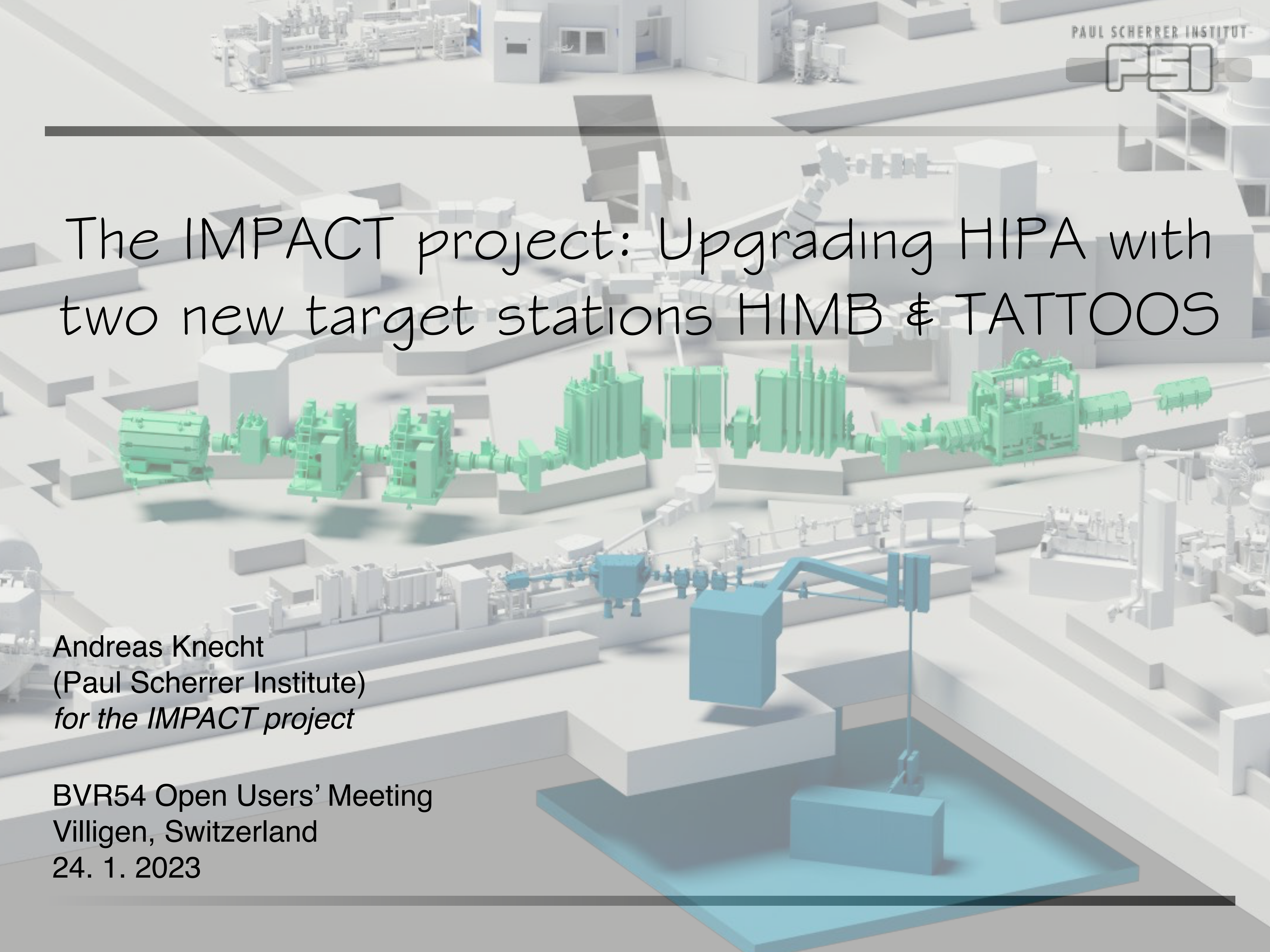
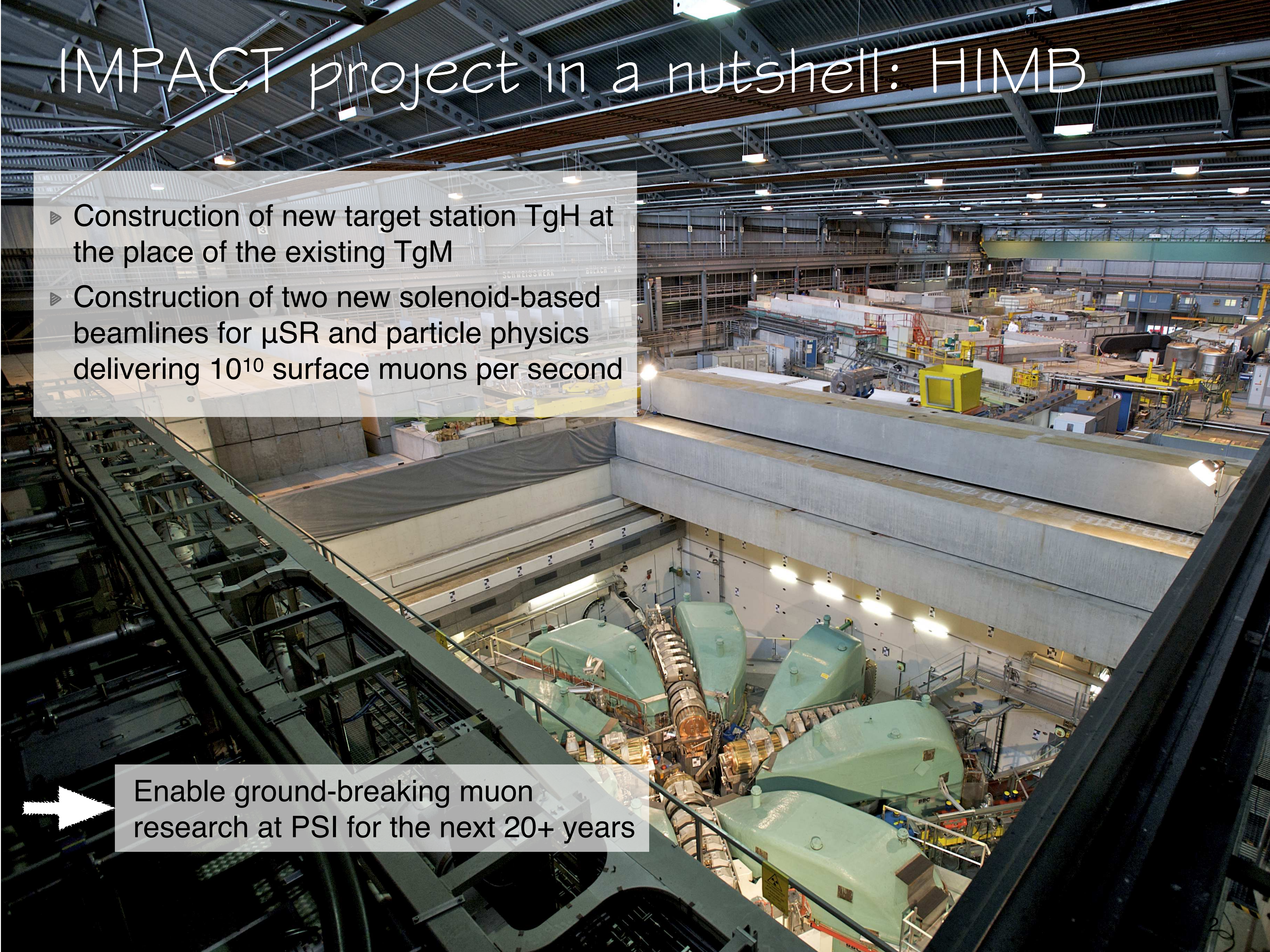
The IMPACT project: Upgrading HIPA with two new target stations HIMB & TATTOOS



Andreas Knecht
(Paul Scherrer Institute)
for the IMPACT project

BVR54 Open Users' Meeting
Villigen, Switzerland
24. 1. 2023

IMPACT project in a nutshell: HIMB



- Construction of new target station TgH at the place of the existing TgM
- Construction of two new solenoid-based beamlines for μSR and particle physics delivering 10^{10} surface muons per second

→ Enable ground-breaking muon research at PSI for the next 20+ years

IMPACT project in a nutshell: TATTOOS

- Construction of new spallation target with online isotope mass separation
- Production of radioisotopes for medical applications in quantities suitable for clinical studies

→ Enable novel cancer therapies with isotopes suitable for simultaneous imaging and treatment

HIMB Science Case Workshop & Document

- Workshop held in April 2021 with 122 participants to gather and identify HIMB Science Case
- 116 page long HIMB science case document published on arXiv:2111.05788v1
- Comprehensive overview of all the identified experiments and measurements that benefit from HIMB both in particle physics and materials science

- In short some highlights:
  - Higher-intensity muon rates for particle physics and μSR
  - Better quality muon beams with muCool
  - Pixel detector based μSR
  - μSR with sub-surface muons

Science Case for the new High-Intensity Muon Beams HIMB at PSI

Edited by A. Knecht, F. Meier Aeschbacher, T. Prokscha, S. Ritt, A. Signer

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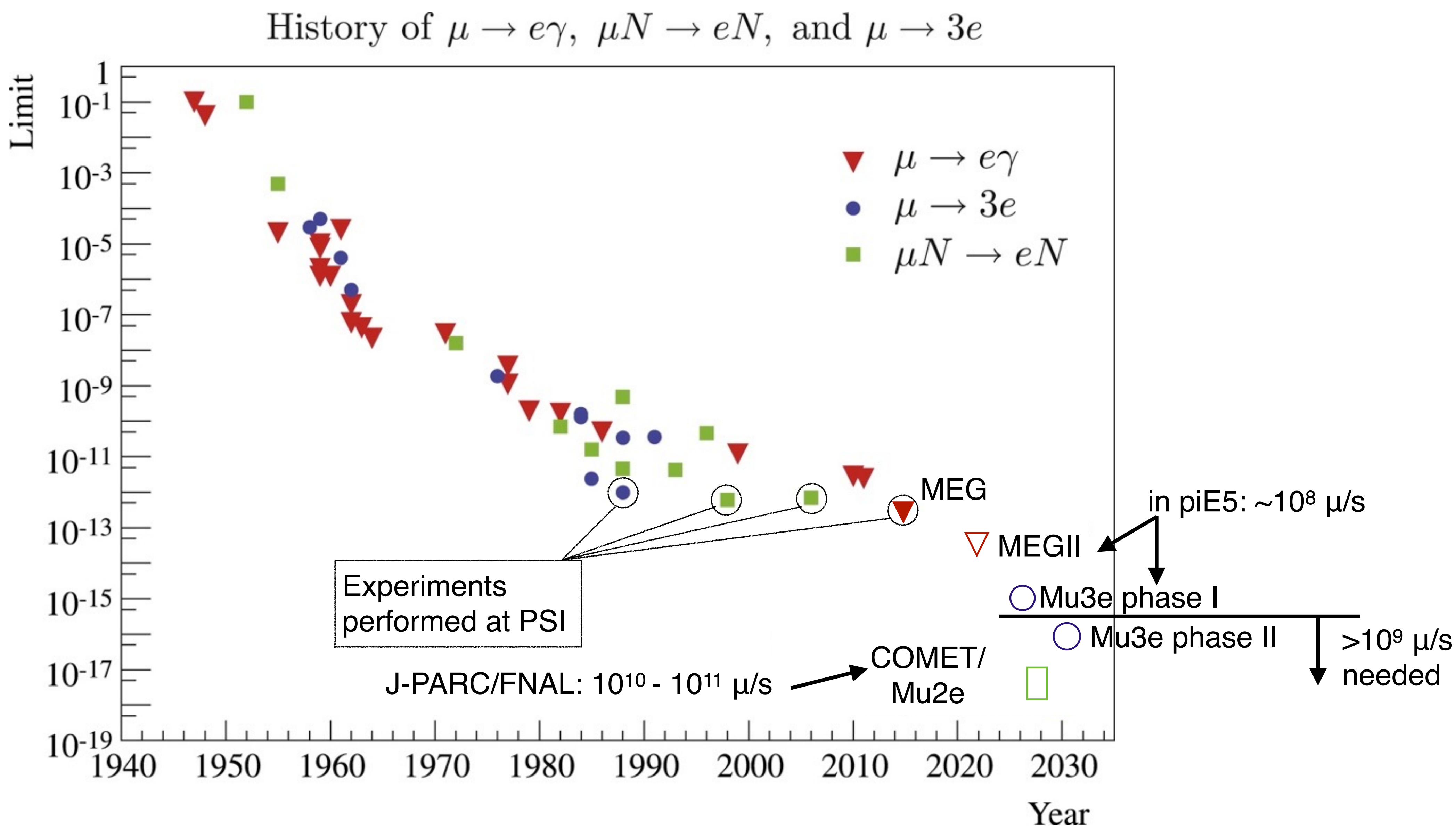
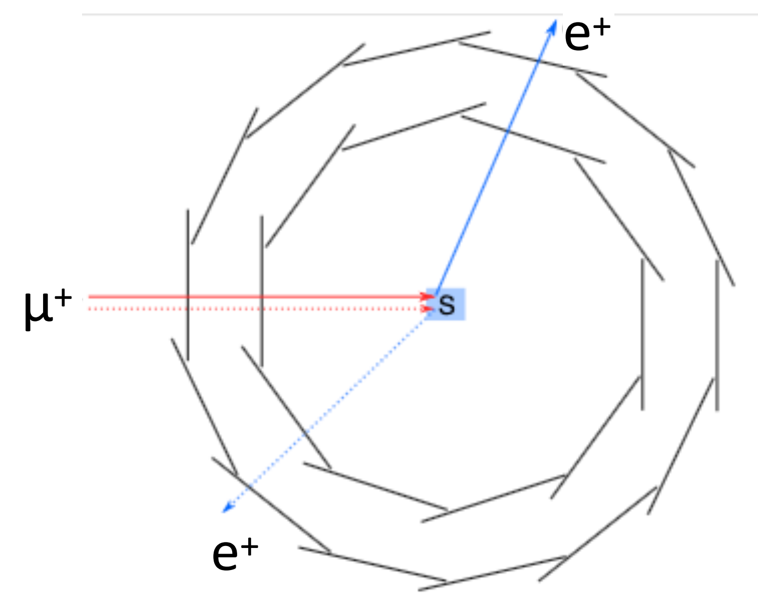
Rare muon decay searches

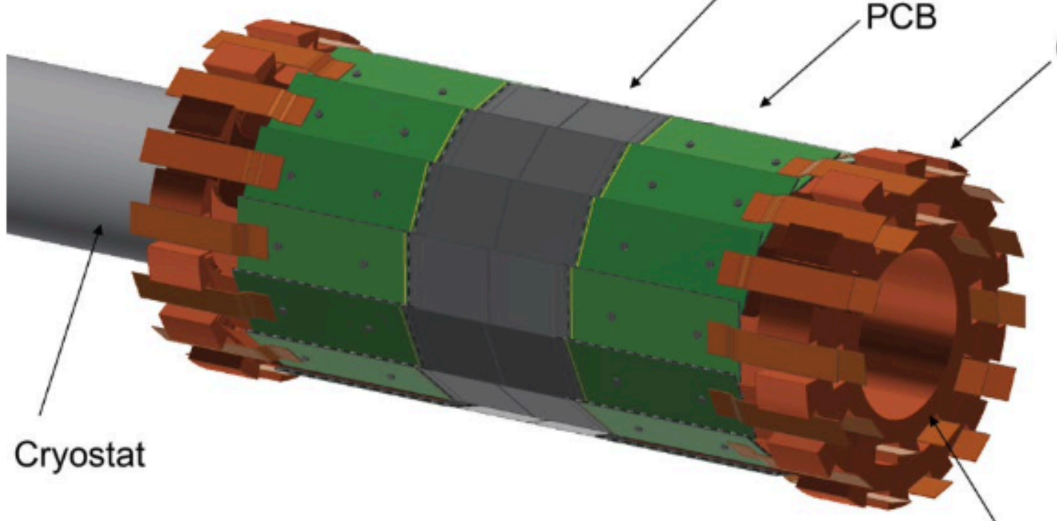


- Neutrinoless muon decays one of the most sensitive probes for new physics
- $\mu^+ \to e^+\gamma$ & $\mu^+ \to e^+e^-e^+$ only possible at DC & intensity-frontier machine such as PSI's HIPA accelerator
- Any future cLFV search at PSI will need higher beam intensities

