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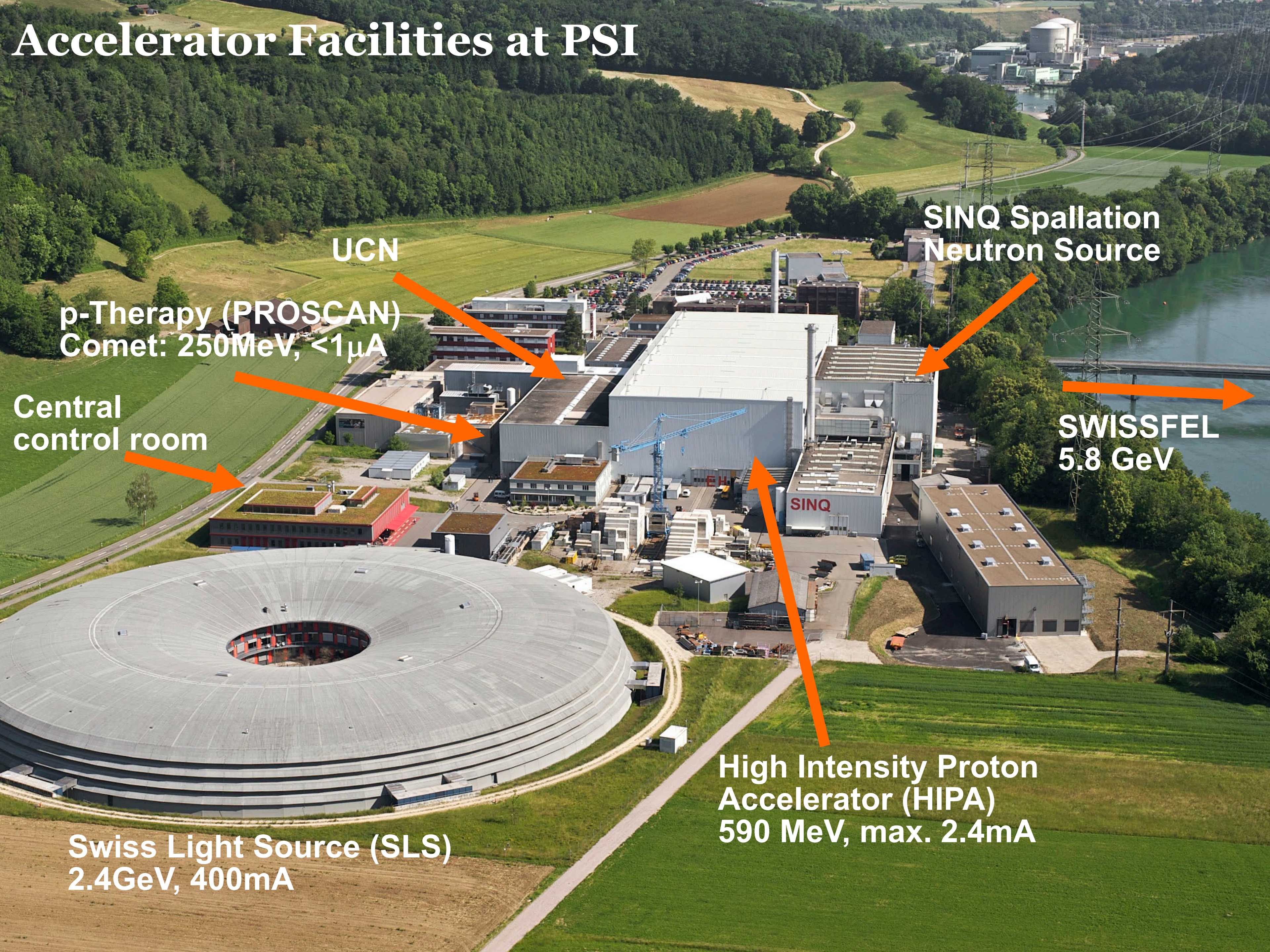
R. Eichler, M. Haj Tahar, M. Hartmann, K. Kirch, A. Knecht, A. Koschik, D. Laube, N. van der Meulen, T. Rauber, D. Reggiani, R. Schibli, J. Snuverink, U. Wellenkamp, H. Zhang

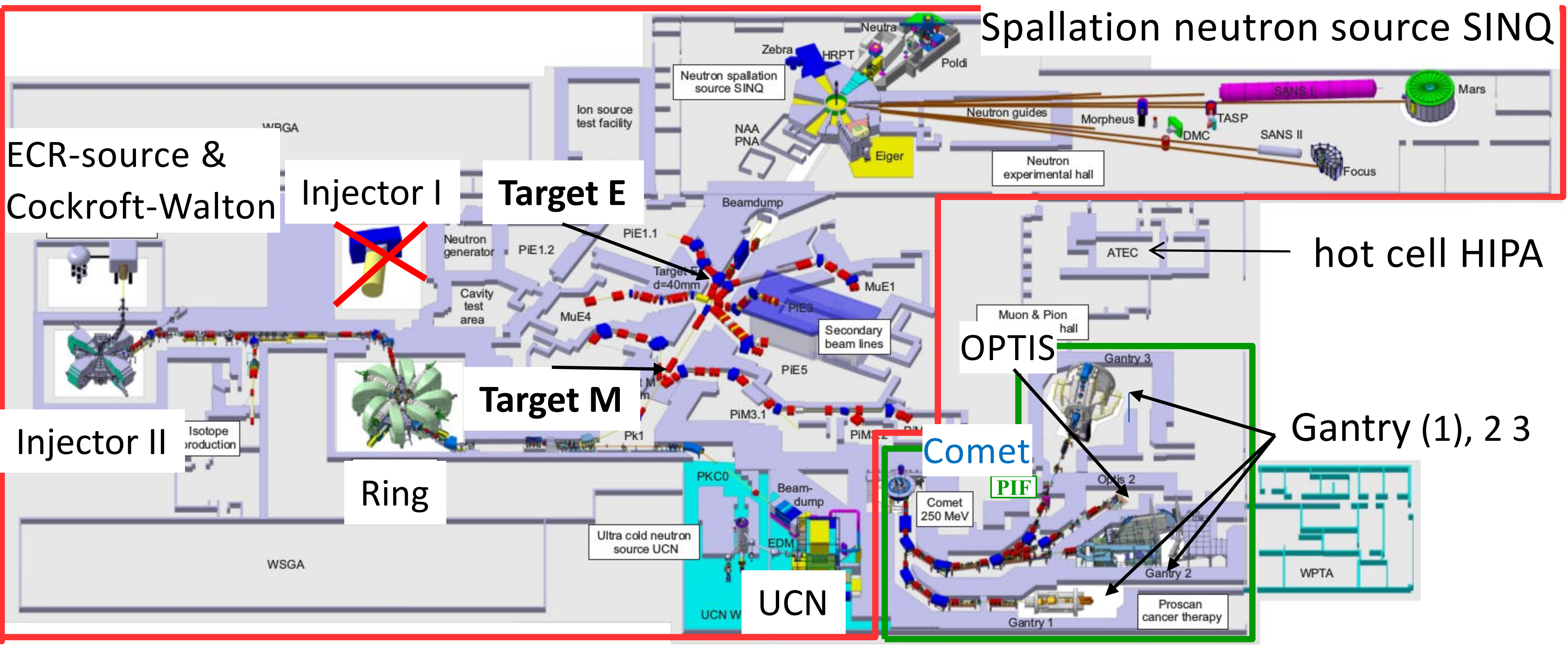
IMPACT: A Substantial Upgrade to the HIPA Infrastructure at Paul Scherrer Institute

