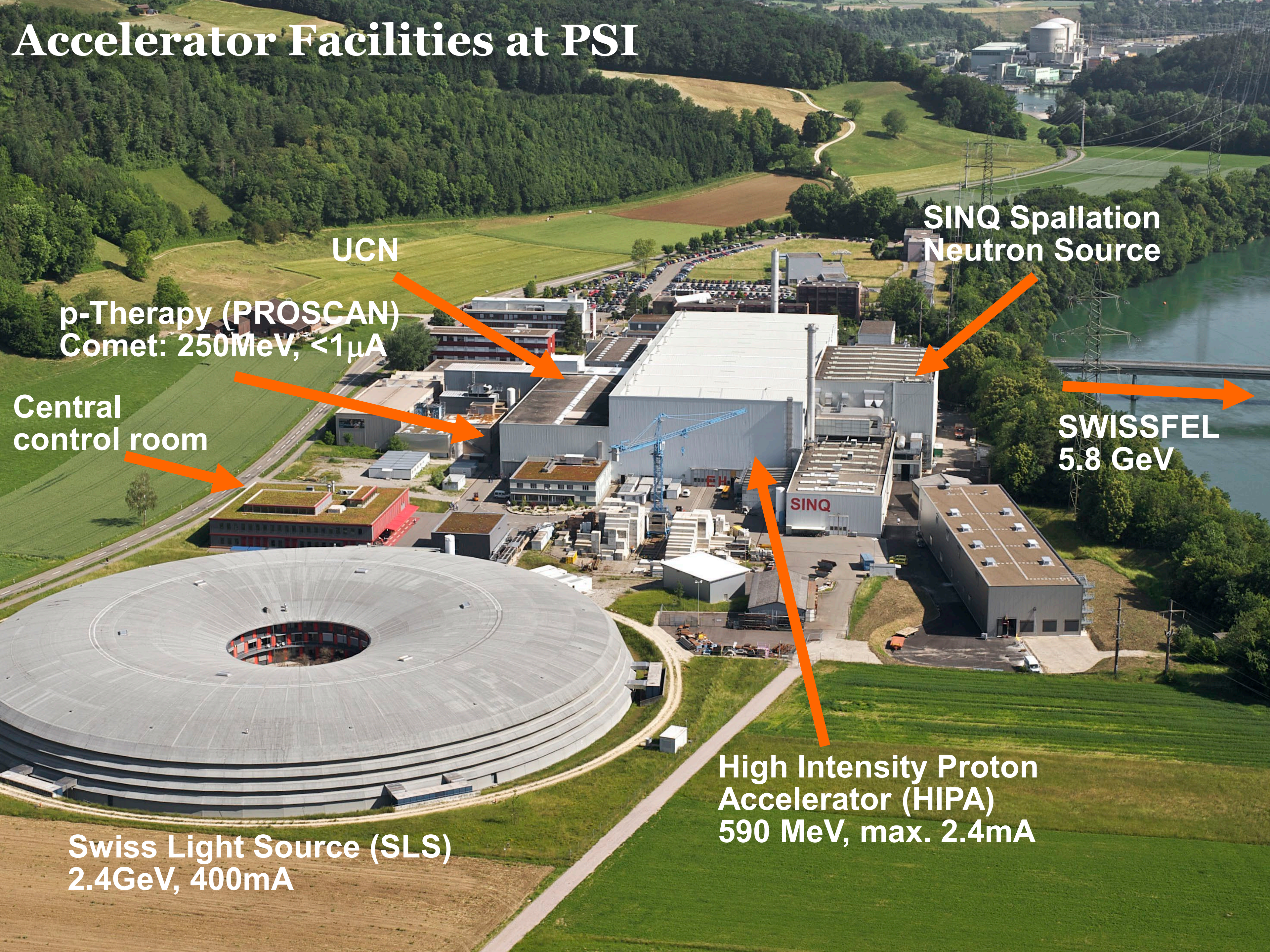
PAUL SCHERRER INSTITUT PSI

Daniela Kiselev :: Department Head Beam acceleration & development :: Paul Scherrer Institut

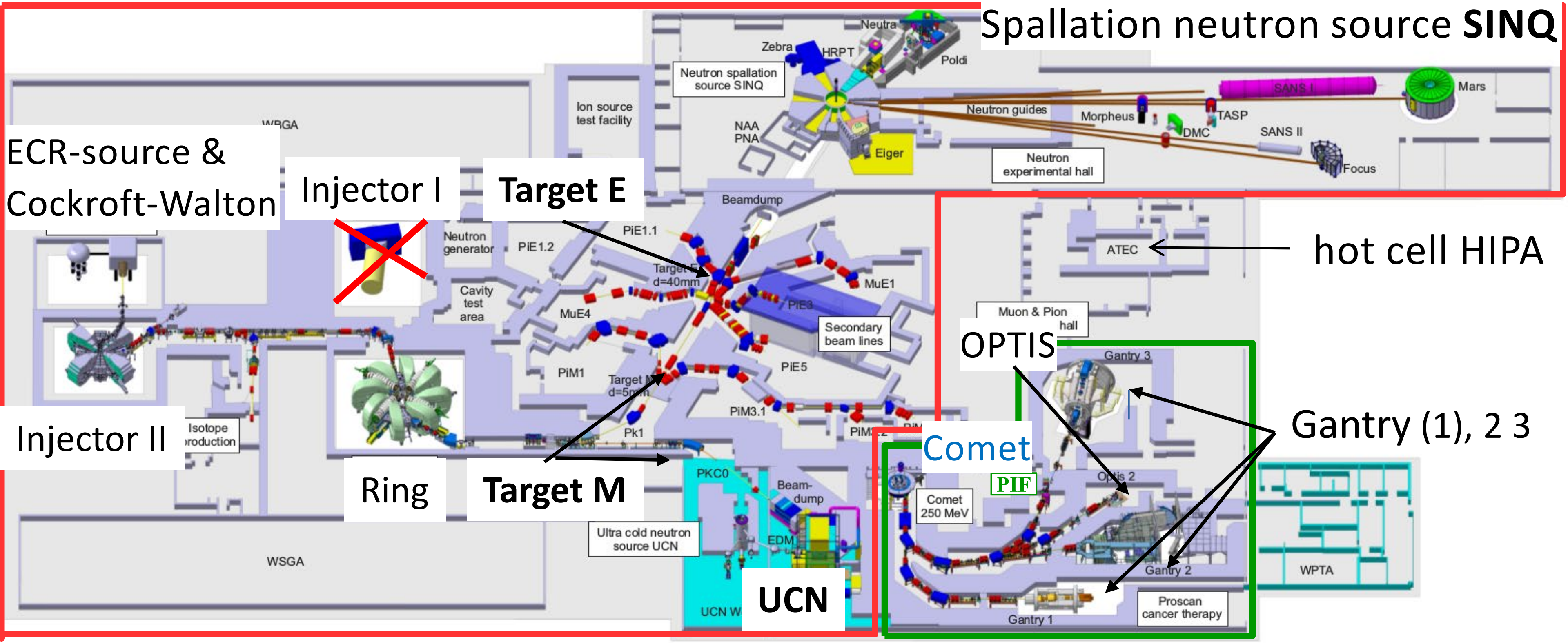
The IMPACT-TATTOOS initiative as part of the substantial upgrade to the HIPA infrastructure @ PSI

FFA23, 10 – 15.9.2023, Jefferson Lab, Newport News, VA 23606 USA

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 (μ, π)
- SINQ and UCN spallation source

PROSCAN (Proton therapy): since 2007

Comet: superconducting cyclotron

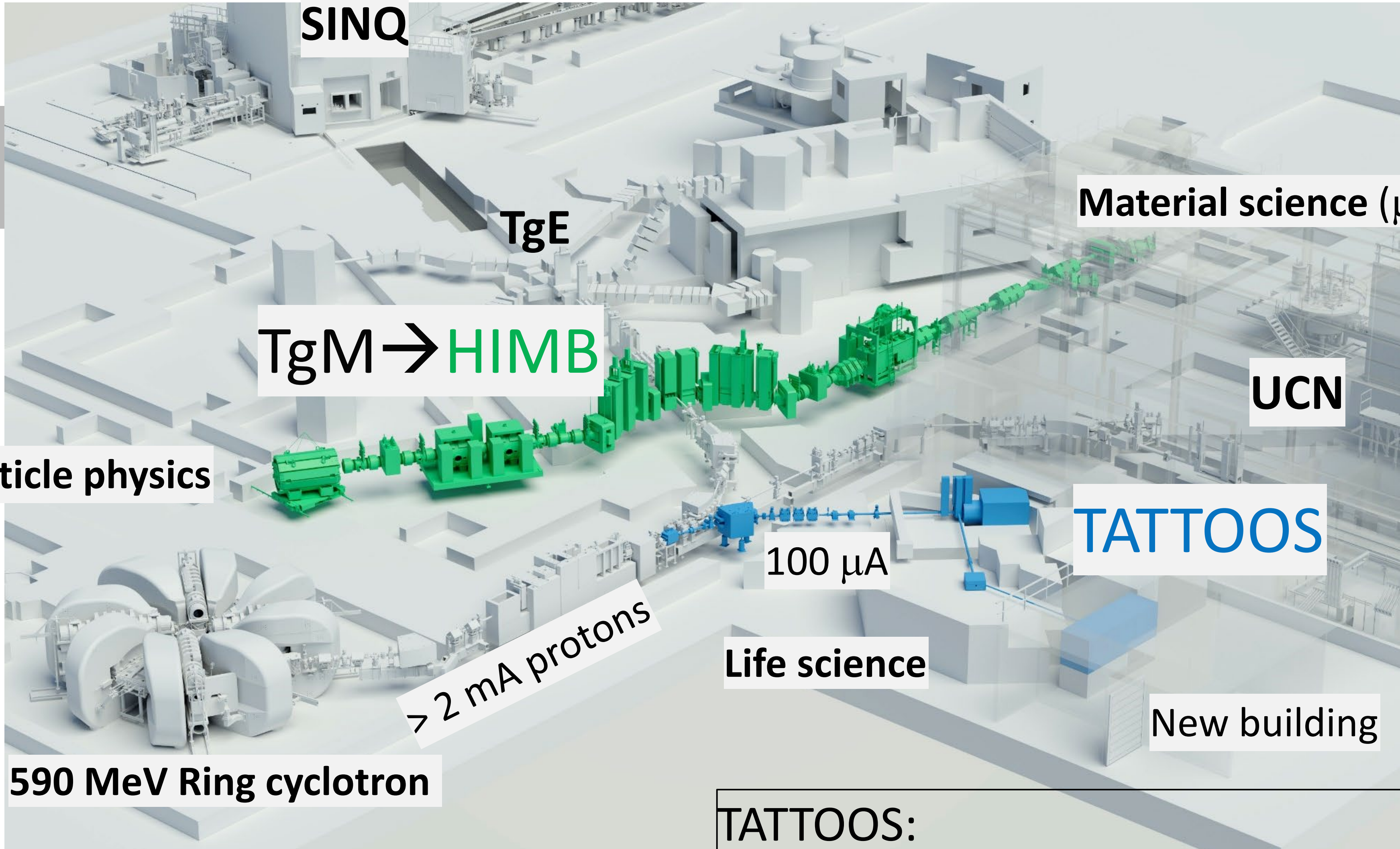
CW, 250 MeV, up to 1 μA protons

medical treatment:

