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Muon Targets at HIPA

BRIDGE Workshop, PSI, 18.10.2023

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Outline

- Introduction to the HIPA facility
- Design and operation of currently employed Muon Targets (TgM and TgE)
- Development of new Muon Target for IMPACT (TgH)
- Remote Handling of Muon Targets
- Conclusion

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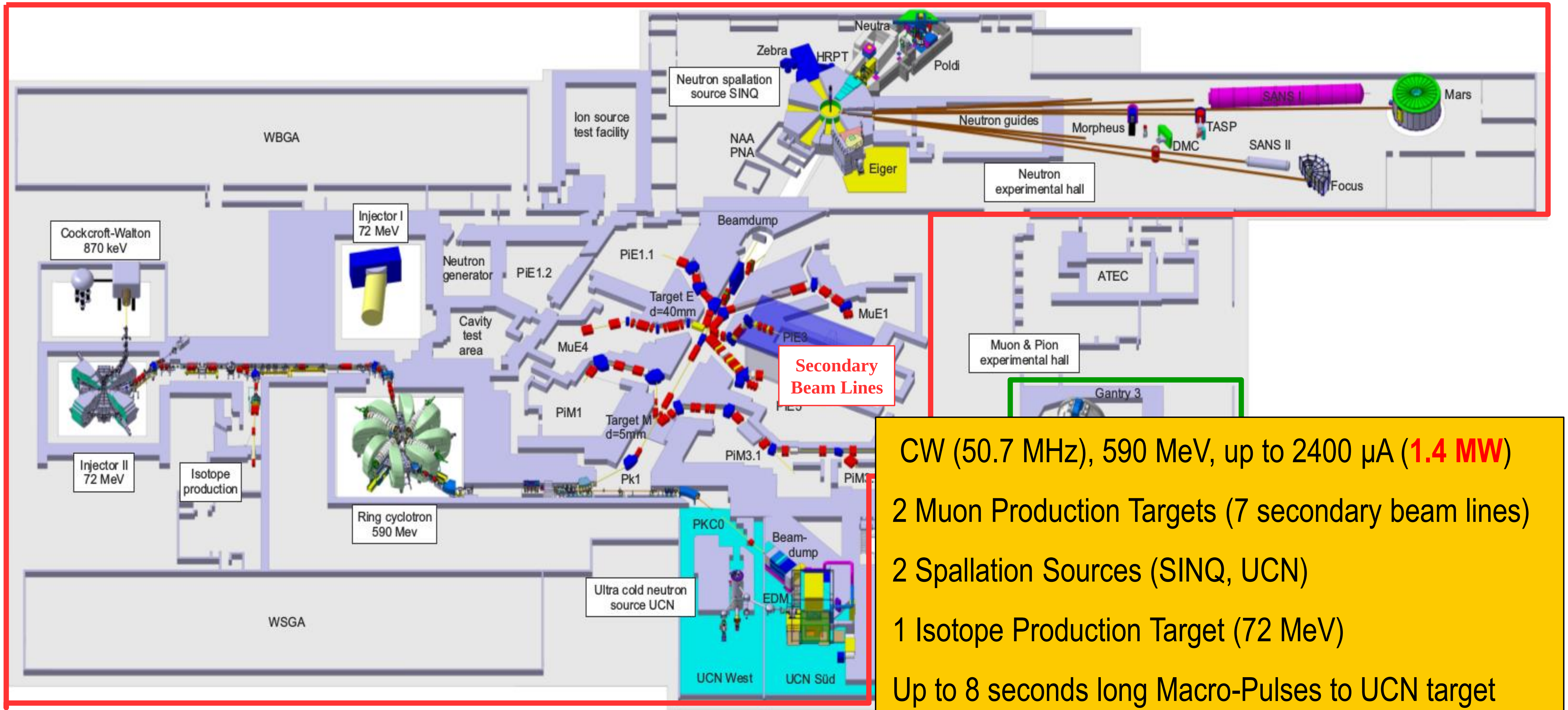
The High Intensity Proton Accelerator (HIPA)



CW (50.7 MHz), 590 MeV, up to 2400 μA (**1.4 MW**)

2 Muon Production Targets (7 secondary beam lines)

2 Spallation Sources (SINQ, UCN)

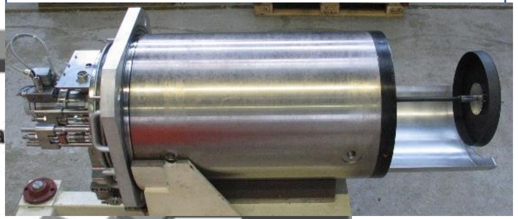
1 Isotope Production Target (72 MeV)

Up to 8 seconds long Macro-Pulses to UCN target

High availability (~90%), stable operation.

