Beam Intercepting Devices

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CERN Accelerator School, Sint-Michielsgestel, 07 June 2024

Outline

- Introduction to Beam Intercepting Devices (BIDs)
    - **Definition**
    - **Challenges**
    - **Design Procedure**
- Collection of Present and Future Beam Intercepting Devices at the PSI High Intensity Proton Accelerator (HIPA)
- Remote Handling of BIDs
- Conclusion

Definition of BID

A BID is a component that intercepts beam for different purposes

- Production of secondary particles (**Targets**)
- Beam cleaning / shaping (**Scrapers / Collimators / Slits**)
  - Protection of sensitive components
  - Concentrate beam losses in one specific location: avoid spreading beam losses over a long beam line section (Keep machine maintainable!)
- Absorb/Dispose “unused” beam (**Beam Dump**)

Challenges of BIDs: The Beam

- In **High Power / Energy Proton Machines** (HIPA, ESS, LHC) the beam can deposit **enormous amounts of power/energy**

- **The way the power is deposited on BIDs depends on the kind of machine**
  - **Continuous Wave**: Power constantly and homogeneously deposited in time

    Ex: HIPA (PSI) 590 MeV, **1.4 MW continuous power**, **50.7 MHz** cyclotron frequency
  - **Pulsed-Beam**: Power deposited constantly but concentrated in pulses

    Ex: SNS (ORNL) 1 GeV protons, **1.4 MW average power**, **60 Hz** repetition rate

    ESS (LUND) 2.5 GeV protons, **5 MW average power**, **14 Hz** repetition rate
  - **Circulating Beam**: Energy deposited on beam dump at the end of each run

    Ex: LHC (CERN) 6.8 TeV protons, **539 MJ** stored energy, **6TW instantaneous** power (89 μs)

Challenges of BIDs: The Risks

A BID can be exposed to (extremely) high:

- **Temperature** (**100s to 1000s °C**): absolute and distribution (hot spot regions)
  - Can lead to deformation or melting
- **Stress** (**100s of MPa**)
  - Can lead to plastic deformation (> Yield Stress) or fracture (> Ultimate Tensile Stress)
- **Radiation Damage** (**several DPAs**, Displacements per Atom)
  - Can lead do swelling, embrittlement, etc.
- **Activation** (**100s of Sv/h**)
  - Problematic handling and disposal

BIDs Design Aspects

- Essential aspects
  - **Geometry**
  - **Material choice**: Physics requirements (Targets), Structural Behavior, Activation
  - **Power/Energy Deposition**: Through beam and/or thermal radiation from neighboring components
  - **Thermal analysis**: Max Temp. and Temp. Distribution
  - **Structural analysis**: Stress, Deformation, Fatigue
  - **(Water) Cooling**: Erosion, Corrosion, Wear (Pipe Material, Water Flow Rate), Cavitation, Boiling, Pressure Drop
  - **Environment**: Vacuum, Shielding, Surrounding Components
  - **Operational Safety**: Critical vs Replaceable BIDs
  - **Manufacturing feasibility**
  - **Installation/Removal/Handling**
- Other important points
  - Movable parts
  - Diagnostics, Monitoring (temperature, vibrations, cooling water flow, ...)

BIDs Design: Power Deposition

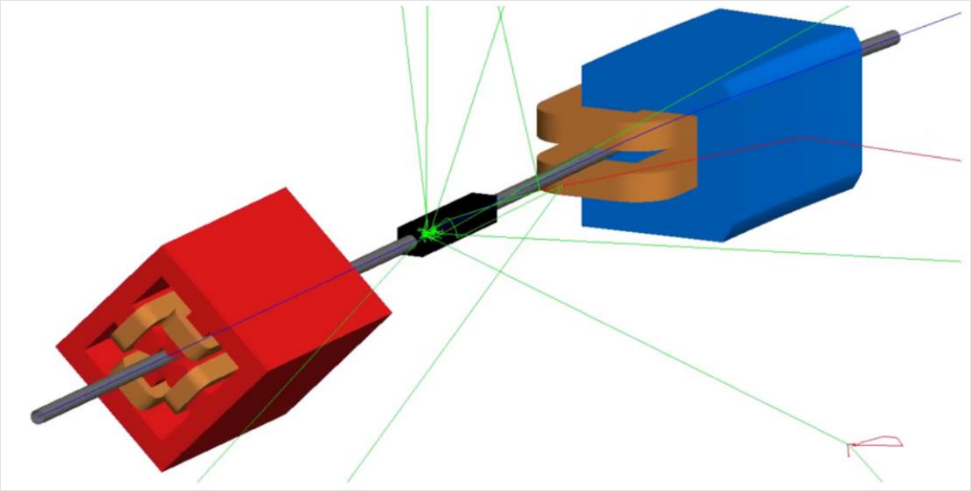
- The **Energy or Power deposited by the beam in a BID (unit: J/m^3 and W/m^3 resp.)** depends on
  - **Beam properties**
  - **BID Material and Geometry**

- **Energy deposited** $\Delta \boldsymbol{Q}$ and **temperature increase** $\Delta \boldsymbol{T}$ of BID related through material **density** ρ and **specific heat capacity** c of BID:

$$\Delta \boldsymbol{Q} = \frac{\Delta \boldsymbol{T}}{\rho\, \boldsymbol{c}}$$

- Well-established **Beam-Matter Interaction Monte Carlo Codes** can assess this figure:
  - **MCNP, FLUKA, BDSIM, MARS, …**

- In some cases, (simple geometry, thin BID) this assessment can be performed analytically with good approximation



BIDs Thermomechanical Aspects: Heat Dissipation

The Heat deposited in a BID can diffuse through different processes

Heat Conductivity [W/(mK)]

Material Thickness [m]

- **Conduction:** $\dot{q} = k\,(T_{out} - T_{in})/L$

  Within Solid

Heat Flux [W/m²]

Heat Transfer Coefficient [W/(m²K)]

- **Convection:** $\dot{q} = h\,(T_{surface} - T_{fluid})$

  Between Solid and Fluid

Heat Flux [W/m²]

Stefan–Boltzmann Constant: $5.67\text{x}10^{-8}$ W/(m²K⁴)

- **Radiation:** $\dot{q} = \sigma\,\varepsilon\,T^4$

Emissivity [0-1]

Choice of Cooling Method must take boundary conditions into account:

Material, Temperature, Emissivity, Thickness, Moving Parts, etc.

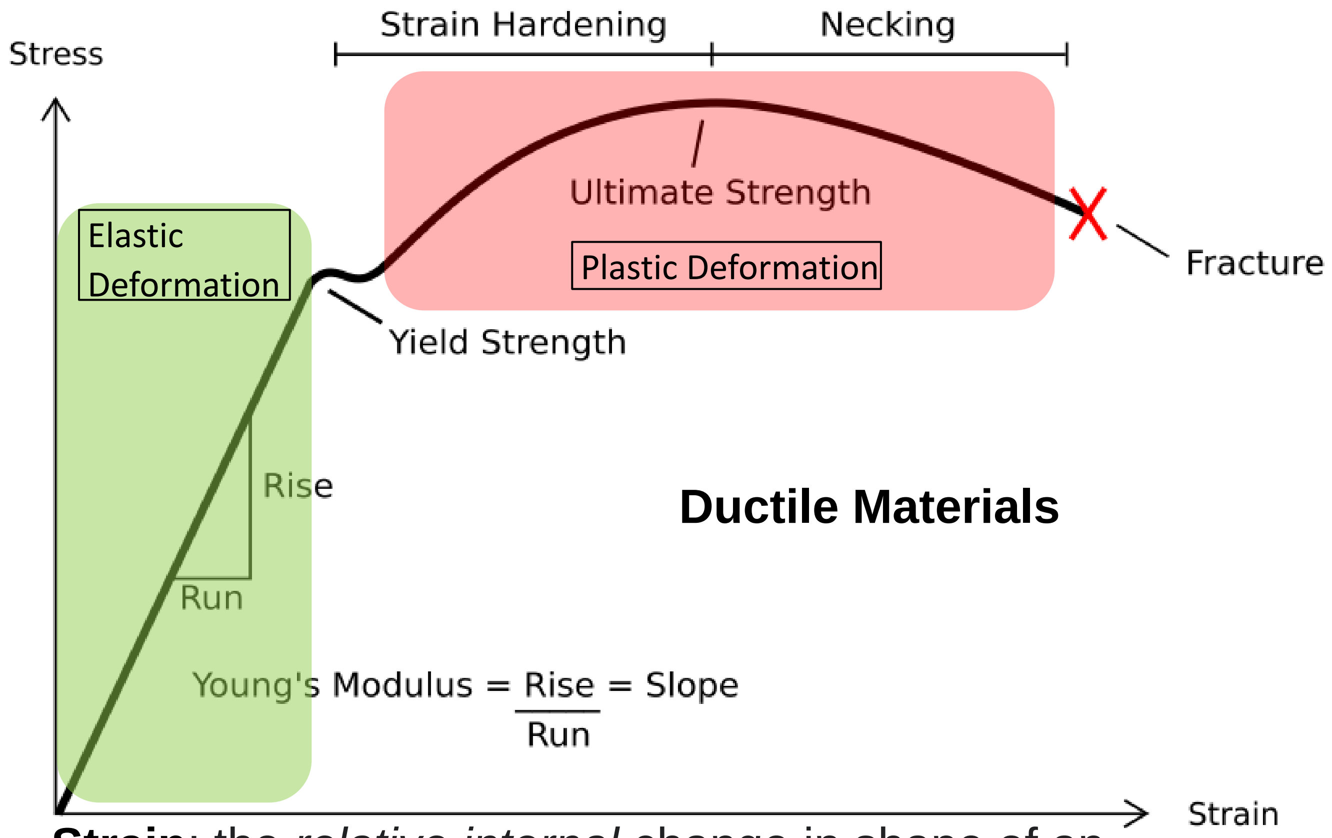
BIDs Thermomechanical Aspects: Stress

Stress describes forces present during deformation [Pa]

Depending on the force direction stress causes different sort of **Deformations:**

Tensile: elongation
Compressive: shortening
Flexural: Bending

Deformation can be
Elastic (Young's Modulus < Yield Strength)
Plastic (Stress > Yield Strength)
Fracture (> Ultimate Strength)



Ductile Materials

Strain: the *relative internal* change in shape of an infinitesimal cube of material [mm/mm]

In BIDs, the main source of **stress** is typically the **non uniform temperature distribution** generated by interaction with the beam

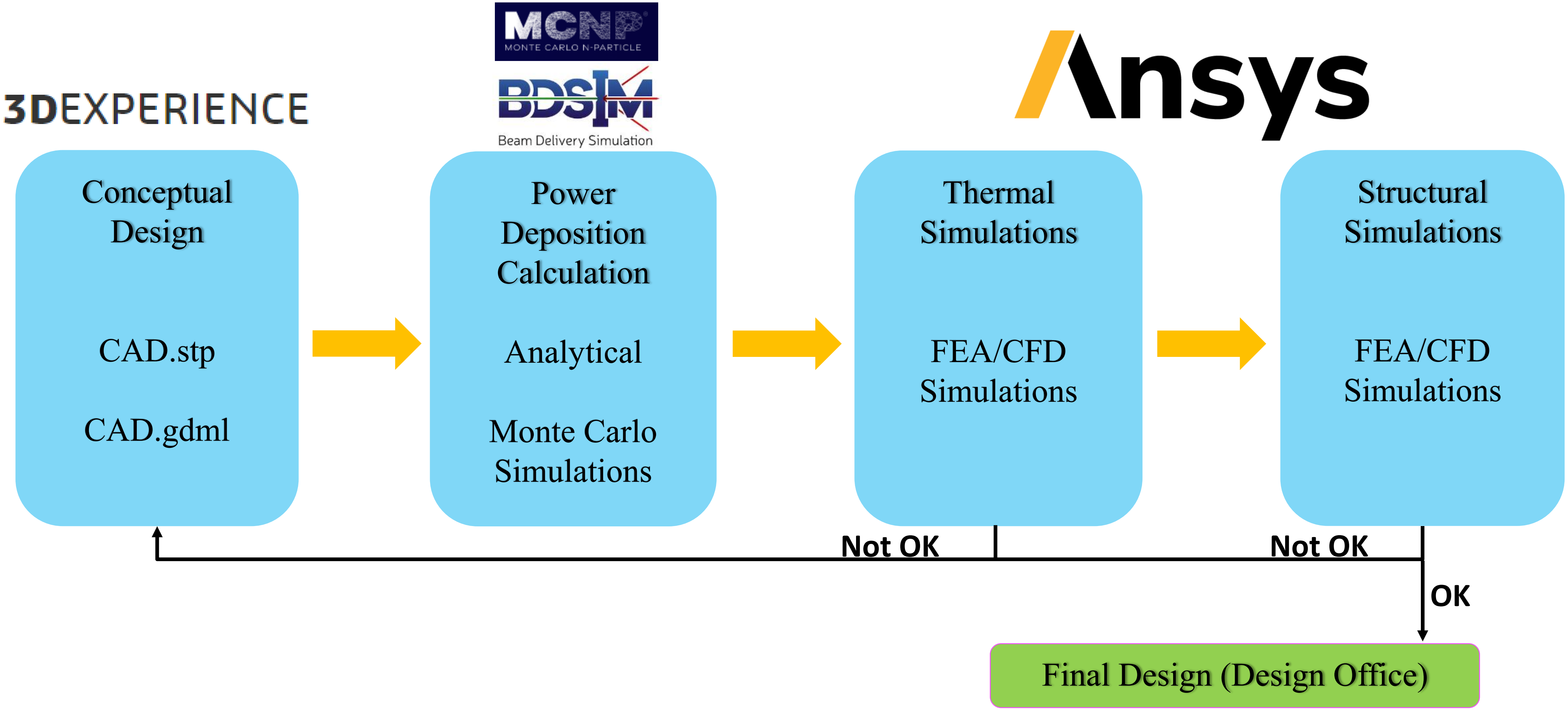
Finite Elements Method/Analysis (FEM/FEA)

For **BID Thermomechanical and Fluid Dynamics Analysis**
FEA-Solver and Computational Fluid Dynamics (CFD)
Multiphysics Simulations Tools are available

- All FEA/CFD calculations presented in this lecture carried out using **ANSYS®**
- Other tools (like COMSOL, OpenFOAM) can also be employed
- FEA/CFD Simulations need **HPC resources** and can be extremely **time consuming**
  - Ex: CFD Simulation of ¼ of the SINQ Target (over 1 Million Cells) on a 20 cores machine with 1.5 TB RAM → **2 Months**

BID Design Workflow

PSI



3DEXPERIENCE

MCNP
MONTE CARLO N-PARTICLE

BDSIM
Beam Delivery Simulation

Ansys

Conceptual Design

CAD.stp

CAD.gdml

Power Deposition Calculation

Analytical

Monte Carlo Simulations

Thermal Simulations

FEA/CFD Simulations

Structural Simulations

FEA/CFD Simulations

Not OK

Not OK

OK

Final Design (Design Office)

What is this Lecture (not) About?

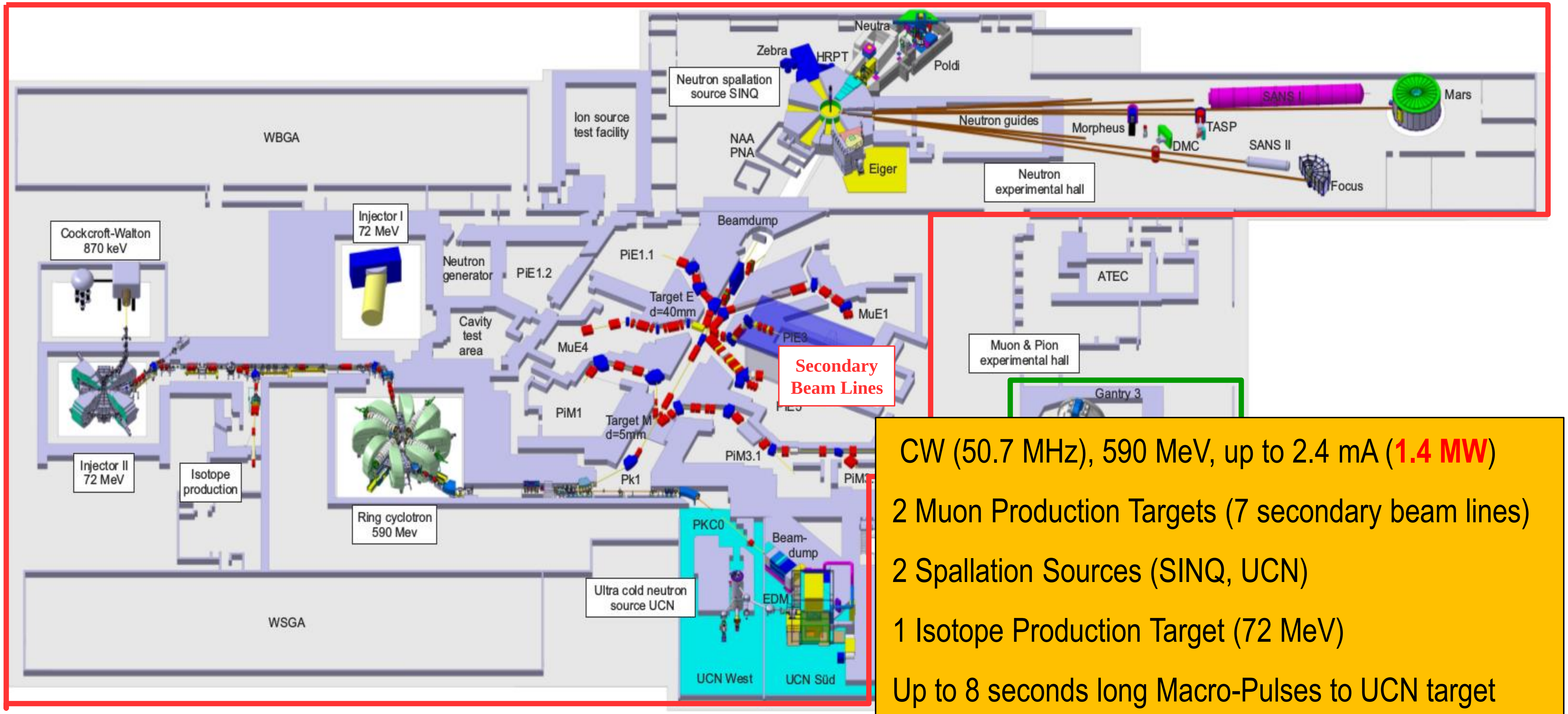
- **Overview of BIDs at the PSI High Intensity Proton Accelerator (HIPA)** ✓
- **Won’t cover other facilities/labs** ✗
- **Won’t enter details of MC or Multiphysics Simulation Codes** ✗

BIDs@CERN by Marco Calviani:

https://indico.cern.ch/event/980520/

https://indico.cern.ch/event/980519/

The High Intensity Proton Accelerator (HIPA)



CW (50.7 MHz), 590 MeV, up to 2.4 mA (**1.4 MW**)

2 Muon Production Targets (7 secondary beam lines)

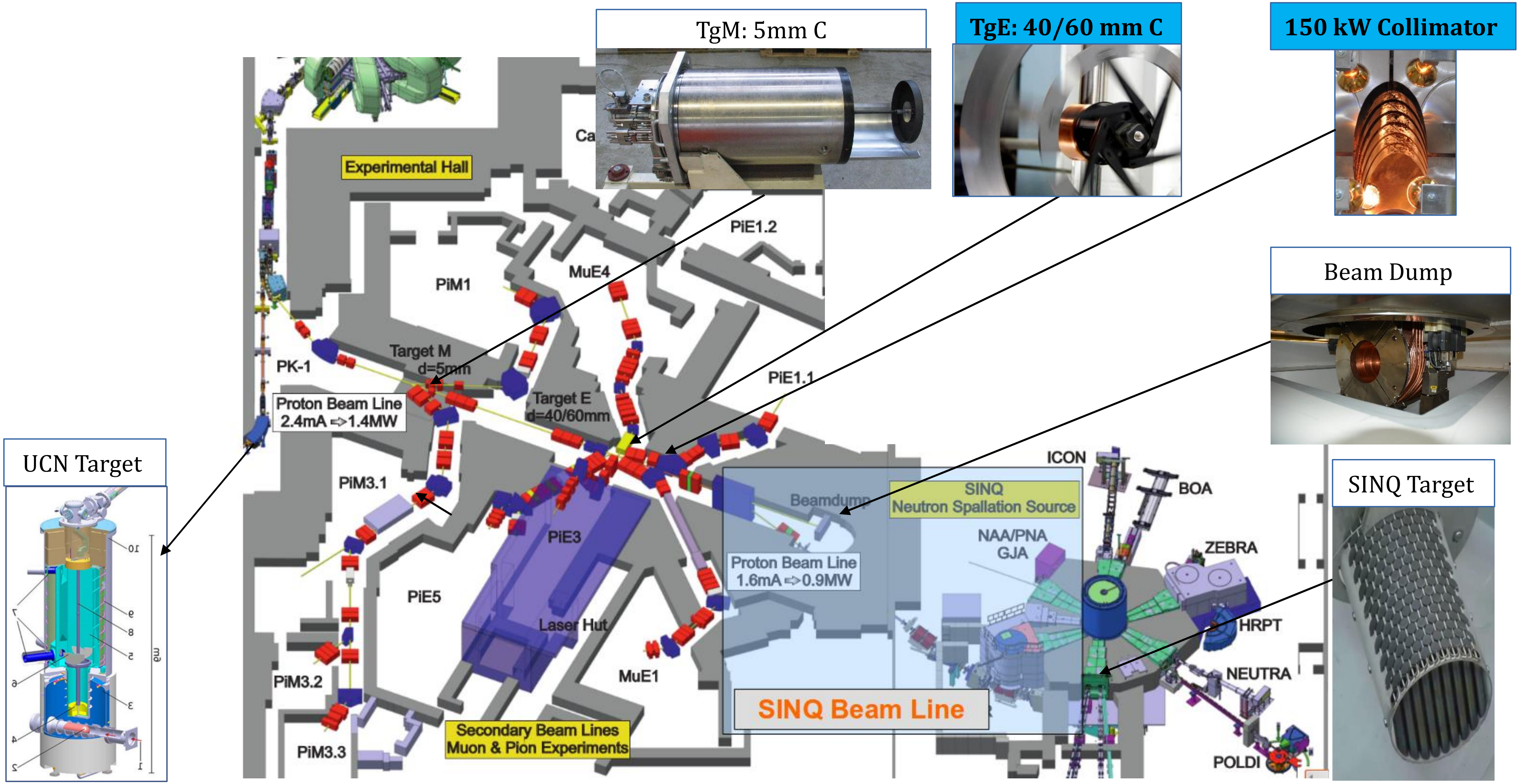
2 Spallation Sources (SINQ, UCN)

1 Isotope Production Target (72 MeV)

Up to 8 seconds long Macro-Pulses to UCN target

High availability (~90%), stable operation.

BIDs in the 590 MeV, 1.4 MW Proton Channel

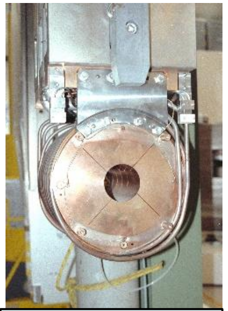


Target E (TgE) Region: 30% Beam Losses

Target Wheel
8% beam loss

Local
Shielding

Target
Chamber



Collimators 0&1

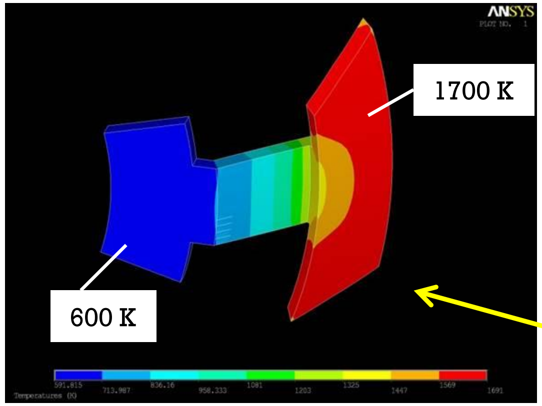
Collimators 2&3
14% beam loss

TgE Wheel Design

Since 2003:
Modified design with **gaps** to allow for thermal expansion

TARGET WHEEL

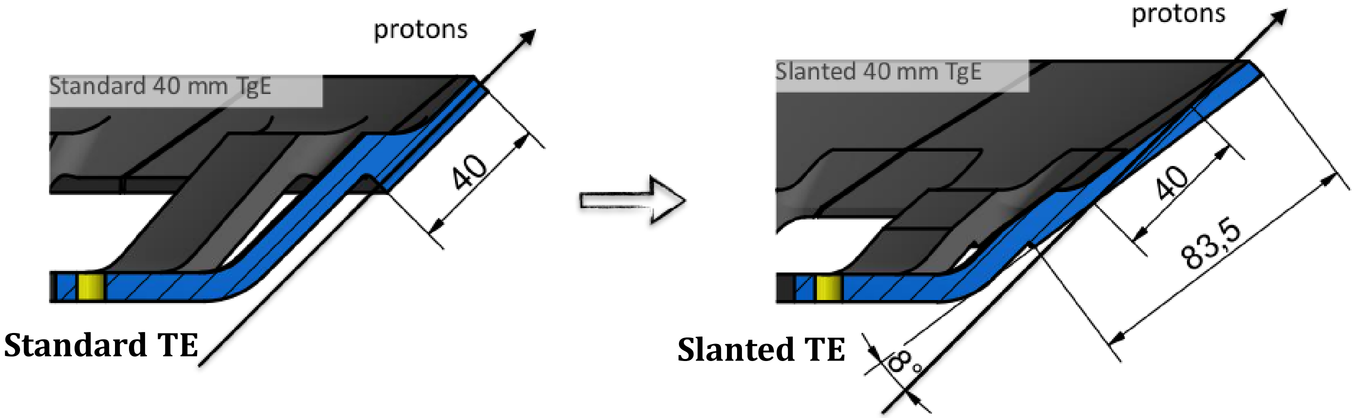
Secondary Particles:	**Muons, Pions**
Material:	**Polycrystalline Graphite**
Mean diameter:	450 mm
Graphite density:	1.8 g/cm^3
Operating Temperature:	**1500 ° C**
Irradiation damage rate:	0.1 dpa/Ah
Rotation Speed:	**1 Turn/s**
Target thickness:	**40** (or 60) **mm**
Beam loss:	**30** (or 42) **%** (after collimation)
Power deposition:	**20 kW/mA** (40 mm thickness)
Cooling:	**Radiation**

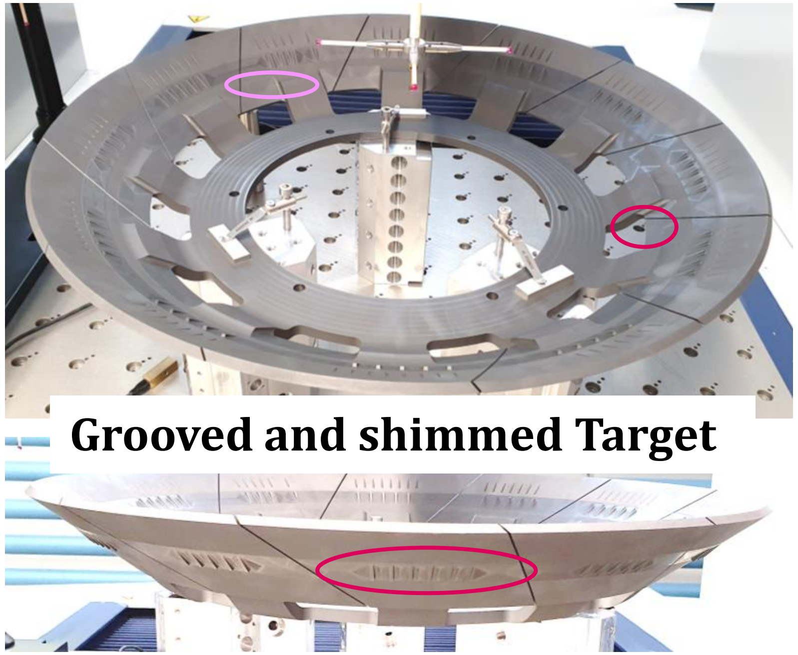


Temperature distribution simulation

Slanted TgE Design

New Slanted Target E tested in 2019 and in operation since 2020

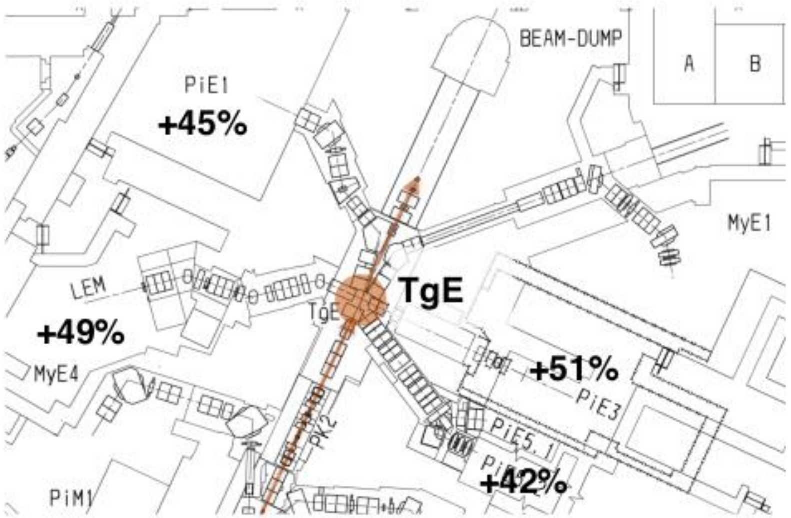




Grooved and shimmed Target

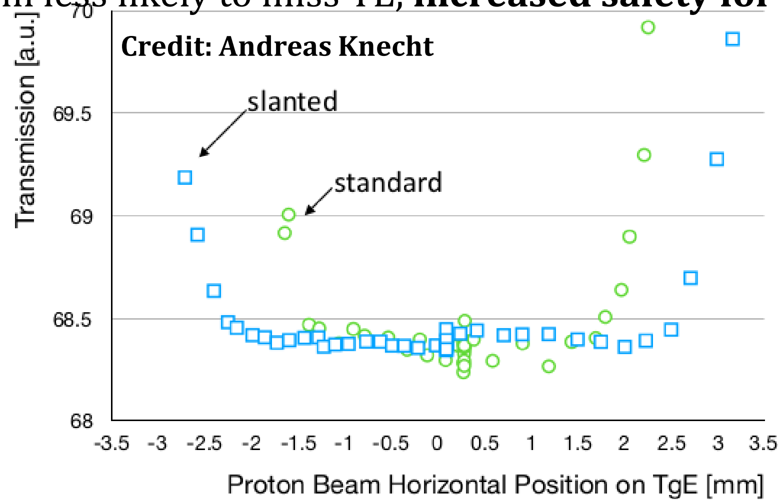
Advantages of Slanted Geometry:

Surface muon rates increase by ~50%



Credit: Andreas Knecht

p-beam less likely to miss TE, **increased safety for SINQ Target**

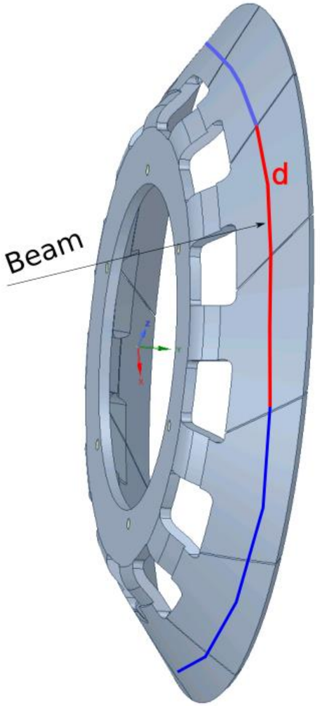


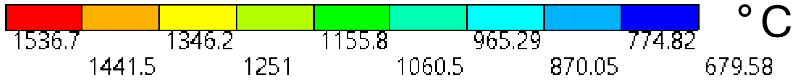
Credit: Andreas Knecht

Straight and Slanted TgE: Temperature Distribution

Steady-state case: simplify and speed up simulation process

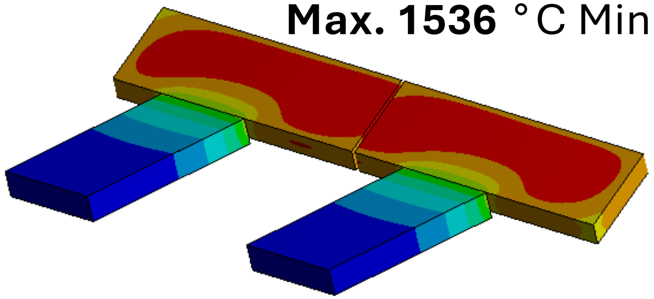
- **No target rotation**
- **Equivalent planar geometry** (no surface curvature)
- **Beam power deposition** integrated along y-coordinate and **smeared on the perimeter of the full target**
- Consider only **2 target tiles** rescaling the current accordingly.