Int. Conf. on Cyclotrons and their Applications (Cyc2022), Beijing, China, 5-9.12.2022, online

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

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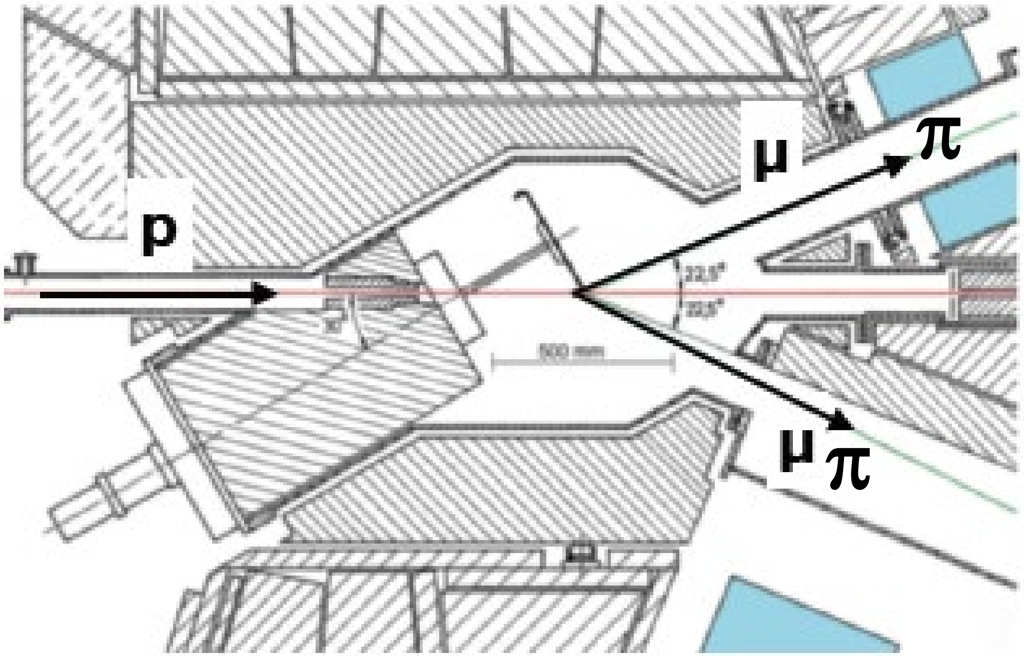
Present TgM station (built 1985)



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, since well shielded!

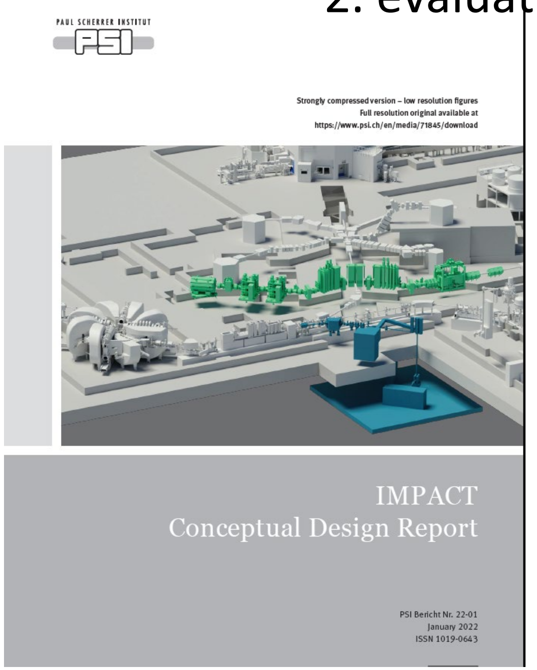
IMPACT = HIMB + TATTOOS

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
- New target station for producing radioisotopes for research in cancer therapy
  → TATTOOS

77 M project, 60 M by Swiss Roadmap for Research Infrastructure

1. evaluation passed in July 2022: best marks!
2. evaluation in Dec. 2022



~ 100 people are involved

9 subprojects and 35 working groups

Conceptional Design Report (Jan. 2022)

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

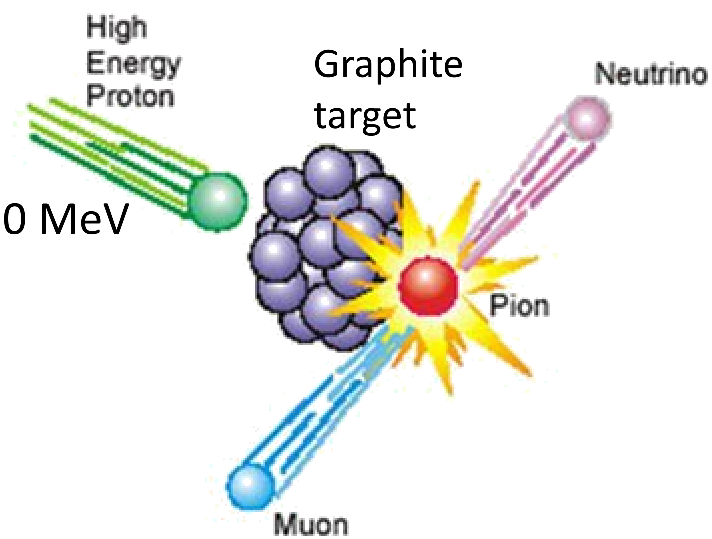
HIMB: High Intensity Muon Beams

Particle & material physics (μSR)

Surface muons (~ 28 MeV/c) rates of 10^{10}/s for

- Increasing the sensitivity for the detection of rare/forbidden muon decay
  → Physics beyond the standard model
- Study of magnetic properties below surface with more sensitivity

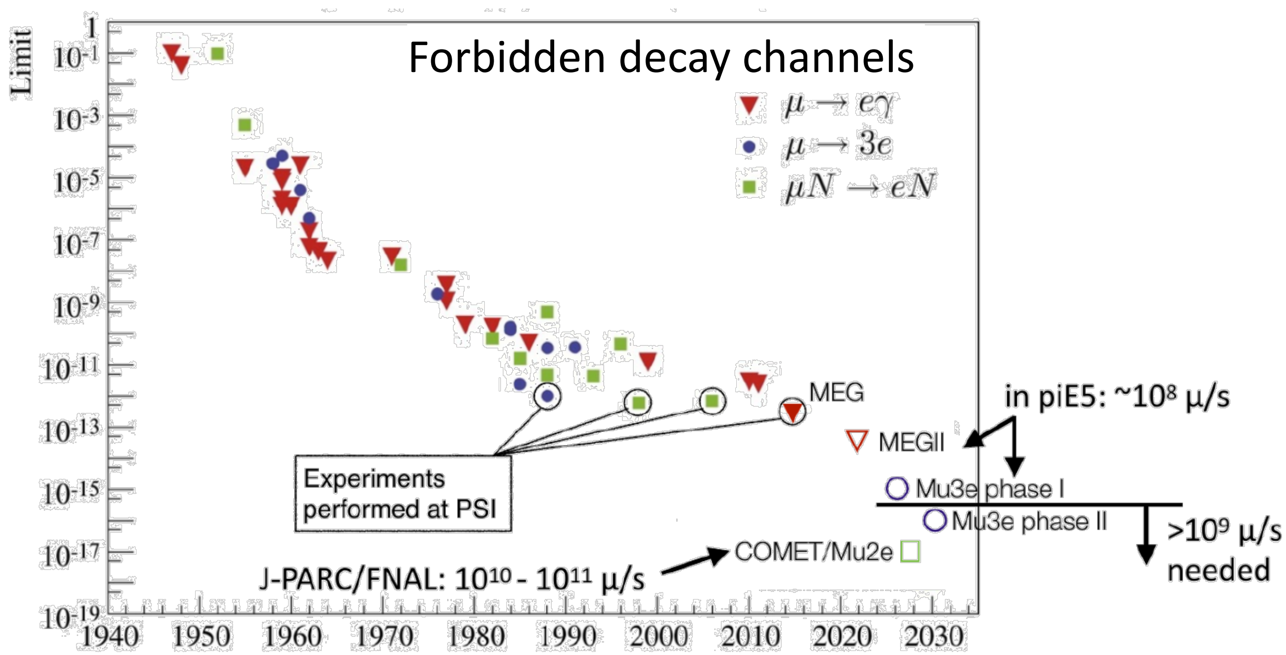
Production of muons:



28 – 120 MeV/c

Keep the competiveness for future experiments & attractiveness for users

→ HIMB



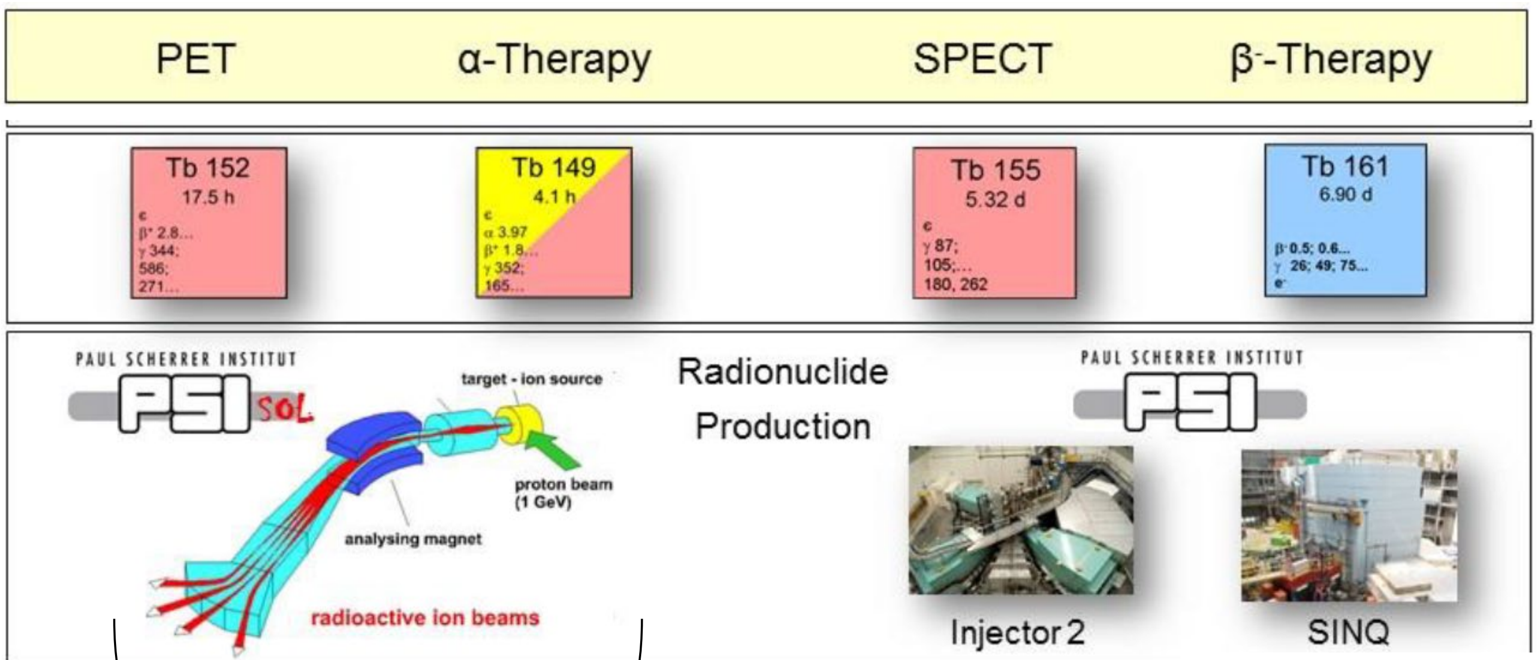
[Plot courtesy of A.Papa/A.Knecht] A. Signer

TATTOOS: Targeted Alpha Tumour Therapy and Other Oncological Solutions

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.



