Beam Dump Facility target: design status, beam tests in 2018 and material studies

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on behalf of the BDF project

CERN, Engineering Department, STI/TCD

Beam Dump Facility
Related talks at HPTW 2018

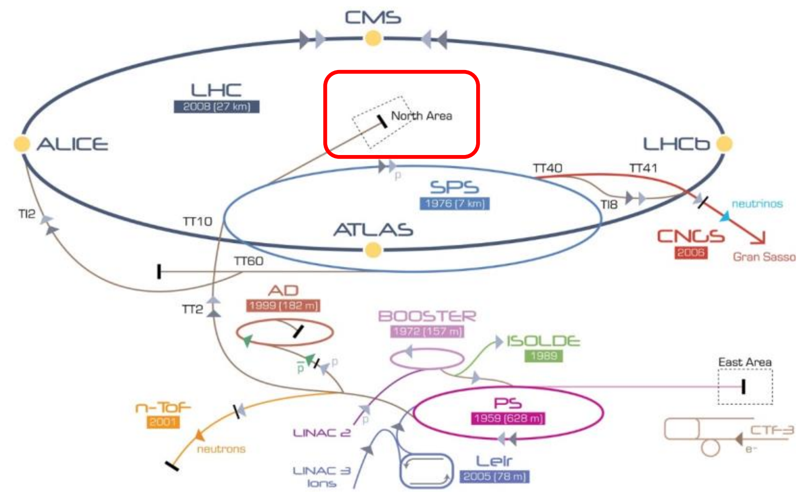
- **M. Lamont,** *Physics Beyond Colliders at CERN,* Fri 8/6

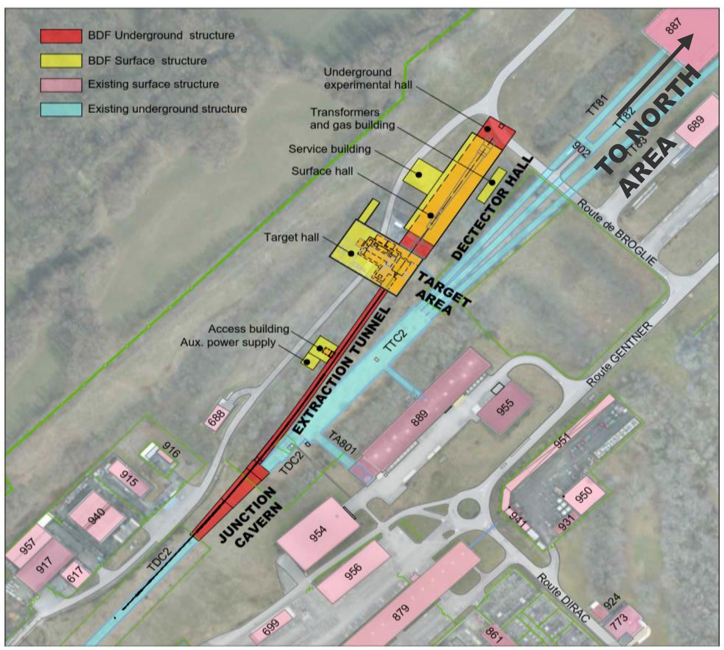
- **H. Vincke,** *Beam Dump Facility (BDF) at CERN radiological and environmental assessment,* Thu 7/6

- **K. Kershaw,** *Preliminary design study of the integration and remote handling processes for the Beam Dump Facility Target Complex,* Thu 7/6

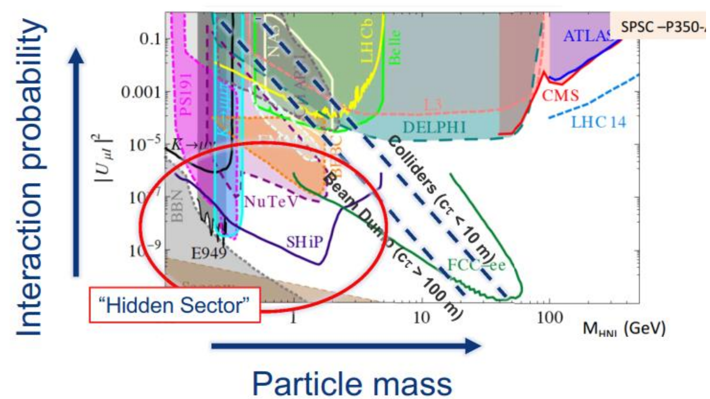
The Beam Dump Facility (BDF)

- General purpose fixed target facility
- Proposed location: **SPS North Area**
- Currently on design phase
- **Search for Hidden Particles (SHiP)** experiment first user of the facility





What can be done in a Beam Dump Facility that cannot be done in a collider?



