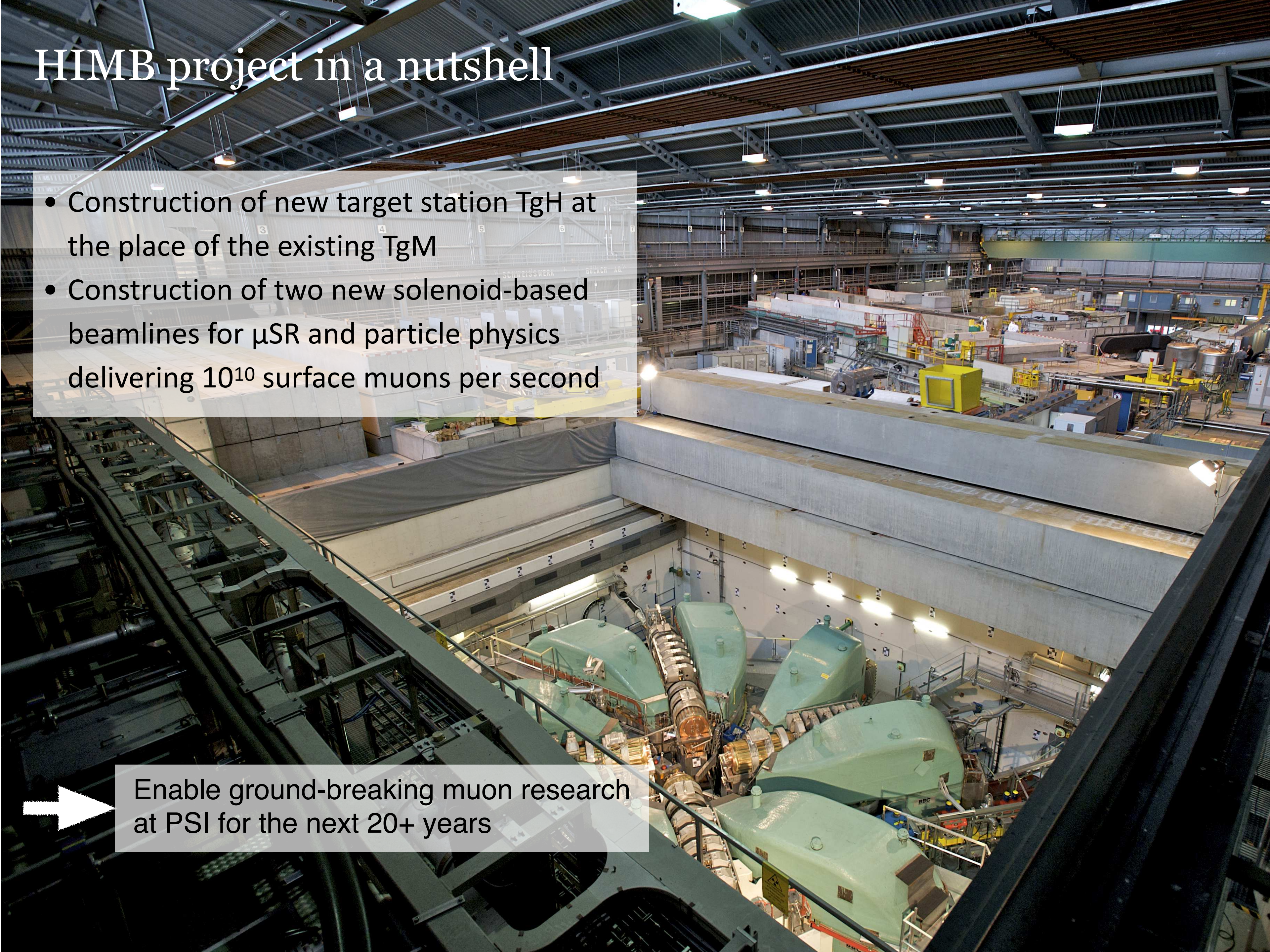

Andreas Knecht  for the IMPACT project

# HIMB: A new target station at HIPA for particle physics and materials science

IMPACT Informationsveranstaltung, 31. 1. 2023

# HIMB project in a nutshell



- 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

# 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

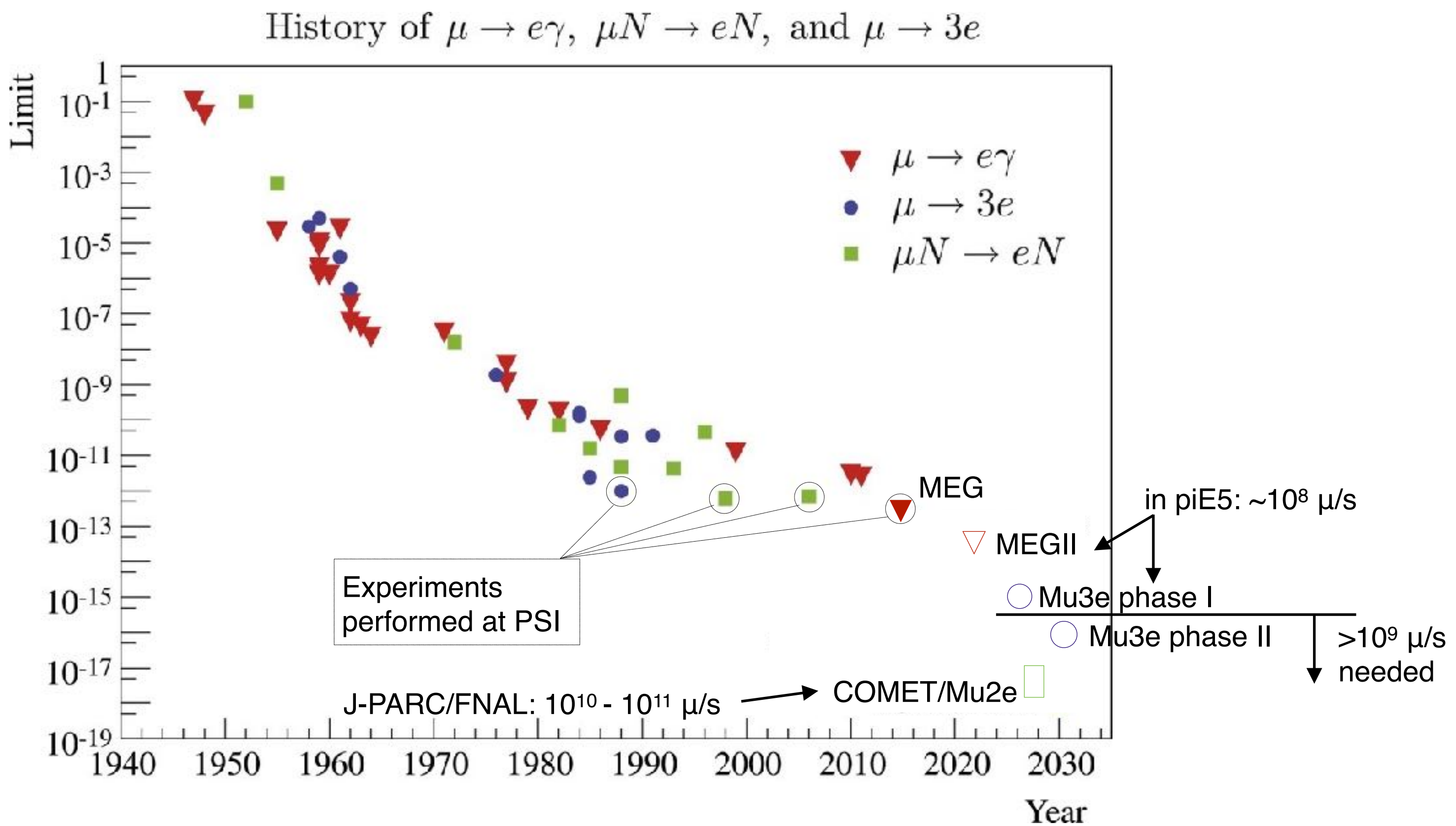
**Science Case for the new High-Intensity Muon Beams HIMB at PSI**

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

M. Aiba[1], A. Amato[1], A. Antognini[1,2], S. Ban[3], N. Berger[4], L. Caminada[1,5], R. Chislett[6], P. Crivelli[2], A. Crivellin[1,5], G. Dal Maso[1,2], S. Davidson[7], M. Hoferichter[8], R. Iwai[2], T. Iwamoto[3], K. Kirch[1,2], A. Knecht[1], U. Langenegger[1], A. M. Lombardi[9], H. Luetkens[1], F. Meier Aeschbacher[1], T. Mori[3], J. Nuber[1,2], W. Ootani[3], A. Papa[1,10], T. Prokscha[1], F. Renga[11], S. Ritt[1], M. Sakurai[2], Z. Salman[1], P. Schmidt-Wellenburg[1], A. Schöning[12], A. Signer[1,5,*], A. Soter[2], L. Stingelin[1], Y. Uchiyama[3], and F. Wauters[4]