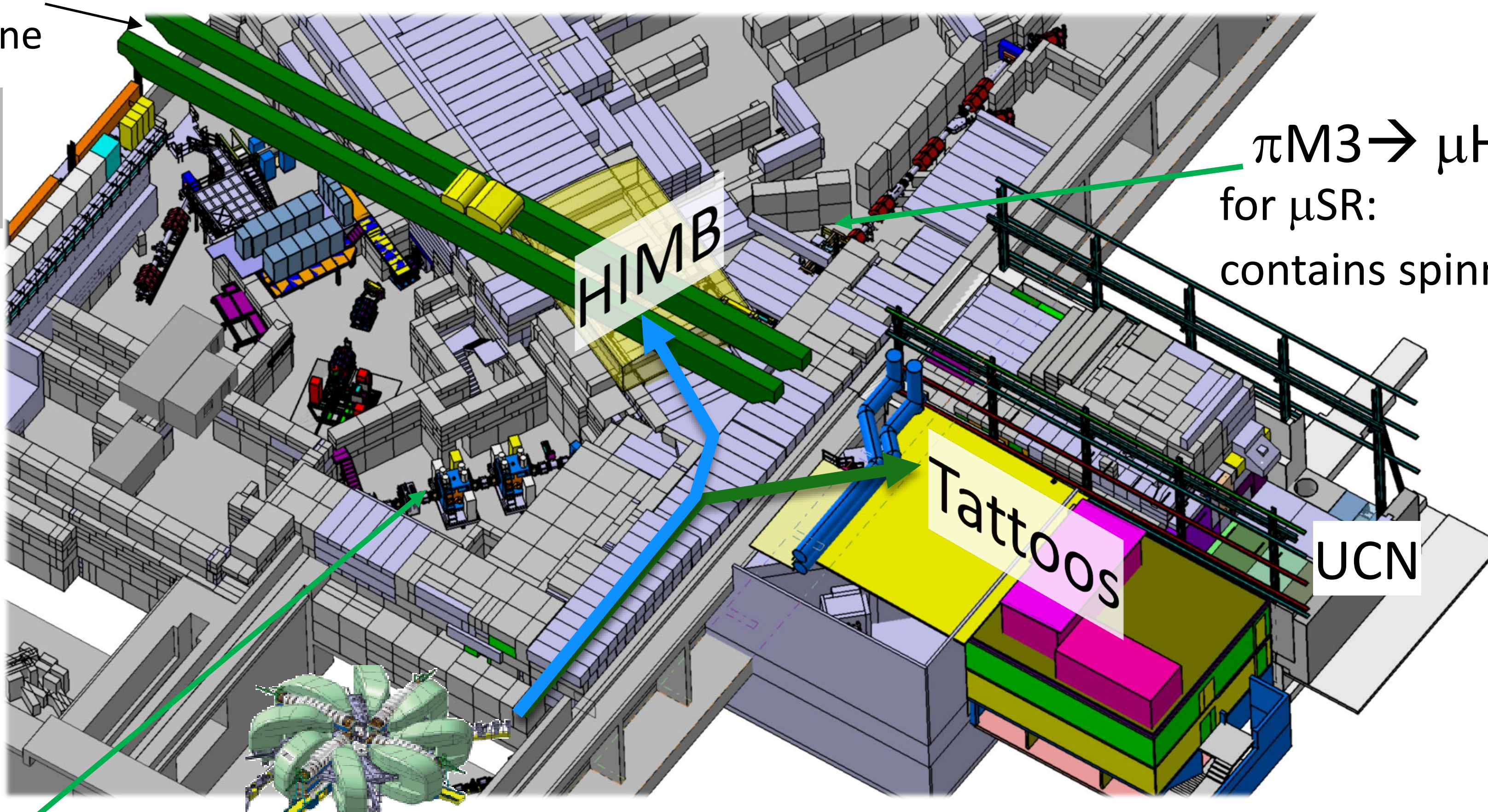
TATTOOS
590 MeV protons on Ta

IP2 (72 MeV)
^{155}Gd target

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

HIPA with HIMB and TATTOOS

This is the
60 t crane



$\pi M3 \rightarrow \mu H3$
for μSR:
contains spinrotator

590 MeV
Ring cyclotron

$\pi M1 \rightarrow \mu H2$
particle physics:
2 separators to remove positrons

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

View in the experimental hall

present TgM,
to be replaced by TgH(IMB)→ remote handling

power
supplies

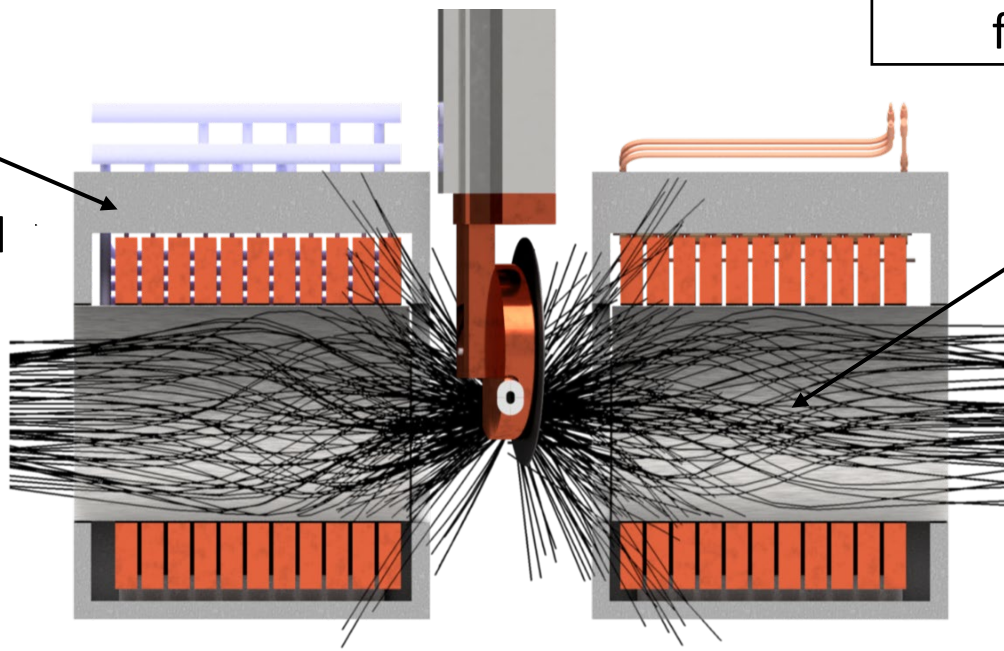
Besides the shielding a lot of infrastructure has to be removed, e.g. He cryo station
and the water cooling loop (below cryo station)
and later built-up

Concept for new target station HIMB at TgM

HIMB = High-Intensity Muon Beams

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

capture solenoid graded-field design
Ø 500 mm



up to 0.45 T field

conceptional & techn. design already advanced

- 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
  - larger rim (> 100 mm) → larger surface
  - large rotating wheel for cooling
  - small angle relative to beam
- beamline optimized for large transmission of surface muons & small losses of the proton beam

Beamline simulations from TgM/H to SINQ

Moving from 5 mm to 20 mm target:

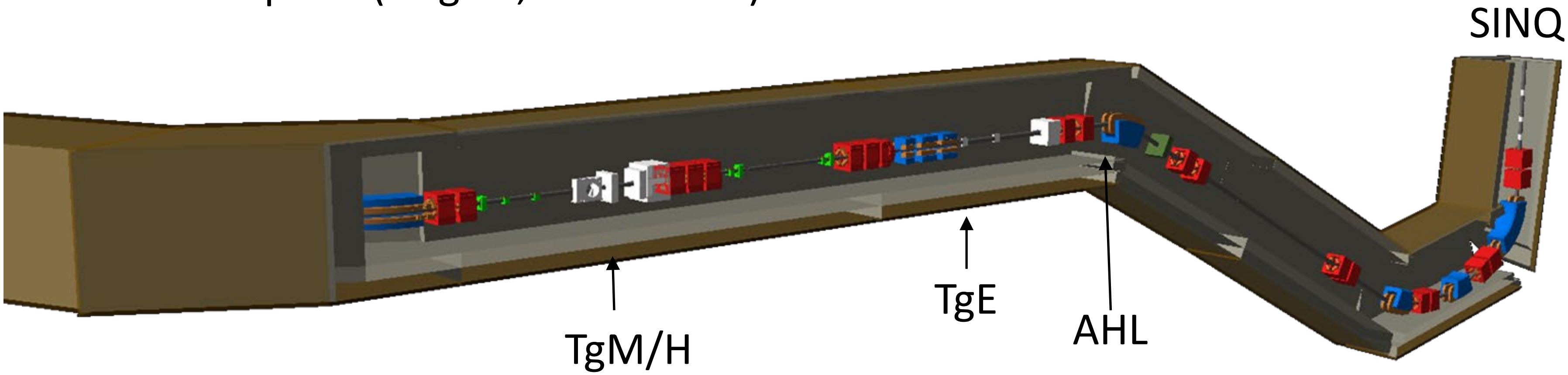
Does the remaining beam line stand the losses?

Is the transmission acceptable?

Can the fringing field from the close capture solenoids corrected?

Can the beam profile required at TgE & SINQ target be fulfilled?