***M. Lamont,** Physics beyond colliders at CERN, Friday 8th*

Beam Dump Facility challenges

Civil engineering
Geotechnical and hydrogeology of site

Existing users

New beam line
Beam dilution

Construction of junction cavern
Switching into new beam-line

Radiation protection of personnel and environment

Safe exploitation

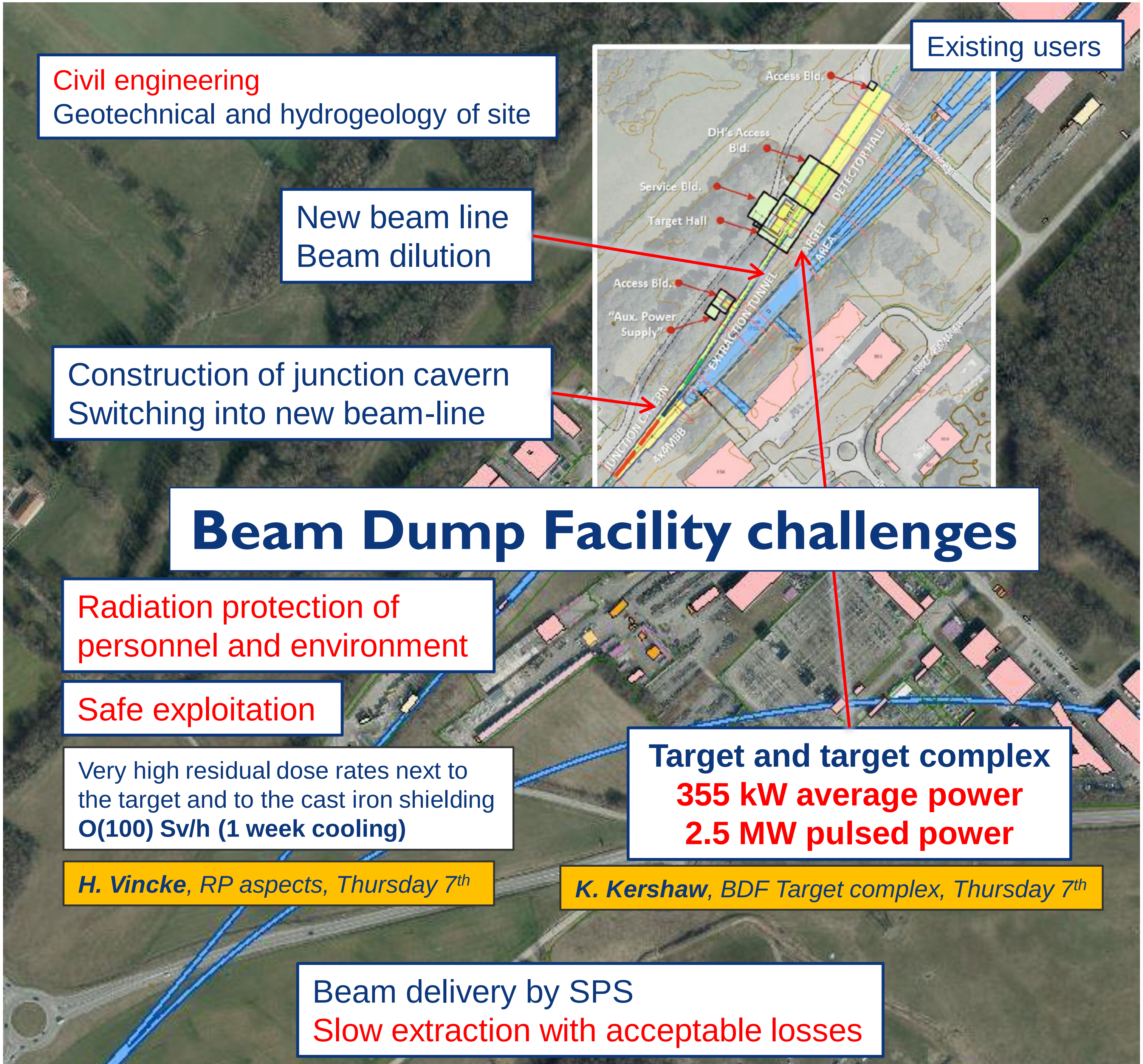
Very high residual dose rates next to the target and to the cast iron shielding
O(100) Sv/h (1 week cooling)

***H. Vincke**, RP aspects, Thursday 7th*

Target and target complex
355 kW average power
2.5 MW pulsed power

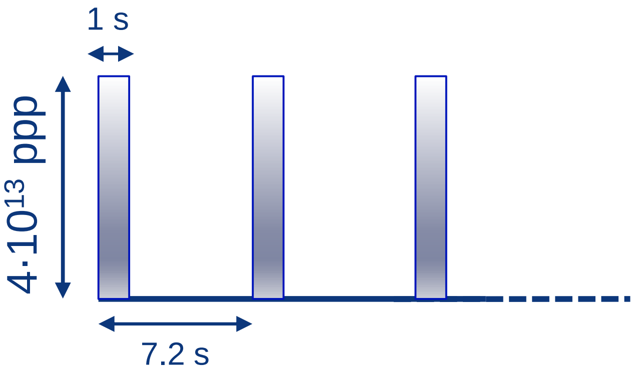
***K. Kershaw**, BDF Target complex, Thursday 7th*

Beam delivery by SPS
Slow extraction with acceptable losses



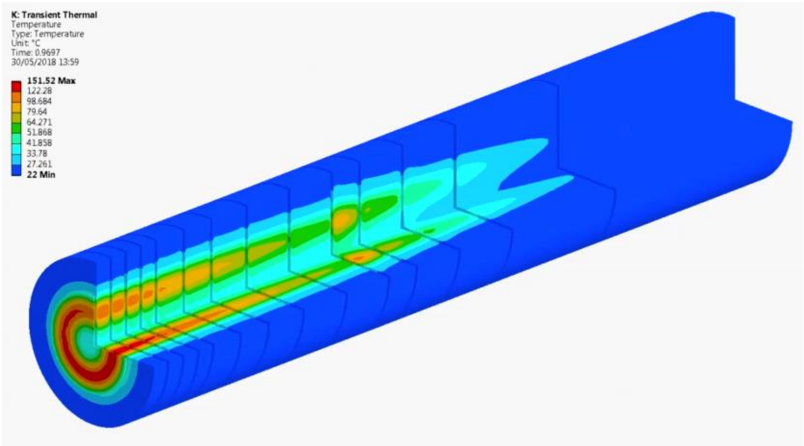
Operational conditions

Baseline characteristics	
Proton momentum	**400 GeV/c**
Beam intensity	$4.0 \cdot 10^{13}$ p+/cycle
Cycle length	7.2 s
Spill duration **(slow extraction)**	1.0 s
Average beam power deposited on target	**320 kW**
Average beam power on target during spill	2.3 MJ