The 590 MeV, 1.4 MW Proton Channel

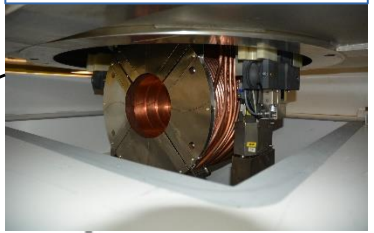
TgM: 5mm C

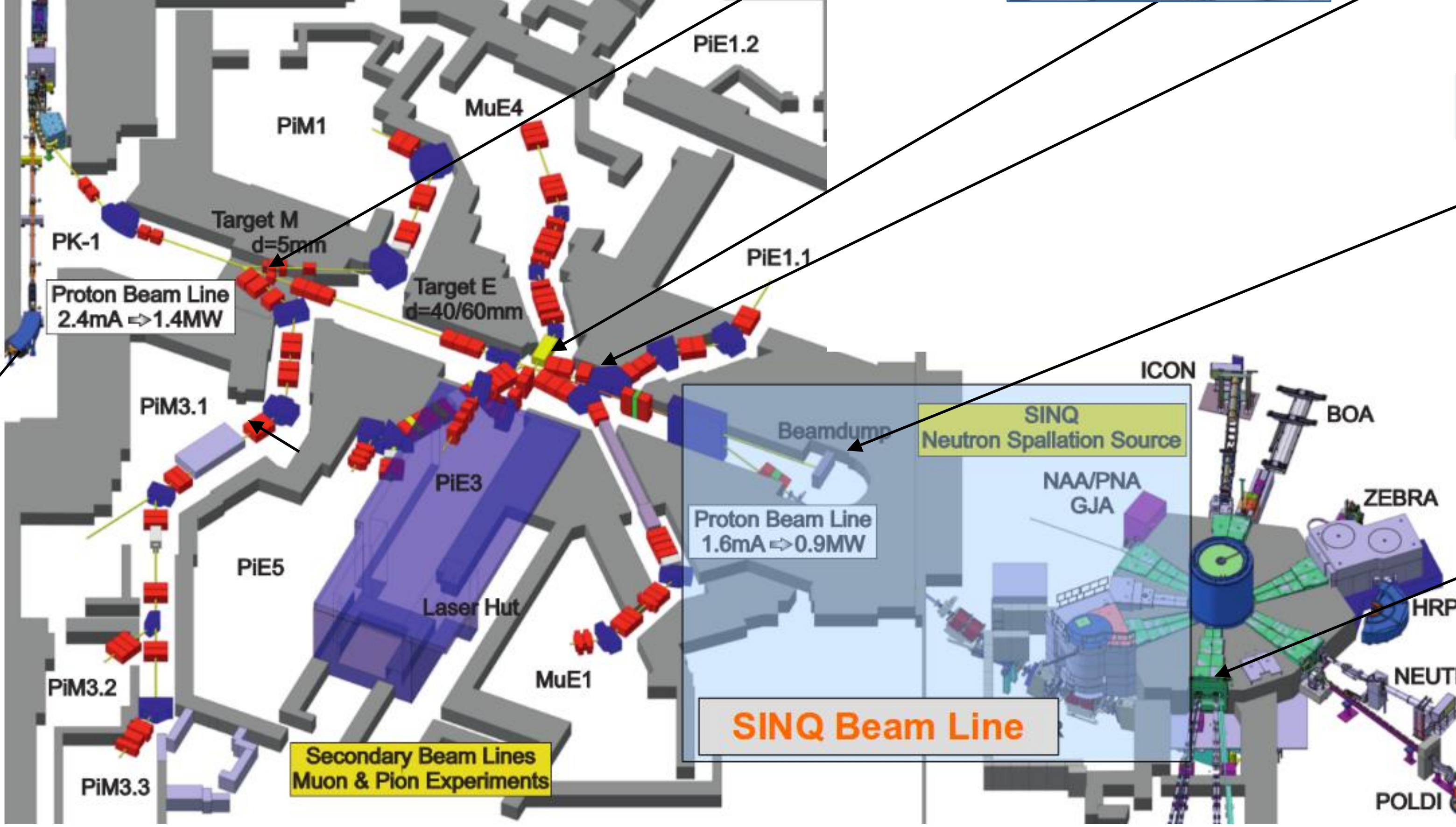


TgE: 40/60 mm C

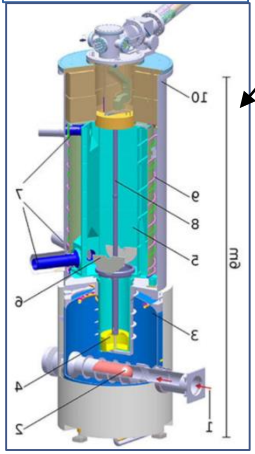
150 kW Collimator

Beam Dump



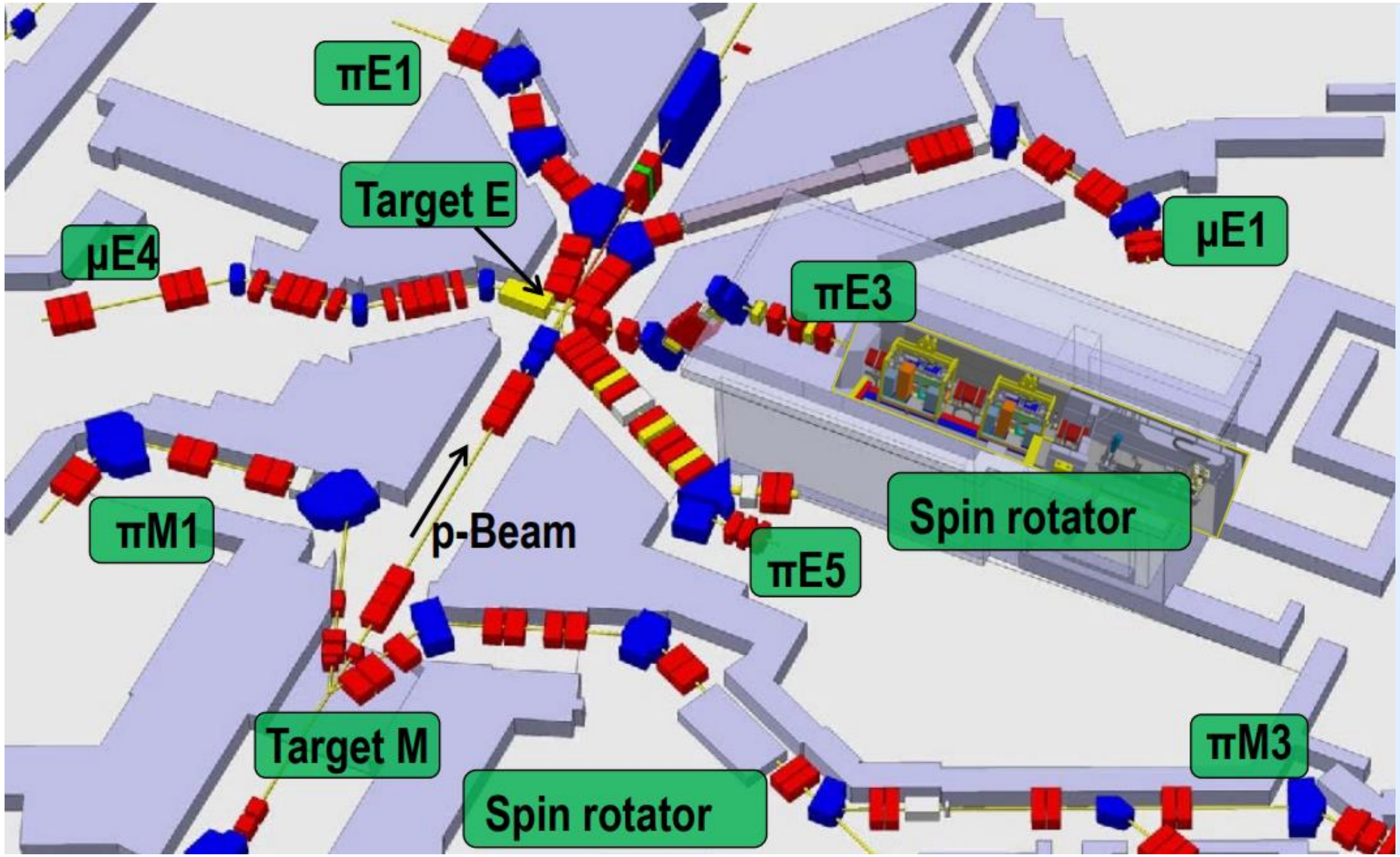


UCN Target



SINQ Target

HIPA Secondary Beamlines



Target M:

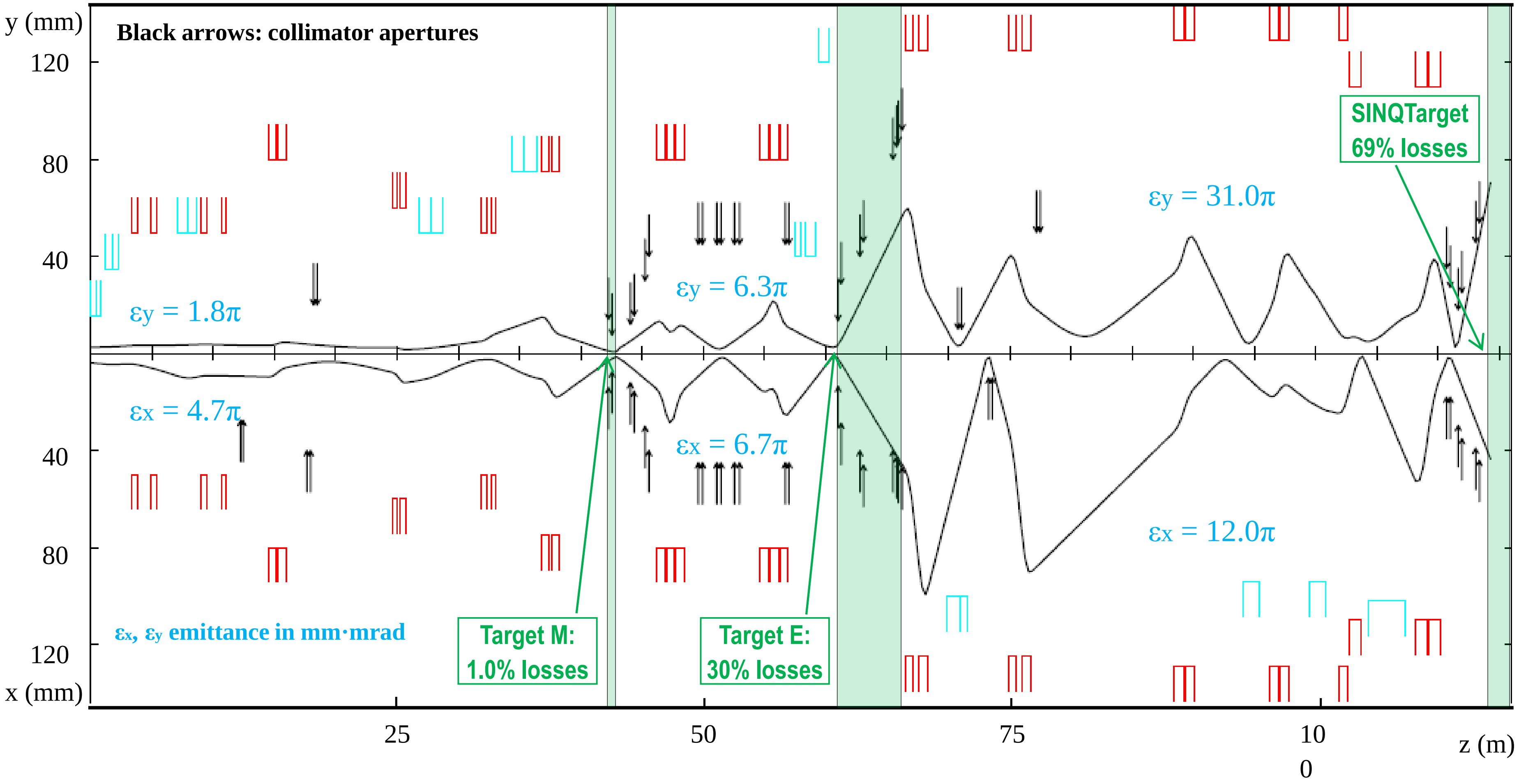
- πM1: up to 450 MeV/c π/μ
- πM3: 28 MeV/c surface μ

Target E

- πE1: up to 450 MeV/c **high intensity** π
- πE3: 28 MeV/c surface μ
- πE5: 10-120 MeV/c **high intensity** π/μ
- μE1: 60-125 MeV/c cloud μ
- μE4: 10-40 MeV/c **high intensity** surface μ

1.4 MW Beam Transport

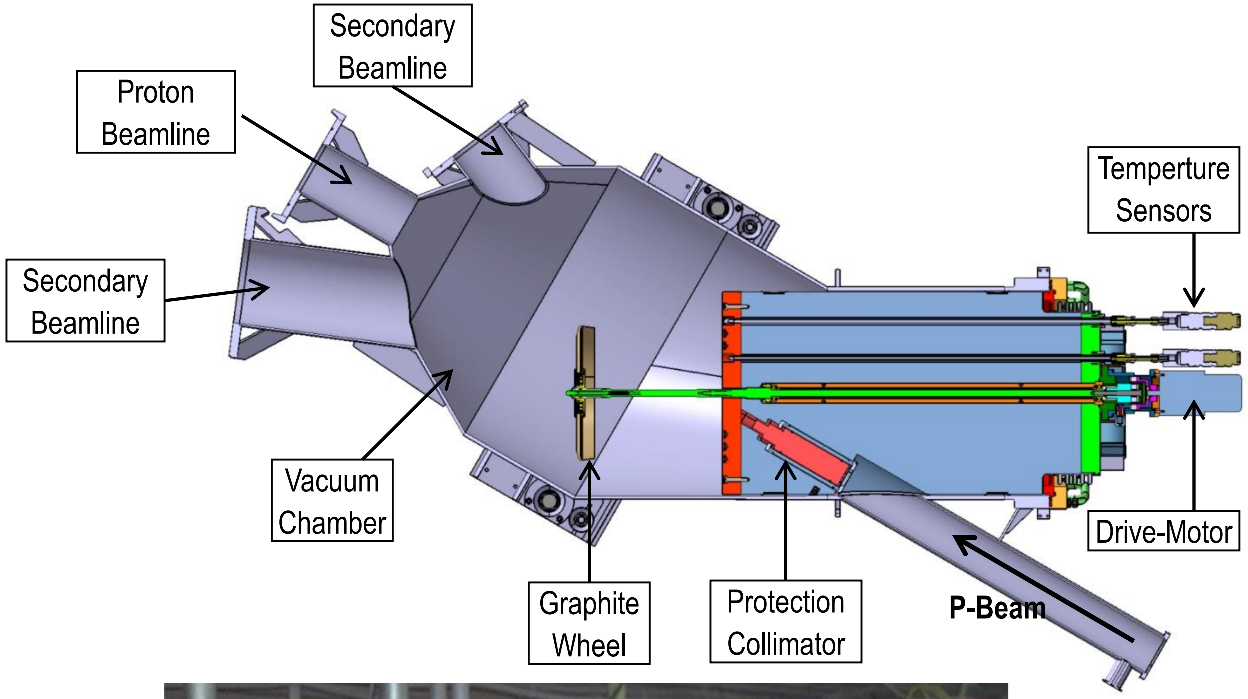
Beam Envelopes from Cyclotron Extraction to SINQ Target (with Magnet and Collimator Apertures)

