High Intensity Muon Beams at PSI

Giovanni Dal Maso

ESR meeting

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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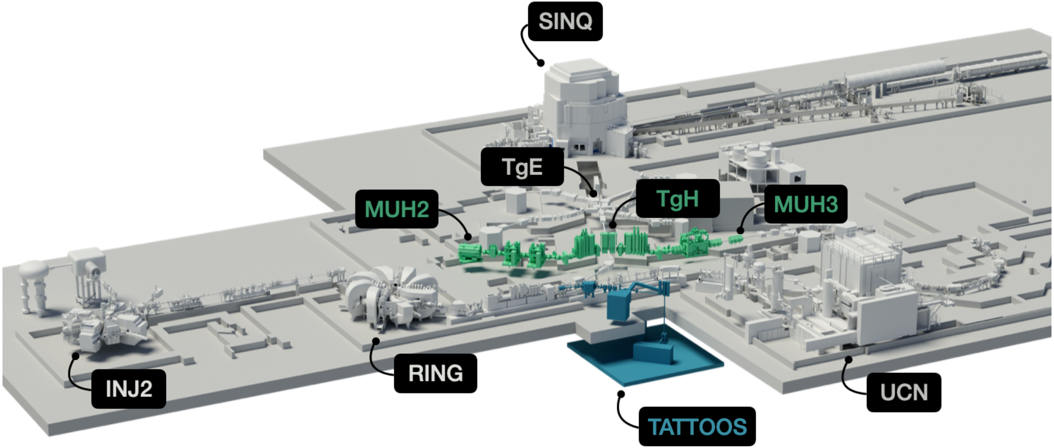
The HIMB project

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 $10^8\ \mu^+/s$ to $10^{10}\ \mu^+/s$, with a new target station and high transmission beamlines.



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

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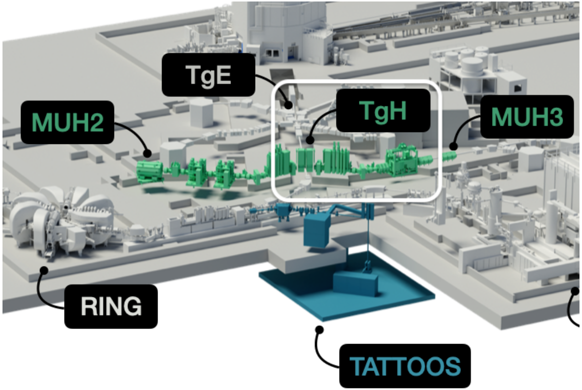

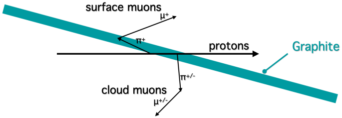

TgM (the thin meson production target) will be substituted by TgH, designed to boost surface muons production:

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

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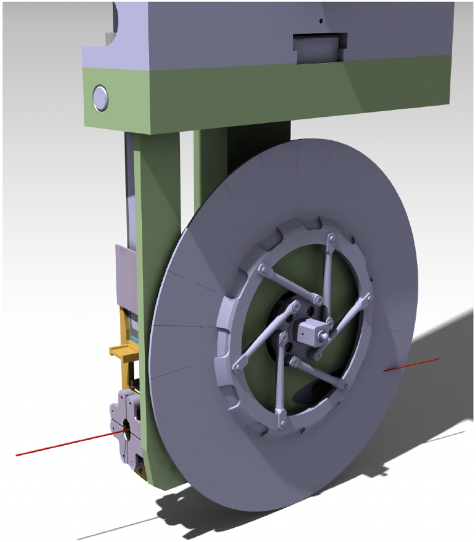