Muon spin rotation

- Vertexing for μSR applications:
  - Pixel detector development together with particle physics
  - Enables 10-100x faster measurements.
  - Unprecedented small samples, 10-100x smaller (“μ-microscope”).
  - Allows putting samples in extreme conditions at unprecedented levels, e.g. 10x pressure





“Matched Pairs” Towards Theragnostics: The Next Generation

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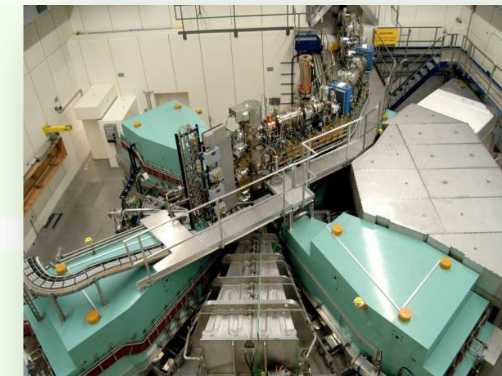
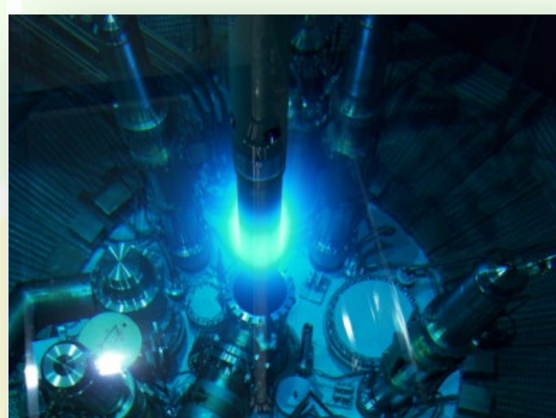
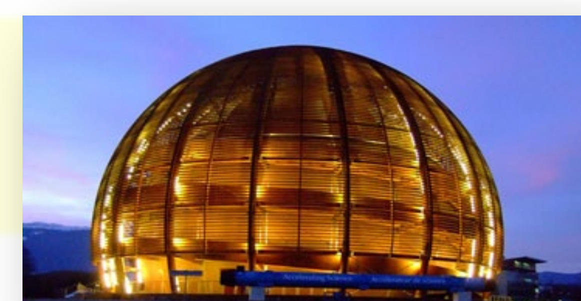
	Clinically Applied	Next-Generation Radionuclides
SPECT (γ)	In 111 2.80 d; Tc 99m 6.01 h	Tb 155 5.32 d
PET (β^+)	Ga 68 68 min	Tb 152 17.5 h
β^--Therapy	Y 90 2.67; Lu 177 6.65 d	Tb 161 6.89 d
Auger-e^- Therapy		
α-Therapy	Ac 225 10.0 d; Bi 213 46 min	Tb 149 4.1 h

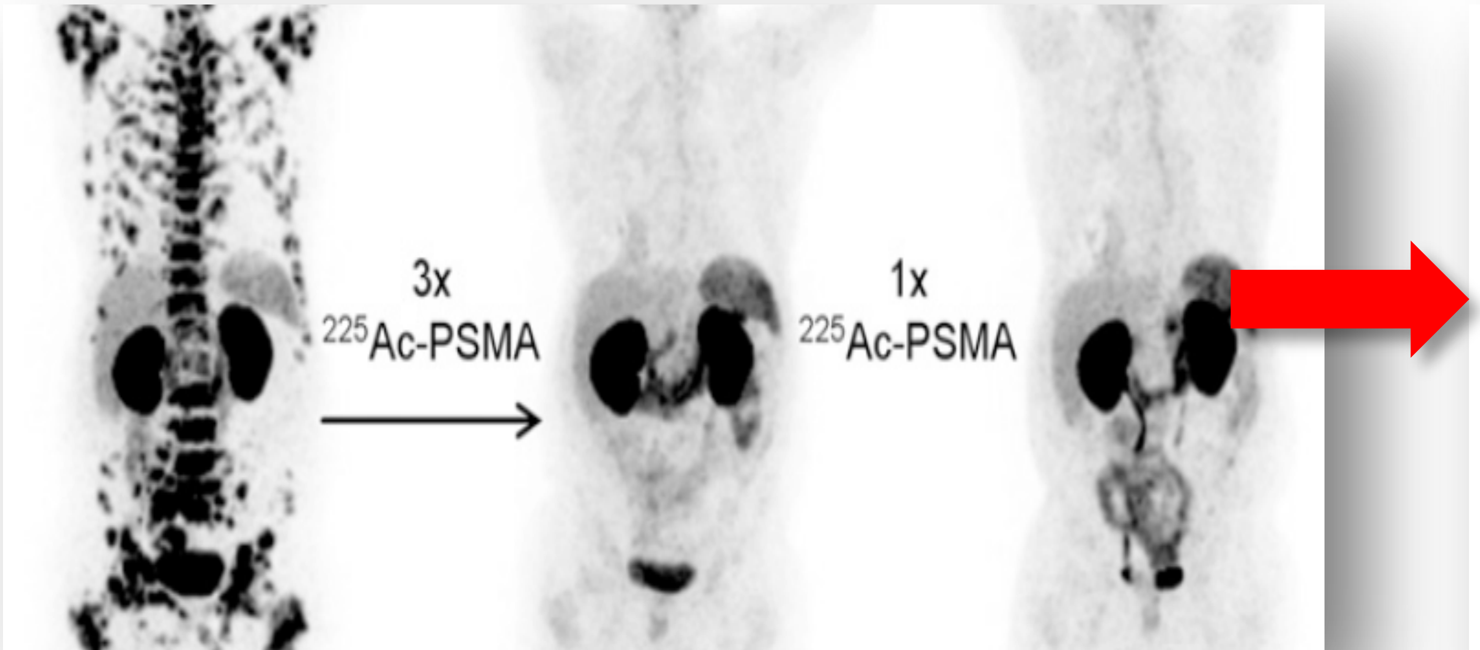


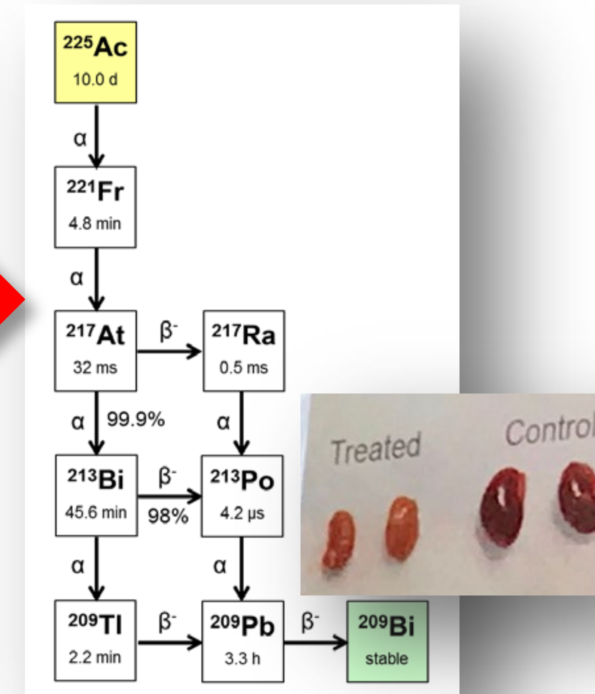




Targeted alpha therapy

^{149}Tb is the IDEAL α-emitter for Targeted Alpha Therapy!

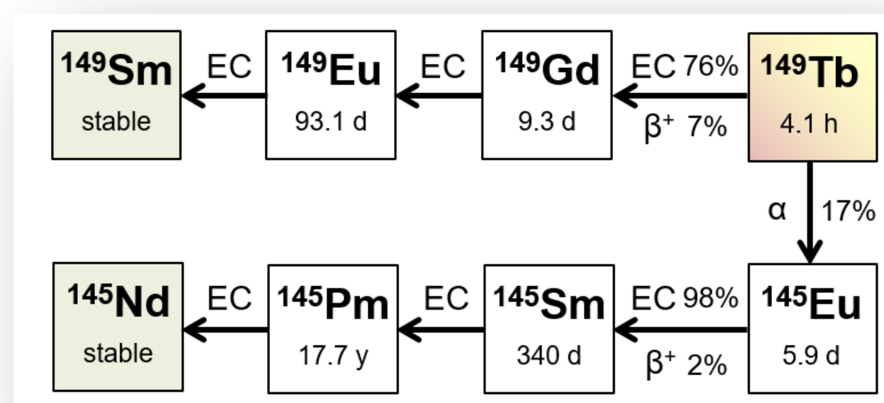




Mulitple α-decay chain can cause much damage,
Resulting in side effects!

Kratochwil et al. **2016**, J Nucl Med Mol Imaging 57:1941

^{149}Tb has NO α-daughters!



PSI Proton Accelerator HIPA

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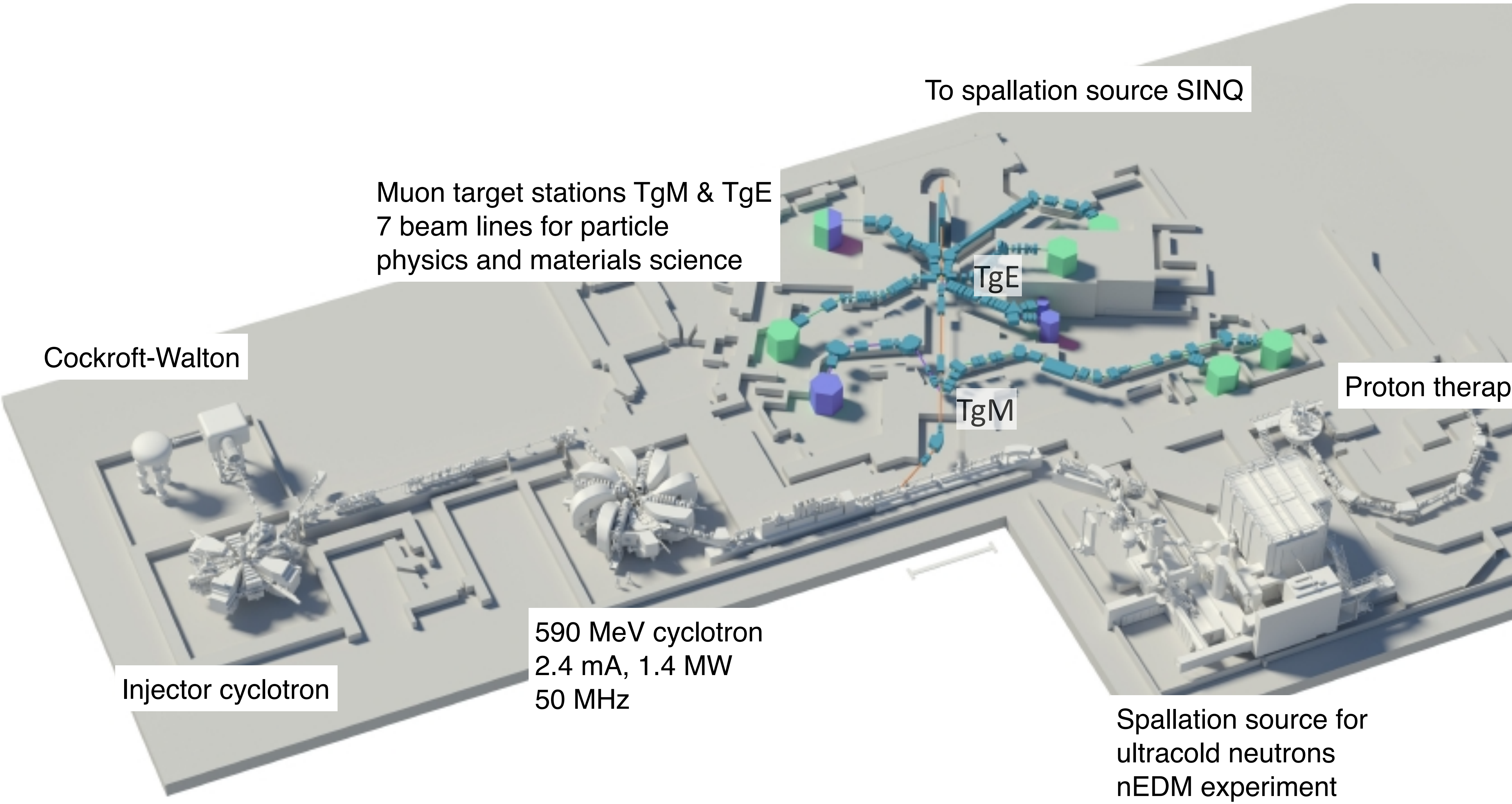
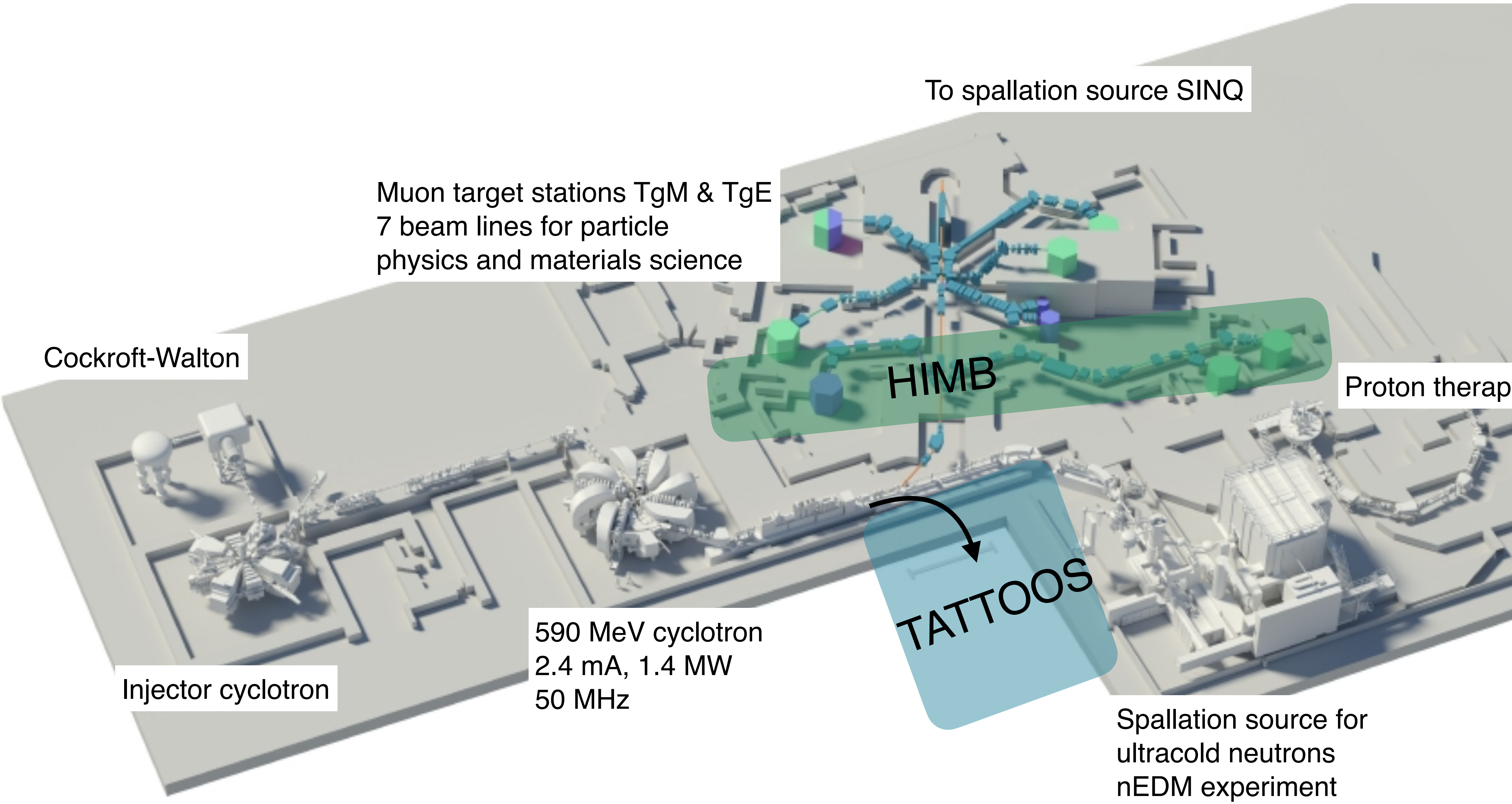
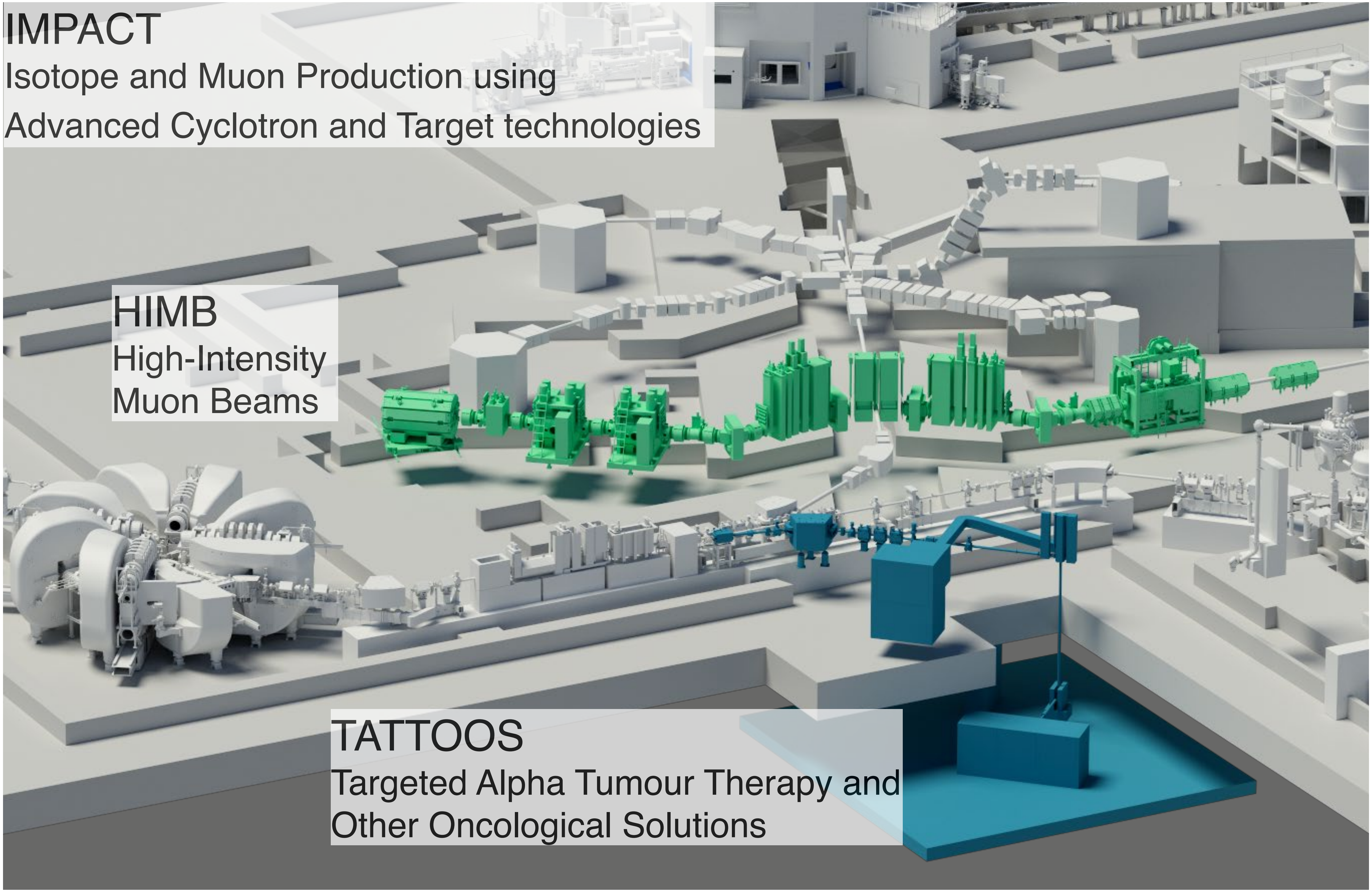