Straight Target

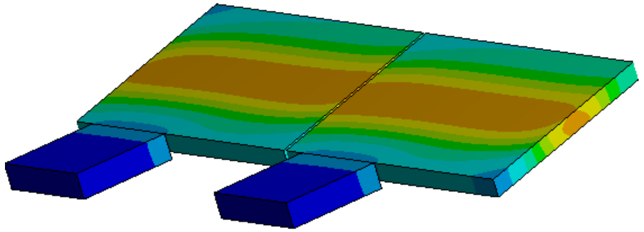
Max. 1536 ° C Min. 679 ° C



Slanted Target Version: 2319

beam entry angle 8 °

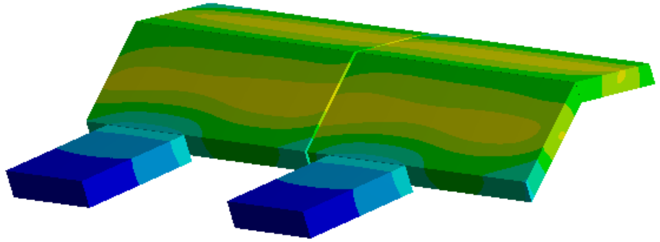
Max. 1459 ° C Min. 703 ° C



Slanted Target Version: 2320

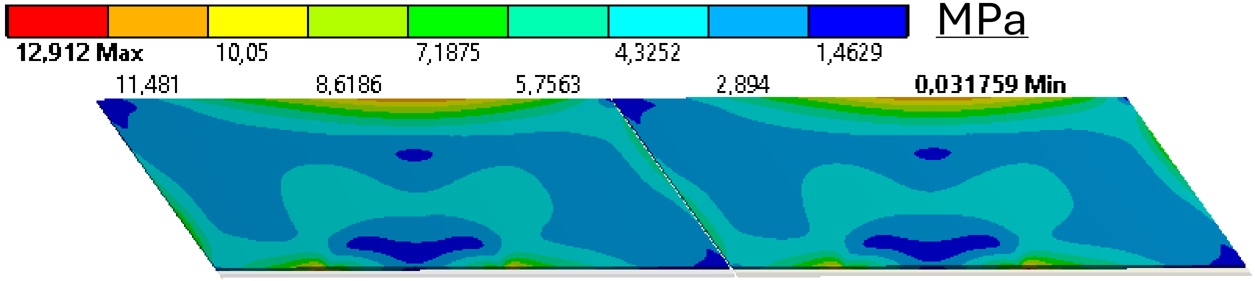
beam entry angle 17 °

Max. 1322 ° C Min. 739 ° C

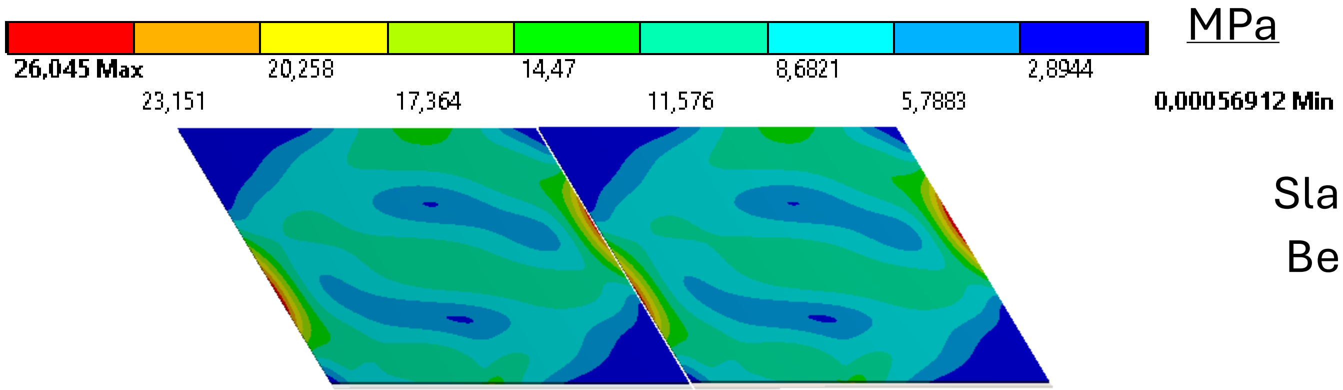


Straight and Slanted TgE: Stress Distribution

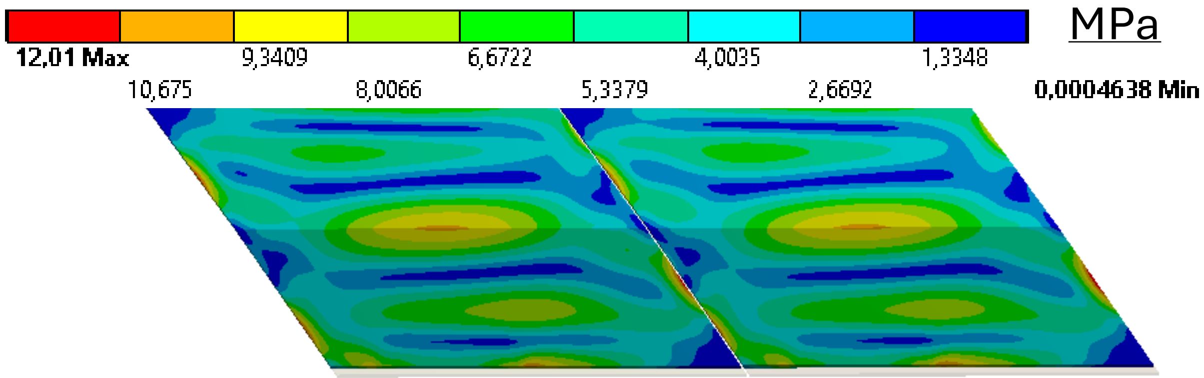
Equivalent planar geometry employed for simulations!



Straight Target
Max. ~ 13 MPa



Slanted version: 2319
Beam entry angle 8 °
Max. ~ 26 MPa



Slanted version: 2320
beam entry angle 17 °
Max. ~ 12 MPa

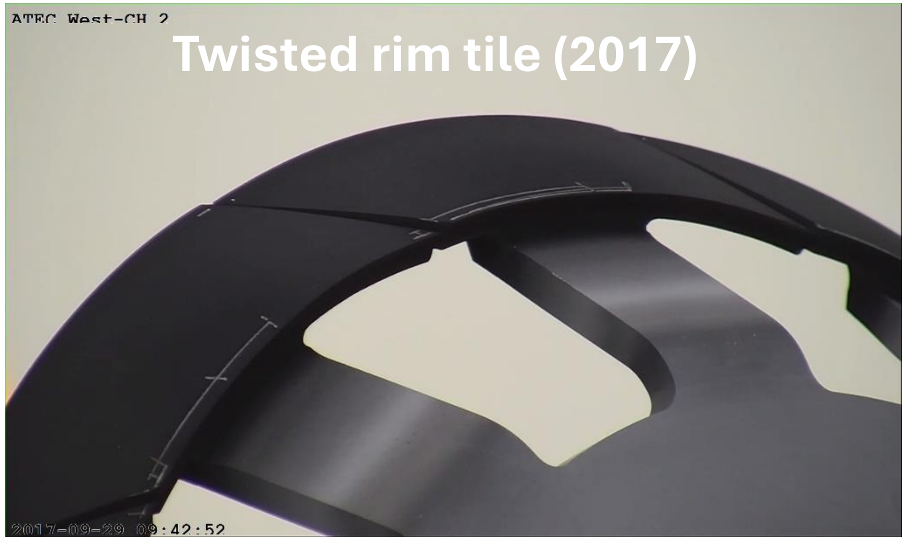
Ultimate Tensile Stress
POCO graphite
(employed for PSI Targets):

~38 Mpa

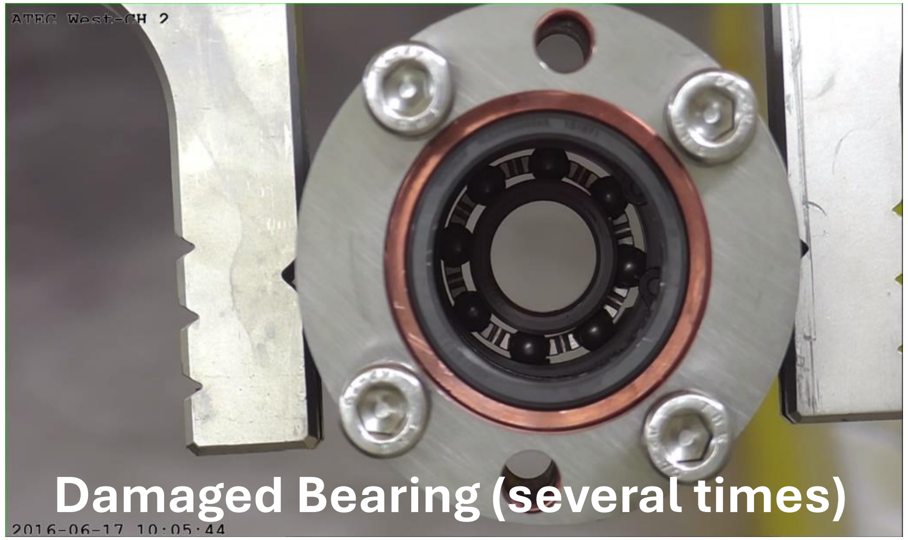
(at room temperature, **larger for higher temperatures**)

Version 2319 chosen due to larger muon production

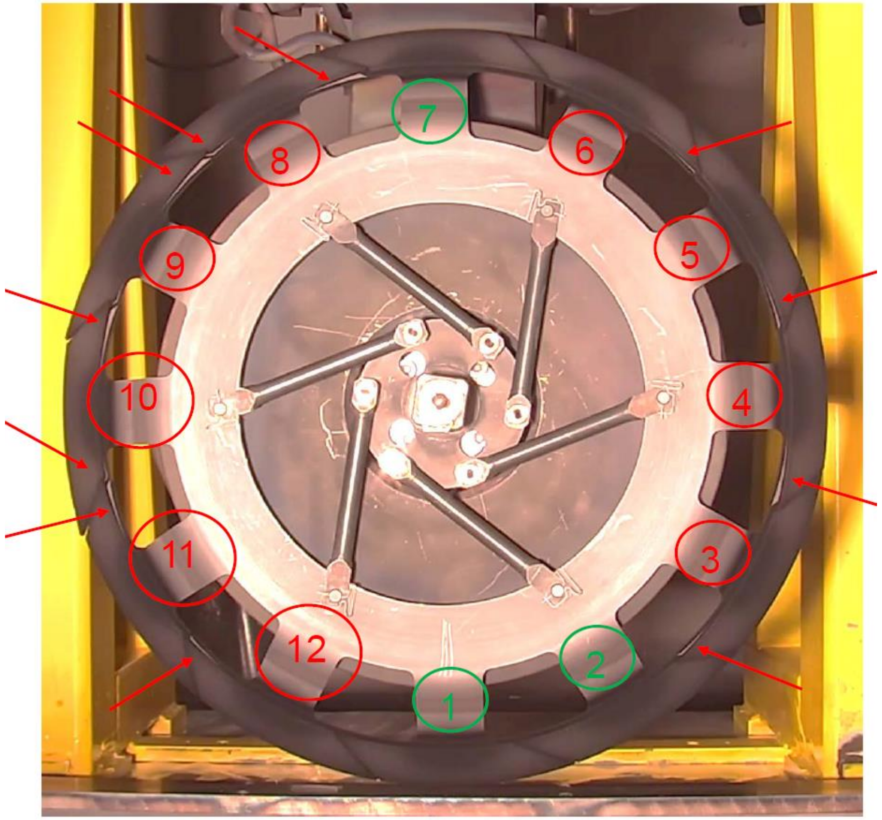
TgE Incidents

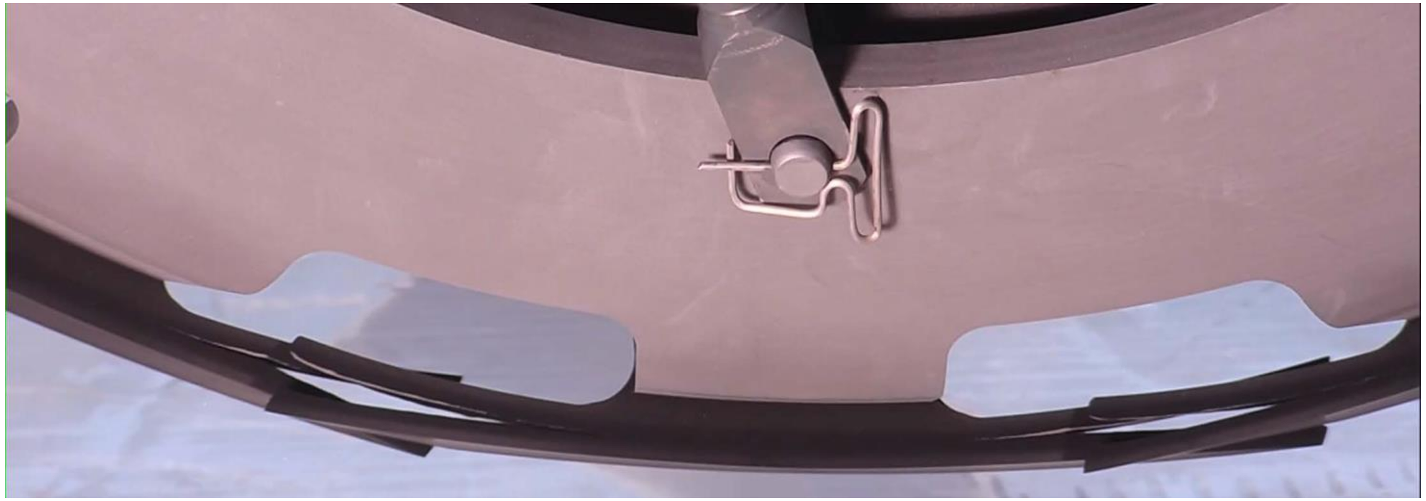


Twisted rim tile (2017)



Damaged Bearing (several times)





Rim cut in beam direction in 9 tiles (2014)

Possible explanation: beam running while switching target rotation on (Interlock failure?)

TgE Collimator KHE2

Collimator Material

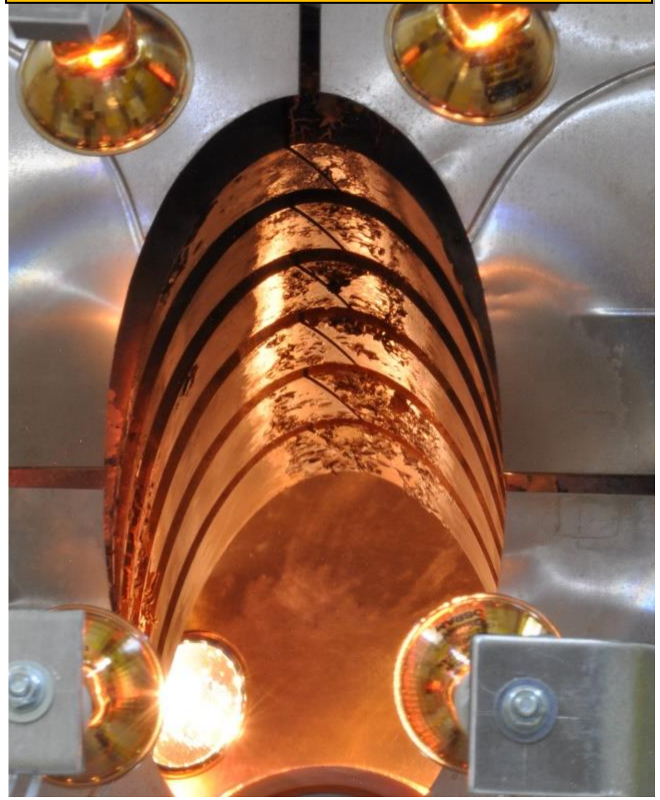
Body: OFHC: oxygen-free high thermal conductivity copper

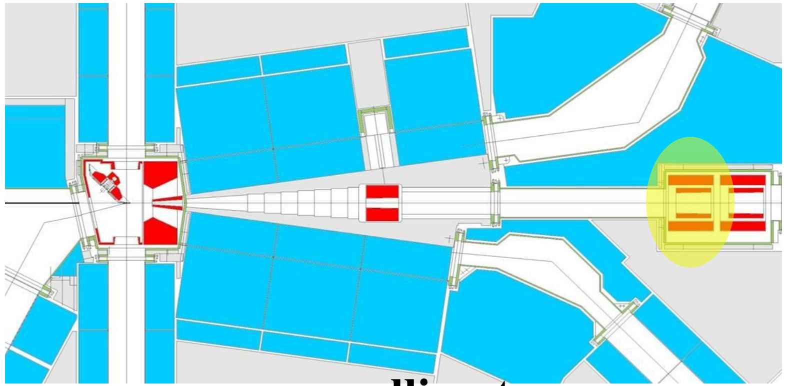
Cooling Water Pipes: **Stainless Steel**

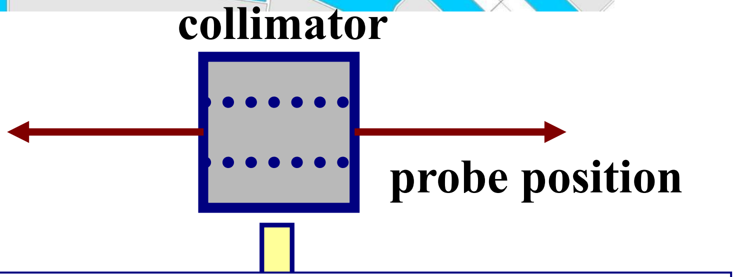
Absorbed beam power: 150 kW

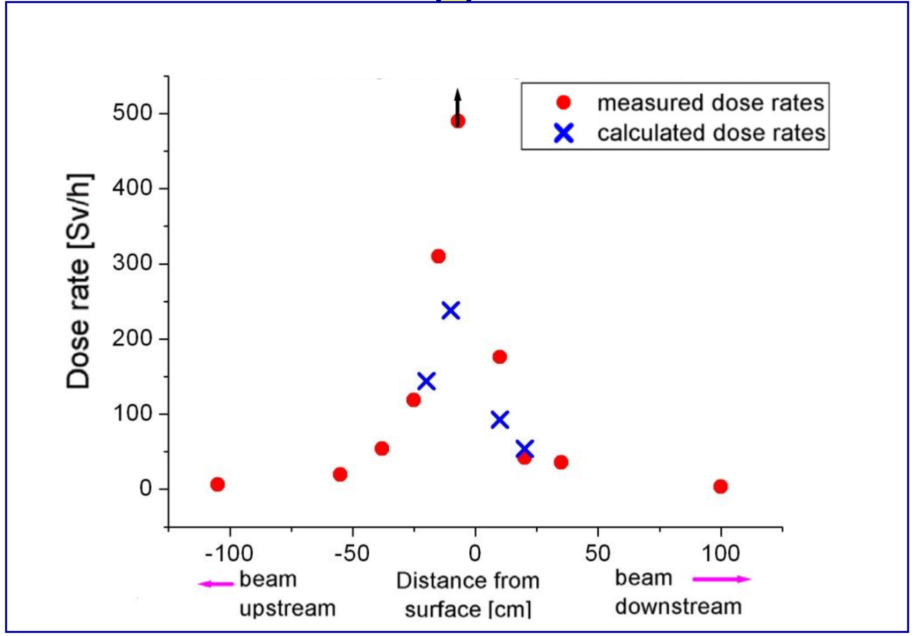
KHE2 during installation (1990)…

…and after 20 years operation (120 Ah total beam charge)



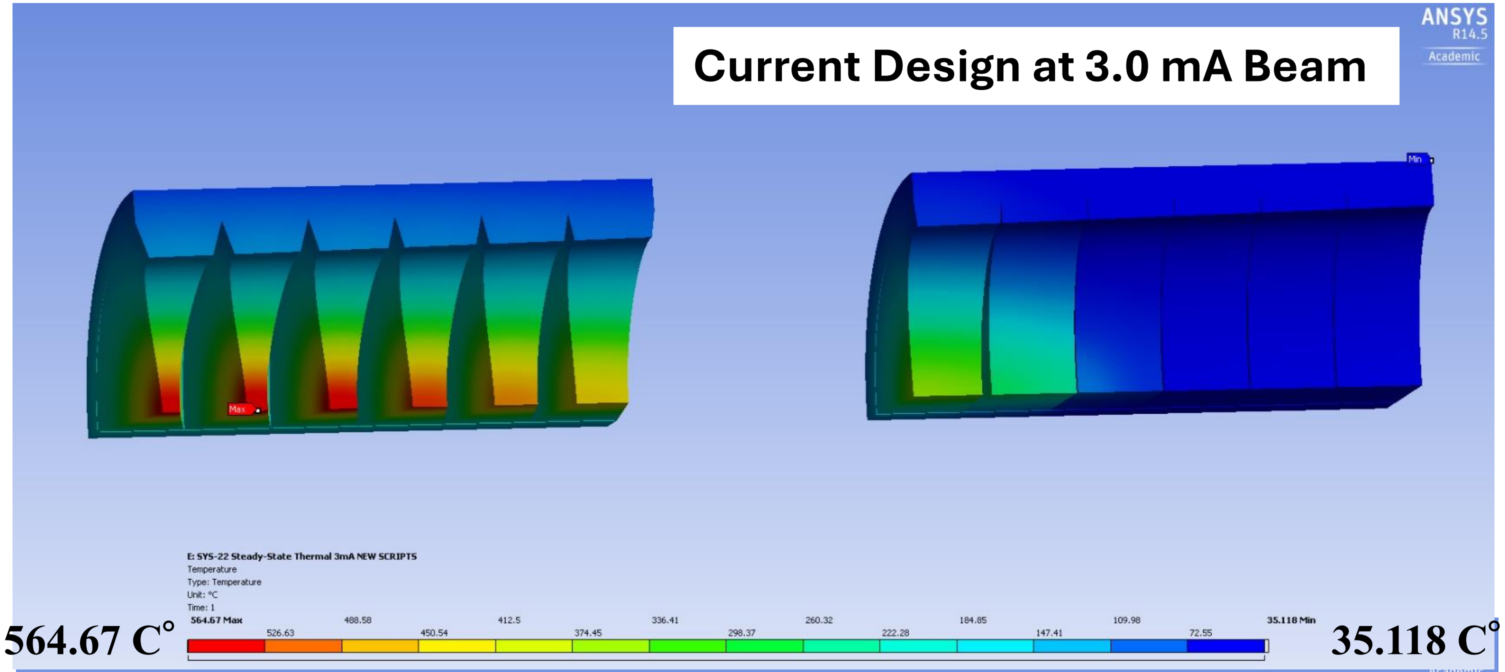






Dose rate up to 500 Sv/h measured at KHE2 during inspection in March 2010!!

KHE2/3: New Design for future 3.0 mA Beam

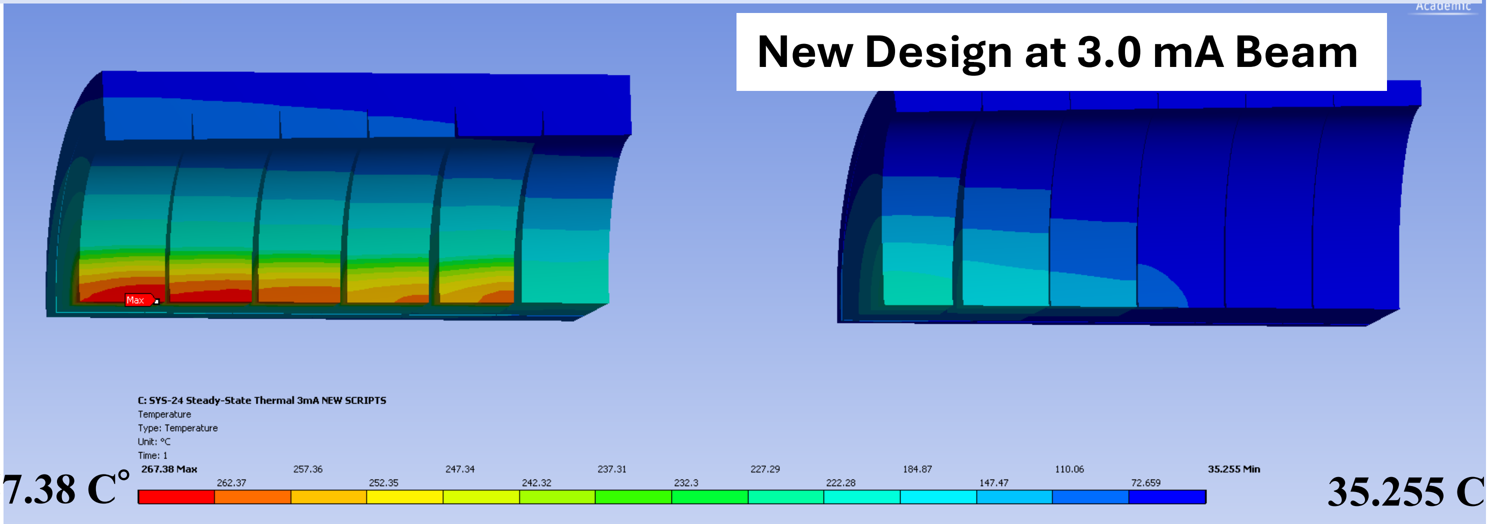


Current Design at 3.0 mA Beam

E: SYS-22 Steady-State Thermal 3mA NEW SCRIPTS
Temperature
Type: Temperature
Unit: °C
Time: 1

564.67 C°

35.118 C°



New Design at 3.0 mA Beam

C: SYS-24 Steady-State Thermal 3mA NEW SCRIPTS
Temperature
Type: Temperature
Unit: °C
Time: 1

267.38 C°

35.255 C°

Copper Temp. **Safety Limit = 405 °C** (~2.6 mA beam)

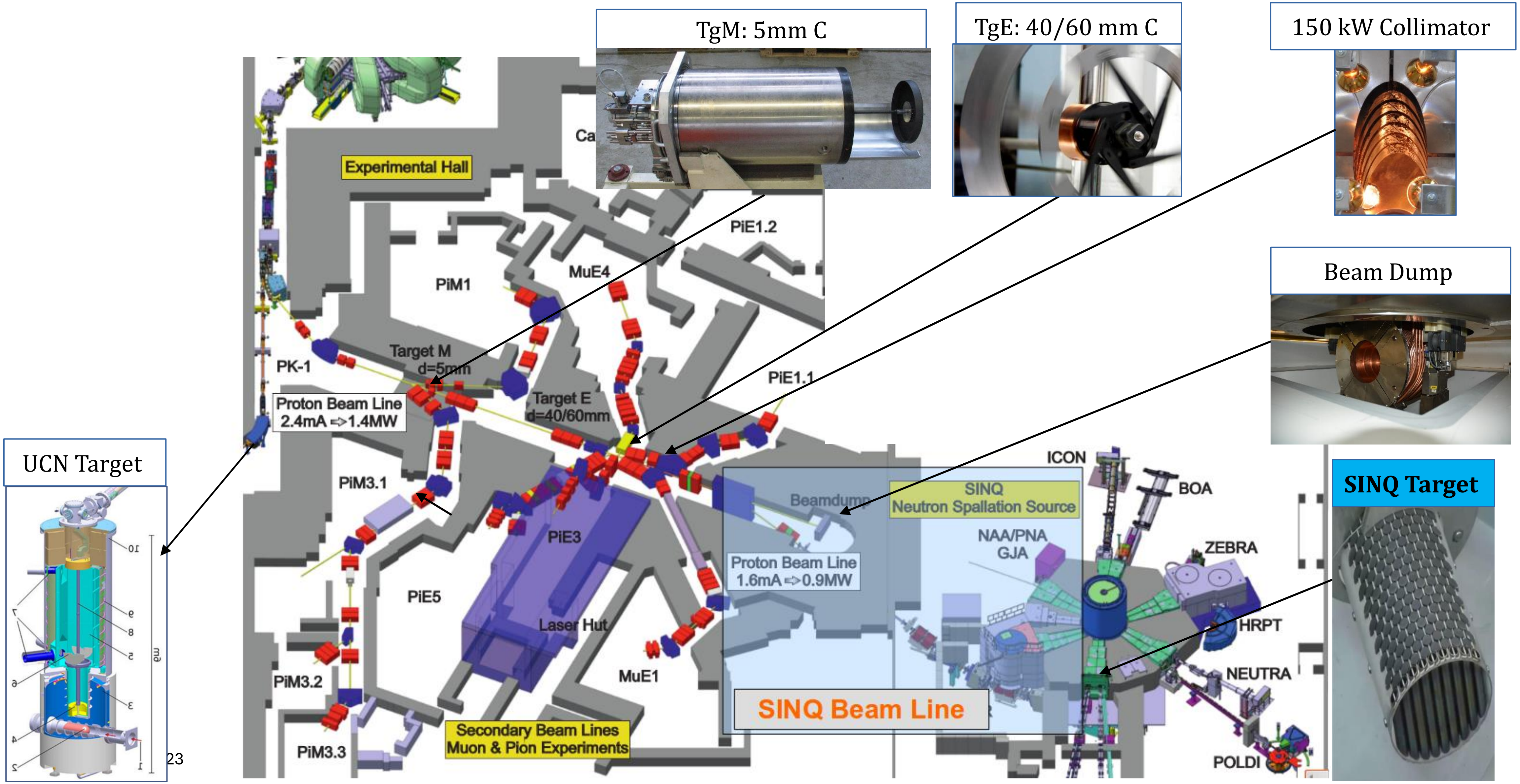
Homologous temperature from which recrystallisation and creep start to occur.
Rule of thumb : T_homologous [K]= 0,5*T_melting [K]

Current KHE2/3 Design
Temperature Distr. for 3.0 mA
Proton Beam on Target E
Tmax = 565 °C

➡ **New Collimator required for 3.0 mA beam!**

New KHE2/3 Design
Temperature Distr. for 3.0 mA
Proton Beam on Target E
Tmax = 267 °C

BIDs in the 590 MeV, 1.4 MW Proton Channel


TgM: 5mm C

TgE: 40/60 mm C

150 kW Collimator

Beam Dump

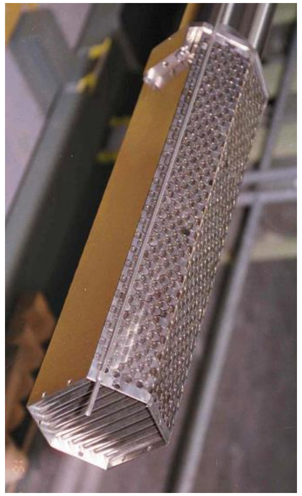
SINQ Target

UCN Target

SINQ Target: a bit of History

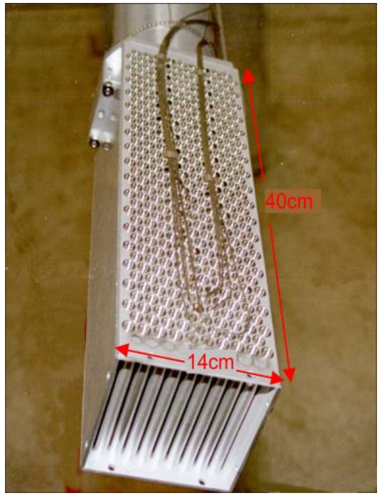
- SINQ **neutron spallation source** commissioned in 1996
- Target material: Zircalloy/Lead (previously Steel/Lead)
- Active target cooling: heavy water circuit
- ~15 targets employed so far: continuous development
- Target lifetime: 2 years
- Up to ~1 MW beam power fully stopped on target