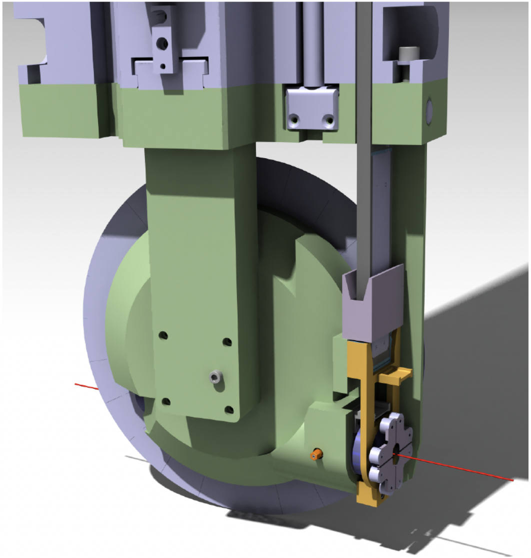

The High-Intensity Muon Beams project (HIMB): beamlines

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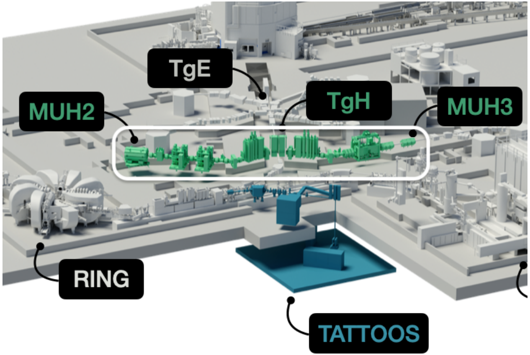
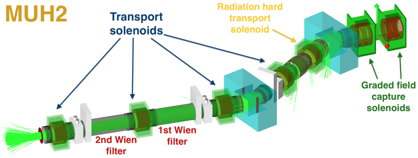
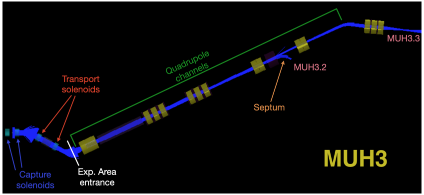


To increase the capture and the transmission of surface muons, the two HIMB beamlines will be based on solenoidal elements.





MUH2 beamline update

The MUH2 beamline is designed to transmit the highest muon beam rates thanks to a big acceptance, which comes with a few drawbacks:

- high positron contamination
- high neutron dose

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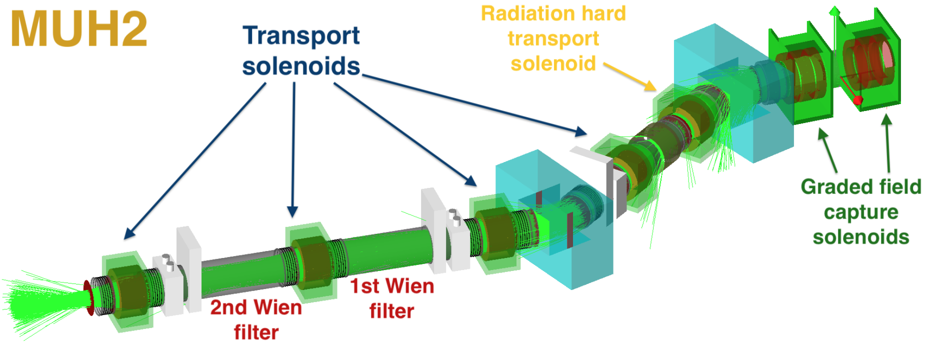
- high neutron dose