PSI Proton Accelerator HIPA

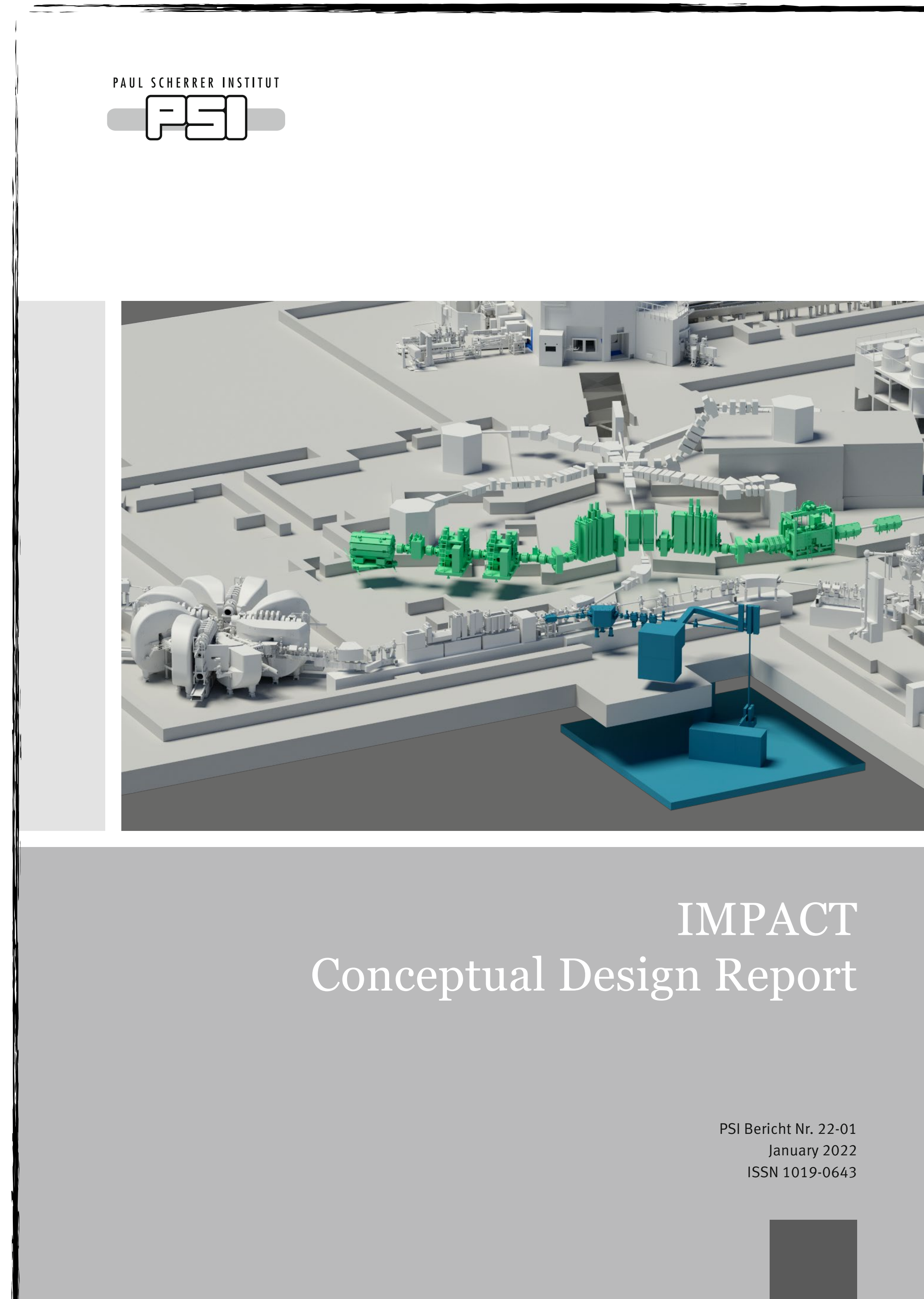


IMPACT: HIMB & TATTOOS

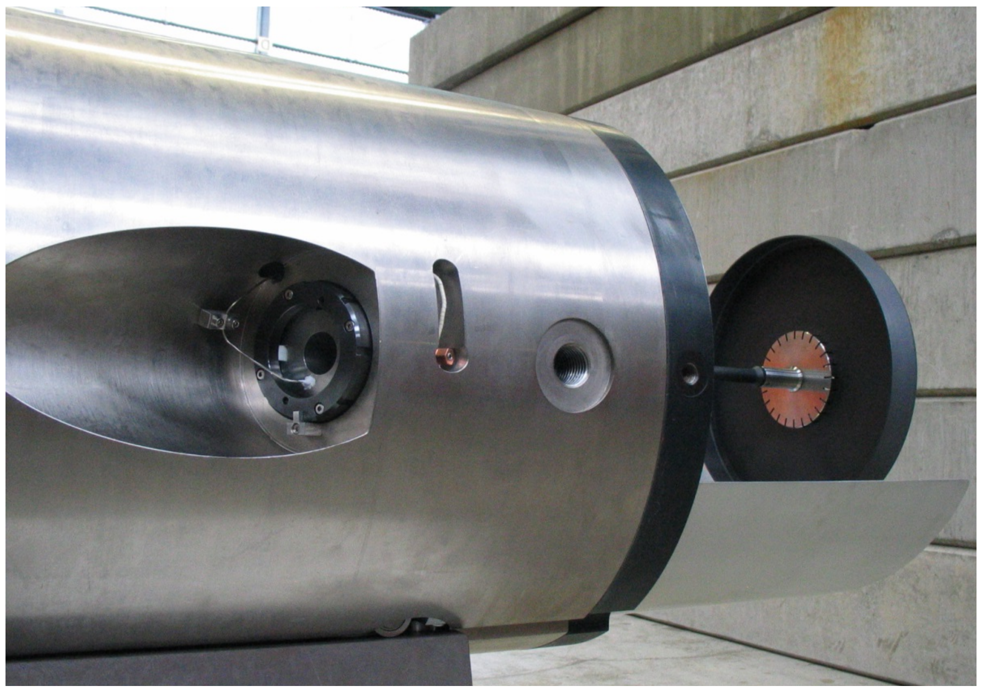


IMPACT Conceptual Design Report

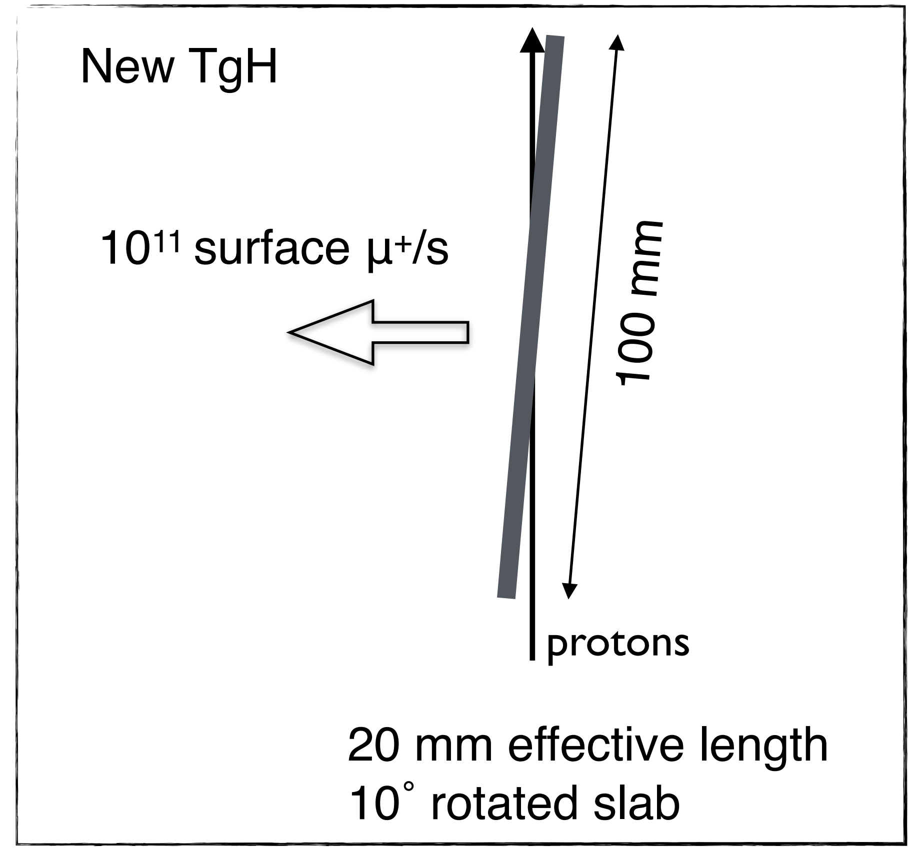
- 304 page document detailing all the concepts
- Forming the basis for the full approval and funding process
- Since January 2022 available at: https://www.dora.lib4ri.ch/psi/islandora/object/psi%3A41209



Target Geometry for new TgH



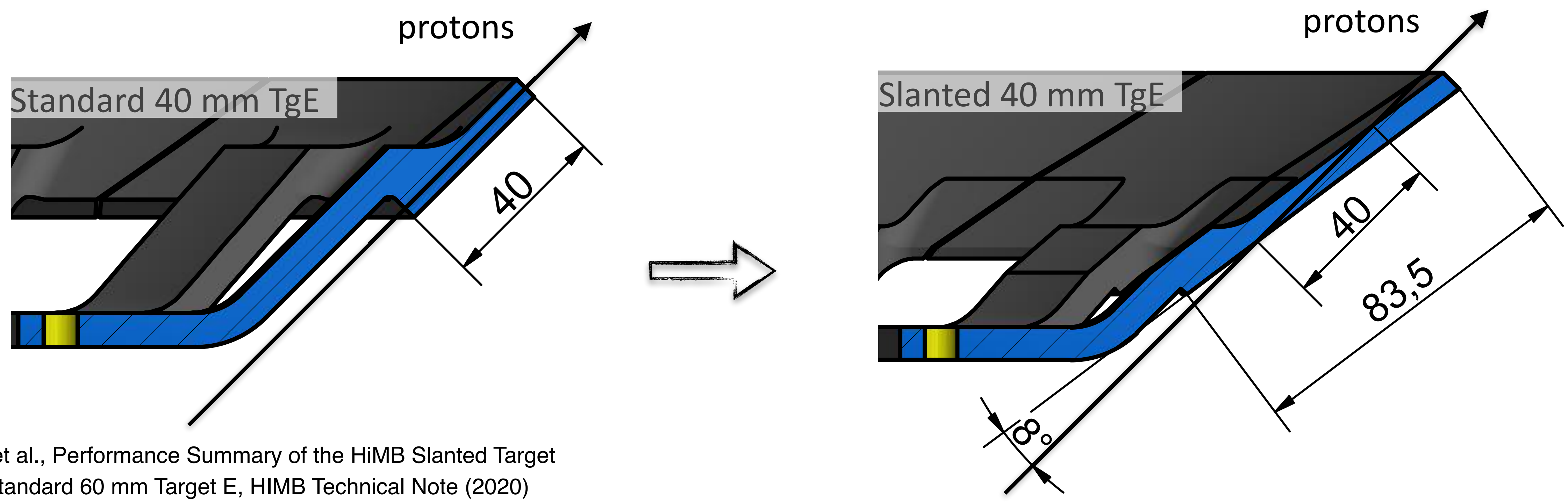
Existing TgM



- Change current 5 mm TgM for 20 mm TgH (known situation from 60 mm TgE)
- 20 mm rotated slab target as efficient as 40 mm standard Target E

