High Intensity Muon Beam project (HIMB): how to improve the most intense muon beam in the world

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Joint Annual Meeting of the APS SPS, Universität Innsbruck

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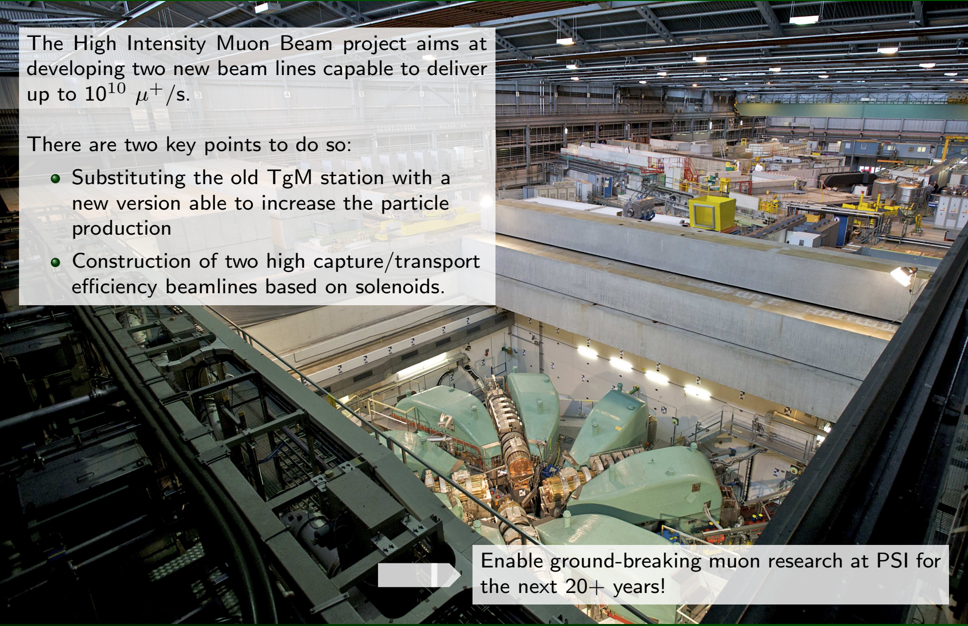
The HIMB project



The High Intensity Muon Beam project aims at developing two new beam lines capable to deliver up to 10^{10} μ^+/s.

There are two key points to do so:

- Substituting the old TgM station with a new version able to increase the particle production
- Construction of two high capture/transport efficiency beamlines based on solenoids.

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

Muon beams at PSI: how do we produce muons?

The High Intensity Proton Accelerator (HIPA) facility

We produce the muons impinging a 590 MeV, 1.4 MW proton beam (world record) on two targets: Target M (TgM, 5 mm thick) and Target E (TgE, 40 mm thick). At the end, the beam is stopped in a spallation target to provide neutrons (SINQ).

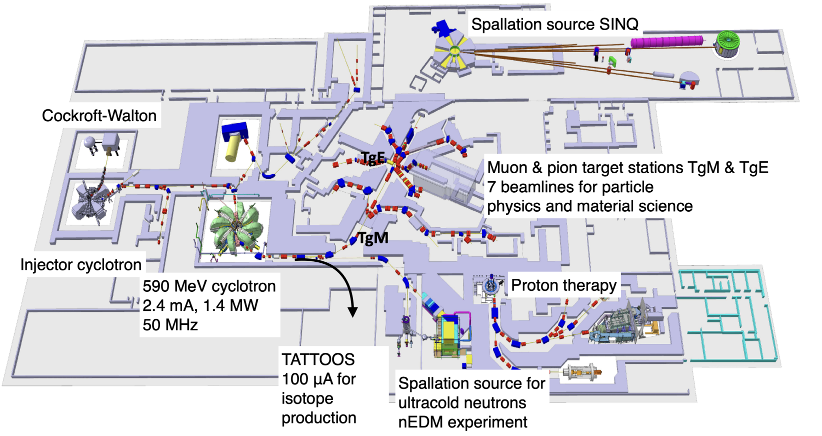
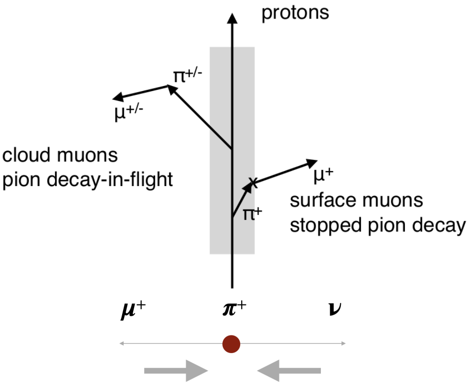


