High Intensity Muon Beams at PSI

Giovanni Dal Maso

Interim review - Intense

H2020 MSCA ITN
G.A. 858199

Bachelor and Master degrees

- Born in Cuneo and grown up in Siena, Italy
- Bachelor in Physics at University of Pisa, 2015-2018
- Master in Fundamental Interactions at University of Pisa, 2018-2020. Thesis title: "Beam diagnostic and calibration tools for the MEGII experiment".
- Started Ph.D. at PSI - ETH Zürich on March 2021

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Lectures and teaching

Courses for PhD credits at ETH Zürich:

- autumn 2021:
  - "Learning to Teach": this course imparted a variety of teaching skills that help Doctoral Teaching Assistants with their teaching tasks
  - "Astronomical Observations and Instrumentations": course focused on the main and recent astronomical observations and description of the most relevant employed instrumentations
- spring 2022:
  - Joint Universities Accelerator School, COURSE 2: technology and applications of particle accelerators
- summer 2022:
  - Engaging Physics Tutoring Summer Camp
  - PSI Particle Physics Summer School - Vision and Precision
- autumn 2022:
  - Pluralist Philosophy of Mathematics: the goal is to introduce students to mainstream philosophies of mathematics.

Teaching at ETH Zürich:

- autumn 2021: Physics 1 exercise class for Medicine and Health Sciences students
- spring 2022: Physics 2 exercise class for Medicine and Health Sciences students
- autumn 2022: Physics 1 Übungschef for Medicine and Health Sciences students

Conferences

Training:

- 20-21 May 2021: *First Muon Community Meetint* (Muon Collider Workshop), Online
- 2-4 August 2021: *Fermilab 2021 Summer Student School at LNF*, Laboratori Nazionali di Frascati INFN Online
- 6-8 September 2021: *Shedding light on X17*, Centro Ricerche Enrico Fermi, Rome Online
- 24-26 November 2021: *International Workshop on Cosmic-Ray Muography (Muography2021)*, Ghent Online
- 4-6 July 2022: *LF(U)V Workshop*, Universität Zürich.

Conferences and workshops:

- 6-9 April 2021: *HIMB Physics Case Workshop*, PSI - Paul Scherrer Institut Online
- 10-11 June 2021: *CHIPP Plenary 2021*, Spiez Switzerland. Poster:"High Intensity Muon Beam project(HIMB): how to improve the most intense muon beam in the world"
- 30 August-3 September 2021: *Joint Annual Meeting of the APS SPS*, Universität Innsbruck. Talk: "High Intensity Muon Beam project (HIMB): how to improve the most intense muon beam in the world"
- 22-28 May 2022: *Pisa Meeting on Advanced Detectors - Edition 2022*, La Biodola - Isola d'Elba, Italy. Poster: "Beam monitoring detectors for High Intensity Muon Beams" + proceedings
- 27-30 June 2022: *Annual Meeting of the Swiss Physical Society*, Université de Fribourg. Talk: "High Intensity Muon Beam (HIMB): how to improve the most intense muon beam in the world"
- 29 August - 2 September 2022: *8th International Symposium on Symmetries in Subatomic Physics*, Universität Wien. Invited talk + proceedings: "Future facilities at PSI, the High-Intensity Muon Beams (HIMB) project".
- 16-21 October 2022: *Physics of fundamental Symmetries and Interactions - PSI2022*, Paul Scherrer Institut. Poster: "Multi-Objective Genetic Optimization for the High-Intensity Muon Beams at PSI".

Publications

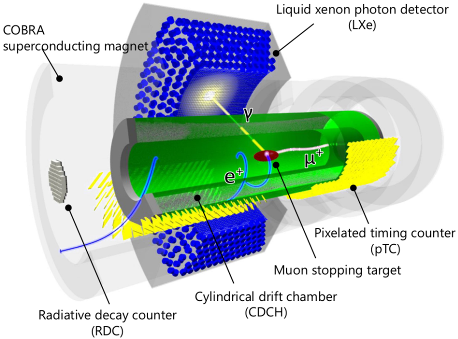
Publications:

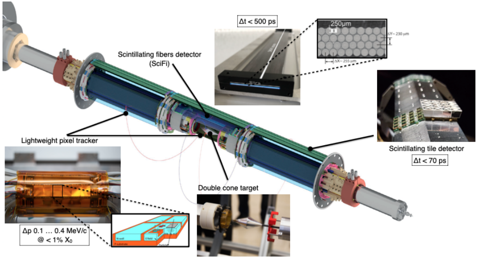
- A. Baldini et al., "The Search for $\mu^+ \to e^+\gamma$ with 10–14 Sensitivity: The Upgrade of the MEG Experiment", Symmetry 2021, 13(9), 1591 (https://doi.org/10.3390/sym13091591);
- M. Aiba et al., "Science Case for the new High-Intensity Muon Beams HIMB at PSI", arXiv:2111.05788.
- Eichler, R. et al. "IMPACT conceptual design report", (PSI Bericht, Report No.: 22-01). Paul Scherrer Institut.
- G. Dal Maso et al., "Beam monitoring detectors for High Intensity Muon Beams", Nucl. Instrum. Methods A (in press)
- G. Dal Maso et al., "Future facilities at PSI, the High-Intensity Muon Beams (HIMB) project", EPJ Web of conferences (submitted)

ΠE5 area

MEG II and Mu3e experiments

The goal of the MEG II experiment is to measure the decay $\mu^+ \to e^+ \gamma$. The current limit on this process - most stringent upper limit on any particle decay - was set by the MEG collaboration at PSI to B($\mu^+ \to e^+ \gamma$) $< 4.2\ 10^{-13}$ (90 % CL). The upgrade aims at reaching a sensitivity of 6 10^{-14} (90 % CL).

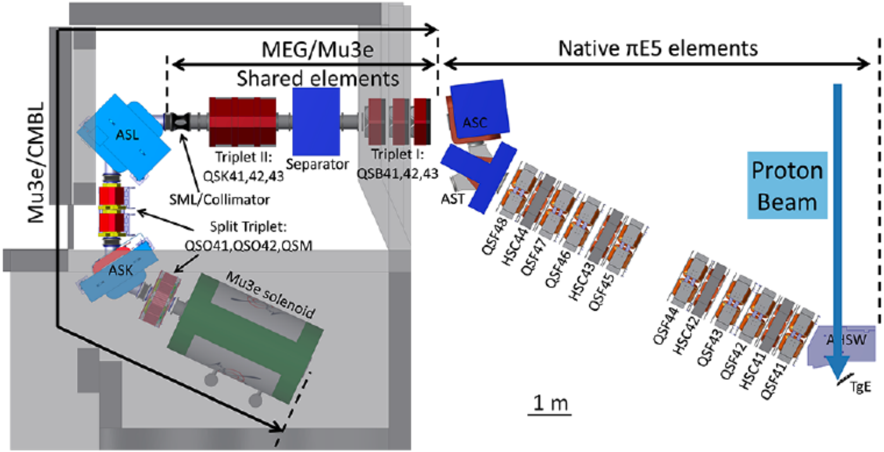




The goal of the Mu3e experiment is to measure the decay $\mu^+ \to e^+ e^- e^+$. The current limit on this process was set at 1.0 10^{-12} (90 % CL) by the SINDRUM II collaboration at PSI. The Mu3e collaboration aims at reaching a sensitivity of 2 10^{-15} (90 % CL) in its first phase, and 10^{-16} (90 % CL) in the second one.

Mu3e: Compact Muon BeamLine (CMBL) commissioning

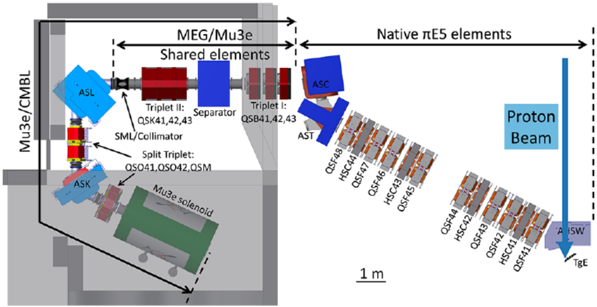
Within the Mu3e experiment I contribute to the commissioning of the beamline: the Compact Muon BeamLine (CMBL).