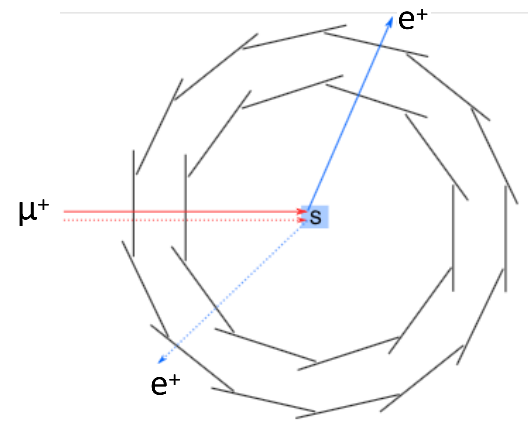
[1]Paul Scherrer Institut, 5232 Villigen PSI, Switzerland
[2]Institute for Particle Physics and Astrophysics, ETH Zurich, 8093 Zürich, Switzerland
[3]ICEPP, The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo, 113-0033, Japan
[4]Institute for Nuclear Physics and PRISMA$^+$ Cluster of Excellence, Johannes Gutenberg University Mainz, Germany
[5]Physik-Institut, Universität Zürich, 8057 Zürich, Switzerland
[6]Department of Physics and Astronomy, University College London, WC1E 6BT, United Kingdom
[7]LUPM, Université de Montpellier, Place Eugène Bataillon, 34095 Montpellier, France
[8]Albert Einstein Center for Fundamental Physics, Institute for Theoretical Physics, University of Bern, Sidlerstrasse 5, 3012 Bern, Switzerland
[9]CERN, 1211 Geneva 23, Switzerland
[10]Dipartimento di Fisica E. Fermi & INFN Sezione di Pisa, Largo Bruno Pontecorvo, Edificio C, 208, 56127 Pisa, Italy
[11]INFN Sezione di Roma, Piazzale A. Moro 2, 00185 Roma, Italy
[12]Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany
[*]Corresponding author: adrian.signer@psi.ch

# Rare muon decay searches

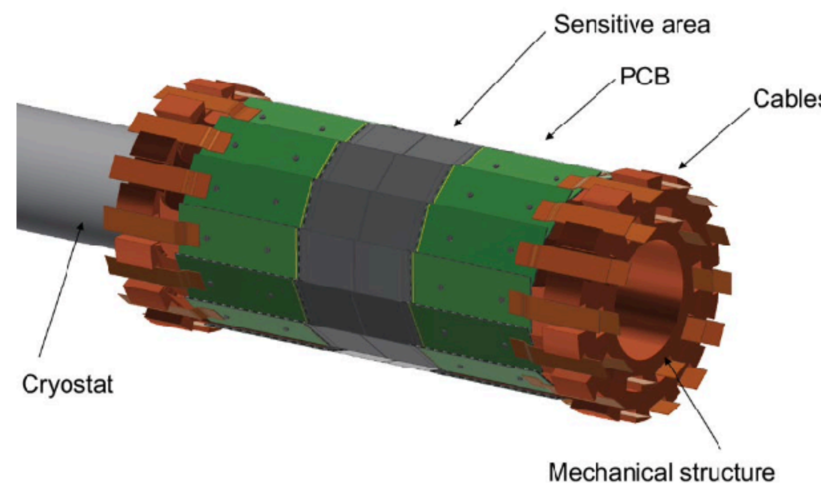


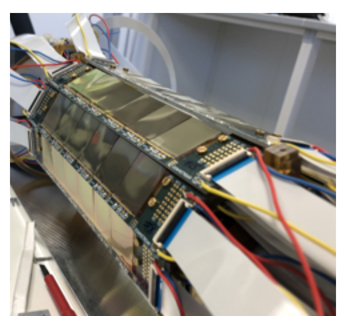

- Neutrinoless muon decays one of the most sensitive probes for new physics
- $\mu^+ \to e^+\gamma$ & $\mu^+ \to e^+e^-e^+$ only possible at DC & intensity-frontier machine such as PSI's HIPA accelerator
- Any future cLFV search at PSI will need higher beam intensities

# Muon spin rotation

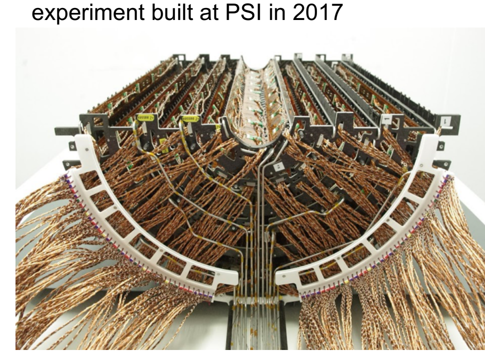



- Vertexing for μSR applications:
  - Pixel detector development together with particle physics
  - Enables 10-100x faster measurements.
  - Unprecedented small samples, 10-100x smaller (“μ-microscope”).
  - Allows putting samples in extreme conditions at unprecedented levels, e.g. 10x pressure

