[HI-ECN3 BDF Target & target complex initial review]:

Looking ahead – Target alternative designs

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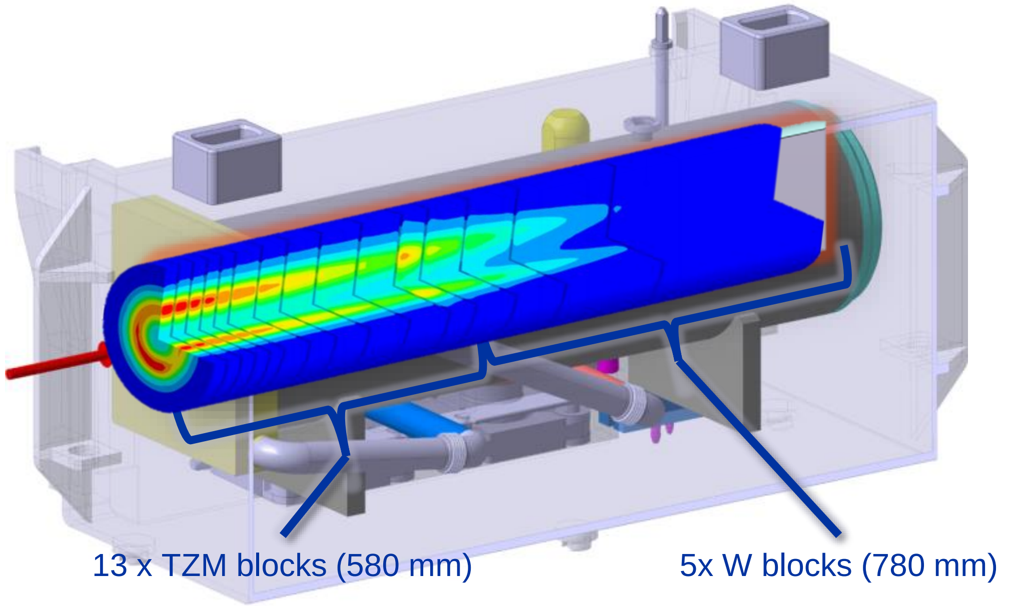
HI-ECN3 BDF target initial review

- **Baseline design.**
- **Alternative designs:**
  1. Removed water channels.
  2. The full W target.
  3. The full W target – exploring other options.
  4. In-beam tests
- **Conclusions.**

WP3 – BDF Target design

Baseline design

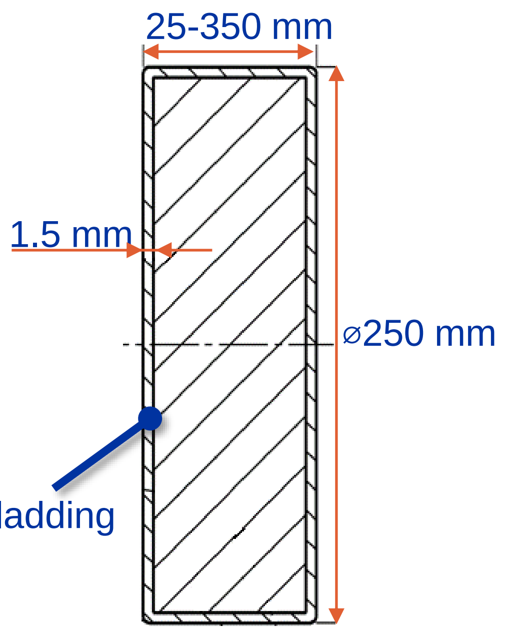


Target will become an extremely radioactive device!
~100 Sv/h after few hours of cool-down

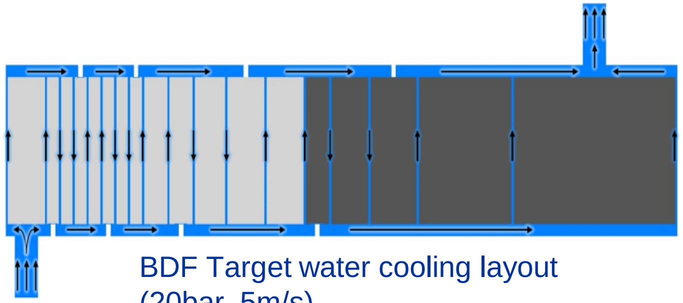
Baseline beam parameters of the BDF Target operation.

Proton momentum (GeV/c)	400
Beam intensity (p^+/cycle)	4×10^{13}
Cycle length (s)	7.2
Spill duration (s)	1.0
Beam dilution pattern	Circular
Beam sweep frequency (turns/s)	4
Dilution circle radius (mm)	50
Beam sigma (H, V) (mm)	(8, 8)
Average beam power (kW)	356
Average beam power deposited in target (kW)	305
Average beam power during spill (MW)	2.3

~ 4.0×10^{19} p^+/y



- Baseline design is robust with thorough design report https://doi.org/10.23731/CYRM-2020-002, representative in-beam tests, PIE plus HIP & other testing.



BDF Target water cooling layout (20bar, 5m/s)

WP3 – BDF Alternative Target design requirements

Now is an opportunity to explore alternative designs.

Physics drivers

- Particle production
  - Want particle interactions with High Z materials, especially in the shower region –large effect. W > TZM > Cu
  -Replacing upstream TZM with W would be beneficial, even if this needs more cooling channels
    - Overall density of target (including water channels) is not so important
- Background signal
  - Capture all electromagnetic shower particles in the target – Need sufficient target ø and density

Operations drivers

- Activation products of water
- Production of Hydrogen

} Reduce volume of water, especially in the beam & shower

Thermal management & engineering drivers

- Want lots of cooling channels in the shower region! (reduces overall ρ)
- Want lots of high thermal conductivity materials in the shower region, eg copper (reduces ρ & Z)
- Want to reduce target ø.
- Want to reduce plate thicknesses (reduces overall ρ)
- Want improved Tungsten grain structure

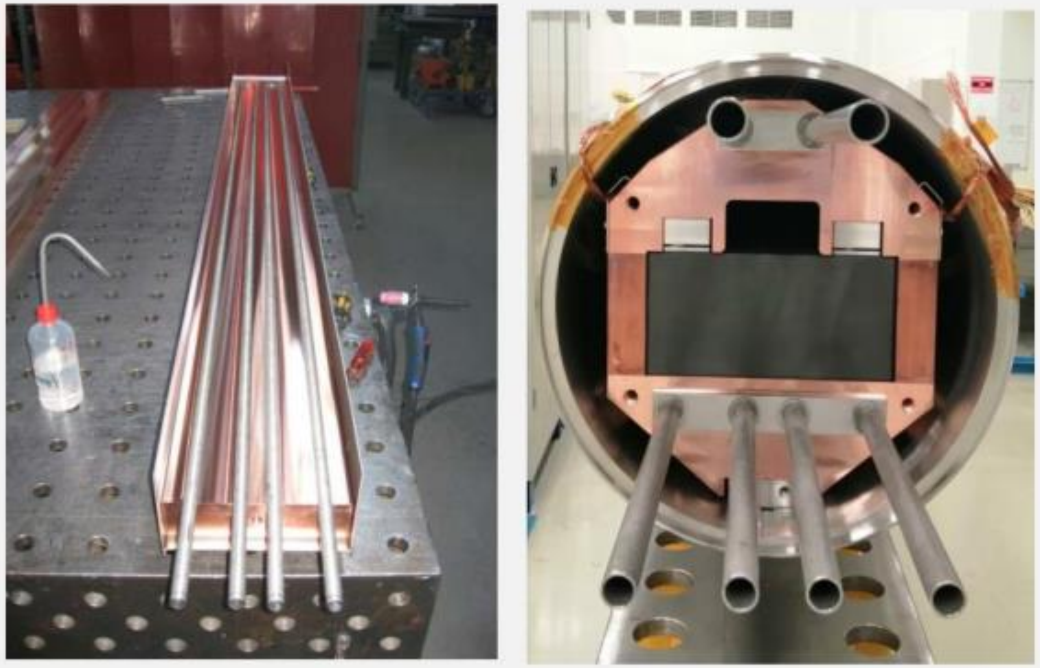
WP3 – BDF Target design

Alternative design – proven concepts

L4 Main Dump

L4 Dump-like cooling serpentine jackets (welded beforehand)