Figure: *The proton accelerator complex at PSI.*

Muons production

The protons impinge on TgM and TgE, producing pions that decay in muons. Depending on where they are created, we classify:

- Surface and sub-surface muons (5-30 MeV/c): they are created inside the target from pions at rest as a monochromatic line of 29.8 MeV/c of momentum. Therefore their energy depends only on their path inside the target. Additionally they are fully polarized.
- Cloud muons: they come from pions decay in flight.



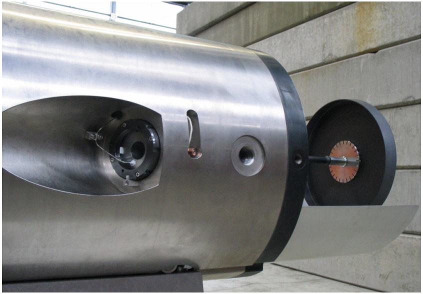
Due to the high intensity and low momentum, the most interesting muons for many experimental applications are surface muons: the HIMB project focuses on the transport of muons with a momentum around 28 MeV/c.

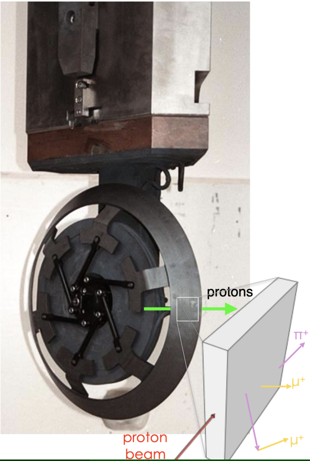
1st step: target H

Target M and Target E

Currently the mesons are produced at two rotating wheels, radiation cooled, polycrystalline graphite targets.

- TgM: 5.2 mm thick, 5 kW energy deposit @2.2 mA
- TgE: 40 mm thick, 40 kW energy deposit @2.2 mA. Delivers the most intense continuous surface muon beams.

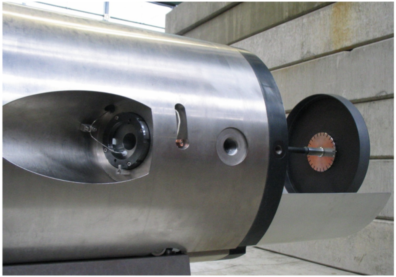




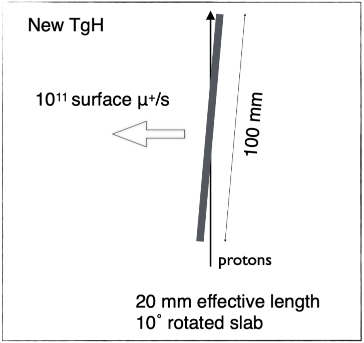
Target H

The plan is to substitute the existing Target M station with a High intensity one using a slanted target geometry:

- 5 mm TgM $\rightarrow$ 20 mm TgH
- 10 deg rotation angle w.r.t. the proton beam, as efficient (surface μ) as a standard 40 mm TgE
- muon collection sideways
- Slanted geometry tested at TgE to significantly enhance the surface muon yield