MUH2 beamline update

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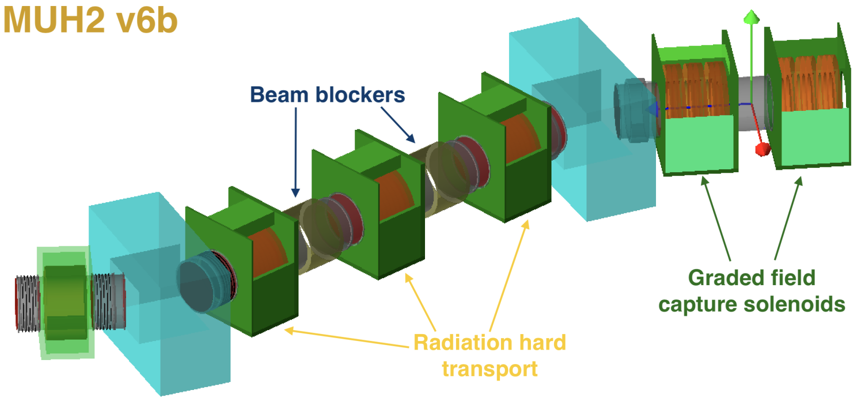
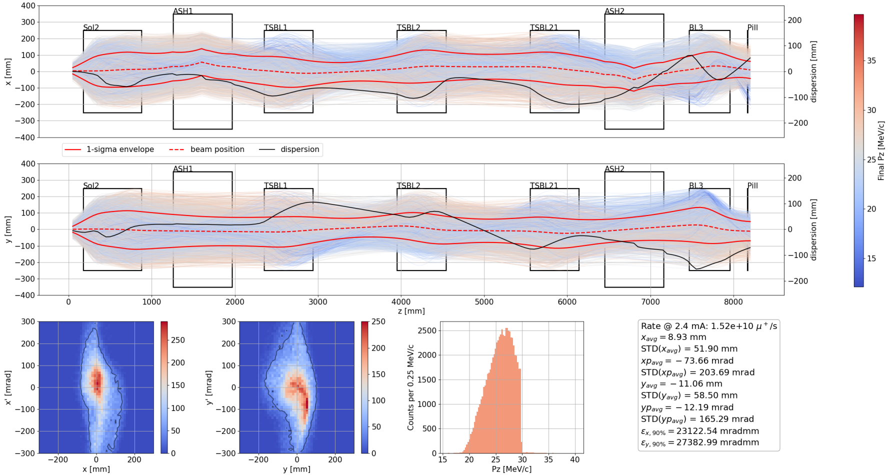
- high positron contamination
- **high neutron dose** → MUH2 v6b



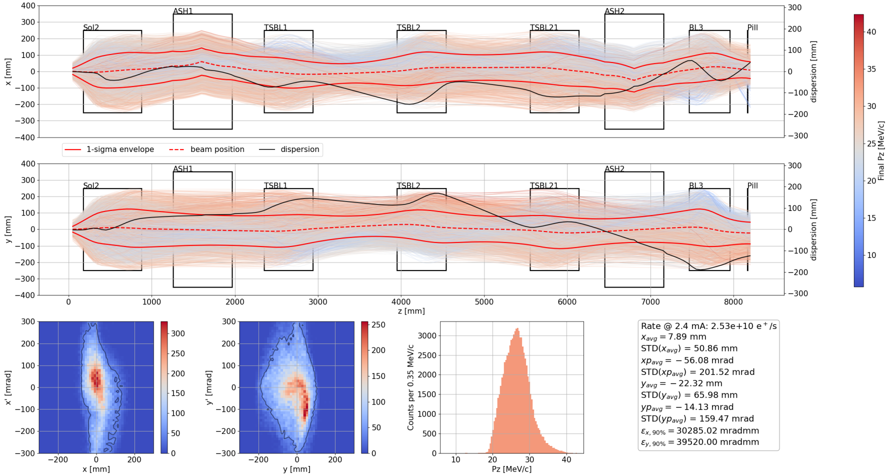
MUH2 v6b optimization: experimental area entrance

The new version of the beamline delivers rates compatible with the previous version even with an elongated first section.