⇨ Challenging target design

- **Dilution of the beam** by the upstream magnets
  - Beam dilution optimization:
    - Target mechanical performance
    - Magnets aperture limits
  - 50 mm radius, 4 turns in 1 second
- **Large beam spot:** 8 mm 1σ



Beam Dump Facility target

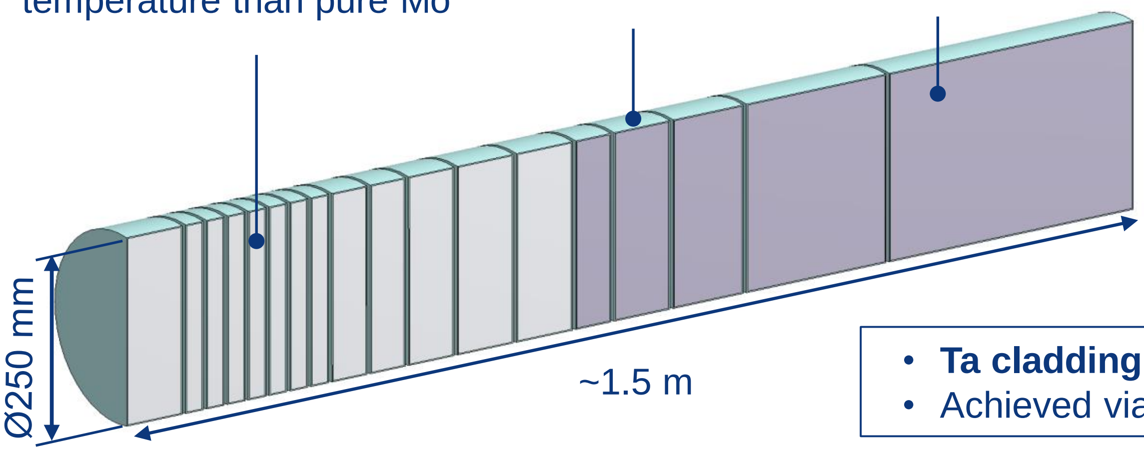
- Main functions:
  - **Full SPS 400 GeV/c beam absorption → Target/dump**
  - Maximize the production of **charmed mesons →** physics performance
- Material requirements:
  - **High-Z materials**
  - **Short interaction length**

  ⇨ Increase the reabsorption of pions and kaons

1st part: **TZM core**
Molybdenum alloy, higher strength and recrystallization temperature than pure Mo

Ta/Ta2.5W cladding

2nd part: **Tungsten core**
High-Z and good performance under irradiation



- **250 mm diameter cylinders**
- **Total length ~ 1.5 m**
- **Optimized segmentation** of the target to minimize the level of temperatures and stresses
- High power deposition

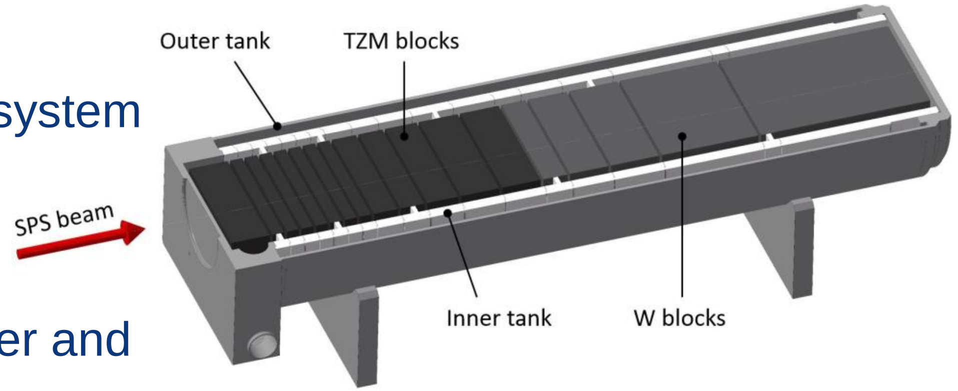
→ forced water cooling required

→ 5 mm gap between the blocks

- **Ta cladding** to avoid corrosion/erosion effects
- Achieved via **Hot Isostatic pressing** (HIPing)

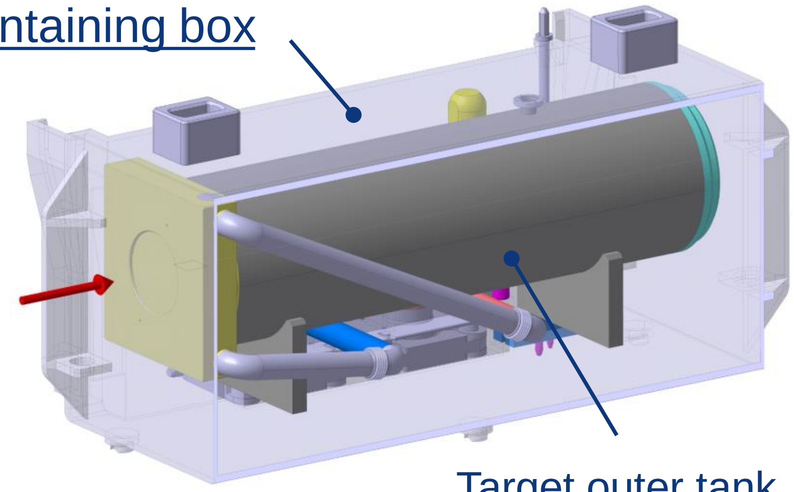
Target assembly design

- <u>Target inner tank</u>
  - Supports target core blocks
  - Encloses the target cooling system
- <u>Target outer tank</u>
  - Water-leak tightness
  - Provides interfaces with water and electrical connectors