SPS Internal Dump



HIPed plates like SPS Main Dump TIDVG5

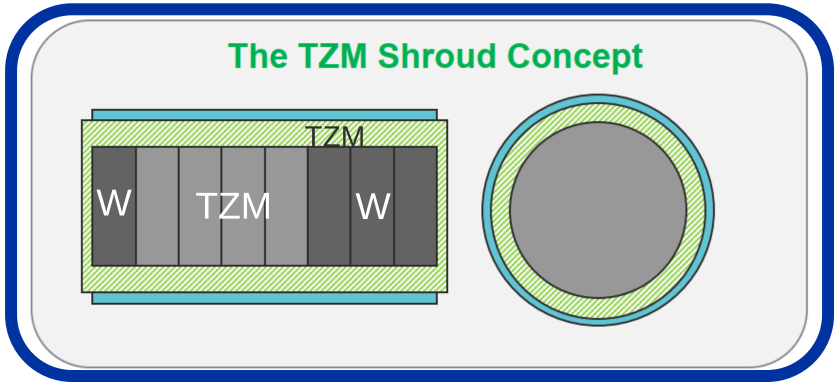
WP3 – BDF Target design

Alternative designs

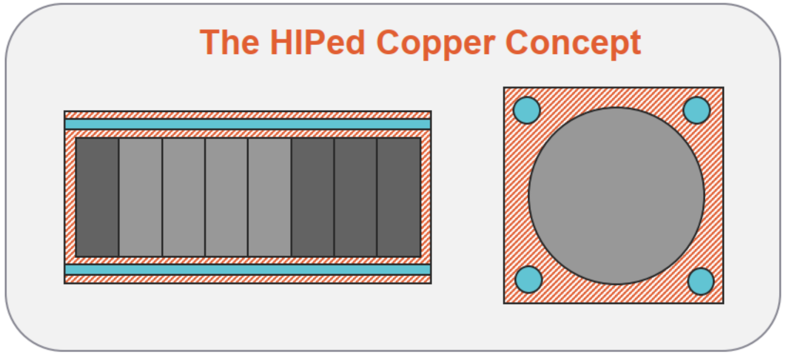
→ Using what the section's learnt experience

Based on L4 main dump

Next slides →



Based on SPS internal dump



Drivers:

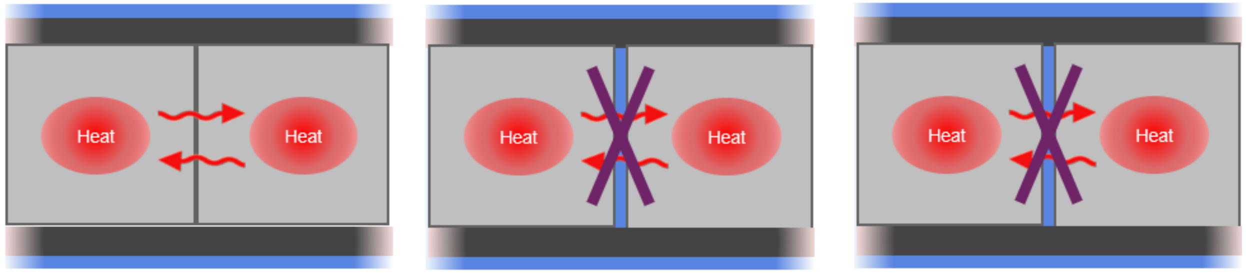
- Reduce the amount radiolysis-produced free hydrogen gas (ATEX)
- Reduce activation of the water (less water) and of the target (less Ta), and decay heat (less Ta)
- Reduce contamination risk of water & W spallation products -(stronger and thicker external shroud instead of thin cladding)
- Shorter target will simplify waste packaging and disposal.
- Increase physics performance. (overall denser without water channels)

WP3 – BDF Target design

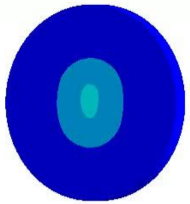
Alternative design – Initial approach

1. Is it beneficial to have the blocks in contact or not?

Contact (perfectly bonded)	**Contact** (not bonded)	**Gap** (not bonded)

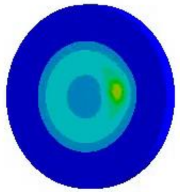


2. Diluted or sweep beam?



Diluted beam

OR



Sweep

…These options were explored in the 26th SHiP Collaboration Meeting, by T.Griesemer

WP3 – BDF Target design

Alternative design – TZM&W blocks, TZM shell

PREMATURE MODELS
with assumptions and simplifications

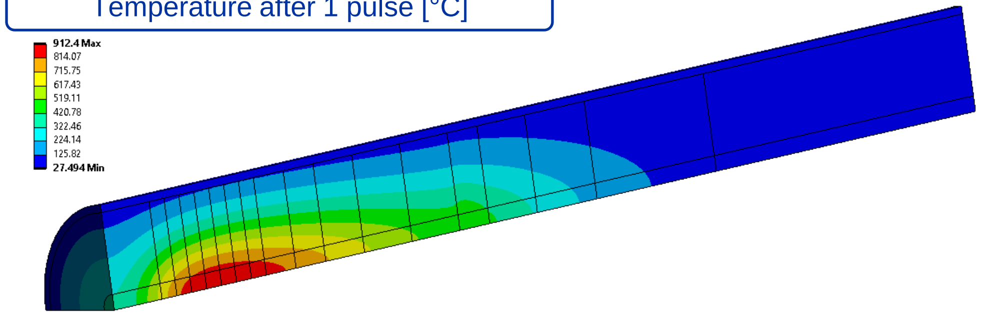
Contact (perfectly bonded)	Contact (not bonded)	Gap (not bonded)

- **Contact (perfectly bonded): the stress distribution along the beam axis is homogeneous. On average, the equivalent stresses are lower.**
- **Contact (not bonded): High stress gradients in single blocks.**
- **Gap (not bonded): Higher temperatures, stress reduction is negligible compared to the perfectly bonded case.**

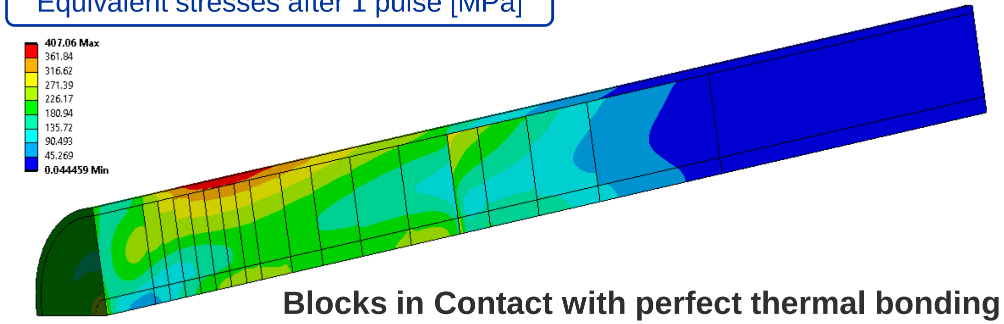
→ Having the blocks bonded is best option

Steady State + One Pulse
35mm centre beam

Temperature after 1 pulse [°C]



Equivalent stresses after 1 pulse [MPa]

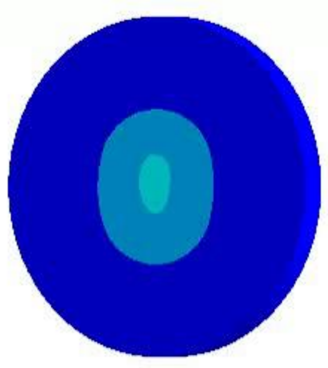


Blocks in Contact with perfect thermal bonding
Cooling water at circumference uses 10 000 W/m^2.K calculated using original water flow rate of baseline.

