Beamline Final Foci Optimisations for High Intensity Muon Beams at PSI

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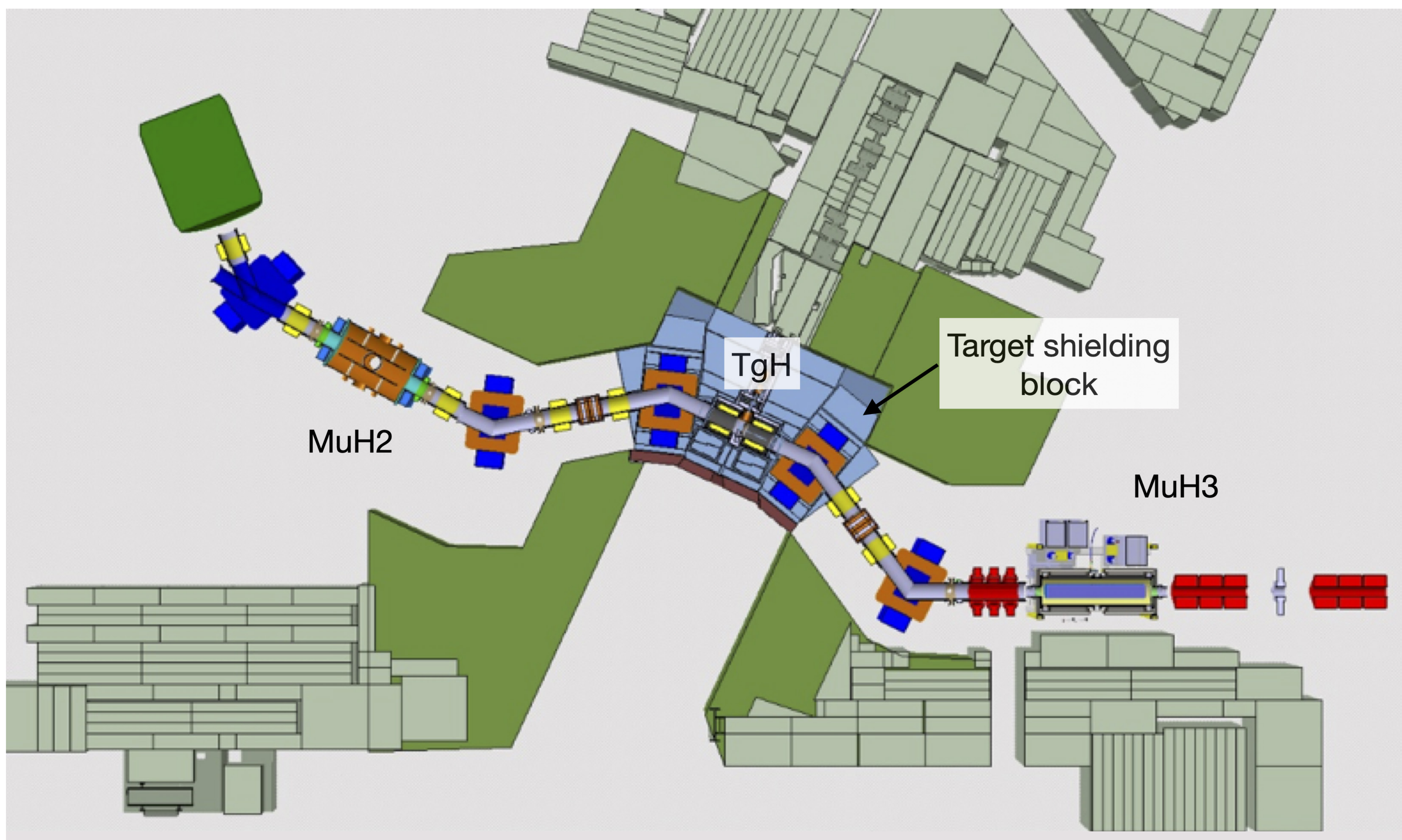
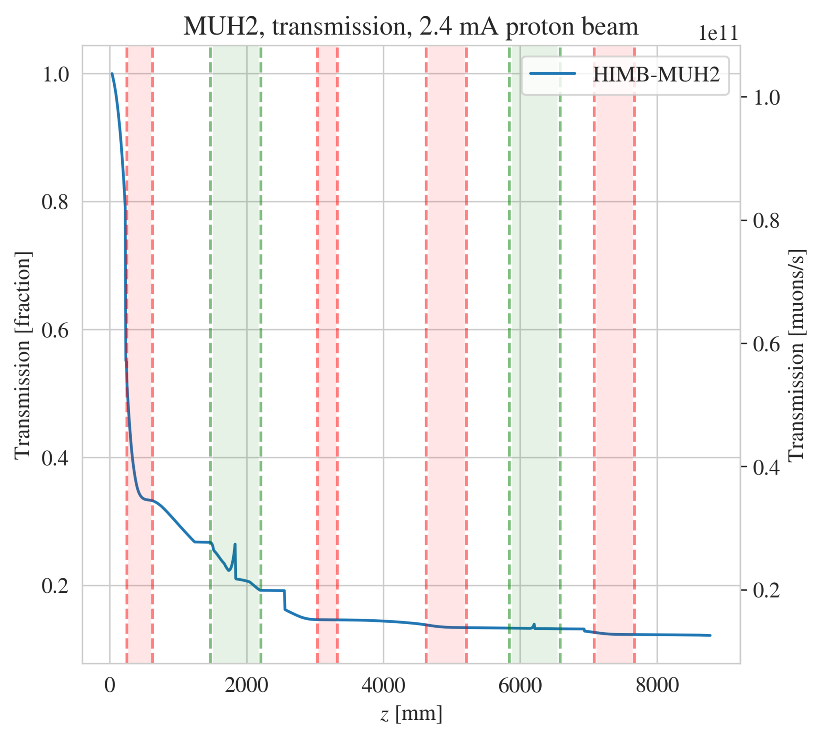