MARK I



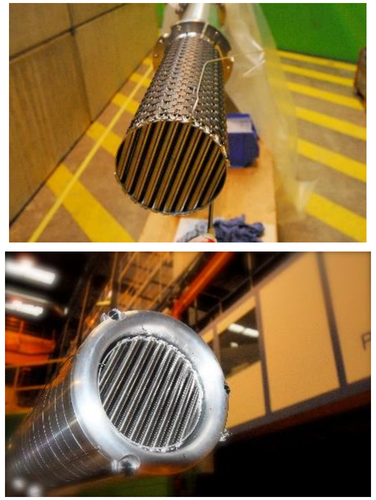
Start-up target: solid Zircaloy rods 1997-1999

MARK II / III

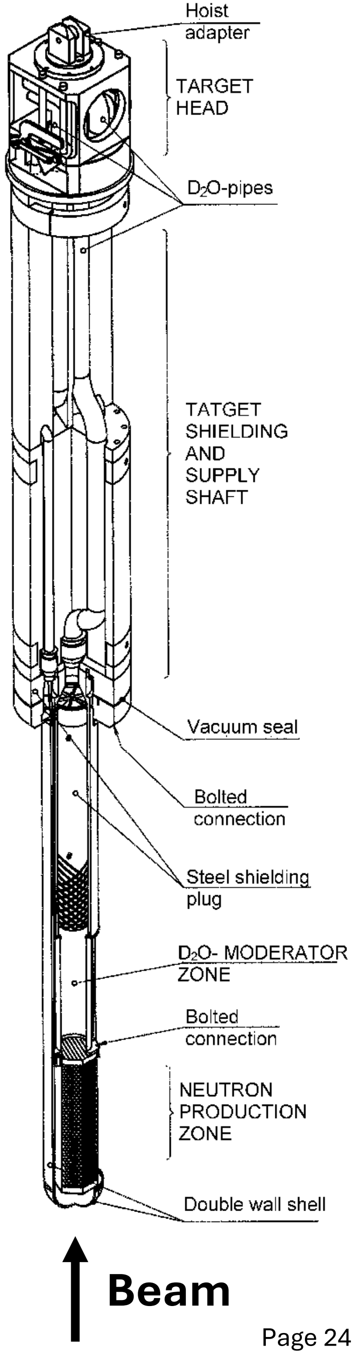


Lead-'Canneloni' Target in stainless steel cladding 2000-2005: ⇒42% more neutrons

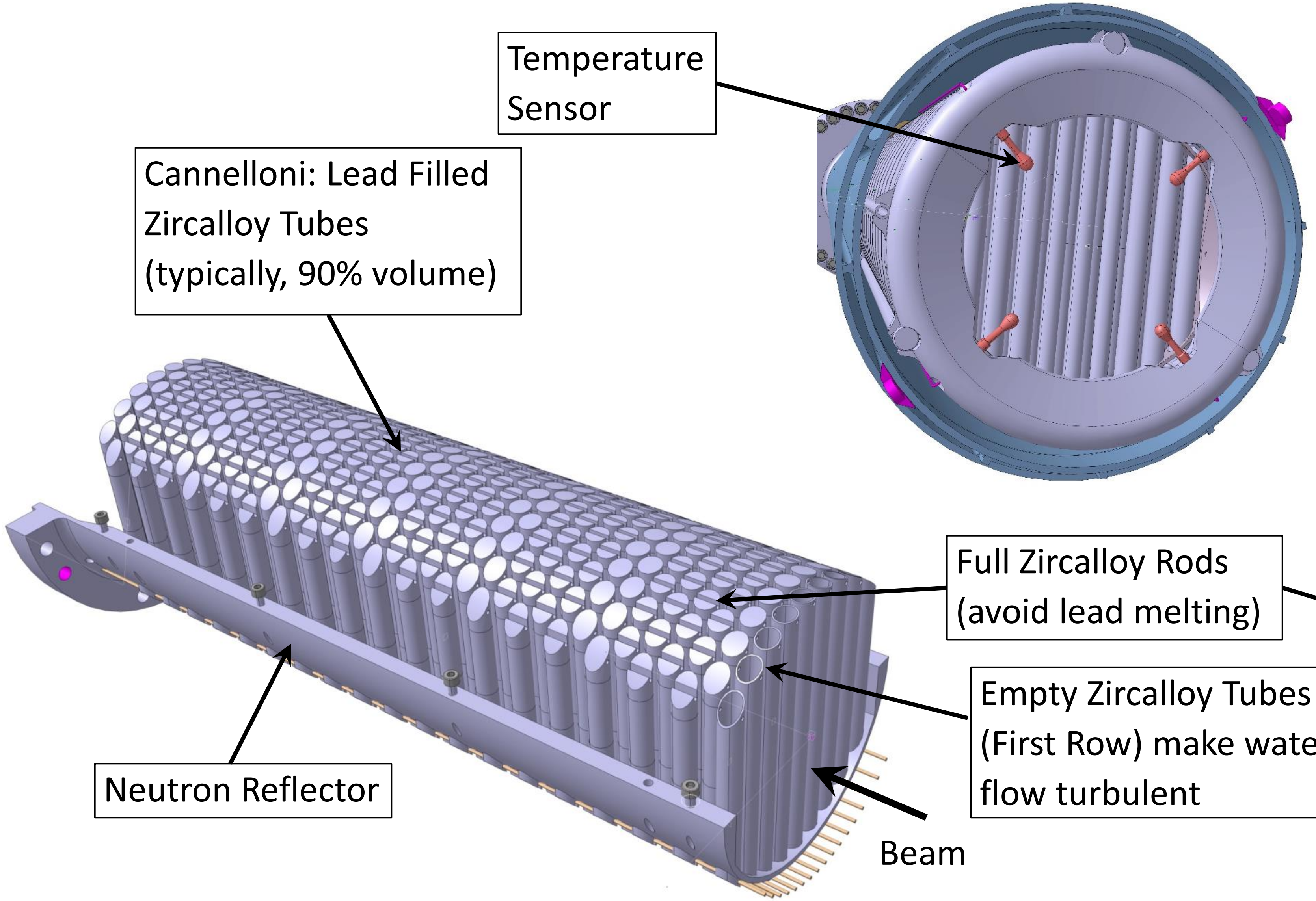
MARK IV



Lead-'Canneloni', cylindrical shape, neutron reflector ("Blanket") 2009-Current: ⇒54% more neutrons vs MARK II/III



SINQ Target 13 (MARK IV)



Temperature Sensor

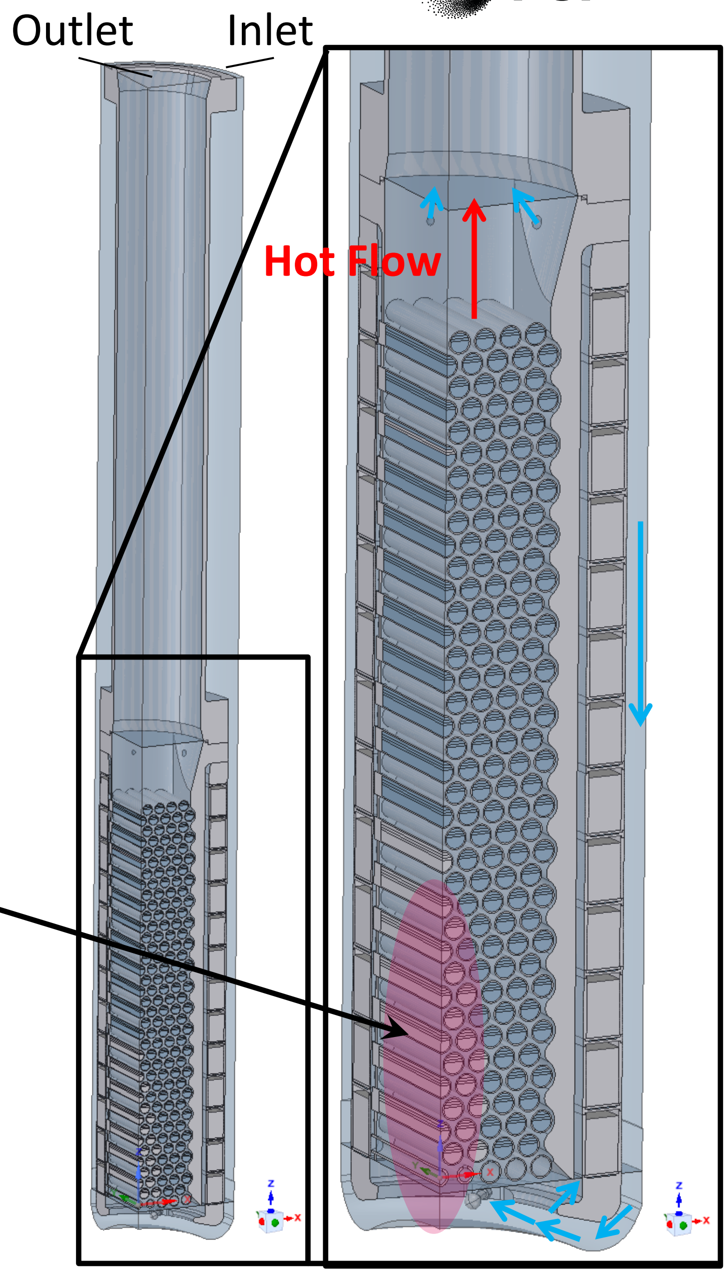
Cannelloni: Lead Filled Zircalloy Tubes (typically, 90% volume)

Full Zircalloy Rods (avoid lead melting)

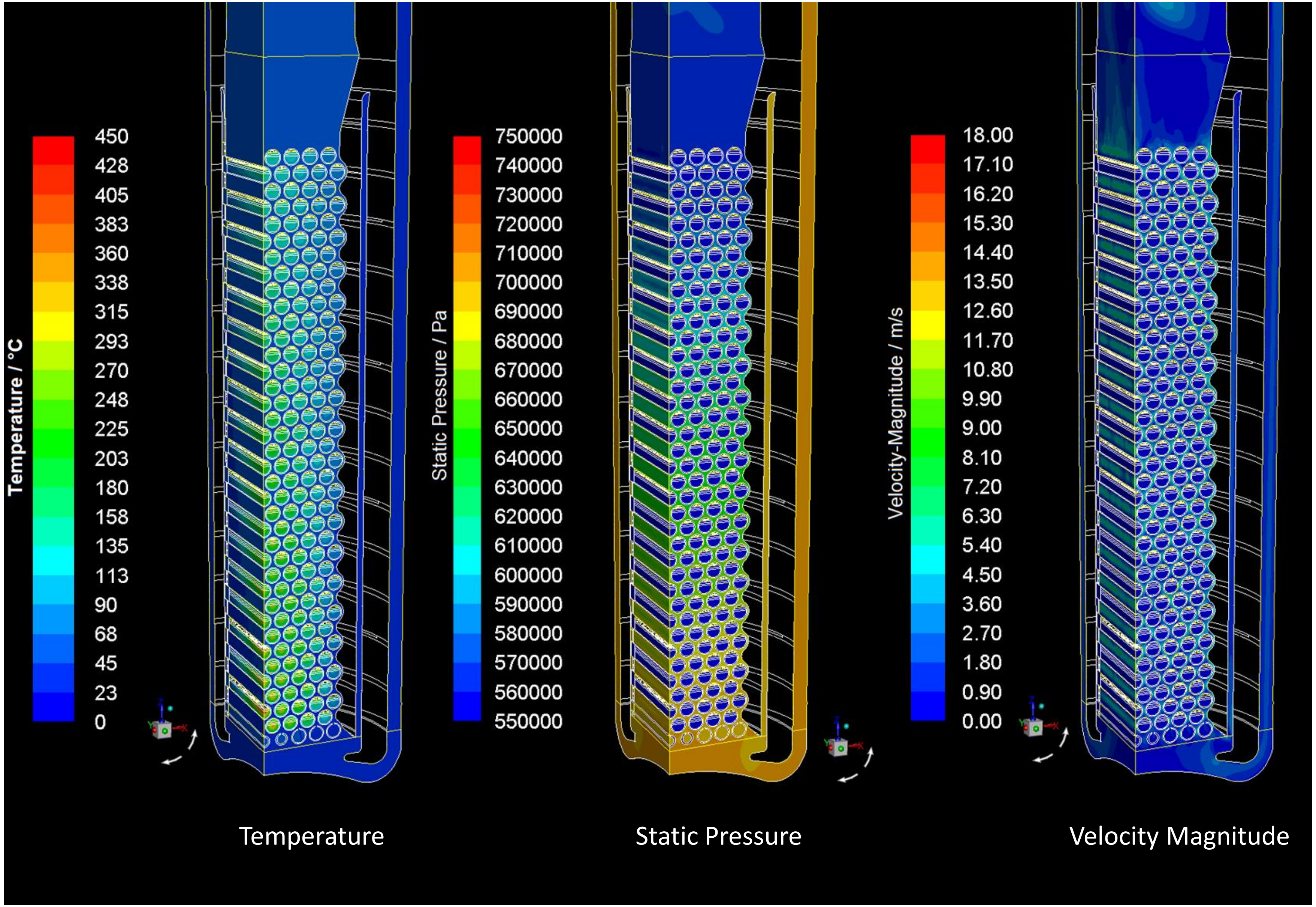
Empty Zircalloy Tubes (First Row) make water flow turbulent

Neutron Reflector

Beam



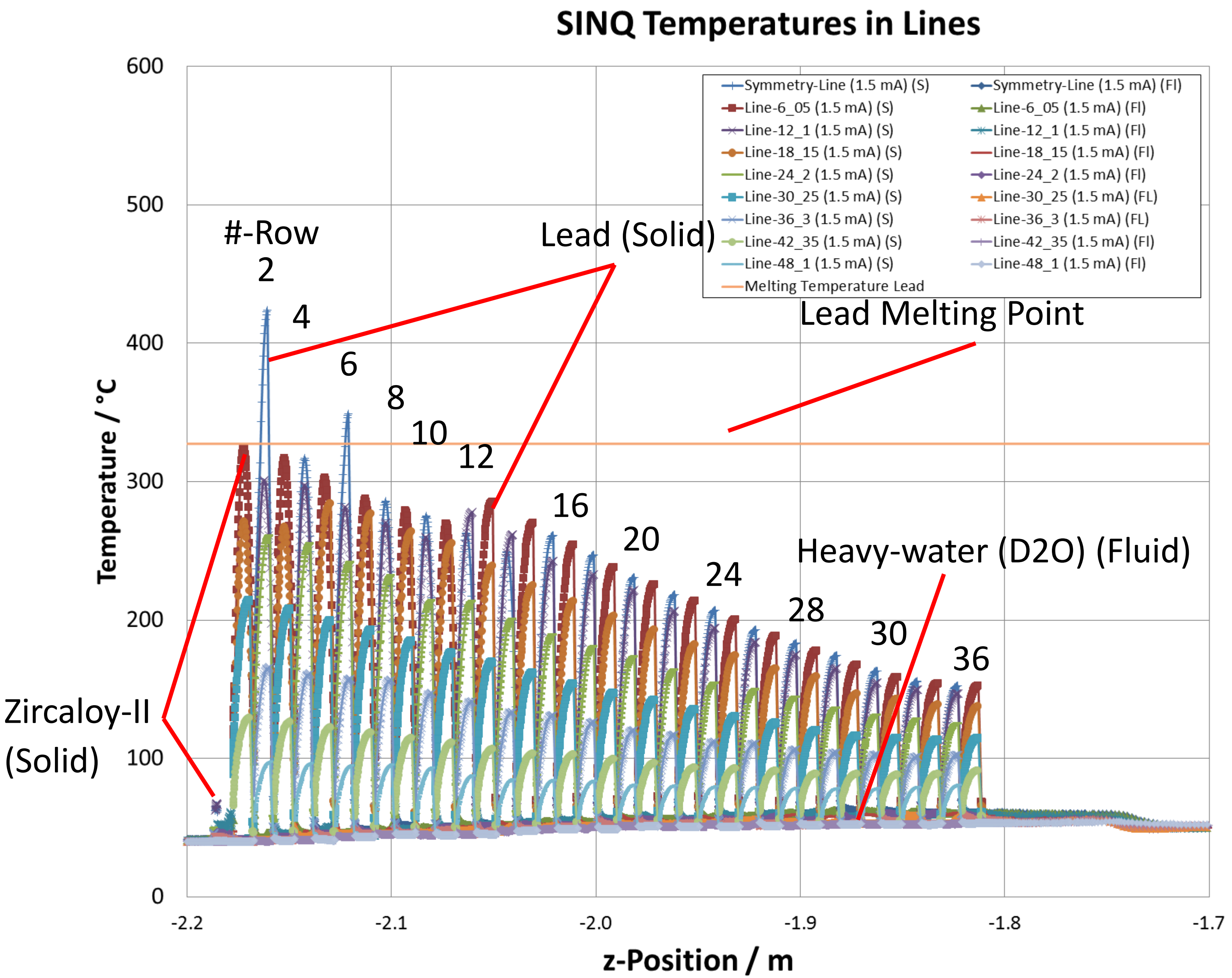
SINQ Target 13 CFD Simulations (1.5 mA Beam)



Beam Power deposition calculated with MCNP Monte Carlo

Fluid Dynamics Analysis performed with ANSYS Fluent

Temperature SINQ Target 13 at 1.5 mA Beam



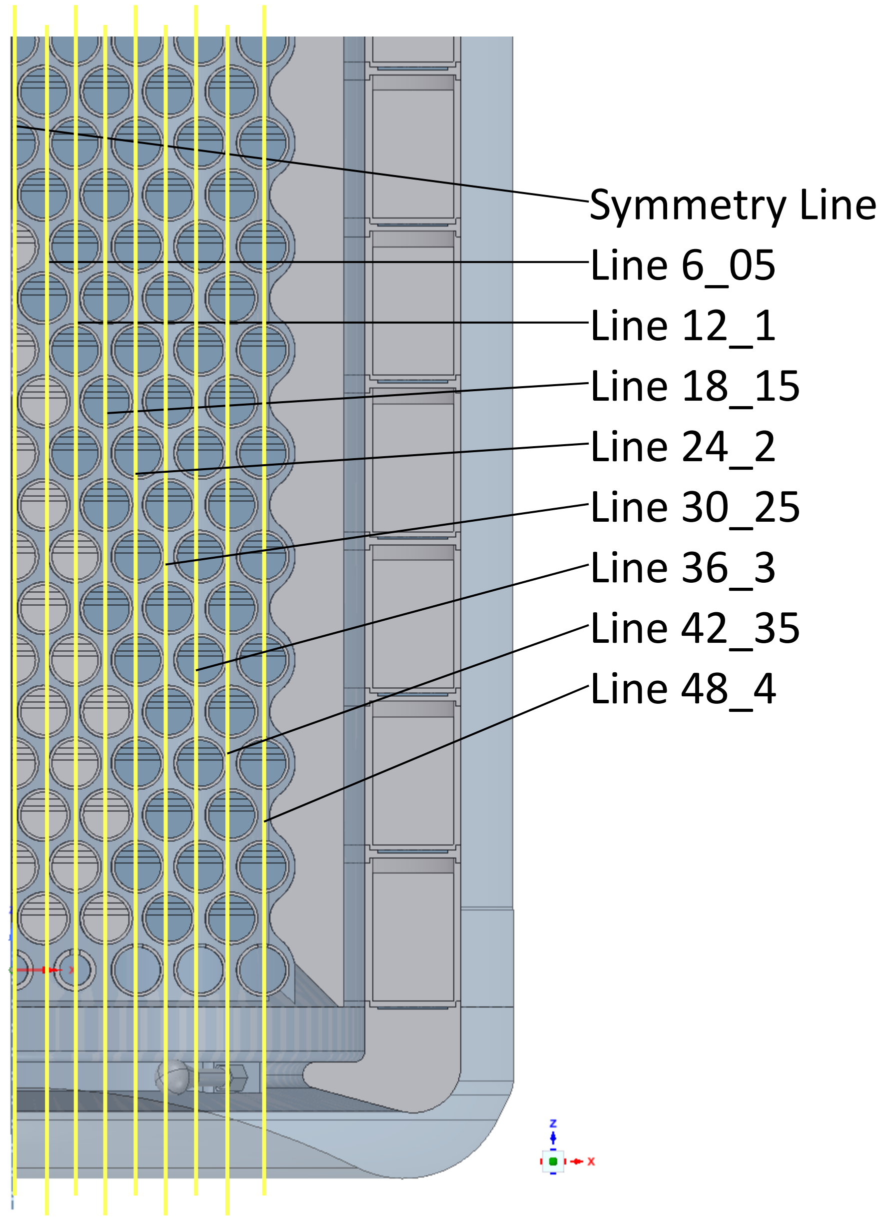
#-Row
2
4
6
8
10
12
16
20
24
28
30
36

Lead (Solid)

Lead Melting Point

Heavy-water (D2O) (Fluid)

Zircaloy-II
(Solid)



Symmetry Line
Line 6_05
Line 12_1
Line 18_15
Line 24_2
Line 30_25
Line 36_3
Line 42_35
Line 48_4

SINQ Target Incidents

Target 6:
One Cracked Steel Tube

No or little operational consequences

Target 8:
One Cracked Zircalloy Tube

No or little operational consequences

Target 11:
Many broken Zircalloy Tubes, Molten Lead poured into cooling water and blocked the circulation

4 Months SINQ Downtime

All Cracked Tubes located in the central, high temperature target region (T>330 °C)

The IMPACT Project

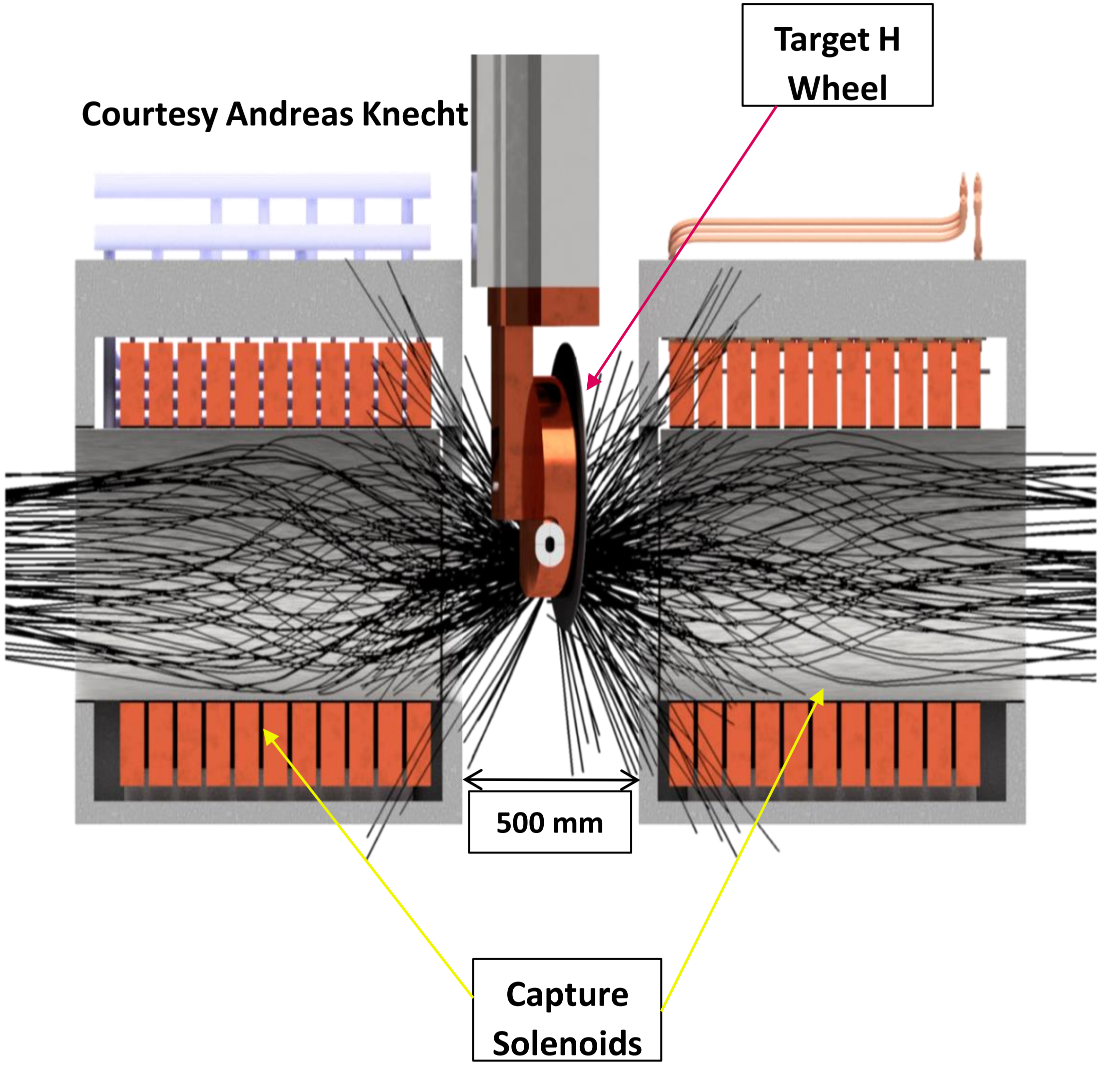
IMPACT: «Isotope and Muon Production using Advanced Cyclotron and Target technology»

- **HIMB**: «High Intensity Muon Beams», up to **10^{10} μ⁺/s** at beamline frontend (Commissioning **2028**)
- **TATTOOS**: Targeted Alpha Tumor Therapy and Other Oncological Solutions (Commissioning **2030**)

IMPACT CDR (Conceptual Design Report) published on 01.2022: https://www.psi.ch/en/impact/documents

IMPACT TDR (Technical Design Report) due 12.2024

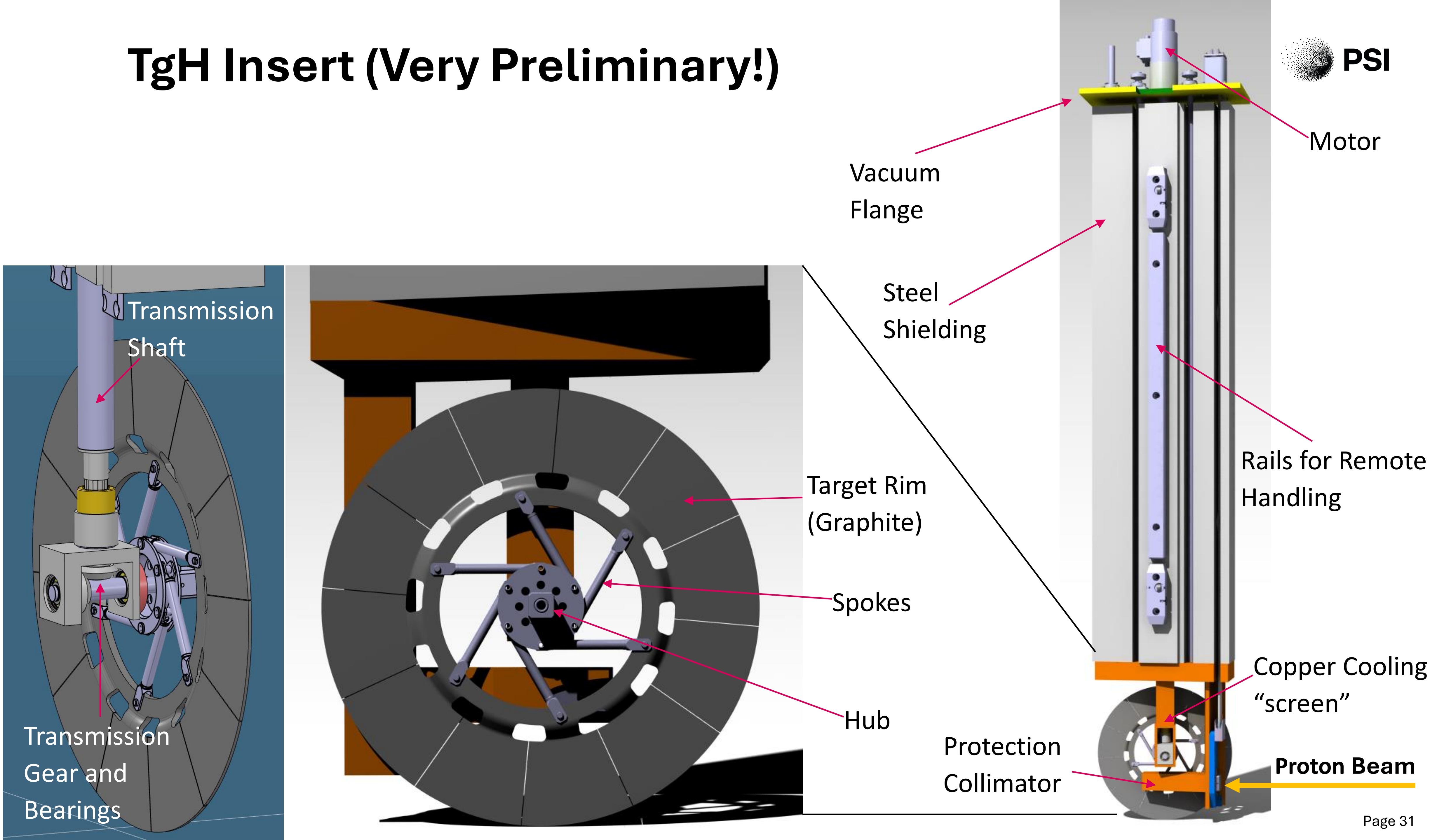
Concept new Target Station H (TgH) for HIMB



Challenges

- Very **limited space for the target** insert: ~500 mm between **2 muon capture solenoids**
- Short and wide solenoids with **large fringing field introduce a vertical bend of proton beam**
- Thicker target (**20 mm TgH** vs 5 mm TgM): **higher beam losses & activation**
- **Slanted target** geometry with large rim to maximize muon production

TgH Insert (Very Preliminary!)