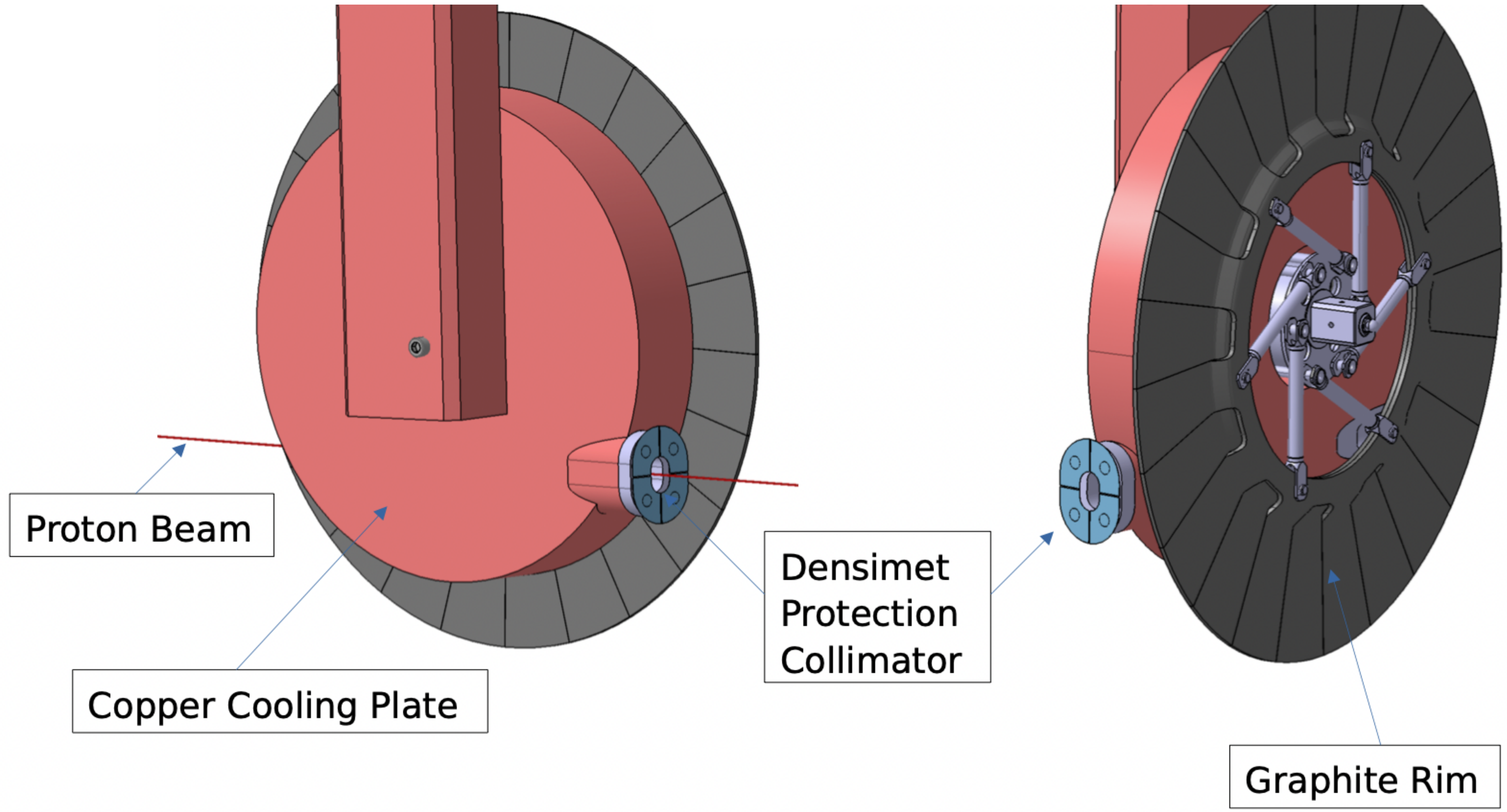
First HIMB development at HIPA: Slanted TgE

- Goals:
  - Change geometry of TgE to increase surface muon rates
  - Increase safety margin for "missing" TgE with proton beam
- First test at the end of 2019; new standard geometry since then
- 40-50% gain in surface muon rate in all connected beamlines



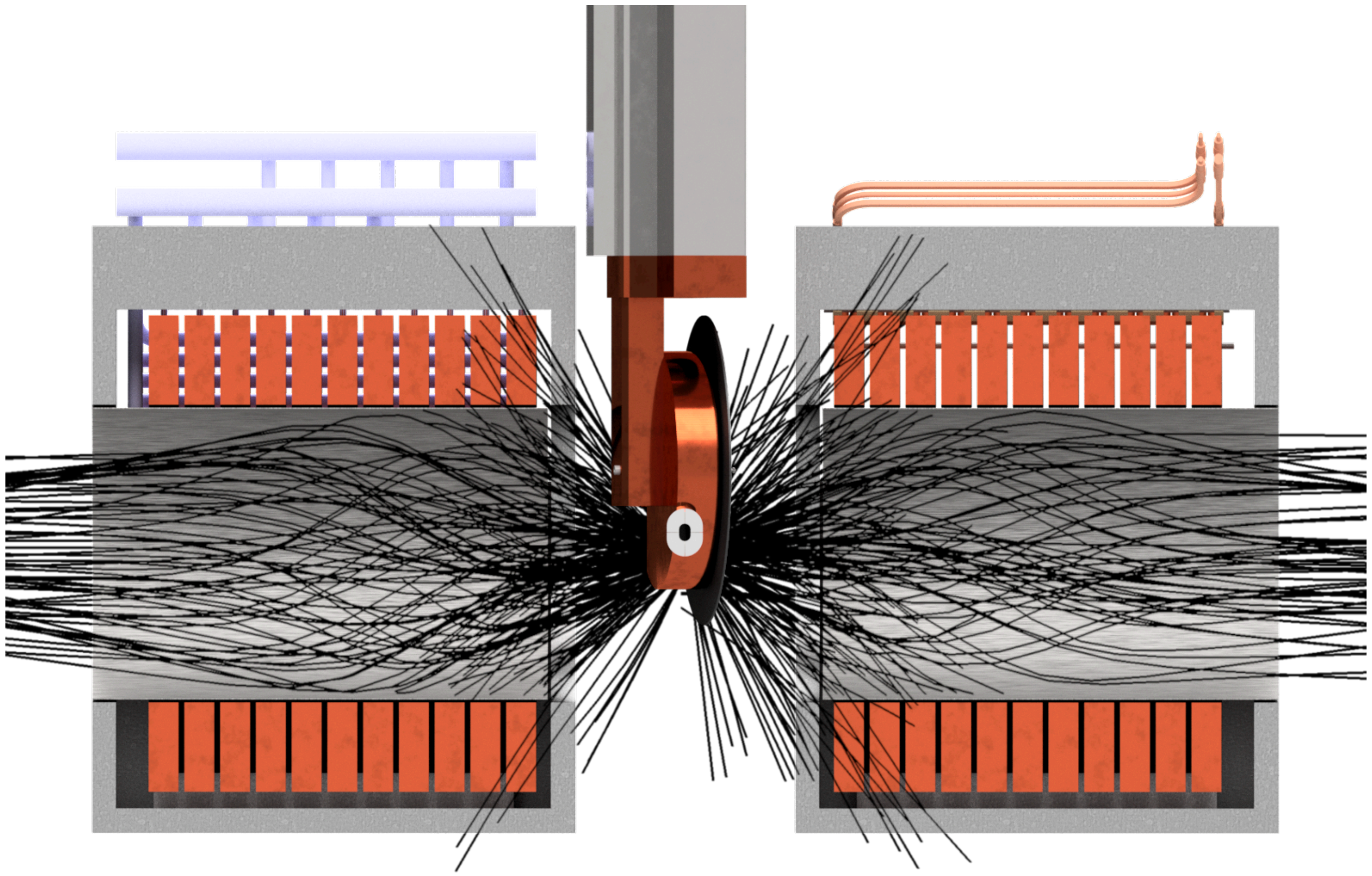
P.-R. Kettle et al., Performance Summary of the HiMB Slanted Target versus the Standard 60 mm Target E, HIMB Technical Note (2020)

New Target H



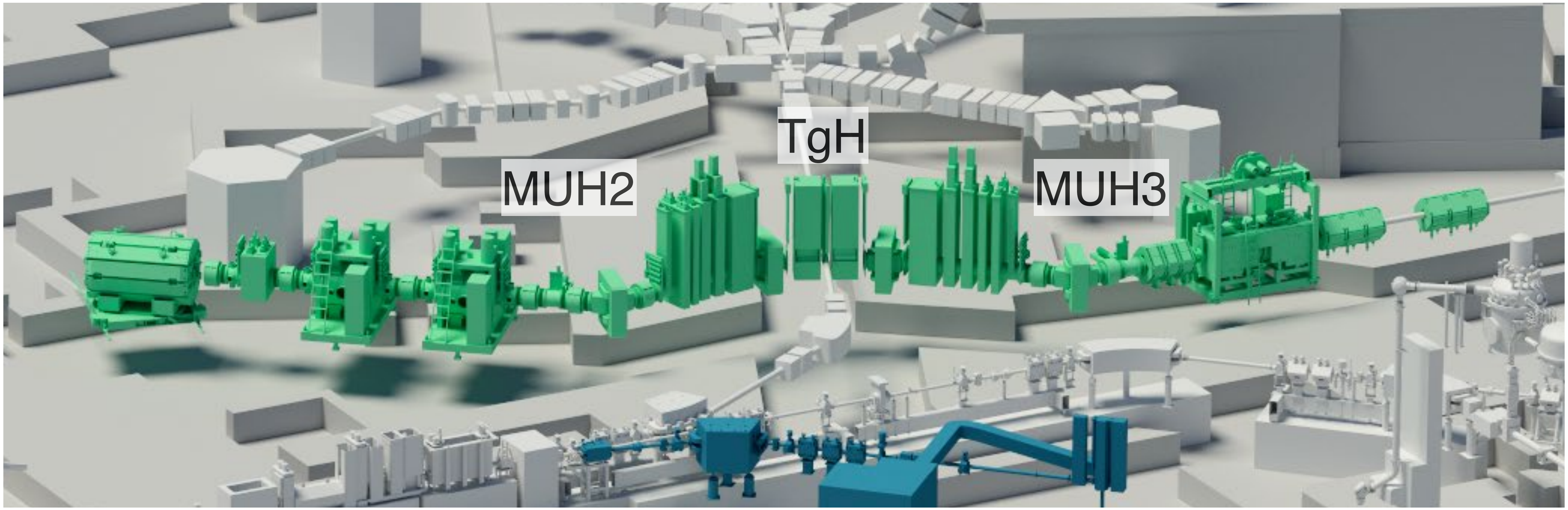
- Target design quite advanced
- Based on experience from TgM & TgE
- Same exchange concept as for TgE

Split Capture Solenoids for Muon Collection



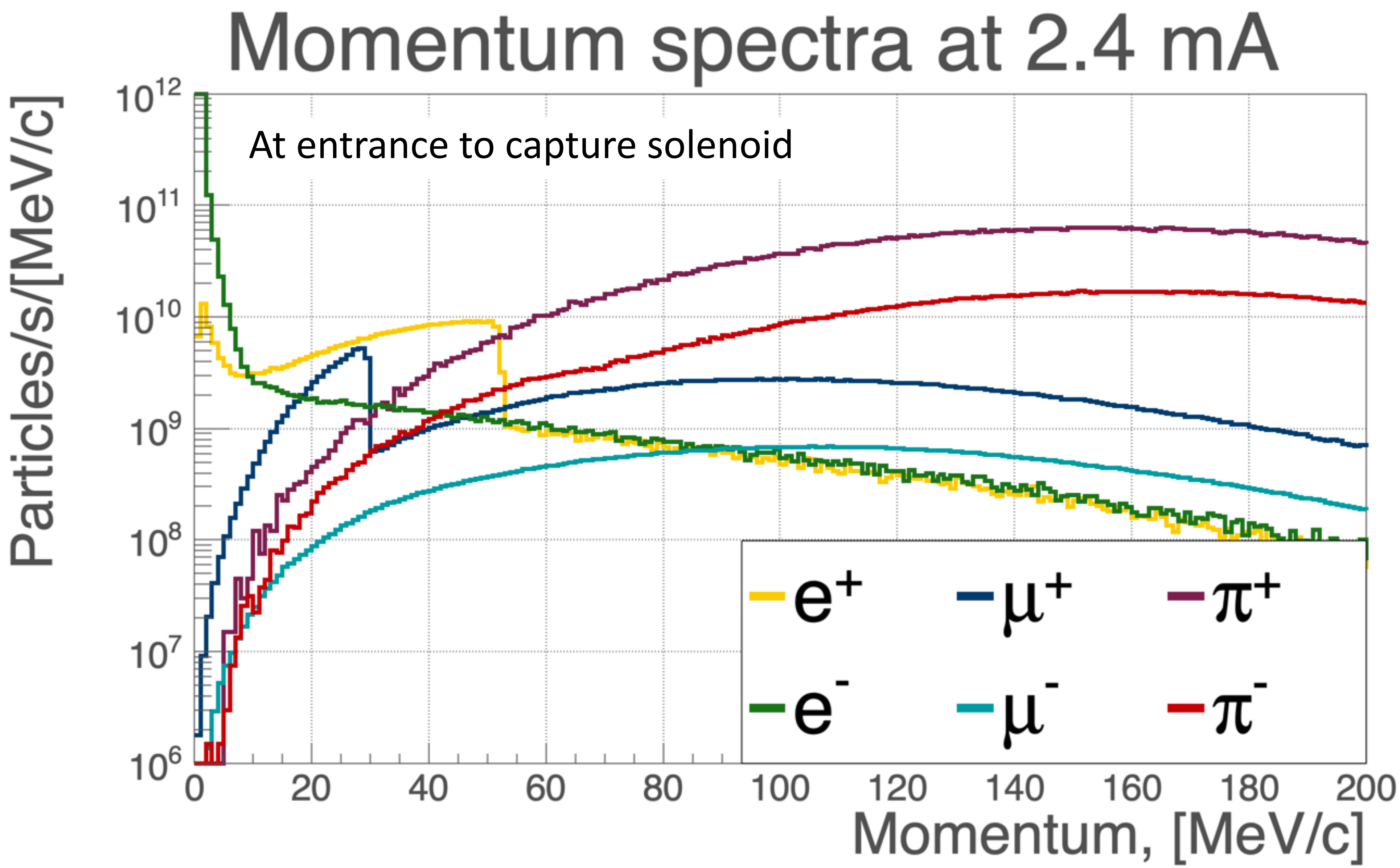
- Two normal-conducting, radiation-hard solenoids 250 mm away from target to capture surface muons
- Central field of solenoids up to 0.45 T
- Currently looking into graded-field capture solenoid: stronger field at capture side, weaker at exit