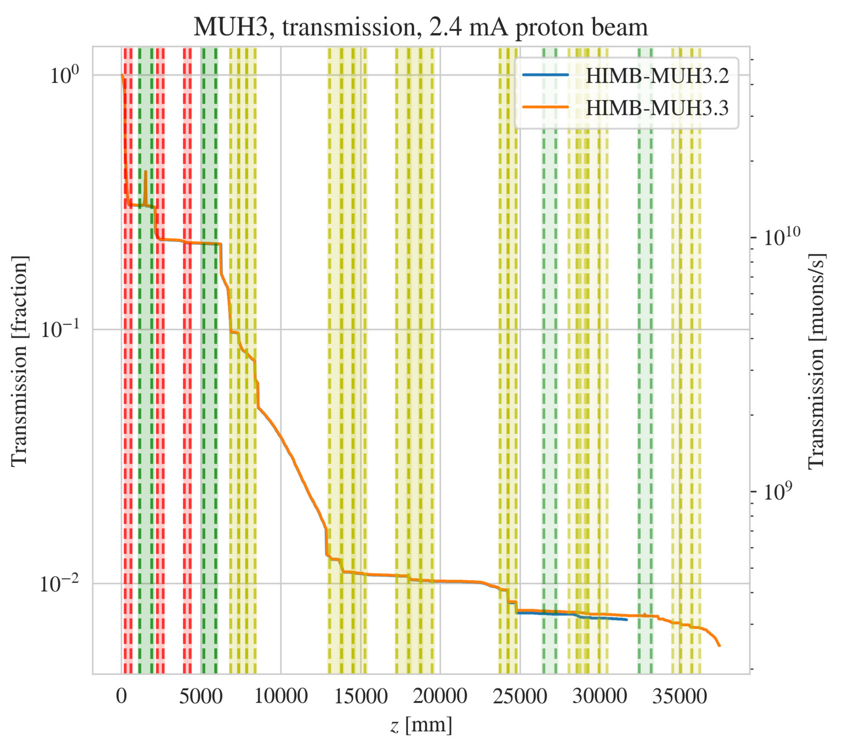
The novel High Intensity Muon Beams project (HIMB) at PSI will provide an unprecedented rate of 10^{10} muons/s to next-generation high-intensity muon experiments at PSI.

