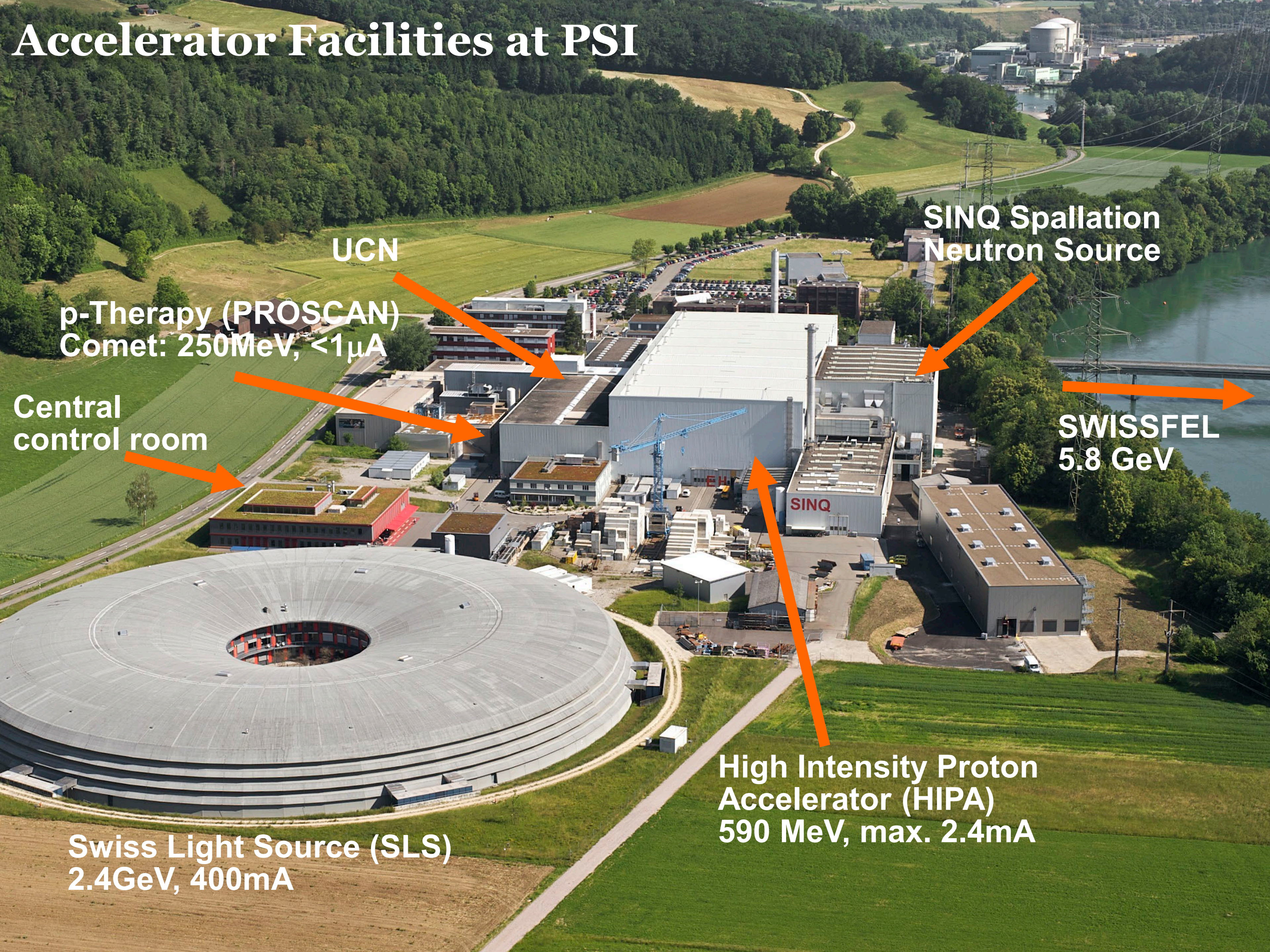
Daniela Kiselev :: ASA/GFA :: Paul Scherrer Institut

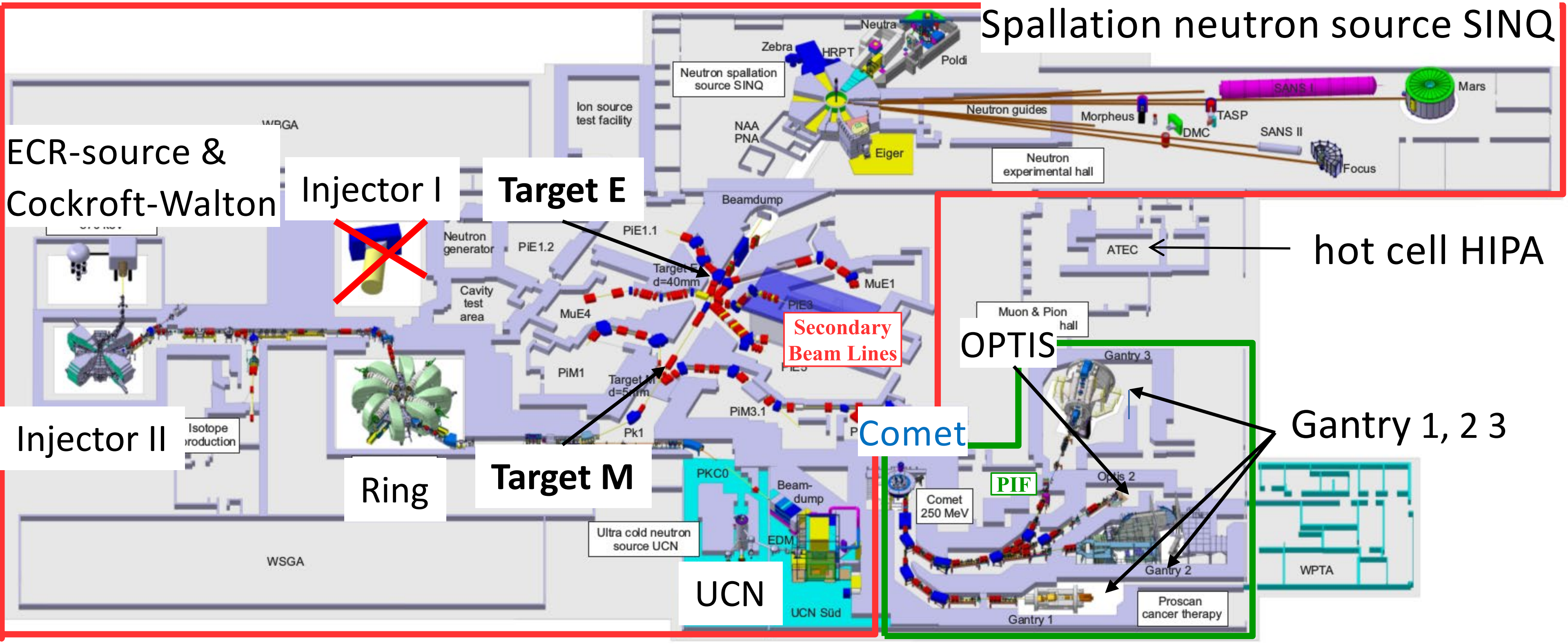
PSI: Meson production target stations and upgrade to HIMB

Muon Properties and Related Topics II, FNAL-online, 21.1.2022

Accelerator Facilities at PSI



The PSI Proton Accelerator Facilities



HIPA (High Intensity Proton Accelerator)

- CW (50.63 MHz), 590 MeV,
- up to 2.4 mA(1.44 MW)
- **2 meson production targets**
- 7 secondary beam lines
- SINQ and UCN spallation source