MUH2/MUH3 Beamlines



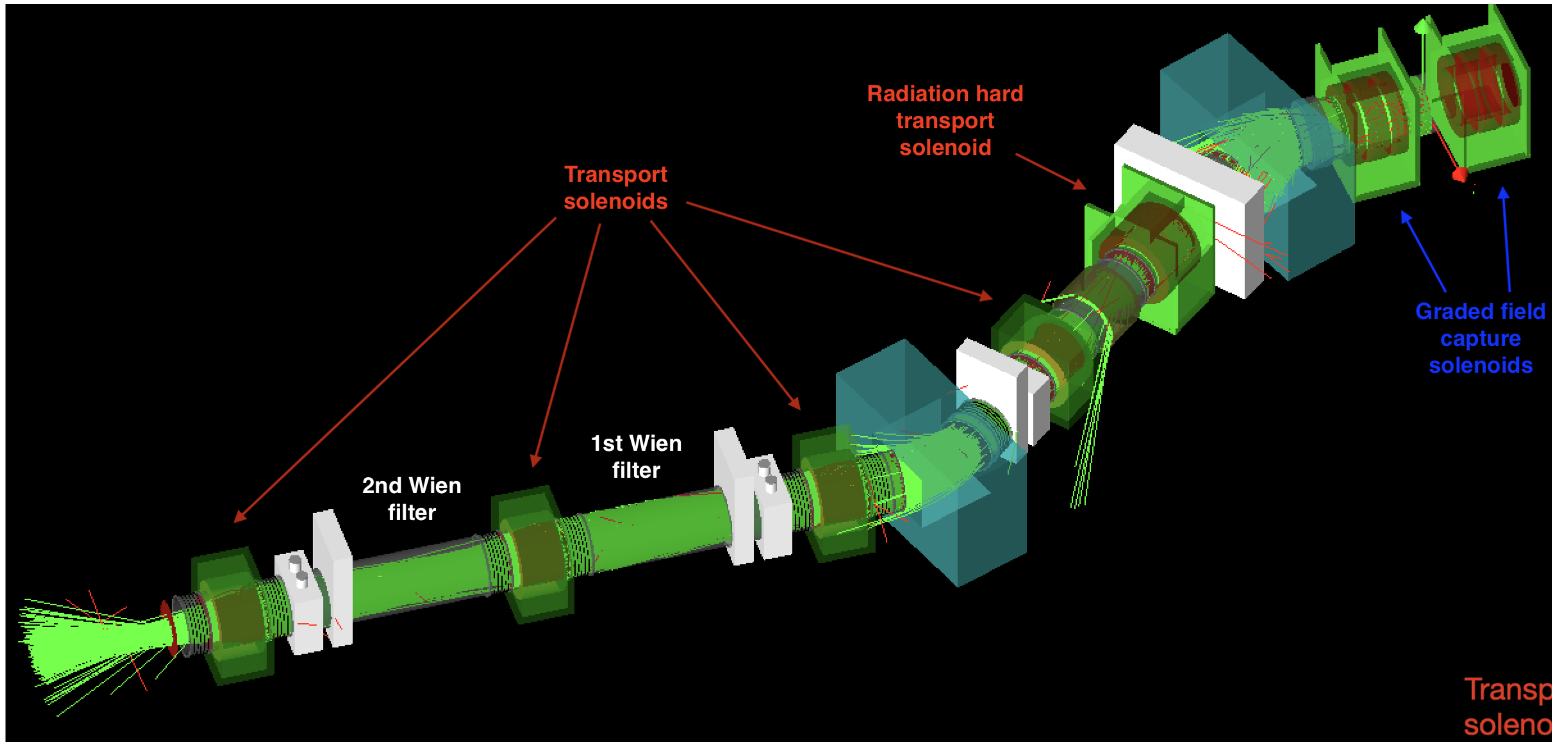
- Baseline scenario for target and beamline layouts:
  - New TgH at the same location as current TgM
  - 90 degree angle of muon beamlines with first bend in the upstream direction
- MUH2 for particle physics using high-transmission solenoid based beamline
- MUH3 for µSR solenoid based beamline until experimental area; couples into existing beamline

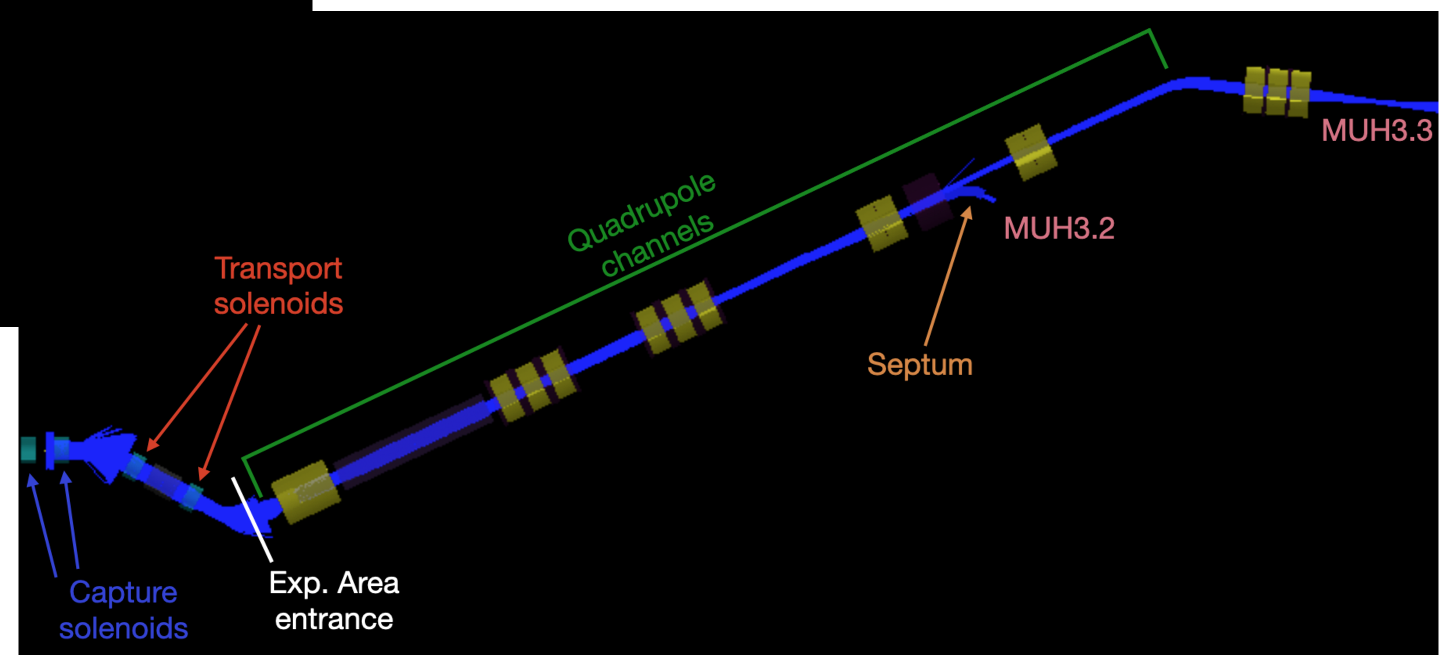
Particle production at TgH



- We are not only producing surface muons
- Will have good capture and transport efficiency up to 40 MeV/c (given by capture solenoid)
- Plan is to design dipoles up to 80 MeV/c

MUH2/MUH3 Beamlines

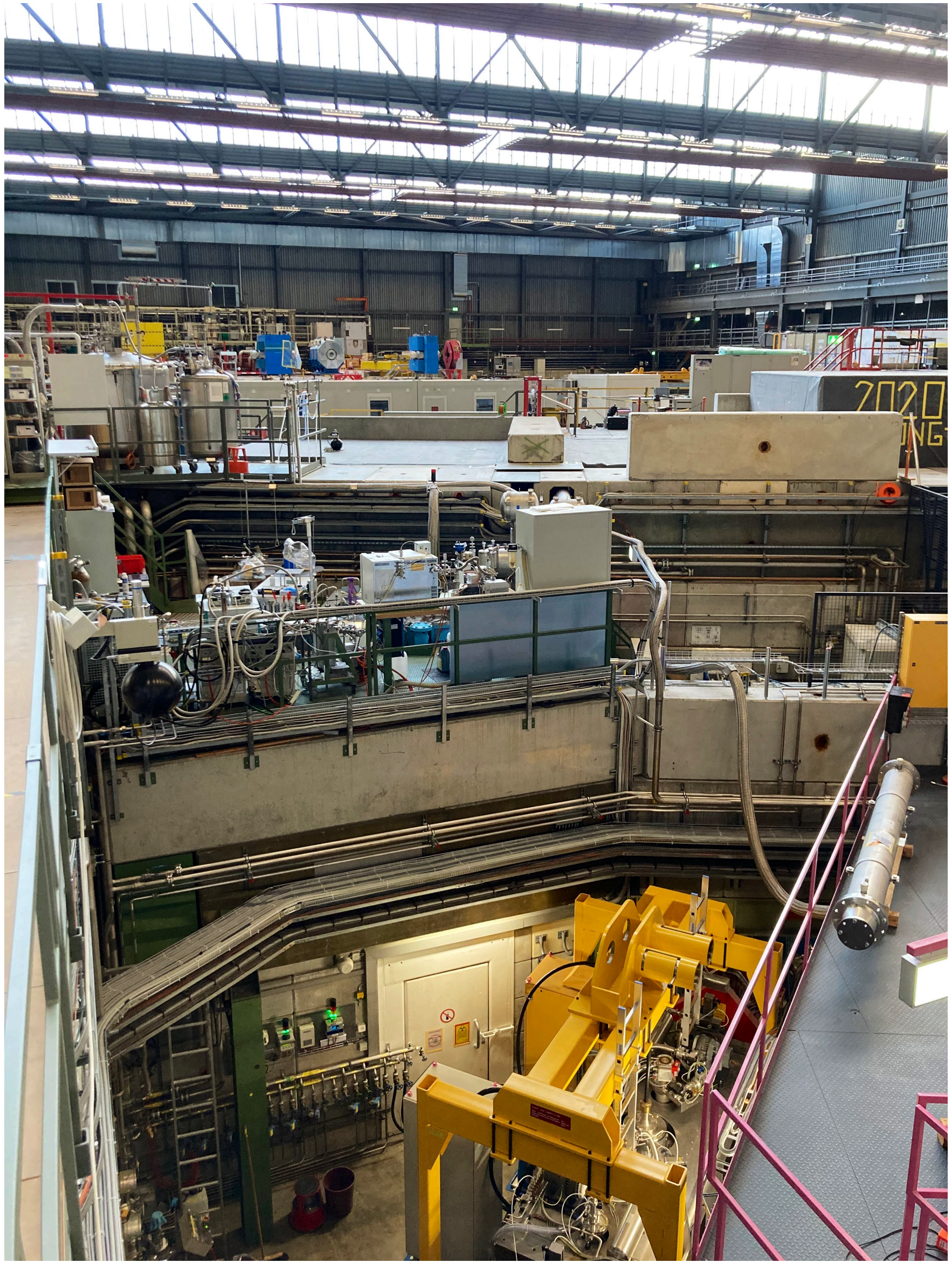




- Both beamlines fully simulated in G4beamline using realistic field maps
- Reach ~10^{10} μ^+/s for MUH2 including double separator with acceptable positron contamination; layout and performance of capture solenoid critical
- Reach 2-3x10^8 μ^+/s for MUH3 in the two experimental areas; limited by spin rotator and quadrupole part of the beamline

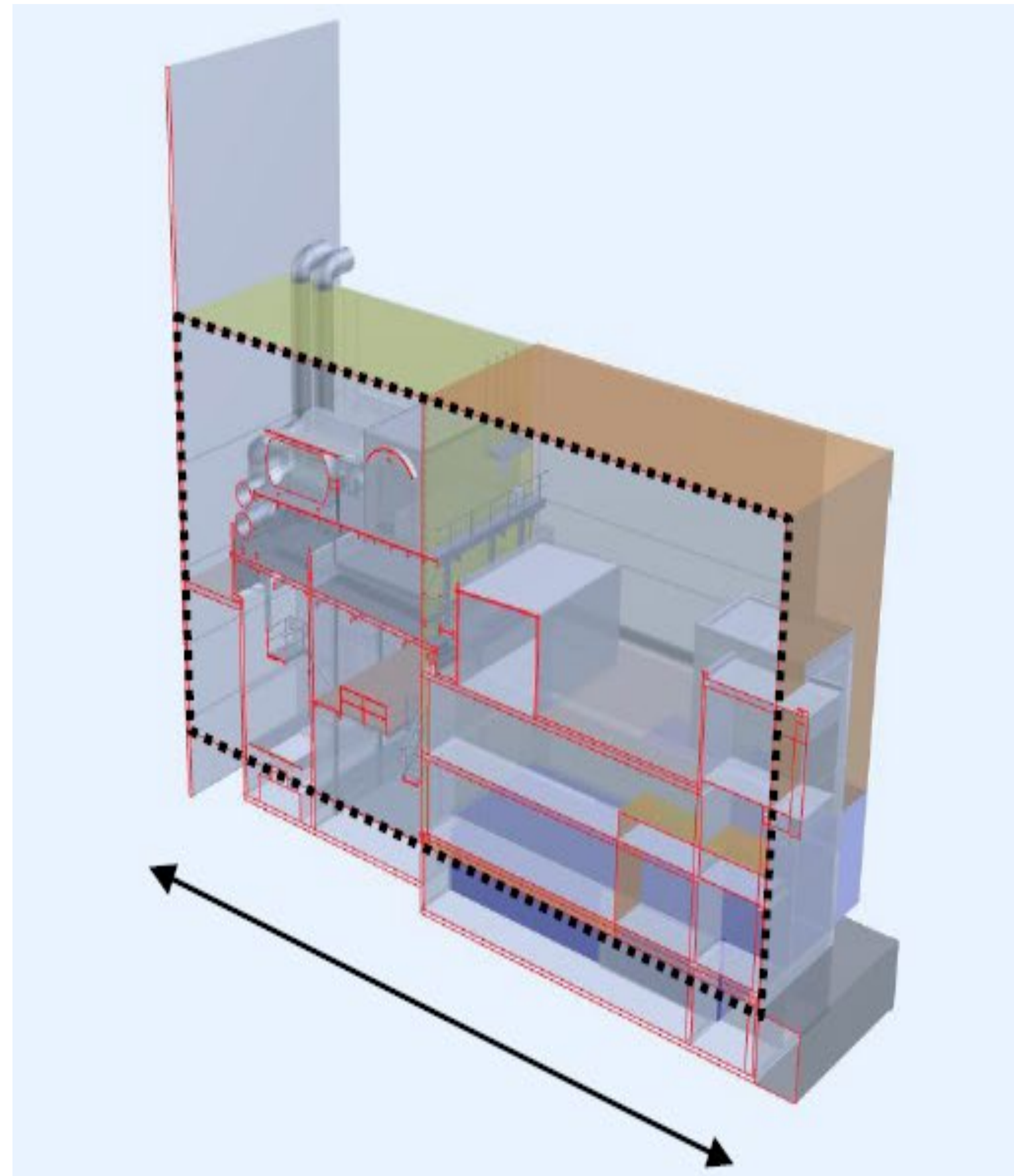
Building a new target station

- Challenging environment around TgM to change layout
- Helium liquefier, tertiary cooling loop 7, lots of pipes, cables and conduits, power supply platforms, …
- And of course in an environment with doses up to several Sv/h