Transmission Shaft

Transmission Gear and Bearings

Target Rim (Graphite)

Spokes

Hub

Vacuum Flange

Steel Shielding

Motor

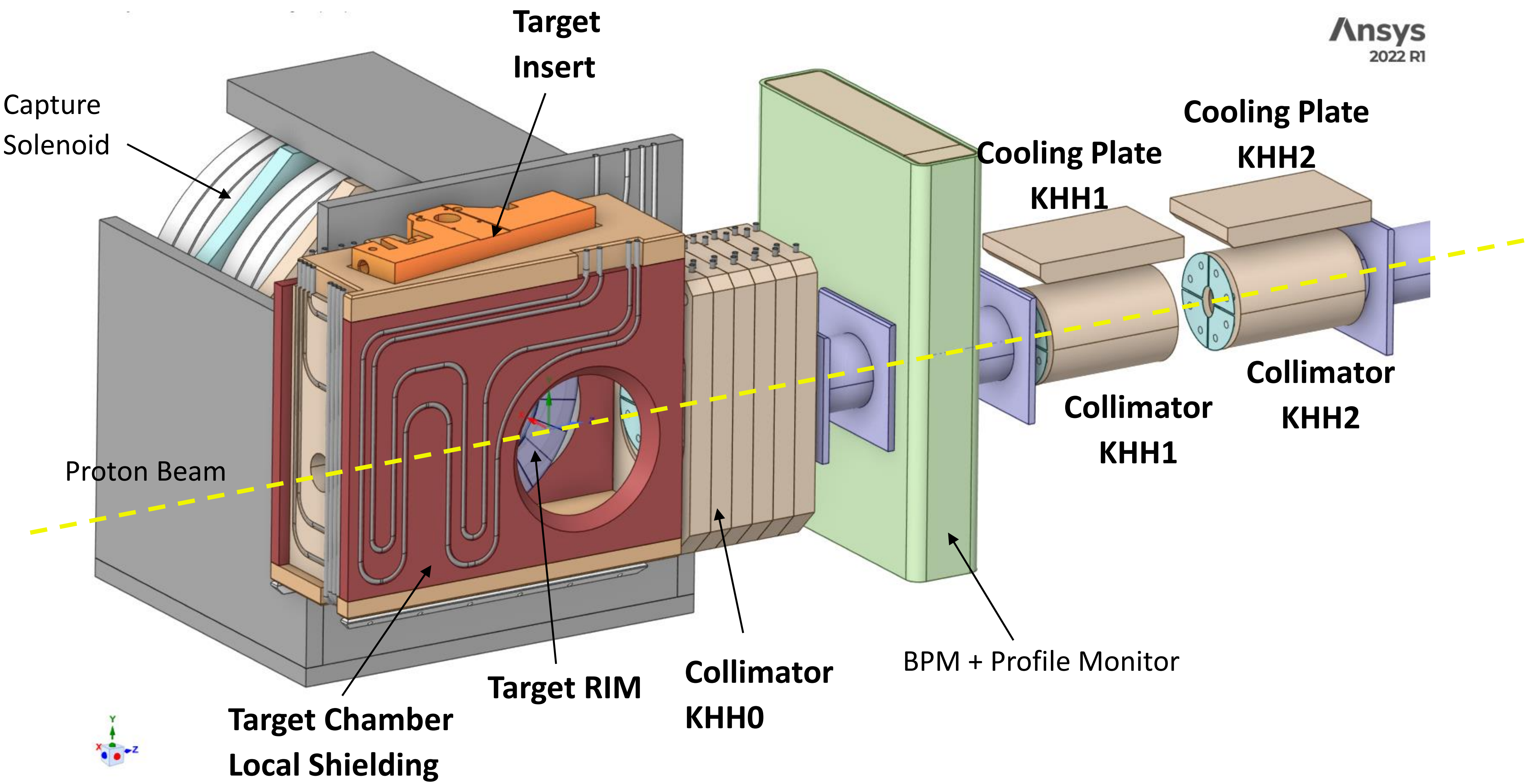
Rails for Remote Handling

Copper Cooling “screen”

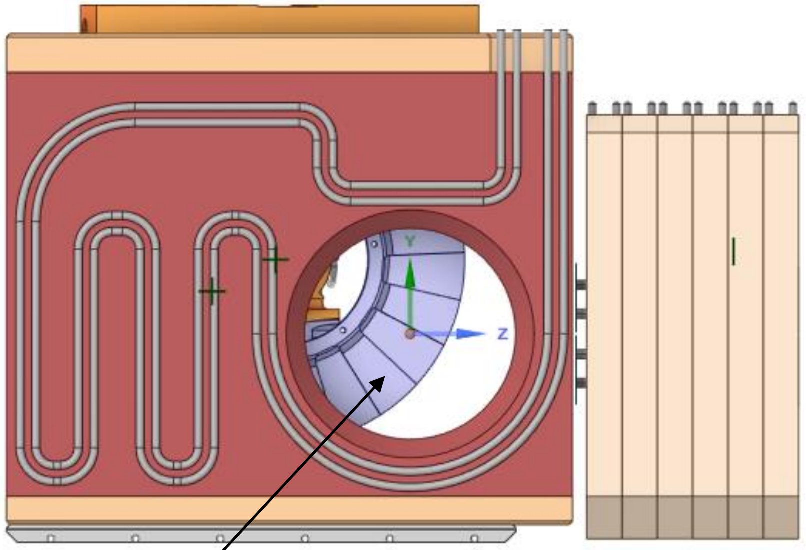
Protection Collimator

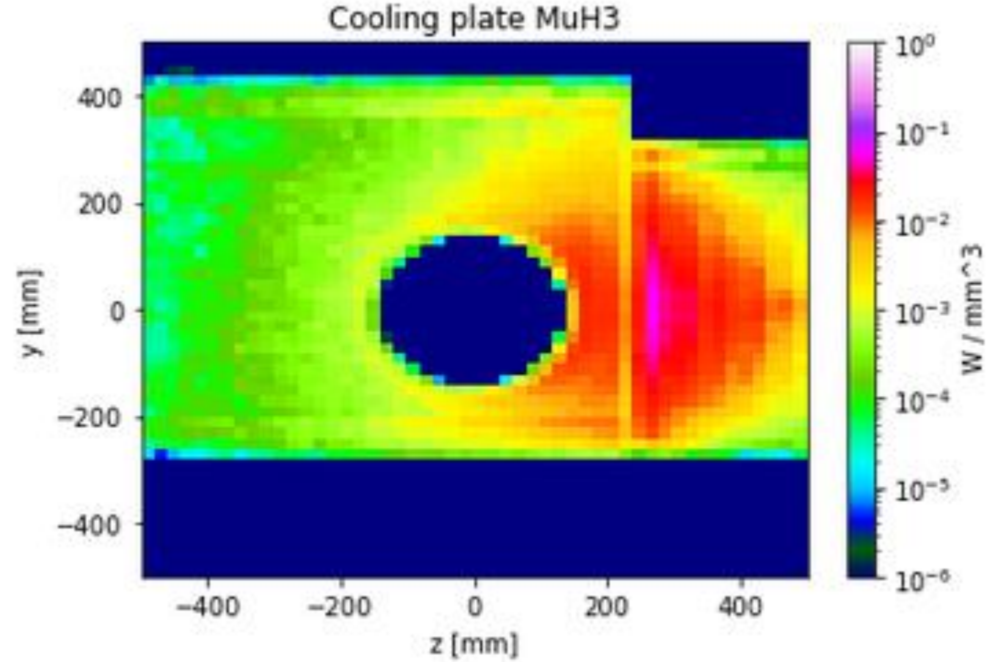
Proton Beam

TgH Region: BIDs

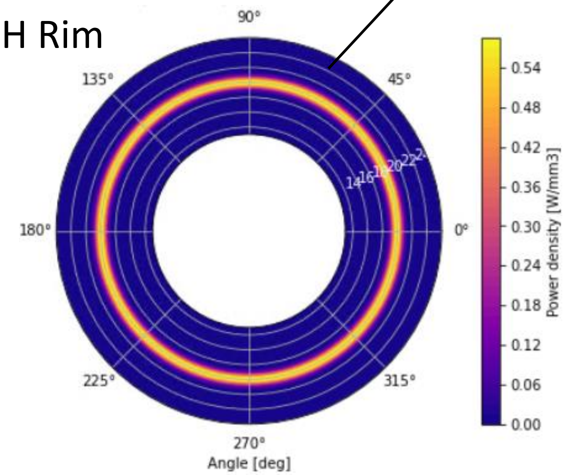


Heat Load from Protons and Secondary Particles



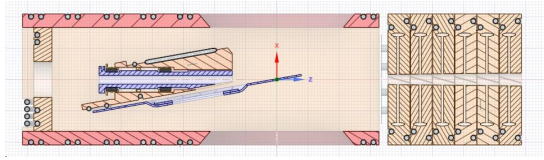


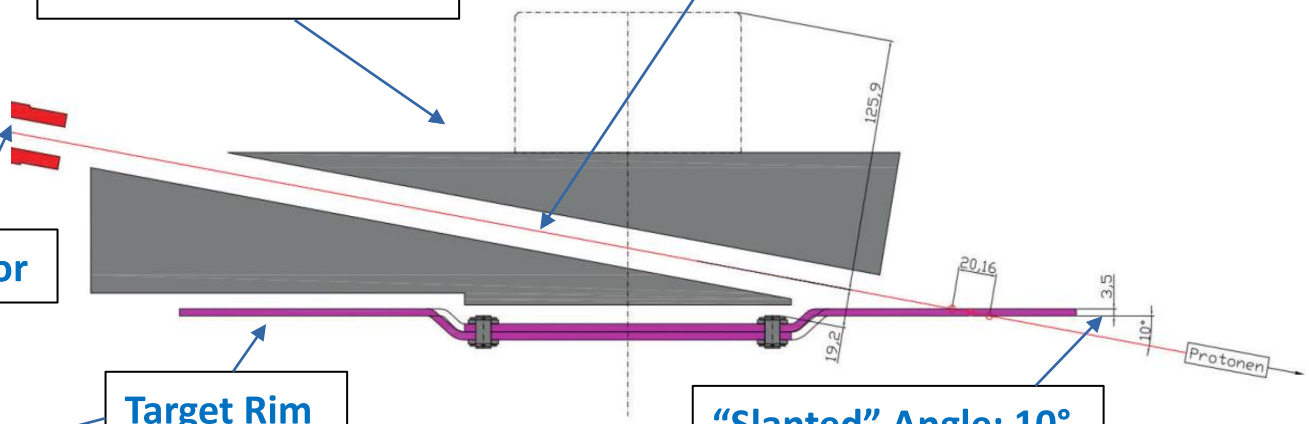
TgH Rim



Component	**Power deposited [kW]**
Target Wheel	*32 kW*
Local Shielding	*5 kW*
Target Insert	*0.225 kW*
Collimator KHH0	*58 kW*
Mirror Plates (Capture Solenoid)	*2.5 kW*
Total	*100 kW*

TgH Rim





Copper Cooling Plate

Proton Beam

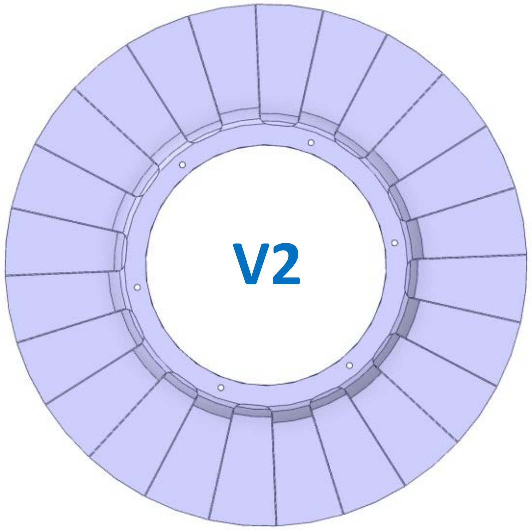
Protection Collimator

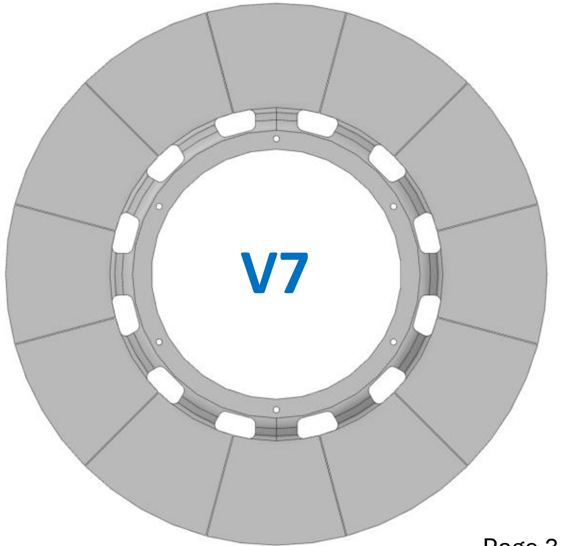
Target Rim

“Slanted” Angle: 10°

Two Rim Versions (out of 7) still under investigation

- **V2: Two superposed half wheels, 24 tiles, 0.5 mm slits**
- **V7: One full wheel, 12 tile, 1 mm slits**
- Material: Polycrystalline Graphite
- **Thickness: 3.5 mm** (effective thickness 20 mm)
- Rim **width: 100 mm**



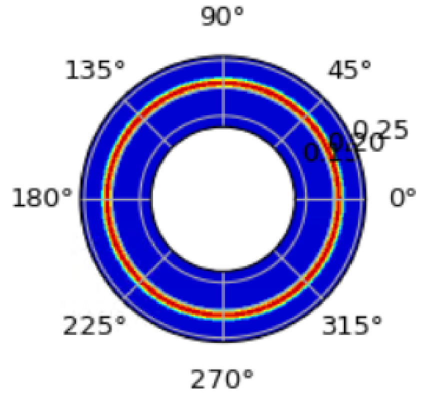


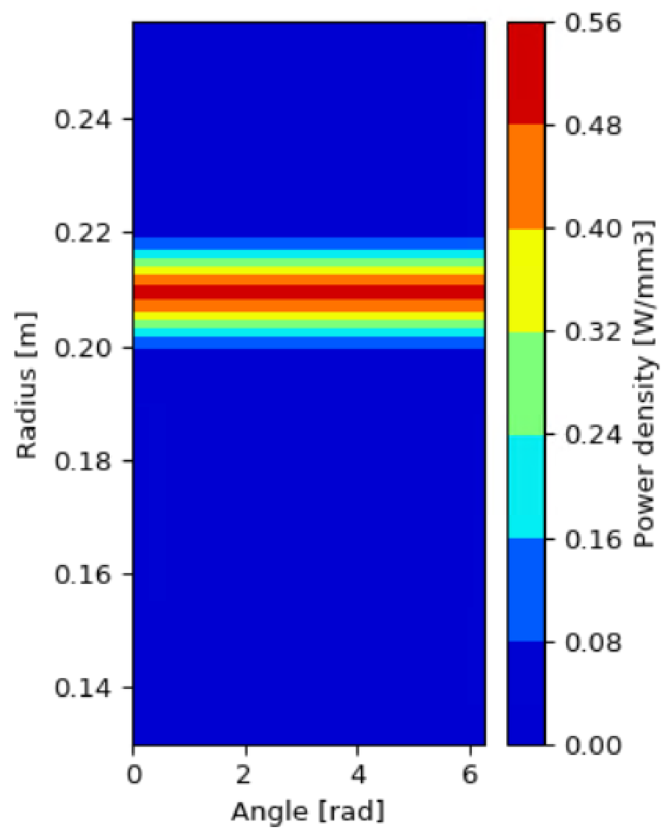
TgH Rim: Thermal Simulations

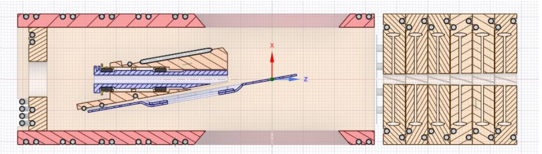
Power Deposition calculated analytically: **32 kW**
Beam Current: **3mA**, Beam Size (σ_x): 1mm

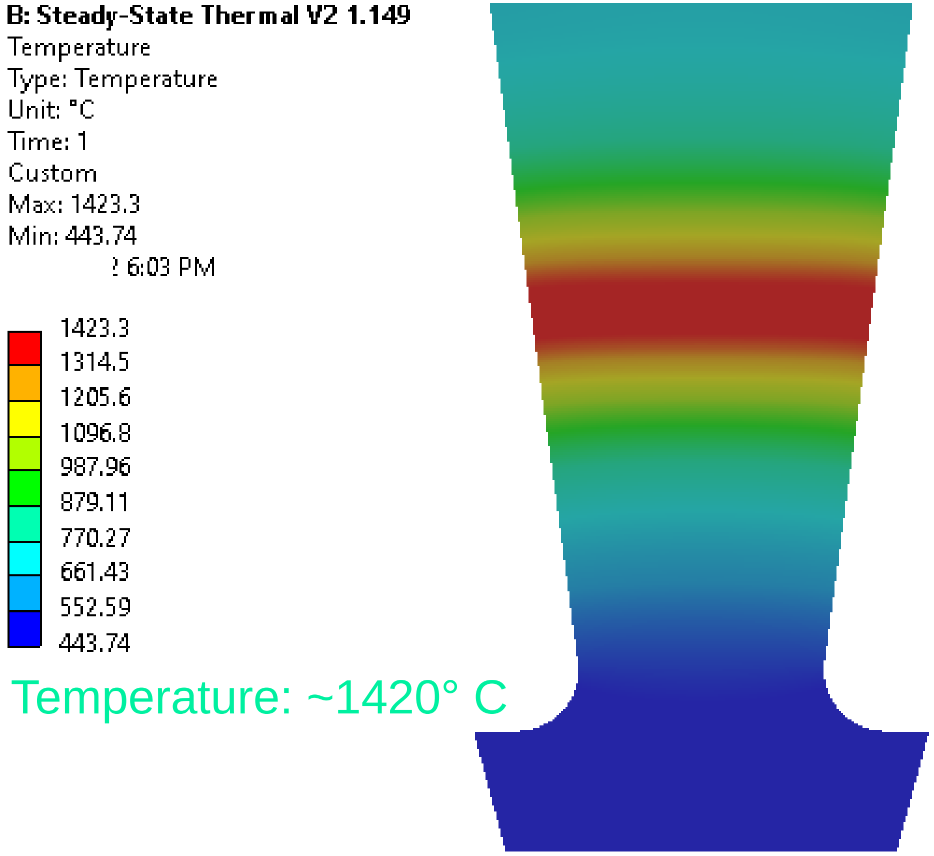
ANSYS simulation of one graphite tile
V2, planar equivalent geometry
Similar results for V7

Power density Target H 3mA





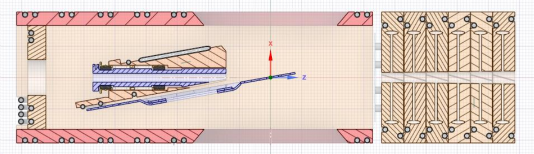




B: Steady-State Thermal V2 1.149
Temperature
Type: Temperature
Unit: °C
Time: 1
Custom
Max: 1423.3
Min: 443.74
? 6:03 PM

Max. Temperature: ~1420° C

TgH Rim: Structural Simulations



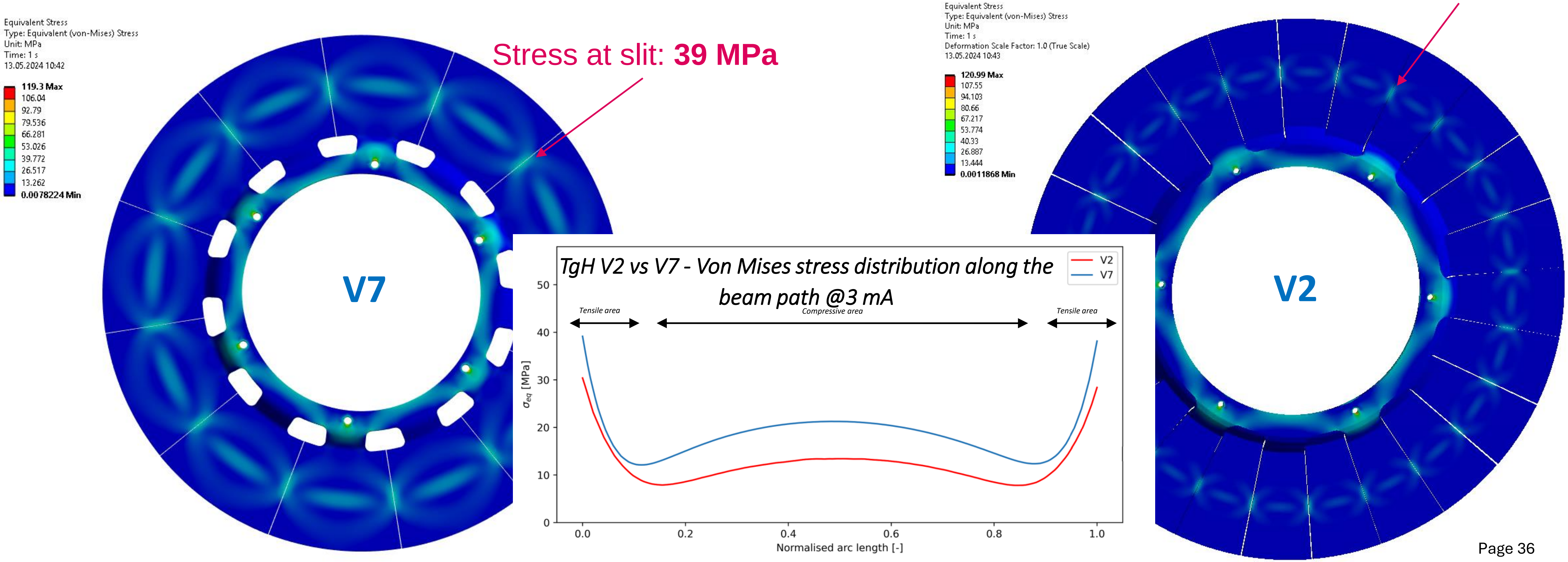
Ultimate stress in tension, flexion and compression (data at room temperature):

$\sigma_f = 60\ MPa$

$\sigma_c = 130\ MPa$

$\boldsymbol{\sigma_t \approx 38\ MPa}$

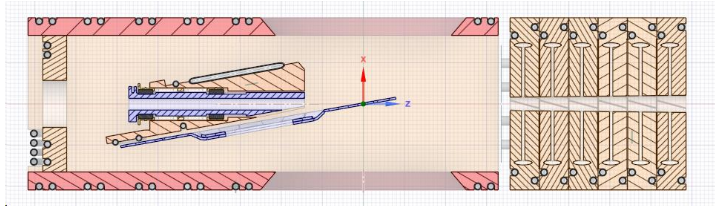
Graphite's strengths increases with temperature (no temperature-dependent data found for R6510):



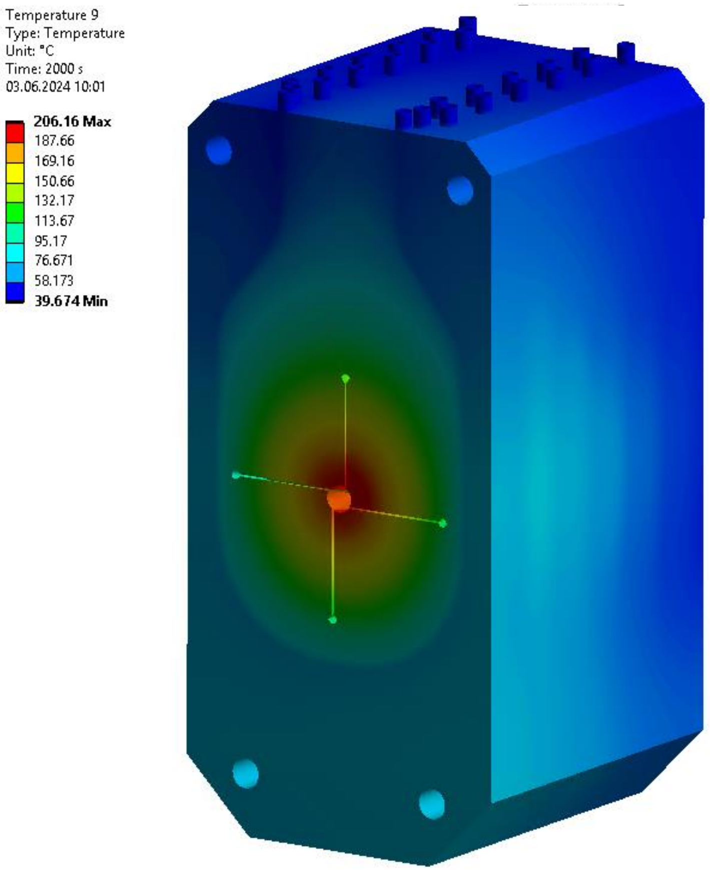
Stress at slit: **39 MPa**

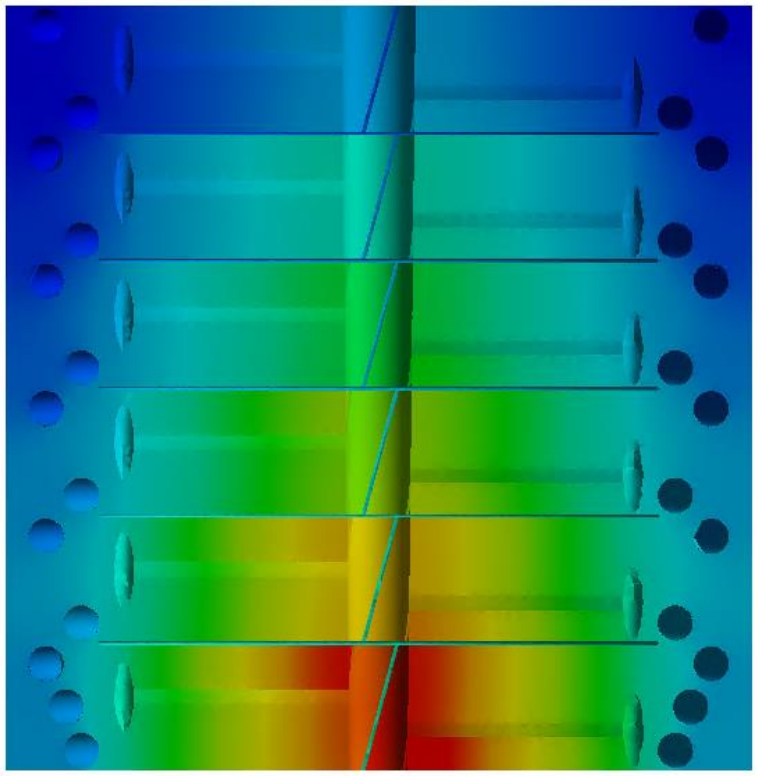
Stress at slit: **30 MPa**

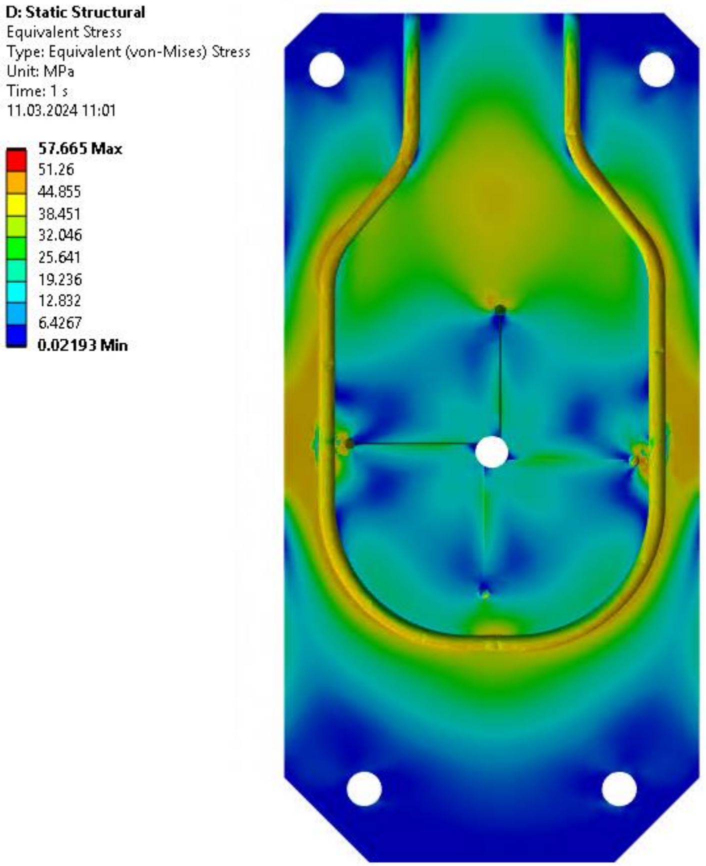
Collimator KHH0 Thermal and Structural Simulation



- Simulated independently from the target station (copper is reflective)
- Max Temperature: 206 °C
- Max Stress = 58 MPa (UTS_Cu = 150 MPa @150 °C)





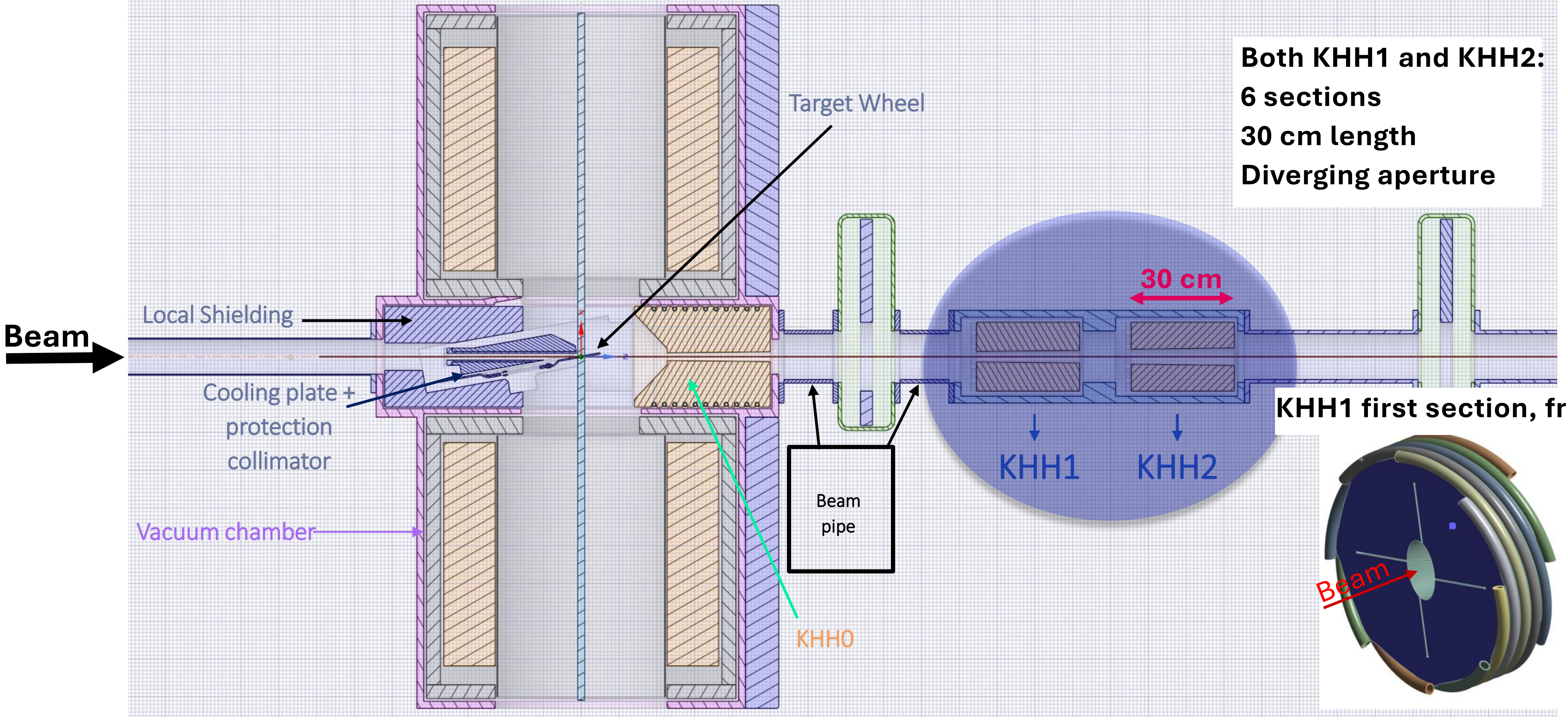


KHH1 and KHH2 Collimators

Function:

Clean/Shape highly divergent beam after passing through 20 mm thick graphite target H