2 Gantries, 1 Eye Cancer Treatment Station

Irradiation Station: PIF

HIPA with IMPACT (= HIMB & TATTOOS)



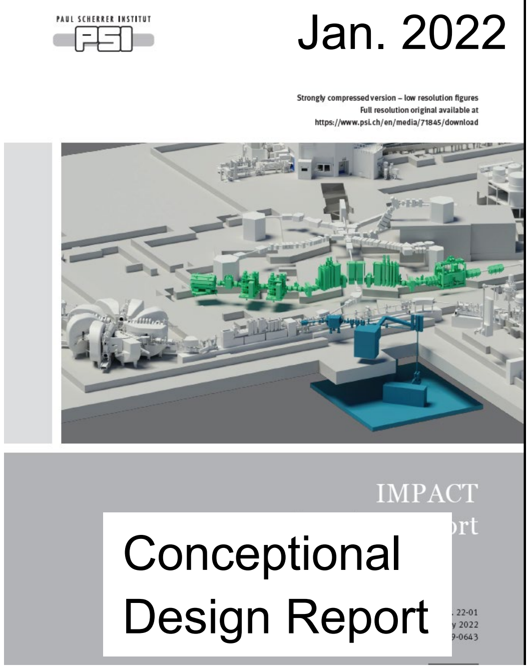
HIMB:
(surface) muons (up to 10^{10} μ/s)

TATTOOS:
radionuclides for cancer therapy & diagnostics (clinical studies)

IMPACT = HIMB + TATTOOS

Isotope and Muon Production with advanced cyclotron and target technology

- Upgrade of target station M to target station H for 100 x more surface muons
  → HIMB = **High Intensity Muon Beams**
- New target station for producing radioisotopes for research in cancer therapy
  → TATTOOS = **Targeted Alpha Tumour Therapy and Other Oncological Solutions**



Jan. 2022

Conceptional Design Report

Application to the Swiss Roadmap for Research Infrastructure

- July 2022: scientific evaluation best marks!
- Dec. 2022: evaluation of technical feasibility + finances
  → ETH Board recommends IMPACT for the admission on the Swiss Roadmap
- June 2023: Publication of Swiss Roadmap

Final decision:

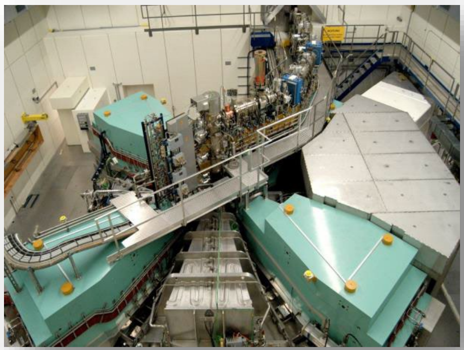
Dec. 24: Decision of Swiss parliament about funding in 2025-2028