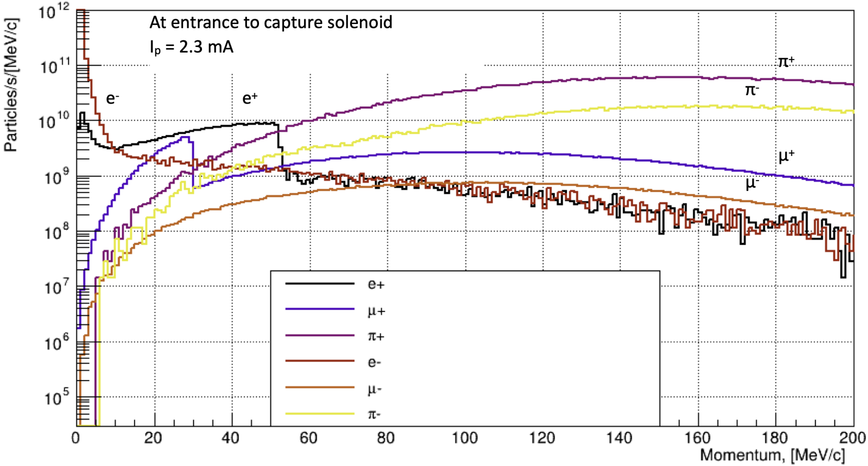


Existing TgM



Particle production at TgH

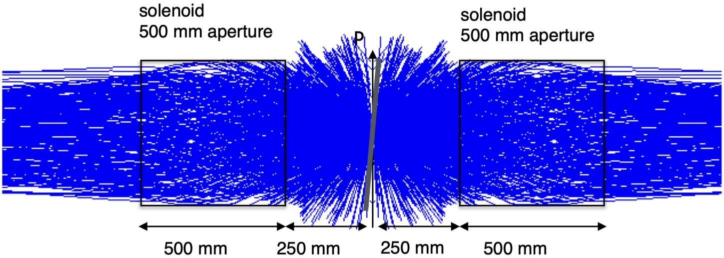
We don't produce only muons of course!



The plan is to design dipoles up to 80 MeV/c.

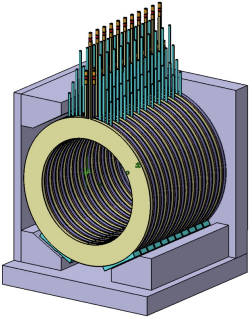
2nd step: capture and transport efficiency improvement $\rightarrow$ the beamlines

Split capture solenoids



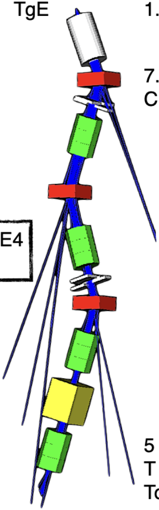
We can't surround our target with a unique solenoid (SINQ) → let's split it:

- Two normal conducting, radiation-hard solenoids close to the target for capture (very similar to the ones used in the existing μE4 beamline at PSI)
- Central field $\sim$ 0.4 T