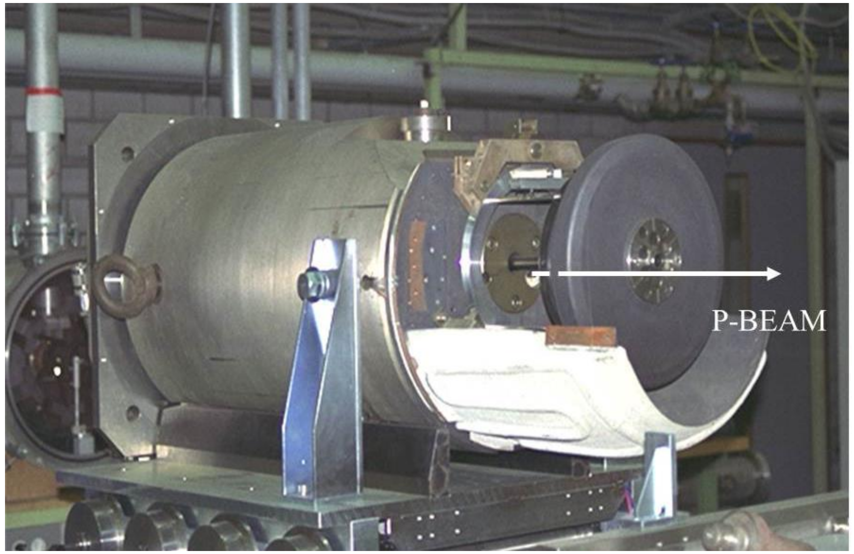


Peak beam current density on target M and E: 200 kW/mm²

Average losses away from targets: 0.6 W/m

Target M Design





Specifications:

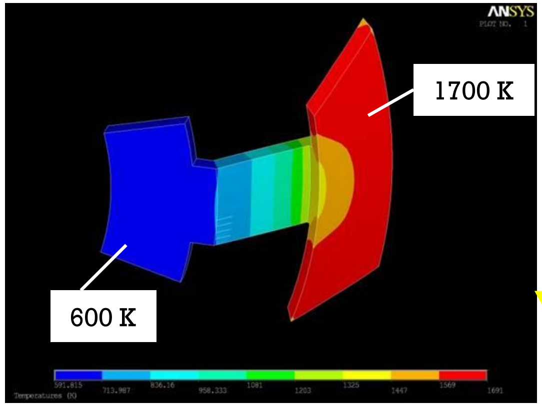
- **Material: Polycrystalline Graphite**
- Mean diameter: 320 mm
- **Target thickness: 5.2 mm**
- Target width: 20 mm
- Graphite density: 1.8 g/cm^3
- **Beam loss: 1.6 %**
- Power deposition: 2.4 kW/mA
- **Operating Temperature: 1100 K**
- Irradiation damage rate: 0.12 dpa/Ah
- Rotational Speed: 1 Turn/s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

Target E Design

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

TARGET WHEEL

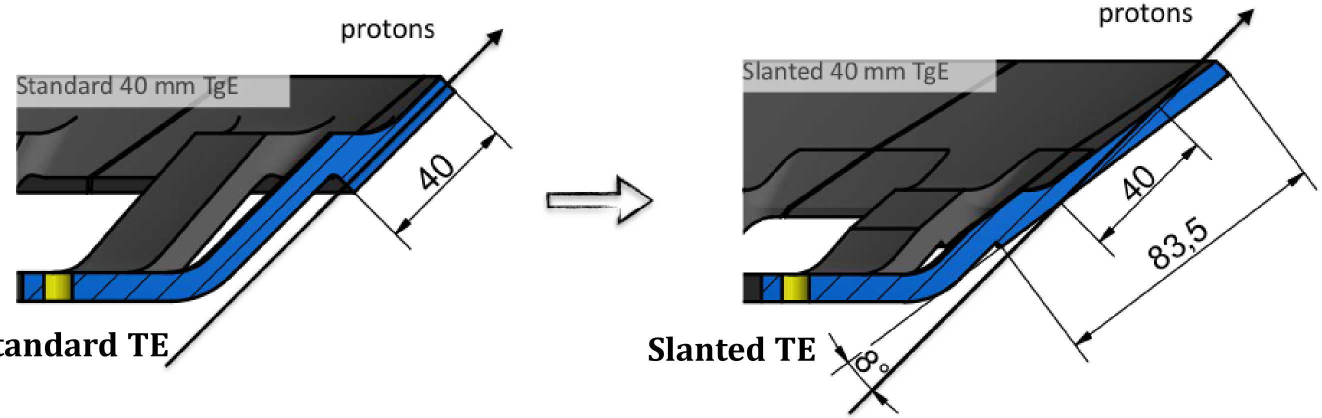
Material:	**Polycrystalline Graphite**
Mean diameter:	450 mm
Graphite density:	1.8 g/cm^3
Operating Temperature:	**1700 K**
Irradiation damage rate:	0.1 dpa/Ah
Rotation Speed:	1 Turn/s
Target thickness:	**40 or 60 mm**
Beam loss:	**30 or 42 % (after collimation)**
Power deposition:	**20 kW/mA (40 mm thickness)**
Cooling:	Radiation



Temperature distribution simulation

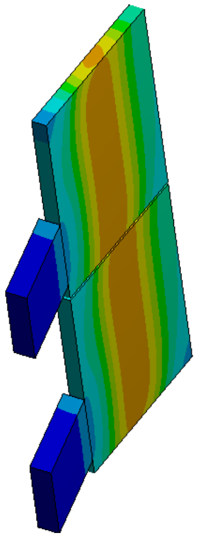
Slanted Target E Design

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



Standard TE

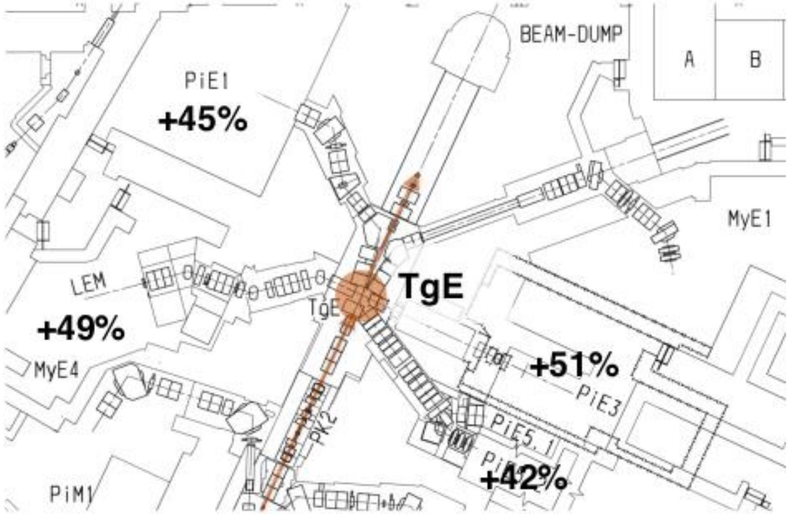
Slanted TE



Temperature and stress simulation of two target tiles (ANSYS)

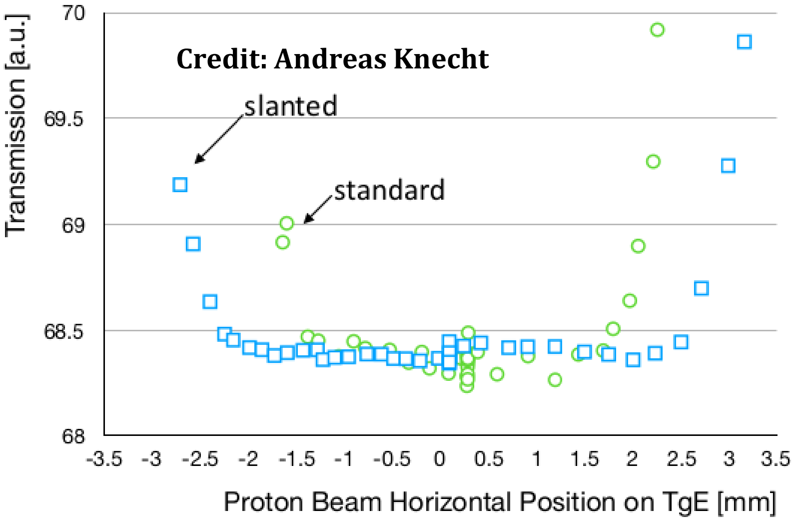
Advantages of Slanted Geometry:

Surface muon rates increase by ~50%



Credit: Andreas Knecht

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



Grooved Standard Target E

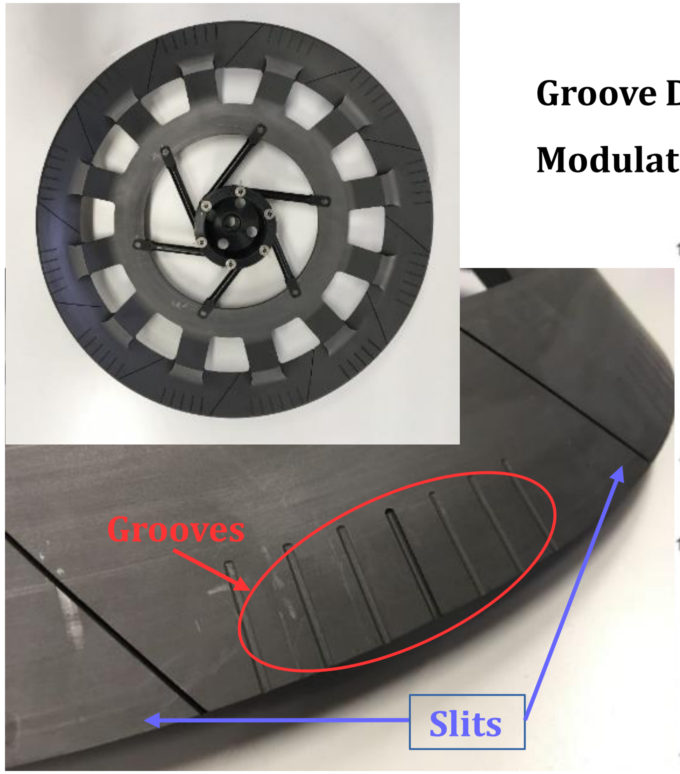
Issue: horizontal centring of proton beam (2σ=1.5mm) on 6mm wide graphite wheel TE