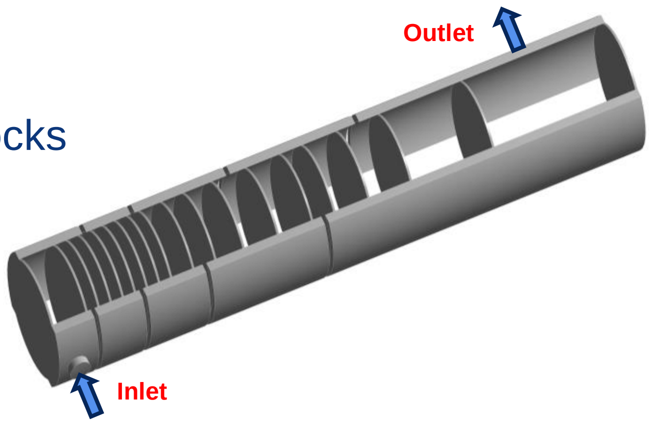
- Target tank enclosed inside a <u>Helium containing box</u>
  - Dry environment + leak monitoring
  - **Replacement of the whole box in case of target failure**
  - **Compatible with target complex handling and integration design**

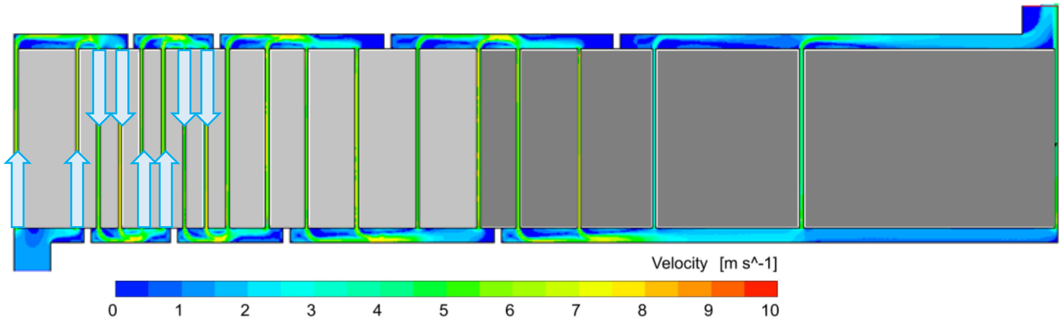
K. Kershaw's talk Thursday 7th



Cooling circuit design

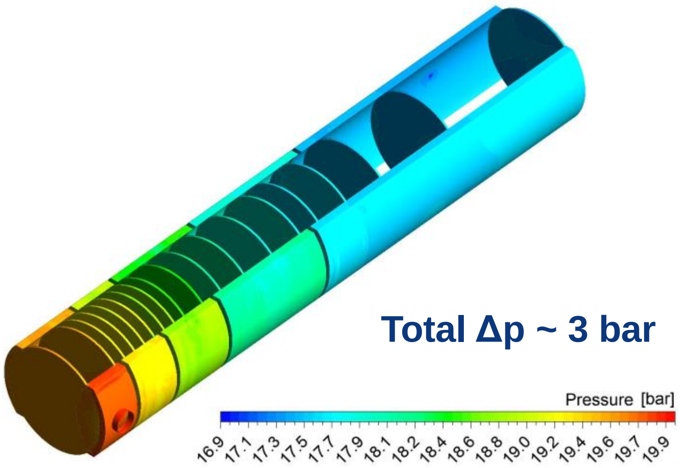
- Water flows through 5 mm gap between the target blocks
  - Cooling of circular face of the blocks critical
    → beam impact
- Preliminary design of the target cooling circuit



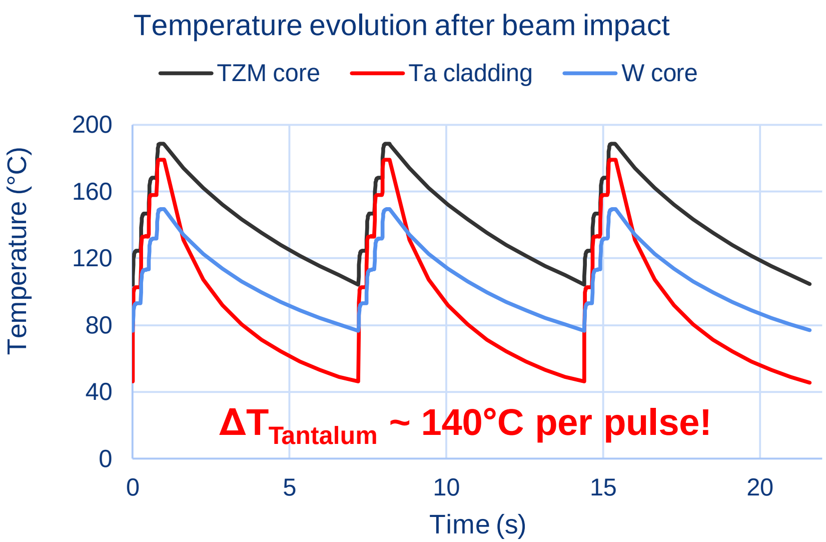


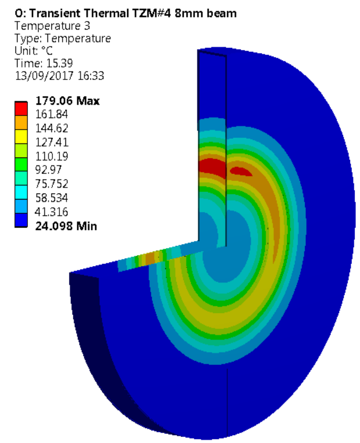
2 parallel streams in series
→ avoid cooling failure in case of blockage of one channel