Complete Beamline from Ring to SINQ in BDSIM by building GDML files, some parts (targets, collimators) from CAD



- Fixing aperture & positions of 3 collimators
- fringing field at Target H included
- non-pencil realistic beam profile before Target H/M
- sensitivity studies of non-perfect beam

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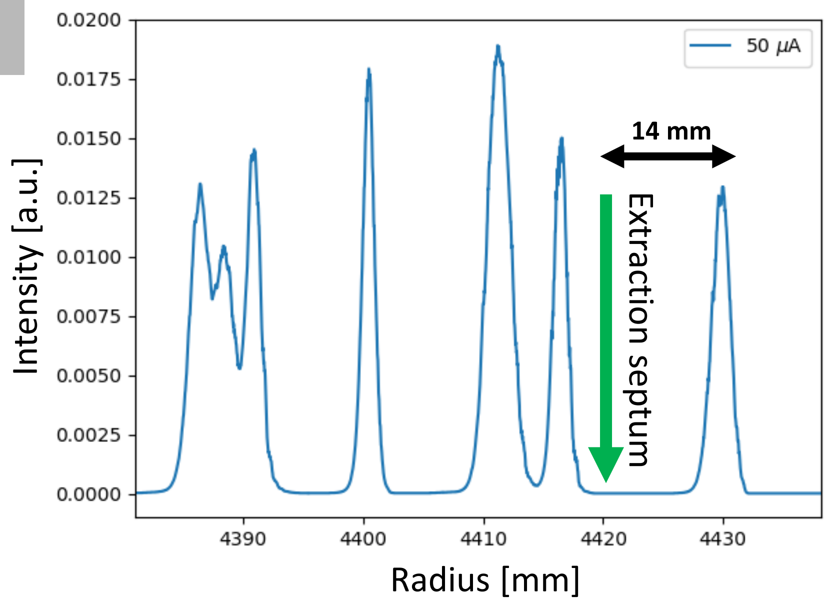
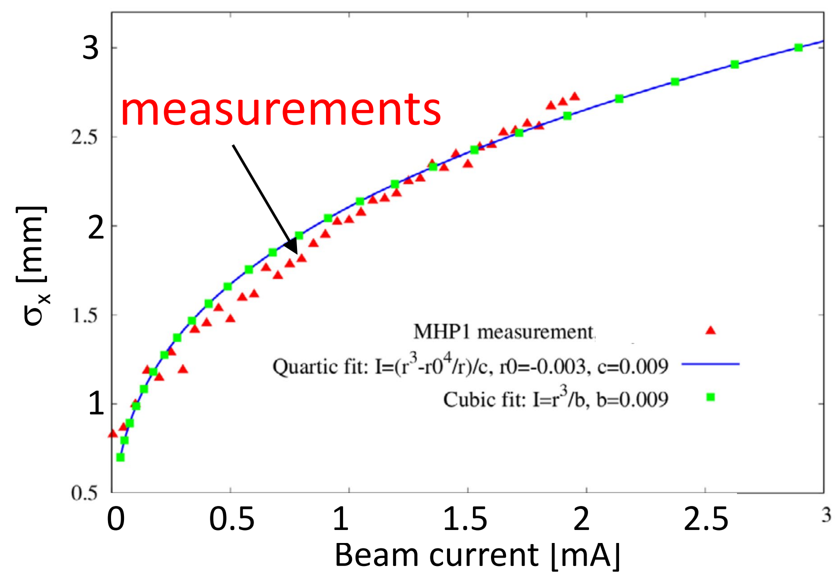
Intensity-dependent beam conditions

- The beam is injected into the cyclotron chain using a movable collimator (KIP2)



Radial probe measurement at the extraction of the PSI 590 MeV cyclotron (June 2021): Normalized bunch intensity



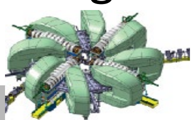
→ Energy deposition on the components and losses depend on the current.

→ Successful benchmarks of present beamline and BDSIM

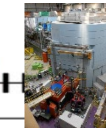
Beam envelope for 5 mm and 20 mm Target

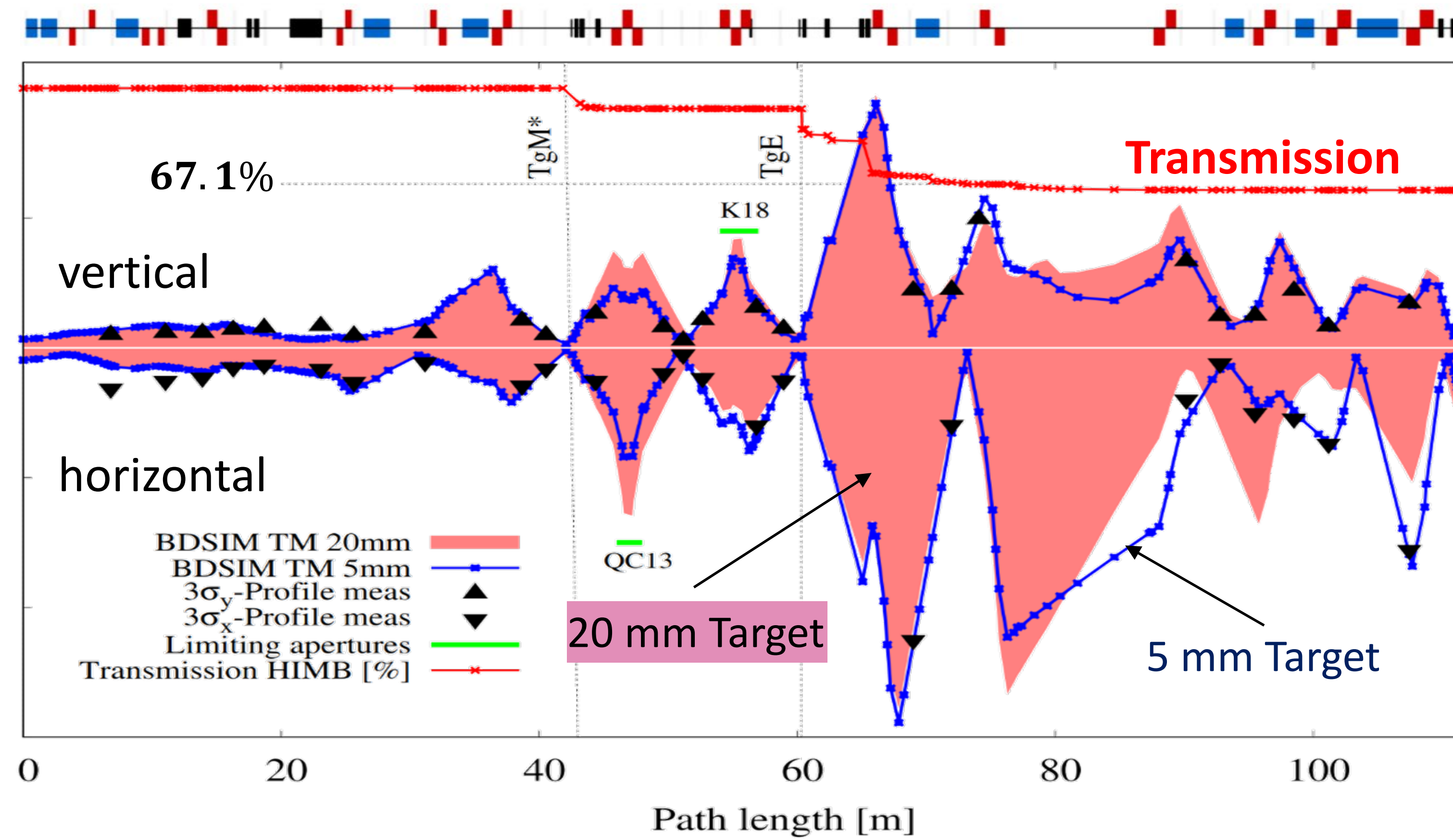
M. Haj Tahar, D. Kiselev, A. Knecht, D. Laube, D. Reggiani, J. Snuverink: NIM A1046, 167638 (2023)

Ring



SINQ



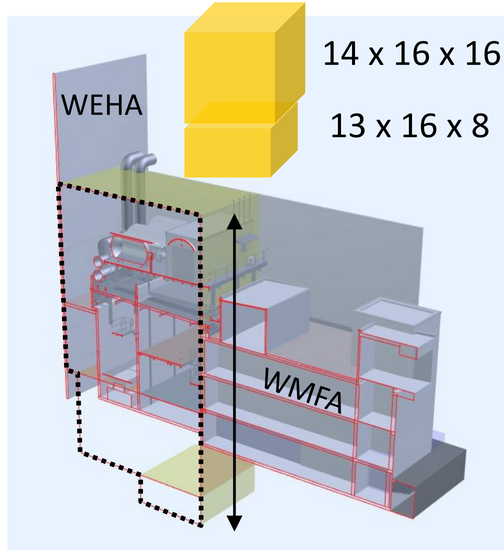


- Very good agreement between simulation and profile measurement for 5 mm TgM.
- Optics tweaked in TgM-TgE region to minimize beam losses.
- Energy spread after TgE about a factor of 2 larger for HIMB.
- Optics tweaked by ±3 % after TgE (strength of Quads).