Mu3e: Compact Muon BeamLine (CMBL) commissioning

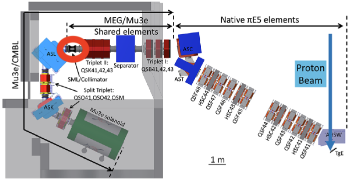
Within the Mu3e experiment I contribute to the commissioning of the beamline: the Compact Muon BeamLine (CMBL). Due to the lack of space the triplet wich couples the beam inside the Mu3e solenoid is "split" in two parts.

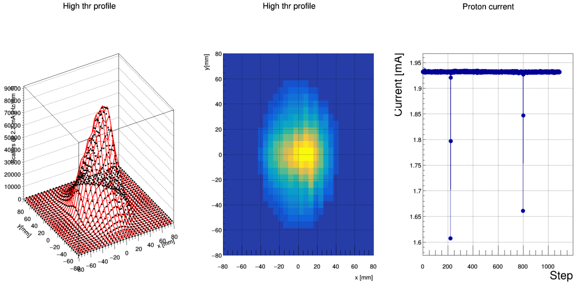
The first complete installation and commissioning was performed in 2021. The aim was to provide a first beam tune for the Pre-Ingeneering run of Mu3e in 2021.
In 2022 we focused on improving the transmission through the beamline.
The main difficulty is coupling straight after the first bend due to the limited aperture of the QSO doublet.



Mu3e: Compact Muon BeamLine (CMBL) commissioning - 2022

We started from settings as obtained after 2019 campaign, obtaining 2.26 10^8 μ^+/s @ 2.2 mA. Last year we got to 1.93 10^8 μ^+/s @ 2.2 mA.





Spline xMPV = 6.64 mm, xMPV_STD = 18.57 mm
Spline yMPV = 2.10 mm, yMPV_STD = 20.66 mm
Spline ρ = 0.026
x = 0.87 mm, xSTD = 18.22 mm
y = 1.42 mm, ySTD = 23.20 mm
ρ = 0.083
Spline rate: 2.26e+08 μ^+/s @ 2.2 mA

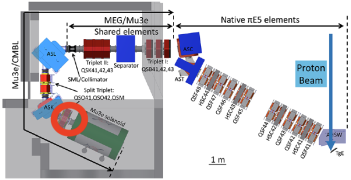
Figure: *Final settings beam profile at collimator*

Mu3e: Compact Muon BeamLine (CMBL) commissioning - 2022

Compared to last year:

- **2021:** 1.1 10^8 μ^+/s @ 2.2 mA, 57 % transmission to QSM
- **2022:** 1.65 10^8 μ^+/s @ 2.2 mA, 73 % transmission to QSM

+ increase by 17 % in rate at collimator.



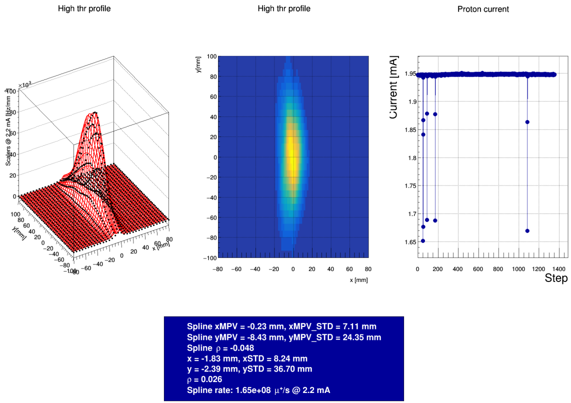
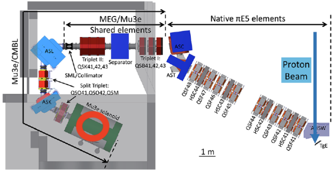
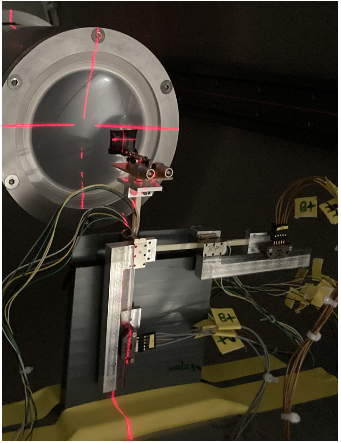