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

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

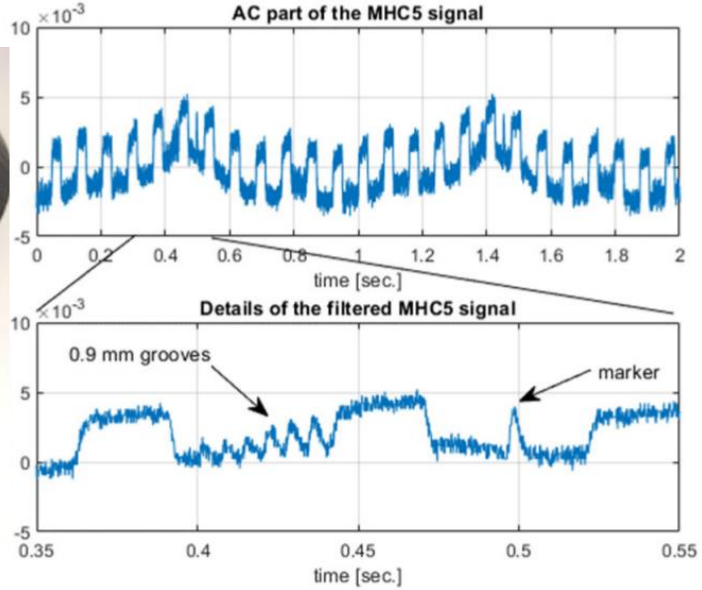
New Idea: grooved TE introduces sizeable modulation of beam current signal if beam not centred

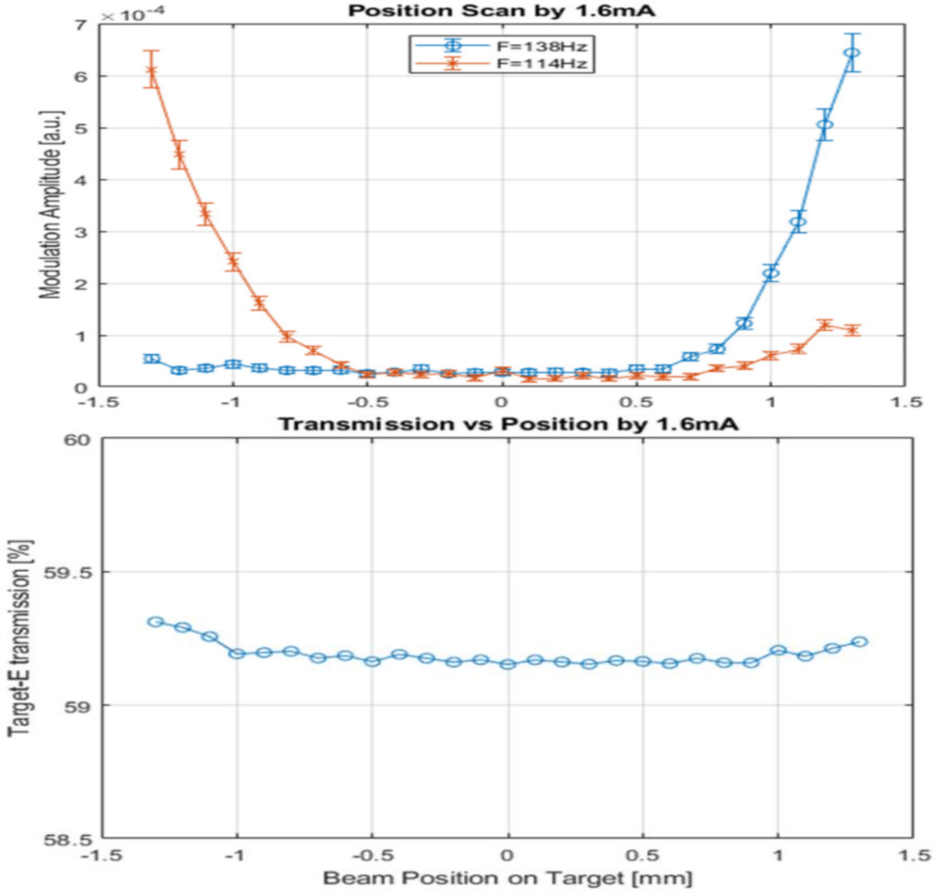
First Tests with Prototype TE: July-September 2019 (Regular TgE)



Groove Depth: 0.3, 0.5, 0.7, 0.9 mm

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





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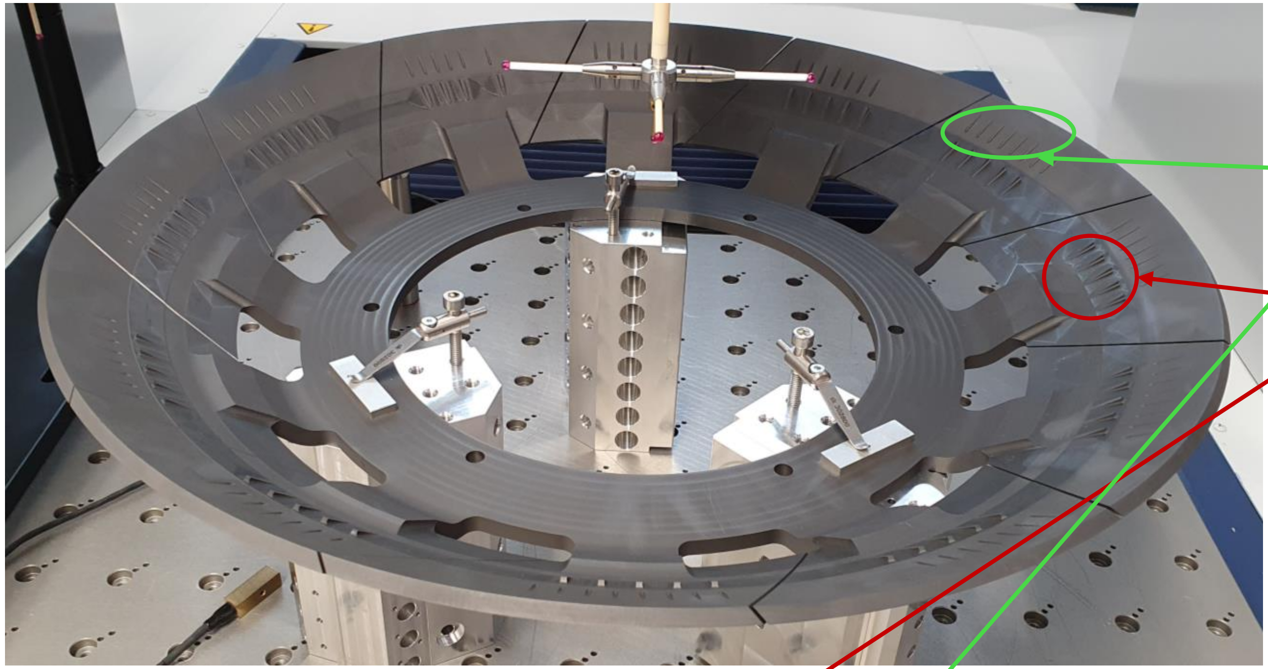
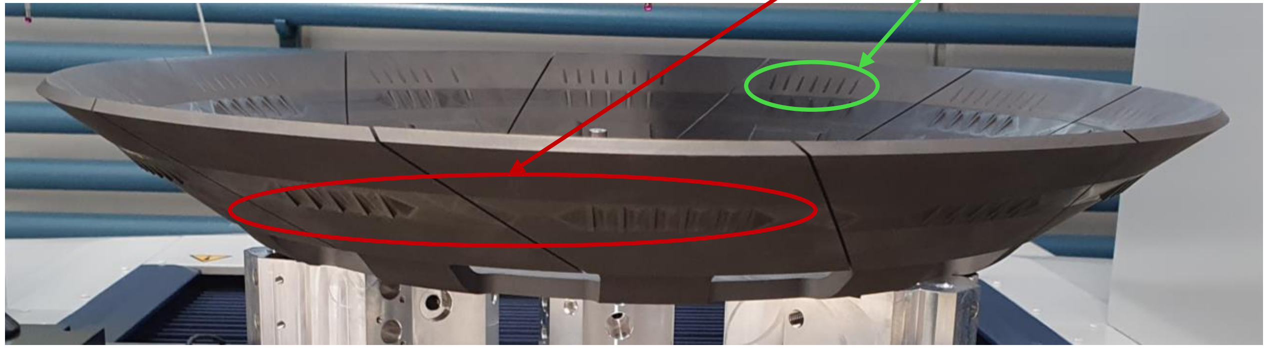
Grooved Slanted Target E





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

Target E 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)

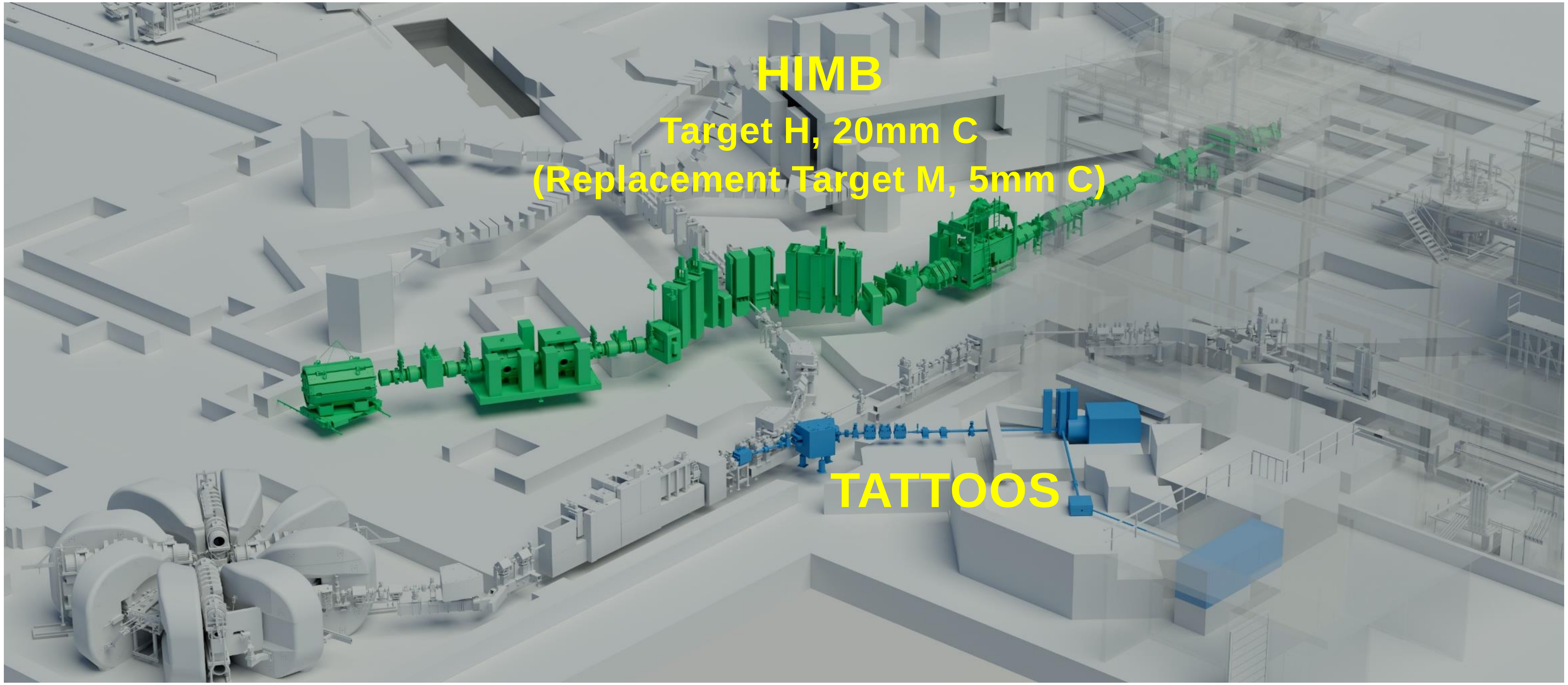
Si3N4 (balls),
MoS2 (Coating),
Ag (ring & cage)
GMN, Germany
1 -2 x exchange/year needed!