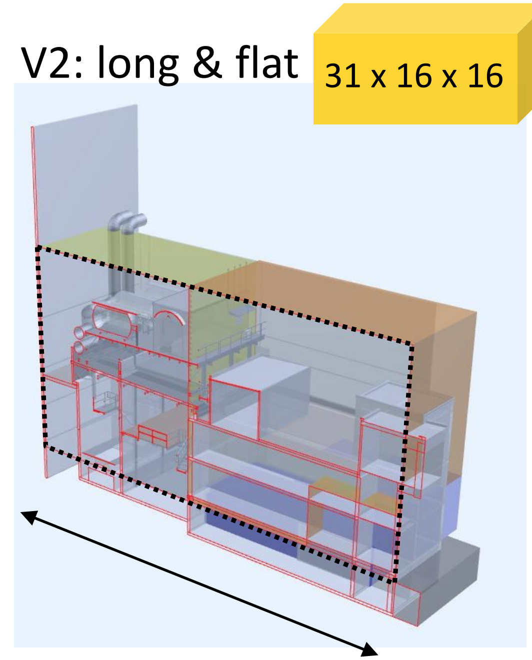
Transmission ~ 67 %
(main losses before TgE)

TATTOOS: Building variants

V1: small & deep



V2: long & flat



Several rebuildings

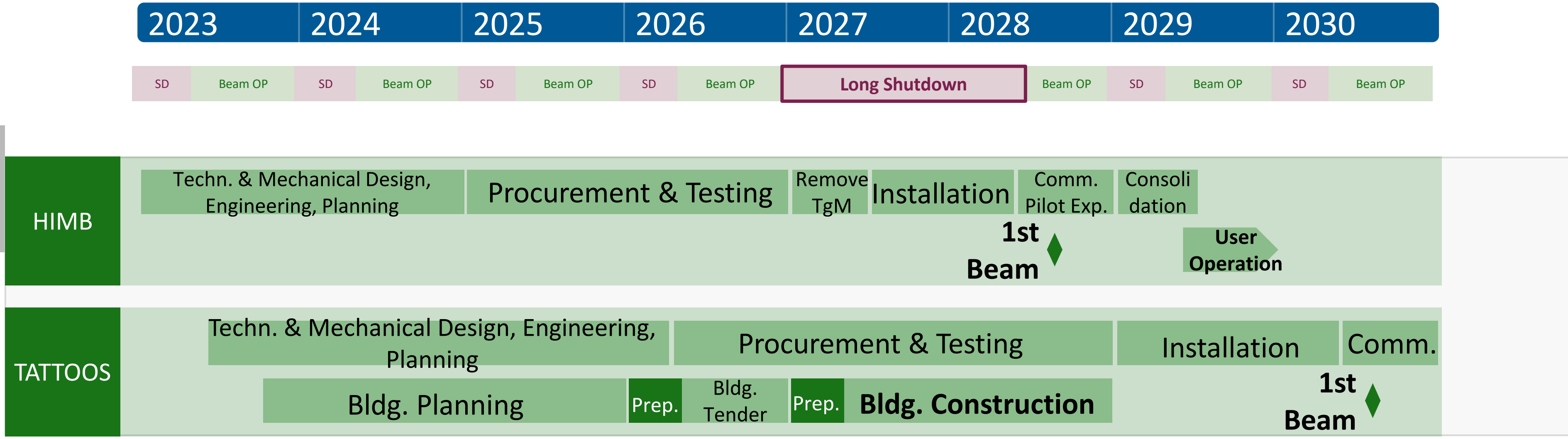
- UCN-D_2 reservoir,
- UCN He buffer tank
- UCN electr. infrastructure
- UCN control room
- WEHA transformers
- PROSCAN ventilation
- SULTAN media pipes
- waste water pipes etc

Up to 14 m deep, difficult & expensive due to small space & close to fundament WEHA

~ 50 % larger but half of cellar will be kept (D_2 water tanks for UCN & entry to active cooling station)

Lots of infrastructure for HIPA, UCN, PROSCAN, SULTAN have to be removed before start of construction