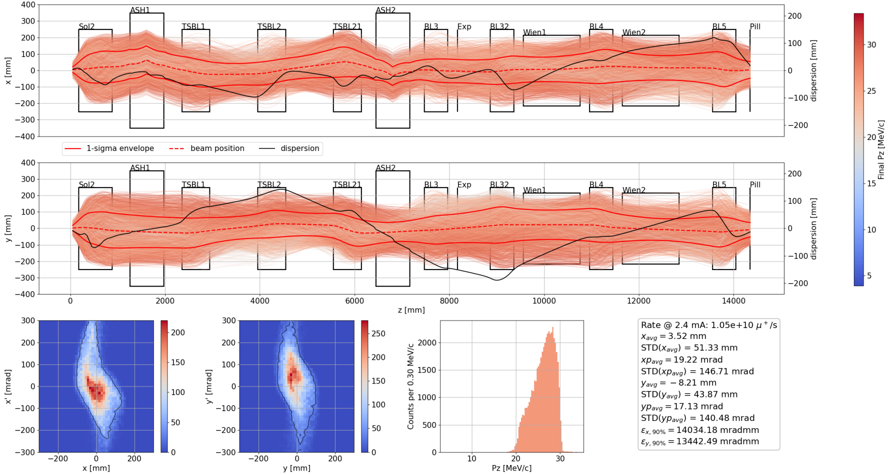
MUH2 v6b optimization: experimental area entrance

The positron contamination at the entrance of the experimental area is compatible as well.



MUH2 v6b optimization: final focus

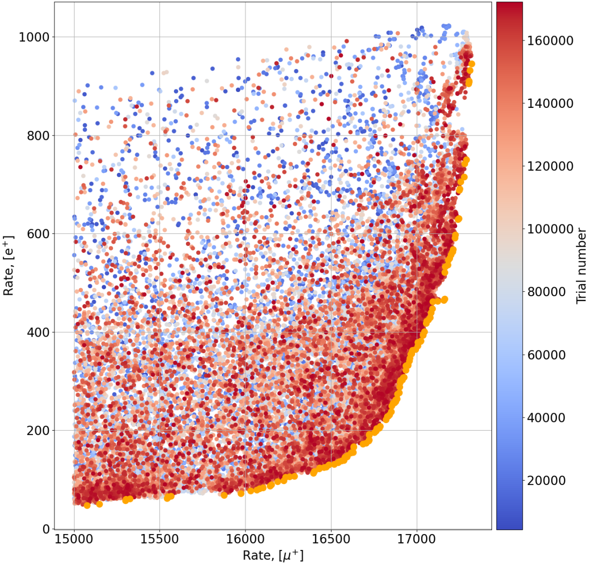
The double Wien filter scheme is still used to reduce positron contamination. The final muon rate is higher than $1 \times 10^{10}\,\mu^+/\mathrm{s}$. Without further optimization the contamination is $25\,\%$.



MUH2 v6b optimization: contamination

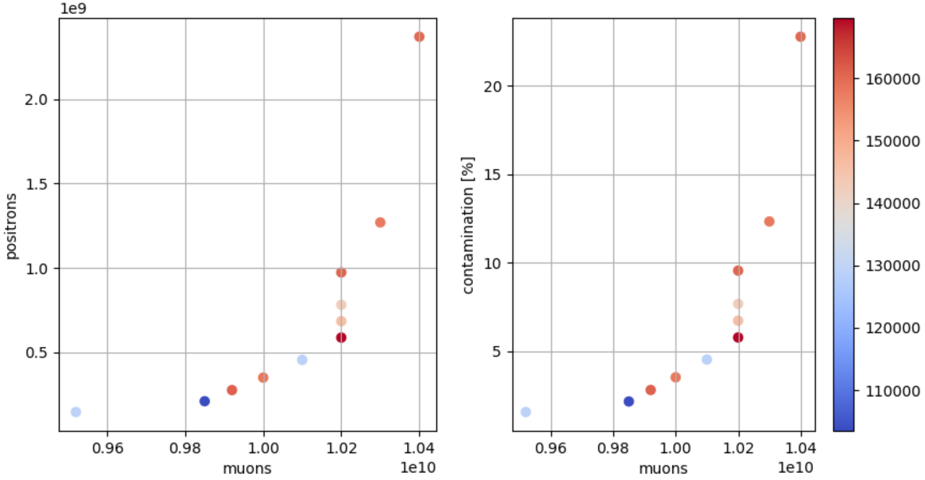
To reduce the contamination I'm employing NSGAII to maximize the muon rate and minimize the positron rate and find the best trade-off curve (orange points).