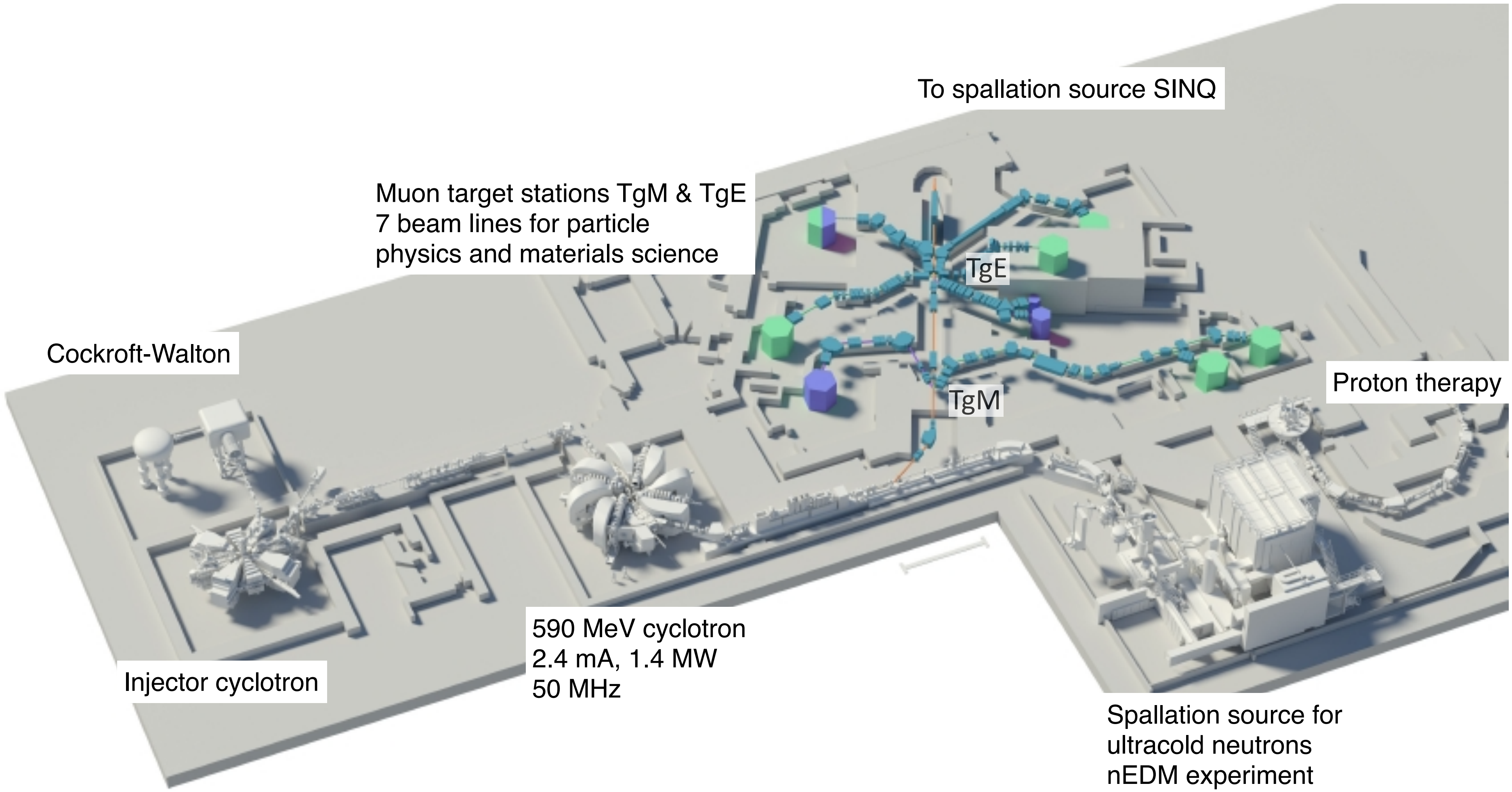




Mu3e pixel detector 2021

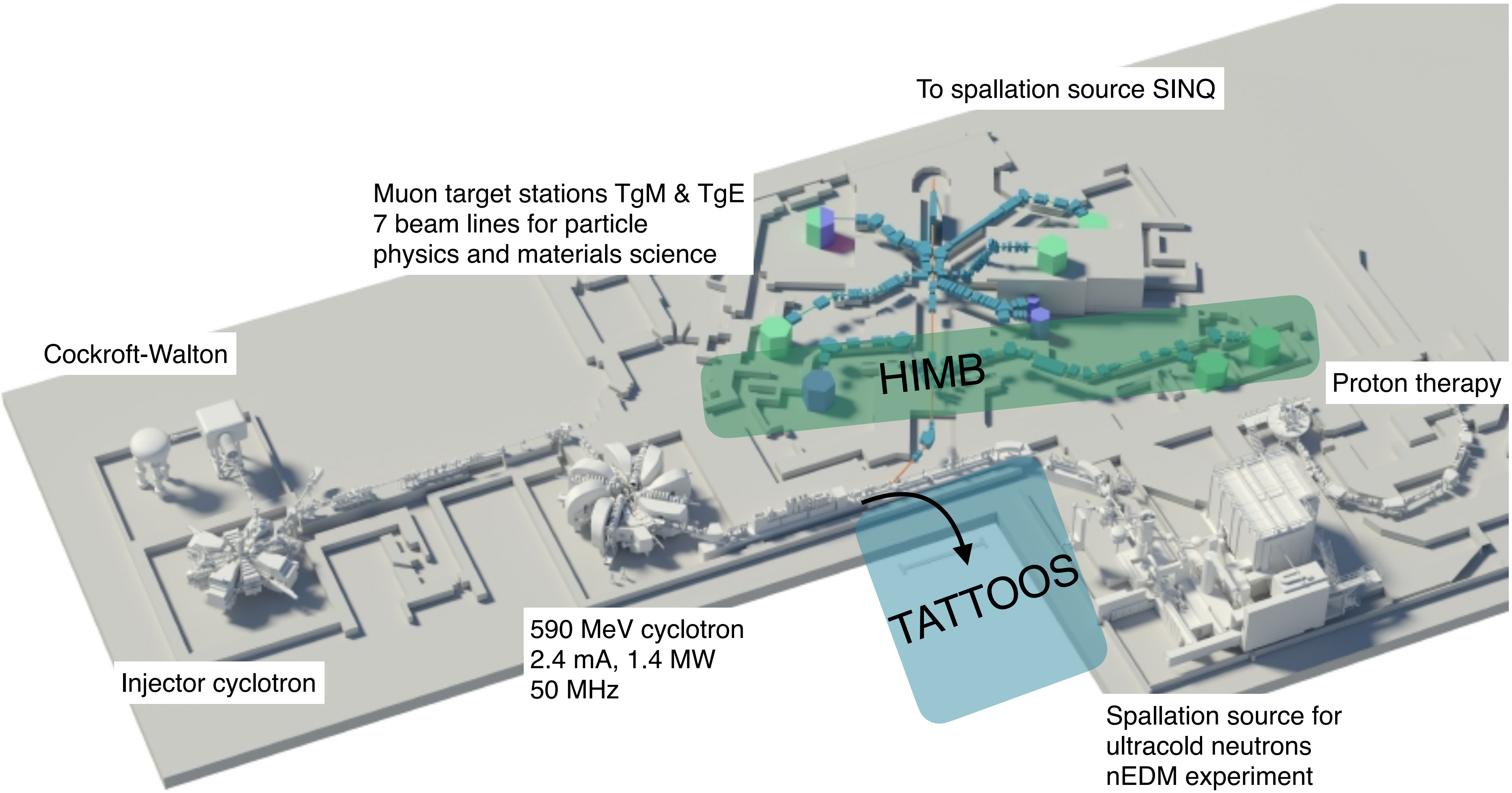
Half of the pixel detector of the CMS experiment built at PSI in 2017