PROSCAN (Proton therapy): since 2007

Comet: superconducting cyclotron

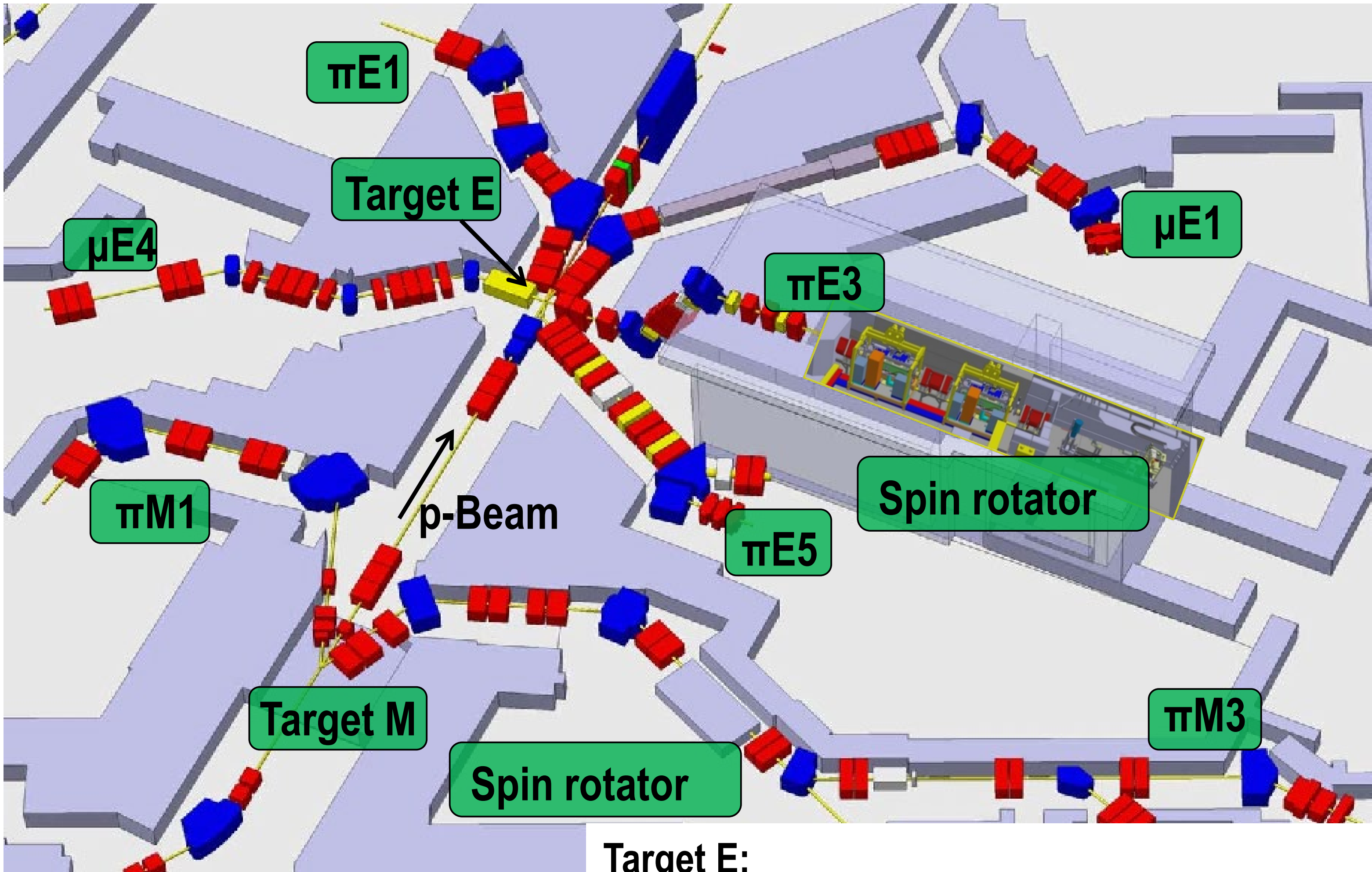
CW, 250 MeV, up to 1 μA protons

medical treatment:

3 Gantries, 1 Eye Cancer Treatment Station

Irradiation Station: PIF

μ/π Secondary Beam Lines



Target E:

πE1: 10 - 500 MeV/c High Intensity Pions und Muons

μE1: Polarized Muon Beam

πE3: 28MeV/c Surface polarized Muons

μE4: 30 - 100 MeV/c High Intensity Polarized Muons

πE5: 10 - 120 MeV/c High Intensity Muons

Target M:

πM1: 100-500 MeV/c Pions

πM3: 28 MeV/c Surface Muons

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μ/π rates

	PiM1	PiE5	PiE1	PiE3	PiM3	MuE4	MuE1
Target	**M**	**E**	**E**	E	M	E	E
Particle Type	**π/e/μ/p**	**μ/π**	**π/μ/p**	μ, π	μ	μ	μ (cloud)
Momentum Range	**10-500 MeV/c (max 300 MeV/c for positive particles)**	**20-120 MeV/c**	**10-500 MeV/c ustream ASK 10-120 MeV/c downstream ASK**	μ:10-40 MeV/c π: 50 – 250 MeV/c	10-40 MeV/c	10-40 MeV/c	60-120 MeV/c
Typical Momentum	**15-300 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 $[mA^{-1}\ s^{-1}]$	**@ 350 MeV/c π^{+}:2x10^{8}**	**@120MeV/c π^{+}:2x10^{10} μ^{+}:5x10^{8}**	**@ 300 MeV/c π^{+}:4x10^{9}**	**μ^{+}:3x10^{7} π^{+} :2x10^{9} @ 170 MeV/c**	**μ^{+}:3x10^{6}**	**μ^{+}:4x10^{8}**	**@ 300 MeV/c μ^{-}:6x10^{7}**
Typical Use	**Particle Physics Test Experiments, Detector/Material Irradiation**	**Particle Physics Experiments**	**μSR Dolly Particle Physics Experiment, Detector Irrad.**	μSR HAL 9500 (High Field)	μSR GPS and LTF	μSR LEM Facility	μSR GPD Facility

Particle physics: (**CHRISP facility**)

μSR (Muon Spin Rotation),
SμS (Swiss Muon Source)

Challenges for meson production targets

- **Power deposition:**

  at 2.4 mA, 590 MeV protons ~ 50 kW on Target E
  → cooling
  → high temperature resistant material
  → thermal stress

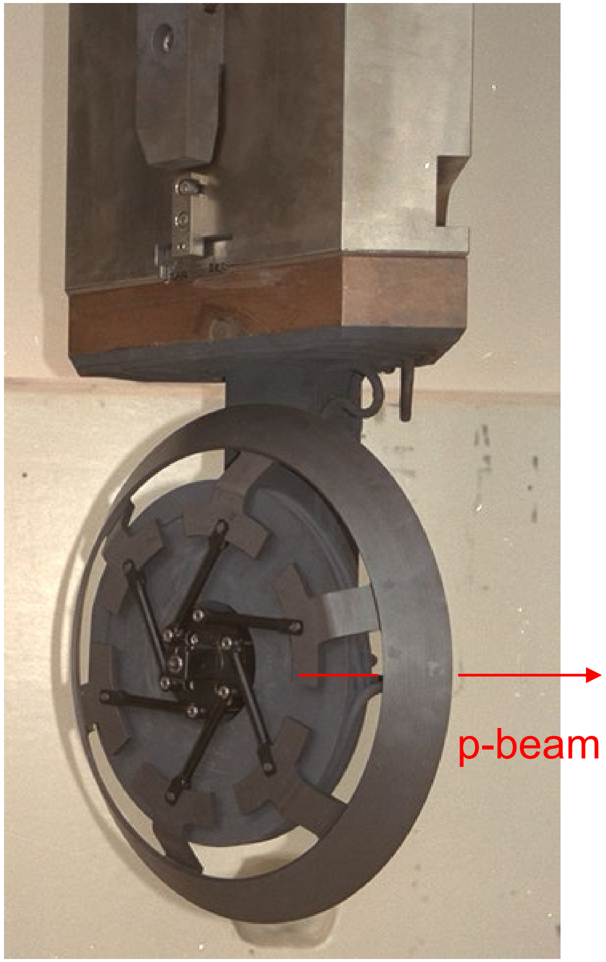
- **Radiation damage:**

  → embrittlement
  → deformation (also due to heating)
  → loss of conductivity

Approach:

- distribute power:
  rotating wheel with 1 Hz → needs bearings
- cooling by radiation:
  - independent of conductivity
  - local shielding (Cu) is cooled by water

