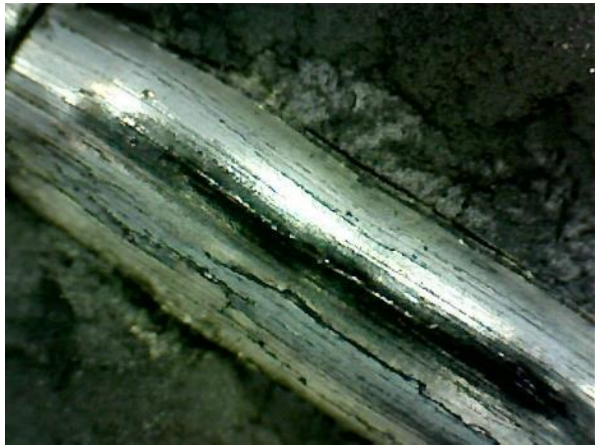
Observation of spalling voids

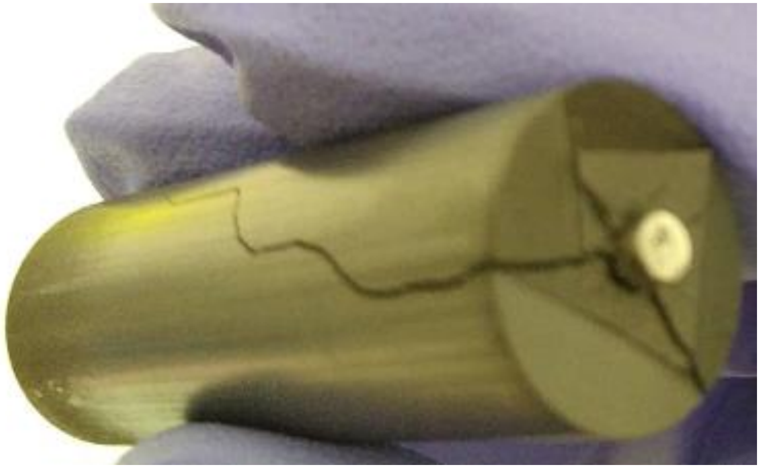
Tensile pressure shall be kept <2-3 GPa to avoid void nucleation

Beam testing of antiproton targets

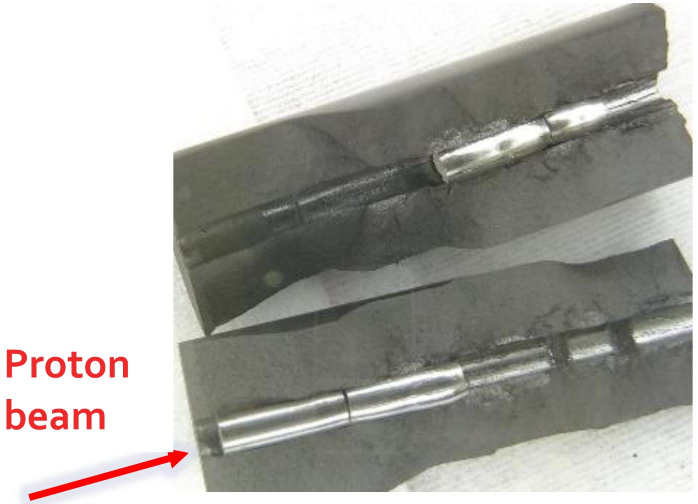
Neutron tomography

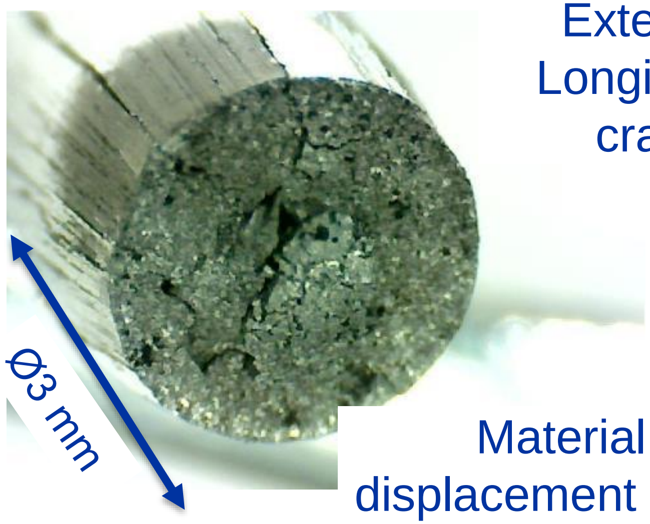






Longitudinal cracks in the isostatic-graphite matrix!





Extensive Longitudinal cracks

Material displacement along the face

Functional reliability / integrity

- **Don’t want the BIDs to break apart under load!**
- Strength, fatigue, cooling performance
- Erosion, corrosion, wear
- High temperature, high strain-rate performance
- Complexity, repairability, repeatability, Quality Assurance
  - If special materials are employed, make sure your material is available in 5-10 years from now for spares

Conclusions

- Beam Intercepting Devices are a **multi-physics**, **multi-expertise** and **cross ”cultural”** systems
- Reliable construction relies on a delicate balance of different requirements and constraints
- Operational experience is a key aspect in the feedback loop

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