~ 100 people are involved

https://www.dora.lib4ri.ch/psi/islandora/object/psi%3A41209

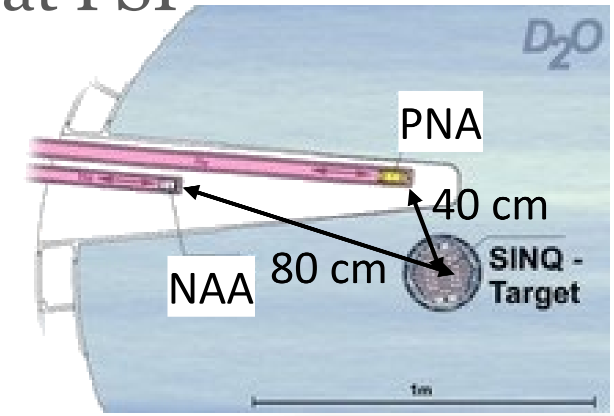
Current Isotope Production at PSI

Injector2, 72 MeV

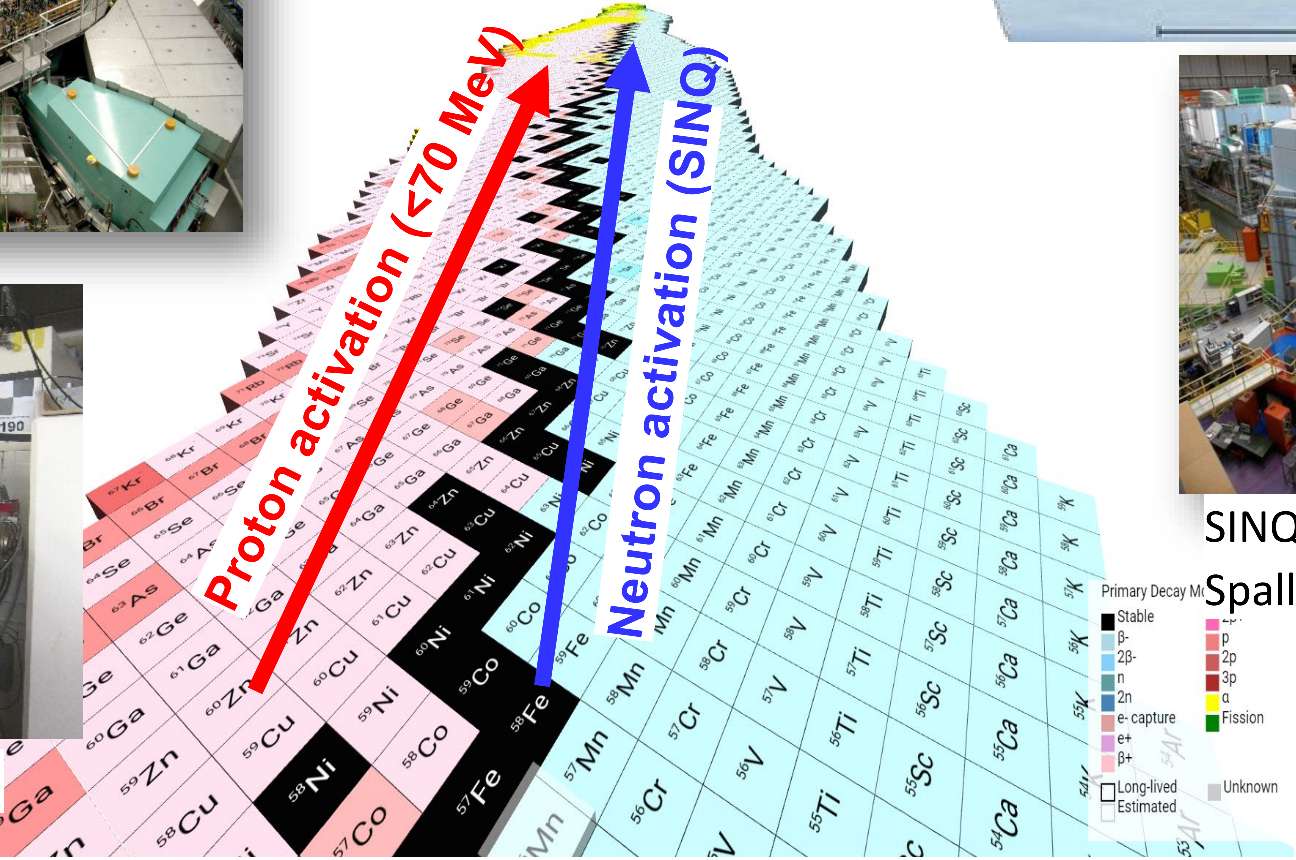


IP2: Target West

Irradiation of samples via pneumatic rabbit system



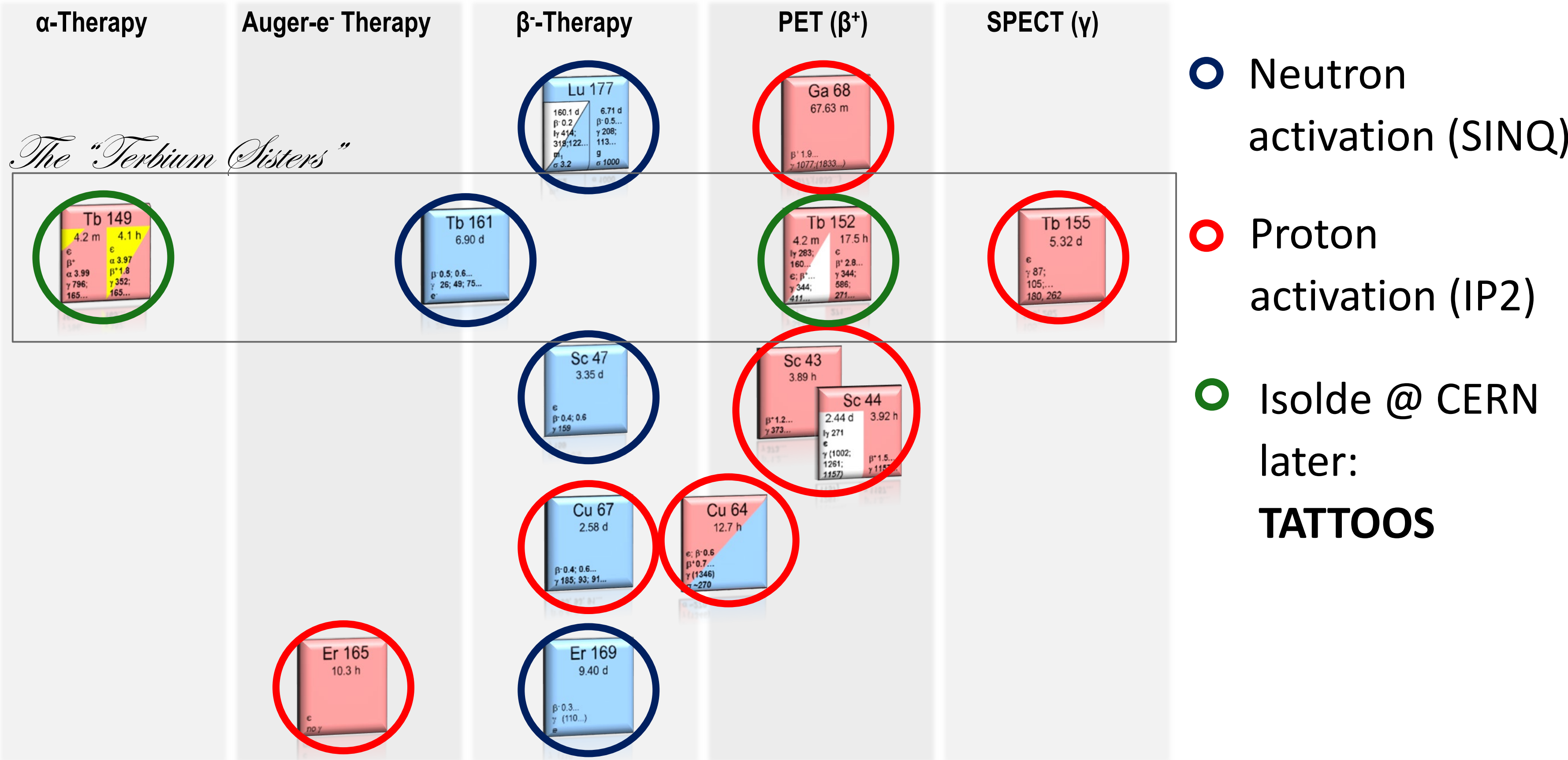
SINQ: Neutron Spallation Source



https://people.physics.anu.edu.au/~ecs103/chart3d/

"Matched Pair" Radionuclides for Theragnostics

Theragnostics: Therapy and Diagnostics

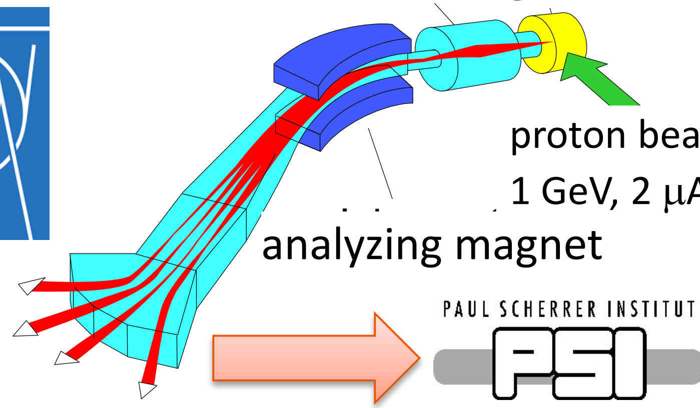


Isotopes, i.e. same element, preferred, because:

- same production process of the pharmaceuticals
- same reaction of human body
- fewer side effects

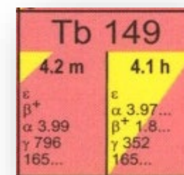
^{149}Tb: Preclinical studies @ PSI

Isotope Separation Online (ISOLDE)



Transport loss
between Geneva and PSI:
50% → 100 MBq

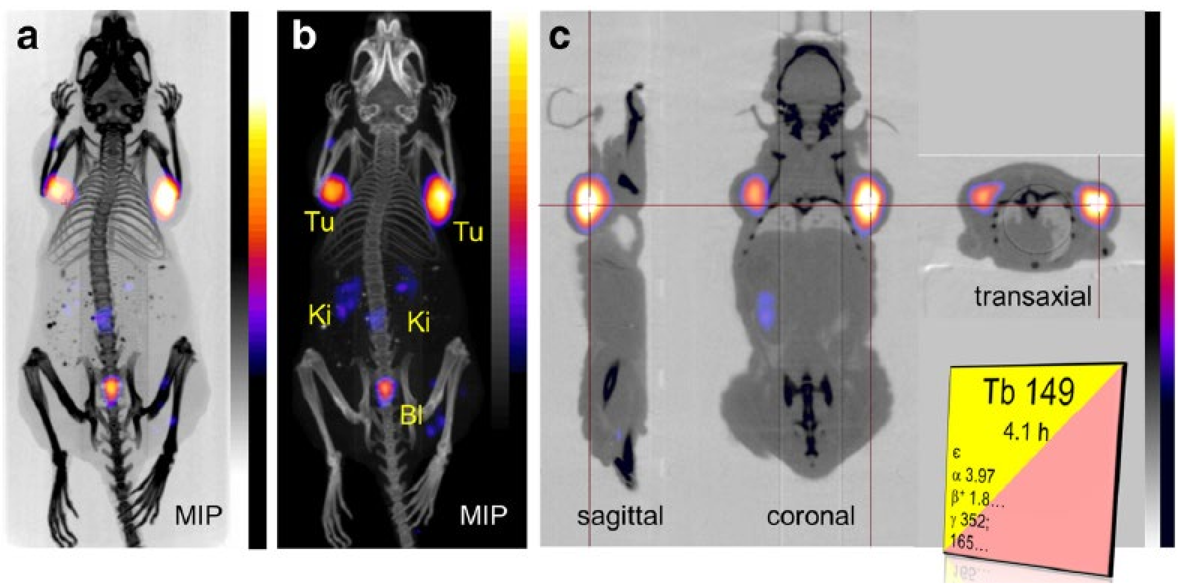
chemical
treatment



99 %
purity

radiolabeling

Imaging@ PSI: 7 MBq ^{149}Tb-DOTANOC,
after 2 h PET(30 min)/CT scan (1.5 min)



Müller et al. EJNMMI
Radiopharmacy
and Chemistry (2016) 1:5
DOI 10.1186/s41181-016-0008-2

+ Promising Treatment & PET/CT
with ^{149}Tb-PSMA-617
Umbricht *et al.*
Sci Rep **9**, 17800 (2019).
https://doi.org/10.1038/s41598-019-54150-w

PAUL SCHERRER INSTITUT

TATTOOS @PSI: Motivation

Present situation:

Current production @CERN-ISOLDE + 50 % losses for transportation:
not enough for killing tumors in humans (clinical studies)
- barely enough for research in mice (not enough for healing tumors)

TATTOOS:

Producing enough radioisotopes with 590 MeV p (100 μA)

- for cancer treatment & diagnostics (theragnostics) in quantities needed for clinical studies on human beings
- research only, no commercial production planned.

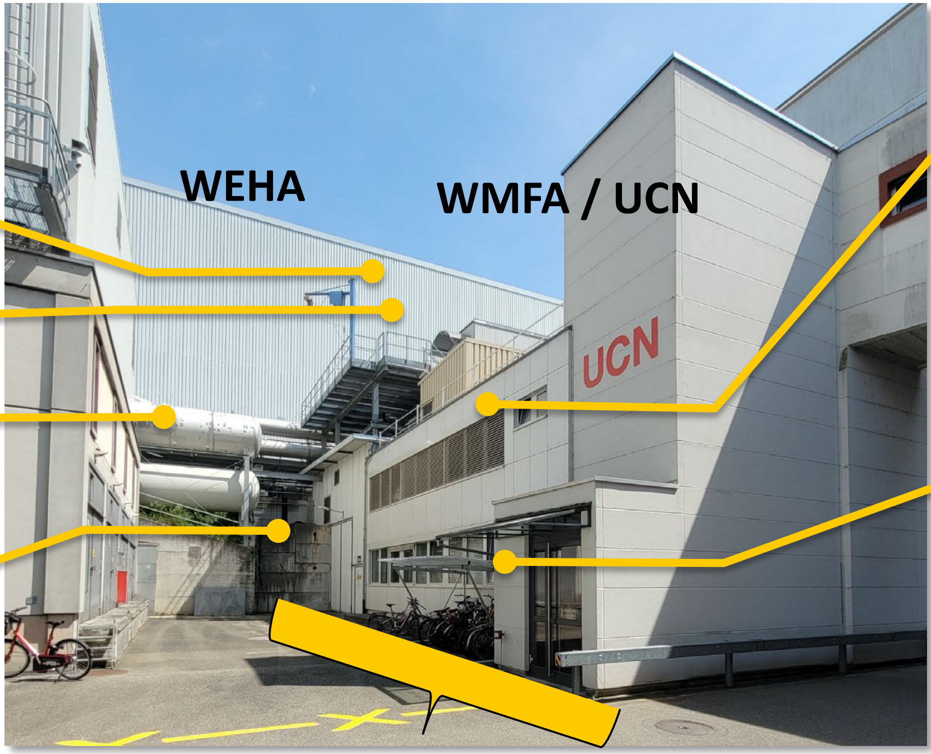
TATTOOS: Current view on location

Facilities at PSI:

UCN | **HIPA** | **SULTAN** | **PROSCAN**

Top
- Proscan ventilation
- Transformers WEHA
- Deuterirum tanks and control room
- He-buffer tanks

Back
- Removal of UCN Coldbox and compressors
- Access to UCN beamline

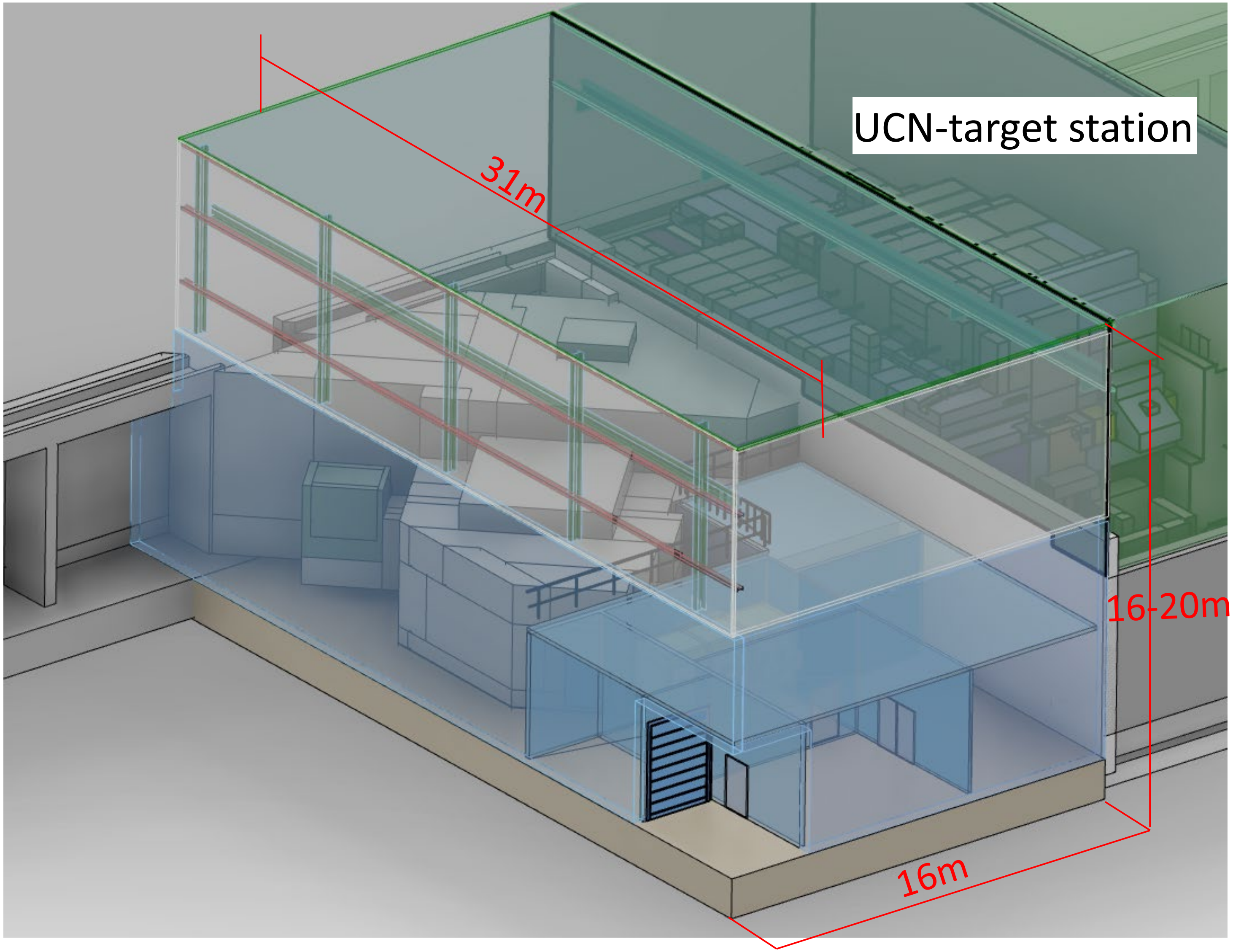


1. floor
- UCN control room
- Offices and Labs

Basement
- Supply lines for UCN beamline, experiments, control room
- Waste water WMFA
- Supply lines for Sultan
- Breathing air supply