- Homogenous water speed in the channels ~ **5 m/s**
- Average **Heat Transfer Coefficient ~ 20000 W/m²K**
- Minimized **mass flow rate: 10 kg/s**
- Pressure supply: **20 bar**
  - Increase water boiling temperature above 200°C
  - Avoid vapor formation in contact with target blocks

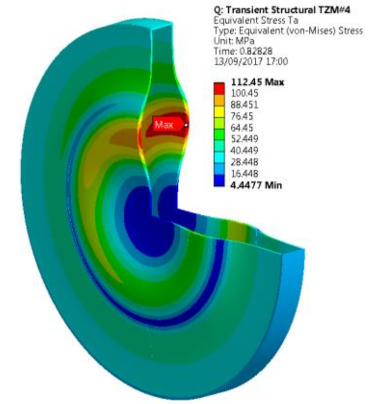


Thermo-mechanical calculations





Max temperature Ta cladding 180°C

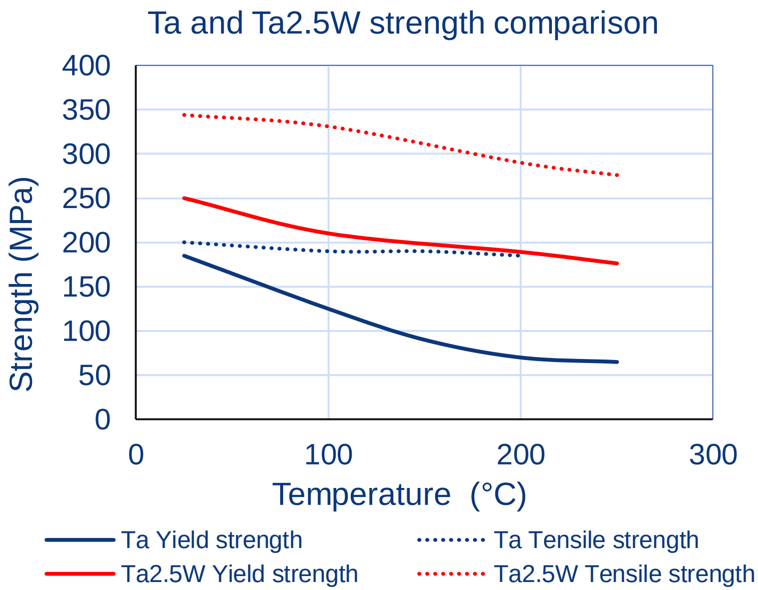


Max Von Mises equivalent stress Ta cladding ~110 MPa

- High raise of temperature during beam impact: **temperature limitations in the Ta cladding →** vapor formation, plastic deformation of the cladding
- The high temperatures reached lead to a high level of stresses
- Properties of **pure Ta** at high temperatures reduced significantly with respect to RT → chosen **cladding material**: tantalum-tungsten alloy, **Ta2.5W**

Material R&D – Use of Ta2.5W

- **Target cladding material**: Ta2.5W
  - 2.5% content of W
  - Similar thermal properties to Ta
  - Good corrosion-erosion resistance
  - **Higher strength, specially at high temperatures**



Cladding material	Maximum Von Mises eq. stress expected	Yield strength	Safety factor
Tantalum (preliminary design)	110 MPa	80 MPa (at 180°C)	0.7 ✗
Ta2.5W (new design)	110 MPa	**200 MPa (at 180°C)**	1.8 ✓

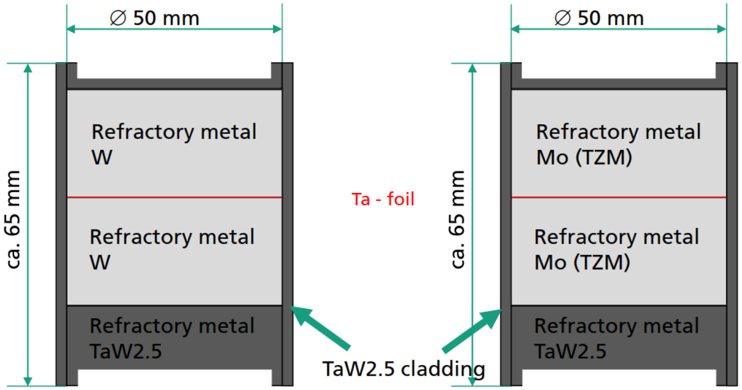
Additional considerations:
- **Fatigue properties for 10^7 cycles**
- **Radiation damage (ongoing)**

- **Bonding quality** with tungsten and TZM expected to be the same

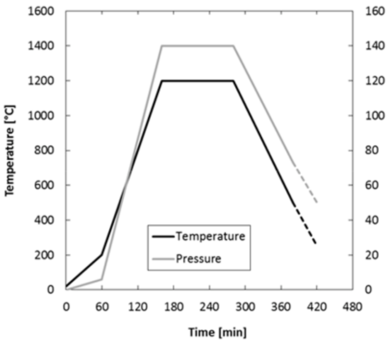
Material R&D

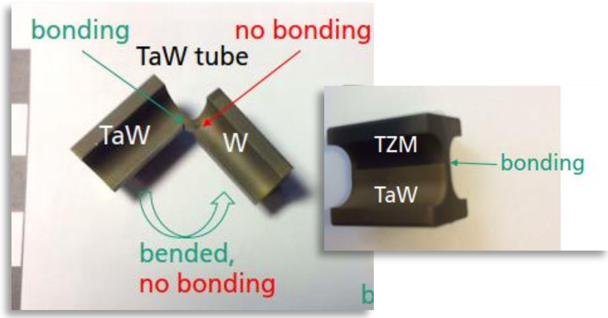
***J. Busom Descarrega,** Recent developments of HIP[…] (poster)*