Prevent activation of downstream beamline components



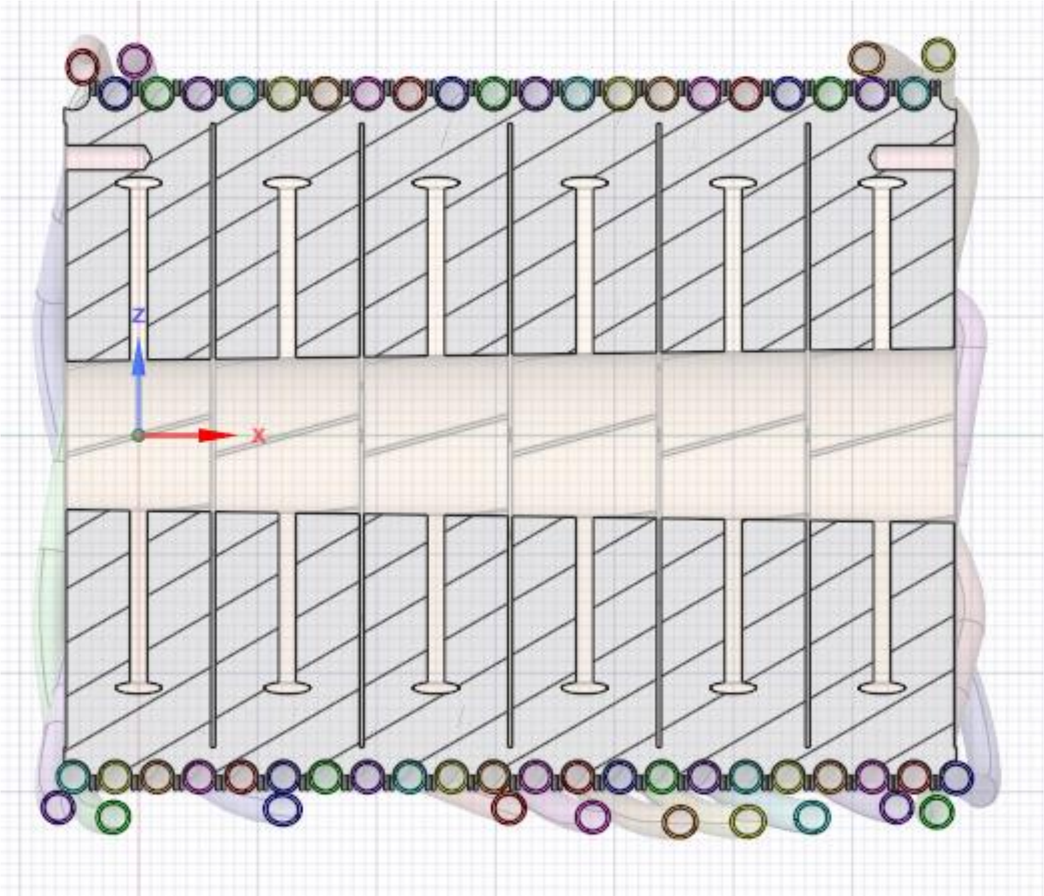
Both KHH1 and KHH2:
6 sections
30 cm length
Diverging aperture

KHH1 first section, front

KHH1 / KHH2: Geometry and Power Deposition

Geometry

- KHH1 / KHH2: Same Geometry, only aperture differs
- Aperture defined through MC proton beam line simulations
- **Each collimator composed by 6 cylindrical sections**



Material

- **Body: OFHC** (oxygen-free high thermal conductivity copper)
- Cooling Water Pipes: **Stainless Steel**

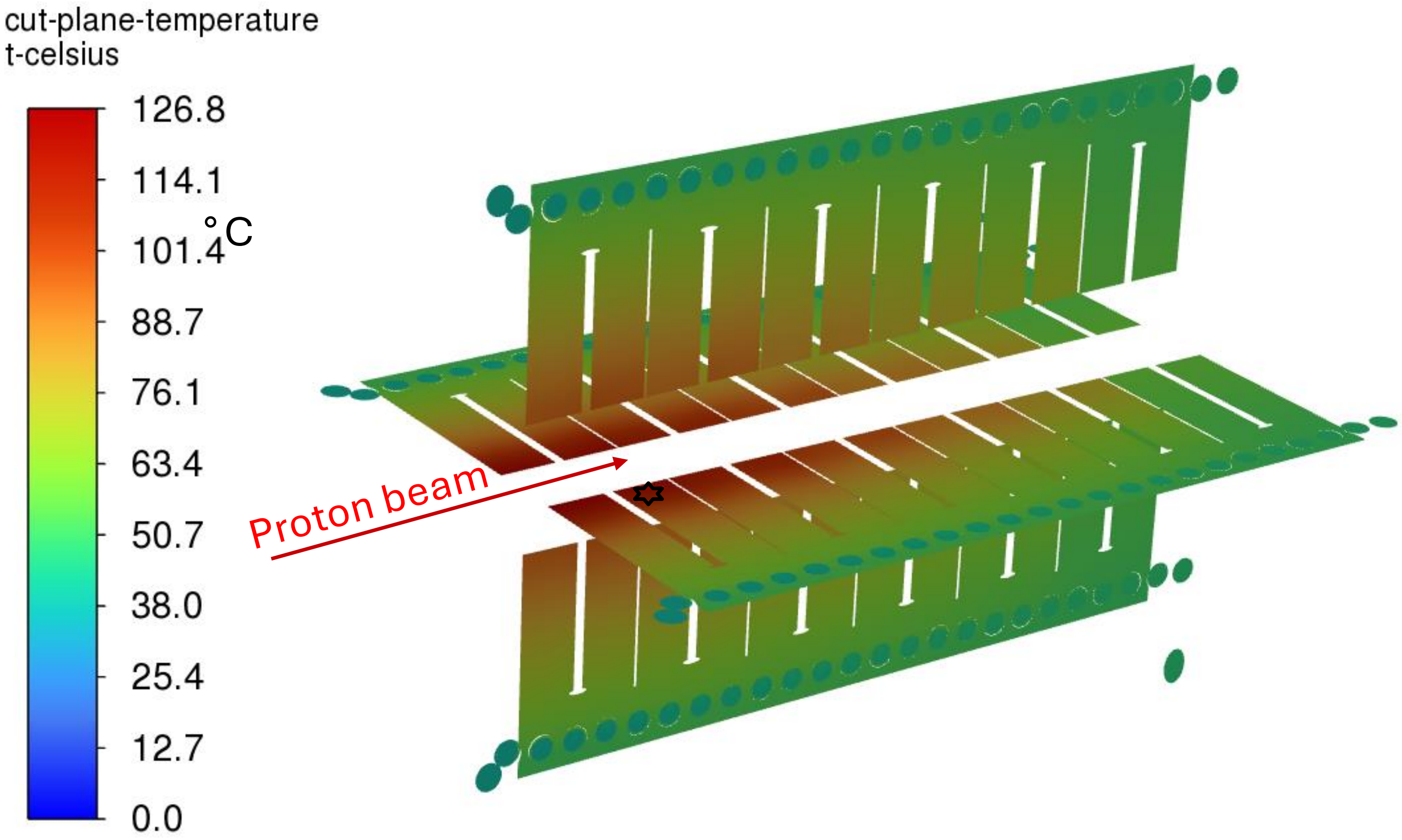
Power Deposition (proton beam current 3 mA):

- **KHH1: 17 kW**
- **KHH2: 2.1 kW**

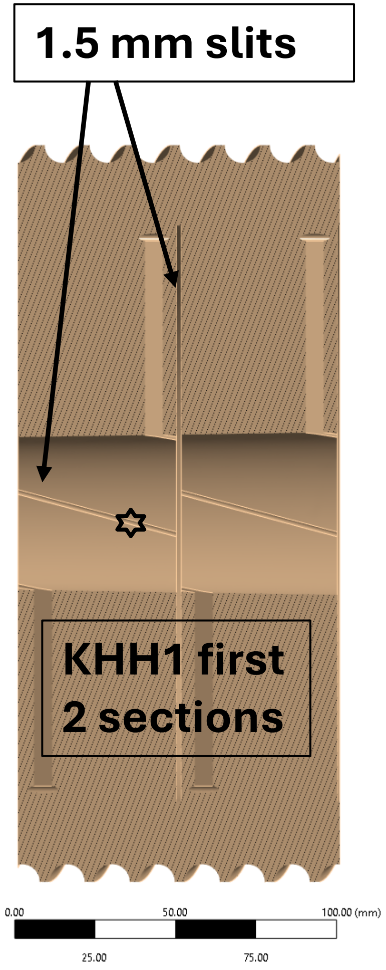
➡ Simulate KHH1 only

Water Flow Rate for Simulation: 0.5 kg/s (very conservative)

KHH1: Thermal Analysis



Proton beam



1.5 mm slits

KHH1 first 2 sections

✡ Position of max. temperature

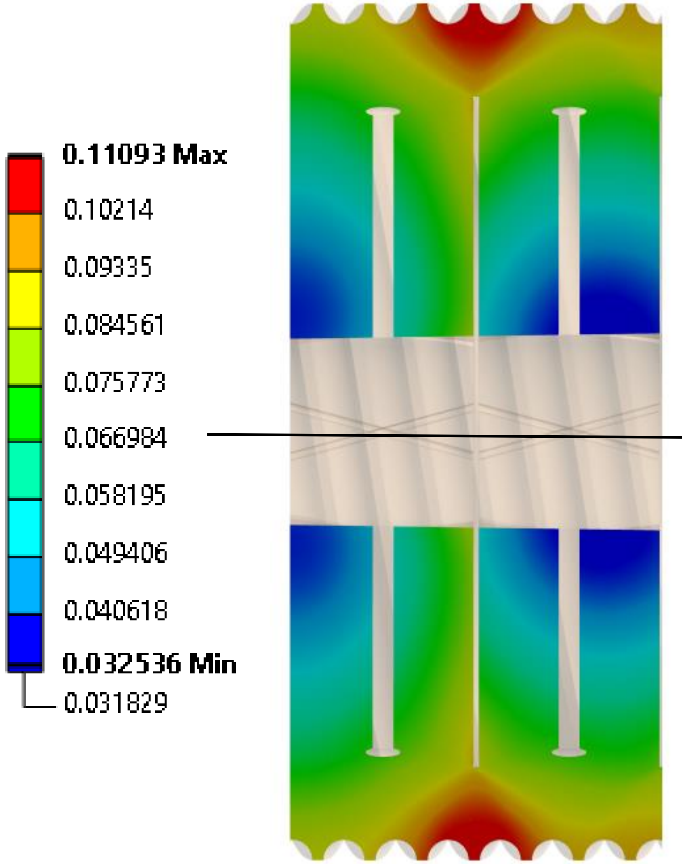
KHH1: Deformation and Stress

First 2 section simulated (highest power deposition)

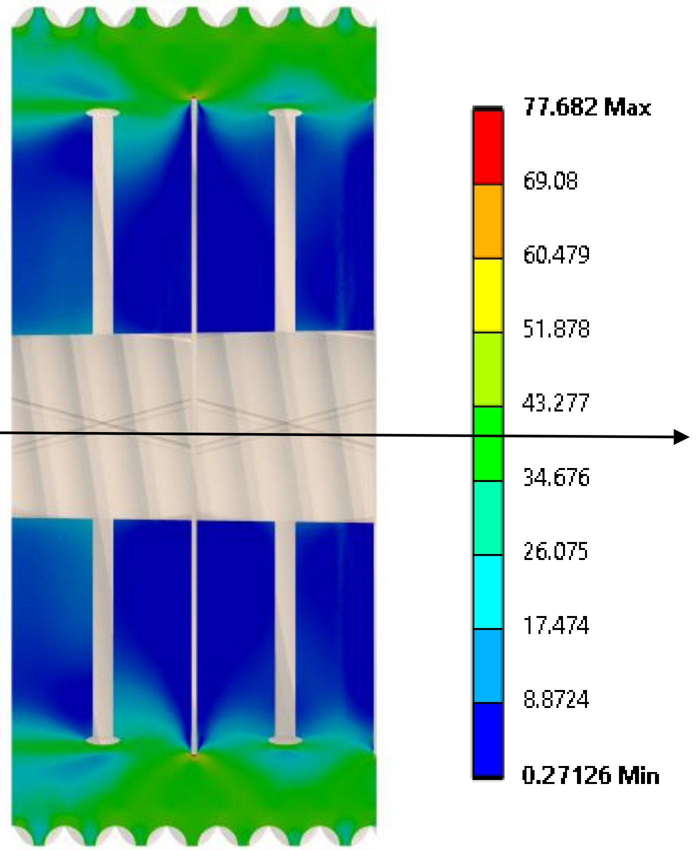
Yield point ~56 MPa (Unirradiated OFHC)

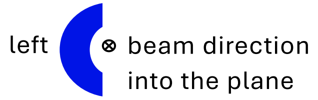
Ultimate Tensile Stress = 150 MPa (@150 °C)

Total Deformation [mm]



Von Mises Stress [MPa]





Only KHH1 left side simulated

Tip: exploit symmetry to speed up simulations whenever possible!

The IMPACT Project

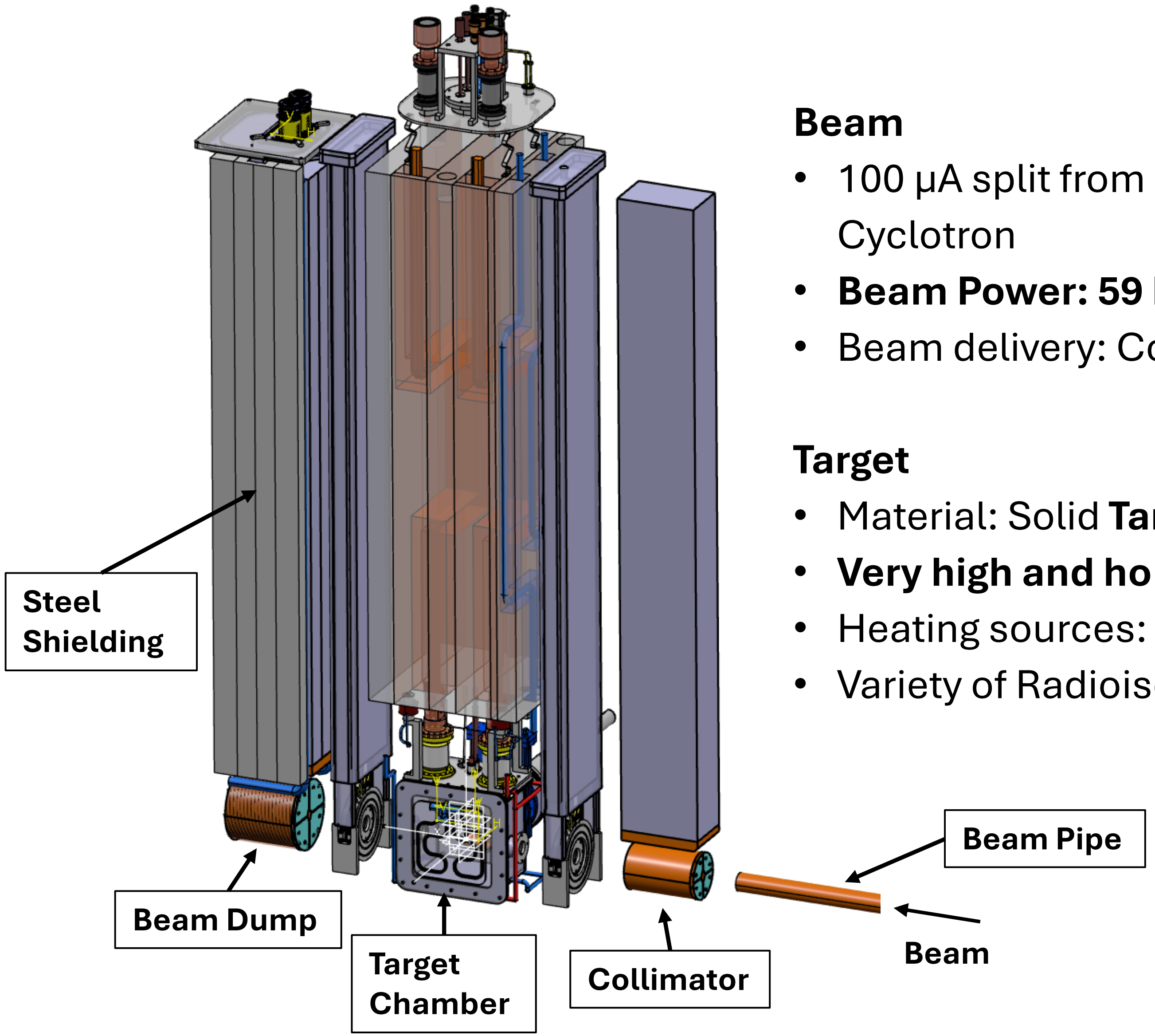
IMPACT: «Isotope and Muon Production using Advanced Cyclotron and Target technology»

- **HIMB**: «High Intensity Muon Beams», up to **10^{10} μ^+/s** at beamline frontend (Commissioning **2028**)
- **TATTOOS**: Targeted Alpha Tumor Therapy and Other Oncological Solutions (Commissioning **2030**)

IMPACT CDR (Conceptual Design Report) published on 01.2022: https://www.psi.ch/en/impact/documents

IMPACT TDR (Technical Design Report) due 12.2024

TATTOOS Target Station Preliminary Concept



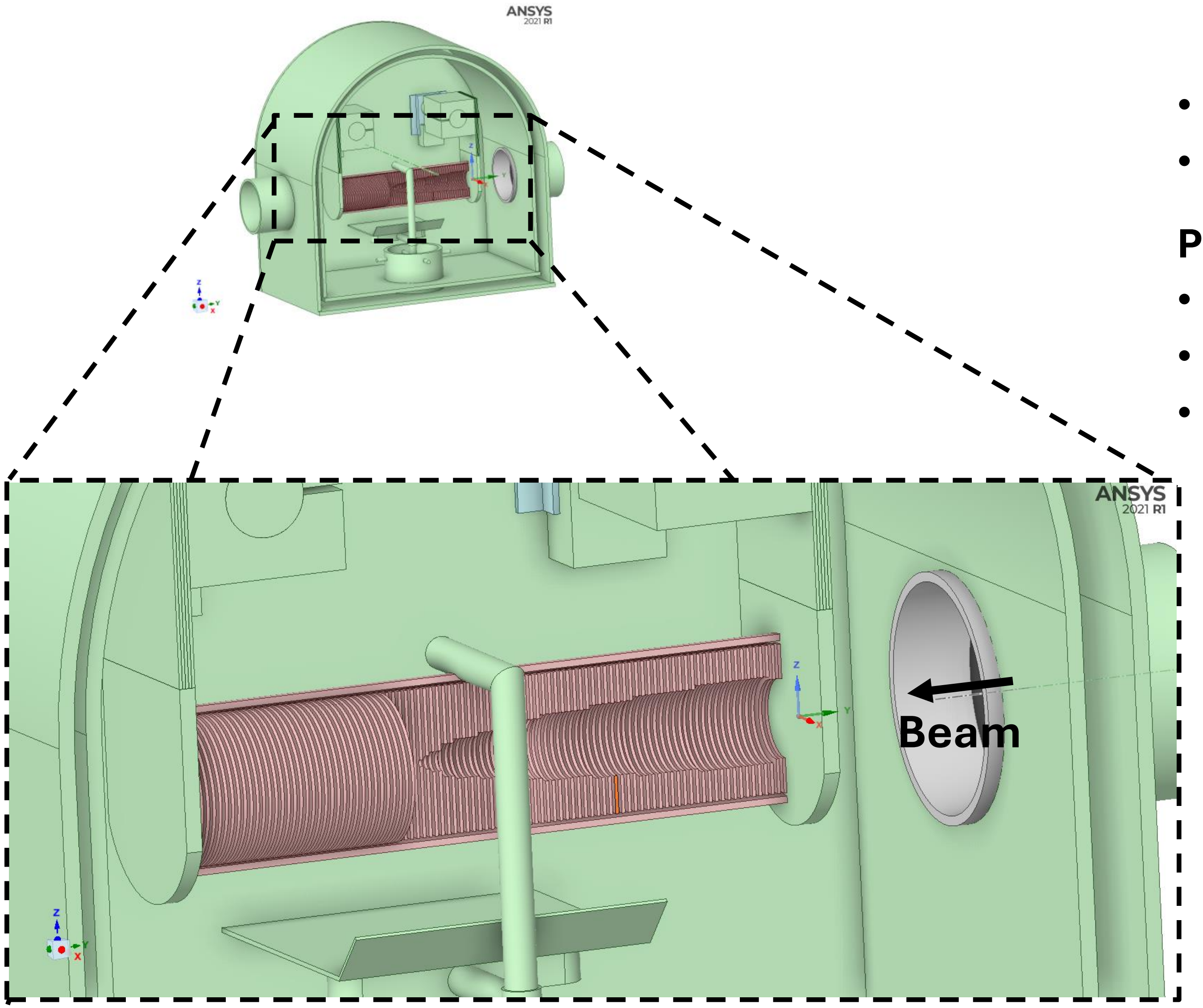
Beam

- 100 µA split from main 590 MeV beam after extraction form Ring Cyclotron
- **Beam Power: 59 kW**
- Beam delivery: Continuous (for 250 s every 300 s)

Target

- Material: Solid **Tantalum** (UCx also an option)
- **Very high and homogeneous temperature (~2500 °C)**
- Heating sources: proton beam and external joule heating
- Variety of Radioisotope (above all Terbium for cancer treatment)

TATOOS Tantalum Target Design

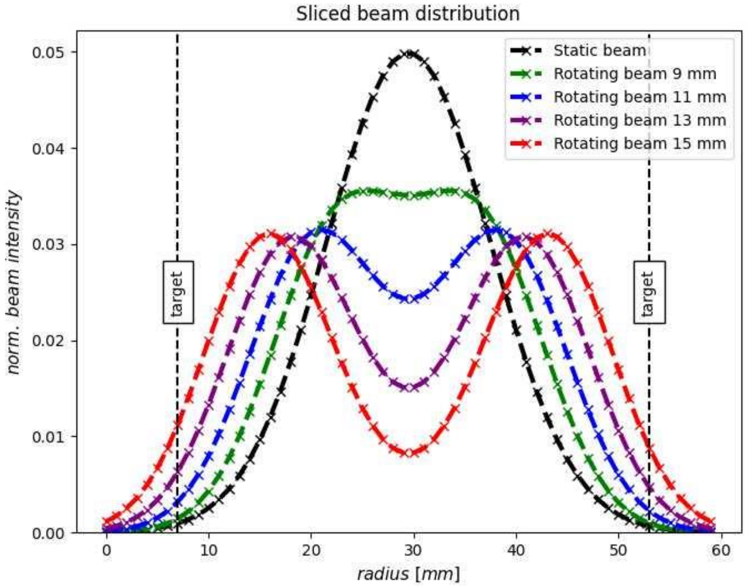


Design Challenge

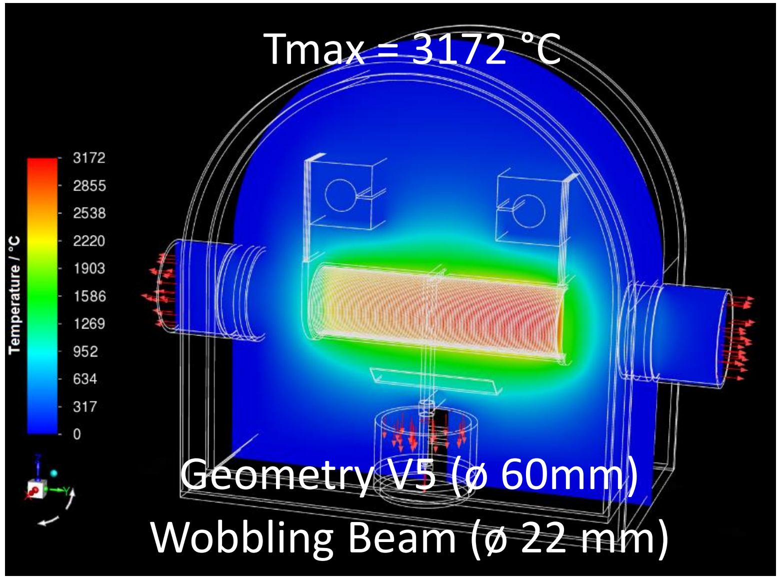
- **26 kW deposited beam can heat the tantalum target to over 3000 °C and melt it** (Ta melting point: 3020 °C)
- **Maximize isotope production**
- **Avoid target melting!**

Possible Approaches

- **Ta arranged in thin discs** to maximite radiation cooling
- **Conical hole** to homogenize beam power deposition
- **Beam wobbling** to flatten beam transverse distribution

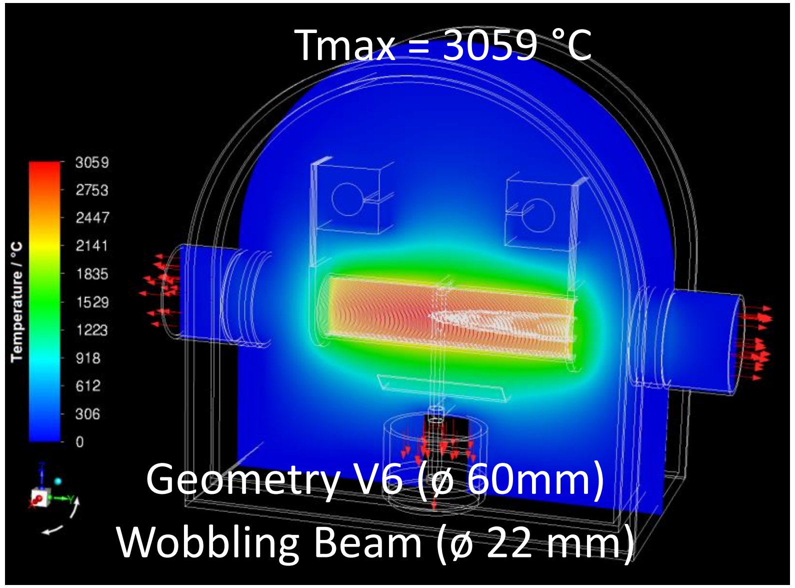


Thermal Analysis for Different Geometries



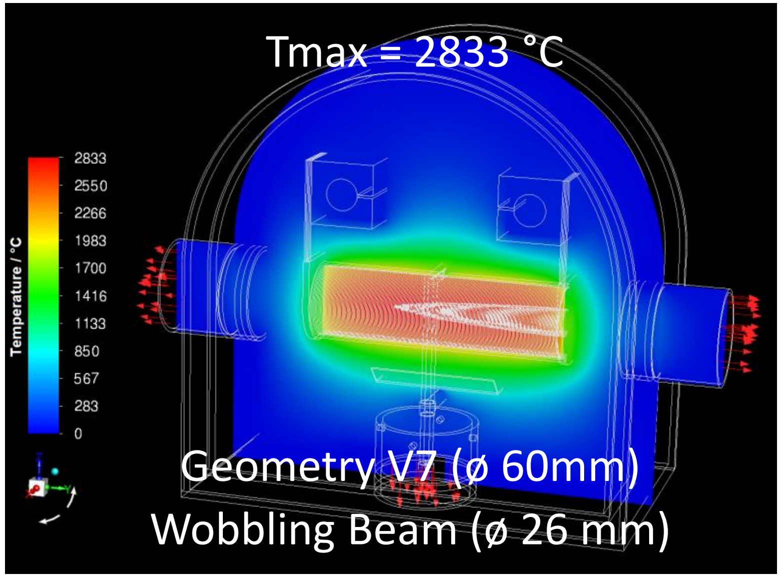
Tmax = 3172 °C

Geometry V5 (ø 60mm)
Wobbling Beam (ø 22 mm)



Tmax = 3059 °C

Geometry V6 (ø 60mm)
Wobbling Beam (ø 22 mm)



Tmax = 2833 °C

Geometry V7 (ø 60mm)
Wobbling Beam (ø 26 mm)

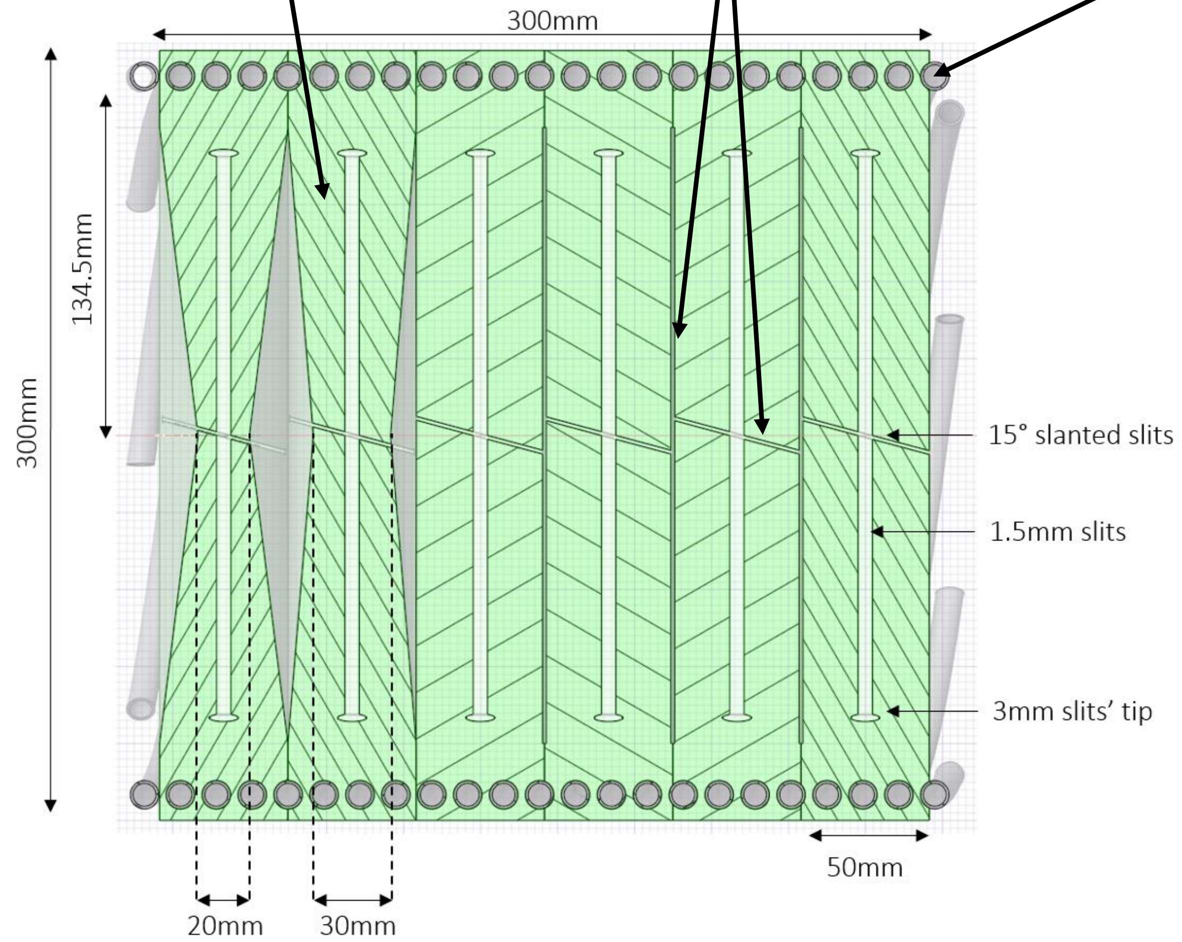
- **Beam power deposition from MC simulation**
- **Target Temperature depends on target geometry and on beam optics**
- **V7: Temperature below Ta-Melting point but still too high (Goal: 2500 °C)**
- **Simulations need further investigations**