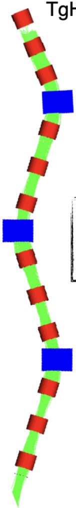
Solenoid-based beamlines

Existing μE4 beamline



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

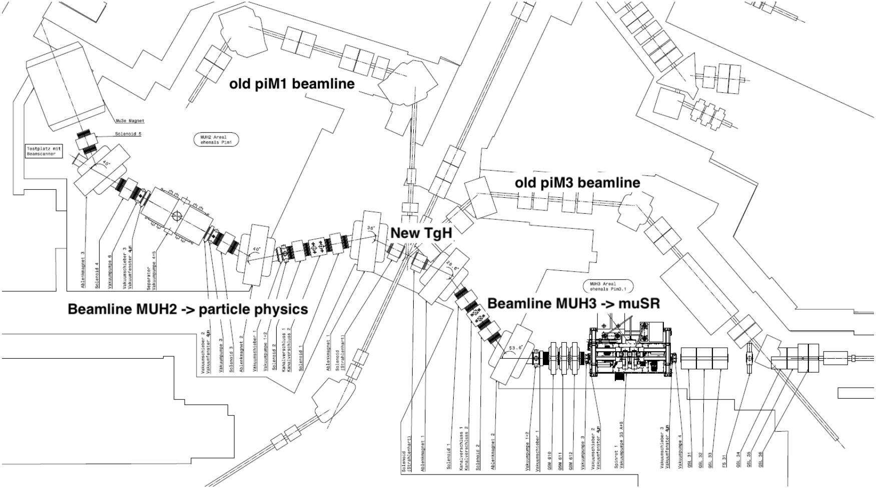
⇨ Gain due to high capture and transmission efficiency



Solenoid-based beamline

Beamline layout

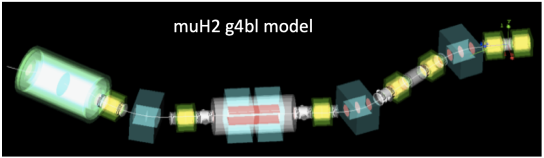
Two new high intensity muon beamlines at 90 deg angle w.r.t. the proton beam. We have started with the single element position optimization.

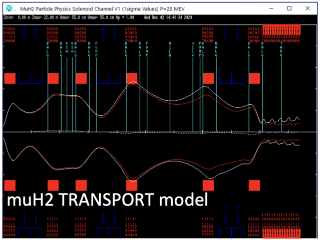


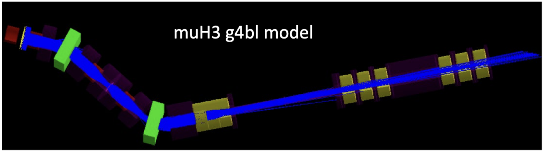
Simulation tools

To do so, we have simulation and optimization tools:

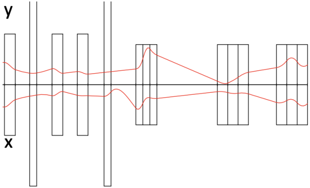
- Simulation:
  - TRANSPORT, COSY INFINITY: optical model programs
  - g4bl: single particle tracking based on Geant4, with in-house parametrised cross sections for pion production, tested with the results in μE4 design and 2019 TgE test
- Optimization: grid searches and hyperparameter searches