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

The IMPACT Project

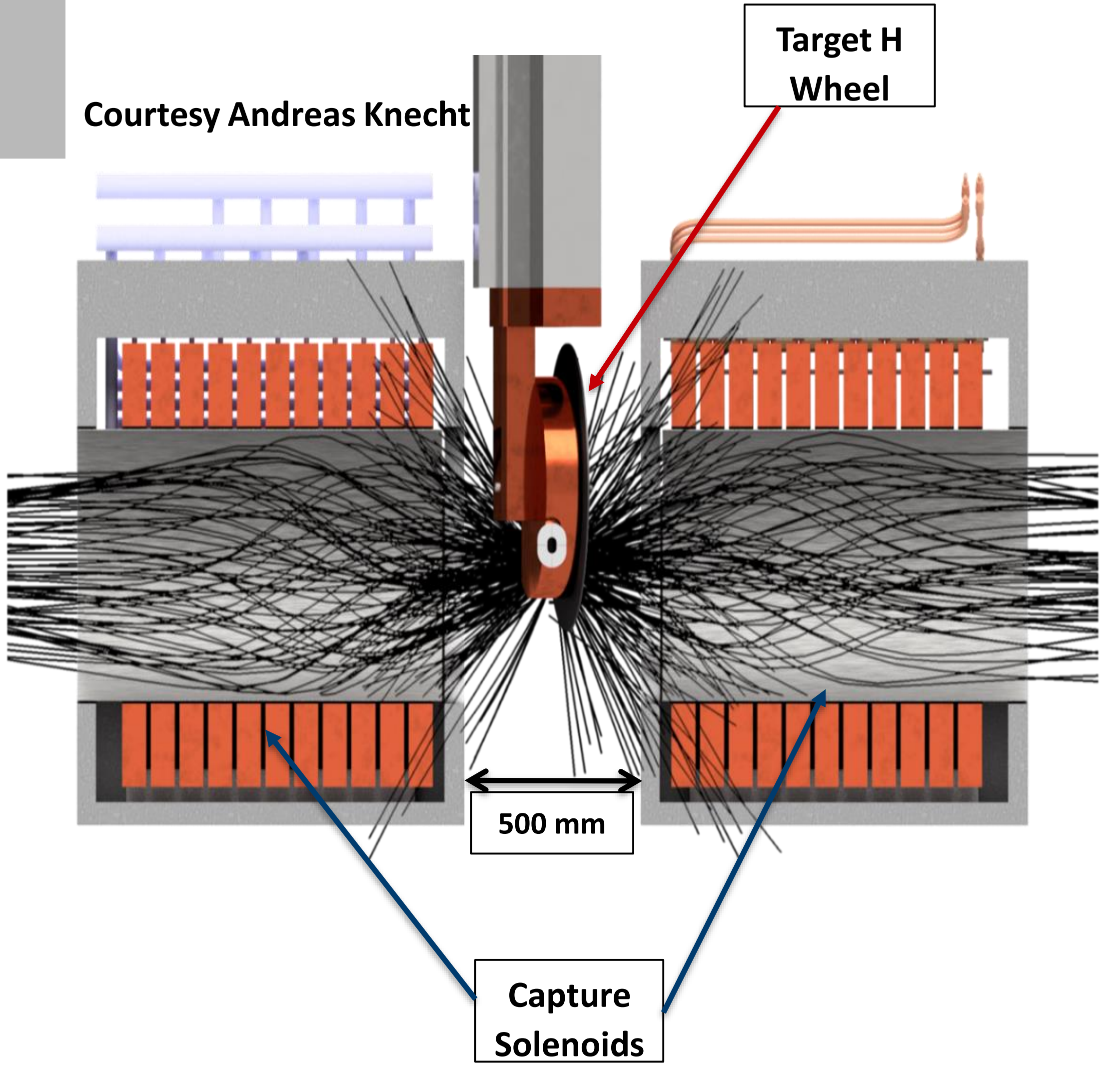
IMPACT: «Isotope and Muon Production using Advanced Cyclotron and Target technology»

- **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**)



Concept new Target Station H for HIMB

Courtesy Andreas Knecht



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

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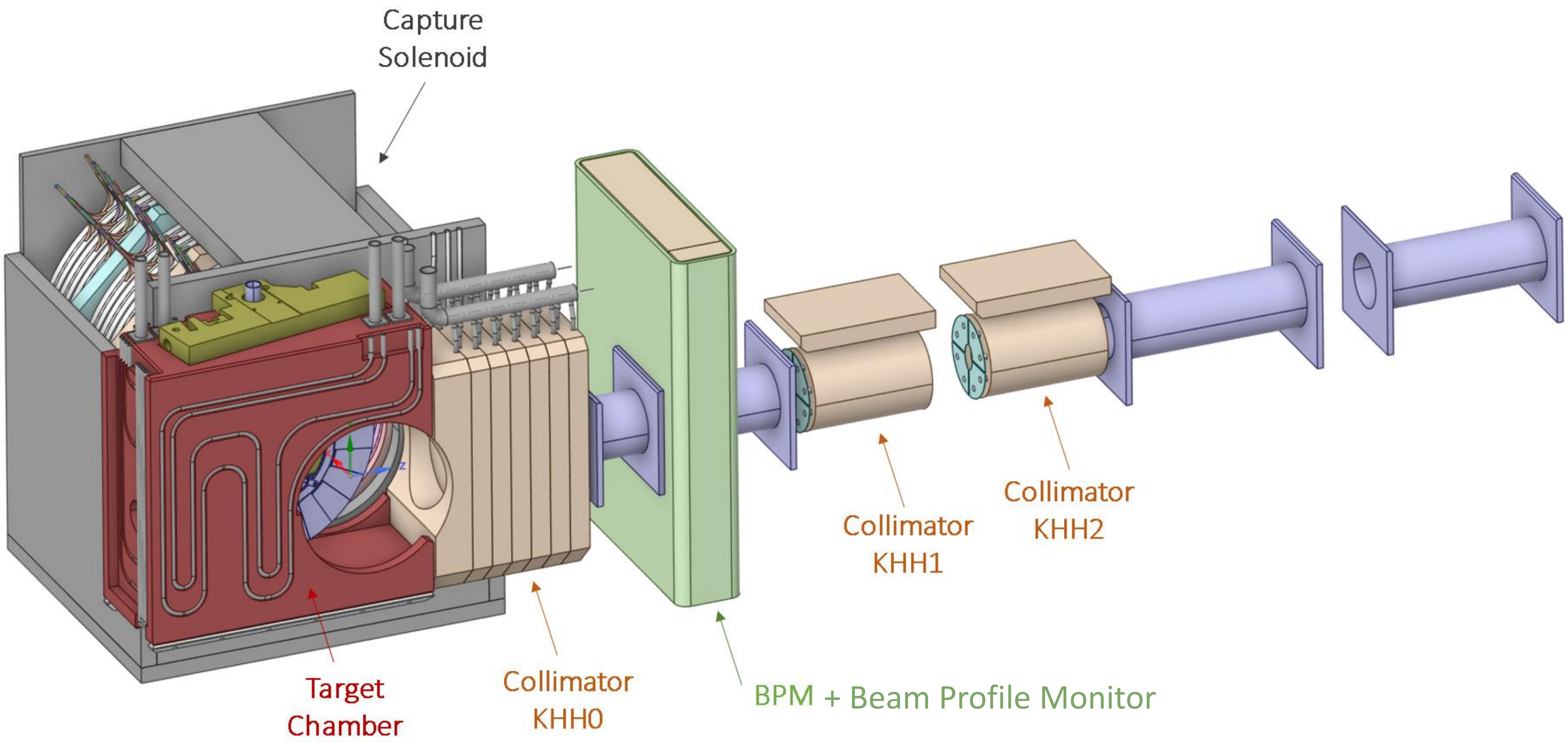
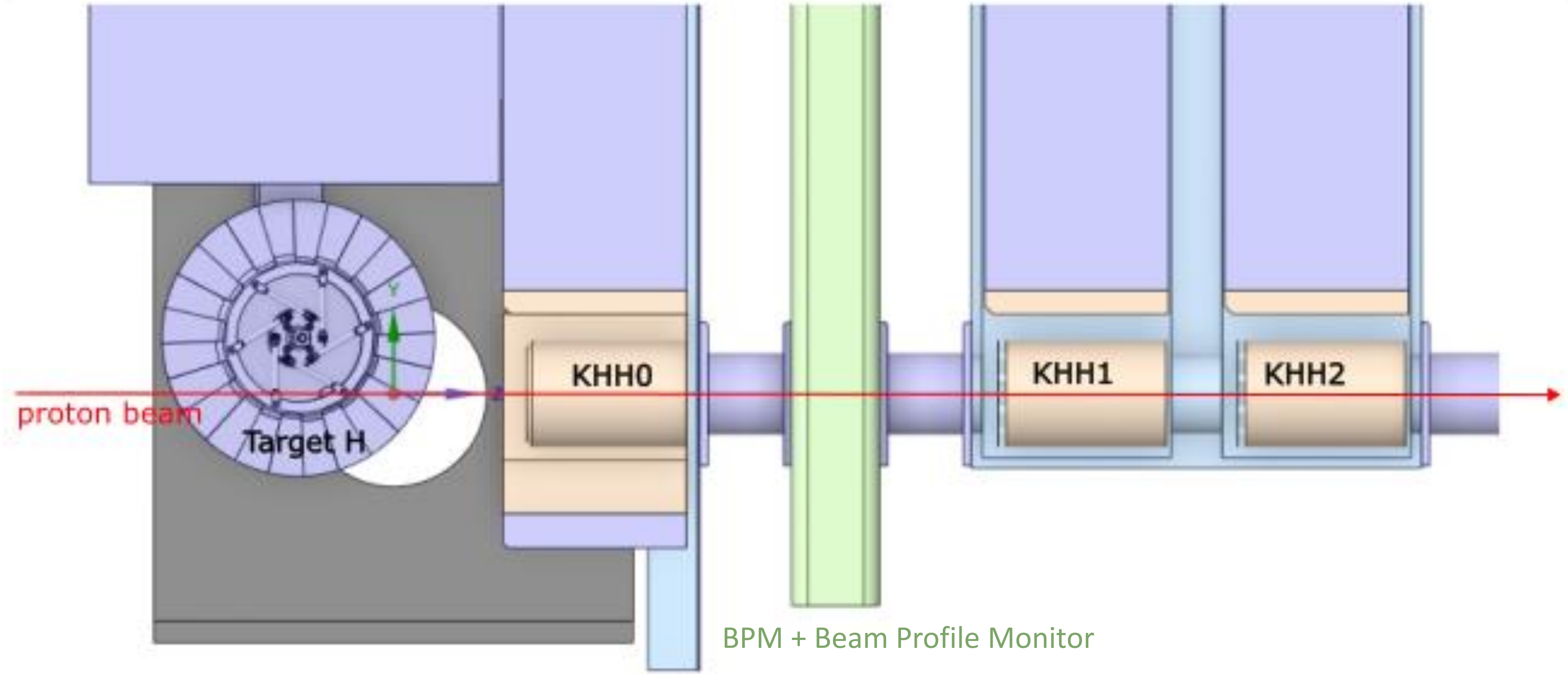
Target H Region