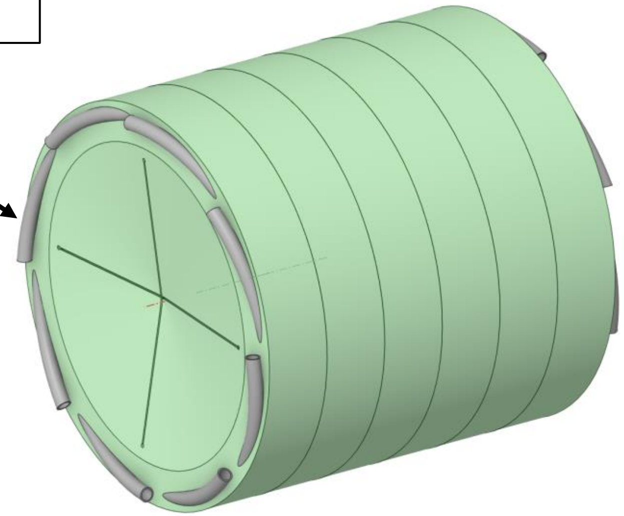
TATTOOS Beam Dump (BD) Design

Copper Body

1.5 mm slits

Cooling Water Stainless Steel Pipes





Body Material

OFHC: oxygen-free high thermal conductivity copper

TATTOOS-BD: Thermal Analysis

Simulation Strategy

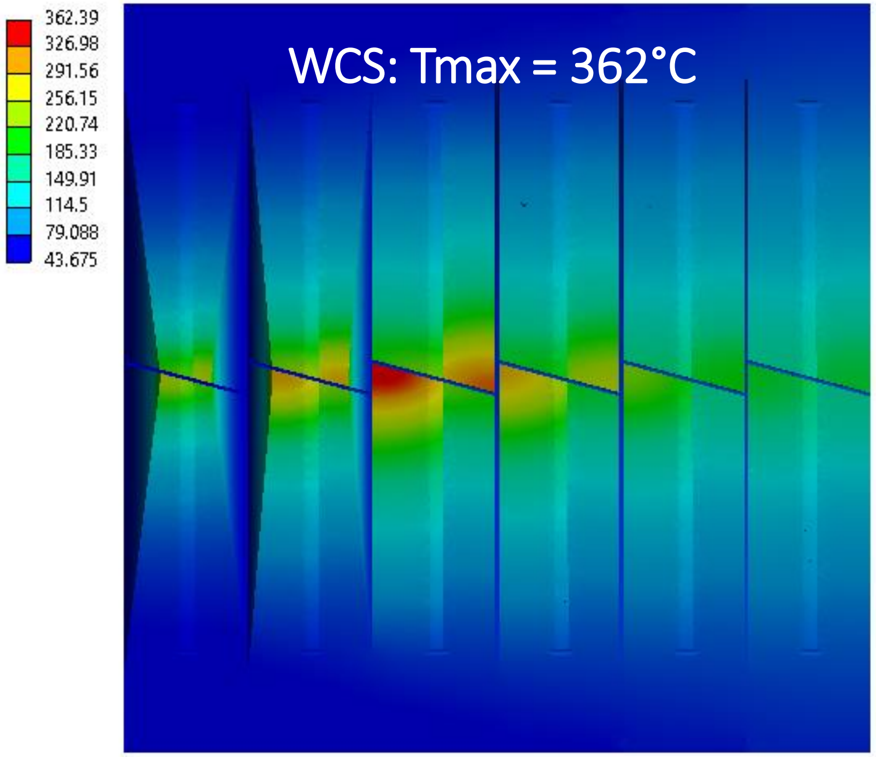
Normal Scenario (NS): UCx Target (Geometry V5) and standard beam optics

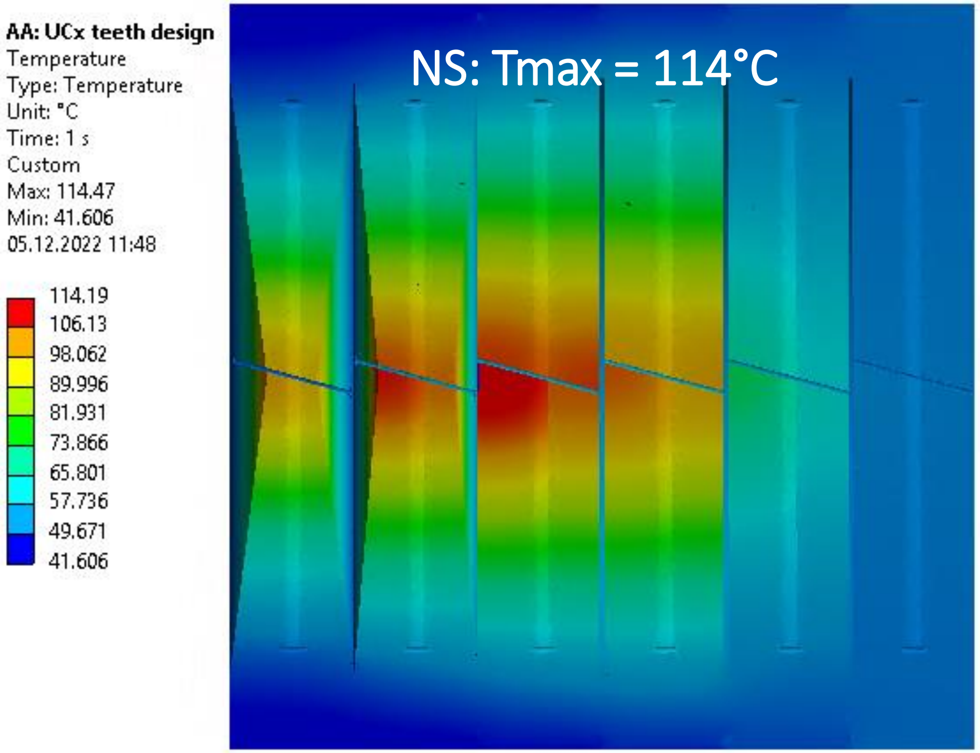
Worst Case Scenario (WCS): No Target and no beam wobbling (commissioning/accident)

Power deposition

UCx Target: 22 kW Target / 23 kW Beam Dump

WCS: No Target / 45 kW Beam Dump





Exchange Flasks for Remote Handling

TargetE-EF

Target E +
~ 15 components
in p-channel
(vertical)

K&P-EF

Diagnostic
Elements,
UCN Collimator
(vertical)

UCN-EF

UCN spallation target
(horizontal)

TargetM-EF

Target M
(horizontal)

Goal: transport highly active elements from beam line to hot cell

Max. dose rate at the flask surface: **2 mSv/h**

Conclusion

- The **Development of Beam Intercepting Devices is a Multidisciplinary Task** requiring Knowledge in Particle Physics, Material Science, Monte Carlo, Multiphysics, Engineering

- A BID constitutes in some cases

  "The Last Line of Defense against Component Damage"

  (M. Calviani, CERN)

- BIDs reliability is crucial!

  Failures of BIDs can lead to long downtime period!

Many Thanks to

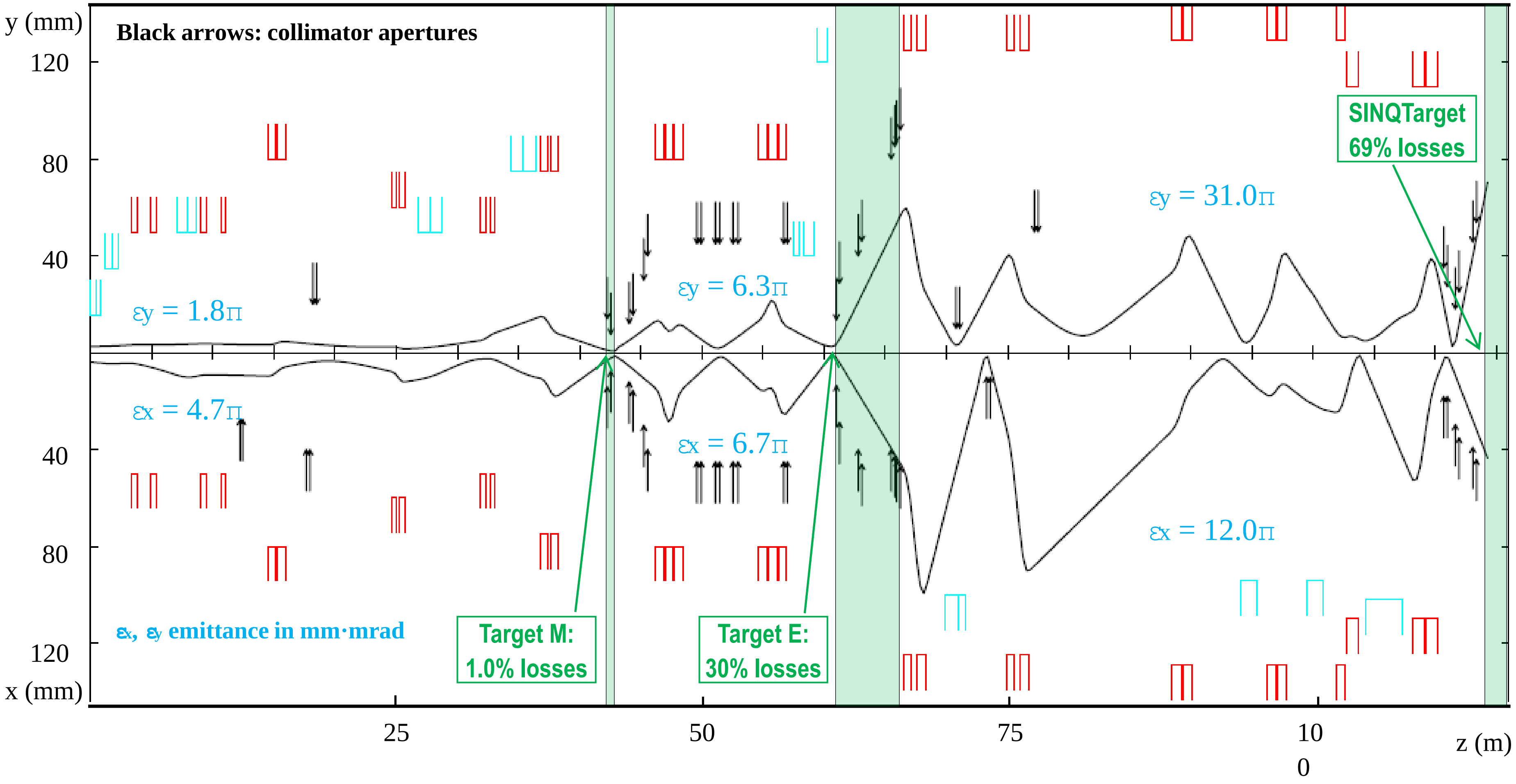
M. Hartmann
A. Ivanov
S. Jollet
D. Kiselev
D. Laube
R. Martinie
J. Snuverink
R. Sobbia
V. Talanov
(PSI)

Marco Calviani
(CERN)

And
All of you!

1.4 MW Beam Transport

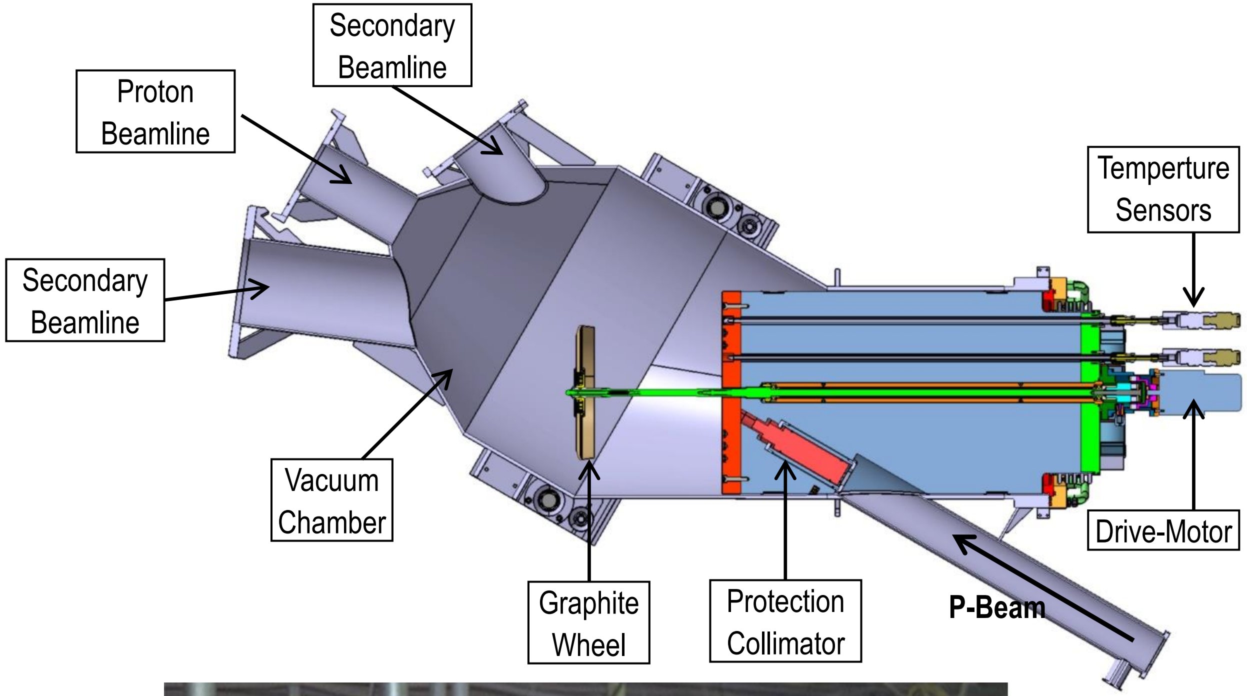
Beam Envelopes from Cyclotron Extraction to SINQ Target (with Magnet and Collimator Apertures)

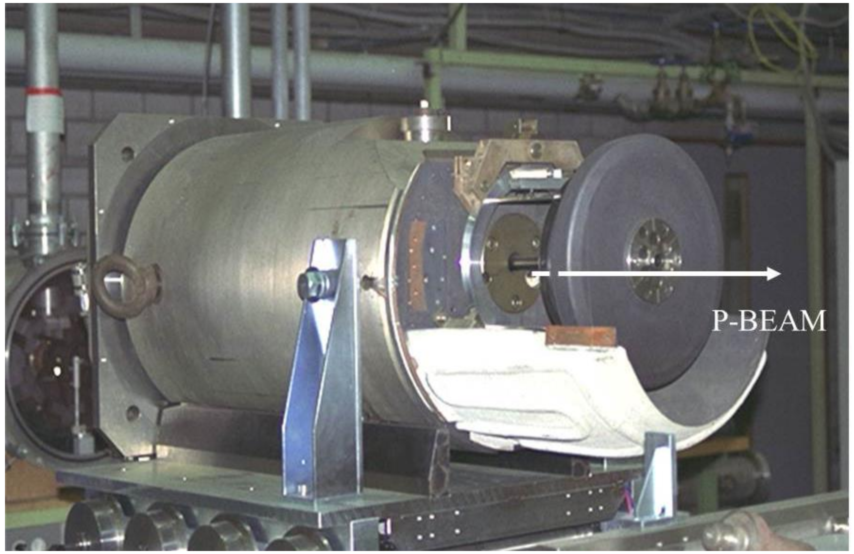


Peak beam current density on target M and E: 200 kW/mm^2

Average losses away from targets: 0.6 W/m

Target M (TgM) Design





Specifications:

Secondary Particles: **Muons, Pions**

Material: **Polycrystalline Graphite**

Mean diameter:	320 mm
Target thickness:	**5.2 mm**
Target width:	20 mm
Graphite density:	1.8 g/cm^3
Beam loss:	**1.6 %**
Power deposition:	2.4 kW/mA
Operating Temperature:	**1100 K**
Irradiation damage rate:	0.12 dpa/Ah
Rotational Speed:	1 Turn/s
Lifetime:	**20000 h**

Grooved Standard TgE

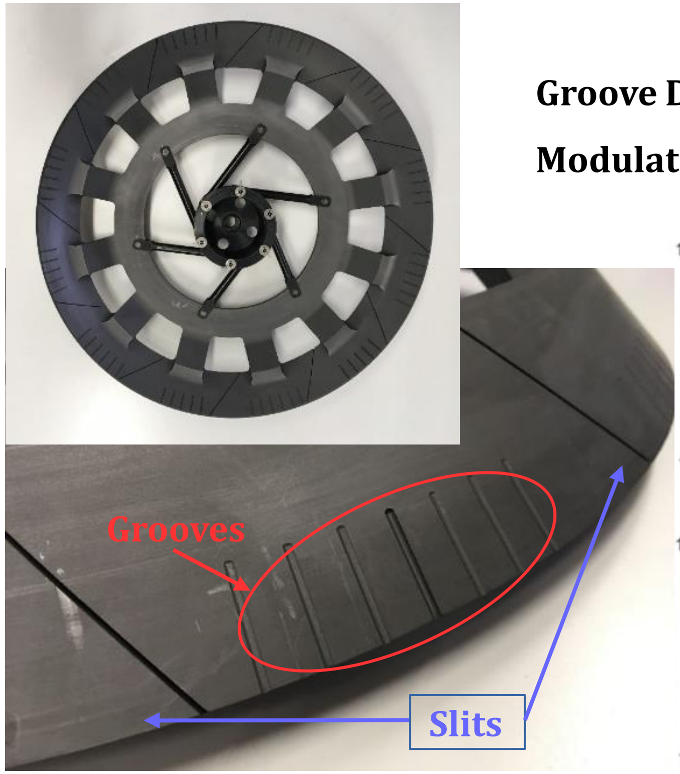
Issue: horizontal centring of proton beam (2σ=1.5mm) on 6mm wide graphite wheel TE

Risk: Unscattered, TE-missing beam delivers hotspot at SINQ target

Transmission Measurement: not a reliable bypassing beam detection due to slits in TE

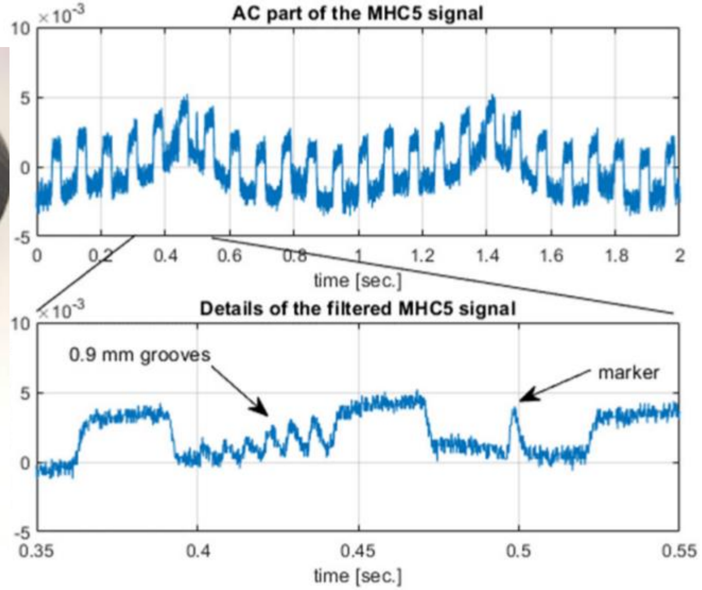
New Idea: grooved TE introduces sizeable modulation of beam current signal if beam not centred

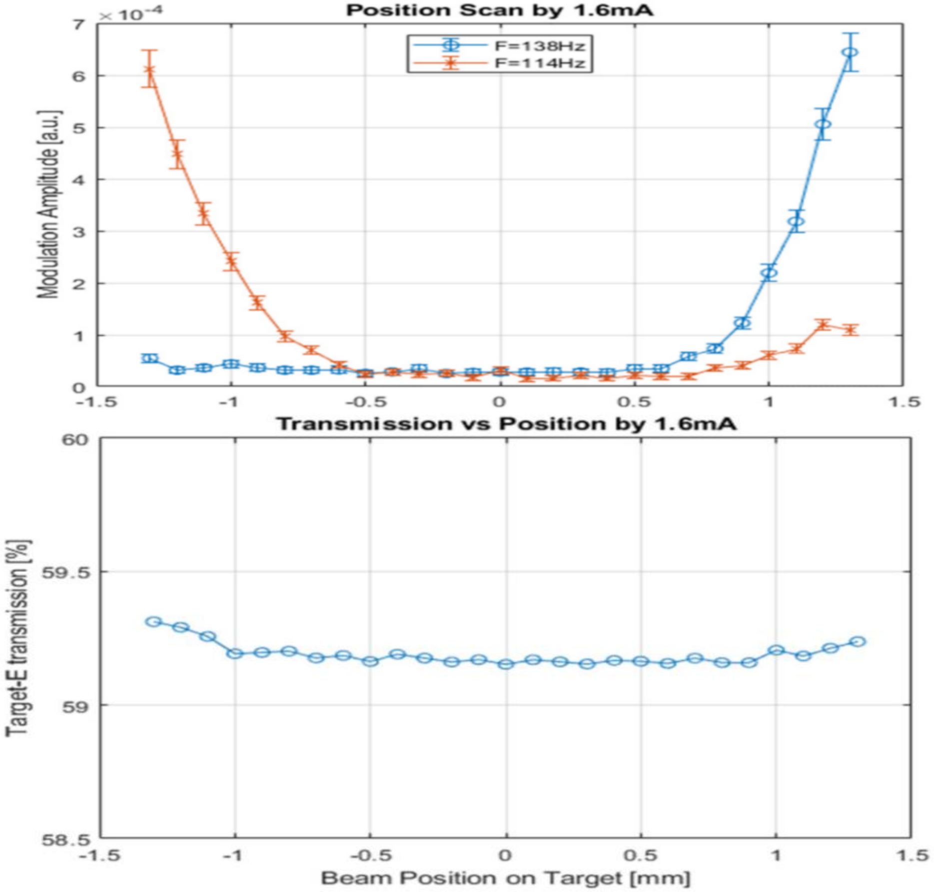
First Tests with Prototype TE: July-September 2019 (Regular TgE)



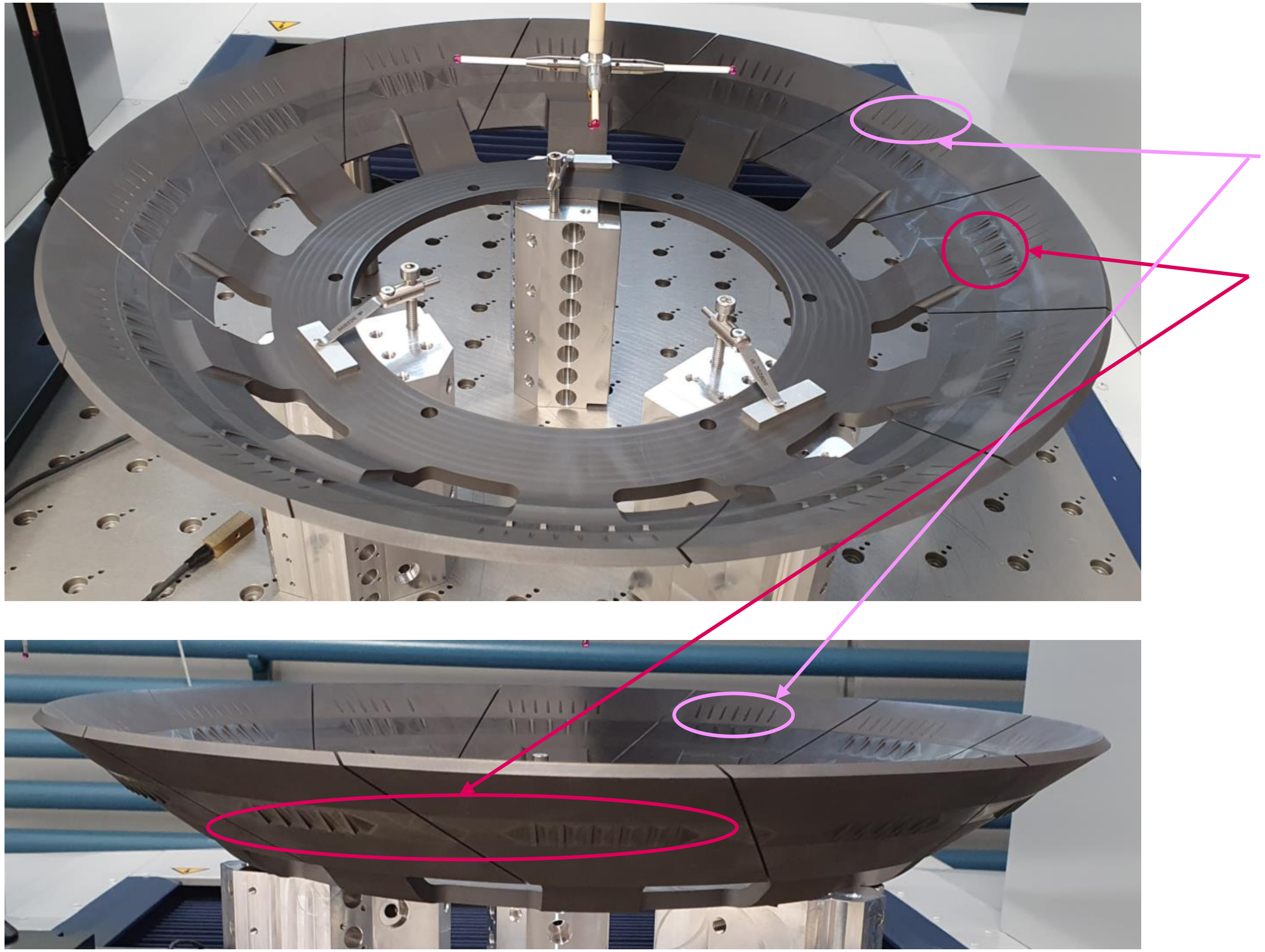
Groove Depth: 0.3, 0.5, 0.7, 0.9 mm

Modulation Freq: 114Hz (left), 138Hz (right)





Grooved Slanted TgE



Currently installed Slanted TgE also equipped with **grooves** (in the center) and **shims** (at the edges) for beam position detection

- ➢ More complicated arrangement because of slanted geometry
- ➢ Analysis of signas from grooves and shims still going on

TgE with New Bearings (Since 2021)

New (since 2021)

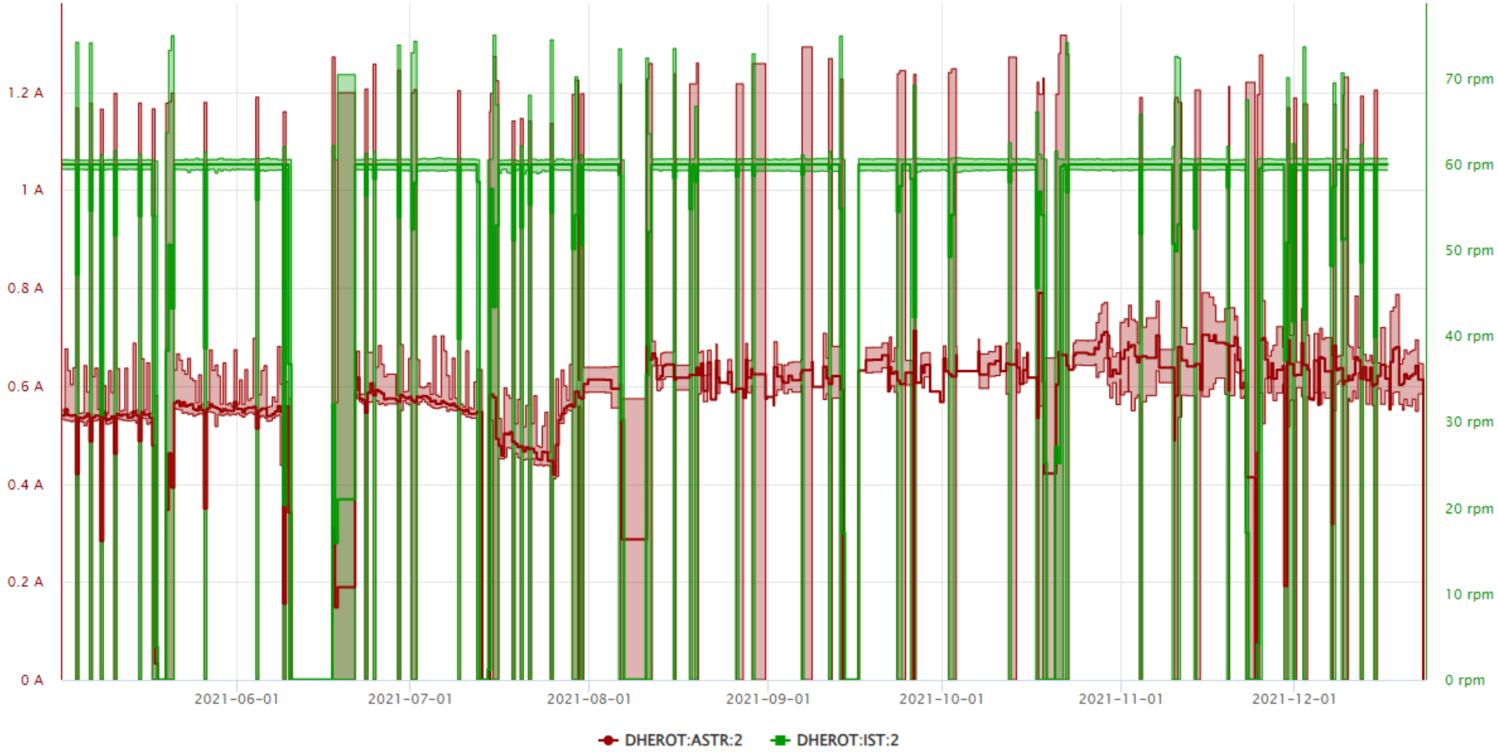
Stainless steel (balls) + WS2 (blocks) **Koyo, Japan** (**Shun Makimura, J-PARC**)

In operation since 2021

- ➢ **No TgE Exchange needed any more throughout the whole year!**
- ➢ TgE exchange during long shutdown only.

Old (2002-2020)

Si3N4 (balls),
MoS2 (Coating),
Ag (ring & cage)
GMN, Germany
1 -2 x exchange/year needed!