WP3 – BDF Target design

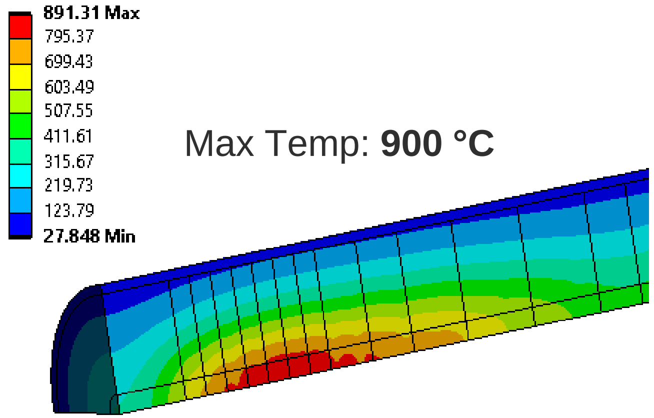
Alternative design – TZM&W blocks, TZM shell

Transient models

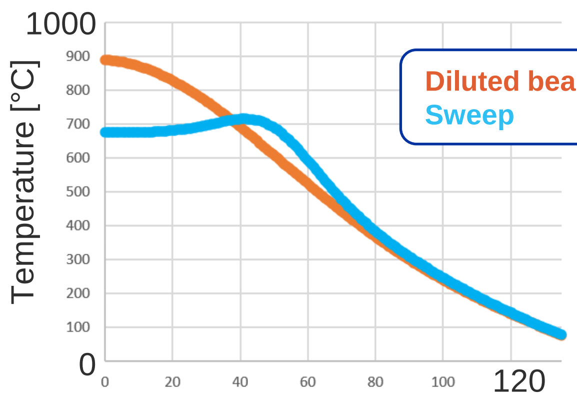


Diluted beam

Max Temp: **900 °C**

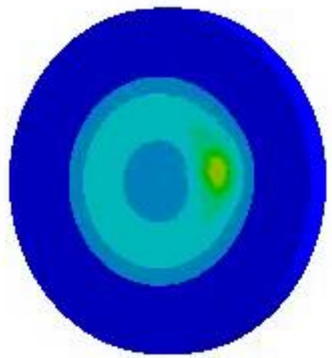


Maximum Temperature in Block 6

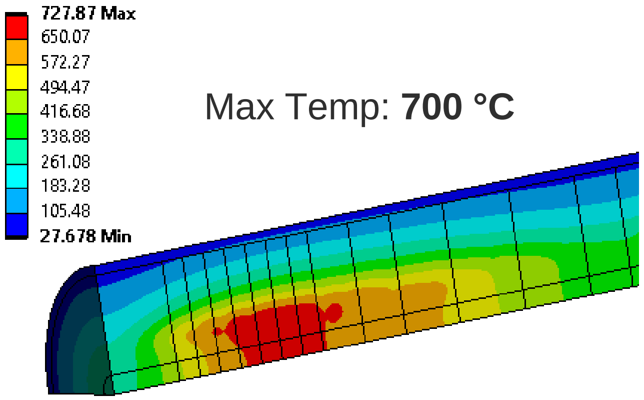


Position in radial axis [mm]
At plane of location of highest temperature

Sweep



Max Temp: **700 °C**



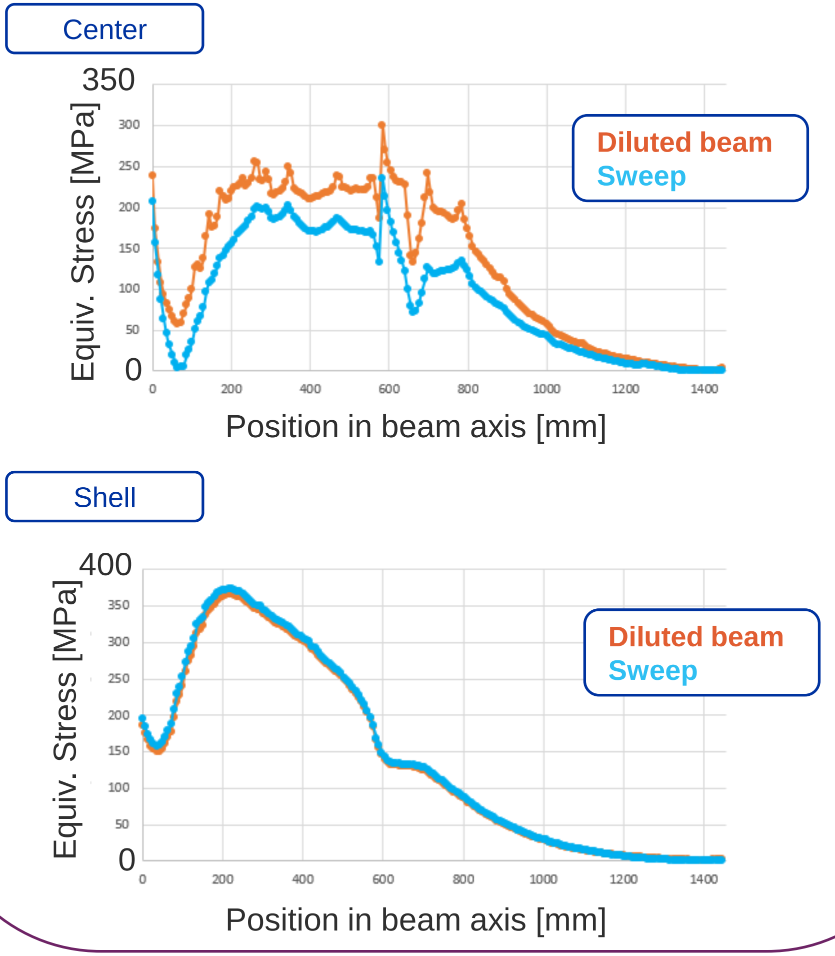
WP3 – BDF Target design

Alternative design – Initial approach

- **The sweep significantly reduces the peak temperature compared to the diluted beam (Δ200ºC)**
- **The sweep reduces peak equivalent stresses by 70 MPa (down to 130 MPa) compared to diluted centrebeam**