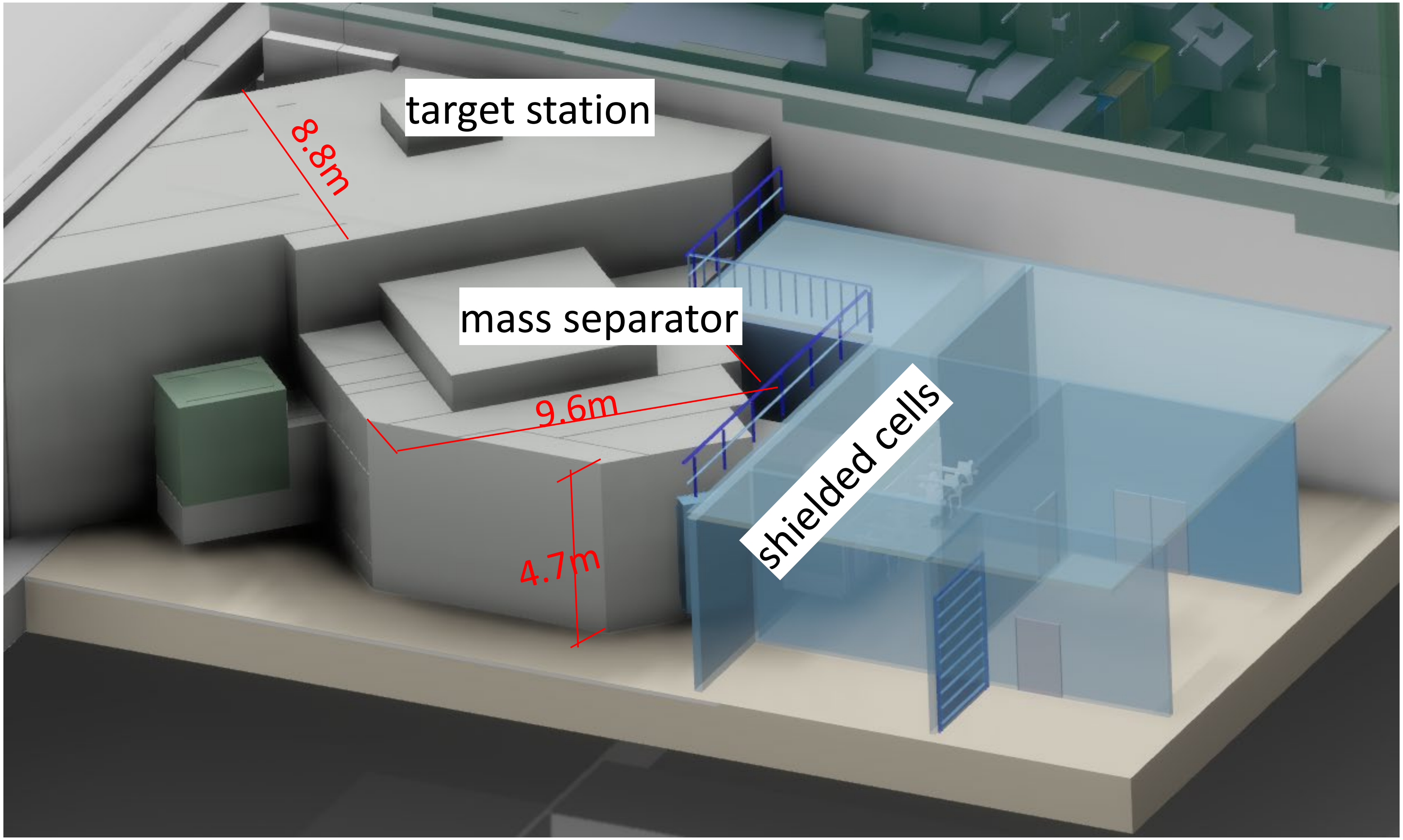
A lot of infrastructure has to be removed for the new building (start 2027)