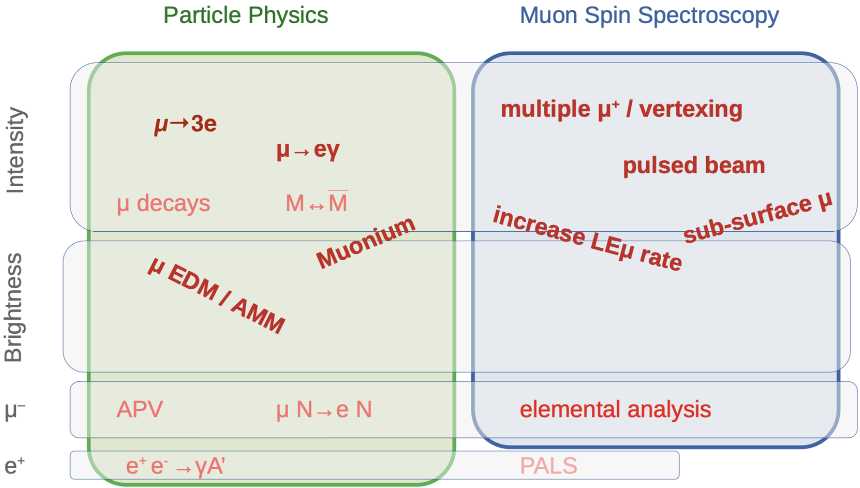
muH3 COSY INFINITY model



What to do with HIMB? Motivations

Science Case Workshop

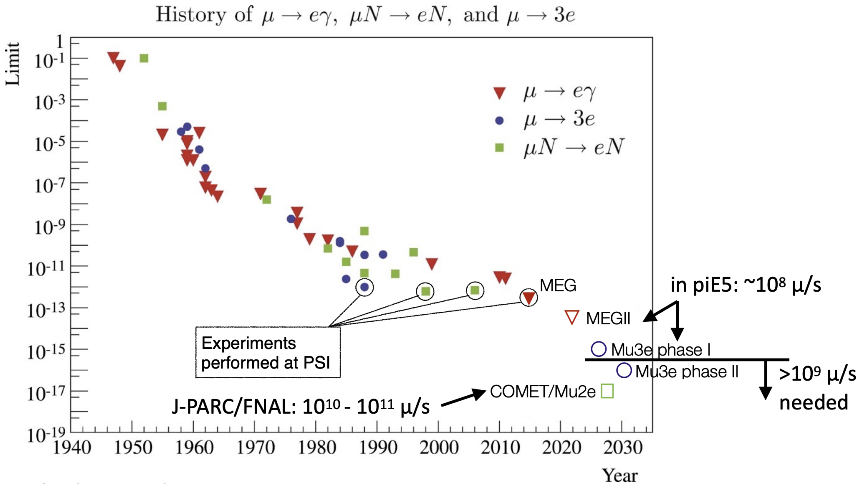
We had a science case workshop between 6-9 April 2021.



https://indico.psi.ch/e/himbws

Charged Lepton Flavor Violation

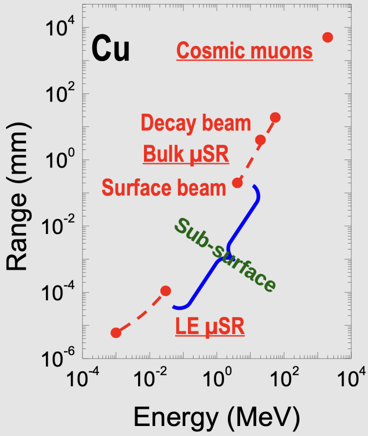
For $\mu^+ \to e^+\gamma$ and $\mu^+ \to e^+e^-e^+$ it is very important to have DC beams and intensity-frontier machines, such as HIPA.



μSR

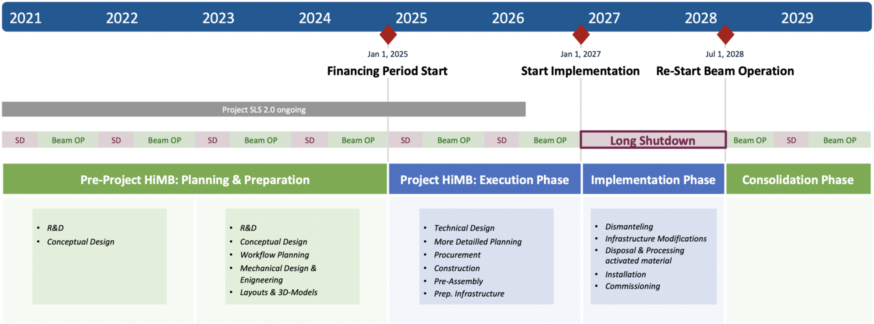
With μSR measurements it is possible to probe the magnetic properties of a material, and the energy of the muons define the depth in the sample. HIMB would allow to:

- Increase the Low Energy muons ($<$ 30 keV) rate by > 10: currently $\sim$ 4.5 10^3 μ/s, because they are degraded surface muons
- Allow to explore the sub-surface gap in depth: the surface muons peak is sharp