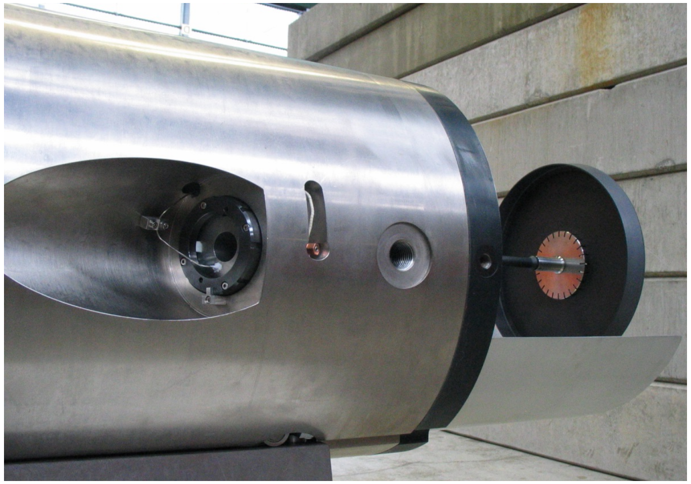
# PSI Proton Accelerator HIPA



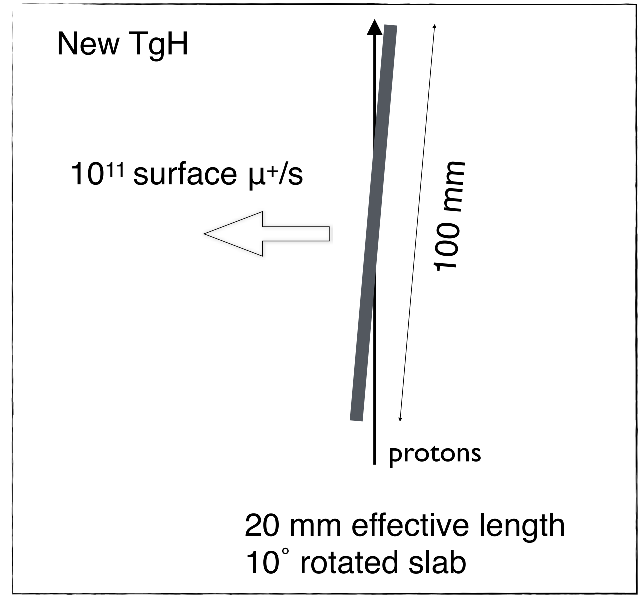
# PSI Proton Accelerator HIPA



# Target Geometry for new TgH



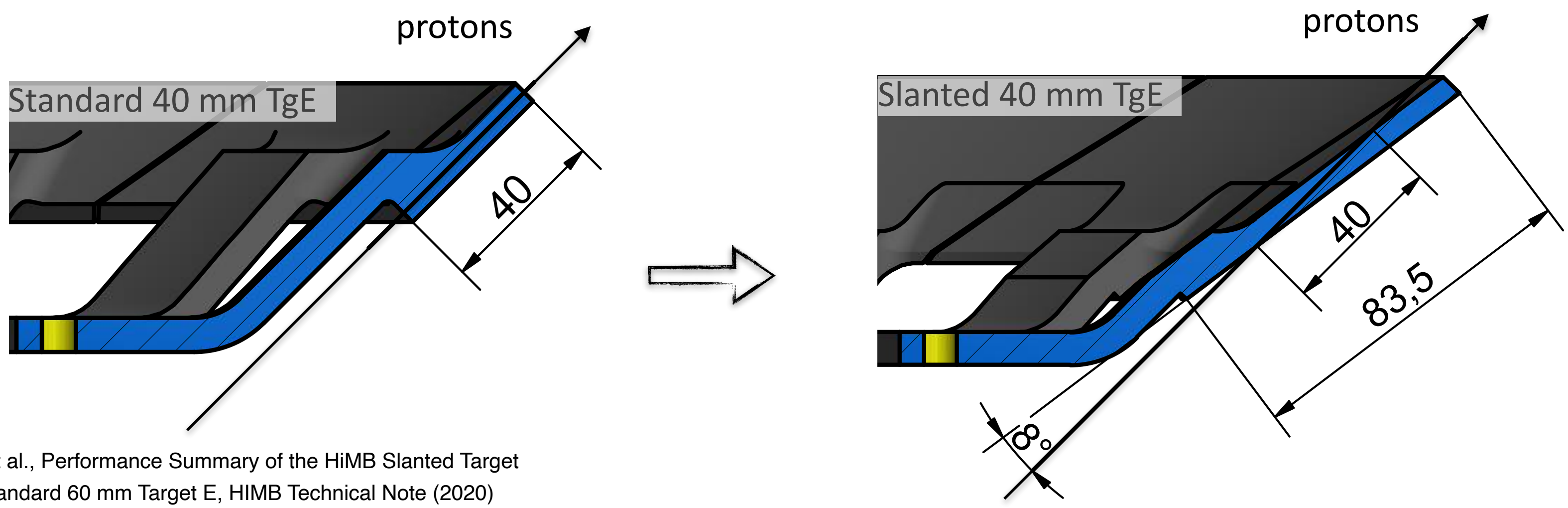
Existing TgM




- 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

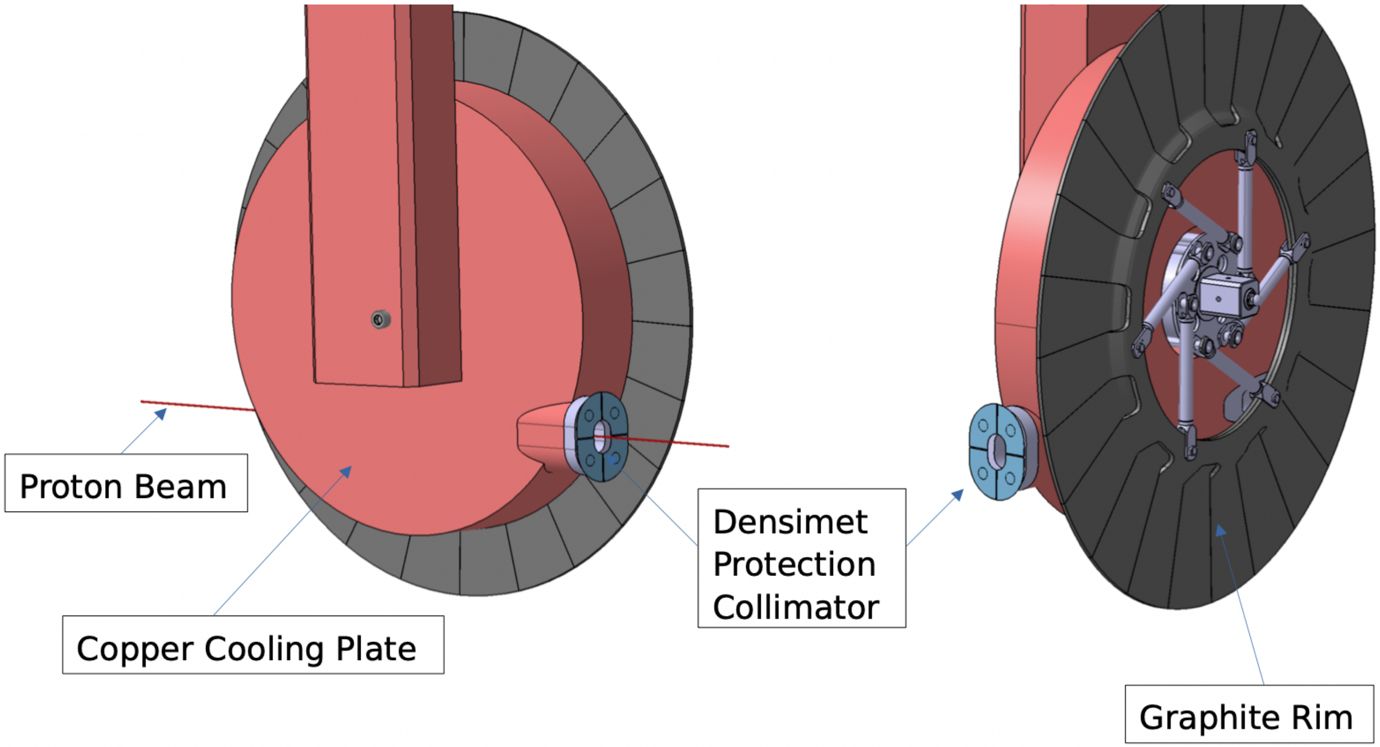
# First HIMB development at HIPA: Slanted TgE

- 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



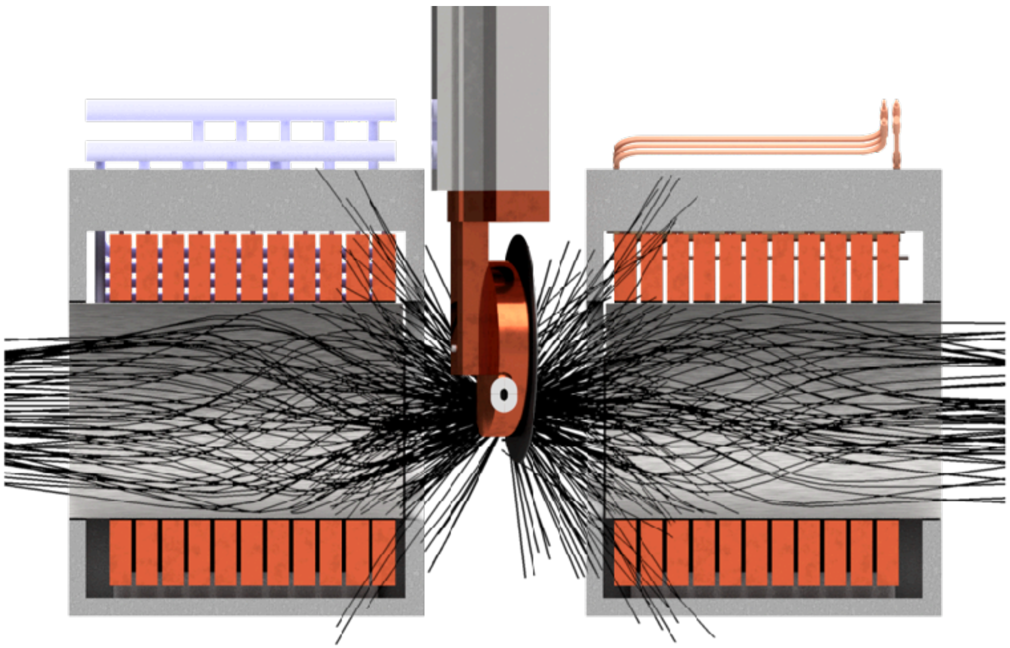

P.-R. Kettle et al., Performance Summary of the HiMB Slanted Target versus the Standard 60 mm Target E, HIMB Technical Note (2020)

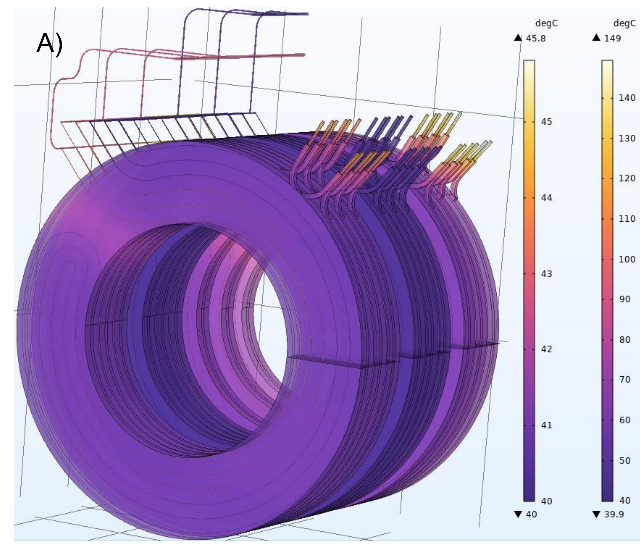
# New Target H




- Target design based on experience from TgM & TgE
- Same exchange concept as for TgE