New Building: 500 m²



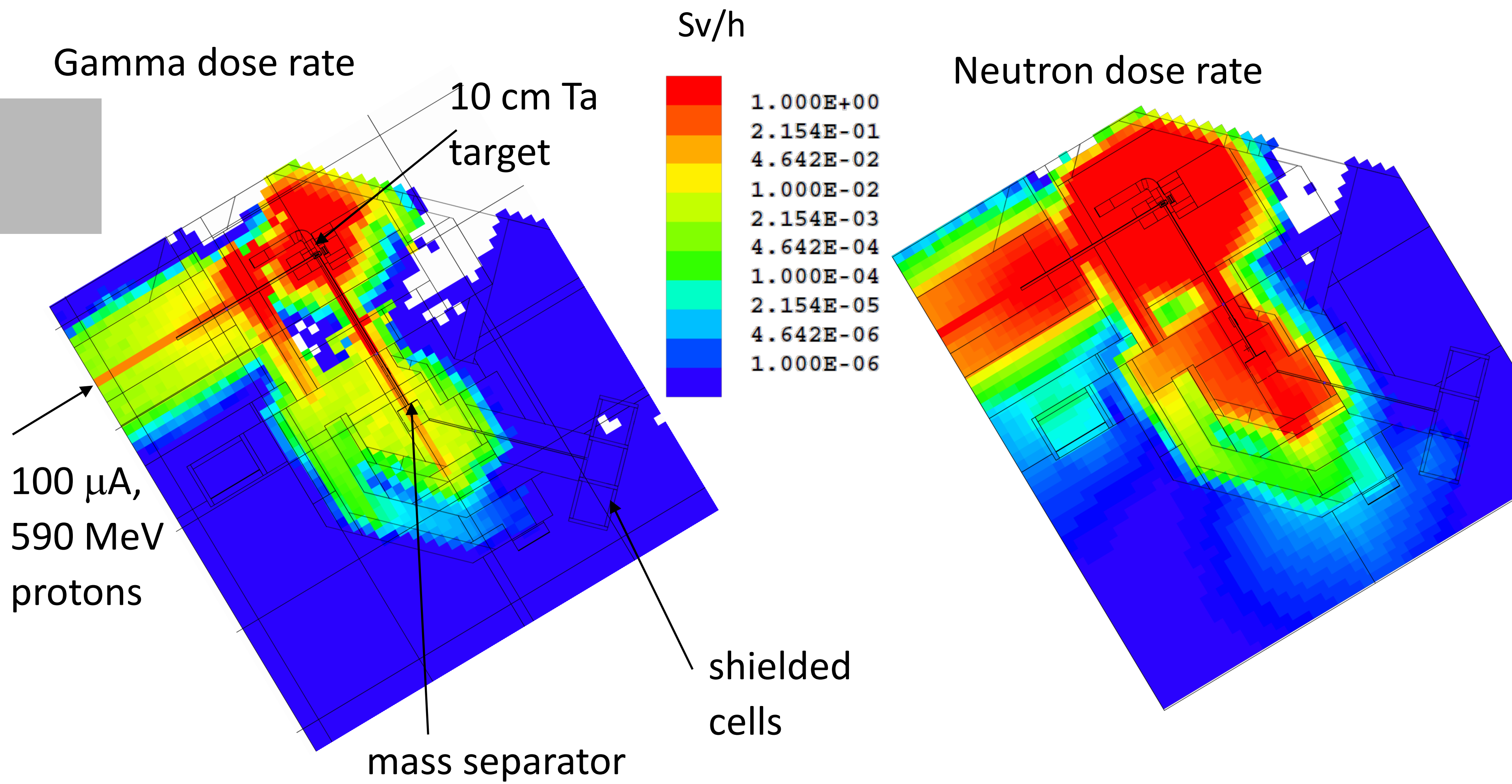
Courtesy of C. Sattler

Massive shielding required



Courtesy of C. Sattler

In-situ Dose & Shielding Target

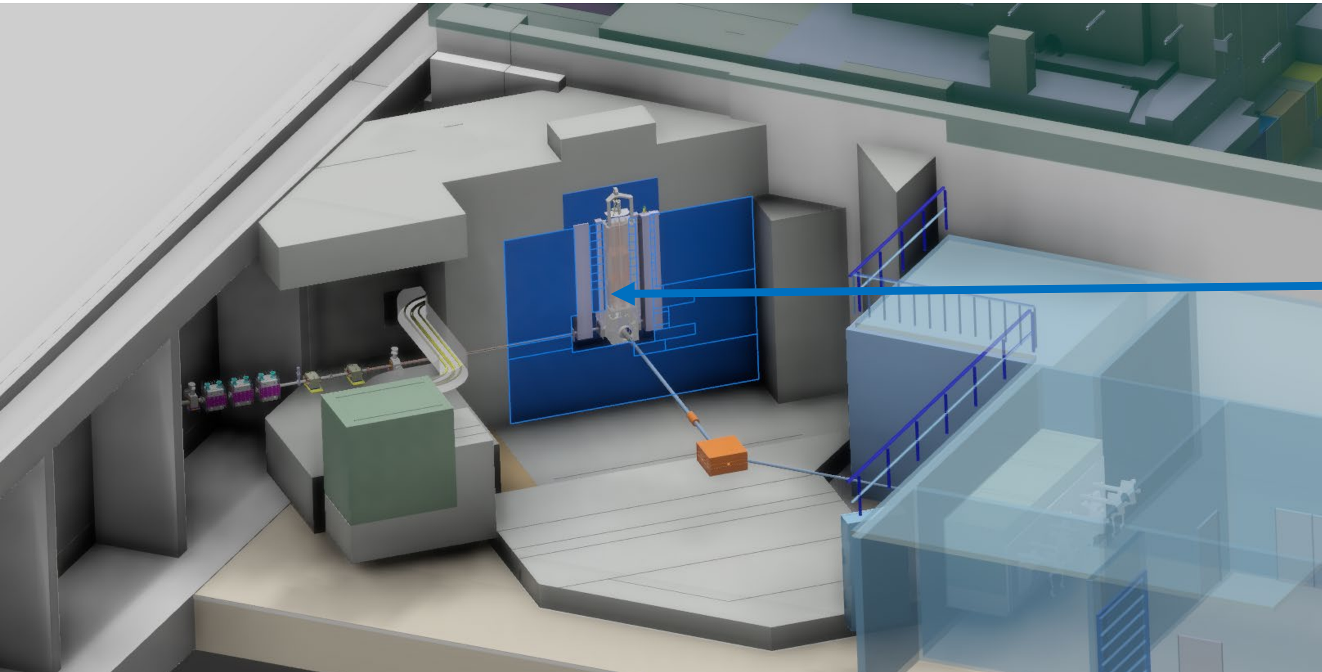


Requirement: < 10 µSv/h: controlled working place

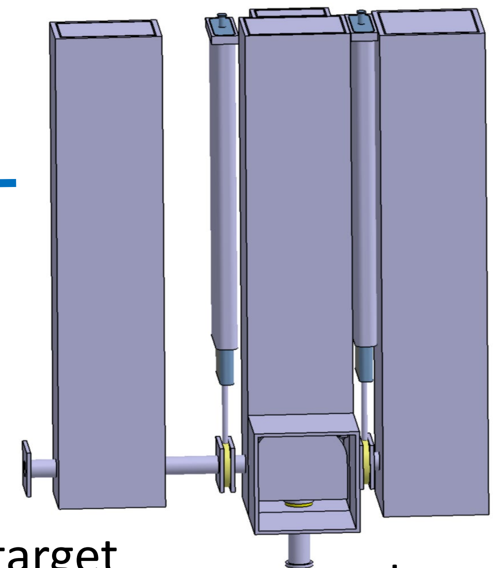
< 25 µSv/h: not permant working place

Courtesy A. Ivanov

Inside the shielding



vacuum chambers
with insert

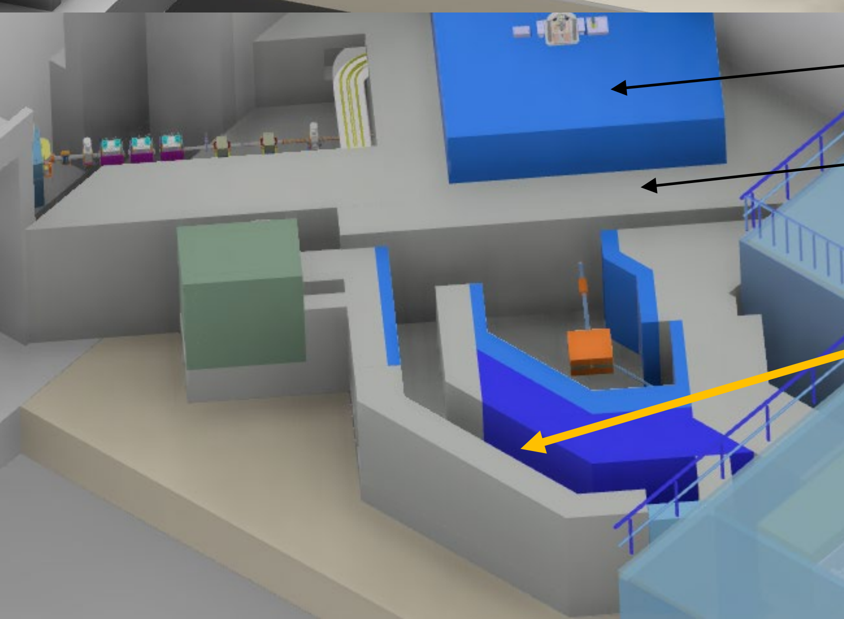


target
protection
collimator

target

beam
dump

Courtesy of D. Laube



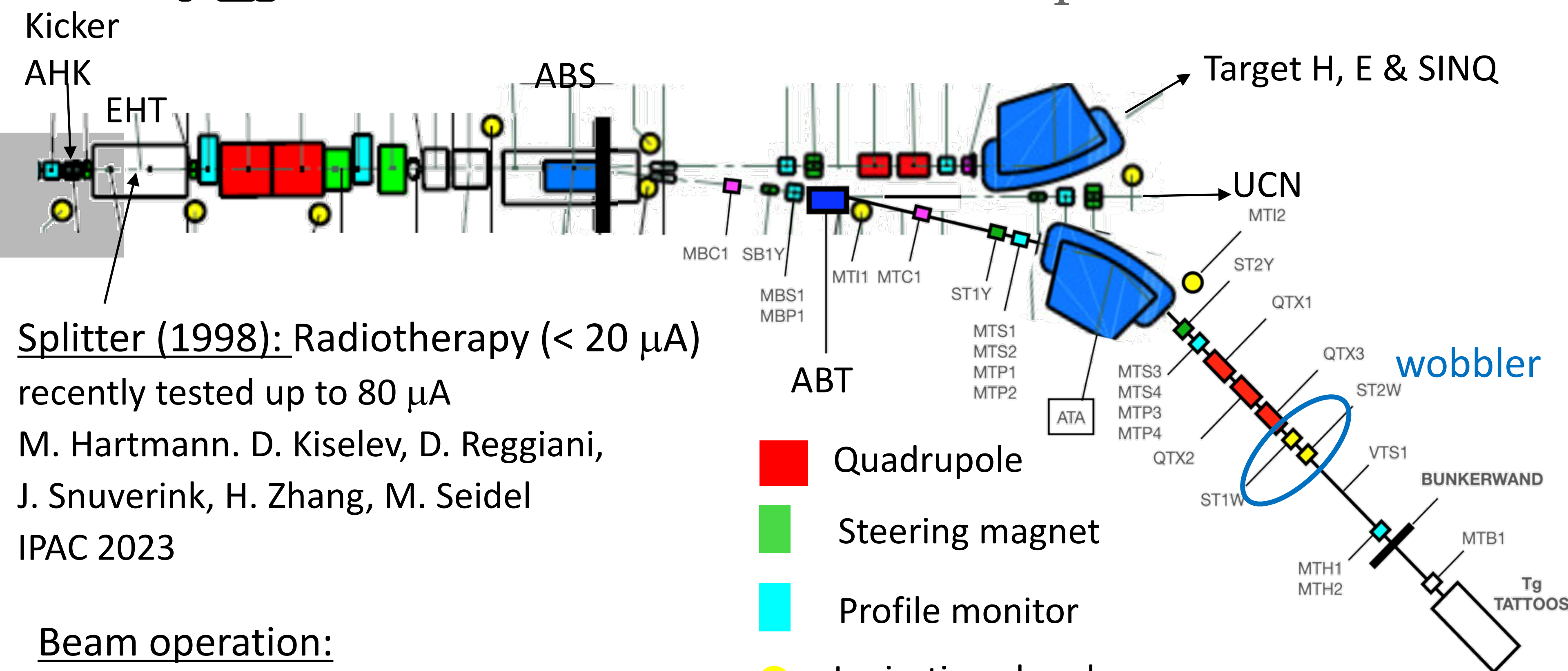
steel

concrete

labyrinth for access
of mass separator magnet

Courtesy of C. Sattler

Beamline to TATTOOS and operation modes



Splitter (1998): Radiotherapy (< 20 µA)
recently tested up to 80 µA
M. Hartmann. D. Kiselev, D. Reggiani,
J. Snuverink, H. Zhang, M. Seidel
IPAC 2023

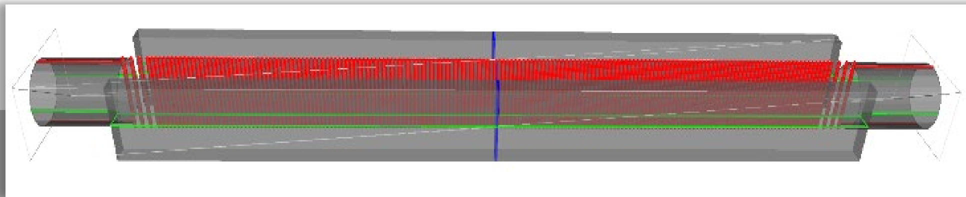
TATTOOS Target:
10 cm Ta (Phase 1),
later U or Th

Beam operation:

- mode 1: SINQ & TATTOOS
  → 100 µA split from main beam to TATTOOS
- mode 2: UCN → ABT polarity change
  full beam (~ 2 mA) swept to UCN by fast kicker magnet ABS

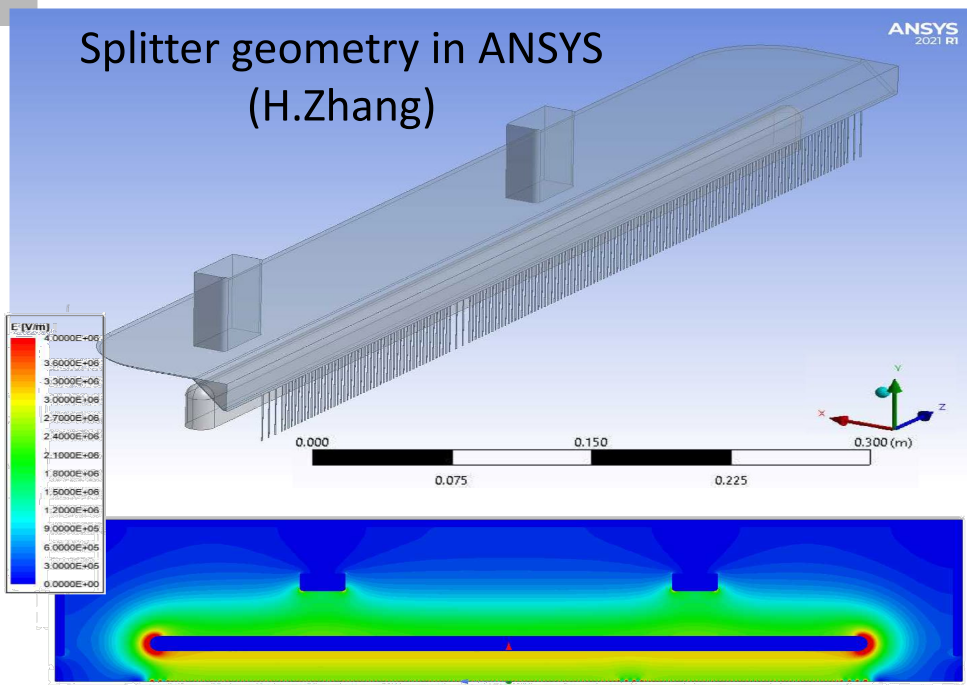
Quasi-parallel beam operation, i.e. no beam to TATTOOS, if pulse to UCN
→ ~ 15 % beam time loss for TATTOOS (acceptable)

Splitter



175 stripes out of a W-alloy
size: 2 mm x 50 µm
2 cathodes operating with 172 kV
deflection: +/- 1.5 mrad

Olivo, M., Mariani, E. and Rossetti, D.
An electrostatic beam splitter for the PSI 590 MeV - 1MW proton beam line (1998).