- MUH2 beamline → particle physics
- MUH3 beamline → μSR

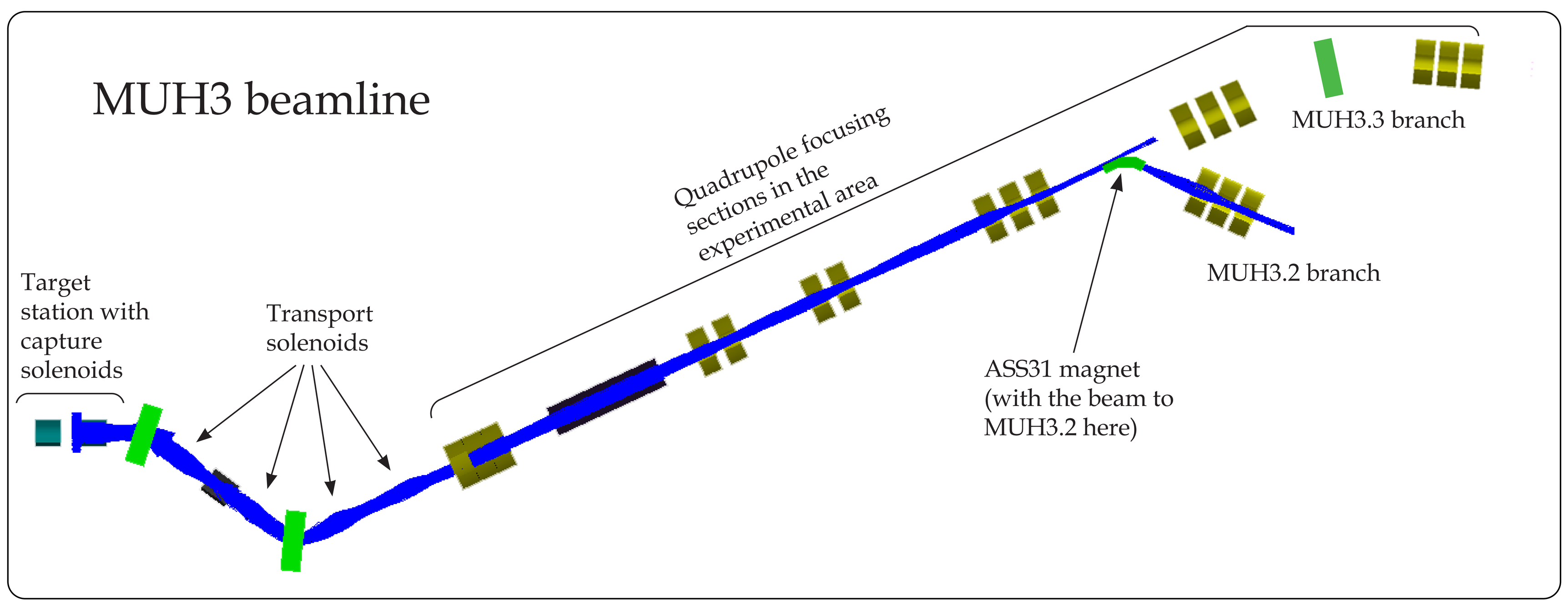
[1] M. Aiba *et al.*, "Science Case for the new High-Intensity Muon Beams HIMB at PSI," 2021, arXiv:2111.05788 [hepex].
[2] R. Eichler, ..., E. Valetov, *et al.*, "IMPACT conceptual design report," Paul Scherrer Institut, Report No. 22-01, 2022.