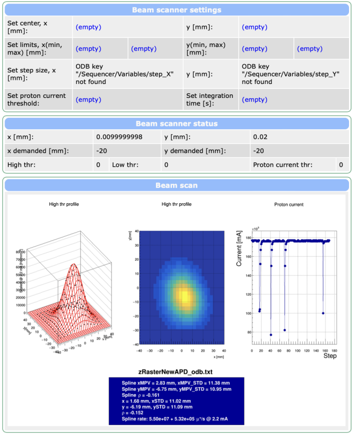
Figure: *Focused beam profile, SEP41 at 180 kV with inner collimator removed.*

Mu3e: Compact Muon BeamLine (CMBL) commissioning - 2022

Measurements at solenoid center are performed using an Avalanche PhotoDiode (APD), moved by two piezoelectric motors with optical encoders. The whole scanner was built by Ioannis. This year we ran with a MIDAS front-end.

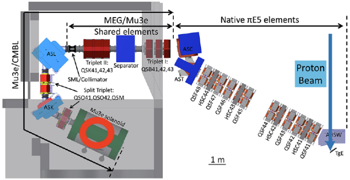






Mu3e: Compact Muon BeamLine (CMBL) commissioning - 2022

Transmission to the solenoid center is limited by the 60 mm beam pipe (-44 %) and by the 40 mm window (-27 % w.r.t. 60 mm beam pipe configuration) at the end, leading to an overall 59 % loss in transmission. w.r.t. QSM41.



Beam Commissioning Comparison @ 2.2 mA			
Rates	Collimator	QSM41	Mu3e
2021	1.93 10^8 μ^+/s	1.1 10^8 μ^+/s	4.36 10^7 μ^+/s
2022	2.26 10^8 μ^+/s	1.65 10^8 μ^+/s	6.83 10^7 μ^+/s

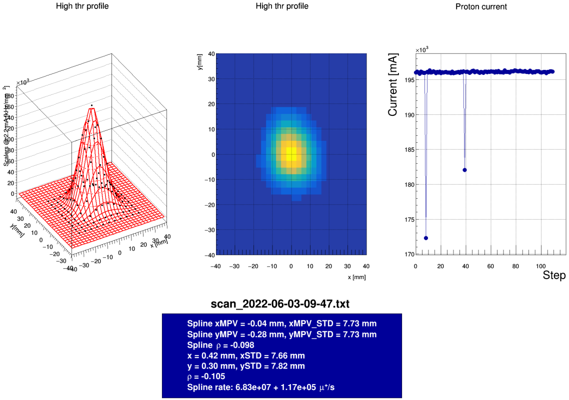
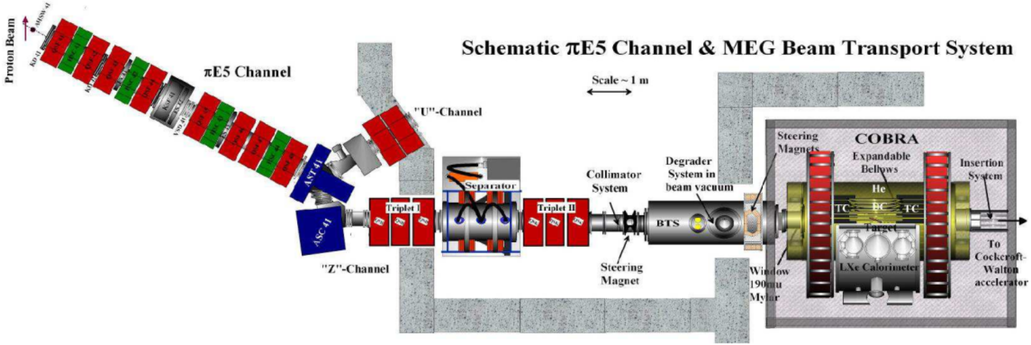


Figure: *Beam profile at Mu3e center*

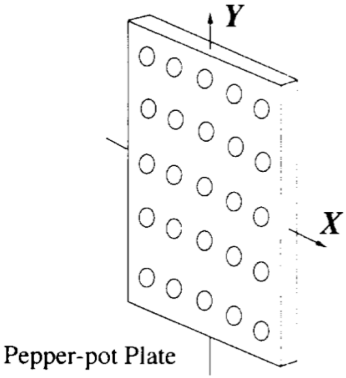
MEG: beamline tuning and phase space studies - 2022