The optimization is run on a limited momentum bite ($27(5)$ MeV/c), then the full spectrum in high statistics is run on a small number of settings.

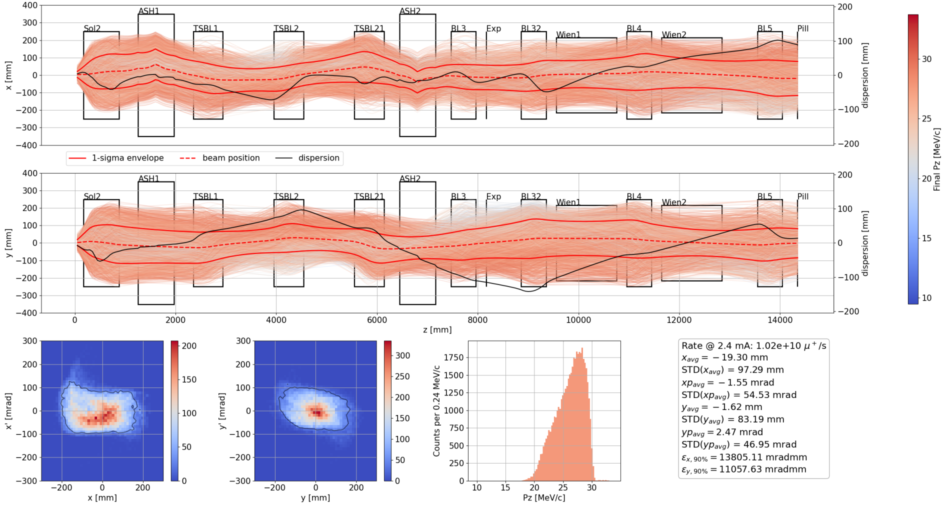


MUH2 v6b optimization: final focus

The vertical edge is given by changes in the fields of the last solenoid only.