Time schedule



HIPA: 2027 no beam

→ Installation of HIMB

→ 2028 first beam with new target station H

TATTOOS: New building necessary → Realization 2 years after HIMB

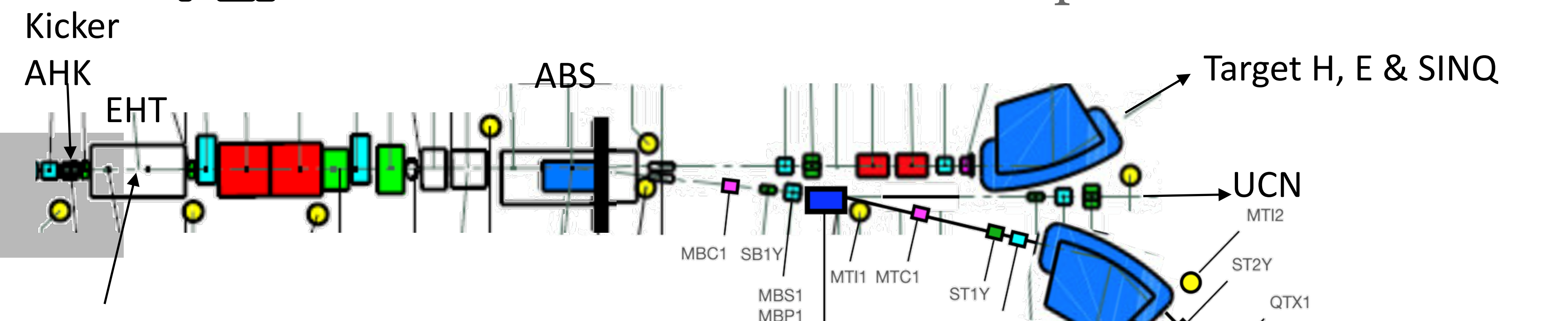
<u>Advantages:</u>

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

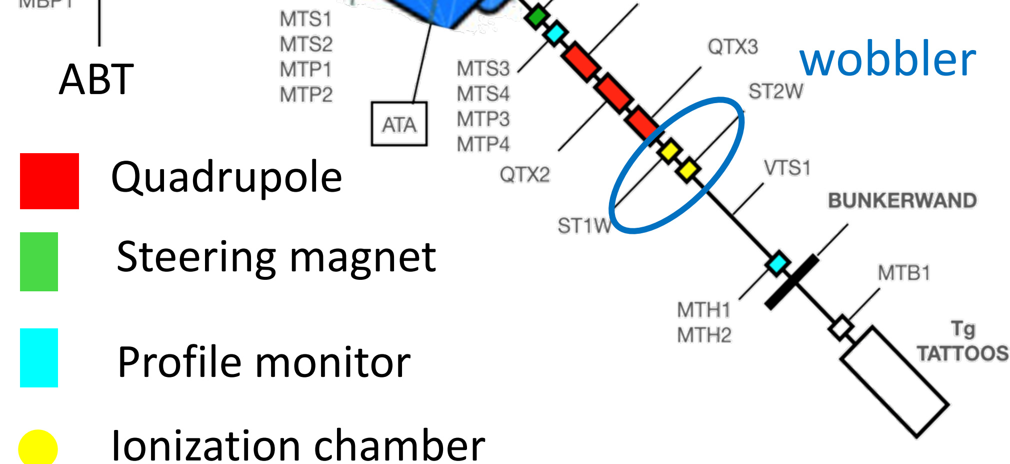
→ less shortage on storage place for new components, shielding

→ more PSI resources available, less temporary hired staff

Beamline to TATTOOS and operation modes



<u>Splitter:</u> made for max. 20 μA
used for Piotron, Pyrex
Olivo, M., Mariani, E. and Rossetti, D.
An electrostatic beam splitter for the PSI 590 MeV - 1MW proton beam line (1998).



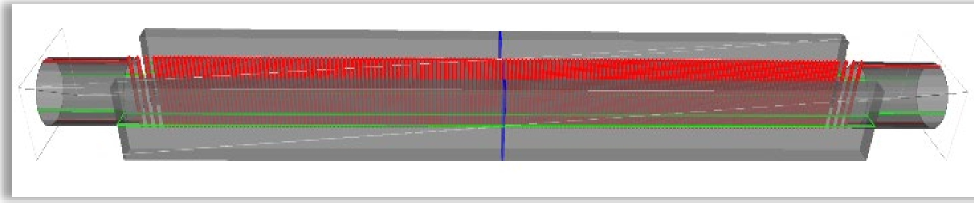
<u>Beam operation:</u>

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

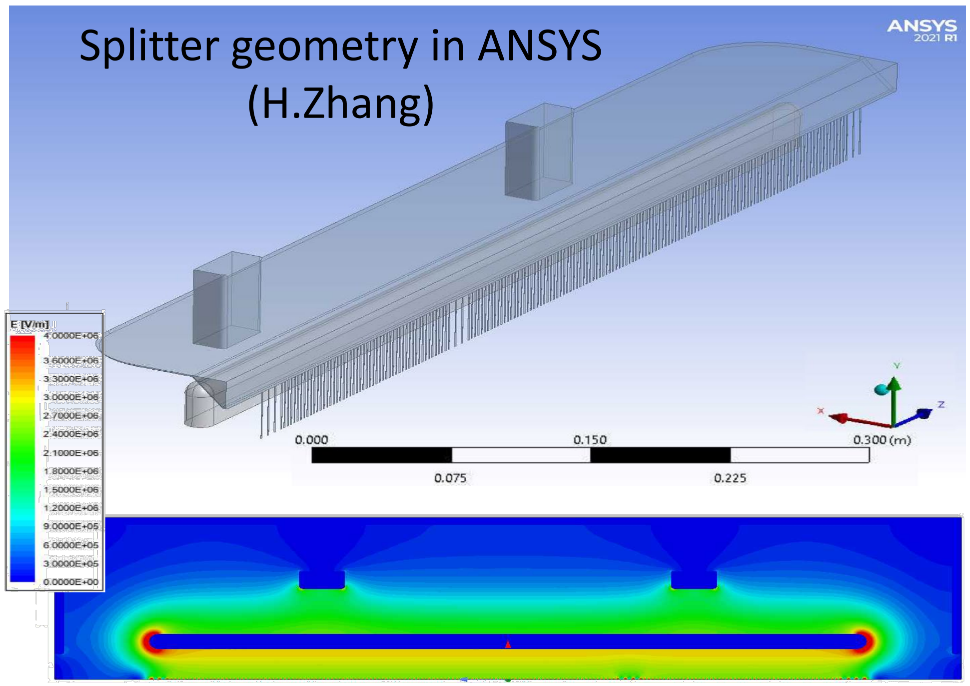
TATTOOS Target:
10 cm Ta (Phase 1),
later U or Th

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

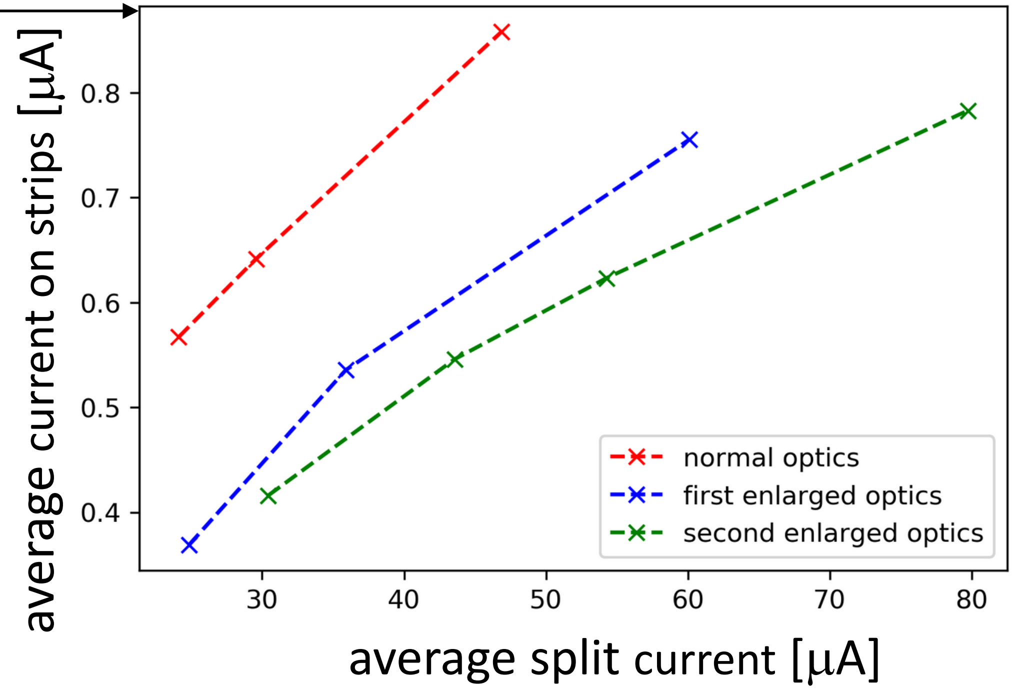


Electric field map,
resolution :
25 μm by 3000 μm by 500 μm

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

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

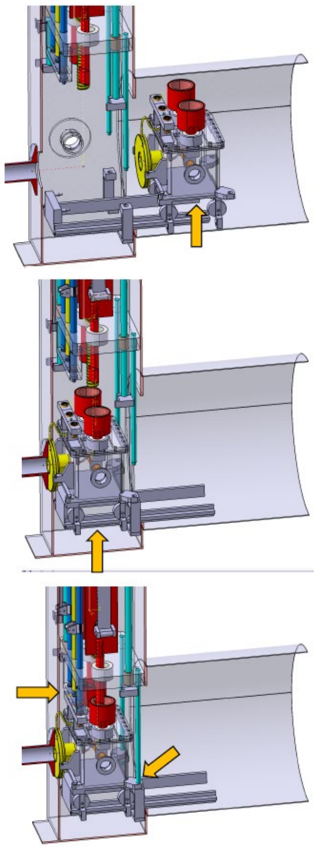
→ dose rate measurements above proton beam line are analyzed