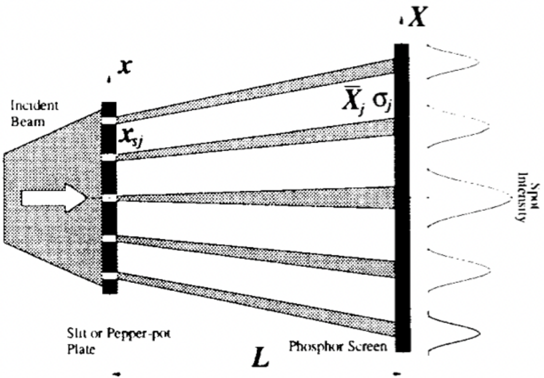
Within the MEG experiment I contribute to the yearly tuning of the beamline, the characterization of the beam and the development of novel beam monitors.



MEG: beamline tuning and phase space studies - 2022 - Pepper Pot

The idea is to collimate the beam through a grid of points and the size of the spots at the screen are proportional to the divergence at the grid location.





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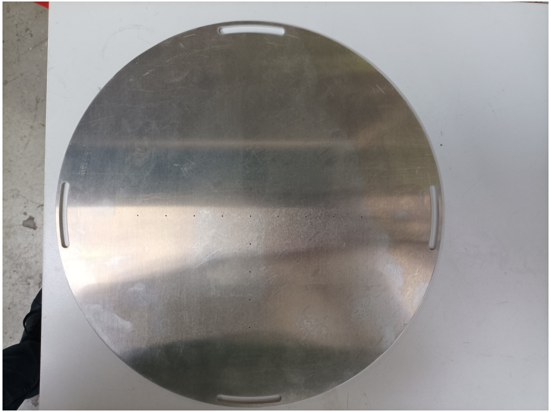
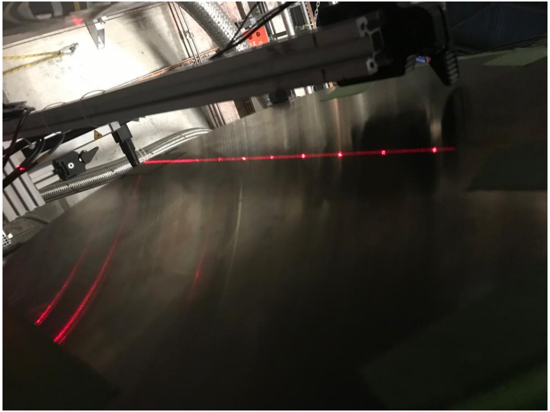
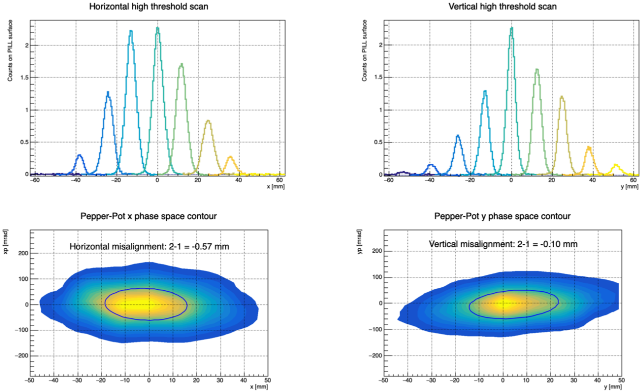




MEG: beamline tuning and phase space studies - 2022 - Pepper Pot

The phase space is then obtained by interpolating the "slices" (single peaks).

→ I'm currently working at improving the reconstruction by combining all the data collected during both Mu3e and MEG 2022 beam campaigns.



MEG: beamline tuning and phase space studies - 2022 - SciFi

The Scintillating Fibers (SciFi) detector is a grid of scintillating fibers coupled to SiPMs. During 2021 beam time we managed to use the coincidences betweeen perpendicular fibers to perform a full 2d scan and measure the space correlation of the beam.