Electric field map,
resolution :
25 µm by 3000 µm by 500 µm

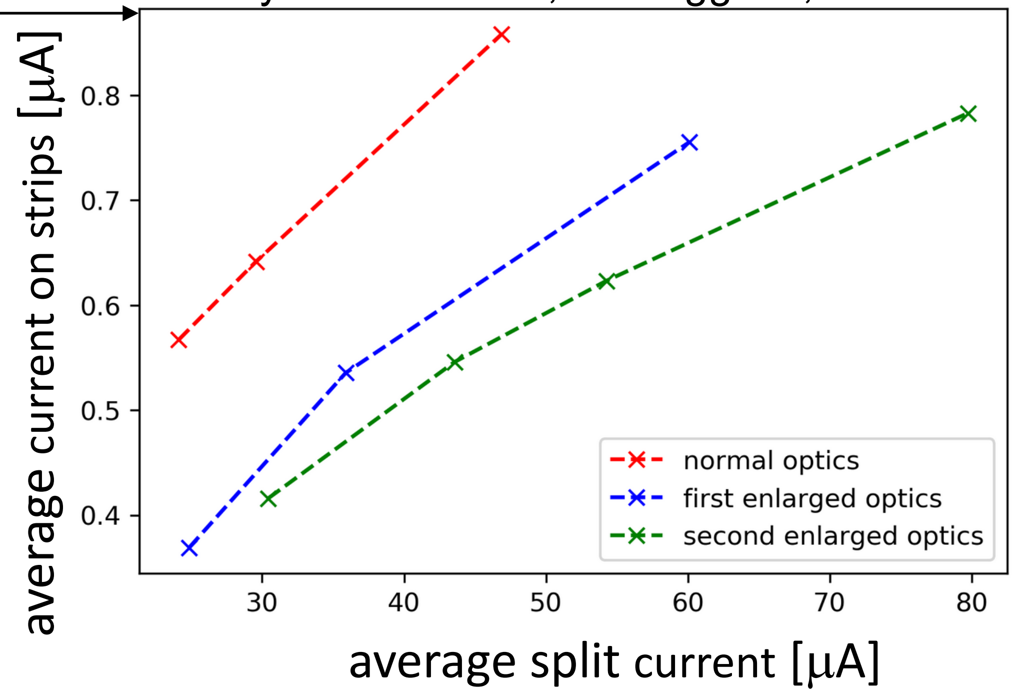
Electric field map (ANSYS):
Courtesy of H. Zhang

First 3 stripes measure the current.
For protecting the splitter from damage:
→ current limit on stripes was set by comparing to the splitter EXT used at 72 MeV for the isotope production simulations

Result of splitter test

Courtesy M. Hartmann, D. Reggiani, J. Snuverink

max. allowed current on strips



80 μA beam could be split off with horizontally increased beam optics!

As expected: larger losses about a factor 2

→ dose rate measurements above proton beam line are analyzed

→critical, since the beamline is maintained hands-on

→ further measurement (dose rates) & simulations needed

2023: Ongoing Beam tests using water cooled quadrupoles

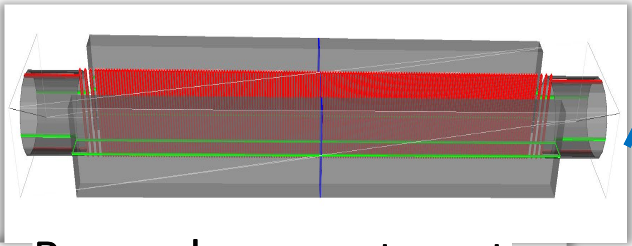
→ larger beam optics should be possible

aim: increase current of splitted beam (up to 100 μA)

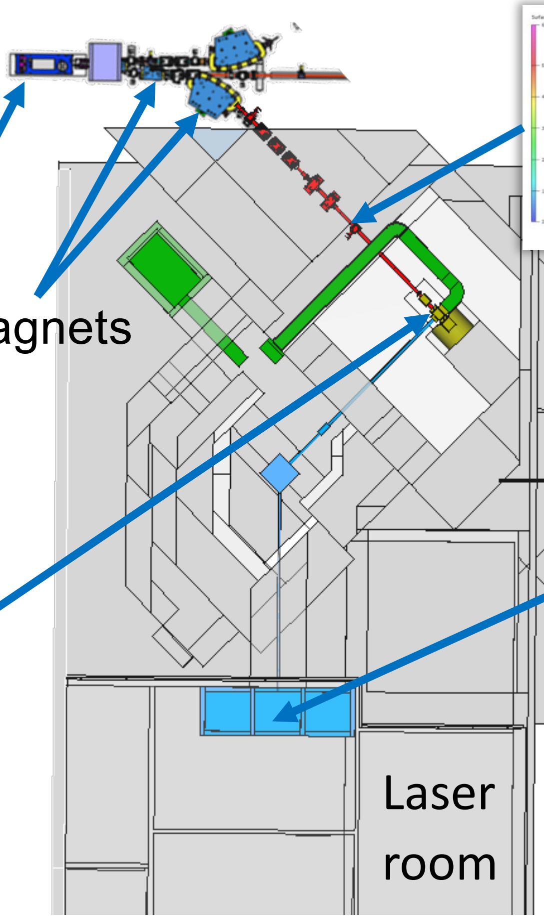
TATTOOS target station

proton beam

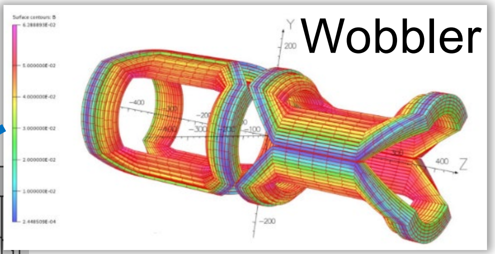
Beam splitter for 100 µA 590 MeV p



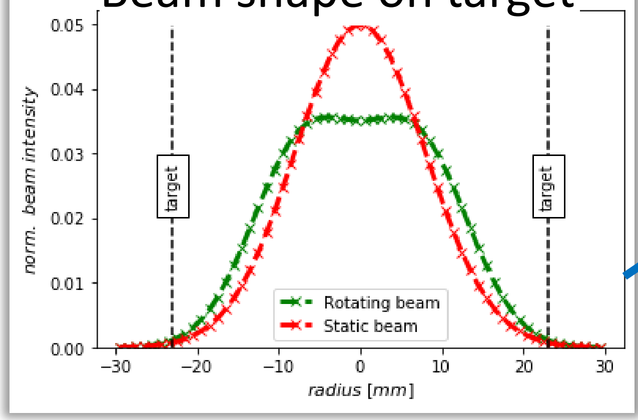
Magnets

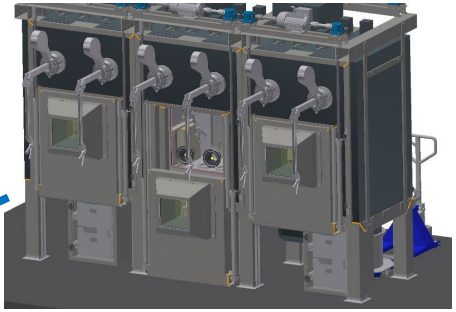


Wobbler



Beam shape on target





3 shielded cells

Laser room

<u>Separation of ions</u>

by Laser: RILIS (Resonance Ionization Laser Ion Source)

& mass separation→ Magnet: ISOL (Isotope Separation Online)

& chemistry in shielded cells

Clinical preparation (radiolabeling) in a separate clean room (GMP), collaboration with University hospital Zurich (USZ)

Target

Target: 10 cm Ta distributed on 20 cm

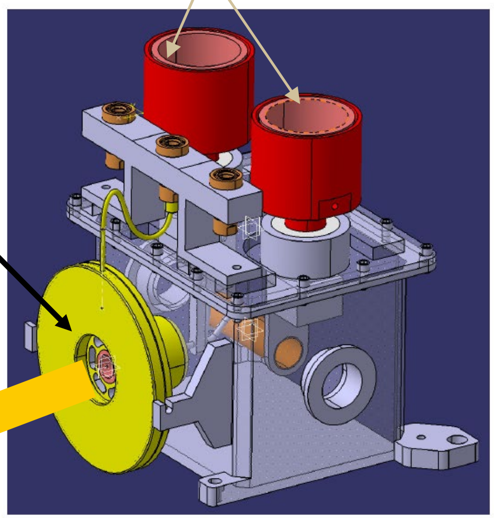
- A challenge to cool the 100 μA proton beam, ~ 26 kW on target
- Operation temperature: ~ 2500 – 2800 °C

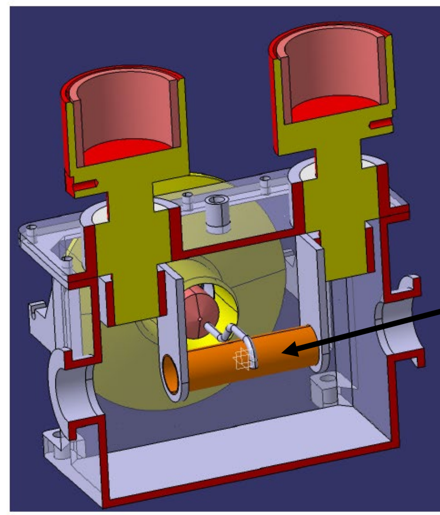
→ required for good diffusion of the radioisotopes out of the target

up to 6000A for heating (~ 2000 – 2800 °C)

Pillow seal

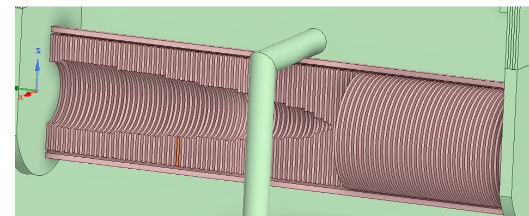
ion extraction & transport





Courtesy of U. Wellenkamp

possible target design:



Ø 60 mm

aim:
homogeneous temp. distribution

TRIUMF High Power Target

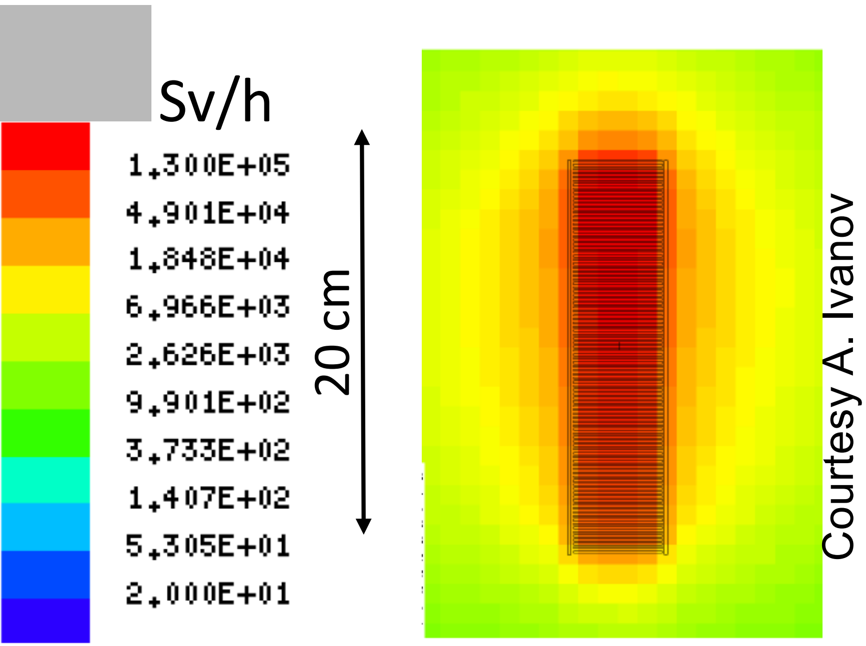
Target for 500 MeV, 100 μA, ~ 25 kW in target

90 fins (55 x 55 mm) increase effective emissivity from 0.35 to 0.92

Bricault et al, NIM B204, 319 (2003)

Target exchange

Remanent gamma dose of Ta target (28 d, 100 μA, 12 h cooling)

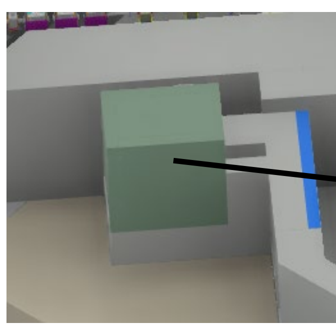


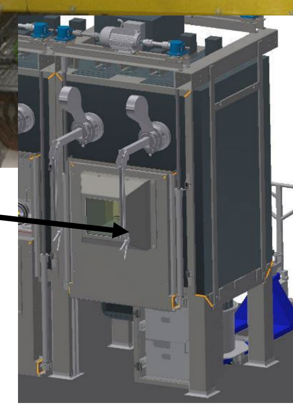
1000 Sv/h in 10 cm

New exchange flask needed

shown:
existing flask,
45 t due to
shielding

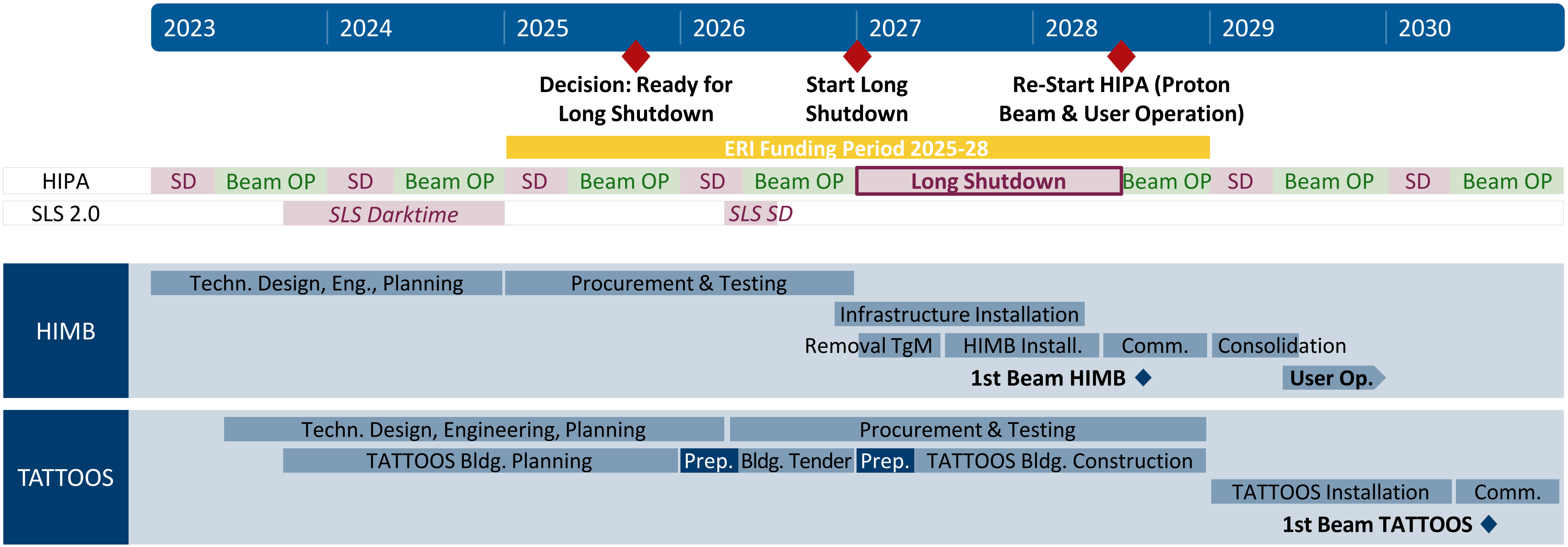
Target, beamdump etc
incl. shielding
can be pulled
by exchange flask





Service cell
for target exchange

IMPACT schedule



HIPA: 2027 no beam

→ Installation of HIMB

→ 2028 first beam with new target station H

TATTOOS: New building necessary → Beam 2 years after HIMB (2030)

Advantages:

- Target station installations for HIMB and TATTOOS not at the same time

→ more PSI resources available, less temporary hired staff

→ less shortage on storage place for new components, shielding

Next Steps

- Target chamber design
- Prototype of Ta target for testing purposes
- ion beam simulation:
  presently 45^{o} analyzing magnet, 90^{o} might be required
  → challenge is the limited space
- 2024 TDR IMPACT

Summary

- IMPACT: a 77 MCHF project
  HIMB: upgrade of the existing meson production station M
  TATTOOS: new target station to produce radioisotopes with 590 MeV protons
  - covers a broad field of applications: particle, solid state physics, life science ......
  - to be realized in 2027 to 2030

We appreciate the support of TRIUMF ISOLDE MEDICIS

With contribution of:

- C. Baumgarten
- R. Eichler
- S. Gerhardt
- M. Hartmann
- A. Ivanov
- S. Jollet
- D. Laube
- R. Martinie
- N. van der Meulen
- M. Mostamand
- N. Preiss
- D. Reggiani
- C. Sattler
- J. Snuverink
- S. Warren
- U. Wellenkamp
- H. Zhang
- & Design office @ PSI

Thank you for your attention!

IMPACT: TATTOOS collaborations 2022

- ISAAC TRIUMF… Collaboration Meeting in April 2023 in Vancouver

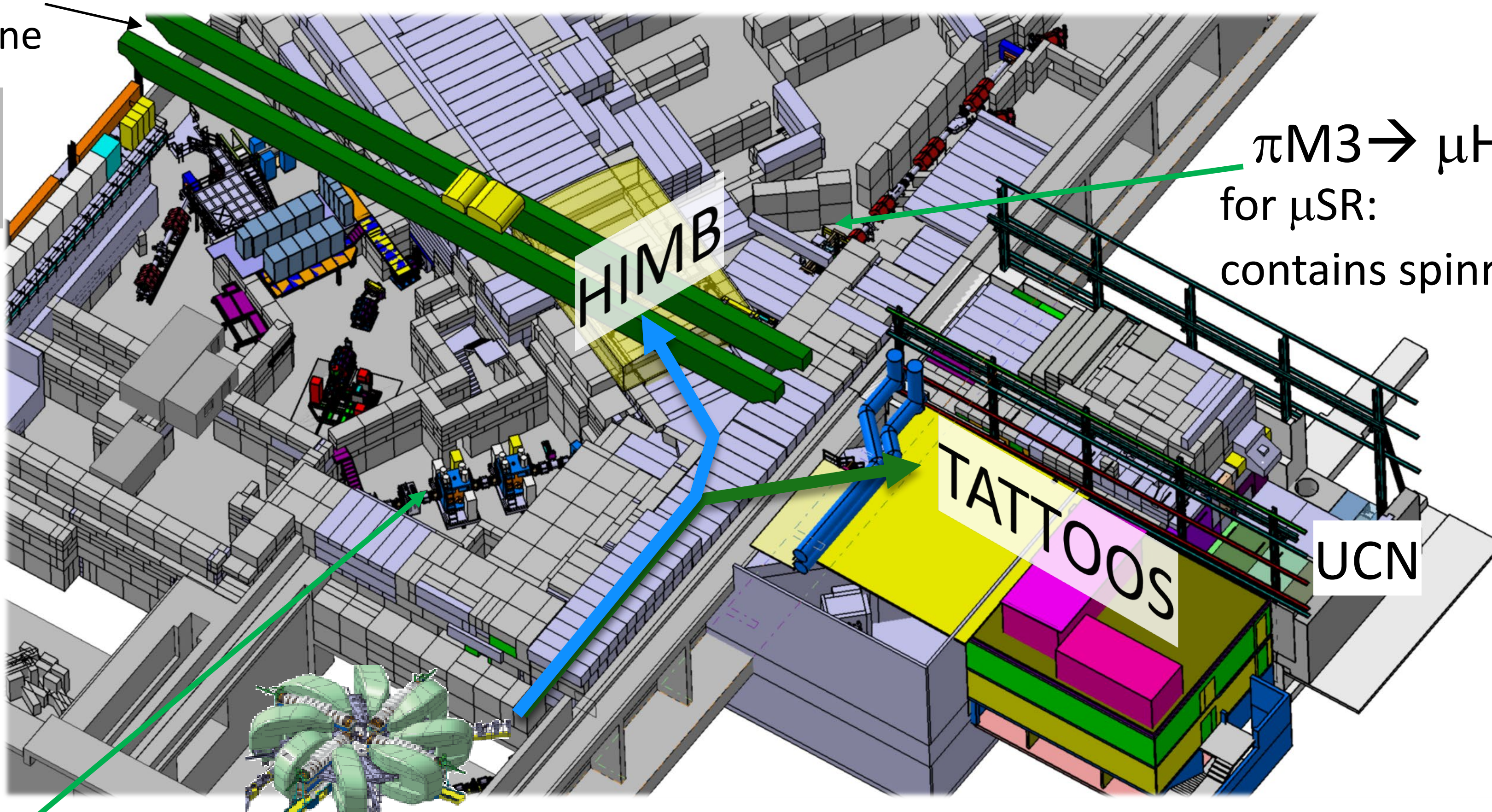
- CERN-ISOLDE… MOU to be signed in 2023 : PSI Part of ISOLDE Collaboration