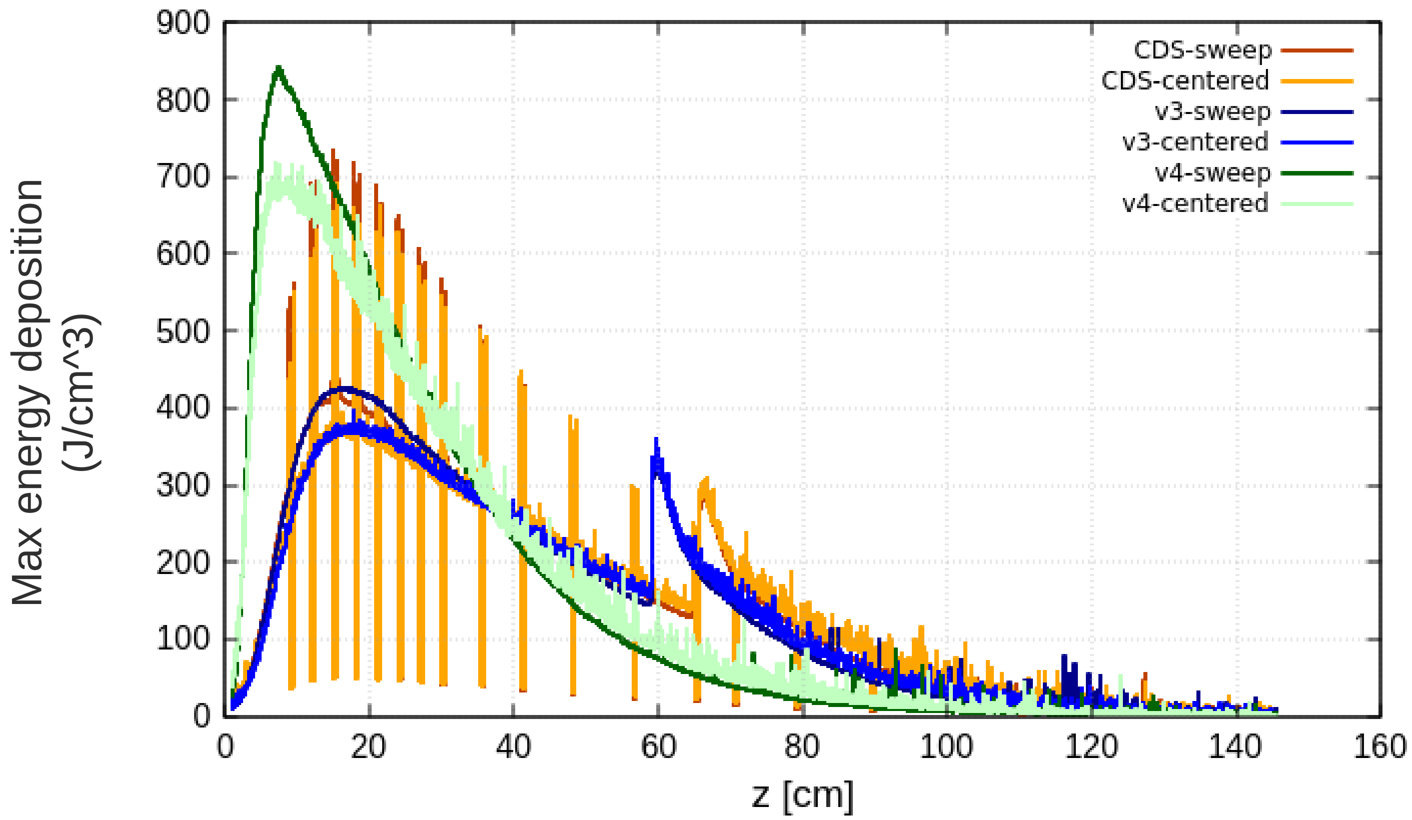
✓ It is beneficial to have the blocks in contact.
✓ The swept beam reduces the peak temperatures & stresses.
How would a **full W target** behave using this design?...

Equivalent stresses after 1 pulse



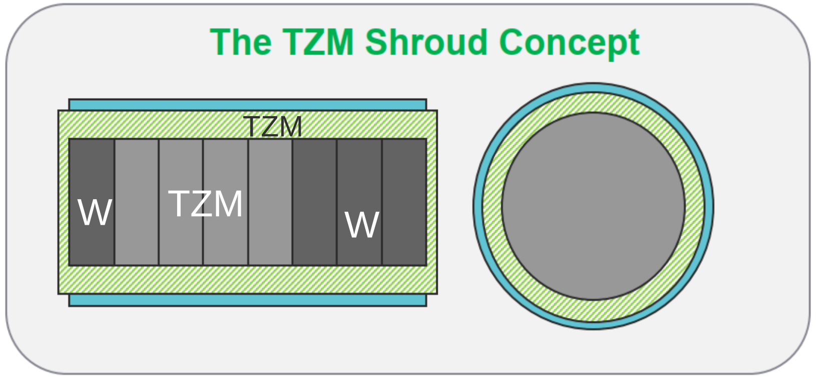
WP3 – BDF Target design

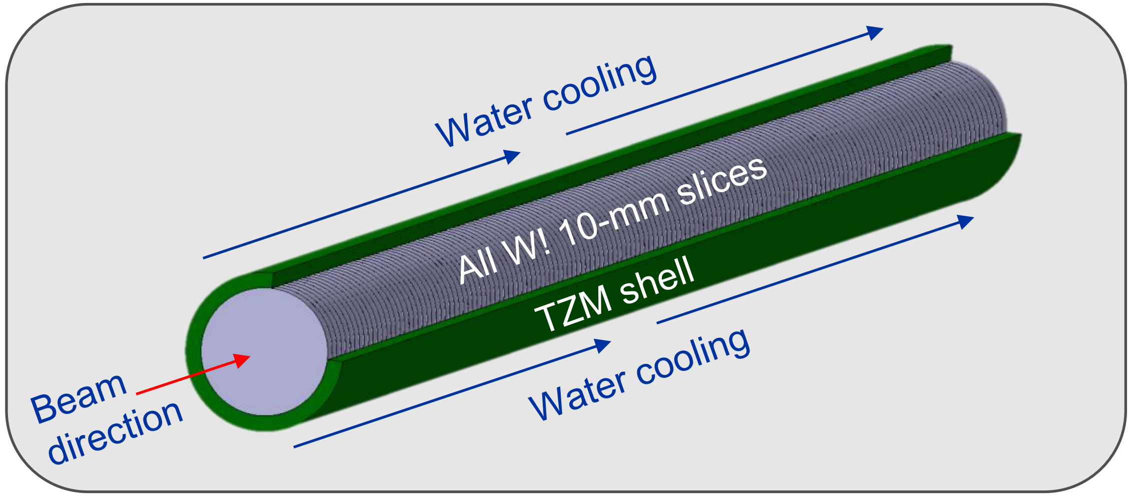
Alternative design – The full W target



WP3 – BDF Target design

Alternative design – The full W target





- **Full W compact target,** **encased in an actively cooled TZM shell.**
- **The TZM discs in the baseline design are replaced with W. – Good for physics**
- **The water-cooling channels in the baseline design are removed. – Good for operations**
- **To achieve efficient heat evacuation, the W slices and the TZM shell are diffusion bonded by means of hot isostatic pressing (HIP). – better grain structure for mechanical properties**
- **The thickness of the W slices is limited to the maximum capability through cold rolling.**

WP3 – BDF Target design

Alternative design – The full W target

Proton momentum (GeV/c)	400
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Beam dilution pattern	Circular
Beam sweep frequency (turns/s)	4
Dilution circle radius (mm)	50
Beam sigma (H, V) (mm)	(8, 8)
Average beam power (kW)	356
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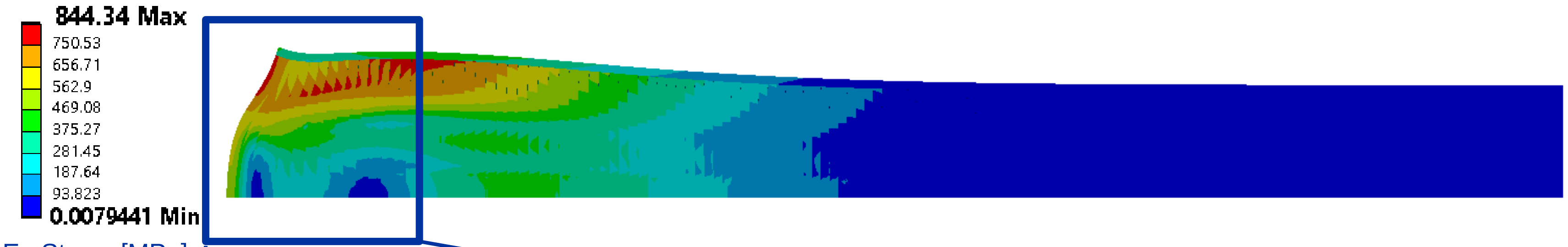
Steady state simulations!