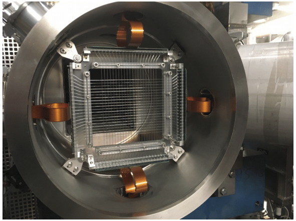


Figure: *SciFi detector.*

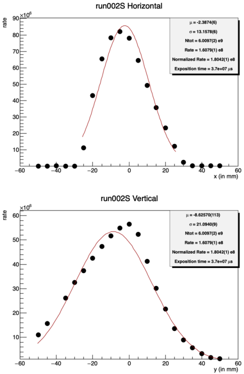


Figure: *SciFi detector marginal profiles.*

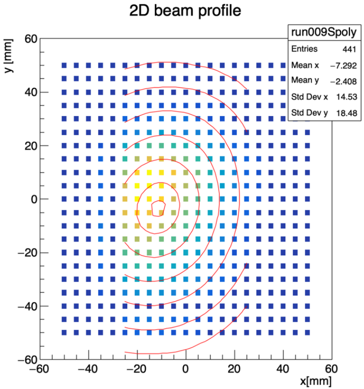


Figure: *SciFi detector coincidence profile.*

MEG: beamline tuning and phase space studies - 2022 - MatriX

The MatriX detector is a matrix of plastic scintillators coupled to SiPMs.
The current prototype has been successfully tested at collimator.

In 2021 we built a prototype for low energy muons, able to discriminate them from positrons.

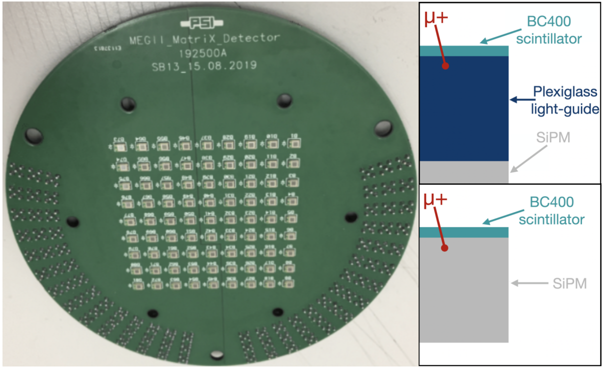
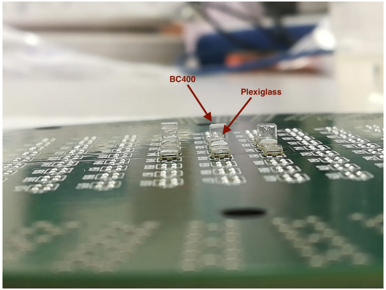
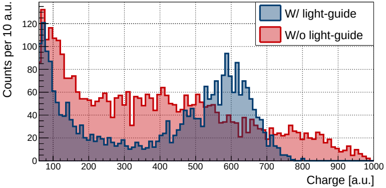


Figure: *MatriX detector.*

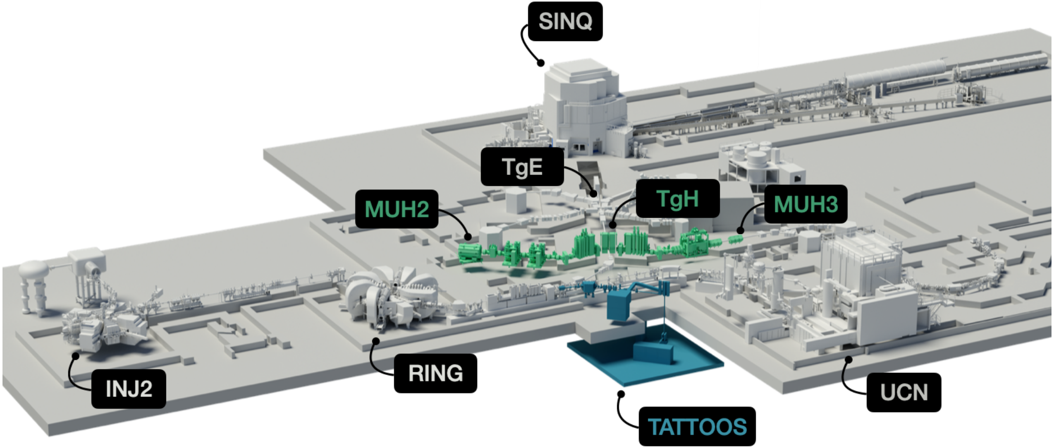




The HIMB project

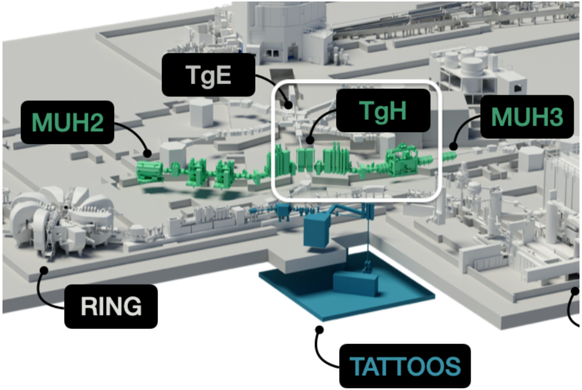
The High-Intensity Muon Beams project (HIMB)