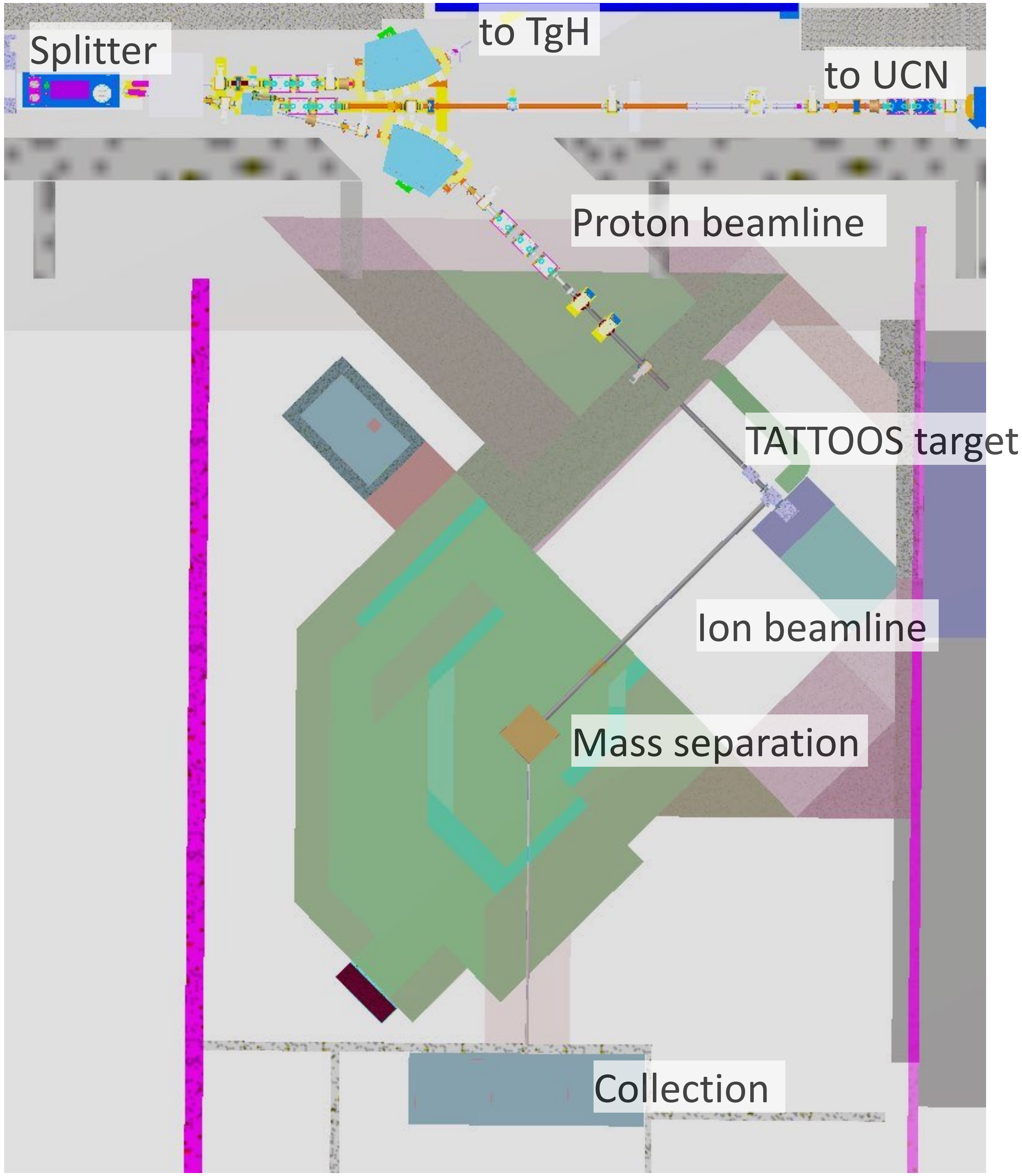
New TATTOOS building

- Next to UCN source; large part of UCN office building will need to be demolished
- A lot of existing infrastructure needs to be moved



TATTOOS beamlines & target

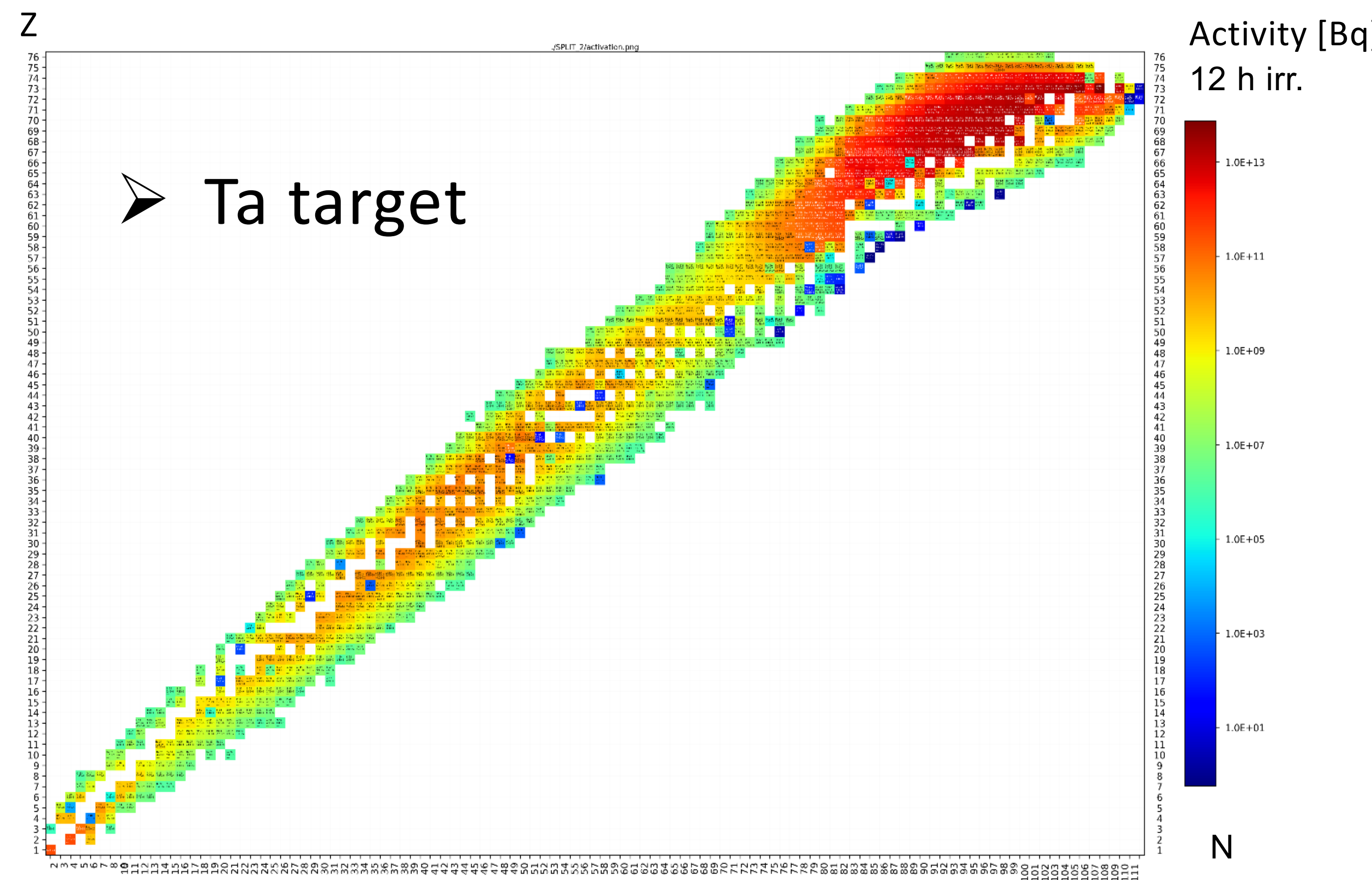
Ring cyclotron



- Use of existing splitter to take out 100 µA from the 590 MeV proton beam
- Kicks to UCN with full intensity
- Wobbler in front of tantalum target to spread power density
- Laser ionisation and further mass separation of extracted isotopes
- Processing of collected isotopes in shielded cells

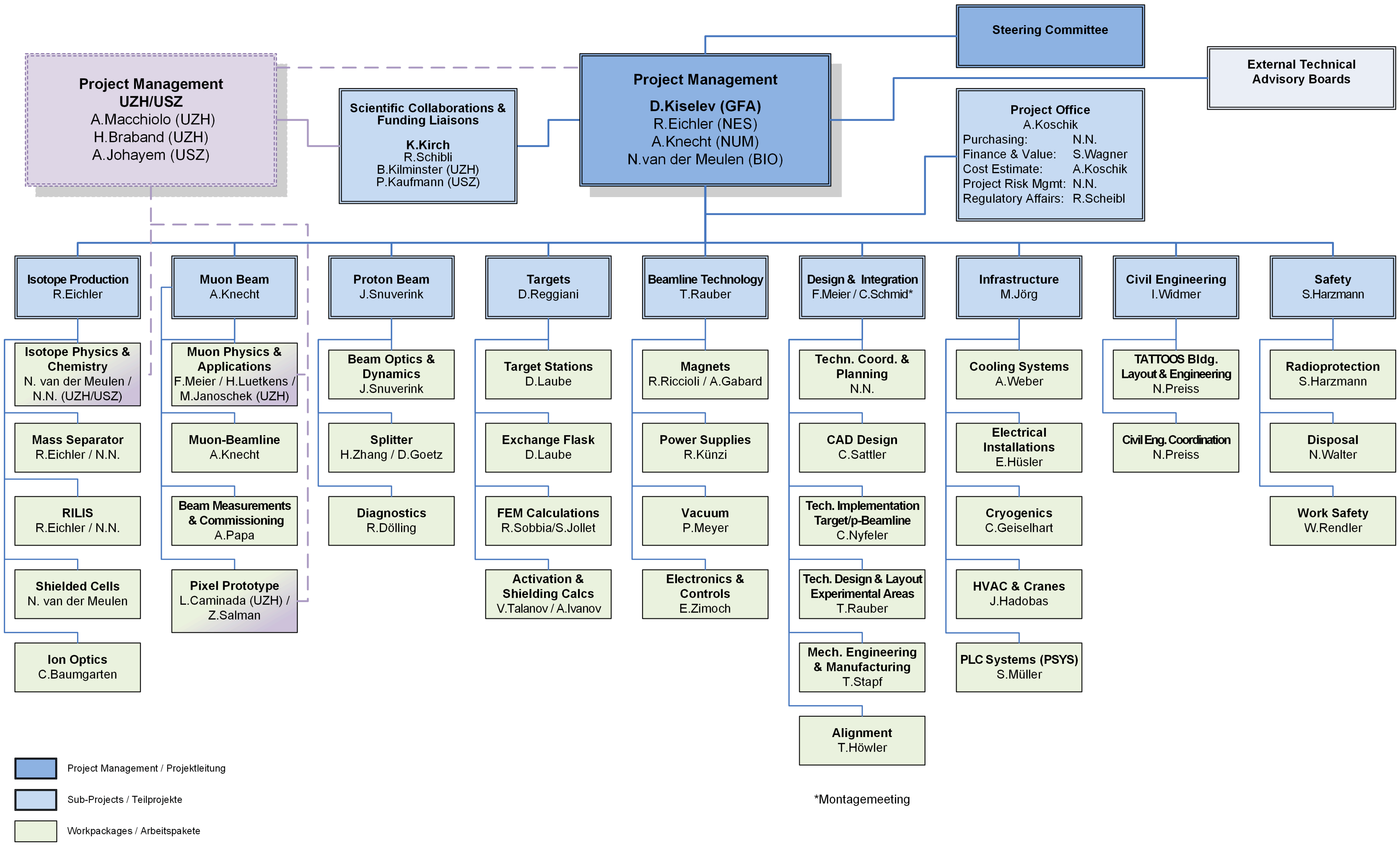
TATTOOS isotope production

- Lots of isotopes produced in spallation from tantalum target
- Uranium carbide target possible at a later stage
- Many opportunities beyond the terbium isotopes



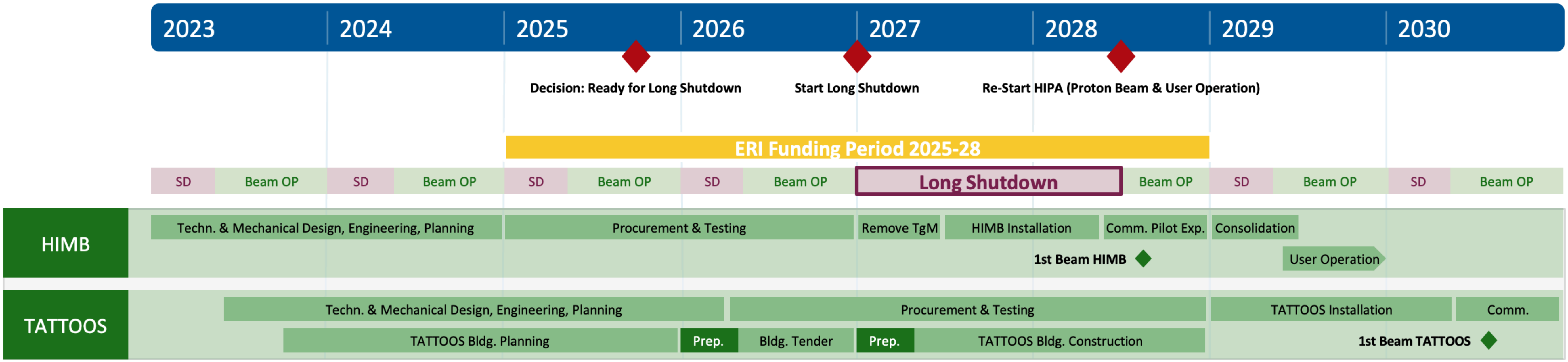
See also: https://www.psi.ch/en/impact/list-of-selected-medically-relevant-radionuclides-produced-at-tattoos

Organisation



- Big commitment by PSI to see IMPACT realised; large number of people working already since a couple of years
- Additional efforts at UZH towards pixel detectors, high-pressure cells and clinical research with radioisotopes

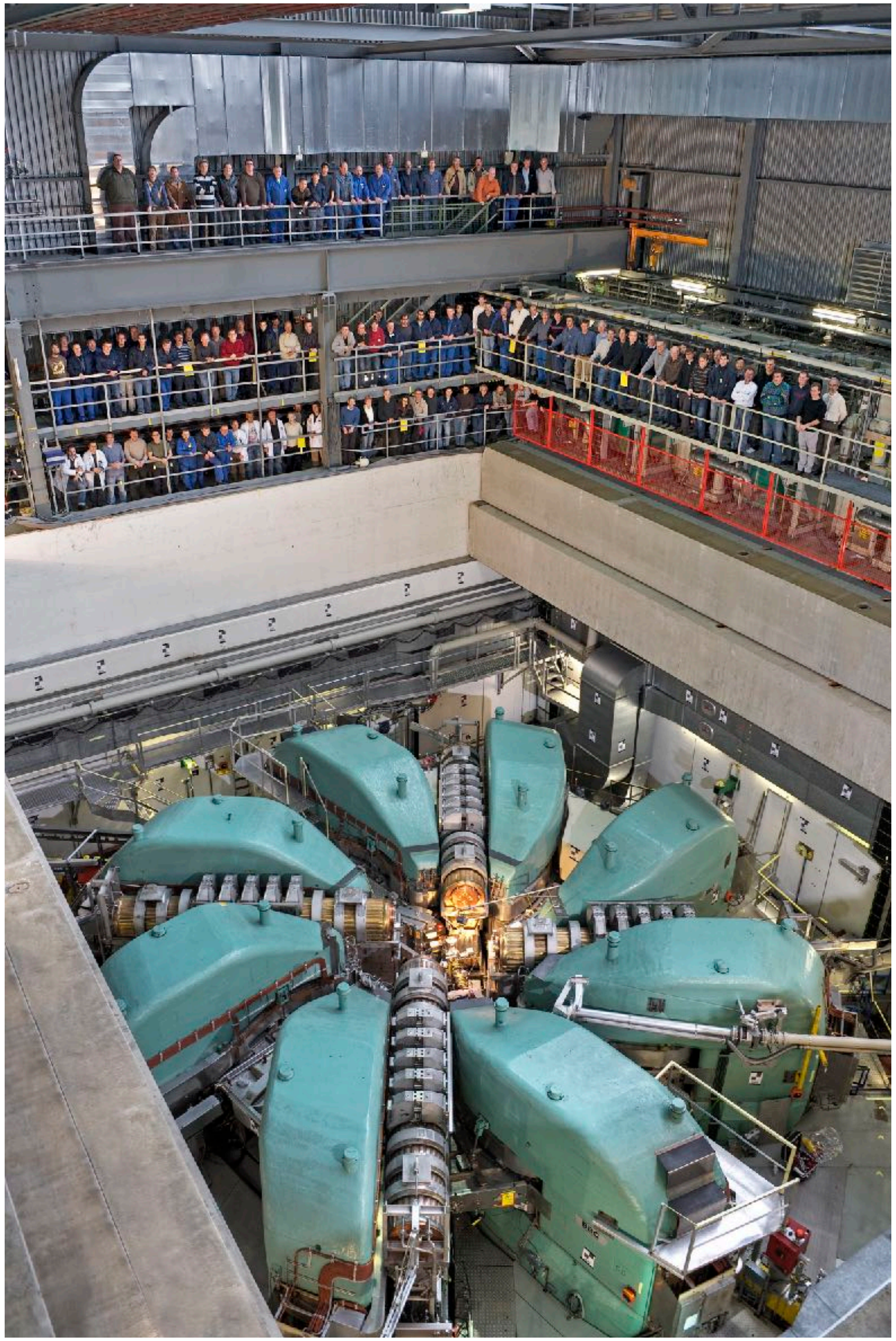
Timeline & next steps



- Scientific review passed with highest ranking in summer 2022
- Decision by ETH council on supporting inclusion into Swiss Roadmap for Research Infrastructures in December 2022
- Final funding decision by Swiss parliament end of 2024
- Long shutdown of ~1.5 years beginning of 2027
- Commissioning and pilot experiments at HIMB starting mid 2028, at TATTOOS mid 2030