- **Initial HIP cycle tests**



D. Wilcox et al., *Stress levels and failure modes of tantalum-clad tungsten targets at ISIS,* Journal of nuclear materials

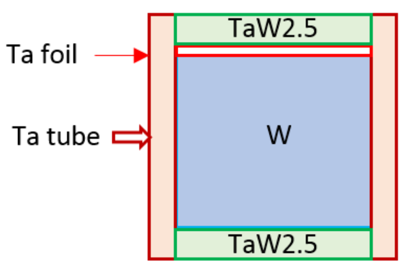




- Bonding achieved between Ta2.5W and TZM
  - **Interfacial strength = 260 MPa** ~ yield strength of Ta2.5W, very good results
- No bonding achieved between Ta2.5W and W

- **New HIP cycle tests**

(different temperature and pressure)



- Bonding achieved between Ta2.5W and TZM
  - **Interfacial strength = 325 MPa** ✓
- Bonding achieved between Ta2.5W and W
  - **Interfacial strength = 200 MPa** ✓

⇨ Promising results for future BDF target cladding materials

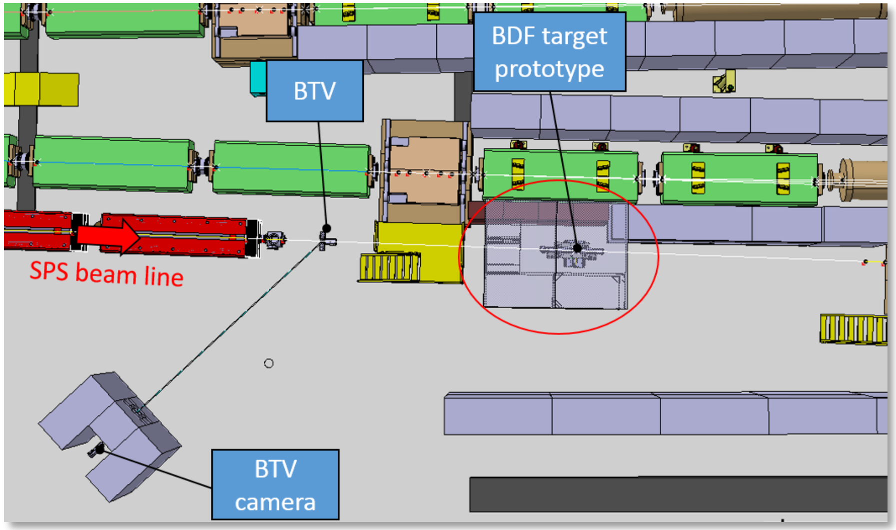
BDF target prototype beam tests

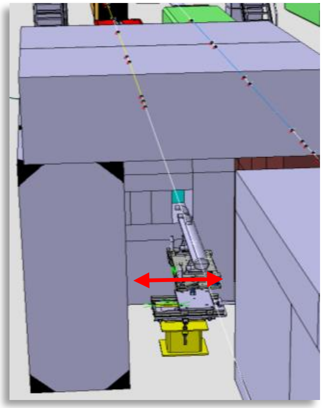
- **A prototype of the BDF target** will be tested under beam in the North Area of CERN in **September/October 2018**
  - Dedicated beam during 3 periods of 10 hours → **10^4 cycles** approx.
- Motivation for the test:

1. **Reproduce the level of temperatures and stresses of the final target**
   - High intensity beam (up to **10^{13} protons**) from SPS
   - **Slow extraction**: 1s pulse, 7.2 period
   - 3 mm 1σ beam, **non-diluted**
2. **Crosscheck the FEM calculations performed**
   - Several instrumented blocks: strain gauges, optical fibers, Pt100
3. **Post Irradiation Examination after irradiation**
   - Remote opening and extraction of the blocks

BDF target prototype assembly

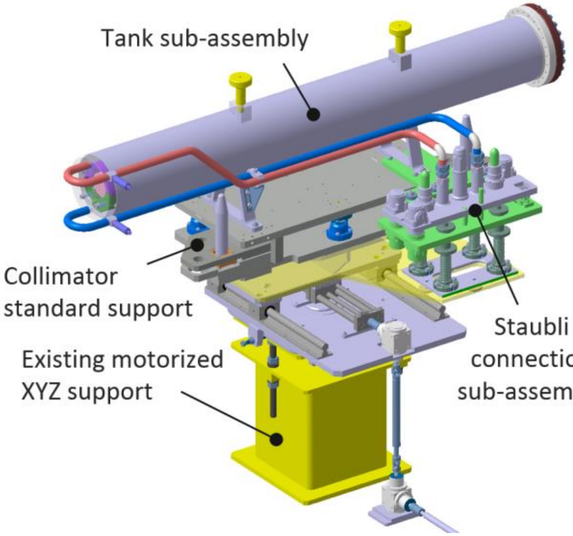
- **Target prototype assembly:**
  - Installed upstream existing beryllium targets
    - Surrounded by concrete shielding