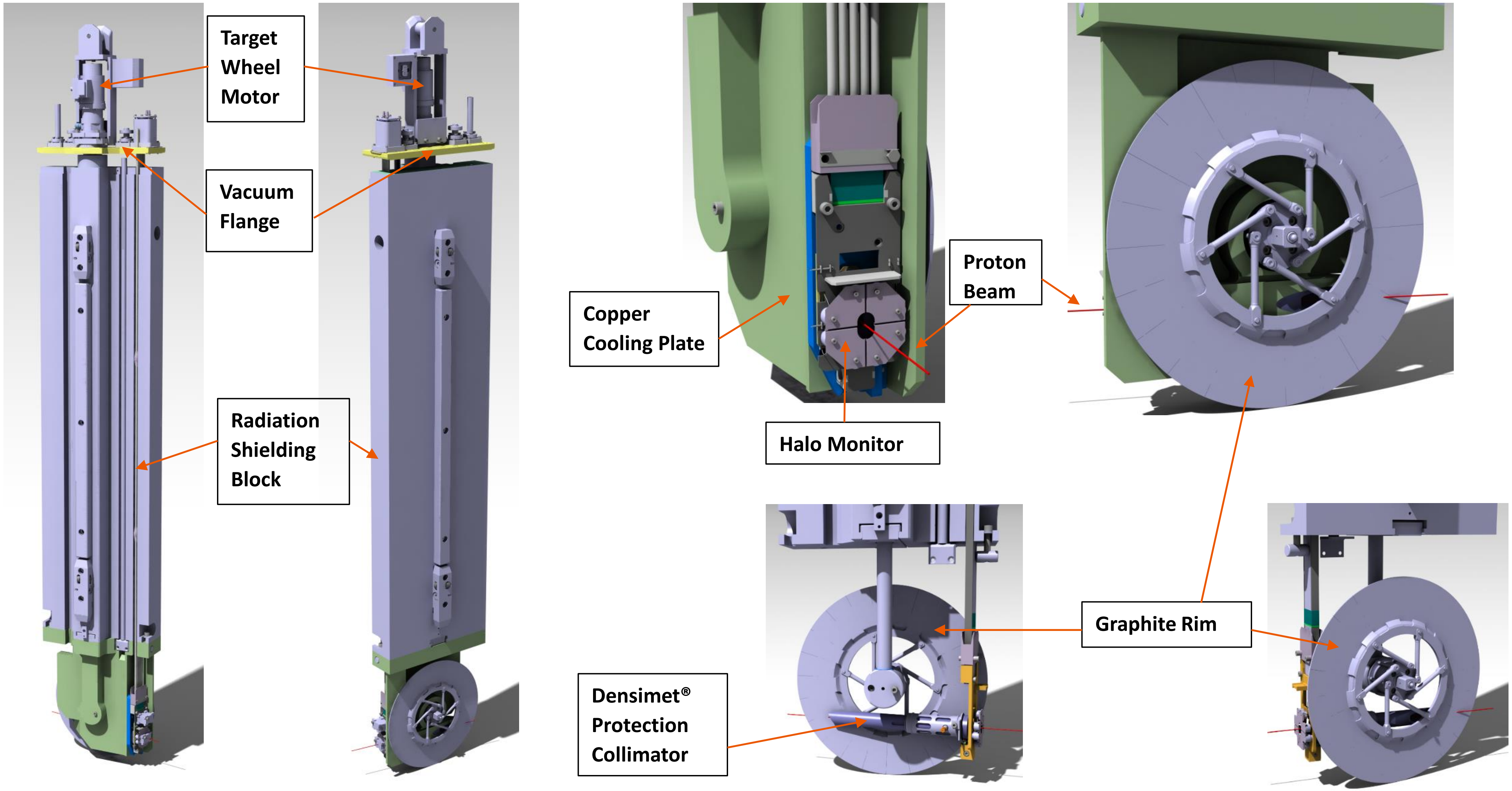


Target H Region

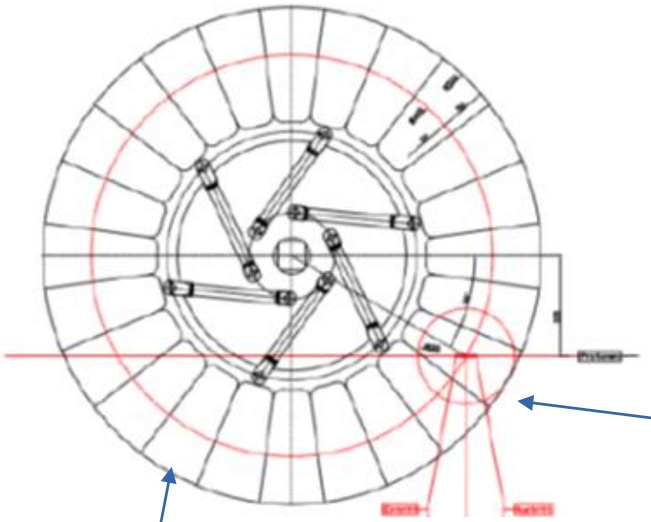


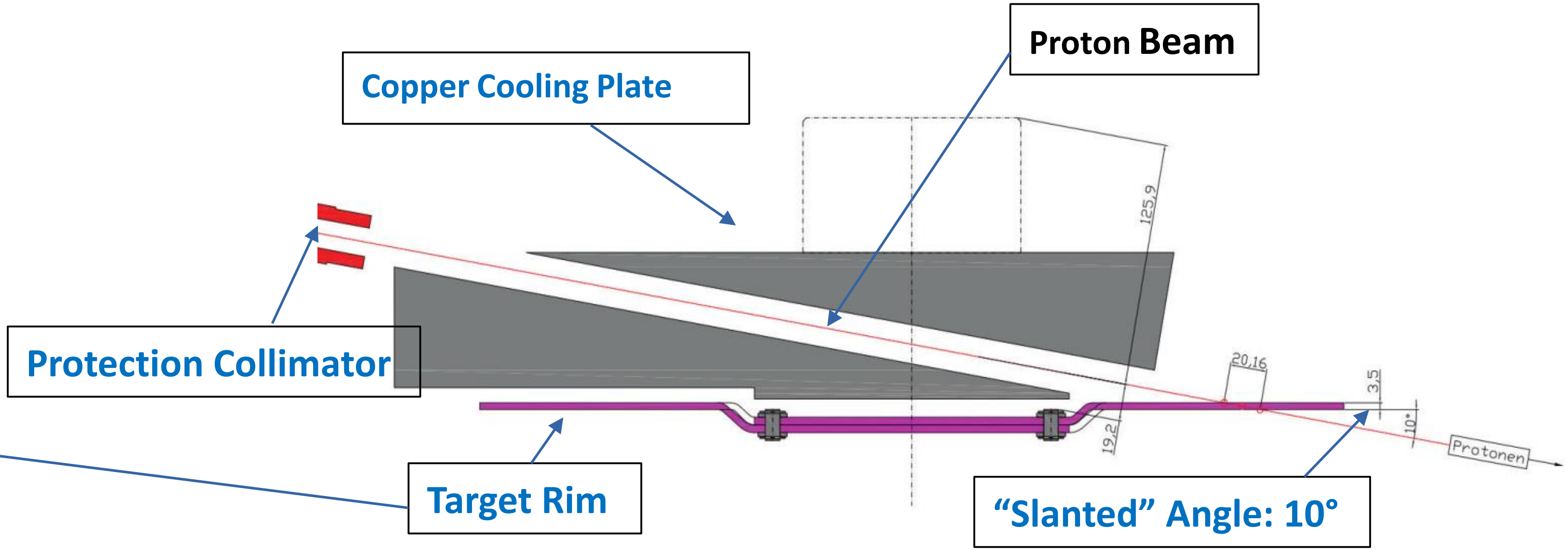
BPM + Beam Profile Monitor

Target H Insert



Target H Rim

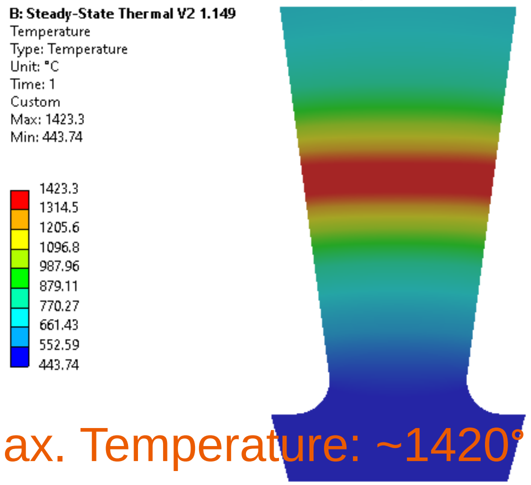


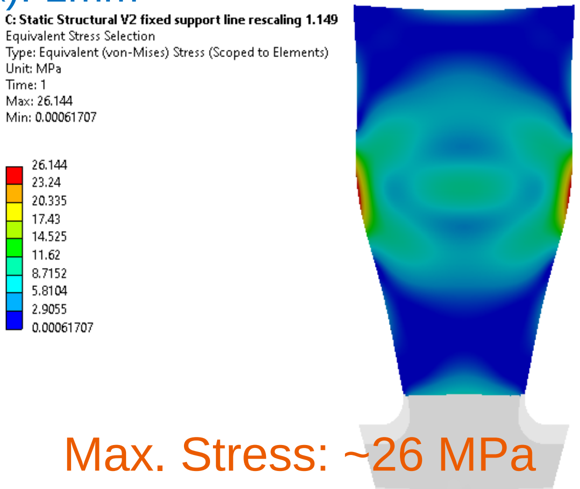


Chosen Geometry (out of 6 considered)

- **Two superposed half wheels (gaps allow thermal expansion)**
- Polycrystalline Graphite, **thickness: 3.5 mm** (effective thickness 20 mm)