Conclusions

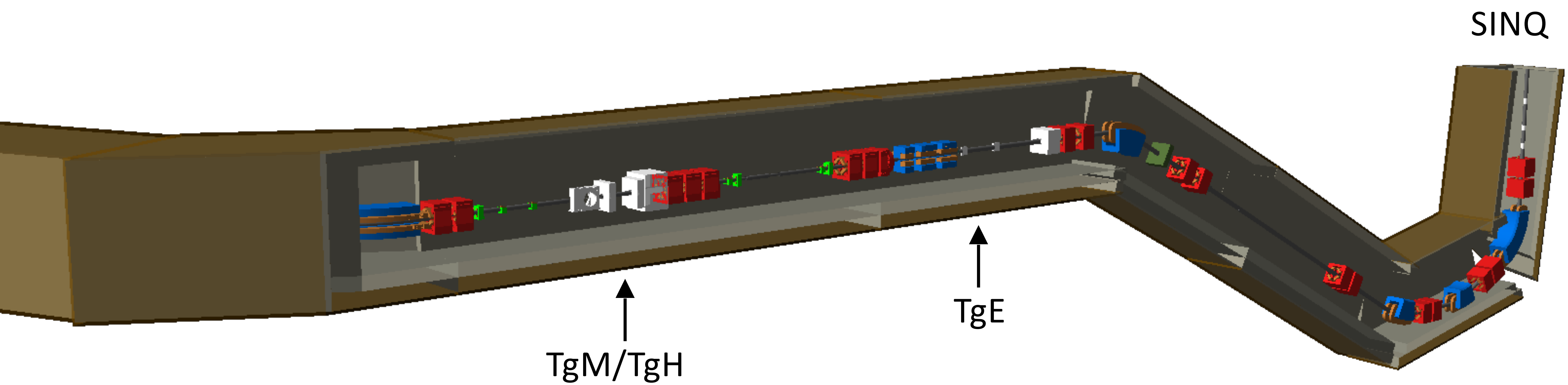
- On track for realising IMPACT at PSI!
- HIMB will enable forefront muon research at PSI for the next 20+ years
- TATTOOS will bring novel radioisotopes into clinical studies and open a whole new research field at PSI



Many thanks to everyone from the IMPACT project for providing slides and input for this presentation!

Backup

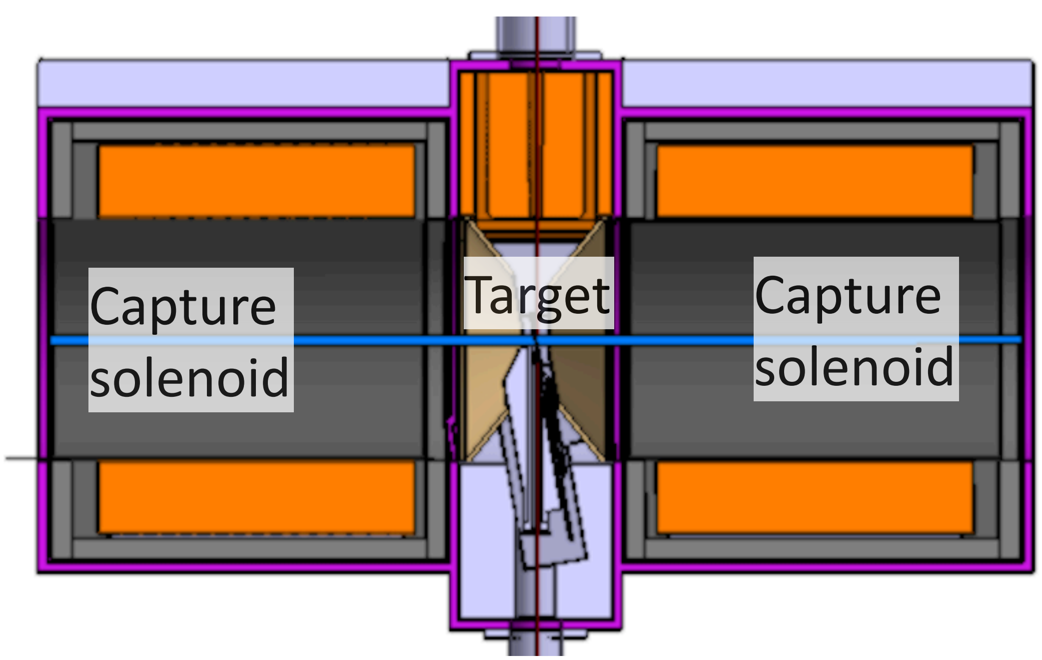
Impact on other facilities of HIPA

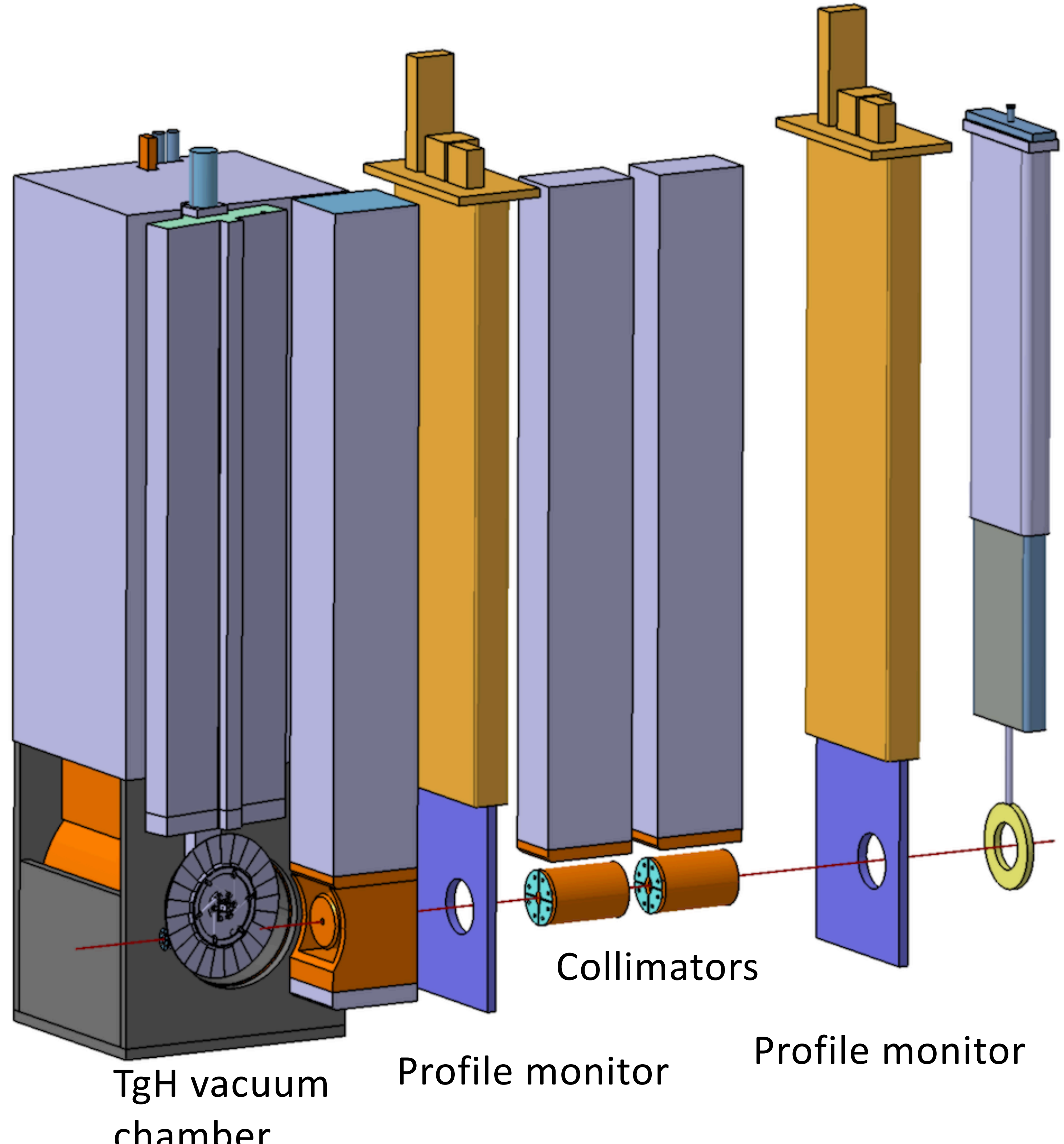


- Full simulation of high-energy proton beam line in BDSIM using either TgM or TgH to assess impact on the other HIPA target stations
- Transmission to SINQ with TgH 67% compared to 69% with TgM
- Can increase transmission back up to 69% when collimators after TgE are optimised
- Beam shape at TgE and SINQ preserved

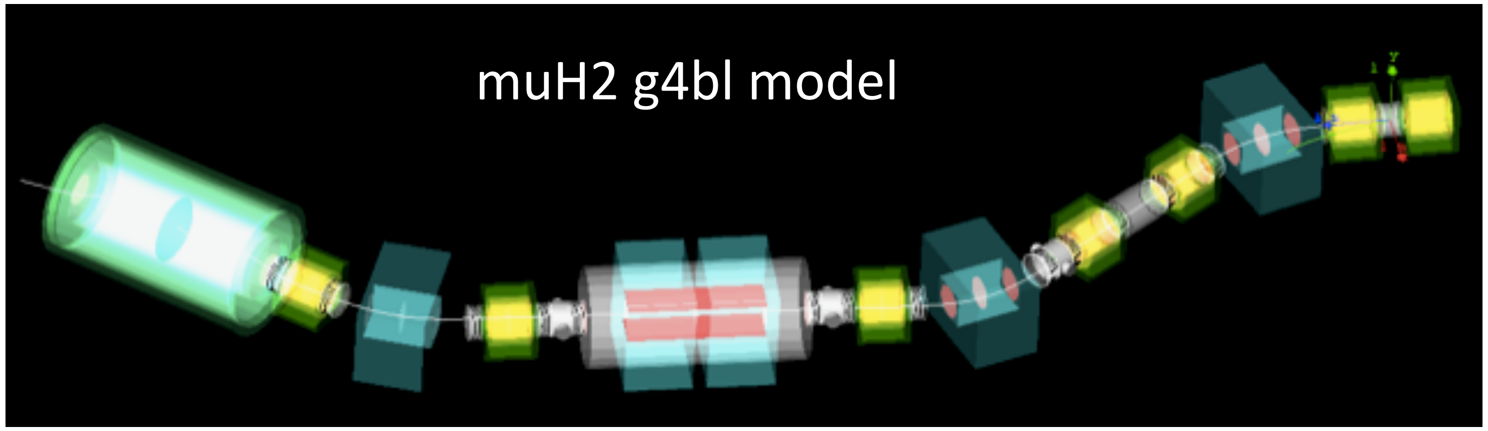
Concept for new target station TgH

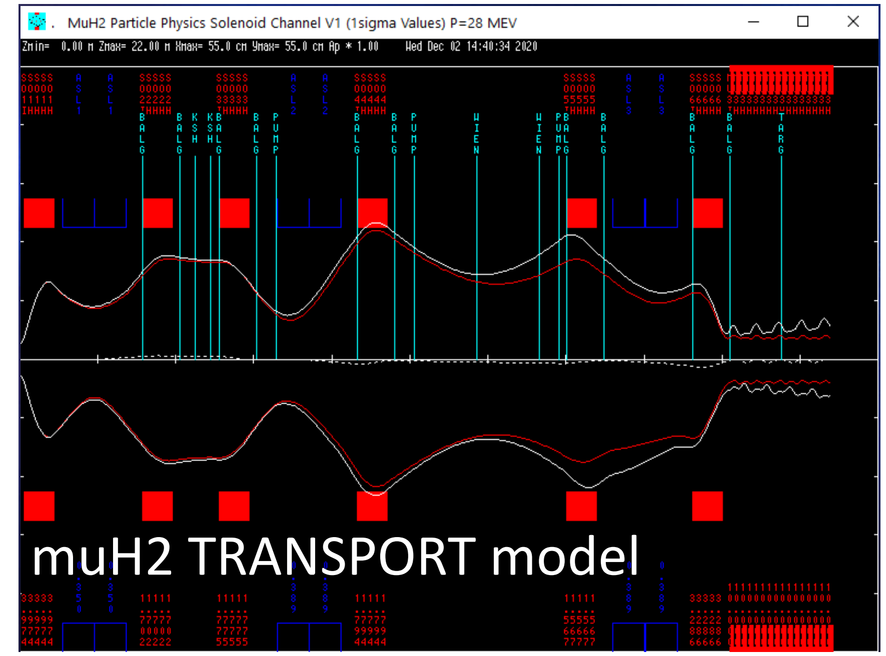
- Concept similar to existing TgE
- In order to have capture elements for muons as close as possible, they are integrated into the target vacuum chamber
- Separate exchange flask for capture solenoids