- CERN-MEDICIS…PSI Partner since 2017

HIPA with HIMB and TATTOOS

This is the
60 t crane

πM3→ μH3
for μSR:
contains spinrotator



590 MeV
Ring cyclotron

πM1→ μH2
particle physics:
2 separators to remove positrons

Both secondary beamlines are optimized for low energy «surface» muons (~28MeV/c)

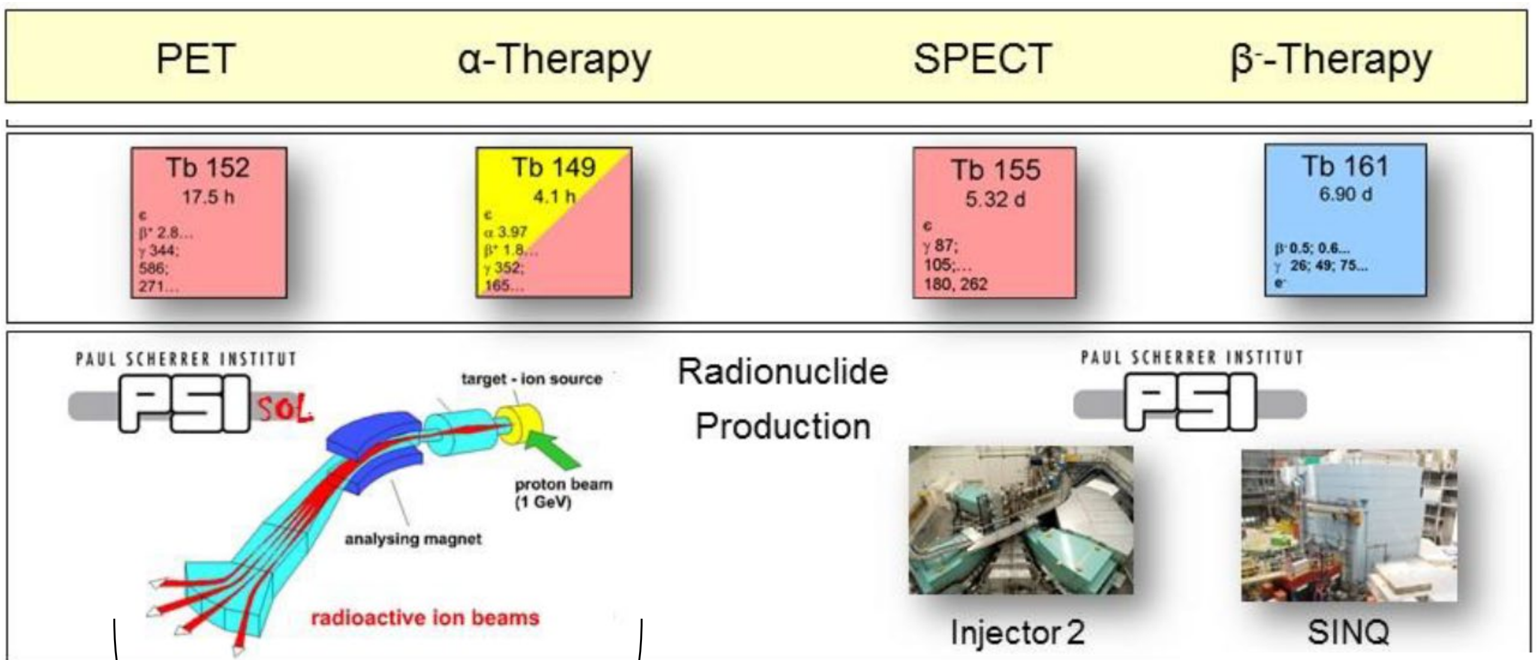
TATTOOS: Targeted Alpha Tumour Therapy and Other Oncological Solutions

PAUL SCHERRER INSTITUT PSI

Life science:

Producing enough radioisotopes with 590 MeV p (100 μA)

- for cancer treatment & diagnostics (theranostics) in quantities needed for clinical studies on human beings
- research only, no commercial production planned.



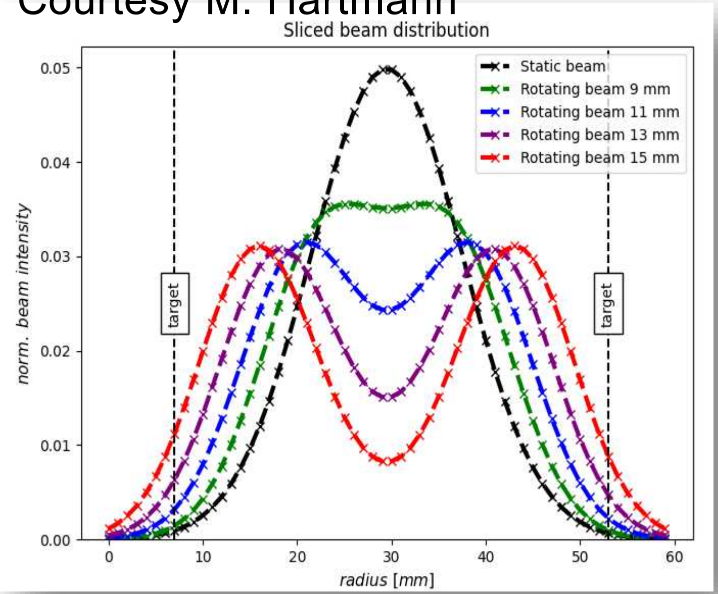
TATTOOS
590 MeV protons on Ta

IP2 (72 MeV)
^{155}Gd target

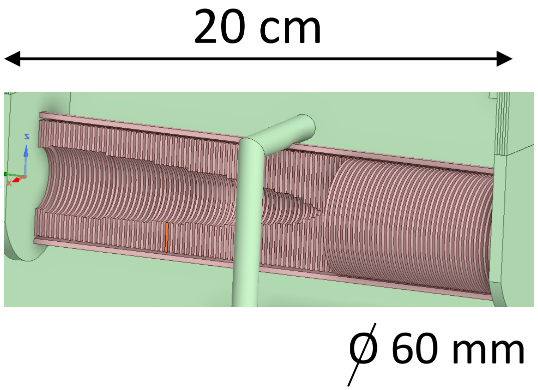
$^{160}Gd(n,\gamma)^{161}Gd \rightarrow ^{161}Tb$

Target design

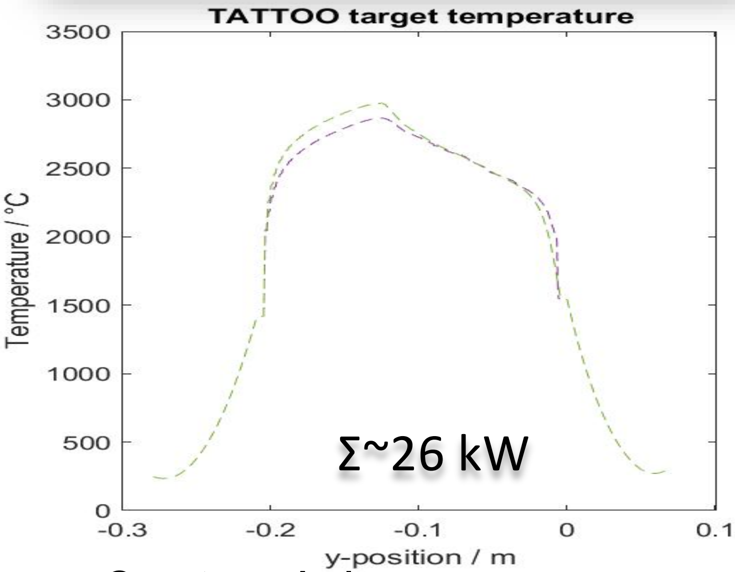
Courtesy M. Hartmann



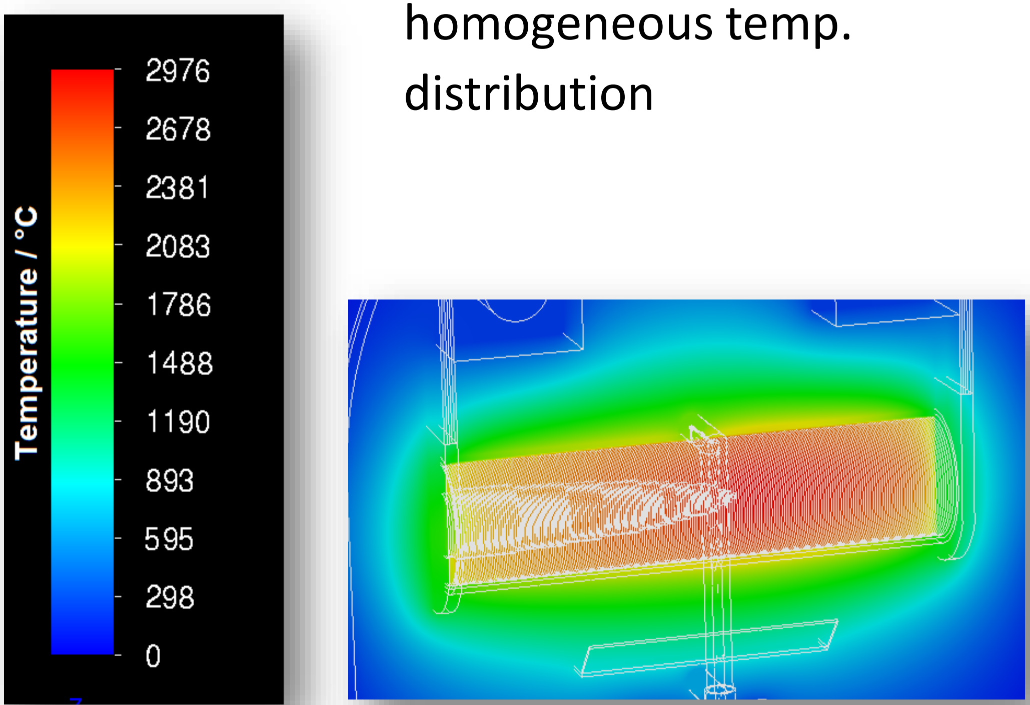
100 mA,
590 MeV protons



aim:
homogeneous temp. distribution



Courtesy A. Ivanov



Courtesy S. Jollet

PAUL SCHERRER INSTITUT

TATTOOS is Part of the 60 MCHF-IMPACT Proposal accepted by SNF & ETH-Rat to be included in Roadmap of Swiss Research Infrastructures in 2023