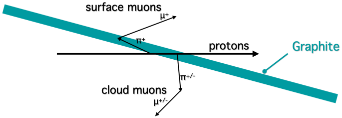
The HIMB project aims at further pushing the current muon rates at PSI by two orders of magnitude, from $10^8\ \mu^+/\mathrm{s}$ to $10^{10}\ \mu^+/\mathrm{s}$, with a new target station and high transmission beamlines.



The High-Intensity Muon Beams project (HIMB): target

The HIMB project aims at further pushing the current muon rates at PSI by two orders of magnitude, from $10^8\ \mu^+/s$ to $10^{10}\ \mu^+/s$, with a new target station and high transmission beamlines.



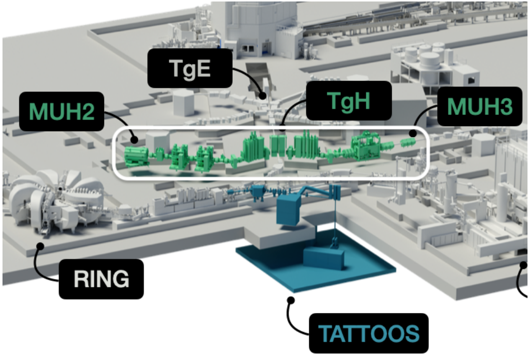


TgM (the thin meson production target) will be substituted by TgH, designed to boost surface muons production:

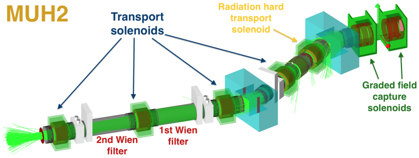
- thicker target: $5.2\,\text{mm} \rightarrow 20\,\text{mm}$
- target tilted w.r.t. to the proton beamline

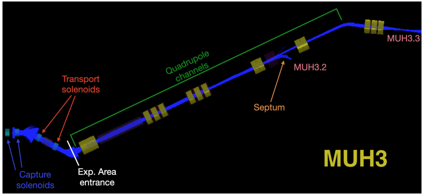
The High-Intensity Muon Beams project (HIMB): beamlines

The HIMB project aims at further pushing the current muon rates at PSI by two orders of magnitude, from 10^8 μ^+/s to 10^{10} μ^+/s, with a new target station and high transmission beamlines.



To increase the capture and the transmission of surface muons, the two HIMB beamlines will be based on solenoidal elements.

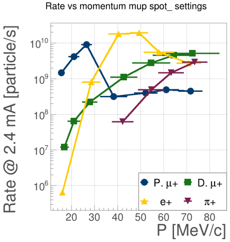


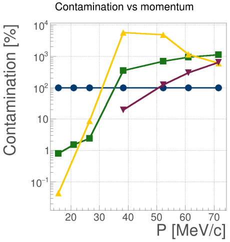


The High-Intensity Muon Beams project (HIMB): optimization

My contribution to the project consists of the optimization of the MUH2 beamline in the full momentum spectrum for the different particle beams.

To do so I'm employing both Bayesian optimization to find the highest transmissions, and Genetic Algorithms to optimize at once the figures of merit we are interested into, like the beam spot size and the average momentum.





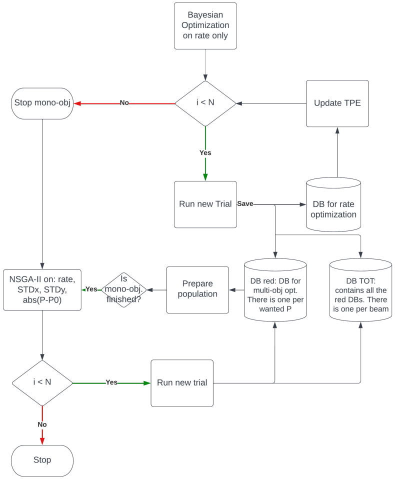


Figure: Hybrid optimization algorithm.