# Split Capture Solenoids for Muon Collection

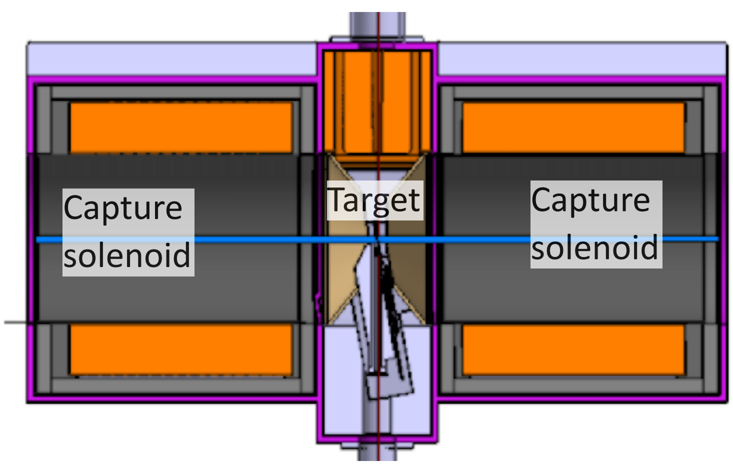


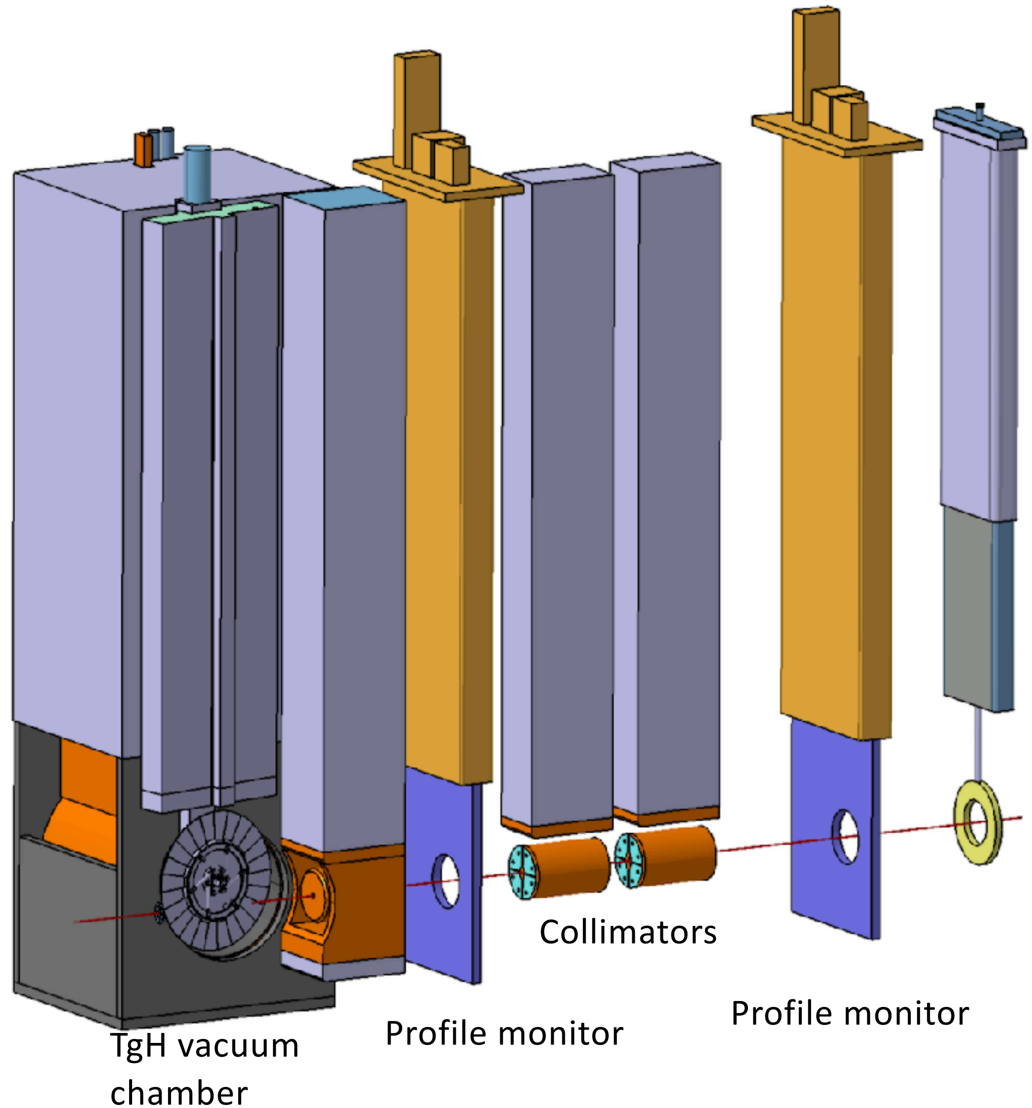



- Two normal-conducting, radiation-hard solenoids 250 mm away from target to capture surface muons
- Central field of solenoids up to 0.45 T
- Graded-field capture solenoid for improved muon collection: stronger field at capture side, weaker at exit