- Rim **width: 100 mm**

ANSYS simulation of one graphite tile (planar equivalent geometry)
Beam Current: 3mA, Beam Size (σ_x): 1mm





Max. Temperature: ~1420° C

Max. Stress: ~26 MPa

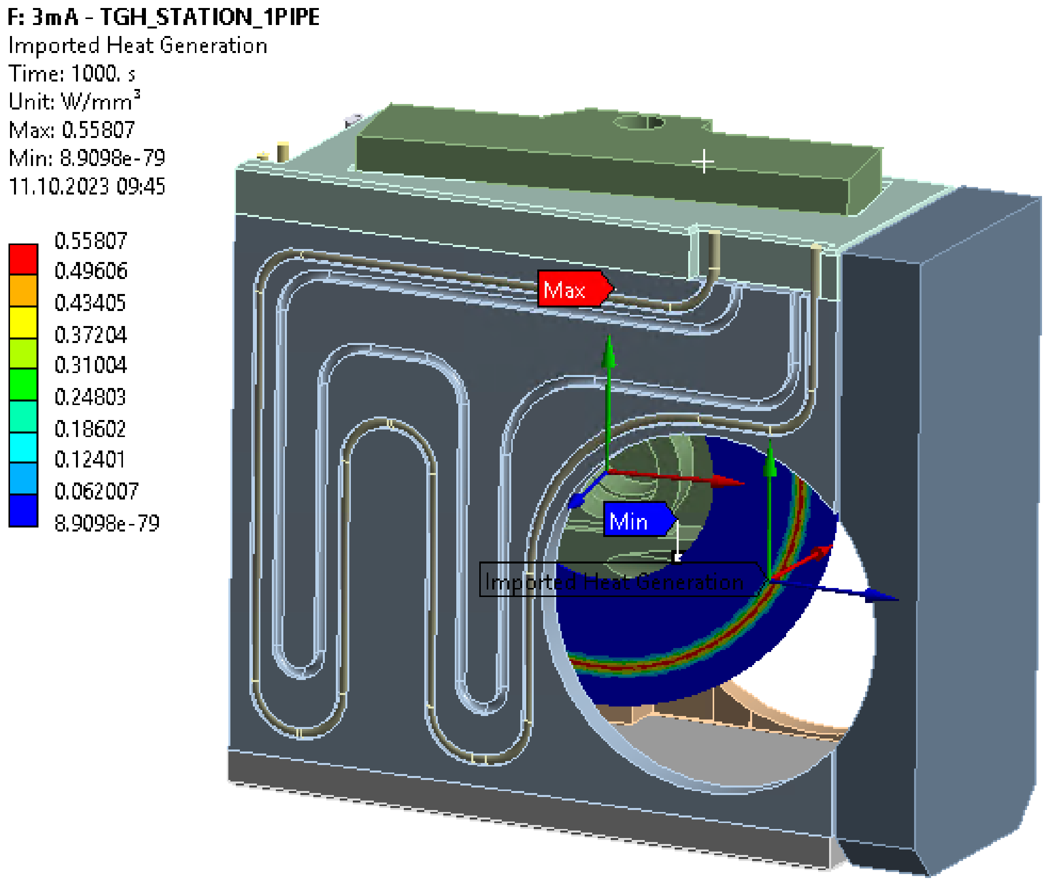
Target H Chamber: Design and Simulations

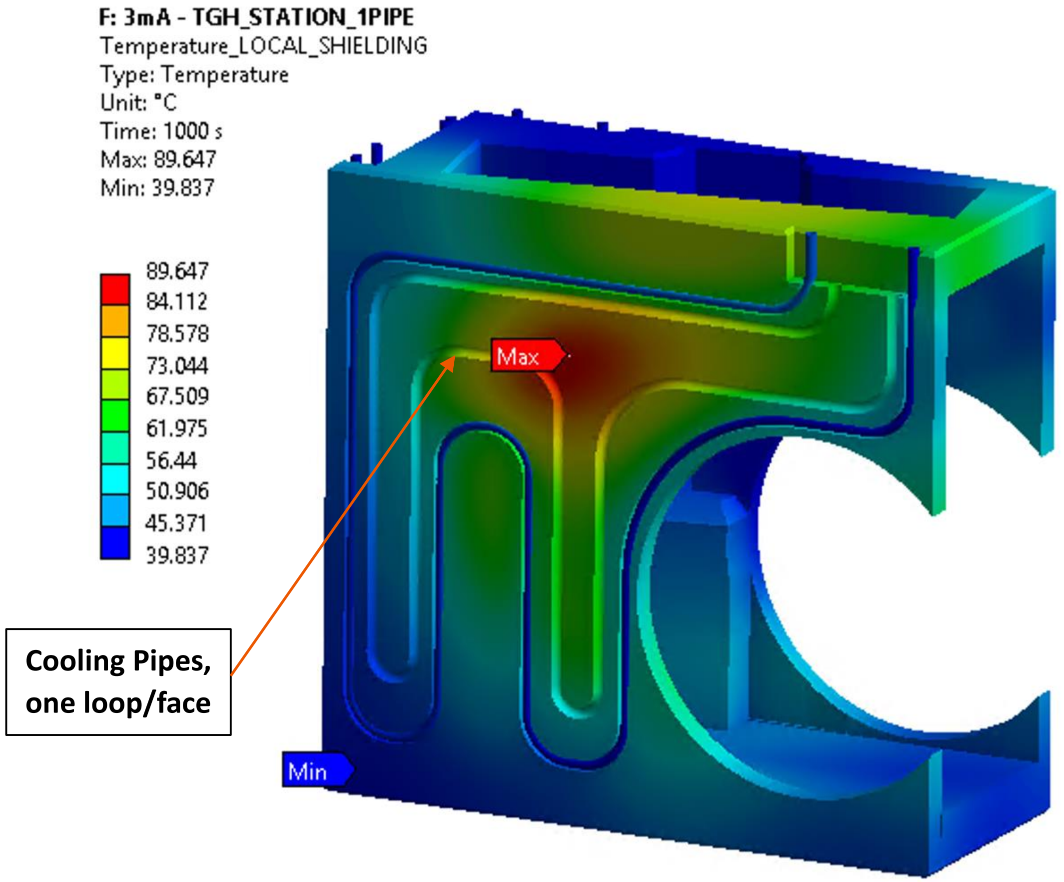
Power Deposition from proton beam (3mA):

- 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 90°C)
- Heat from secondary particles not yet accounted for