Placed on motorized support

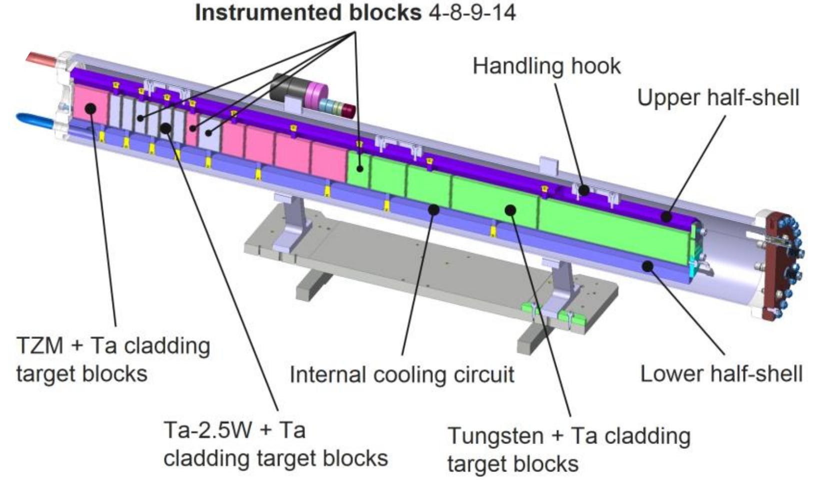
→ Removed from beam after operation



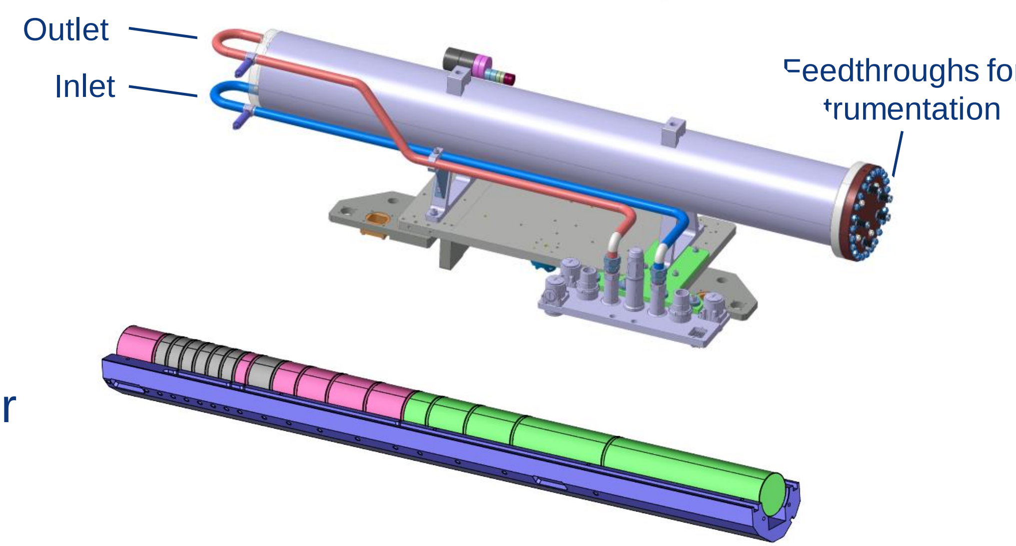
- Fully compatible with remote handling
  - Lifting of the target for removal
  - Remote disconnection of the interfaces
  - Radiation level O(Sv/h) after 2 months

BDF target prototype design

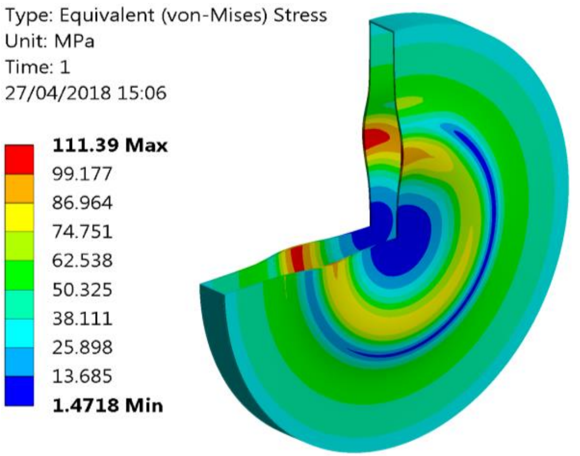
- **Reduced scale prototype**
  - Same total length (~1.5 m)
  - Reduced diameter **(80 mm)**
  - Same block length distribution
  - TZM/W core, Ta/TaW cladding



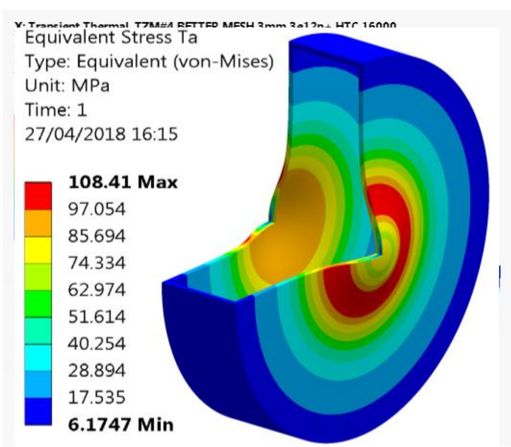
- **Two concentric tanks** (~ final BDF target)
  - Outer tank:
    - Leak tightness
    - Connections interface
  - Inner tank: two half shells
    - Target core blocks holder
    - Enclosing cooling circuit