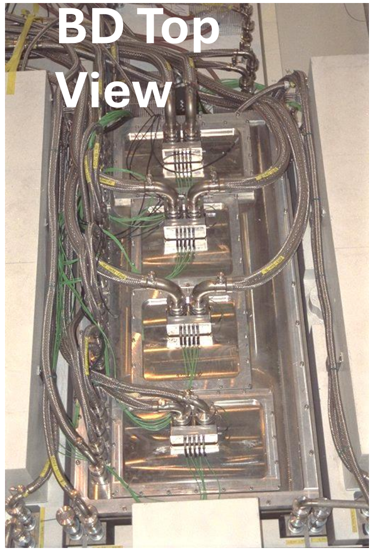
Operation in 2021:
Stable **TgE rotation** and **TgE motor current** throughout the whole year
(same in 2022)

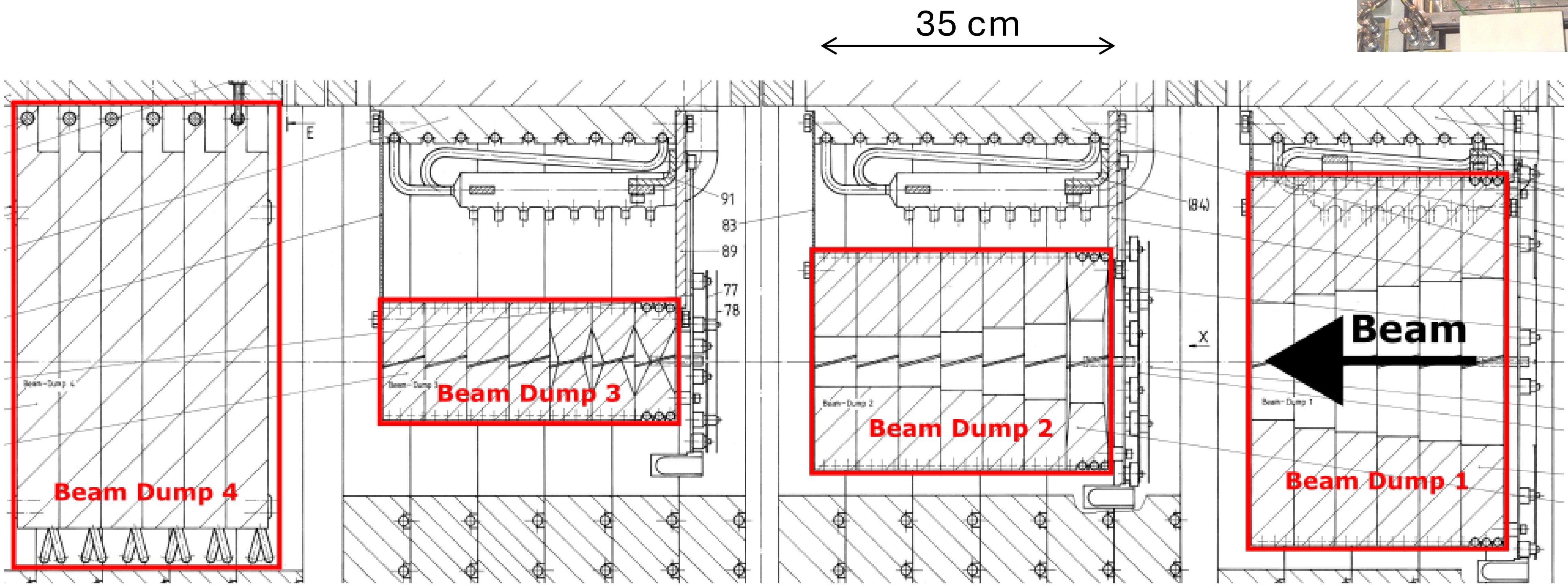
Beam Dump: Introduction

700 kW, four stage, water cooled, Beam Dump allows beam operation on TgM and TgE in case the SINQ Target does not work

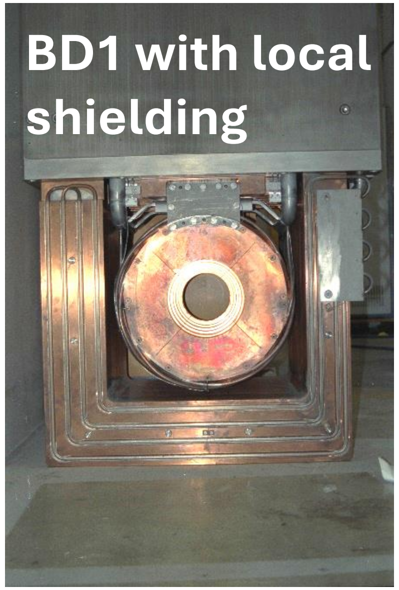
Body Material OFHC: oxygen-free high thermal conductivity copper
Cooling Water Pipes: **Stainless Steel**

BD1 exchanged in 2018 (27 years operation) **due to water leak in cooling pipe**

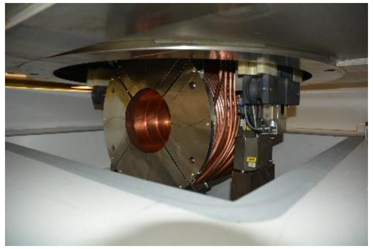




Beam-dump overview



590 MeV Beam Dump: Energy Deposition



Energy deposition

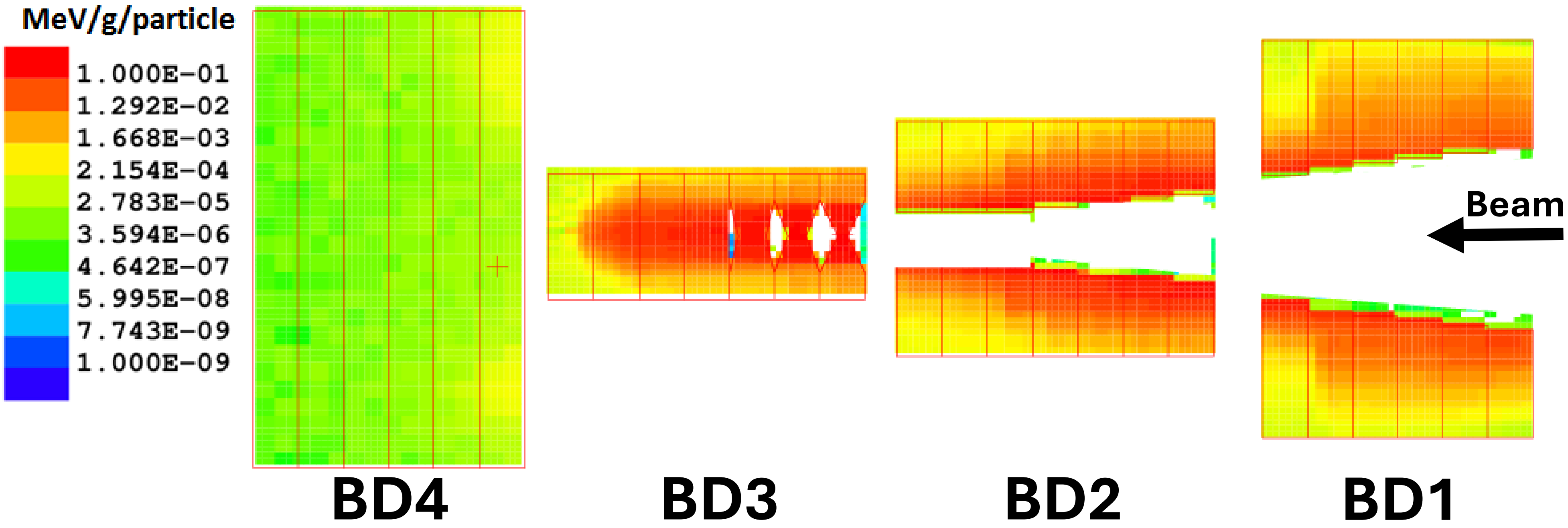
- 4 cm thick Target E
- Present KHE2/3 system
- Transmission 74.1%
- TURTLE beam distribution

Proton Beam Parameters

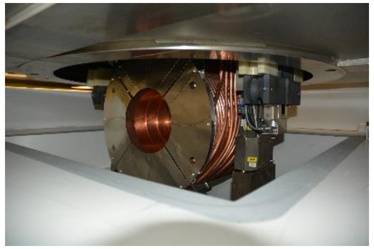
10cm in front of BD1

σ_x [mm]	x' [mm]	σ_y [mm]	y' [mm]
79.9	17.6	58.8	8.2

Energy distribution computed with **MCNPX2.7.0**



590 MeV Beam Dump: Temperature Distribution

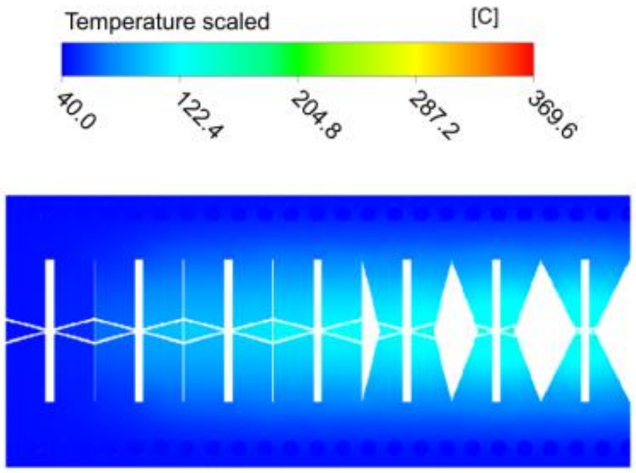


Temperature overview

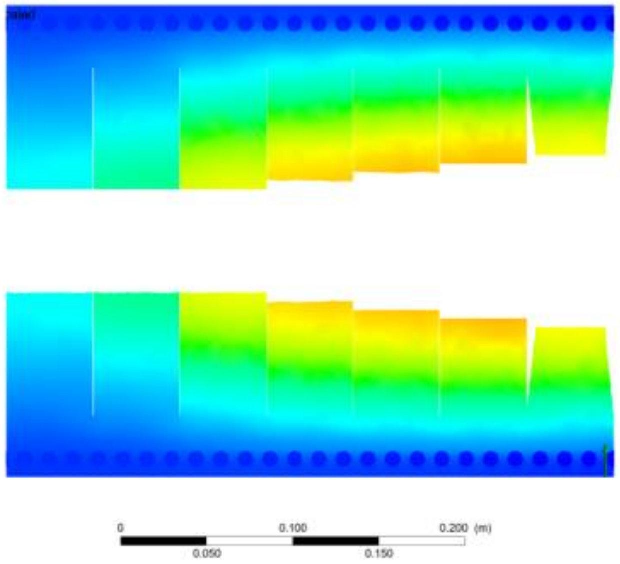
- BD1 experience the highest temperatures
- BD2 temperatures are significantly lower
- BD3 temperatures are almost negligible
- BD4 is not considered

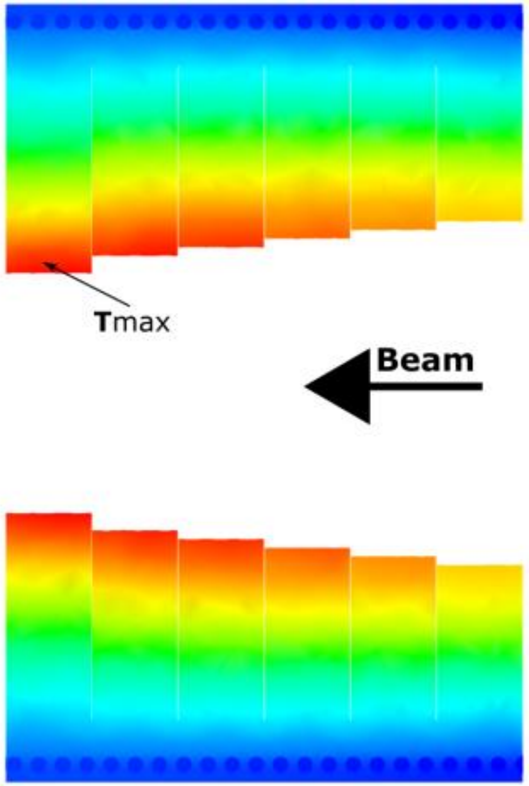
Simulated with

ANSYS FLUENT

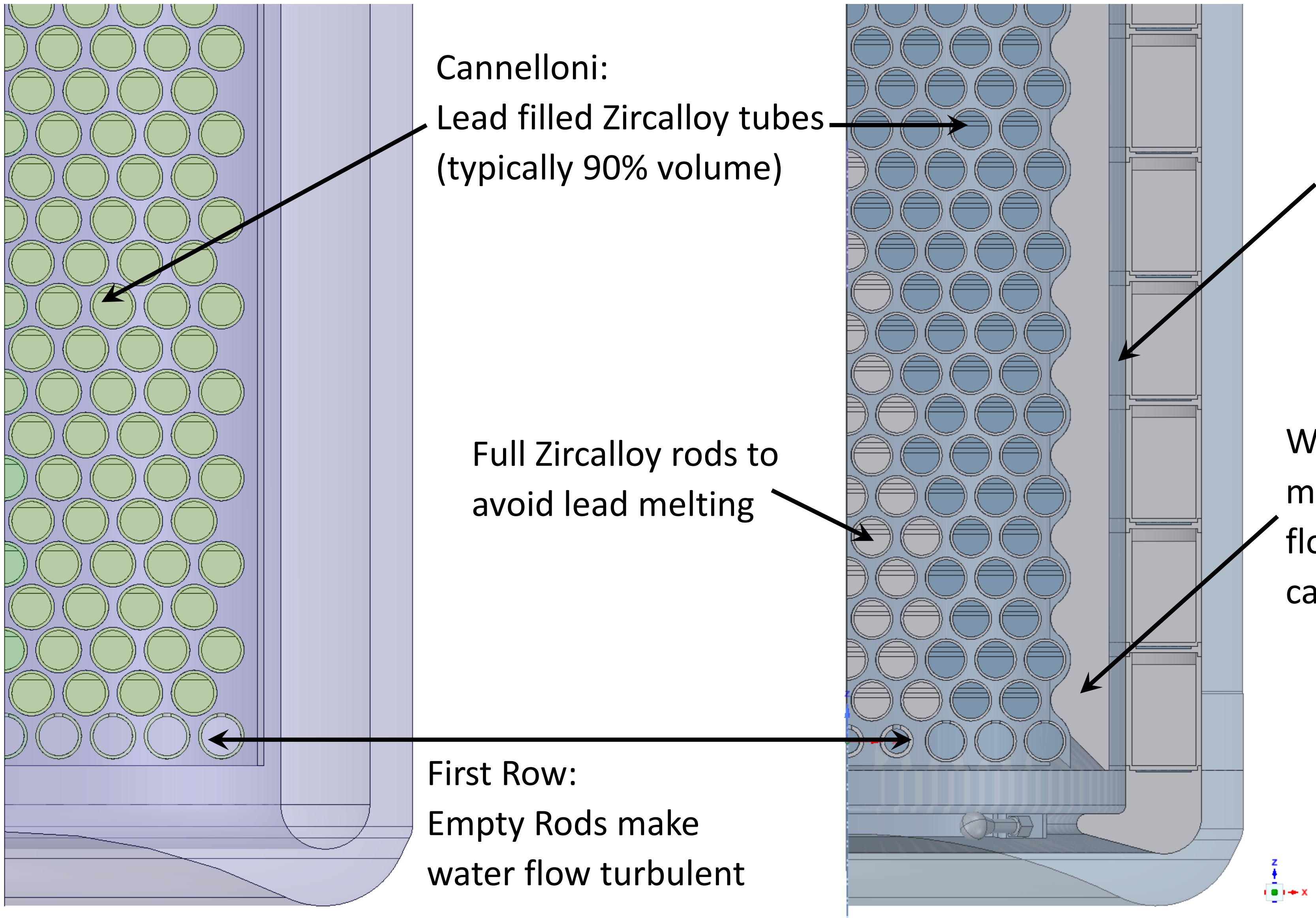


1.7mA-scaled temperature distribution in the YX plan





SINQ Target 13 vs 9 (MARK IV)



Cannelloni:
Lead filled Zircalloy tubes
(typically 90% volume)

Water bypass for
blanket cooling

Full Zircalloy rods to
avoid lead melting

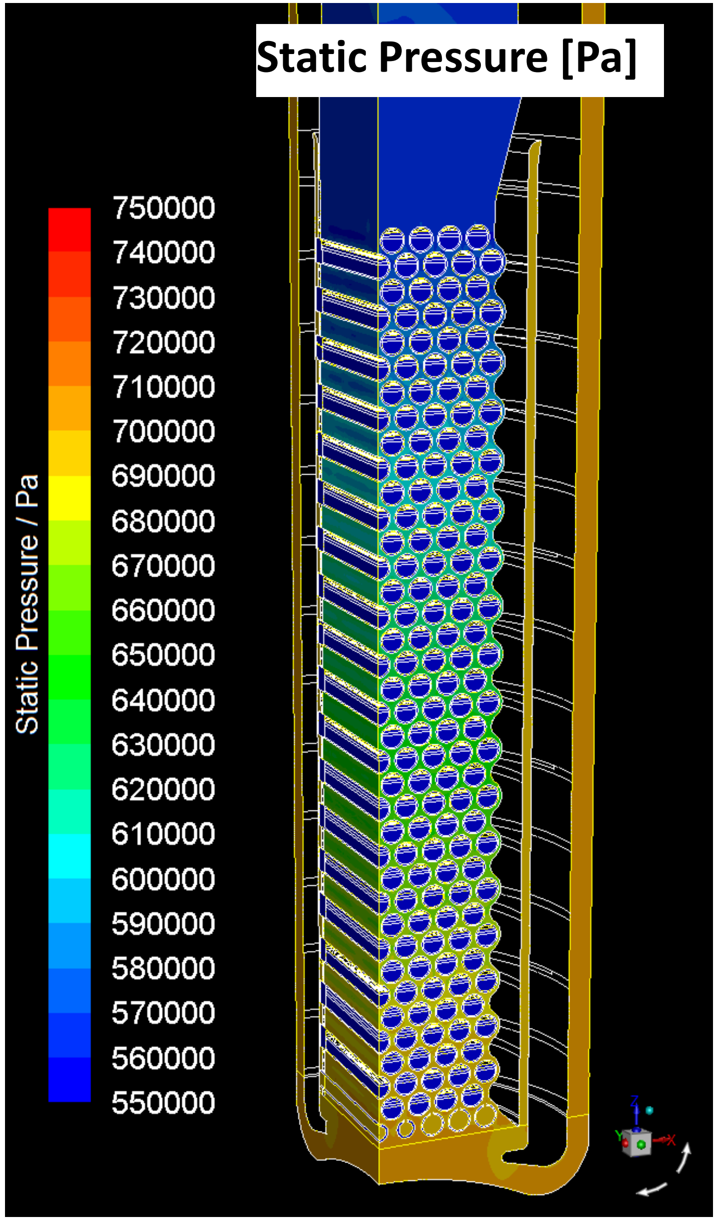
Water channel
modified to increase
flow through
cannelloni

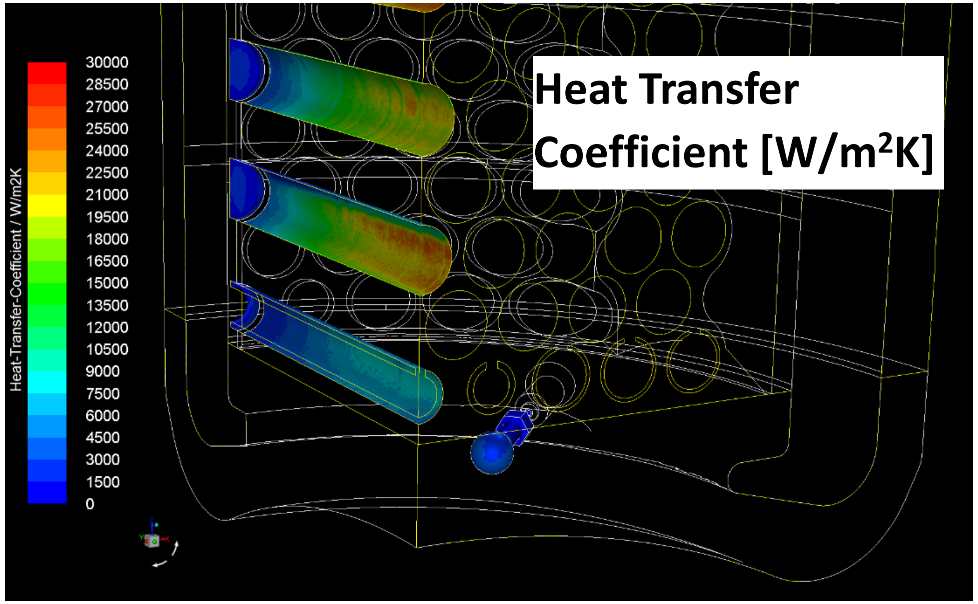
First Row:
Empty Rods make
water flow turbulent

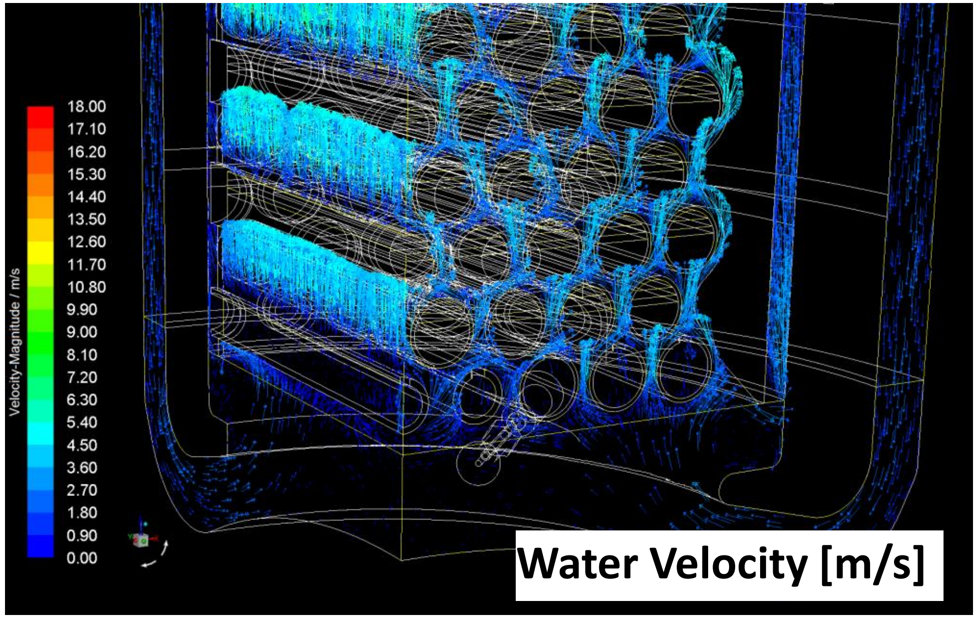
SINQ Target 9

SINQ Target 13

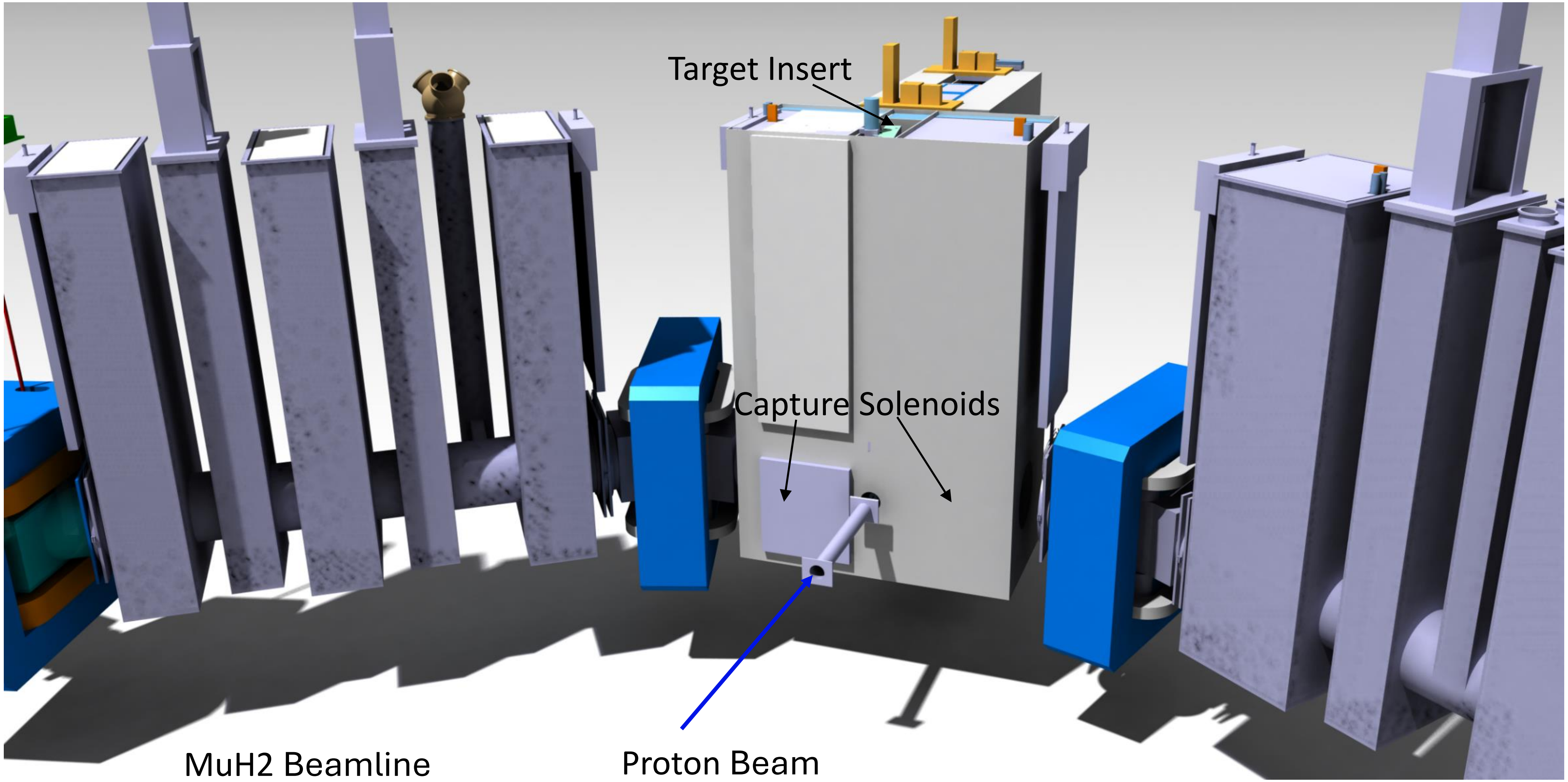
SINQ Target 13: Other Interesting Parameters





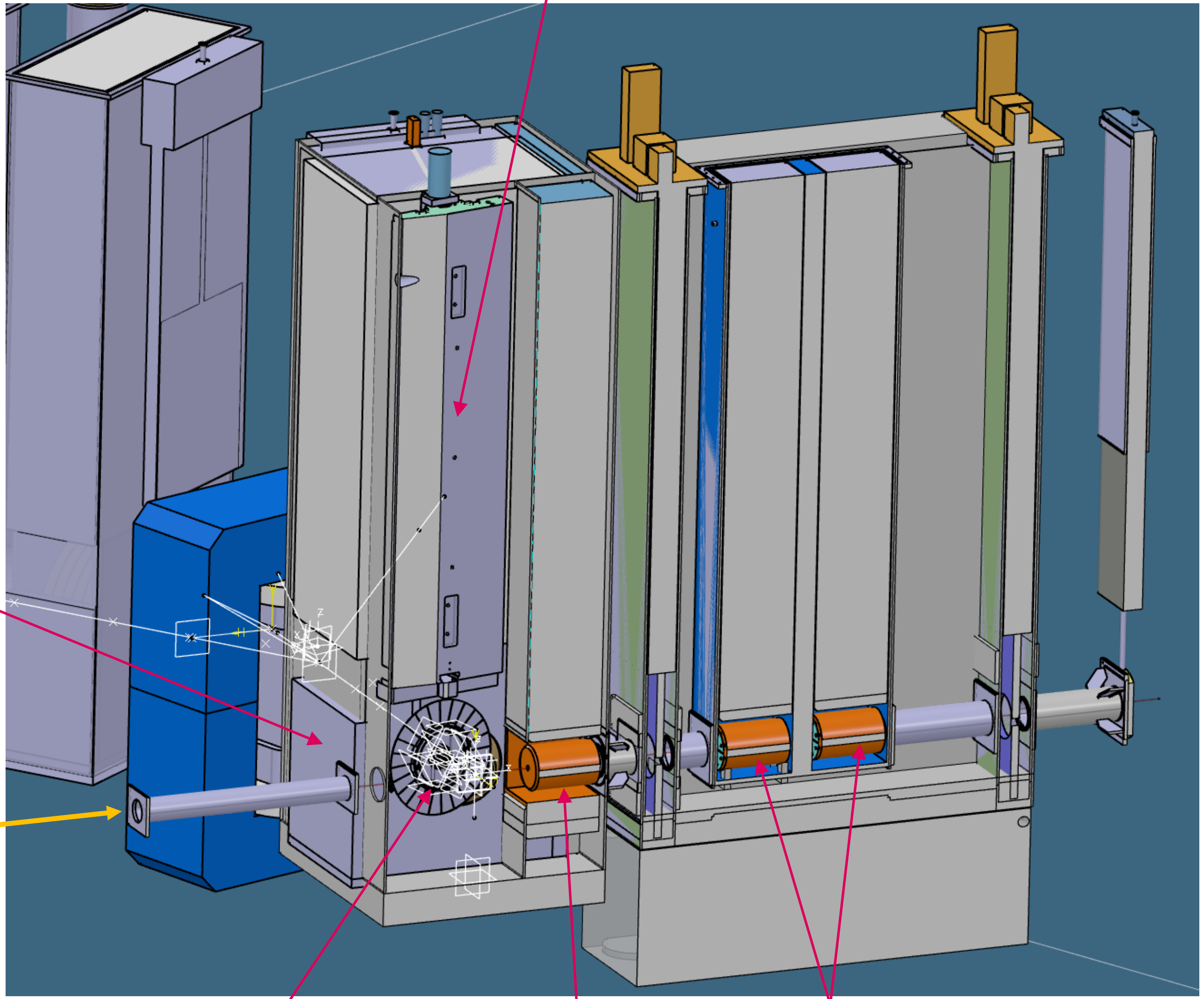


TgH Region



MuH3 Beamline

TgH Region Vertical Cut



Target Insert

Capture Solenoid

Proton Beam

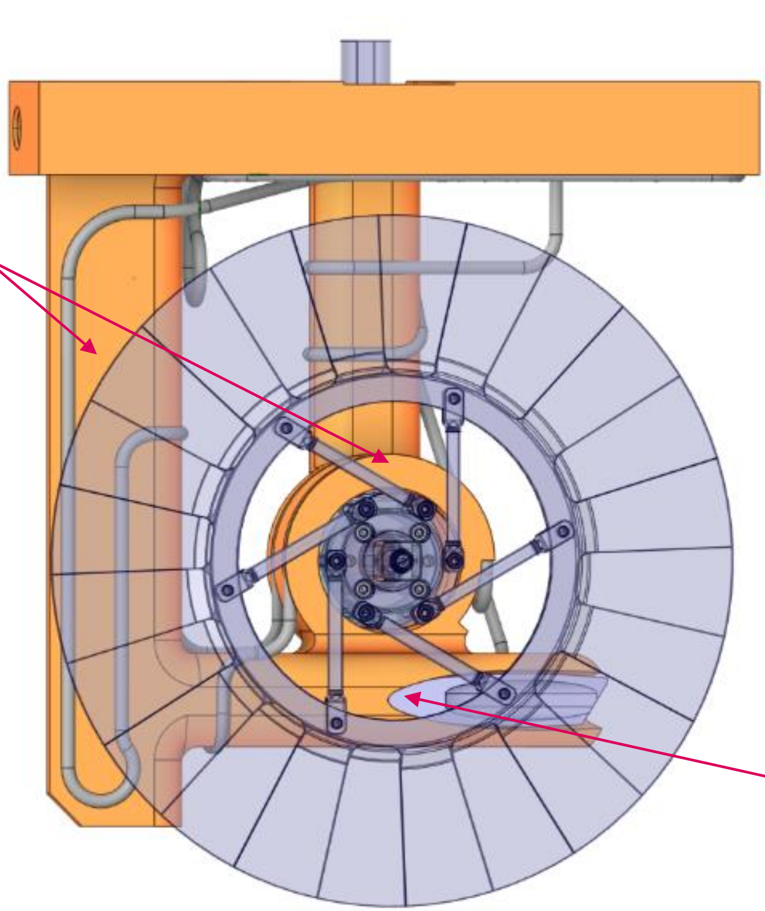
Target Rim

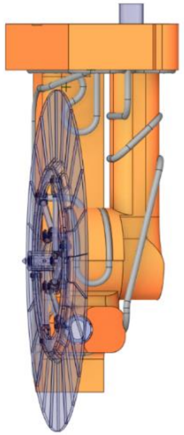
Collimator KHH0

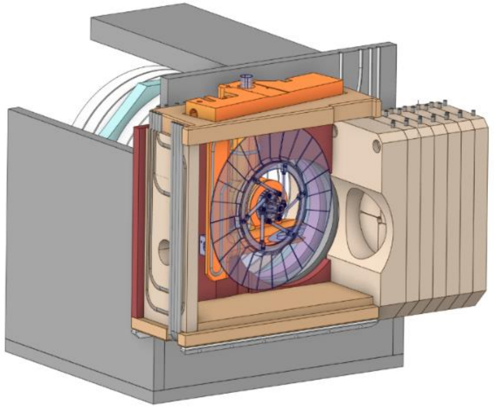
Collimators KHH1/2

Cooling Plate and Protection Collimator

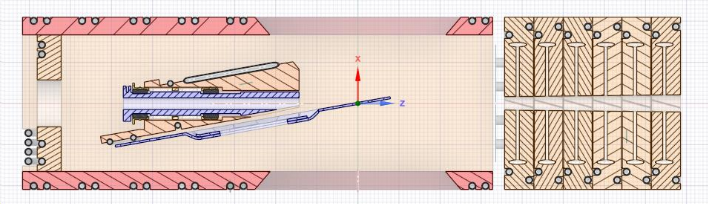
Cooling Plate
Function:
protect berings, collimator and halo monitor
Material: Copper