Target E



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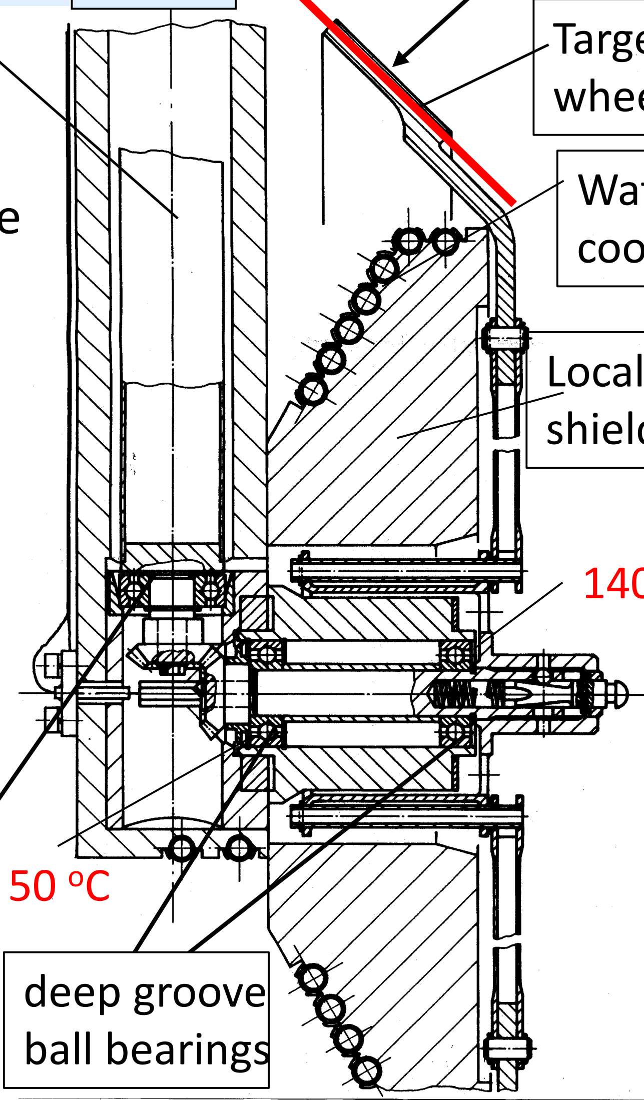
Challenges for meson production targets

- Wheel deformation reduced by
  - polycrystalline graphite → isotropic properties
  - slits in wheel rim für thermal expansion
  - spokes: allows thermal expansion of target cone
    hollow to avoid high temperature at bearing

12 segments with 1 mm slit



- Motor:

2.5 m above the beam line
→Functioning is not affected by irradiation
→ life time ~ 5 – 8 years

Critical components: Bearings

- Ball bearings:

No grease as lubrication! → brittle due to hard irradiation
so called radiation hard grease does not help → proofed

in use since ~2002:

Balls Si_3N_4, GMN, Germany
Coating: MoS_2, Ag for ring & cage
1 -2 x exchange/year
←→ Graphite wheel lasts much longer: ~ 4Years
(39 Ah record)

in test this year:

Shun Makimura (JPARC)

Balls stainless steel + WS_2 blocks
Koyo, Japan
Test (without radiation): > 420 days
<u>In beam 2021, no change!</u>

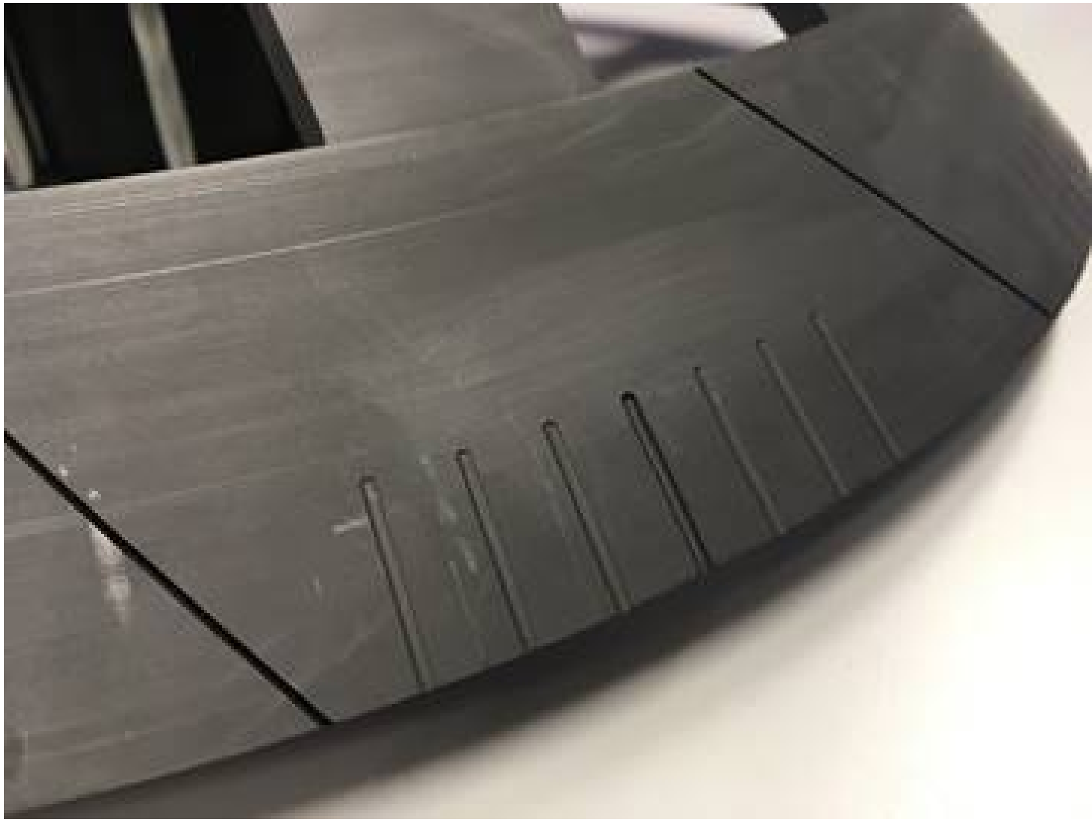
Target development I: Target E with grooves

Purpose: **Beam centering** on the 6 mm rim of Target E

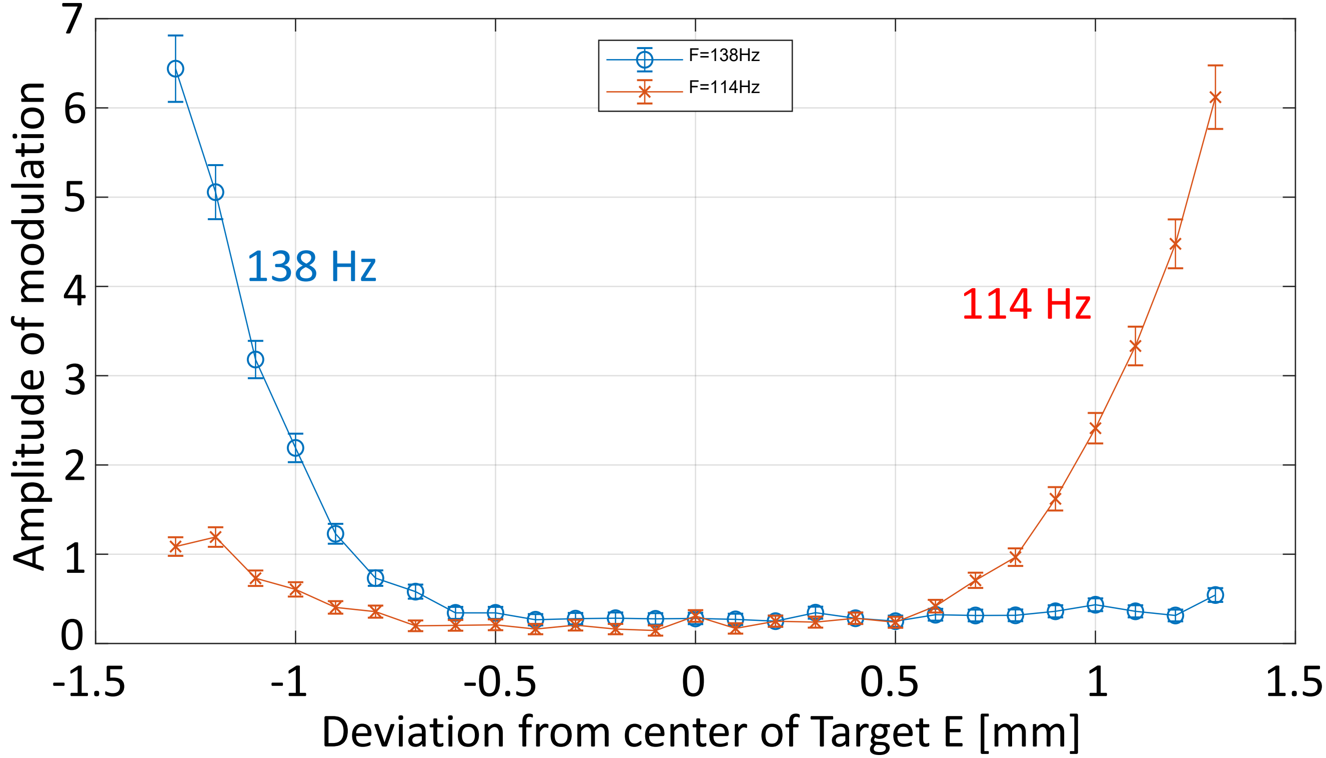
Idea:
Modulation of the beam current measurement (MHC5) after Target E
→ Strength of the signal is a measure for the deviation of the beam from center