Thermal simulation

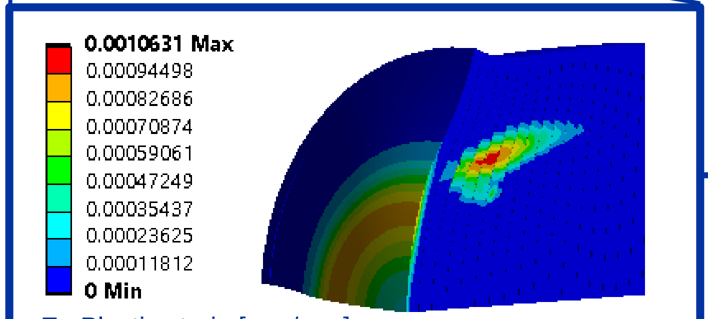
W recrystallizes at 1200-1300 ℃.



Eq.Stress [MPa]

Structural simulation

Very high mechanical stresses, with beam-induced plastic deformation in the upstream W.



Eq.Plastic strain [mm/mm]

Plastic deformation

These are steady state simulations. After each spill from steady state temperature, the temperature may raise up to 1100 ℃.

WP3 – BDF Target design

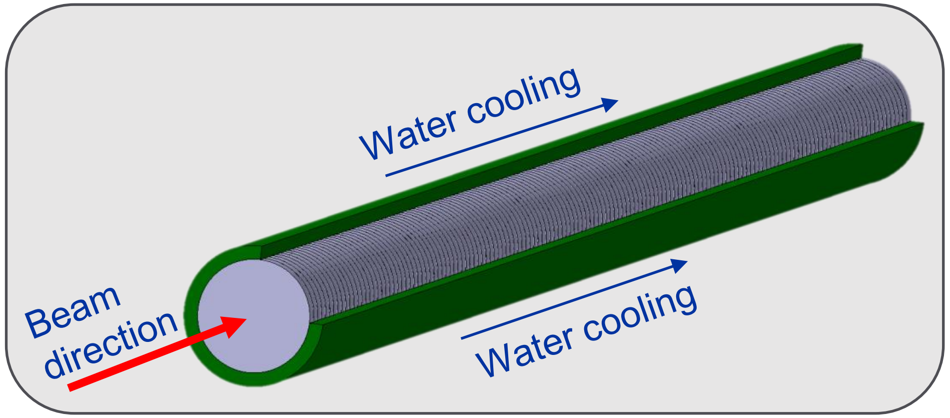
Alternative design – The full W target

A full W target core has improved physics performance…
..but the temperature in the W discs, and the beam-induced mechanical stresses must be reduced

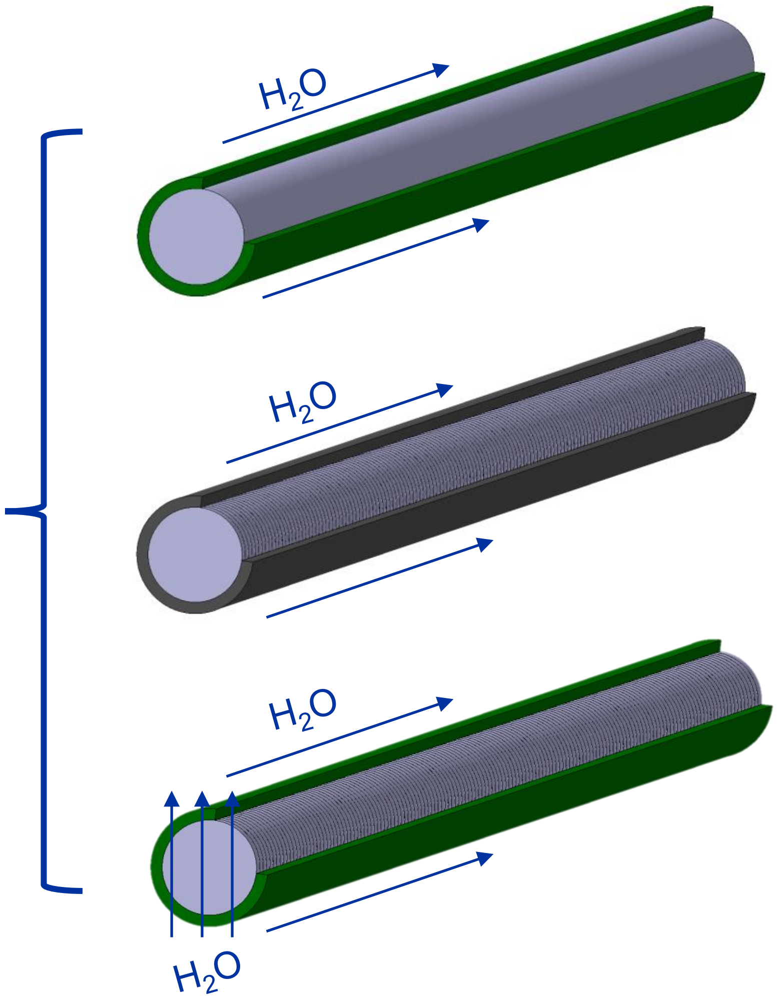
- Currently, we are exploring alternatives to optimize the design of the full W target…

WP3 – BDF Target design

Alternative design – The full W target (exploring other options)



Alternative designs: Full W core



Single core W-target TZM shell

To improve the mechanical behavior in the W core.

W-target – Ta shell

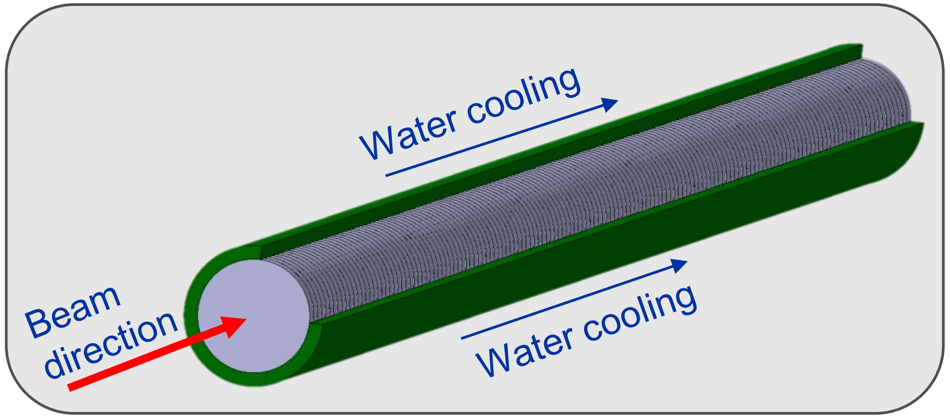
To improve the mechanical behavior in the shell.

W-target – TZM shell + Upstream cooling

To reduce the upstream temperatures and therefore, beam-induced stresses.

WP3 – BDF Target design

Alternative design – The full W target (exploring other options)



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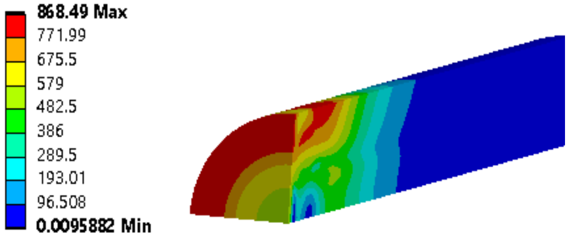
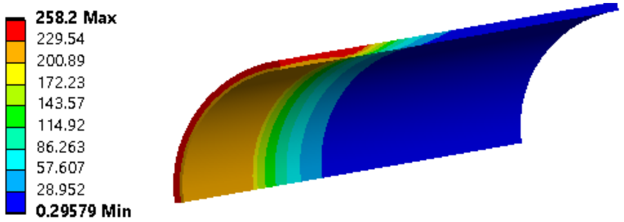


Eq.Stress [MPa]

Single core W-target TZM shell

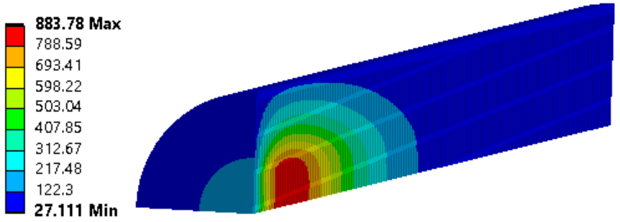
Similar stresses in core.