Conclusions

Timeline


2021
2022
2023
2024
2025
2026
2027
2028
2029
Jan 1, 2025
Financing Period Start
Jan 1, 2027
Start Implementation
Jul 1, 2028
Re-Start Beam Operation
Project SLS 2.0 ongoing
SD
Beam OP
SD
Beam OP
SD
Beam OP
SD
Beam OP
SD
Beam OP
SD
Beam OP
Long Shutdown
Beam OP
SD
Beam OP
Pre-Project HiMB: Planning & Preparation
Project HiMB: Execution Phase
Implementation Phase
Consolidation Phase
R&D
Conceptual Design
R&D
Conceptual Design
Workflow Planning
Mechanical Design & Enigneering
Layouts & 3D-Models
Technical Design
More Detailled Planning
Procurement
Construction
Pre-Assembly
Prep. Infrastructure
Dismanteling
Infrastructure Modifications
Disposal & Processing activated material
Installation
Commissioning

Conclusions

A lot of work still to be done, but we are on track to achieve such a result.

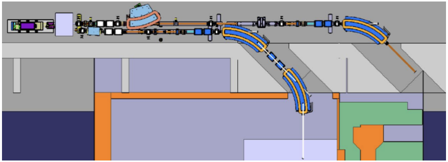
Thank you for your attention!

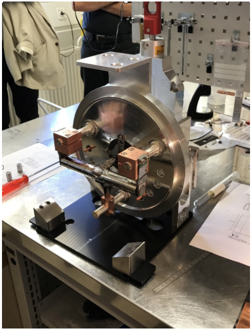
Back-up

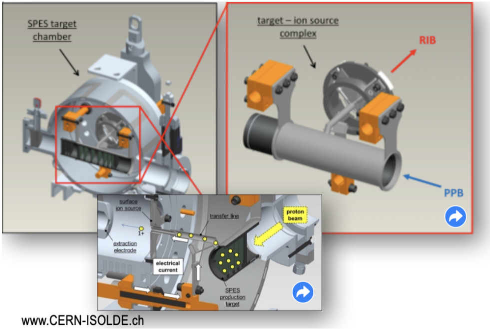
TATTOOS: Targeted Alpha Therapy using Terbium and Other Oncological Solutions

This project aims at producing radionuclides for oncological treatments, focusing mostly on Alpha therapy with ^{149}Tb.

The plan is to stripe the proton beam right after RING, and to collect ~ 100 μA to produce radionuclides.





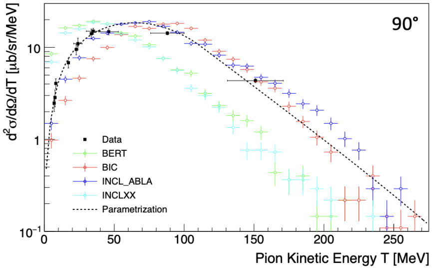


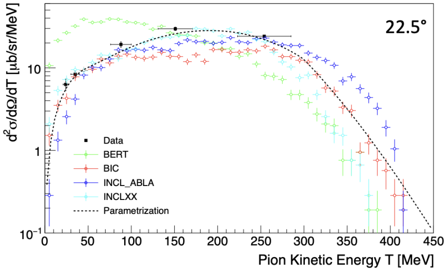
π cross section

The models distributed with Geant4, perform poorly or they are valid only on specific proton energies and scattering angles.

Therefore we implemented a data-based parametrization valid for protons up to $<$ 1000 MeV kinetic energy, at all scattering angles and materials.

$\rightarrow$ Reliable at 10 % level.





μSR

With μSR measurements it is possible to probe the magnetic properties of a material: with a fully polarized muon beam you can measure the polarization resulting from the interaction with the sample. The energy of the muons define the depth in the sample.

For surface muons, the limit in rate is due to the apparatus: one muon at a time inside the sample $\rightarrow$ max O(30 kHz). Under development: multiple μ measurements. The detectors development aims at switching to a vertexing approach