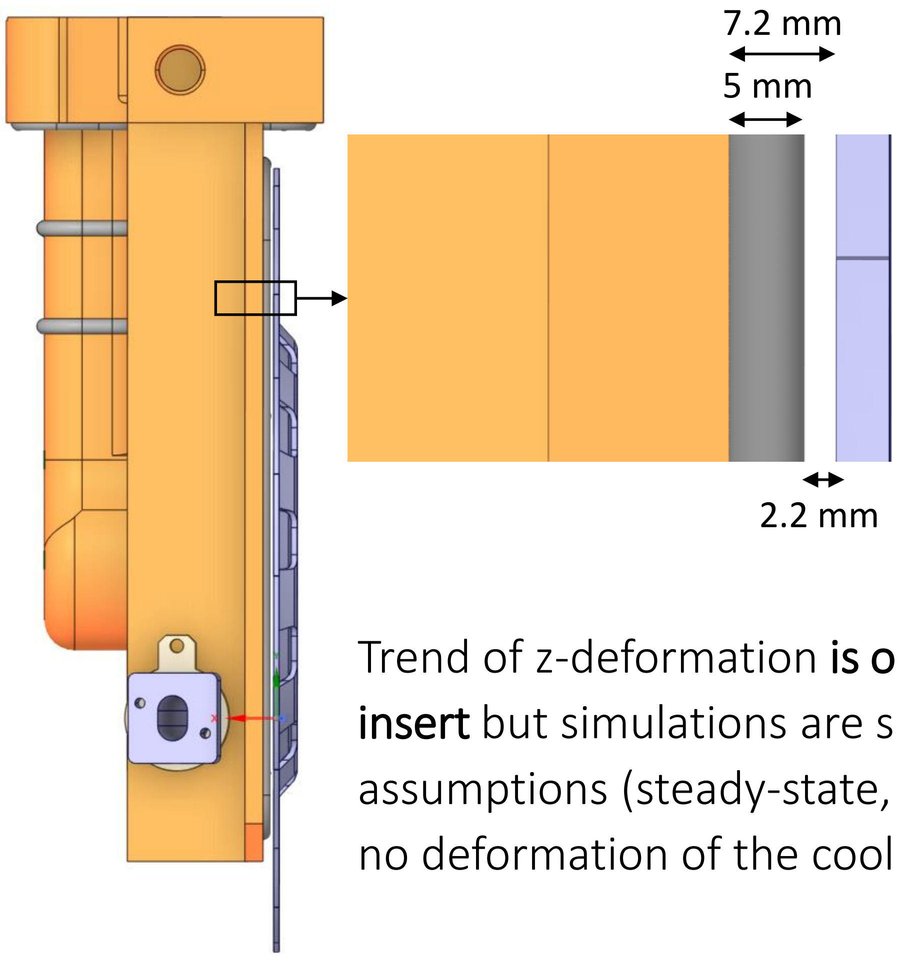




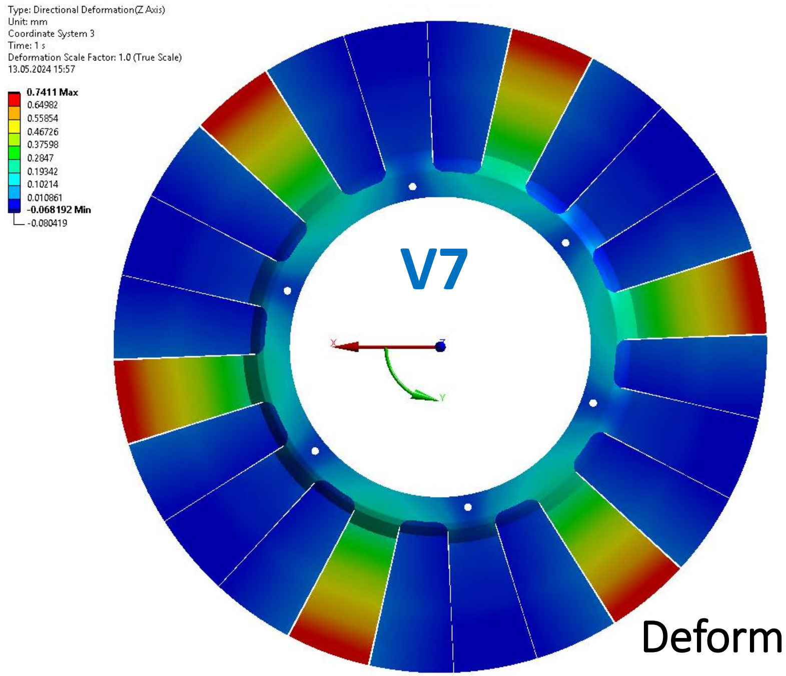
Protection Collimator
Function: protect target station from missteered beam
Material: Densimet (Tungsten Alloy)



TgH Rim Deformation

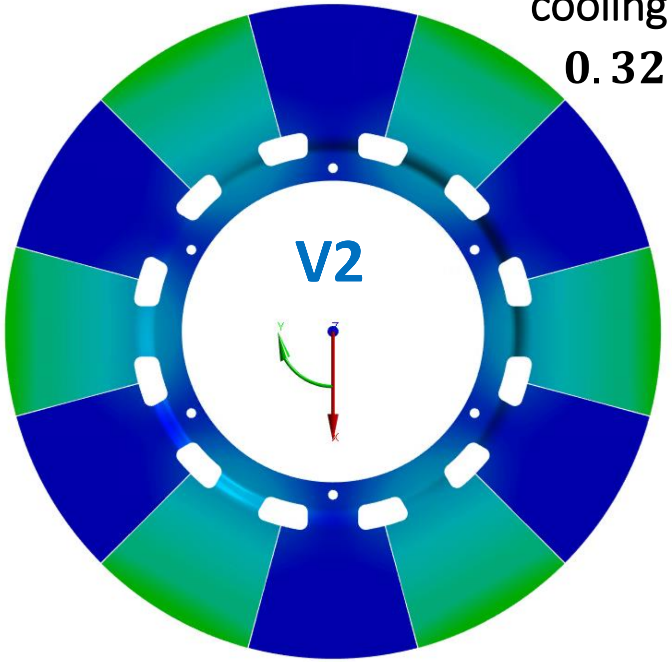


Trend of z-deformation **is outward from the TgH insert** but simulations are simplified by several assumptions (steady-state, no radiation damage, no deformation of the cooling plate simulated).



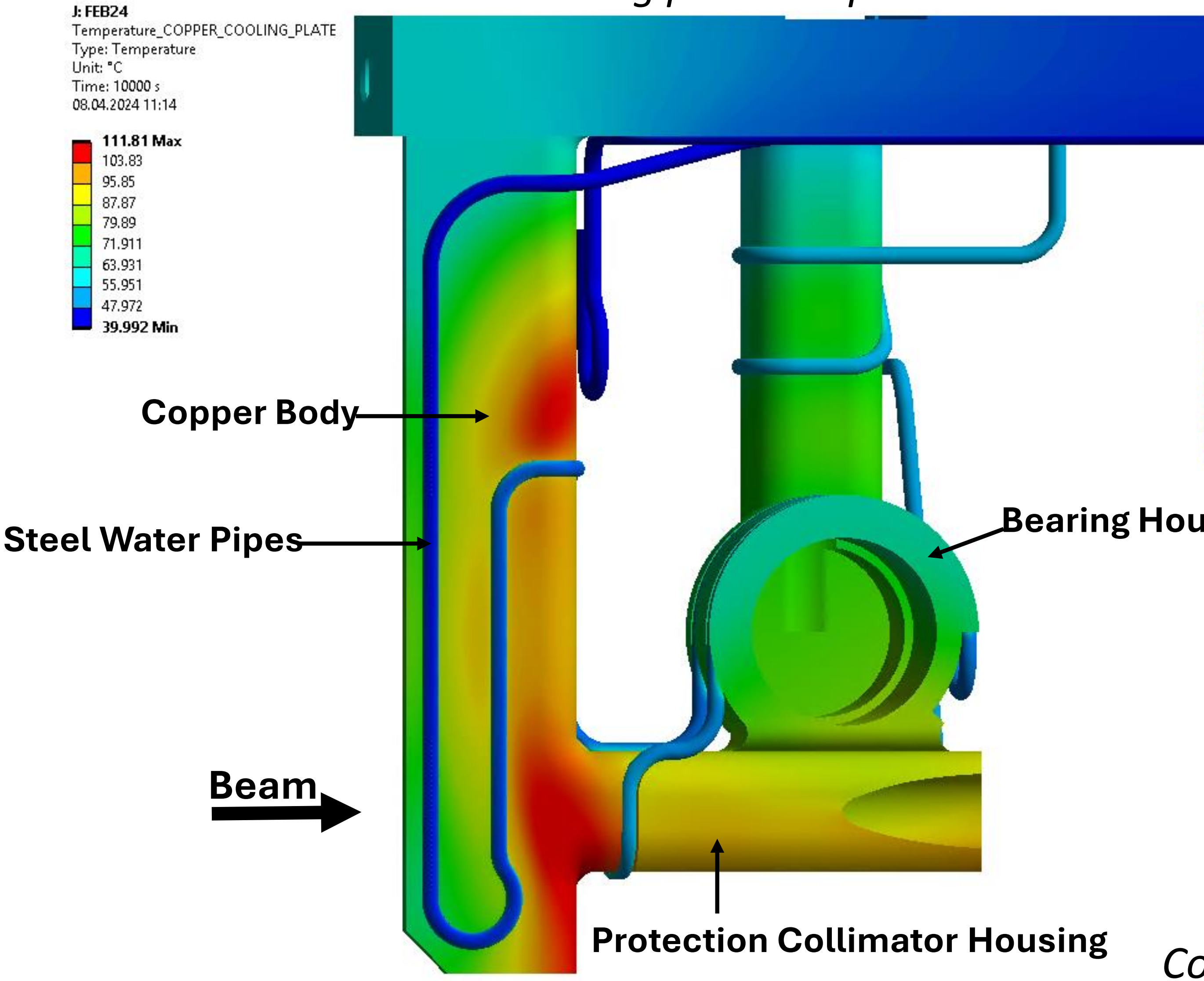
Deformation toward the cooling plate lower in V7:

$$0.32\ mm < 0.74\ mm$$



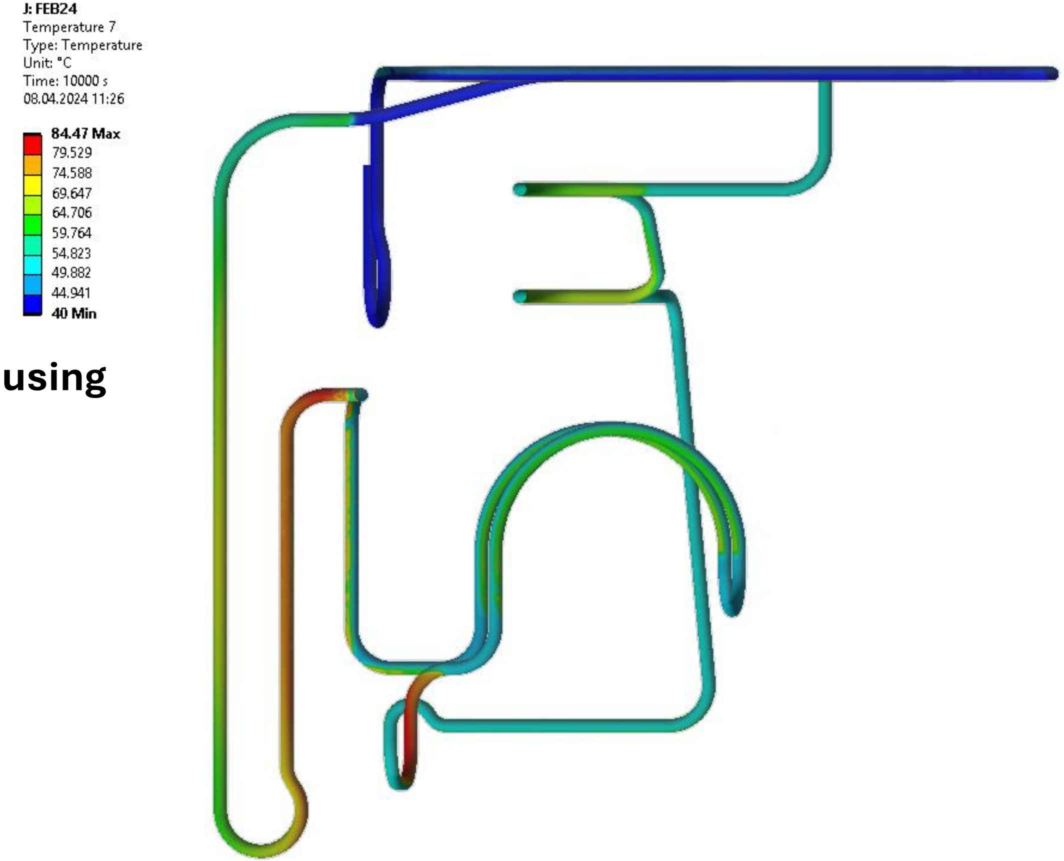
Cooling Plate Thermal Analysis

Cooling plate temperature



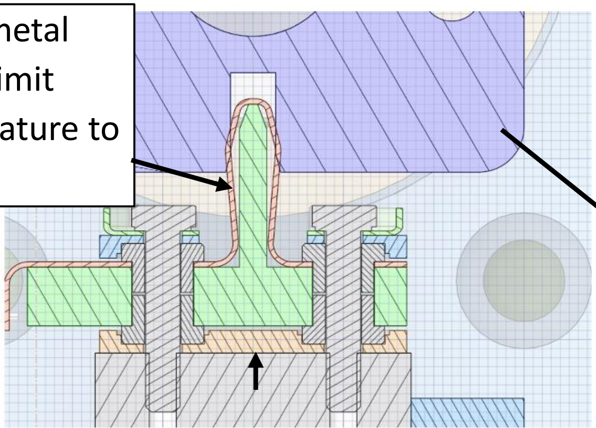
Requirements

- Copper Temperature: $T_{Cu} < 150$ °C
- Water Temperature: $T_W < 80$ °C
- Water Velocity: $V_W = 1.5$ m/s



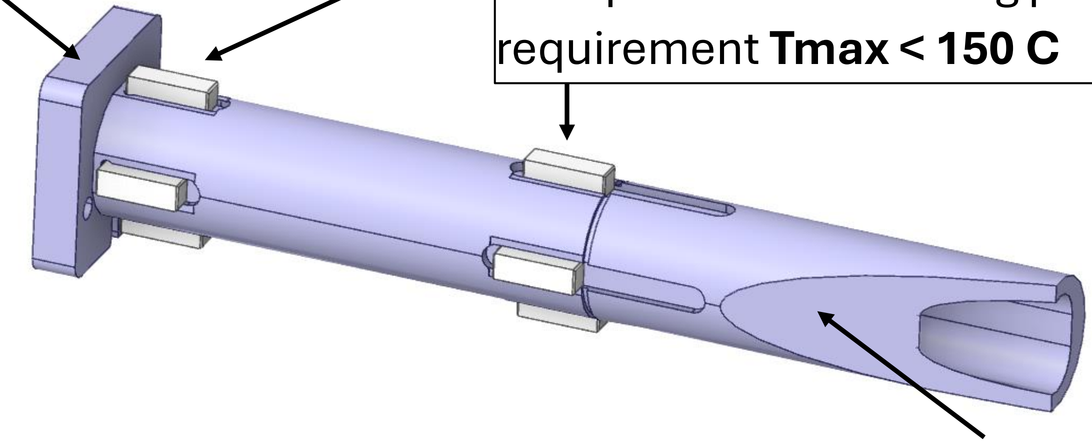
Cooling plate water surface temperature

Protection Collimator: Thermal Analysis



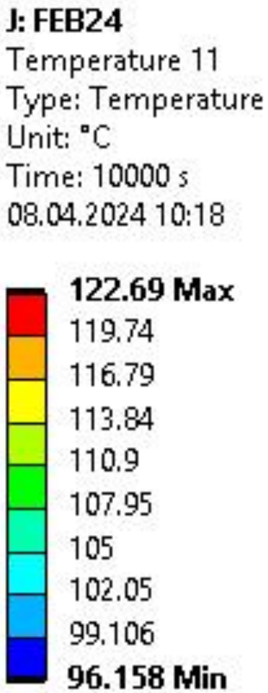
Cu-Be metal spring limit Temperature to 150 C

Nickel Foil Beam Monitor



Ceramic Holders made of **Alumina** ($k = 13\,{}^{W}/_{mK}$) instead of MACOR ($k = 1\,{}^{W}/_{mK}$) to transport heat to cooling plate and meet requirement **Tmax < 150 C**

Densimet Body (Tungsten Alloy)



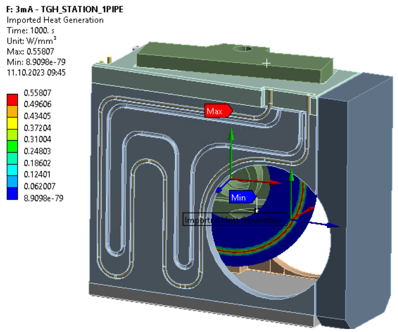
Protection collimator temperature distribution

Beam →

Beam → X

Beam-Target IP

Local Shielding around TgH: Thermal Analysis

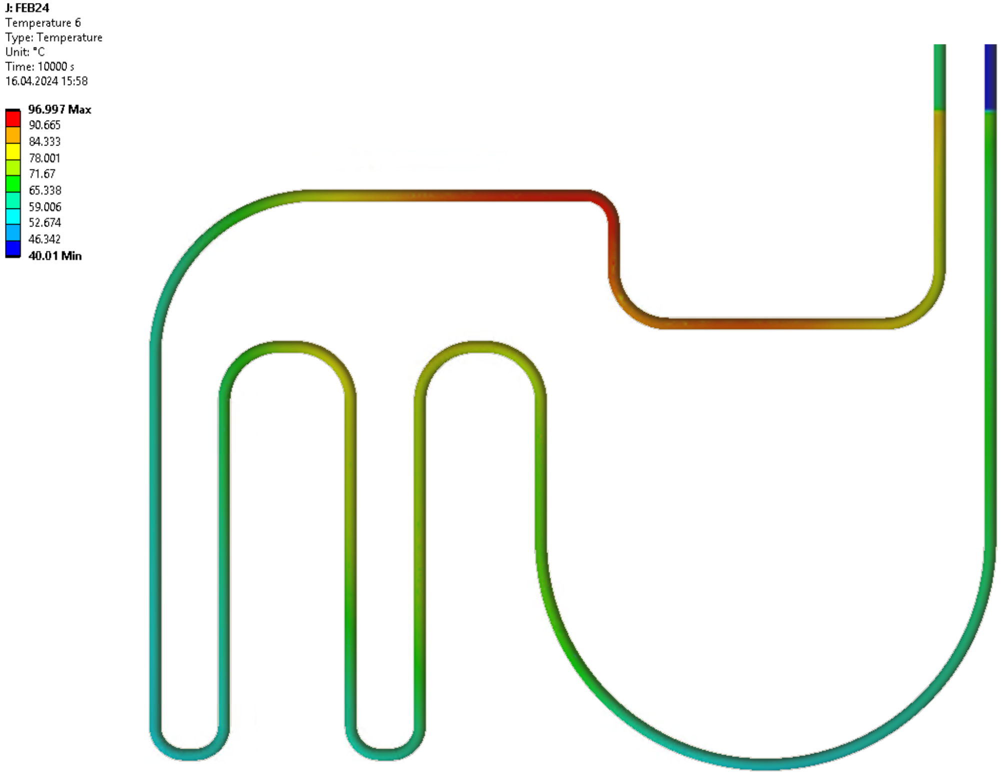


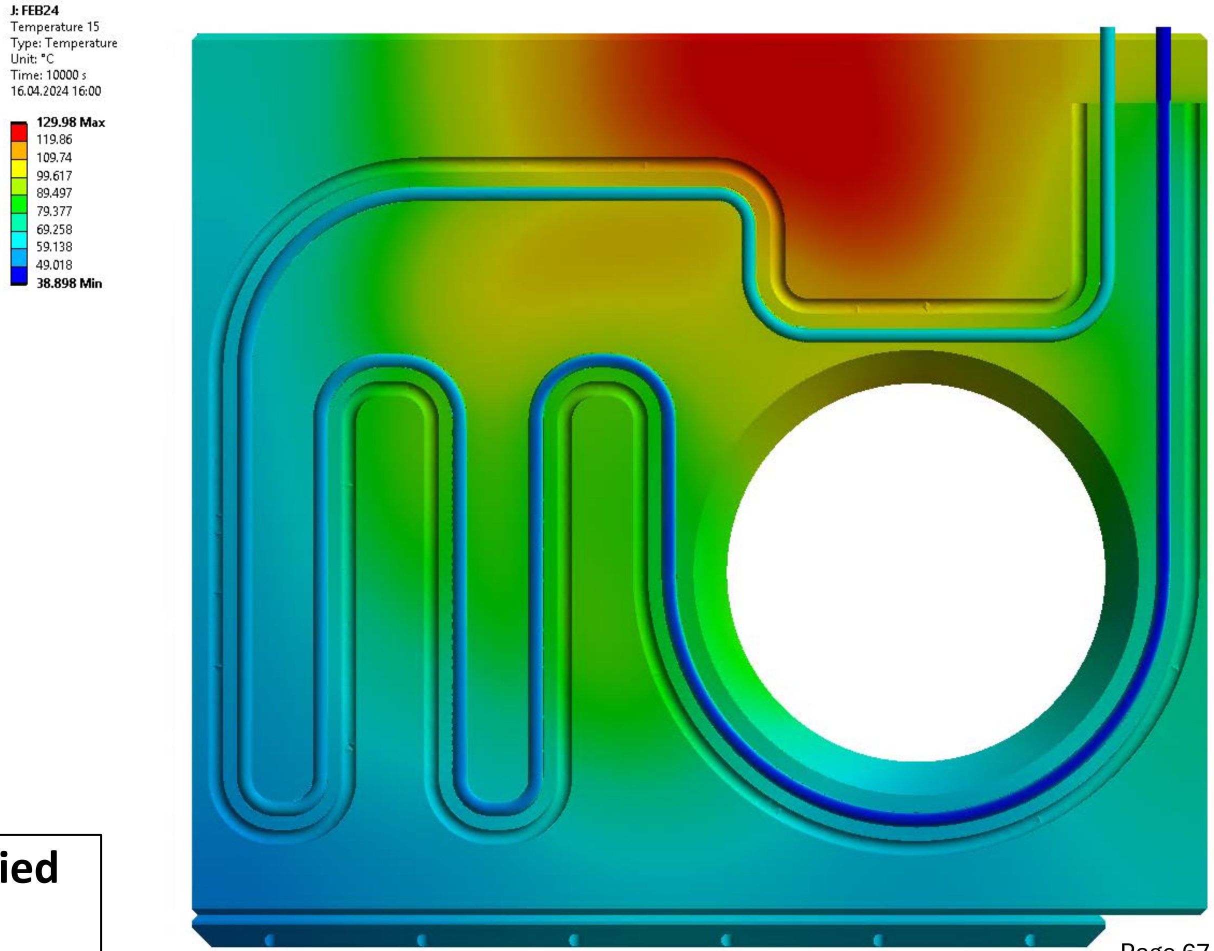
Power Deposition from proton beam (3mA):

- 28 kW on target rim
- 35 kW on collimator KHH0

ANSYS Simulation of temperature distribution

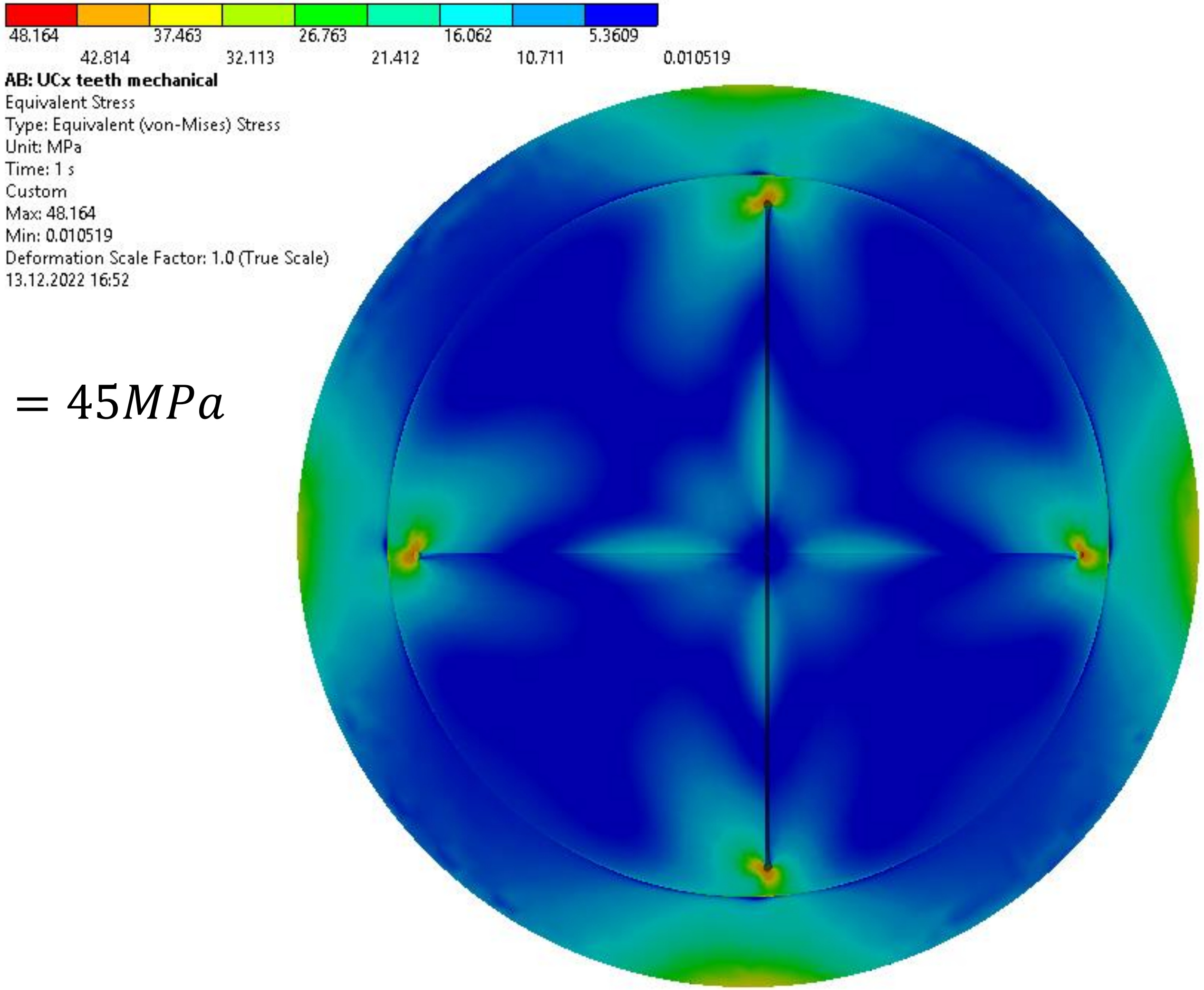
- Total water flow rate: **1.5 kg/s**
- Acceptable temperature values (**max 130°C**)
- Heat from secondary particles not yet accounted for





Two water loops foreseen, but **simulatuion carried out only with one loop** (conservative approach)

TATTOOS-BD: Structural Analysis (UCx Target, V5)



AB: UCx teeth mechanical
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 1 s
Custom
Max: 48.164
Min: 0.010519
Deformation Scale Factor: 1.0 (True Scale)
13.12.2022 16:52

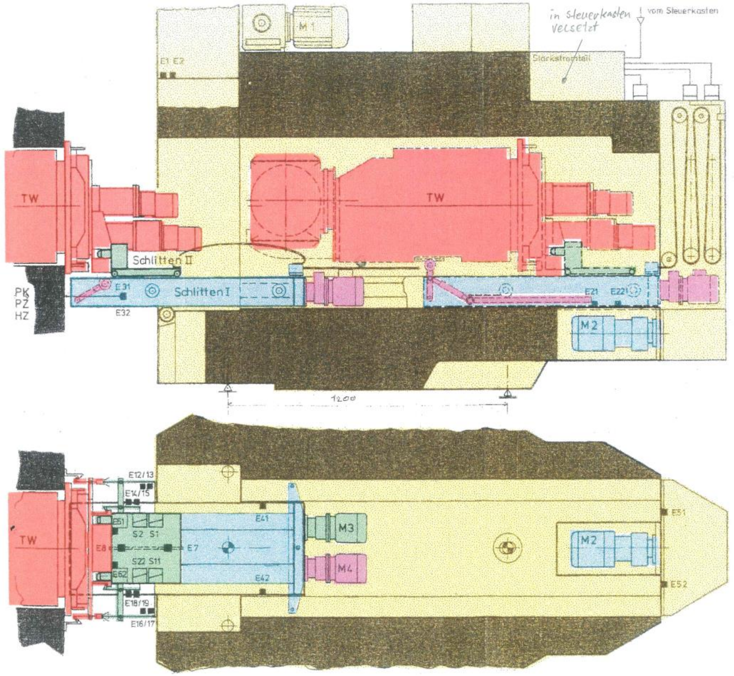
$$Stress_{yield} = 45MPa$$

Deformation

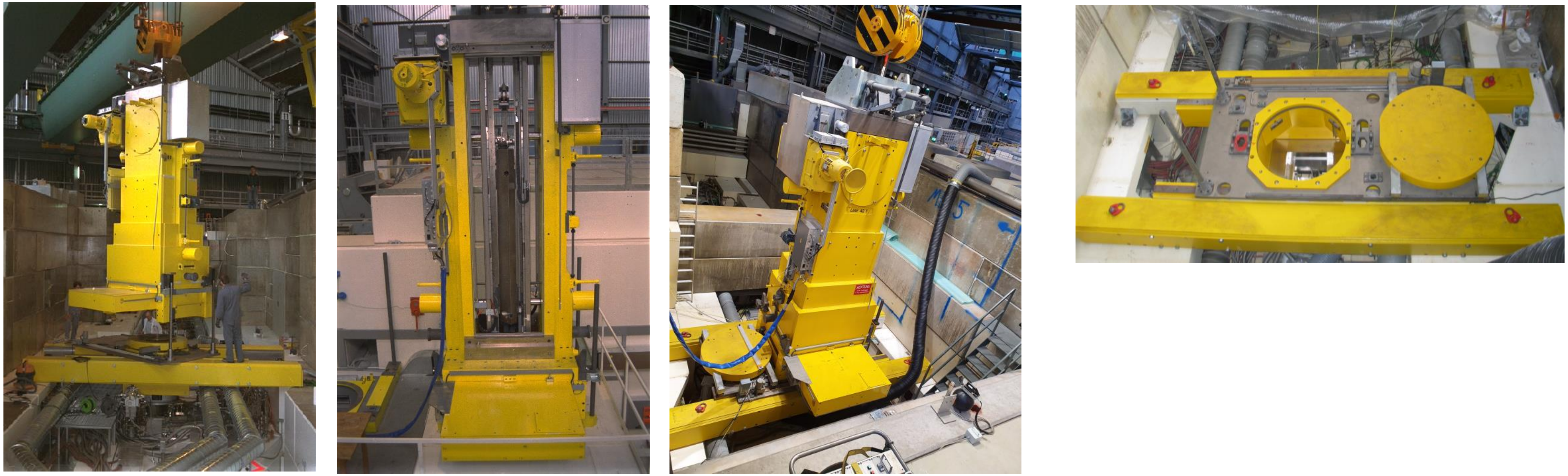
- Maximum deformation:**0.1 mm** for the Normal Scenario
- Maximum deformation: **0.32 mm** for the Worst Case Scenario

Remote Handling: Target M Exchange Flask

- Horizontal pull
- Weight empty: 19t
- Weight loaded: 20.5t
- Height: 1.7m
- Length: 2.5m



Remote Handling: Target E Exchange Flask



- Vertical Pull
- Weight empty: 42t
- Weight loaded: 50t
- Height: 5.3m
- Transports TgE + ~15 other P-Channel elements