Eq.Stress [MPa]

Ta shell

Unacceptable mechanical stresses for Ta.



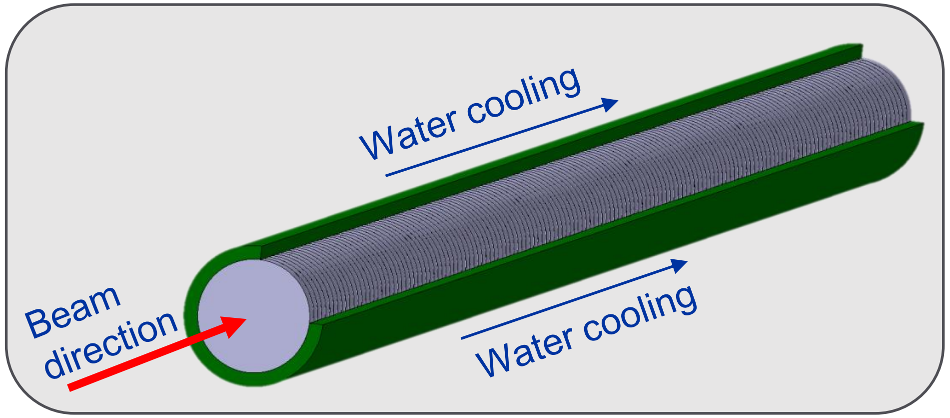
Temperature [Cº]

TZM shell + Upstream cooling

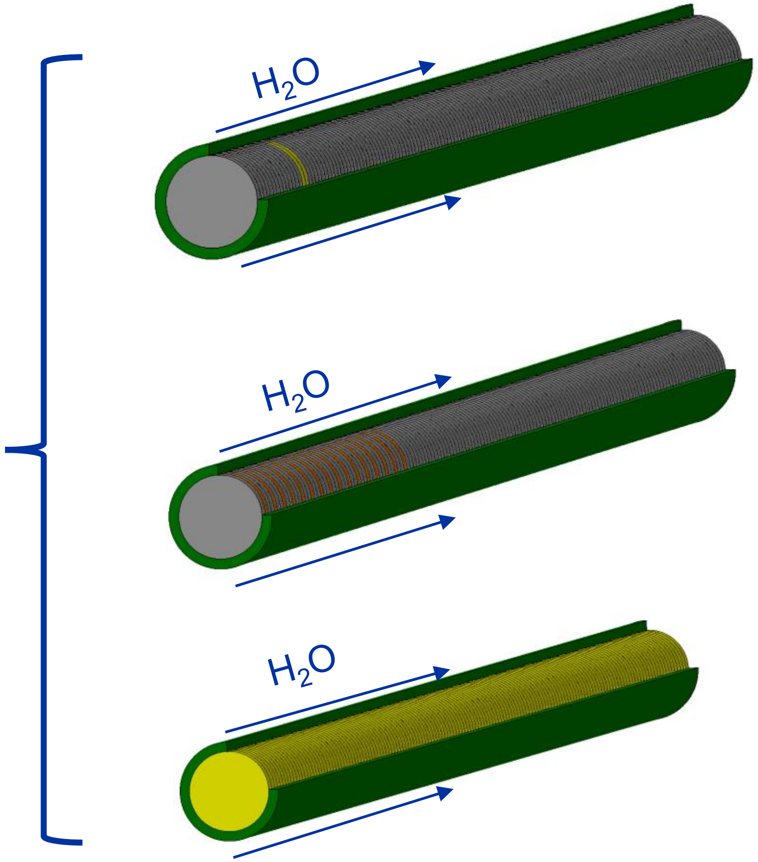
~10% Temperature reduction.

WP3 – BDF Target design

Alternative design – The full W target (exploring other options)



Alternative designs: Full W core with internal sheets



Gold sheets in peak energy density deposition

Enhance heat evacuation with two gold sheets in the location with the highest peak energy density deposition, while keeping the interaction length.

1-mm Copper slices between each W sheet

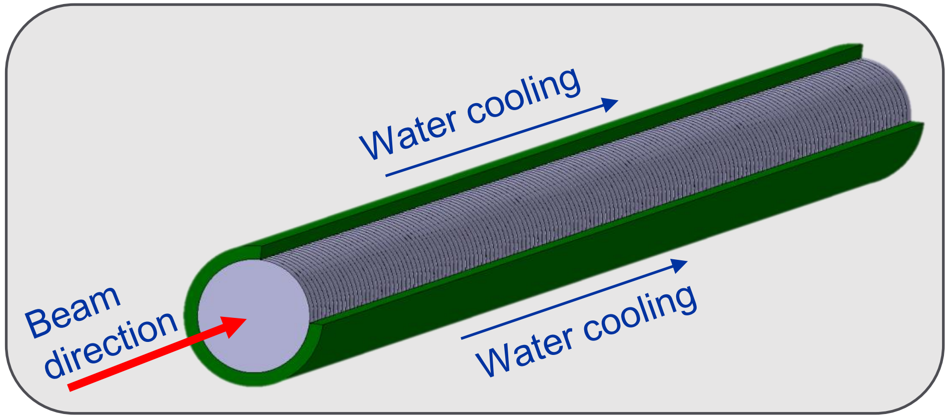
Enhance the heat evacuation in the upstream of the target

The full Gold target

Enhance heat evacuation a full gold target while increasing the interaction length

WP3 – BDF Target design

Alternative design – The full W target (exploring other options)



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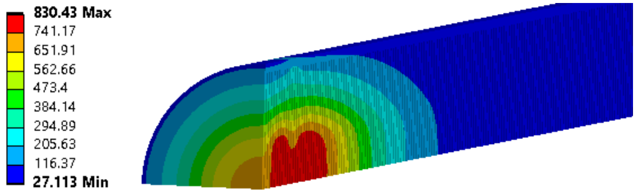
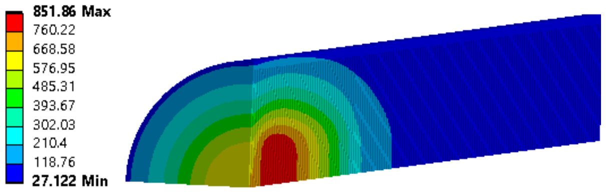


Temperature [Cº]

Gold sheets in peak energy density deposition

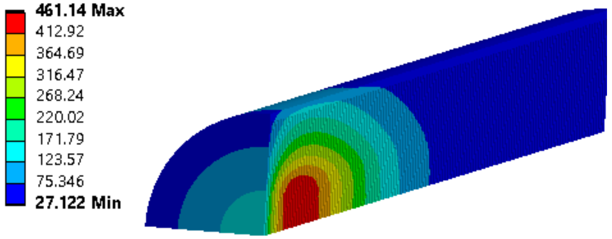
$\sim$15% ***Temperature reduction***



Temperature [Cº]