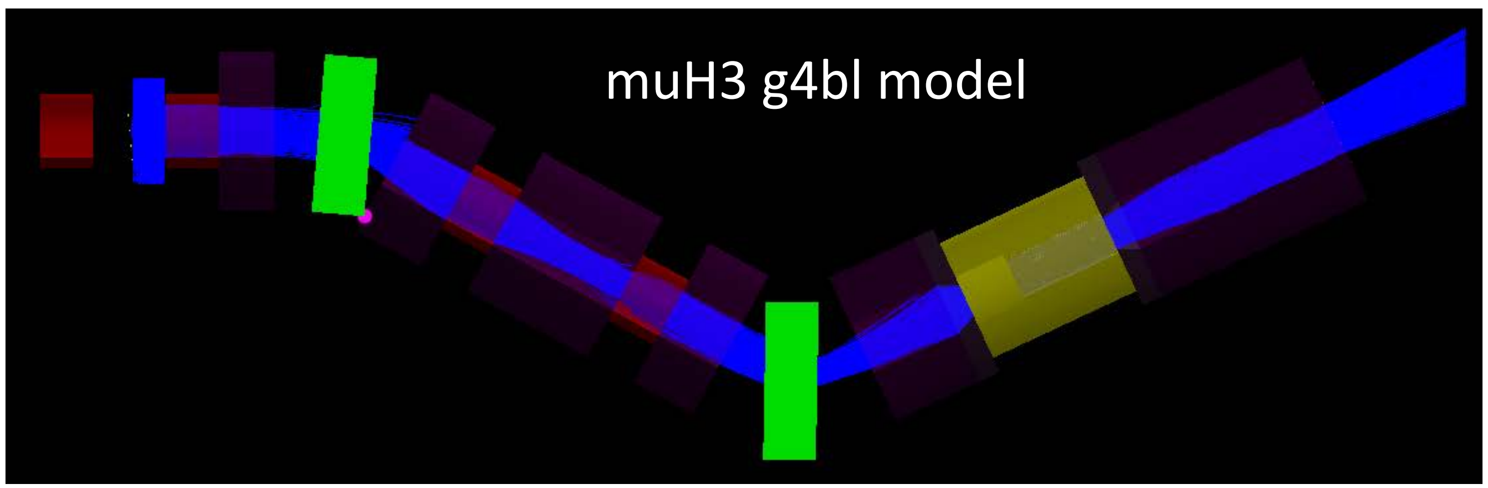




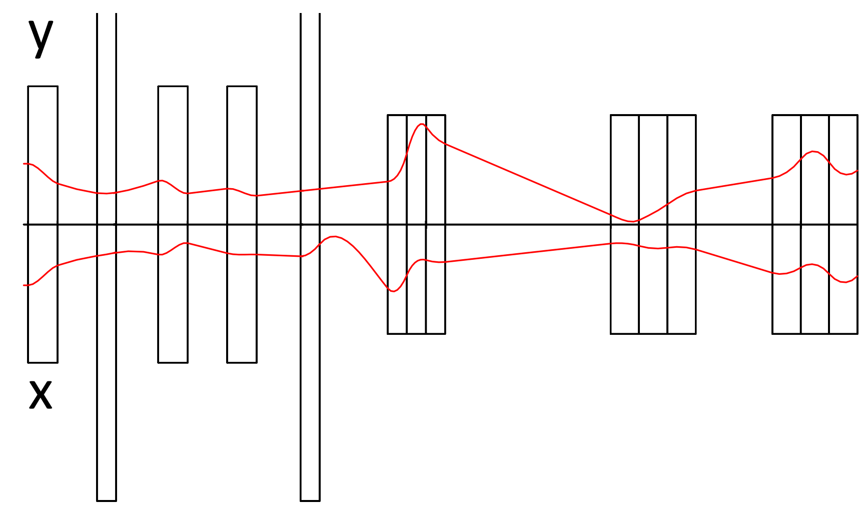
Simulation of beamlines





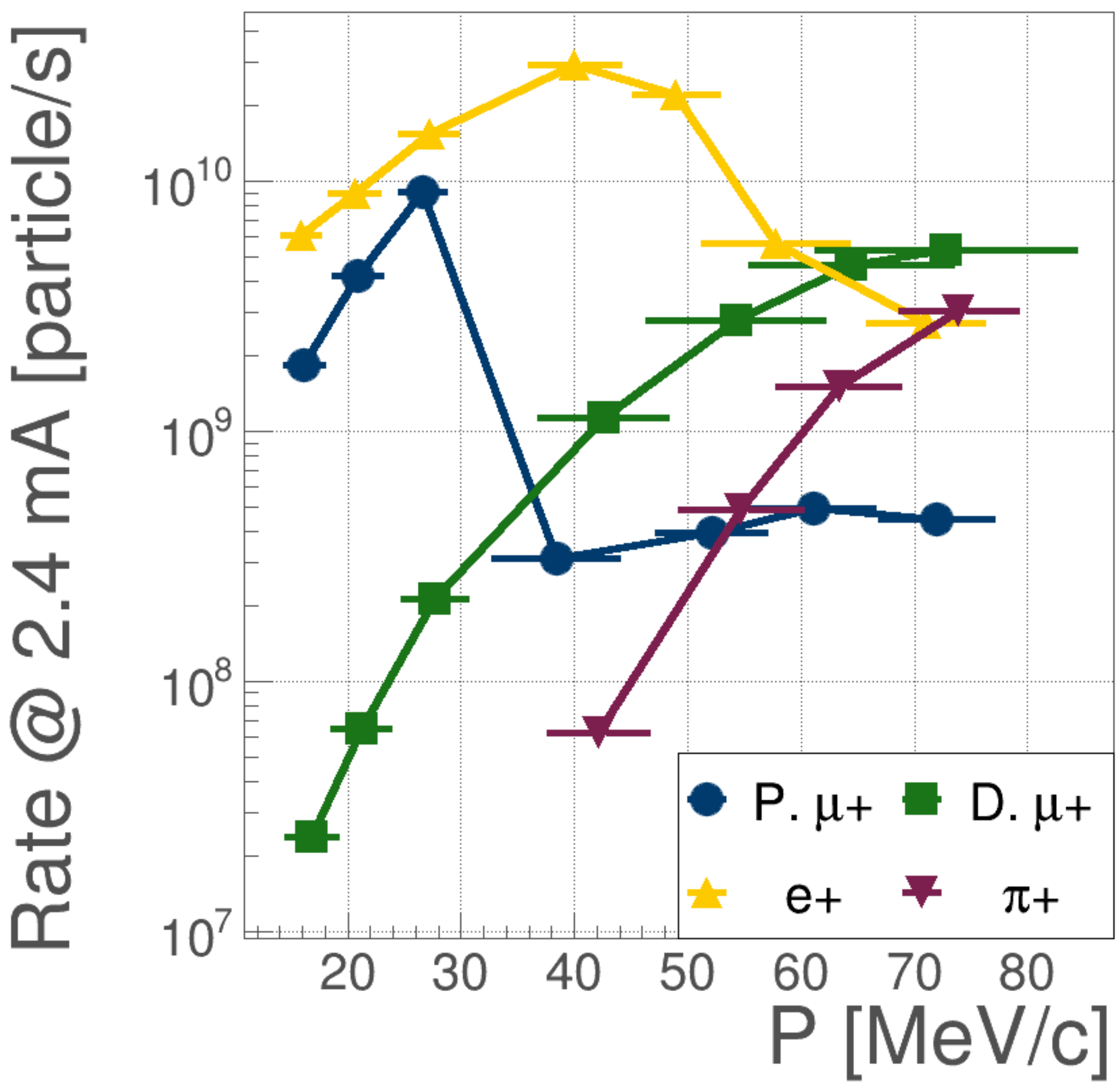


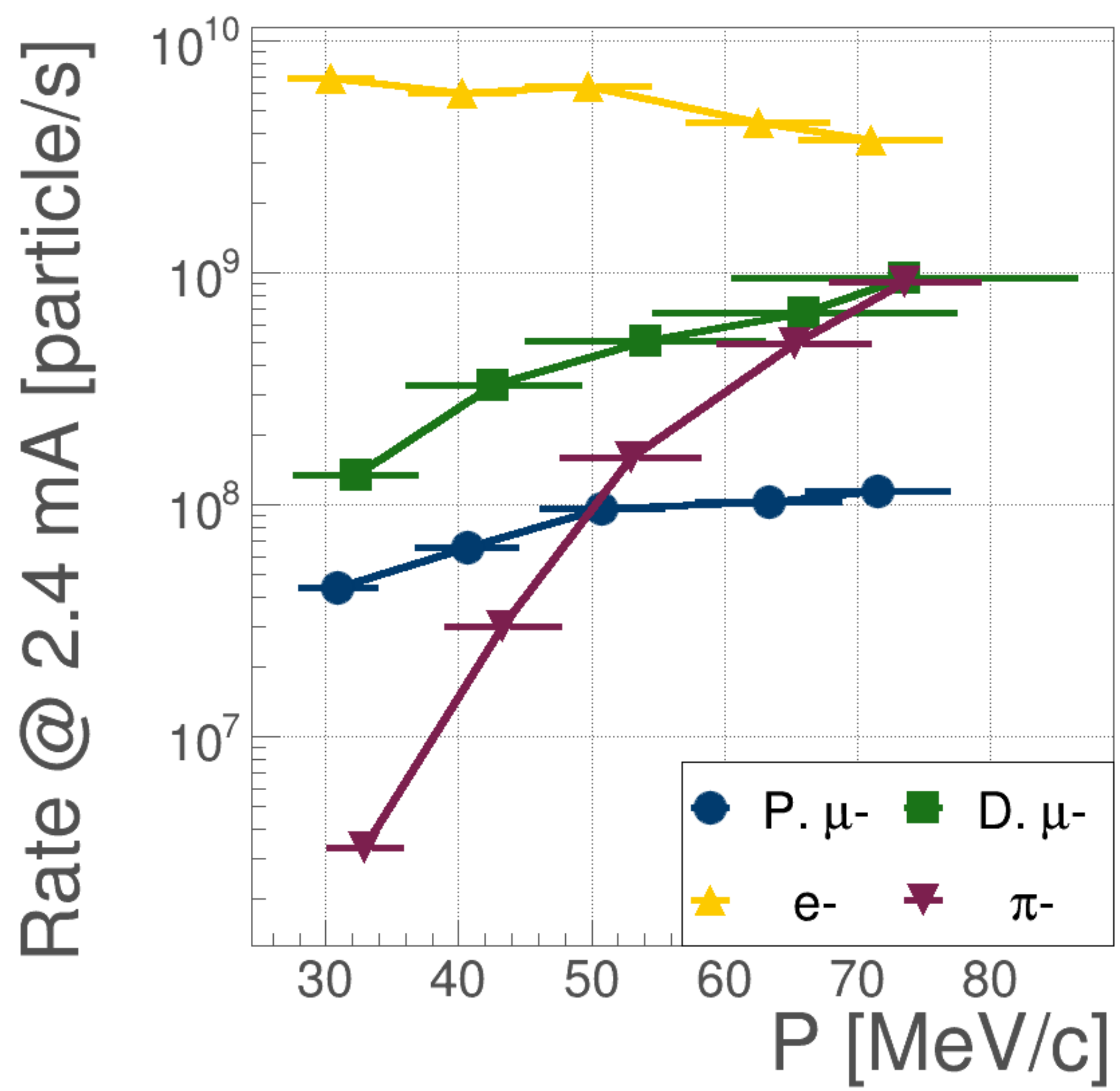
muH3 COSY INFINITY model



- Simulation tools: g4bl, TRANSPORT, TURTLE, COSY INFINITY
- Optimisation tools: grid searches, hyperparameter searches, genetic algorithms

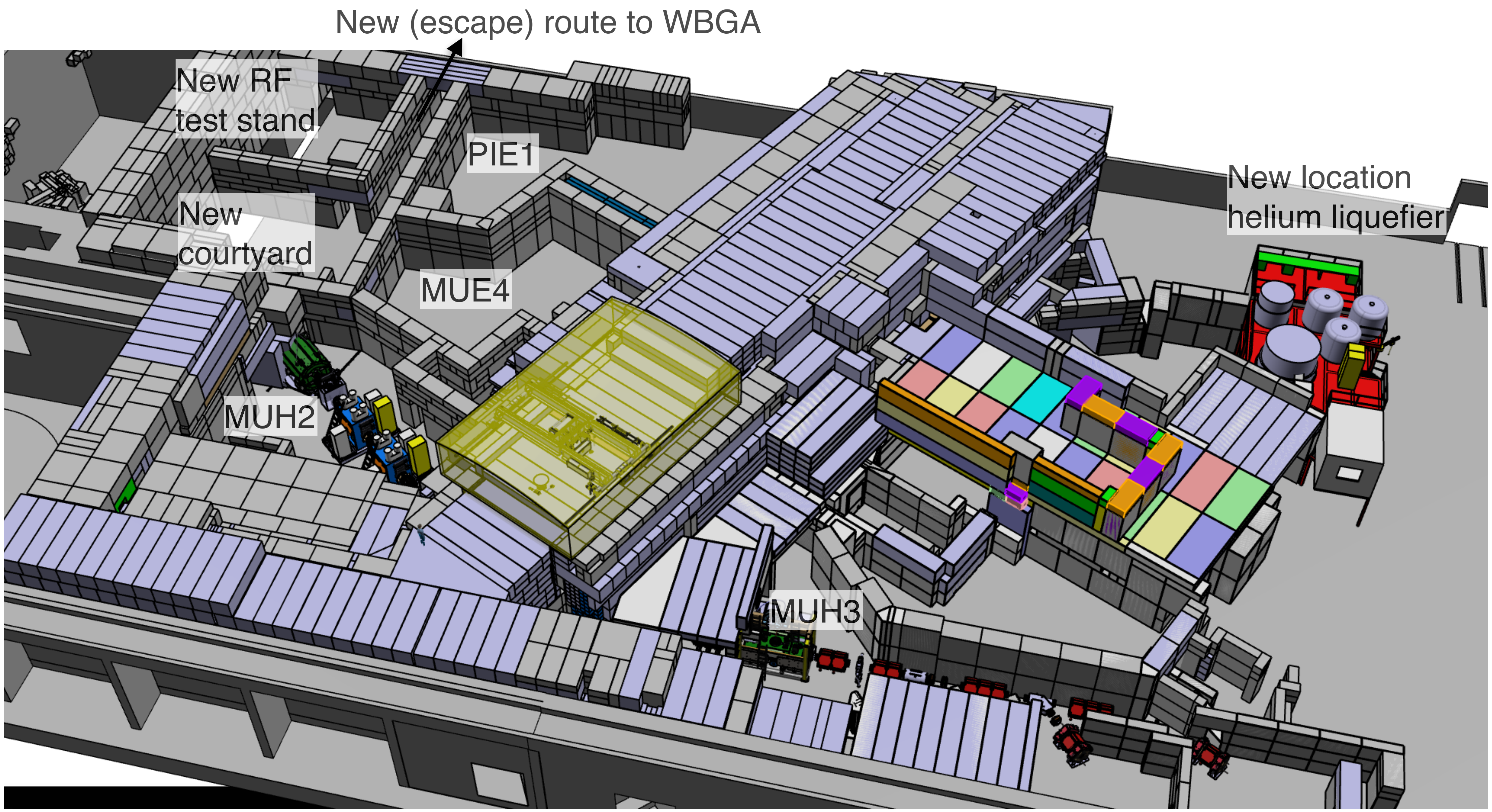
Other particle estimates





- Simulated rates for all particles as a function of momentum at the end of the MUH2 beamline

3d Model of Full WEHA

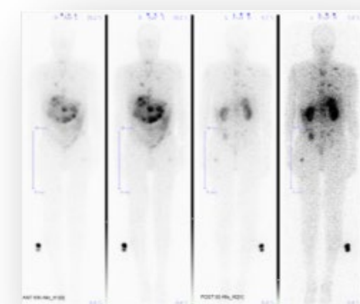


- Full 3d model of WEHA available
- Cleaning up legacy installations, complying with modern safety regulations and improving general operations in WEHA

Achievements To Date With Tb Radioisotopes

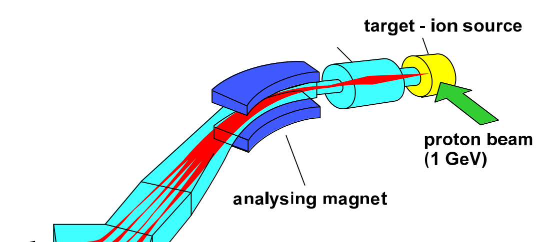
RADIONUCLIDE DEVELOPMENT

^{161}Tb



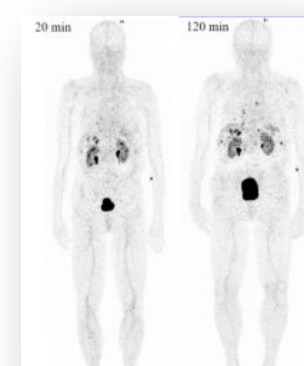
β-Therapy

Baum et al., J. Nucl. Med. (2021)



ISOL (CERN)

^{152}Tb



PET imaging

Baum et al., Dalton Trans (2017)
Müller et al., EJNMMI Res (2019)

Targetry | Irradiation Facility | **First-in-human Application**