Trial 169649 - muons, BL5 = 0.192179 T



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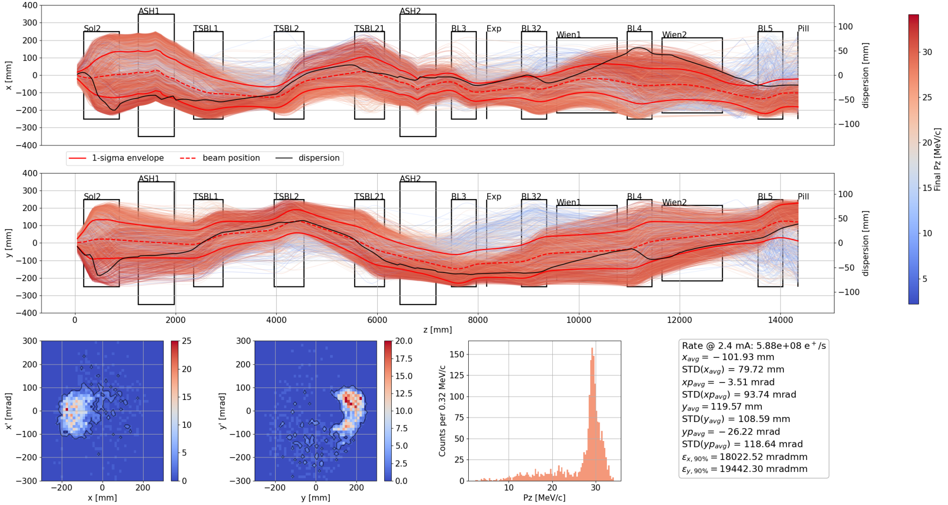
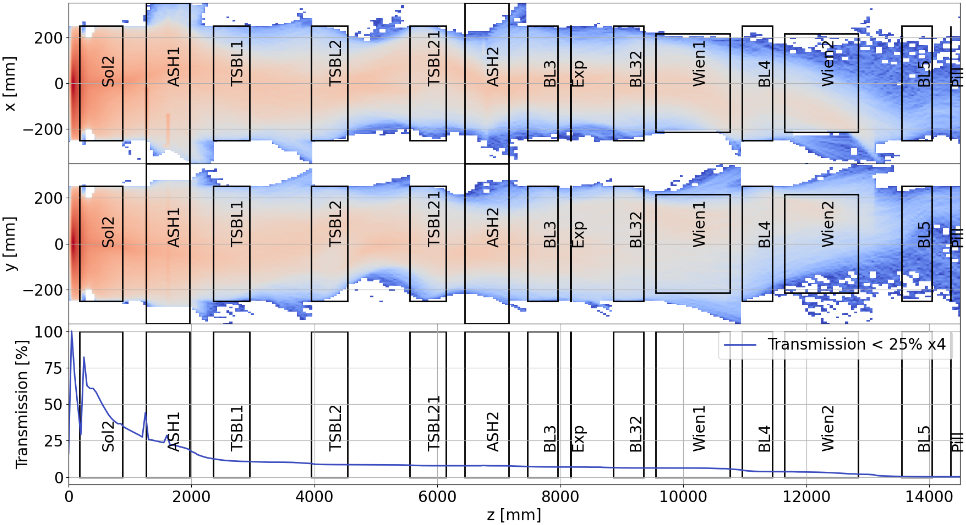
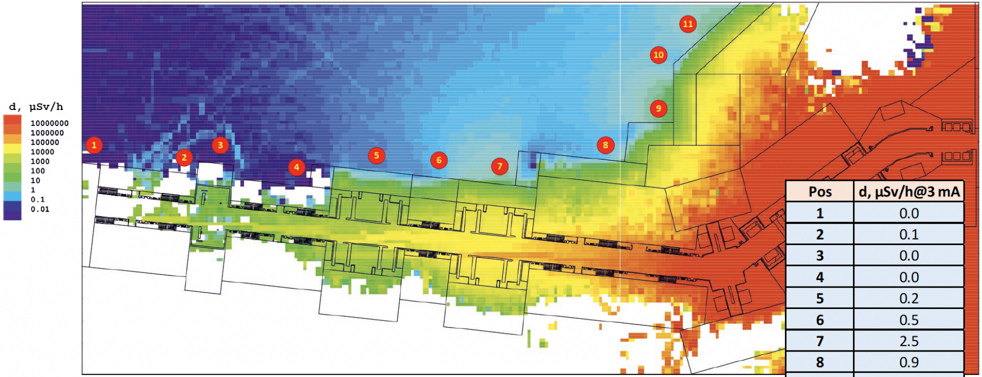