Target prototype vs. final target

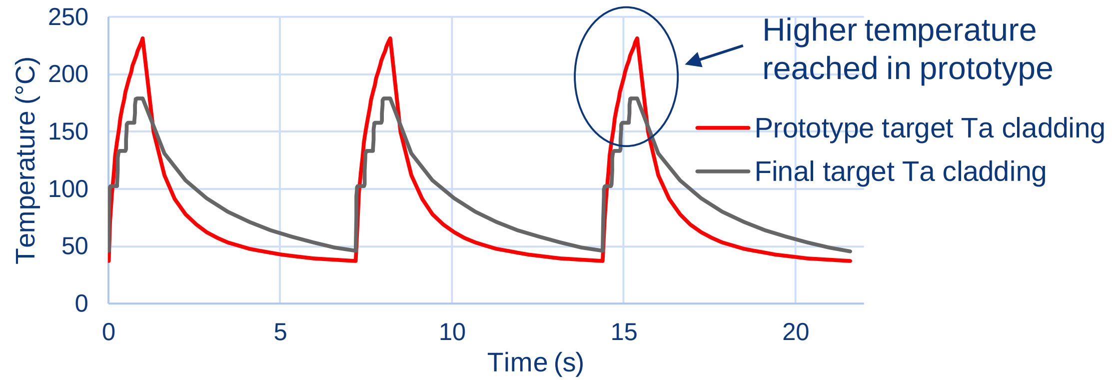


Final BDF target

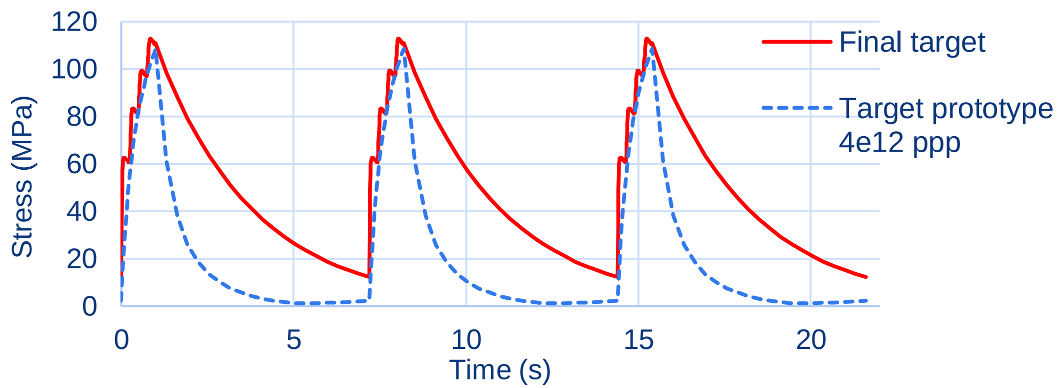


BDF target prototype

Maximum temperature Ta2.5W cladding



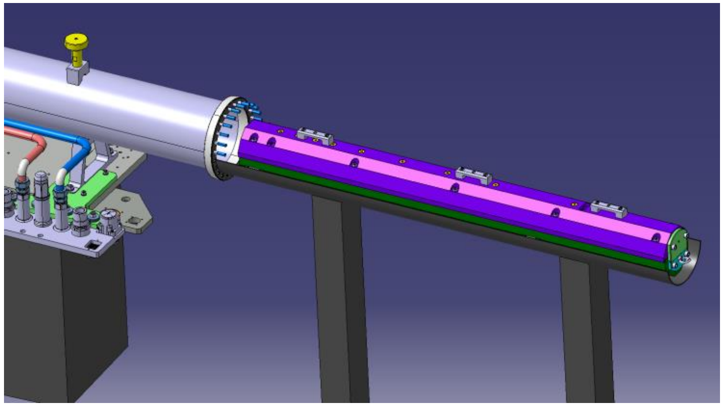
Von Mises Equivalent stress Ta2.5W cladding

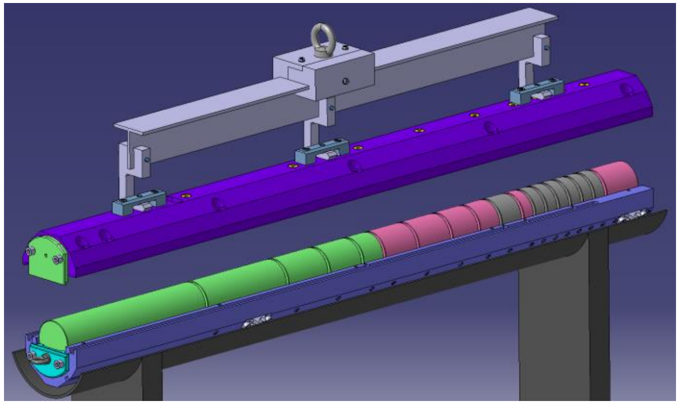


Reasonable approximation of the level of stresses in the core and cladding materials

Post Irradiation Examination

- After 6 months cool-down remote extraction of several target blocks for **Post Irradiation Examination** (100 mSv/h at 10 cm)
  - Microscopic analysis on **bonding surfaces**
  - Hardness and microstructure analysis around the **impact point**
  - Micromechanical tests on **irradiated targets** → material weakening
  - Profilometry/metrology to identify **swelling effects** on target blocks





Conclusions

- A new **Beam Dump Facility** is proposed to be installed at CERN's SPS North Area.
- The **BDF target is one of the most challenging aspects** of the new facility.
- The BDF target design involves a complex material selection process and important mechanical constraints.
- **Material R&D on-going**: new target materials and bonding of refractory metals.
- A **prototype of the BDF target** will be tested at CERN in 2018
- The prototype test under beam will aim to **reproduce the operational conditions of the final BDF target**.

Thank you for your attention!