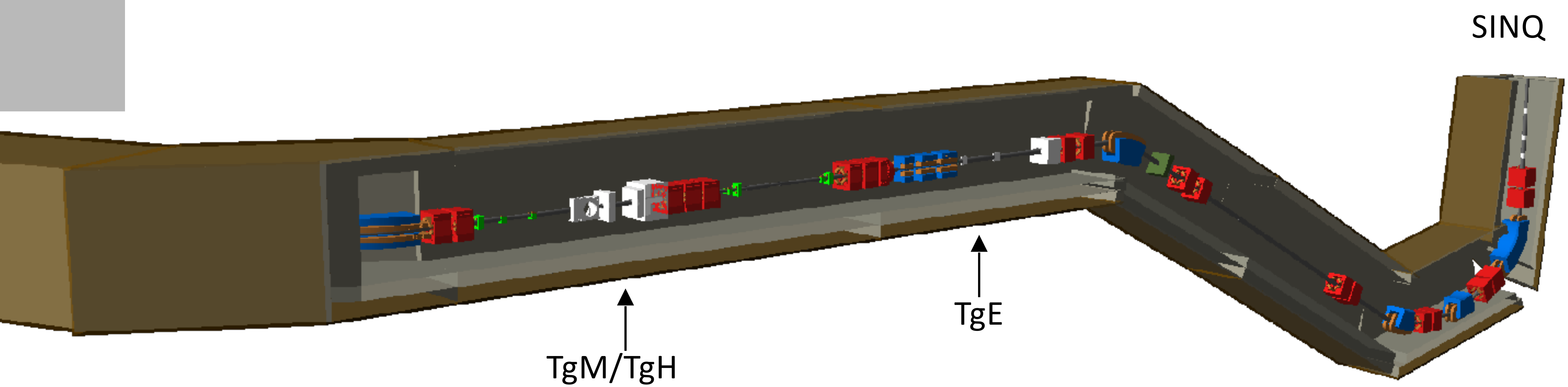
# Concept for new target station TgH

- 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



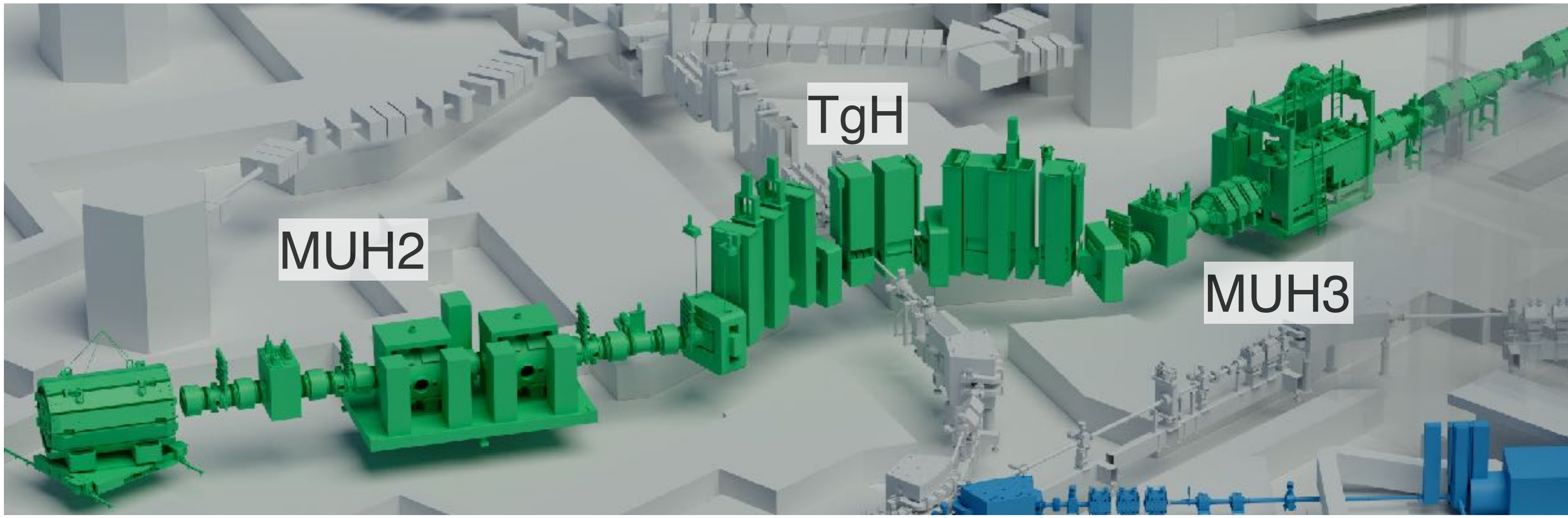



# Impact on other facilities of HIPA



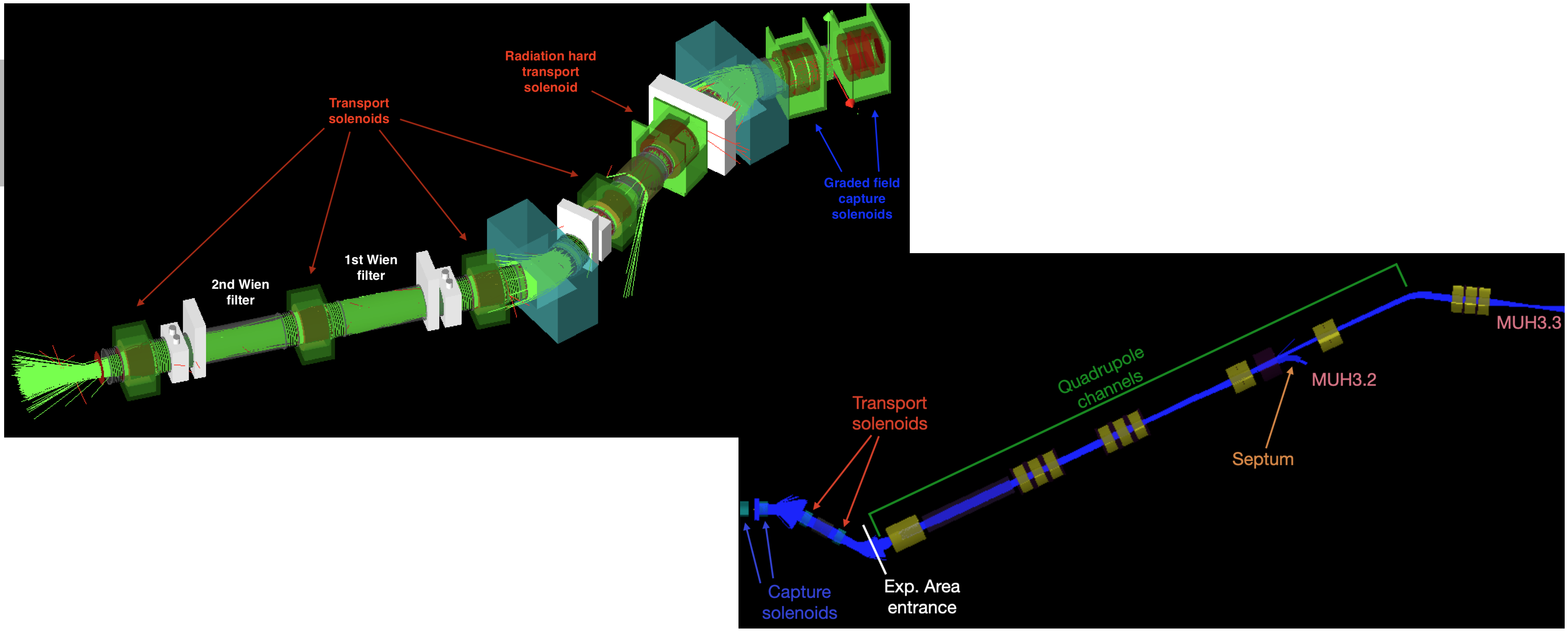

- Full simulation of high-energy proton beam line in BDSIM using either TgM or TgH to assess impact on the other HIPA target stations
- Transmission to SINQ with TgH 67% compared to 69% with TgM
- Can increase transmission back up to 69% when collimators after TgE are optimised
- Beam shape at TgE and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