Grooves inside and outside

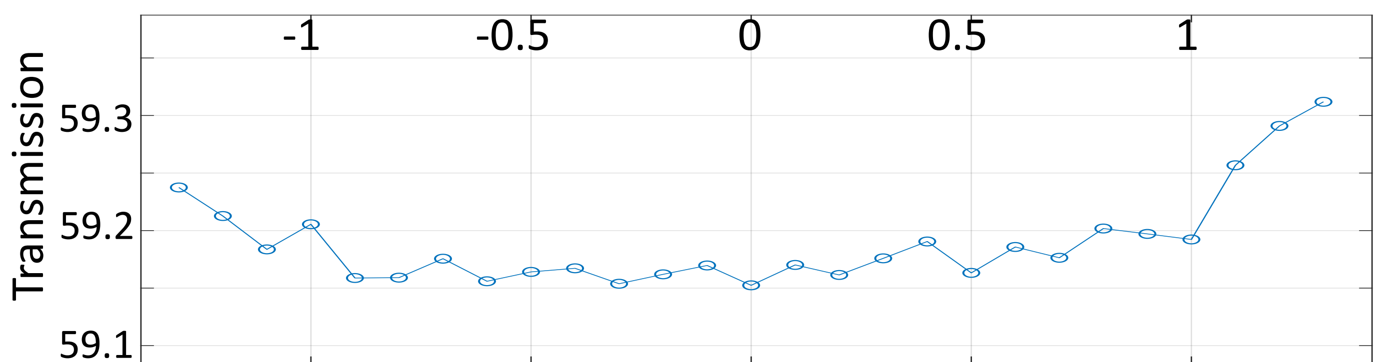
- with different frequencies: 114 Hz and 138 Hz
- to distinguish beam left and right from center
- different depths: 0.3mm, 0.5mm, 0.7mm, 0.9mm
- to find compromise between losses and signal



Signal as a function of position



- Very sensitive method of ~factor 10 in signal change!
- Much more sensitive than transmission T = MHC5/MHC4



- Small change in Transmission
- Slower than modulation analysis

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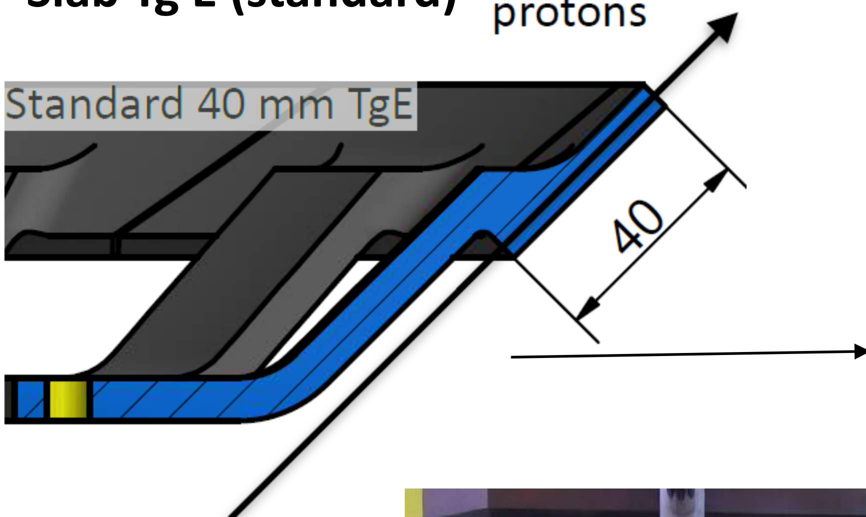
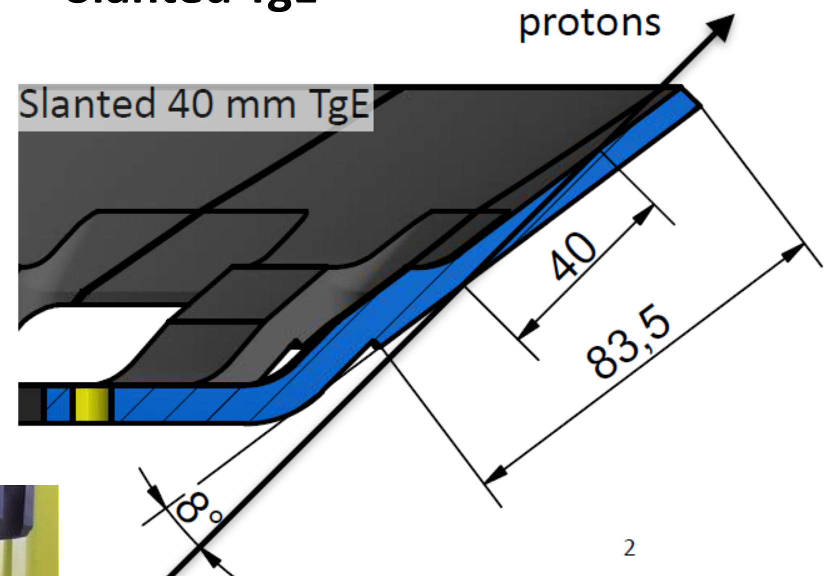
Target development II: Slanted Type

Slab Tg E (standard)



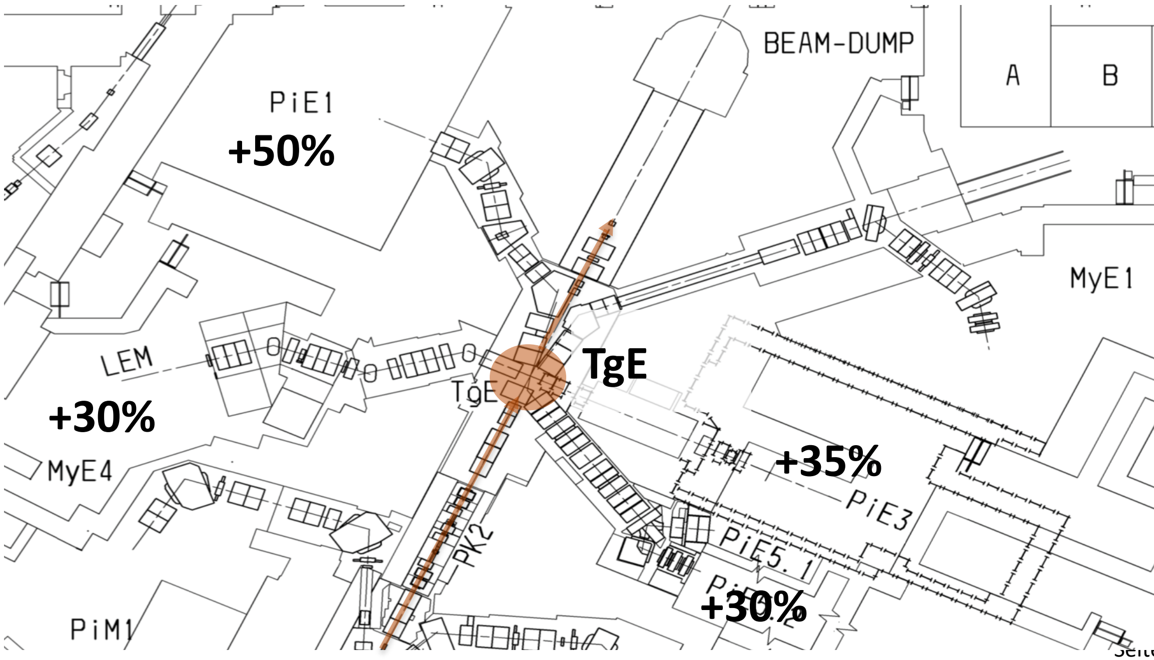
Slanted TgE



Results with slanted target type

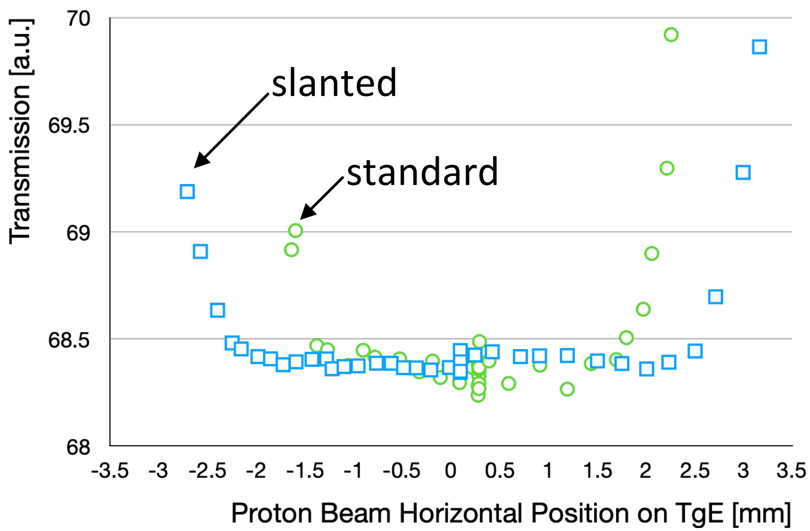
- Significant increase of surface muon rate