1-mm Copper slices between each W sheet

$\sim$13% ***Temperature reduction***



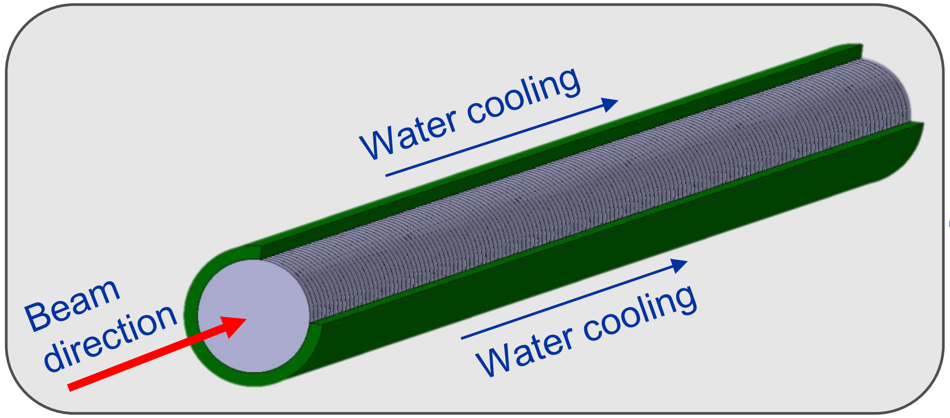
Temperature [Cº]

The full Gold target

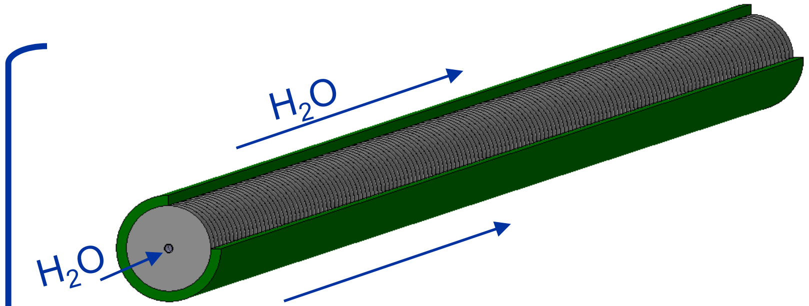
$\sim$53% ***Temperature reduction***

WP3 – BDF Target design

Alternative design – The full W target (exploring other options)

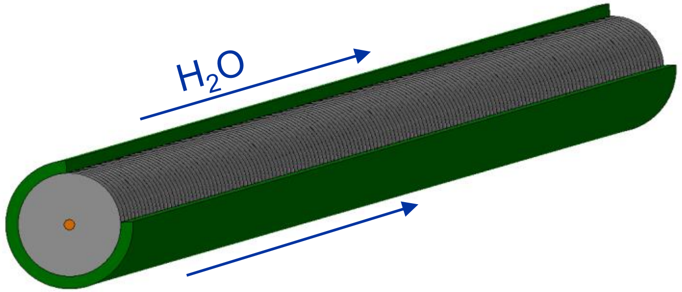


Alternative designs: Full W core with inserts



Ta pipe in the center with Water cooling

To enhance the heat evacuation by introducing a HIP Ta pipe in the center of the target.

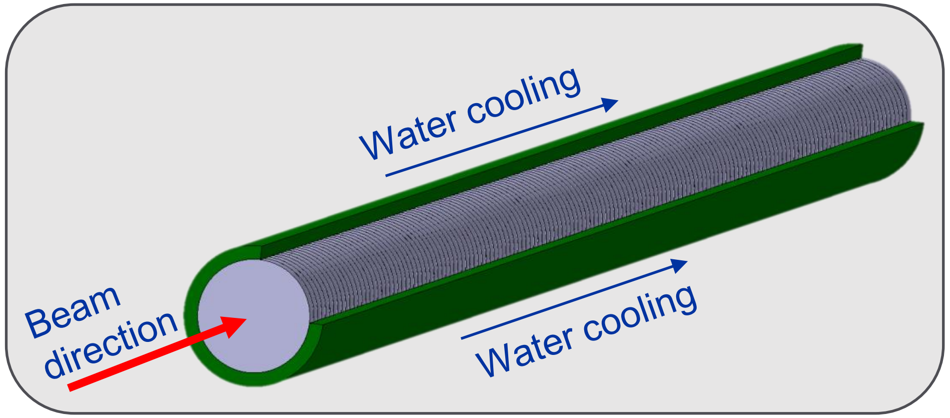


Copper insert in the center

To conduct the heat towards the downstream of the target, where it could be evacuated by means of alternative cooling systems.

WP3 – BDF Target design

Alternative design – The full W target (exploring other options)



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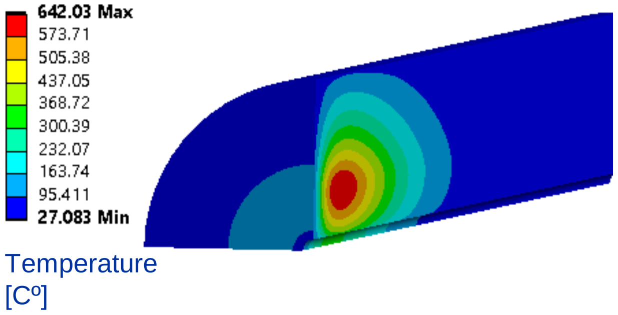
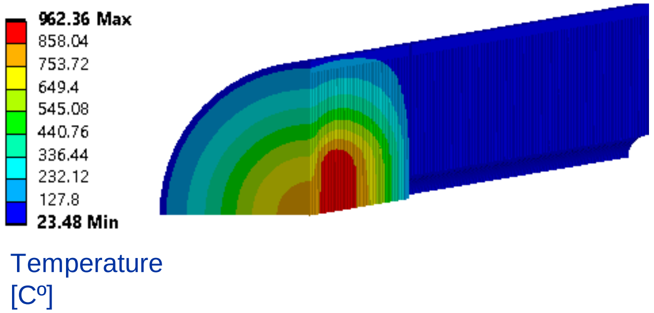