Next steps

I'm currently half-way through my Ph.D. Below is a list of the steps foreseen for the remainder of the grant period:

- 2022:
  - MEG II & Mu3e Beam monitors
  - X17 data taking with the MEG II apparatus (see backup)
  - HIMB simulations
- 2023:
  - X17 data analysis
  - last CMBL commissioning campaign
  - Full Mu3e detector commissioning
  - MEG II beam tuning and data taking
  - Beam monitoring upgrade for HIMB
  - HIMB simulations

Backup

Bayesian optimization

A Bayesian optimizer is a "black-box" global minimum finder.

At each iteration the parameters to be tested are randomly sampled from the domain to be explored, with a distribution which is weighted based on the previous results: at each iteration it is more probable to sample the parameters where the uncertainty on the "black-box" function is higher.

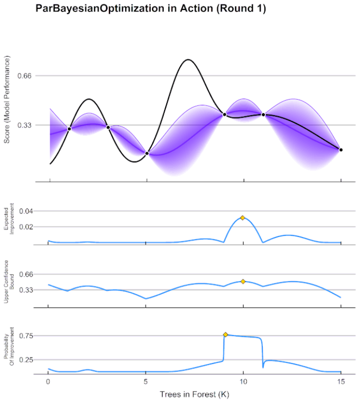


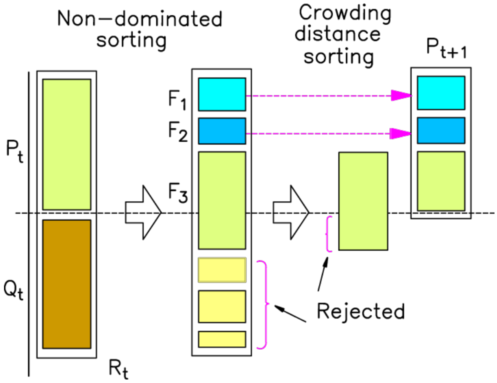
Figure: Wilson, Samuel (2019-11-22), ParBayesianOptimization R package, retrieved 2019-12-12

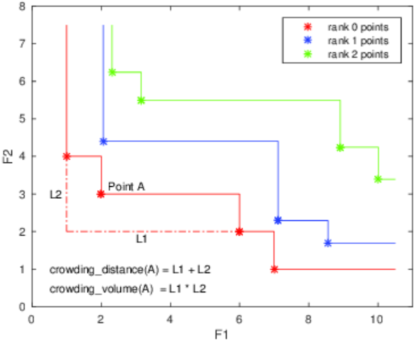
Non-dominated Sorting Genetic Algorithm-II

The basic idea is to define a population where each individual is characterized by his genes, namely the parameters of the problem.

At each epoch the individuals mix through breeding, crossover, mutation ...

The population is classified based on dominance and crowding distance





X17 measurement

I'm contributing to the measurement of the anomaly in the Lithium to Beryllium process with the MEG II apparatus. This measurement can be performed during the HIPA service days as we already have a Cockroft-Walton in the experimental area to calibrate our calorimeter.
The Cylindrical Drift Chamber of the MEG II apparatus can provide a measurement of this anomaly based on a different detection method then that used by the ATOMKI collaboration.
We assembled the target chamber last September for first tests and tested our DAQ last January. We plan on doing data taking by February 2023.

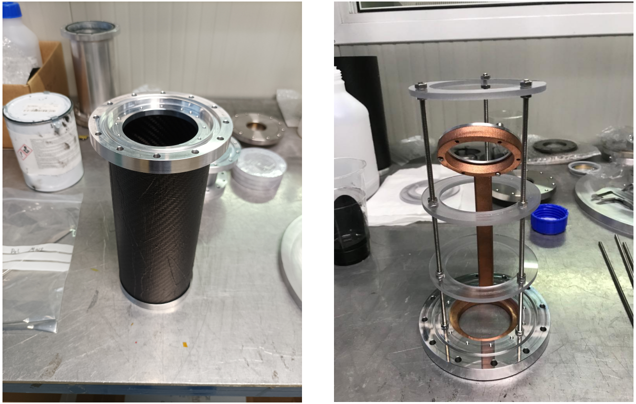


Figure: Carbon vacuum chamber + target