- 1. Measurement (2019): 30 – 50 % increase



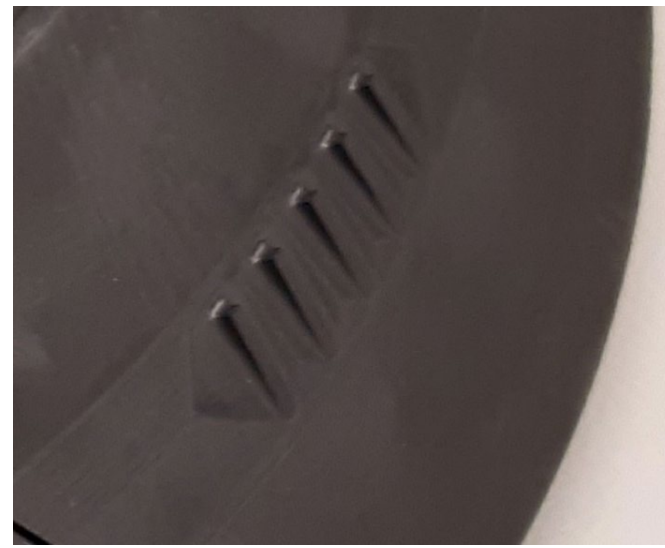
- Increased safety margin for “missing” TgE with the proton beam

→ pencil beam to the neutron spallation target has to be avoided (several diagnostics in place)



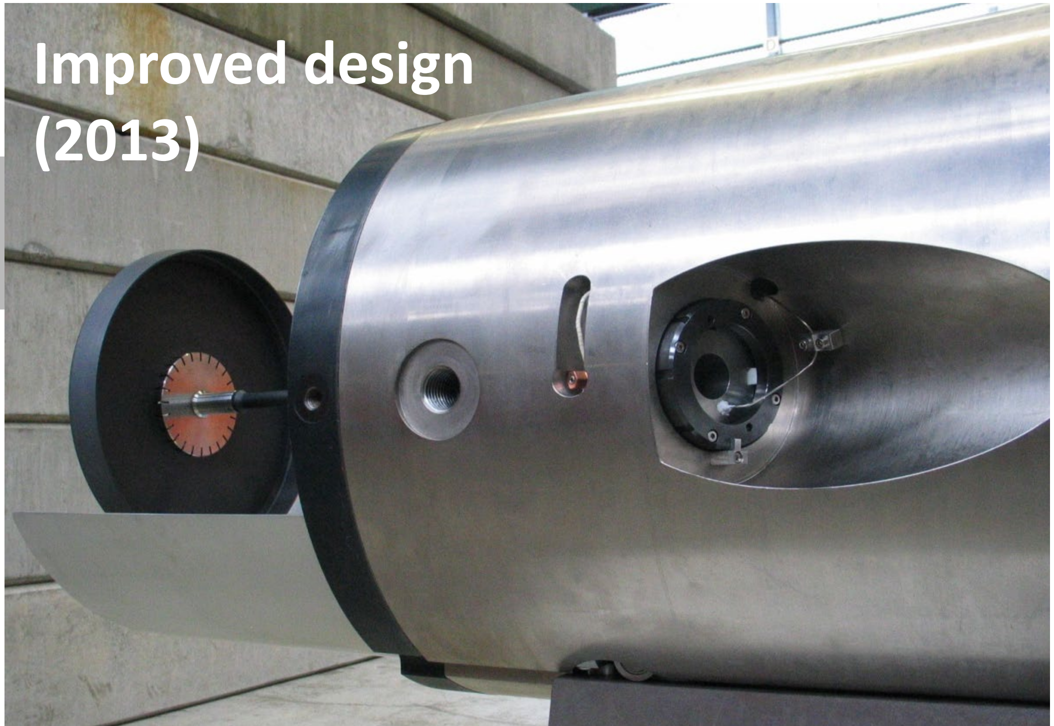
Combining grooves and slanted

& KOYO bearing



planned for beam period starting May 2022

Present Target-M



Target M:

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

Temperature: 1100 K

Irradiation damage: 0.1 dpa/Ah

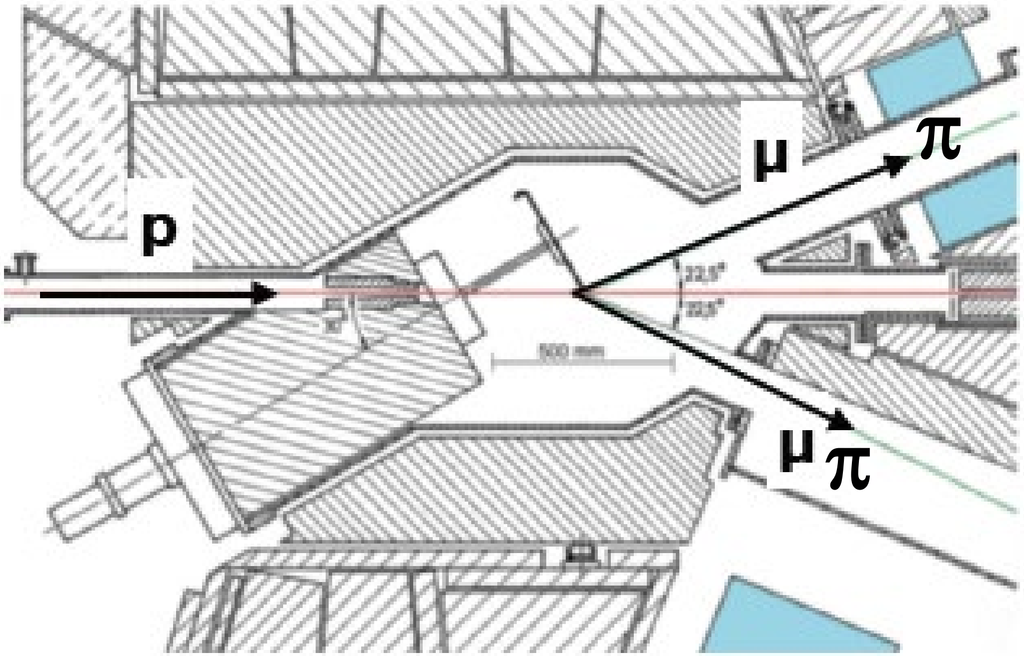
Rotational Speed: 1 Hz

Current limit: 5 mA

Life time: up to several years

up to ~ 60 Ah ~ 6 DPA

Present TgM station (built 1985)



PiM1

particle physics

PiM3

μSR (GPS, FLAME)

10^7 μ^+/s

} nowadays surface muons needed

Beamlines under 22.5°

→ optimized for high-momentum π > 100 MeV/c,

@ 350 MeV/c: π+: :2x10^8 /(s mA)

Target: graphite

2 mm thick rim

→ effective 5 mm (due to angle),

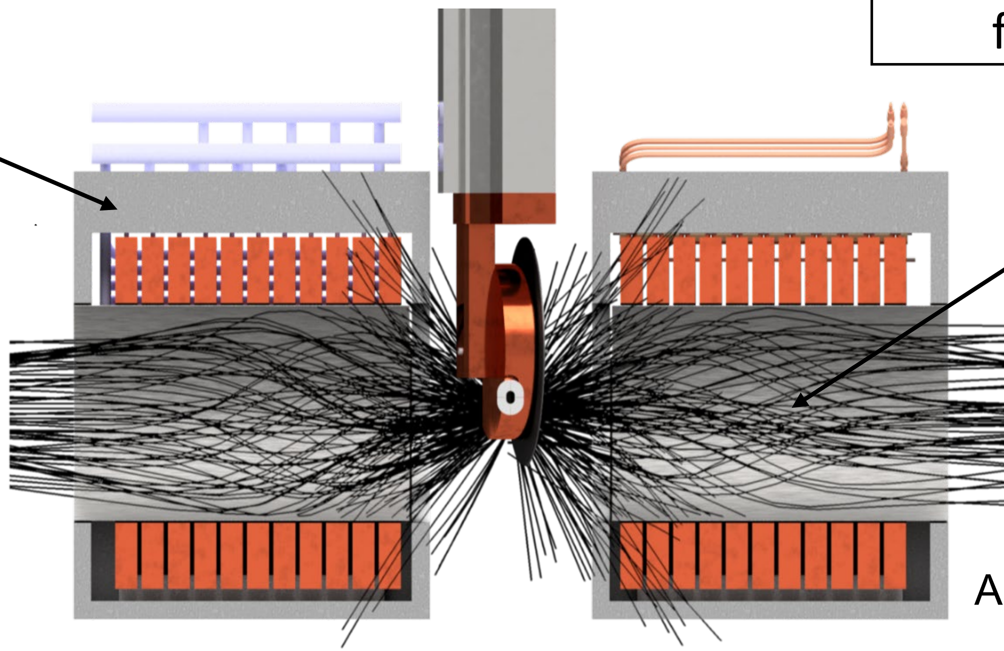
cooled by thermal conduction

no problems with bearings!