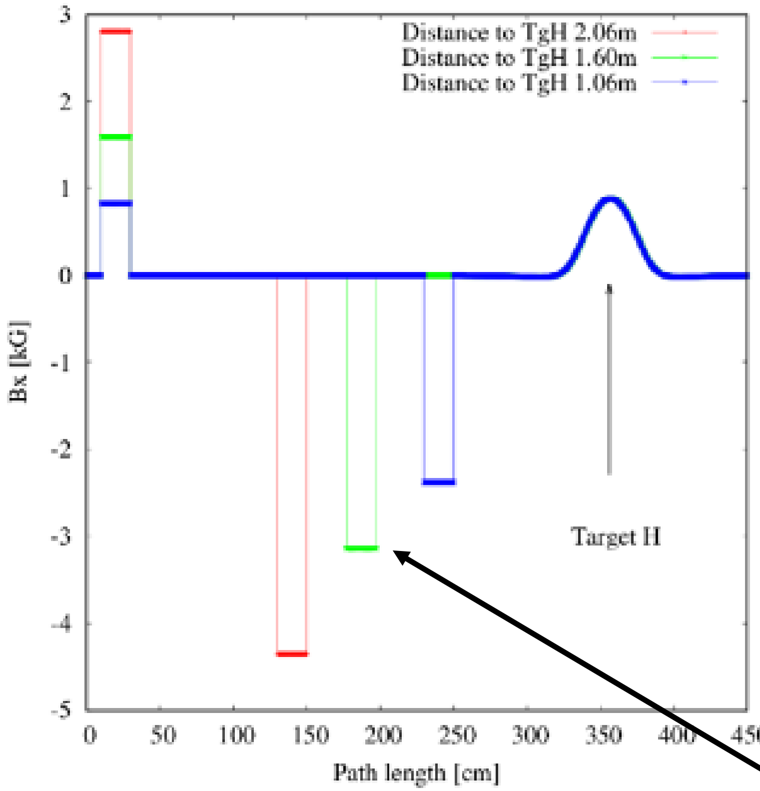


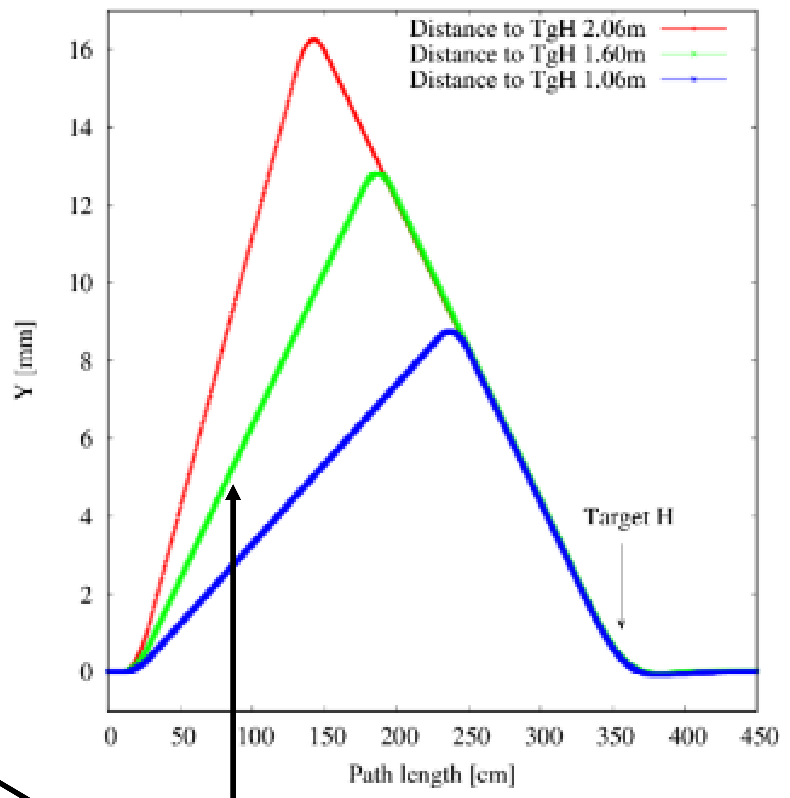


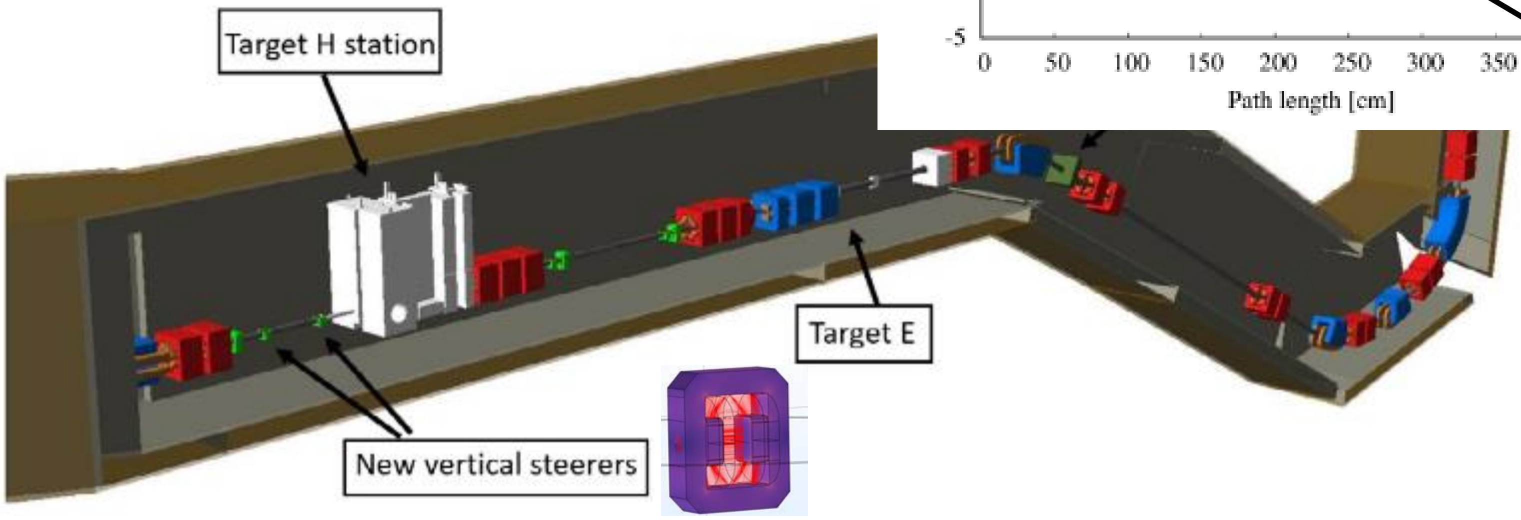
Proton Beam Trajectory Correction

Capture solenoid **fringing field causes proton beam vertical displacement/tilt:**

- Two new vertical steerer needed for bump correction
- **Three scenarios considered**







Green solution adopted:

- 1st steerer at 3.3 m from TgH,
  2nd steerer at 1.6 m from TgH
- **Beam displacement at TgH < 0.5 mm**
  Beam tilt at TgH < 4 mrad

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

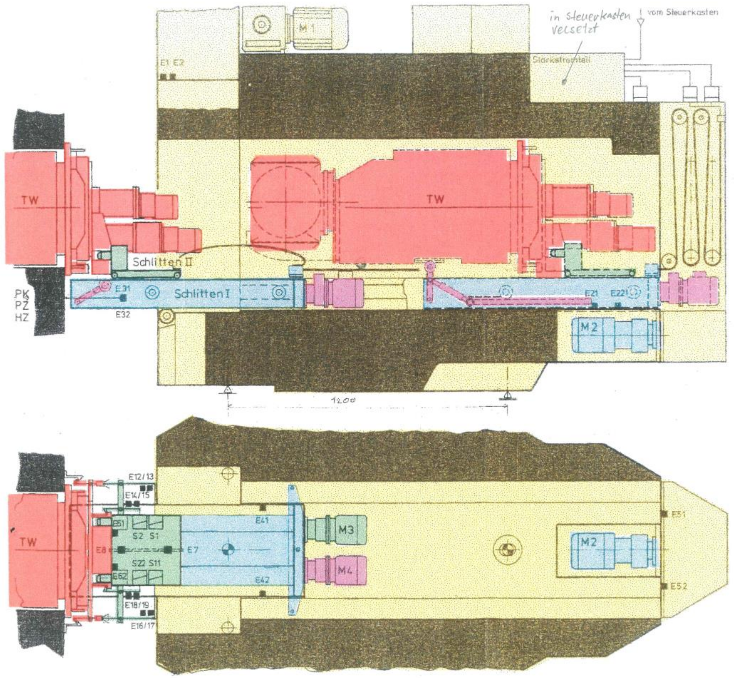
Target M
(horizontal)

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

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

Remote Handling: Target M Exchange Flask

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



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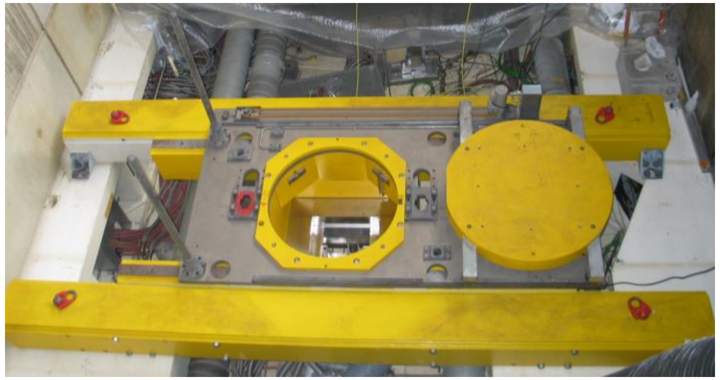
Remote Handling: Target E Exchange Flask



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

Conclusion

- After almost 50 years, HIPA is still at the worldwide forefront of high power proton accelerators.
- Thanks to 2 graphite targets, HIPA delivers muon and pion beams amongst the most intensive worldwide.
- The planned upgrade TgM → TgH will allow for unprecedented muon rates in the range of 10^{10} muons/s.

Acknowledgement

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- **Thomas Rauber**
- **Rebecca Riccioli**
- **Jochem Snuverink**
- **Raffaello Sobbia**
- **Many Others!**

Overview of Secondary Beam Lines Parameters

	PiM1	PiE5	PiE1 Redesigned in 2012	PiE3 Redisigned 2010/2011	PiM3 New S-Rot in 2017	MuE4	MuE1
Target	M	E	E	E	M	E	E
Particle Type	e/μ/π/p	μ/π	π/μ/p	μ (surface)	μ (surface)	μ (surface)	μ (cloud)
Momentum Range	10-500 MeV/c	10-120 MeV/c	10-500 MeV/c ustream ASK 10-120 MeV/c downstream ASK	10-40 MeV/c	10-40 MeV/c	10-40 MeV/c	60-120 MeV/c
Typical Momentum	15-350 MeV/c	28-85 MeV/c	PP: 10-50 MeV/c μSR: 28 MeV/c Irrad: 300 MeV/c	28 MeV/c	28 MeV/c	28 MeV/c	60-125 MeV/c
Max Rate [$s^{-1}mA^{-1}$]	$2x10^8$	$6x10^9$	$4x10^9$	$3x10^7$	$3x10^6$	$4x10^8$	$6x10^7$
Typical Use	Particle Physics Test Experiments, Detector/Material Irradiation	Particle Physics Experiments	μSR Dolly Facility Particle Physics Experiment, Detector Irrad.	μSR HAL 9500 (High Field) Facility	μSR GPS and LTF Facilities	μSR LEM Facility	μSR GPD Facility
Users	- MUSE Coll. - PSI-PIF group - INFN Det. Group - ETH Detector Gr. - PSI HE Section - ETH Students - Others	- MEG Collab. - Muonic Helium Exp - Prot. Radius Exp - μ3E Collab.	- MuSun Collab. - Dolly Group - CERN/PSI Detector - PSI PP Group	μSR-SμS GPS/LTF	μSR-SμS High Field μSR	μSR-SμS Low Energy Muon	μSR-SμS GPD group