→critically, since the beamline is maintained hands-on

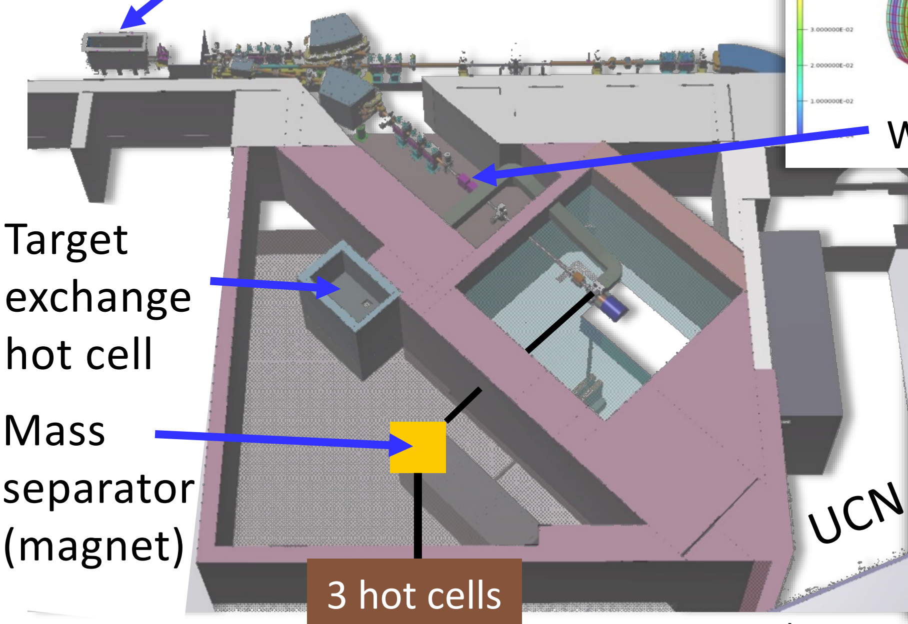
→ further measurement (dose rates) & simulations needed

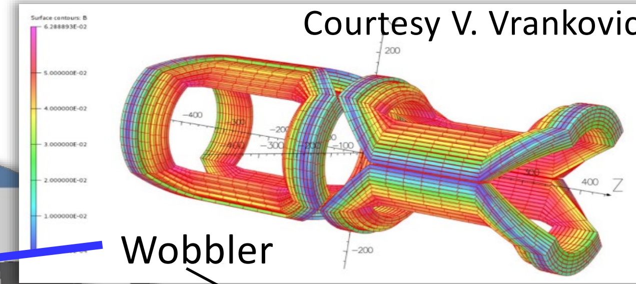
2023: larger beam optic with water cooled quadrupoles should be possible

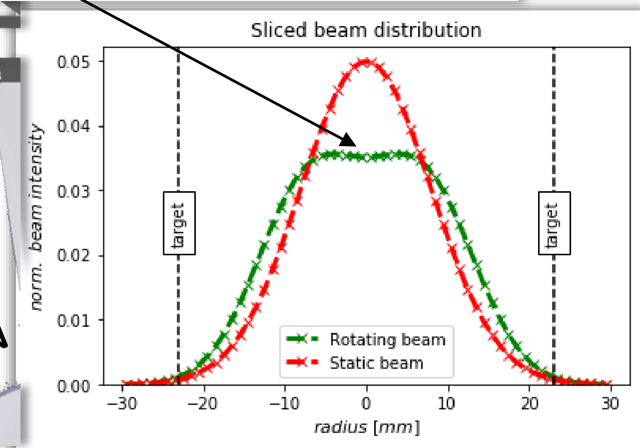
TATTOOS target station



Coupling of target to media supply







Beam profile on 10 cm Ta
→ challenging to cool

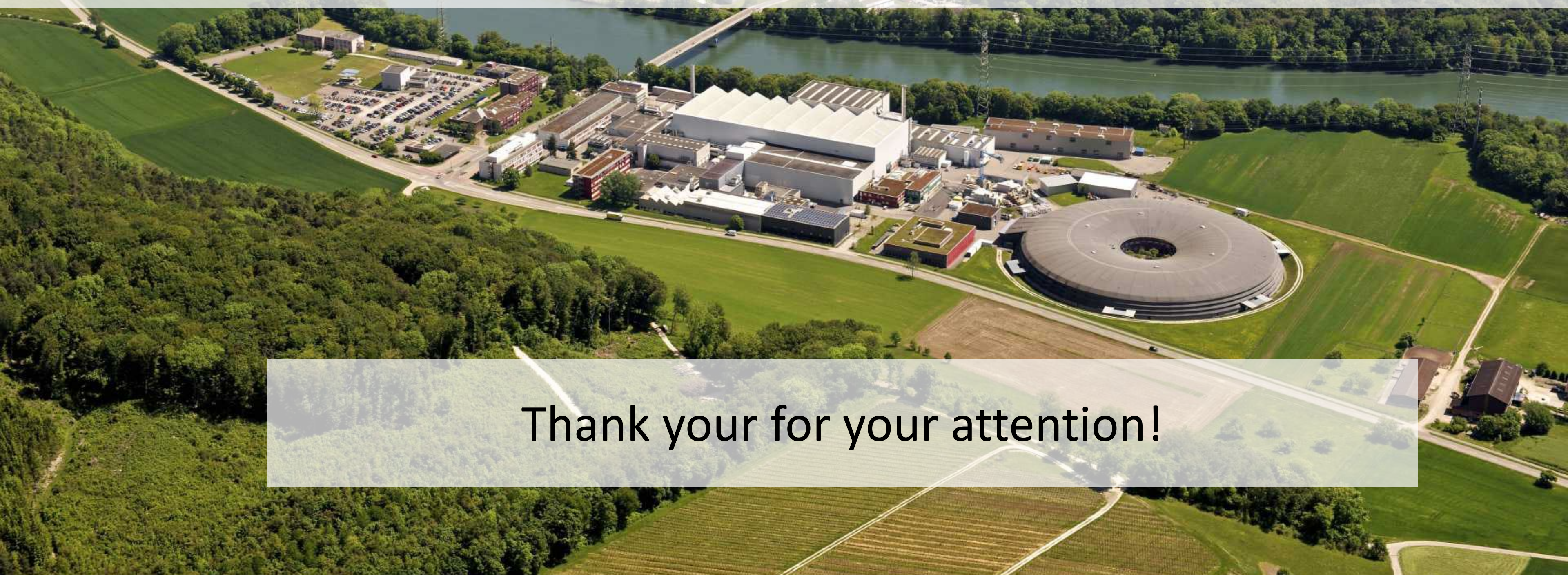
<u>Separation of ions</u>

by RILIS (Resonance Ionization Laser Ion Source)
& ISOL (Isotope Separation Online)
& chemistry

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

Summary

- IMPACT: a 77 MCHF project to upgrade the existing meson production station M
  & a 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
  - CDR finished Jan. 2022, TDR planned for end of 2024



Thank your for your attention!