Concept for new target station HIMB at TgM

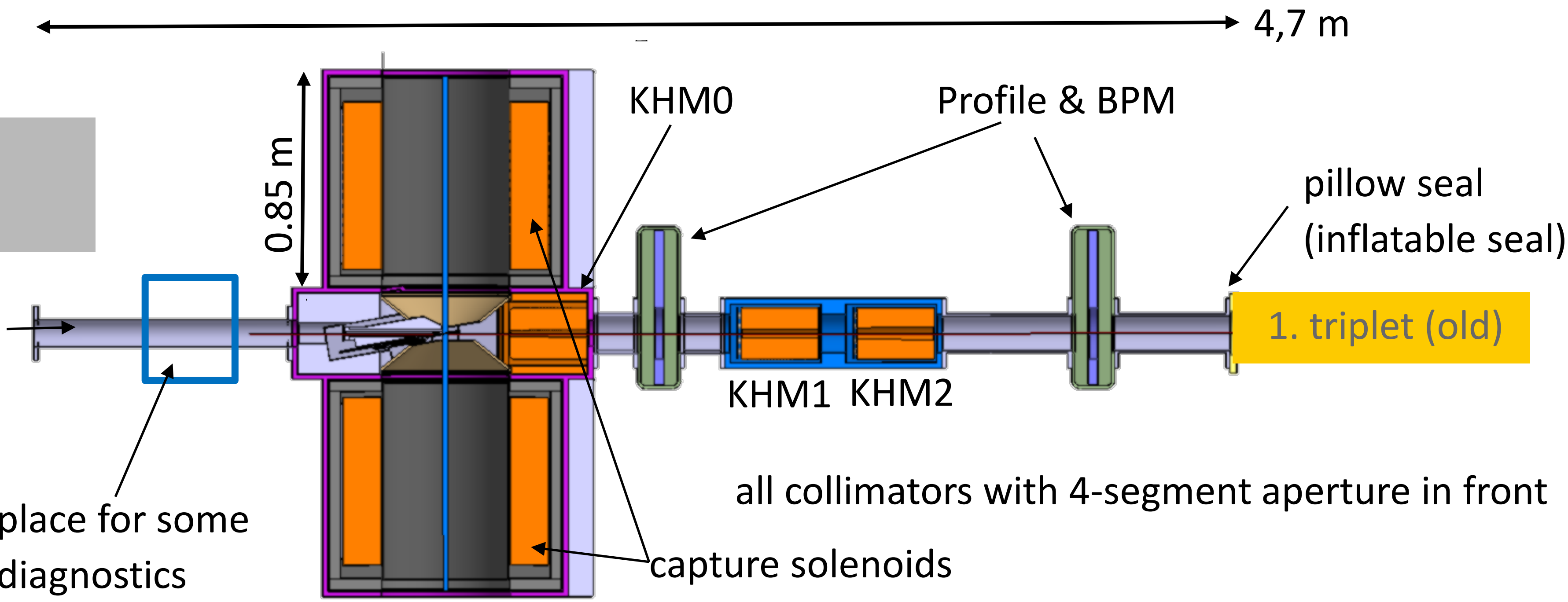
HIMB = High-Intensity Muon Beams

goal: 10^{10} surface muons/s for particle physics



- short wide solenoids with large fringing field in high radiation area
- close distance to the target +/- 250 mm
- thicker target (20 mm instead of 5 mm) → higher losses & activation
- slanted target type
  - large rim (> 100 mm)
  - large rotating wheel for cooling
  - small angle relative to beam
- beamline optimized for large transmission of surface muons

New target station & proton beamline

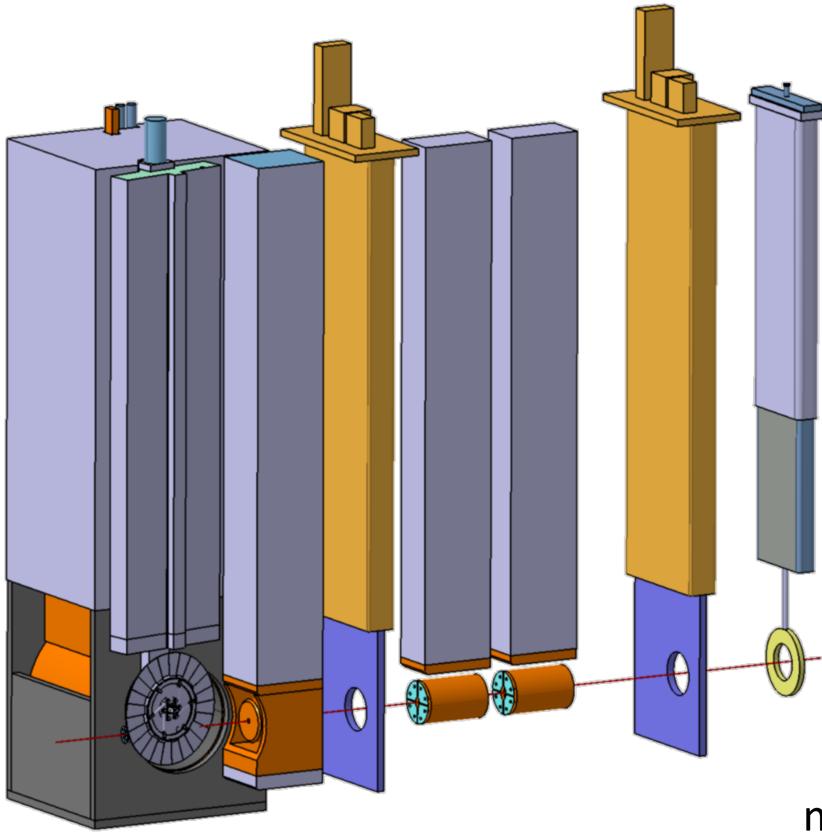


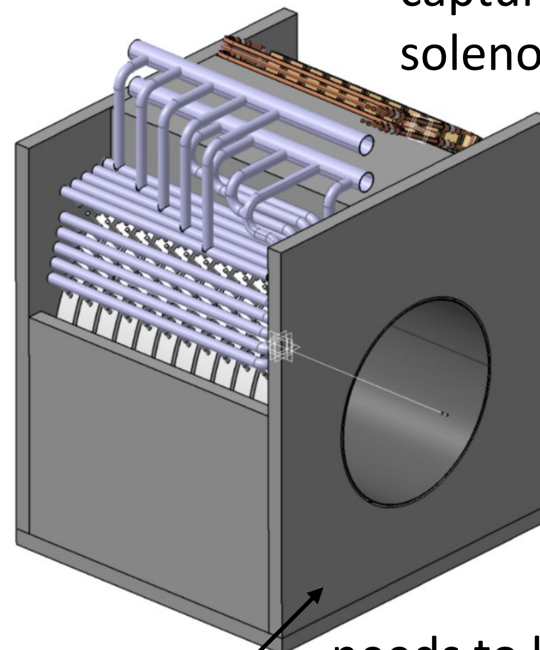
place for some diagnostics
to protect the chamber & guide the beam to the target

- one vacuum chamber for target, capture solenoid, beamline
- pillow seal far away from high radiation zone
- collimator setting optimised using BD-SIM regarding
  - sensitivity to beam misalignment
  - protection of 1. triplet
  - proton beam transmission
- 2 conical heat shields to protect magnets from the hot target (1500 °C)
  (Cooling requires more considerations)

Inflatable all-metal seal

Side view of beamline components





mirror plate (40 mm iron):