# 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

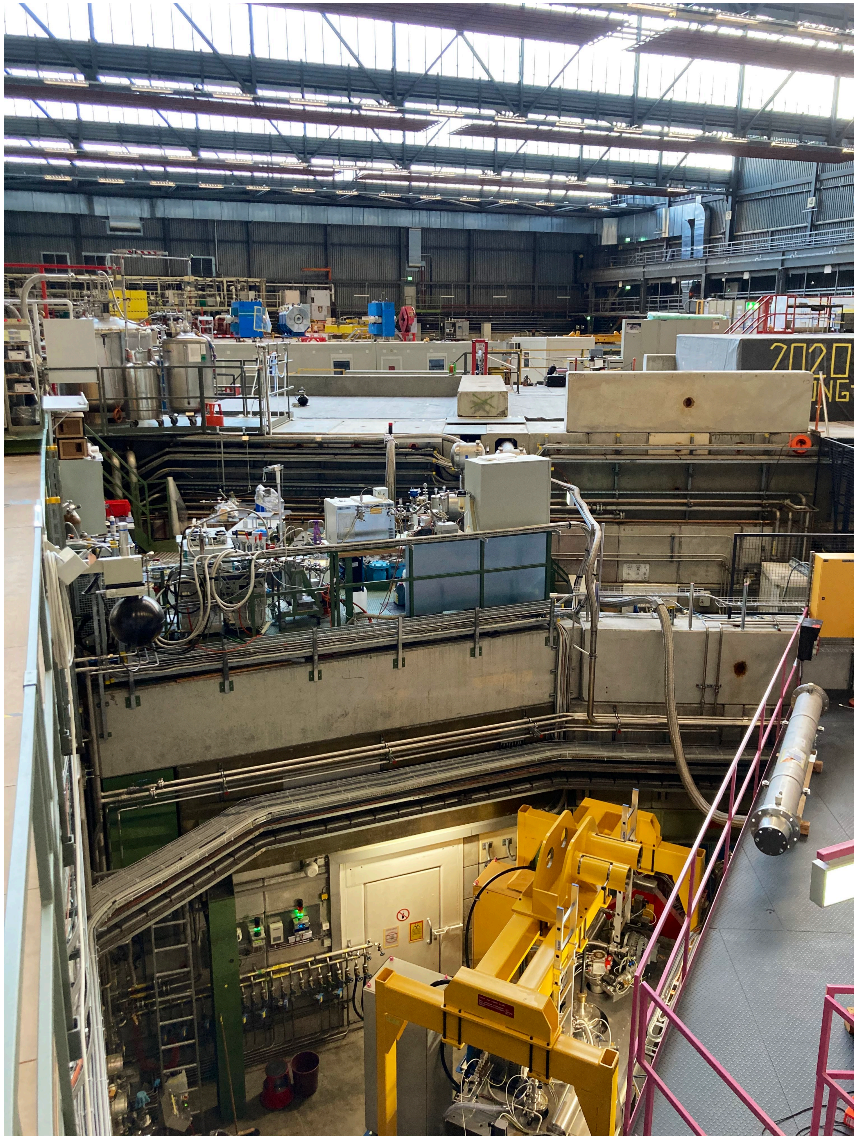
# MUH2/MUH3 Beamlines




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

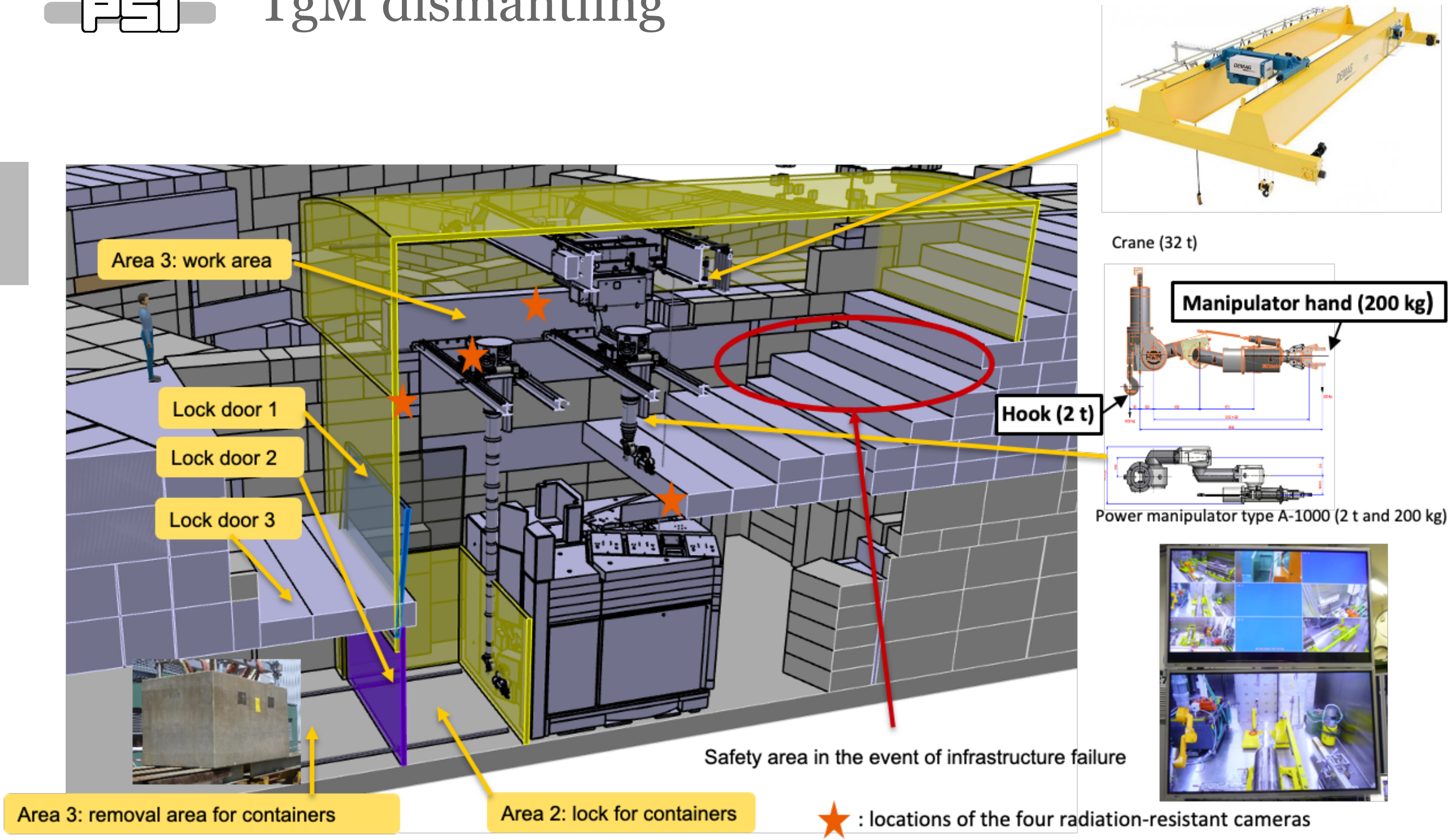
# Building a new target station

- 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



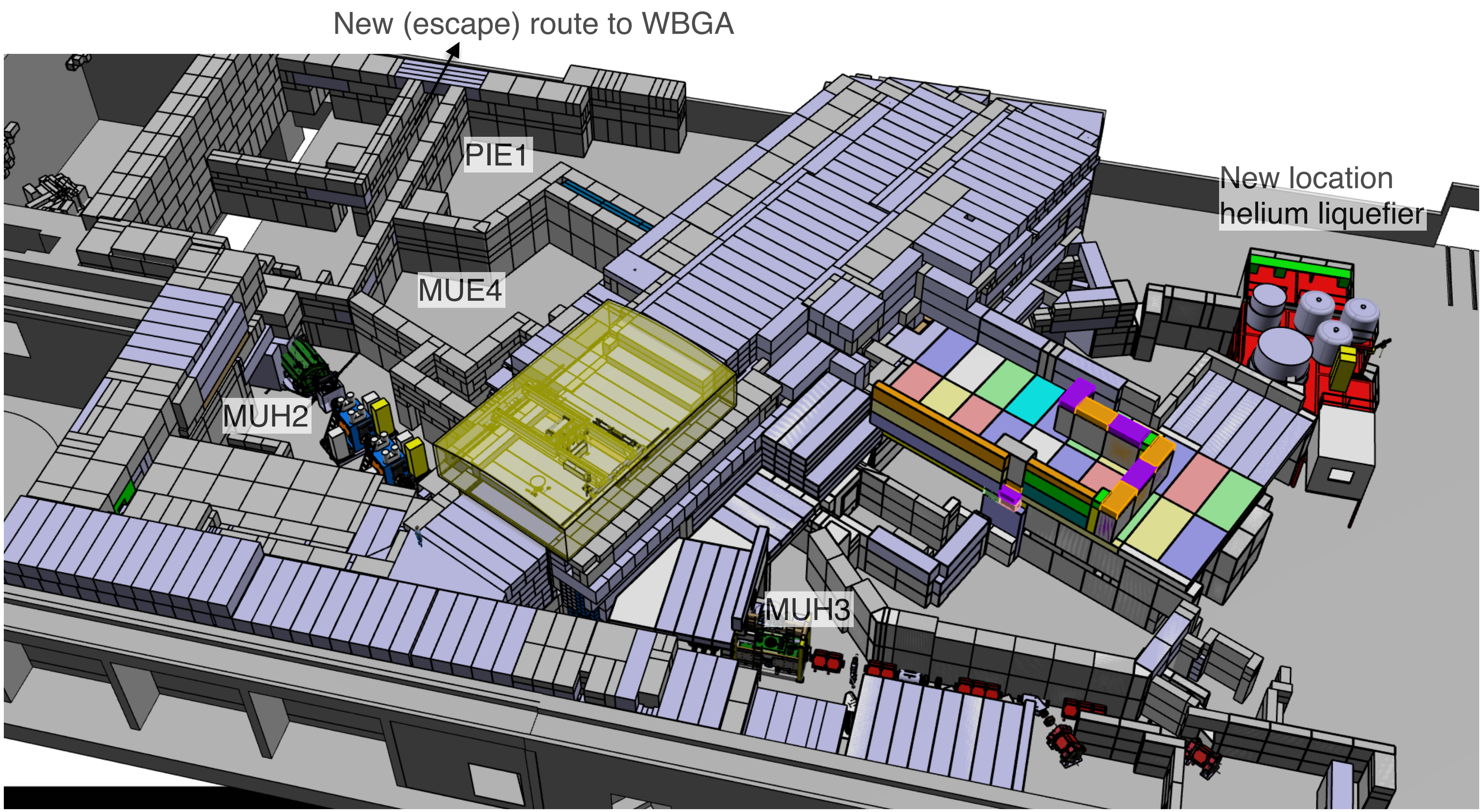
Lots of input and work from and for all the infrastructure groups!

# TgM dismantling




- Remote dismantling of target shielding block
- Similar to high-power upgrade of TgE in 1990/91

# 3D Model of Full WEHA




- Full 3D model of WEHA available
- Complying with modern safety regulations and improving general operations in WEHA

# Conclusions

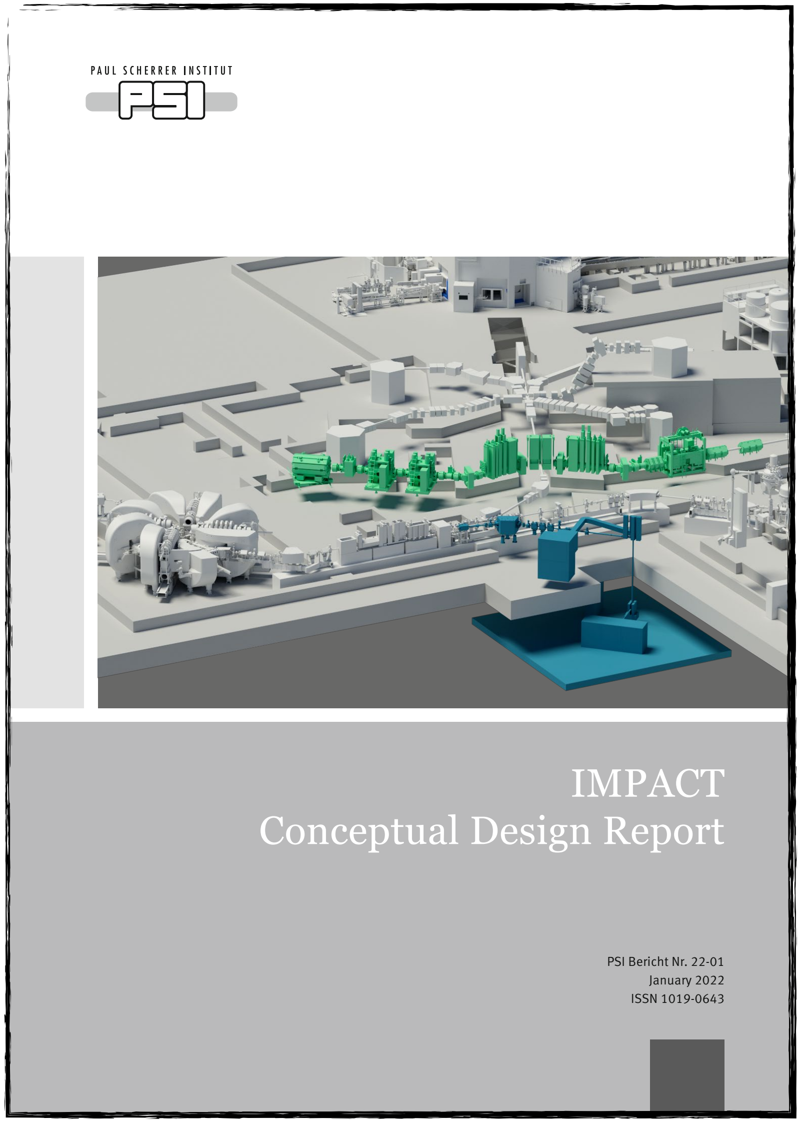
- HIMB dates back to 2010 and first ideas by P.-R. Kettle. We have come a long way!
- On track for realising HIMB at PSI and delivering $10^{10}$ surface muons per second
- HIMB will enable forefront muon research at PSI for the next 20+ years