Trial 169649 - positrons, transmission, BL5 = 0.192179 T



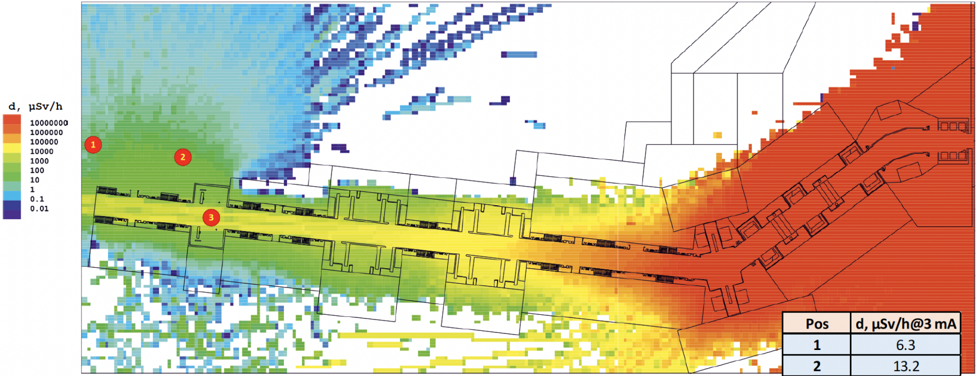
MUH2 v6b neutron dose: BB close



Pos	d, µSv/h@3 mA
1	0.0
2	0.1
3	0.0
4	0.0
5	0.2
6	0.5
7	2.5
8	0.9
9	5.3
10	3.1
11	1.1

- table gives the dose rate at 30 cm from the concrete shielding
- beam blockers closed. Full beamline enclosed in iron/concrete until the very end
- only in such a configuration reach safe dose rates ¡ 10 Sv/h in experimental area

MUH2 v6b neutron dose: BB open

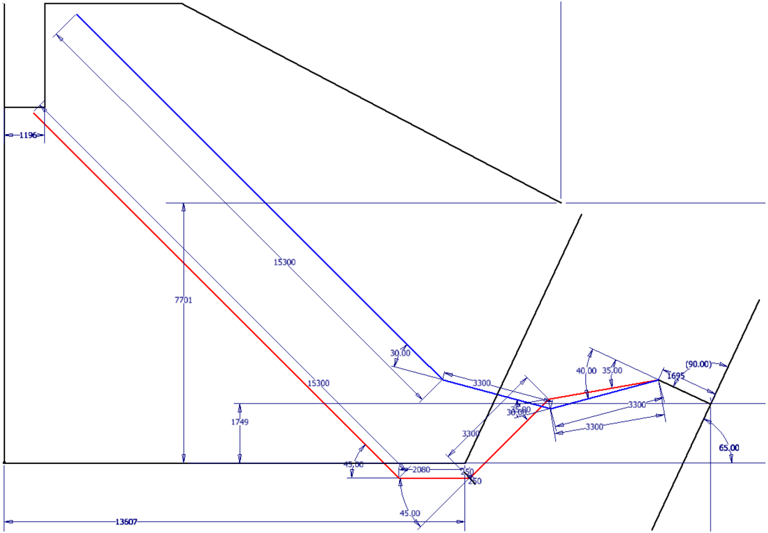


Pos	d, µSv/h@3 mA
1	6.3
2	13.2
3	3079.3

- beam blockers closed. Last shielding blocks removed
- far from ideal situation for running an experiment that needs repeated access
- need improved shielding and/or optimised beamline layout

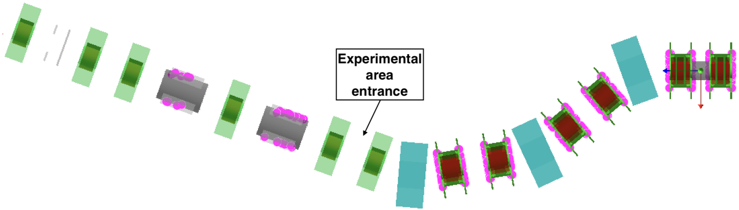
MUH2 with multiple bends

We made two layouts with 3 and 4 bends to reduce the acceptance of the beamline to neutrons.



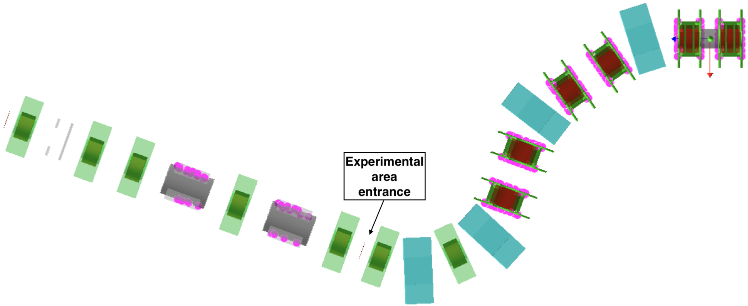
MUH2: 3 bends

The first bend is $40°$, the second and third ones are $30°$. Each of the two BBs is positioned in the corresponding short straight section.