- to reduce magnetic field at beamline
- challenge for cooling

- Target and 2 capture solenoids in 1 vacuum chamber:
  no space for additional wall or pillow seal keeping +/- 250 mm from beamline
- all vacuum chambers are cooled by water
- exchange of solenoid in vertical direction with (new) exchange flask

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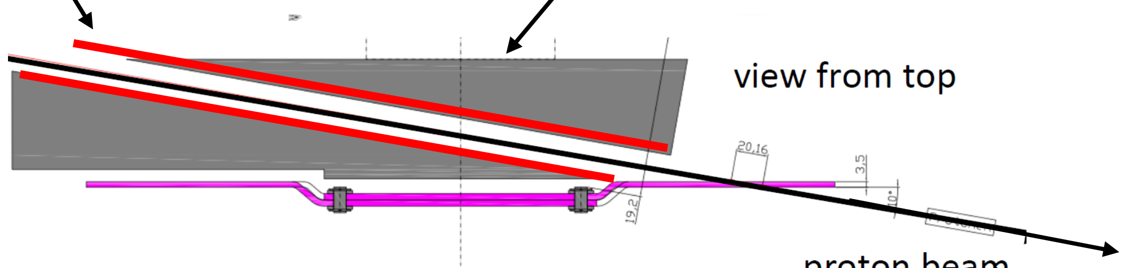
Target insertion

Due to tight space limits:

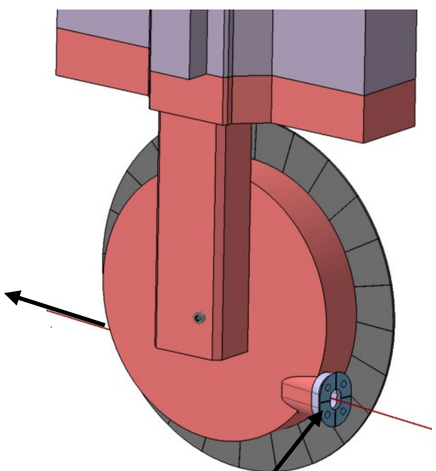
beam passes behind the target through the cooling plate

Cu plate with cooling pipes



view from top

proton beam



4-segment aperture

design & rotation mechanism similar to target E

To avoid beam on the Cu cooling plate:

- tungsten collimator inside
- isolated for current measurement
  → fast interlock
- 4-segment aperture for centring
  → fast interlock

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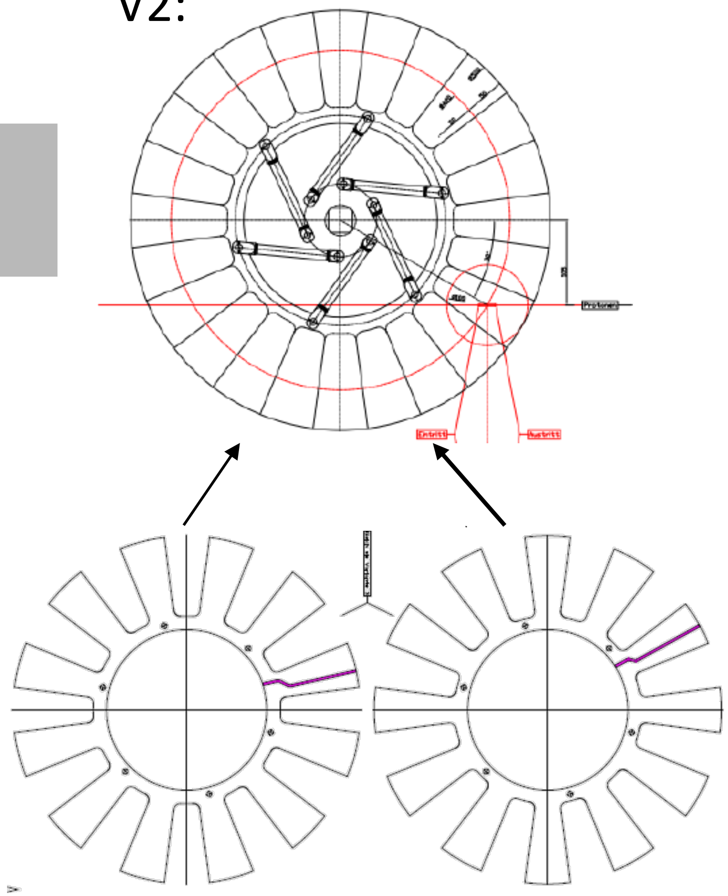
Target graphite wheel

V2:

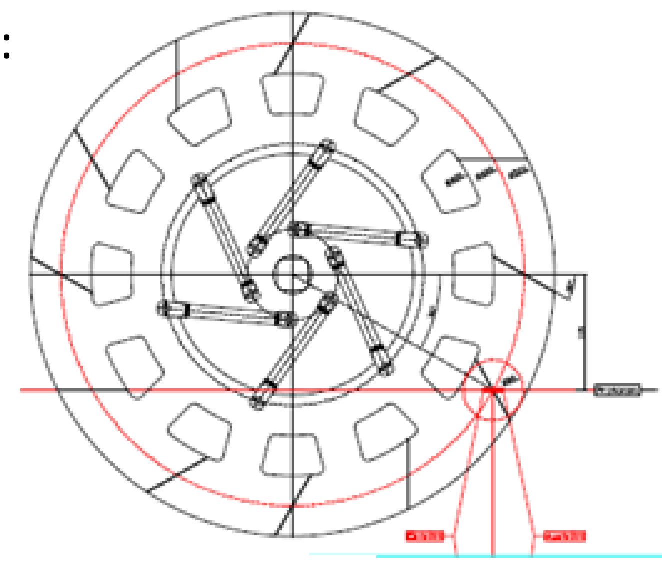


slanted:

protons hit the target under small angle: 10°

- effective length: 20 mm
- 100 mm rim
- target thickness: 3.5 mm
- 7 – 10 % loss in muon rate

V6:



2 wheel version (V2) is preferred.
Reason: Wheels are flat and thin.
Graphite is more stable,
because not so many layers are crossed.

Wheel very similar to Target E
as back-up option

Exchange of the high-activated components

Exchange flask:

- 45 t, shielded with 40 cm steel
- remotely operated
- used for > 15 components

Constraint for insert:
610mm x 480mm (inner cross section)

"Bridge":

- contains contamination protection
- door to close lifting hole
- sticks for positioning of the flask

Working platform:

- ~ 2m above beamline, shielded with steel
- Accessible after removing 3 – 4 m of concrete

For capture-solenoid:

Much simpler exchange flask planned
but with large cross section (1000mm x 800mm)

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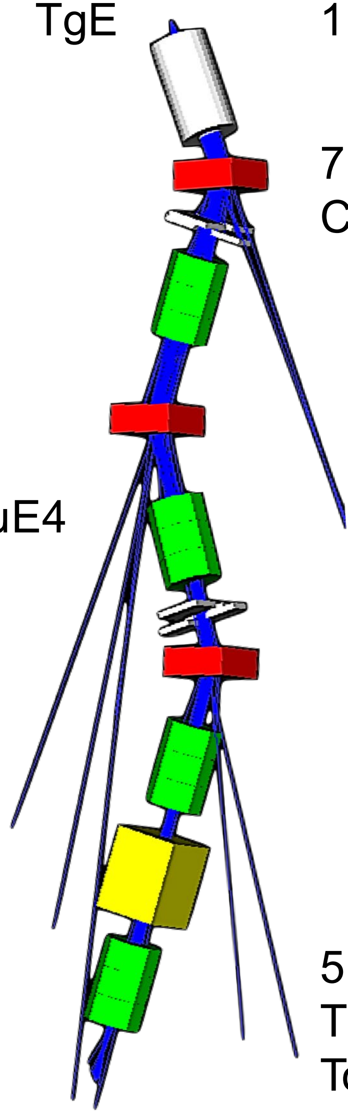
Solenoid Beamline

TgE

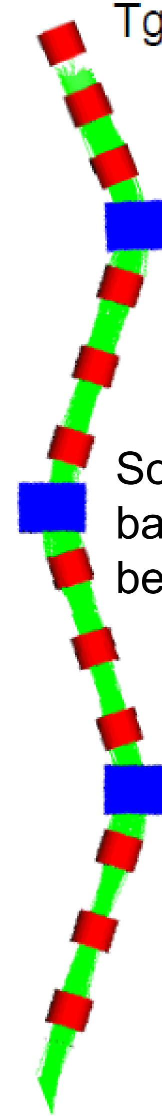


Existing μE4 beamline

1.2×10^{11} μ+/s	Source	1.3×10^{11} μ+/s	
7.2×10^{9} μ+/s C ~ 6%	Capture	3.4×10^{10} μ+/s C ~ 26%	
5×10^{8} μ+/s T ~ 7% Total ~ 0.4%	Transmission	1.3×10^{10} μ+/s T ~ 40% Total ~ 10%	