Ta& H_2O pipe in the center

$\sim 35\%$ ***Temperature reduction***

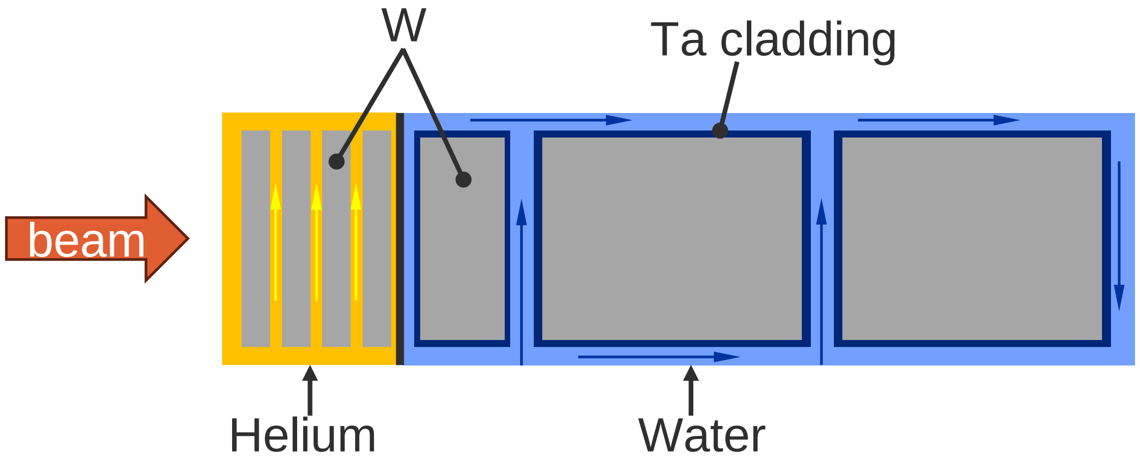


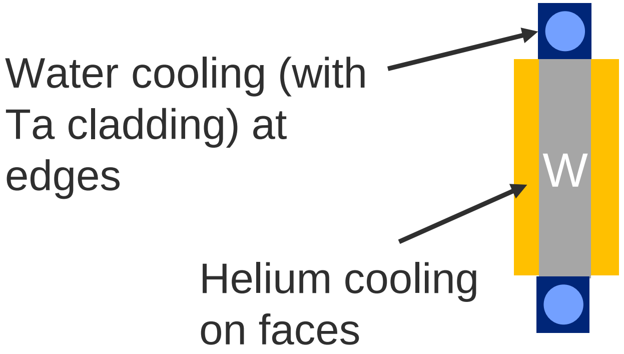
Copper insert in the center

$\sim 2\%$ ***Temperature reduction***

WP3 – BDF. More Alternative Target designs -Helium cooling

W (non-clad) helium cooled, or mix of Helium and Water cooling



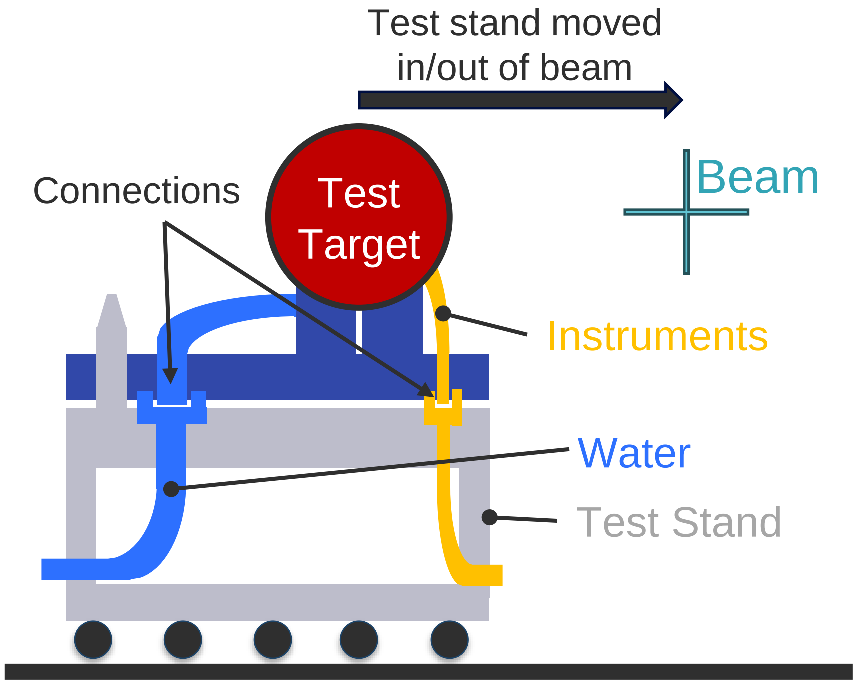


Helium cooled blocks

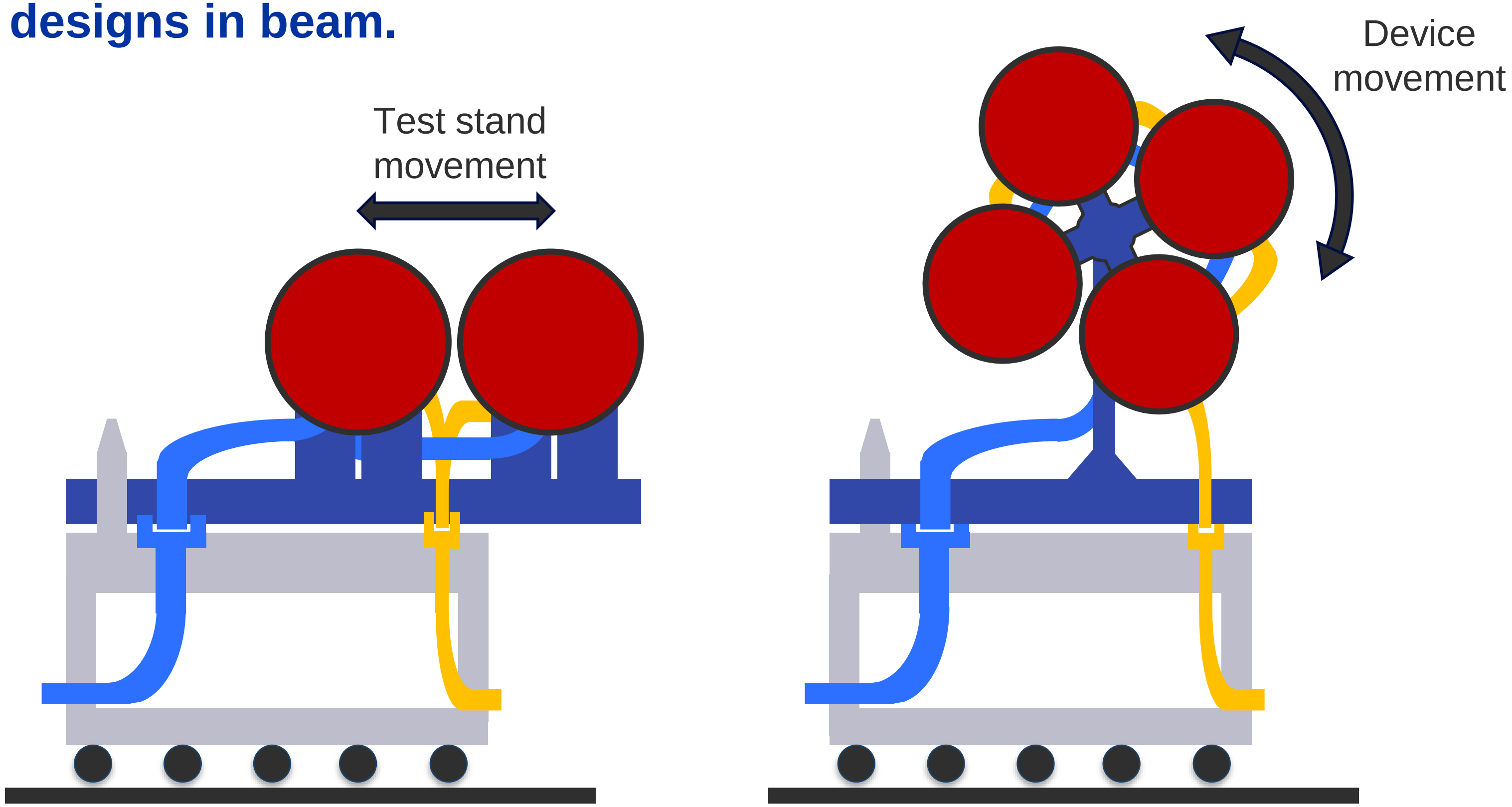
- Removes need for cladding
    - In baseline design, Tantalum has high stress: residual from HIPing + thermal expansion in beam
    - Tantalum bad for accident cases
- Allows higher next-to surface local coolant temperatures (no risk of boiling)
- -But HTC is lower than water
- -Added cooling system complexity and cost
- Studies are ongoing

Target Alternative Designs testing

Scaled representative target(s) will be tested in 400GeV beam in 2025.
Using the Test Stand base, and design of Test Stand top from the Baseline test in 2024
Option exists to test multiple alternative designs in beam.



Test stand setup in 2018.



Alternative options for test/stand in 2025

Conclusions

- **New alternative designs are being explored.**
- **Target with increased W has improved physics**
- **The elimination of the water cooling channels between the core discs:**
  - High stresses in cladding & issues of water in beam (with water channels) will have to be balanced against higher W temperatures and stresses in W (without water channels)
- **The introduction of high thermal conductivity materials such as Copper or Gold:**
  - Promising to reduce the temperature within the core.
  - Issues of thermal expansion mismatch, gold has cost implication
- **We are also exploring “exotic” designs, such as cooling from the centre, or with helium. These studies are in a preliminary phase and may not be viable.**
- **Variations on beam sigma & sweep radius, and target diameter will also be explored.**

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