MUH2: 4 bends

The first two bends are $35°$, the third and fourth ones are $45°$. Each of the two BBs is positioned in the corresponding short straight section.



Optimization result

It looks like the optimiser didn't find the maximum rate at Experimental area entrance.

	Optimisation at				
N. bends	Pill		Exp.	Pill last section	
	@ Exp	@ Pill			
3	1.06	0.829	1.12	0.238	10^{10} μ^+/s
3	1.85	0.343	1.94	0.021	10^{10} e^+/s
4	0.966	0.745	0.919	0.529	10^{10} μ^+/s
4	1.51	0.110	1.36	0.056	10^{10} e^+/s

Table: All rates are normalised to 2.4 mA.

Outlook

- MUH2 design fulfills requirements on muon rate
- positron contamination can be kept under control by trading-off the muon rate and adding a final focusing element
- neutron dose is still a demanding challenge

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
- autumn 2022: Physics 2 Übungschef for Medicine and Health Sciences students

Conferences

Training:

- 20-21 May 2021: *First Muon Community Meeting* (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 and secondments

Publications:

- A. Baldini et al., "The Search for $\mu^+ \rightarrow e^+\gamma$ 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 (https://doi.org/10.1016/j.nima.2022.167739)
- G. Dal Maso et al., "Future facilities at PSI, the High-Intensity Muon Beams (HIMB) project", EPJ Web of conferences, (https://doi.org/10.1051/epjconf/202328201012)

Secondments:

- secondment at University of Tokyo for X17 analysis, 13th March - 5th April 2023
- secondment at University of Pisa for X17 analysis, 11th-28th April 2023

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.

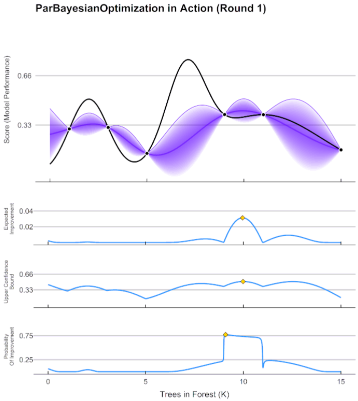


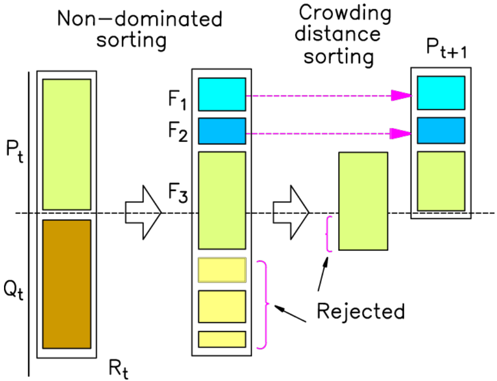
Figure: Wilson, Samuel (2019-11-22), ParBayesianOptimization R package, retrieved 2019-12-12

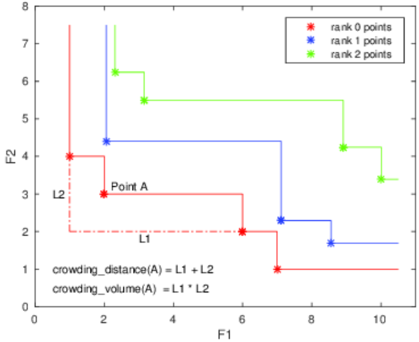
Non-dominated Sorting Genetic Algorithm-II

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





The High-Intensity Muon Beams project (HIMB): MUH2 v6b optimization

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