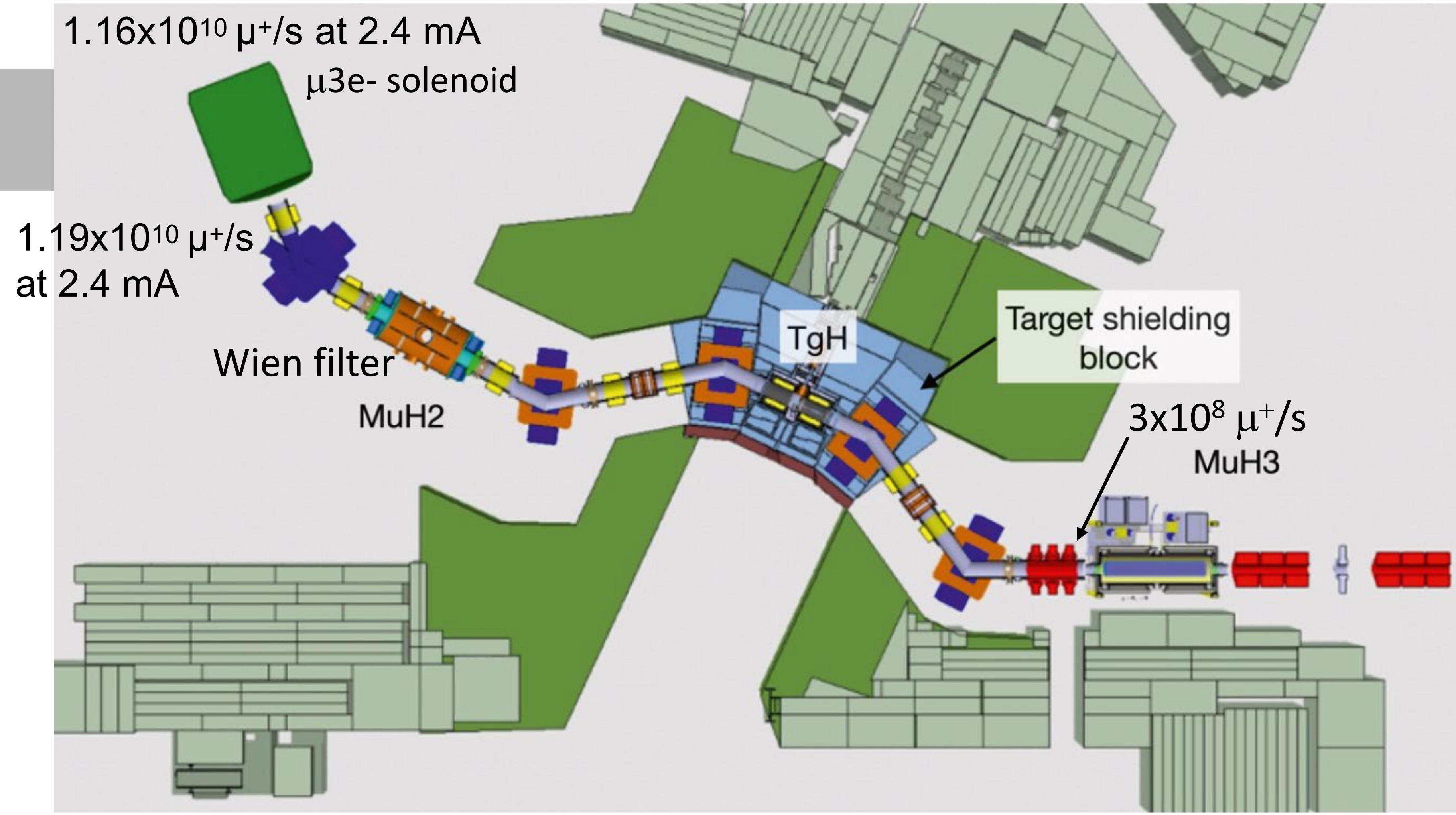
⇒ Gain due to high capture and transmission efficiency

TgH



Solenoid-based beamline

New Target H station



IMPACT = TATTOOS & HIMB

Isotope and Muon Production with advanced cyclotron and target technology

R, Eichler, D. Kiselev, A. Knecht, N. van der Meulen, A. Koschik

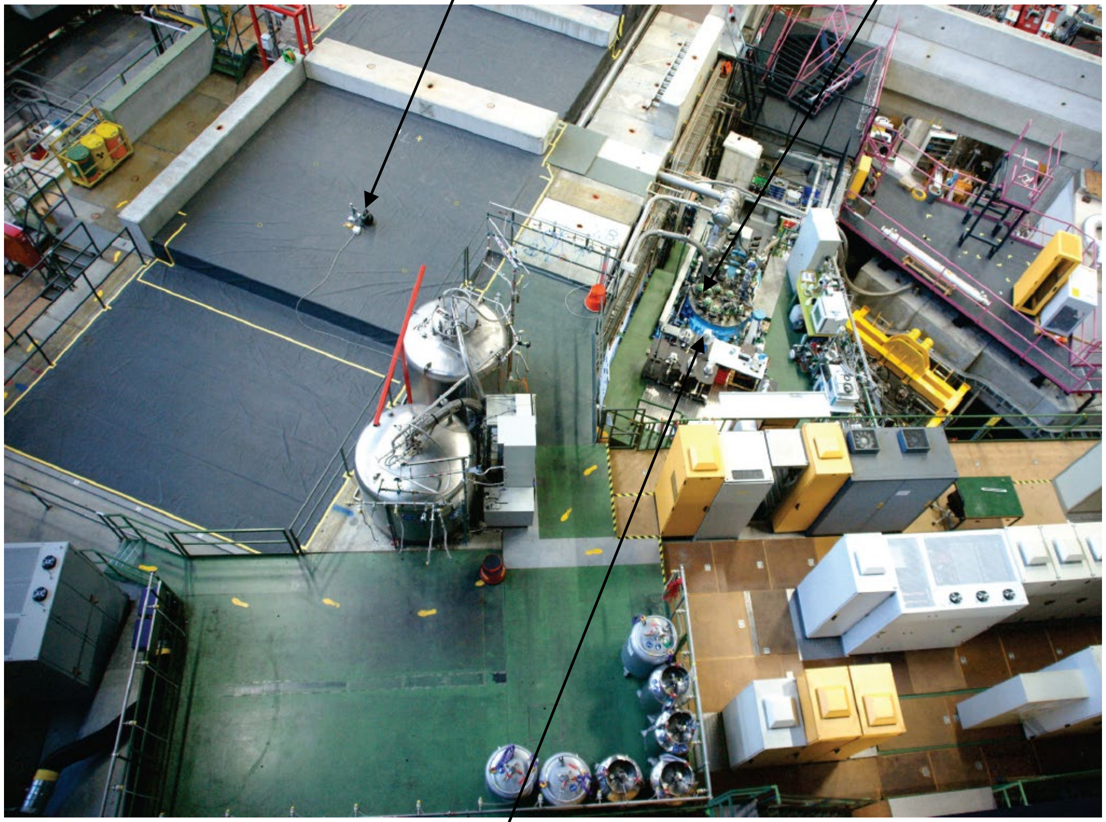
HIMB: High-Intensity Muon Beams is part of IMPACT

TATTOOS: Targeted Alpha Tumour Therapy and Other Oncological Solutions
Producing radioisotopes with 590 MeV protons (100 μA)
for cancer treatment & diagnostics in quantities needed for clinical studies
(no commercial production).

Aim: Support by the Swiss Roadmap of Infrastructure
Final decision: 2024
Installation: 2027
Budget: 70 MCHF

Challenging environment

- Dismantling and assembling of >1000 shielding blocks
- Target block highly activated (~ Sv/h)
- Rebuilt of important infrastructure:
  - Helium liquefier
  - tertiary cooling loop



Summary

- Challenges for the muon target at 50 kW:
  - Cooling, Deformation, Bearings suffer in the high irradiation area!
- KOYO bearing from JPARC worked very well for 2021 run period
- Slanted target type increases muon surface rate by up to 50 %
- Combined groove (for centering) and slanted target is built already
- Conceptual study HIMB for Swiss Roadmap aims for 10^{10} surface-μ/s in particle physics areal