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

# Backup slides

# 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

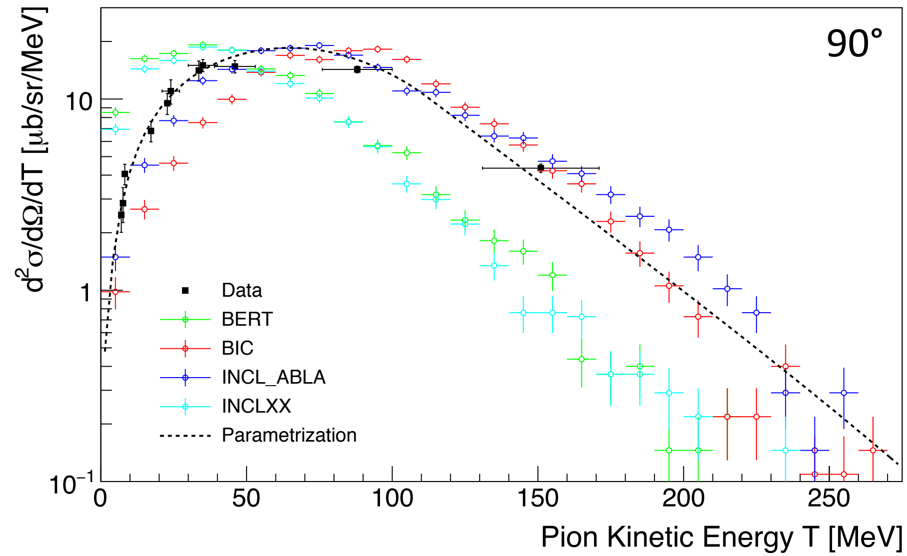


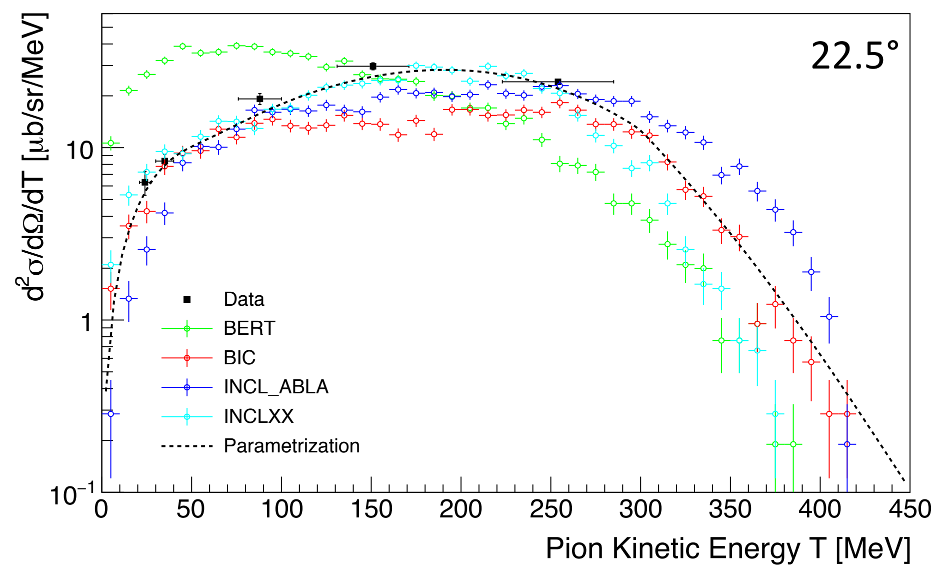
# Simulation

PAUL SCHERRER INSTITUT PSI

- Implemented our own pion production cross sections into Geant4/G4beamline based on measured data and two available parametrizations
- Valid for all pion energies, proton energies < 1000 MeV, all angles and all materials
- Implemented “splitting” of pion production and muon decay to speed up simulation

Reliable results at the 10% level

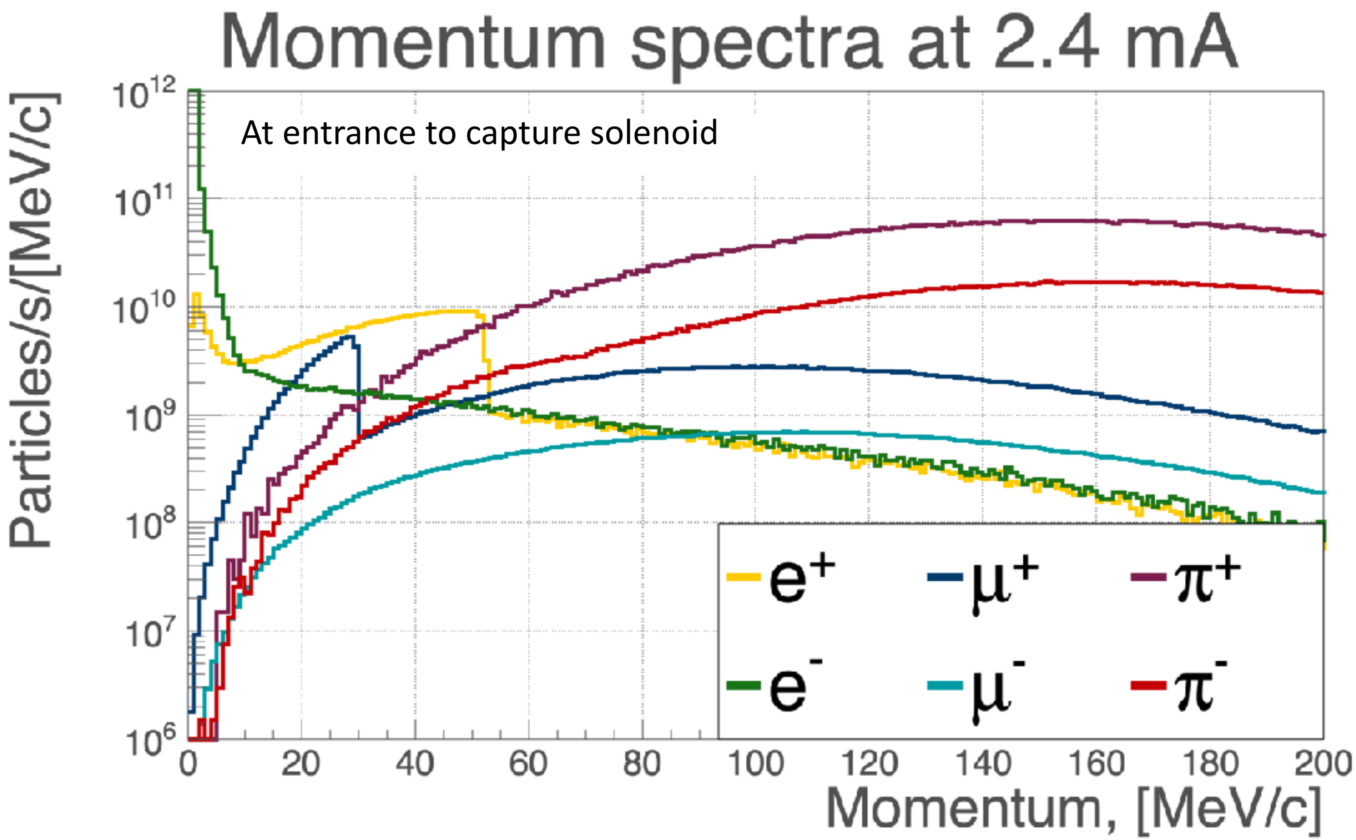




R. L. Burman and E. S. Smith, Los Alamos Tech. Report LA-11502-MS (1989)
R. Frosch, J. Löffler, and C. WIgger, PSI Tech. Report TM-11-92-01 (1992)
F. Berg et al., Phys. Rev. Accel. Beams **19**, 024701 (2016)

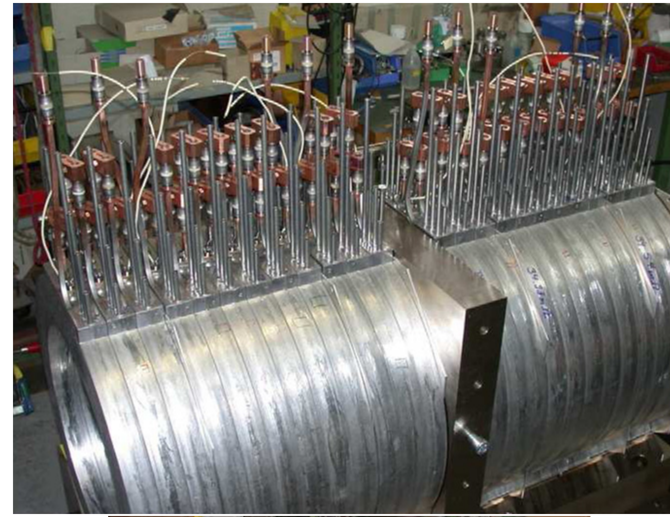
# Particle production at TgH




- 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

# muE4 Solenoids

- 2 x 12 separate radiation-hard coils (mineral-insulated)
- Iron housing
- Aperture: 500 mm
- Length: 2 x 750 mm
- Central field: 0.34 T / 0.27 T
- Roughly 20 kW each



Design of a solenoid with similar characteristics existing
⇨ Not all solenoids will need to be radiation-hard