G4beamline models of the HIMB beamlines





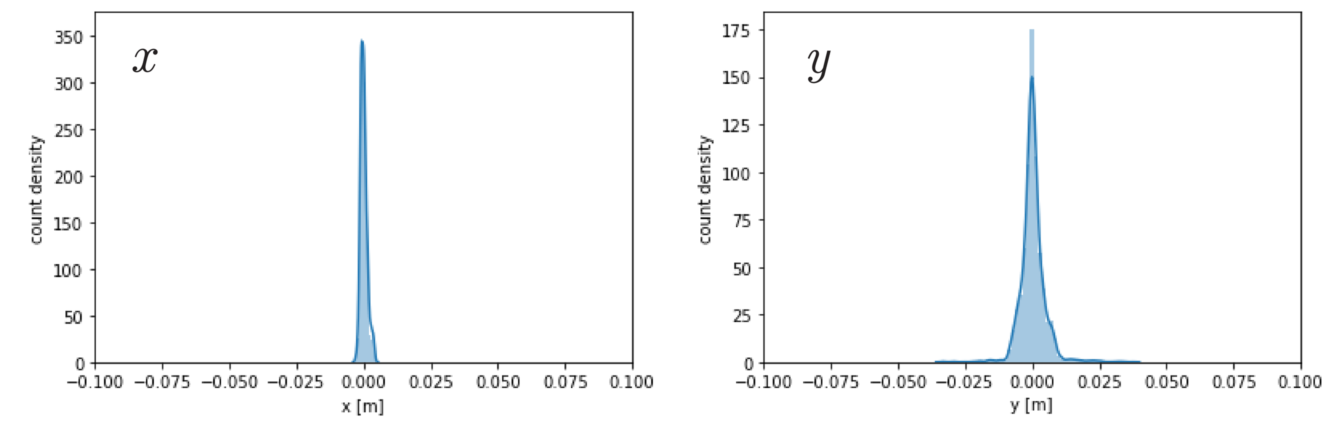
- Generally, we perform HIMB beamline simulations using a custom build of *G4beamline* 3.06
  - PSI's measured pion production cross-sections (more accurate in the relevant range of momenta)
  - Variance reduction using a splitting factor of 100 at both pion and muon production points
- An equivalent of 10^{11} protons on target simulated and used as the initial beam for target station and beamlines optimisation
- We achieved the transmission of 1.34×10^{10} muons/s in a model of the particle physics beamline MUH2 into the experimental area



Optimisation using transfer maps with knobs

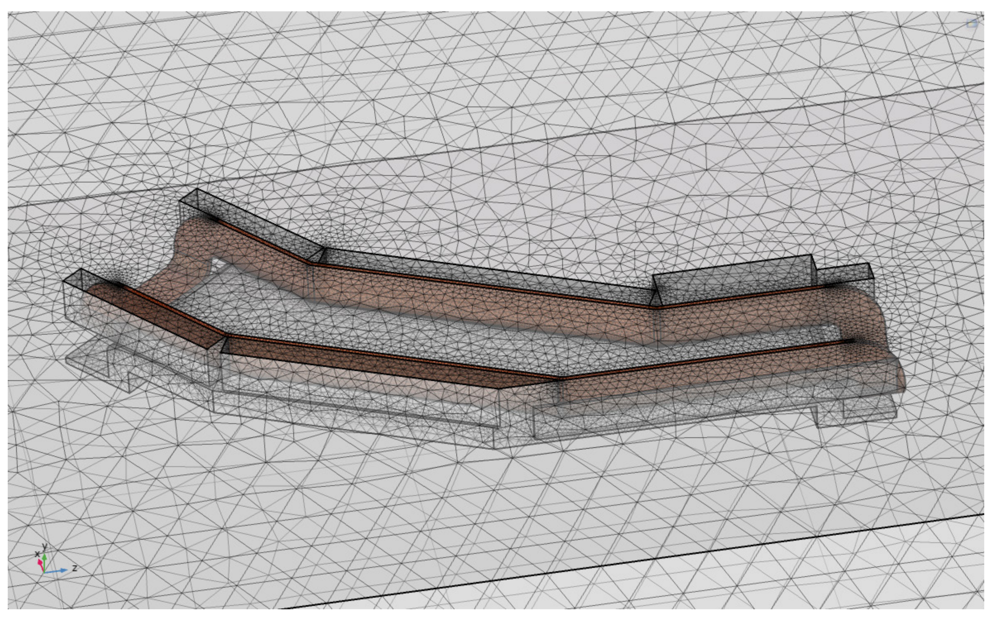
- Final focus optimisation using a *COSY INFINITY* transfer map model
- The motion is represented using a nonlinear differential-algebraic transfer map $\mathcal{M}(\vec{z},\vec{\delta})$ with $2 \cdot 3$ phase space coordinates and system parameters
- Quadrupole tuplet, magnetic dipole, and horizontal steering magnet fields and other parameters can be represented by system parameters
- The beamline coordinates are scaled by the respective beam sizes
- Focusing is achieved by minimising the norms of the horizontal and vertical transverse transfer map components $\mathcal{M}_x(\vec{z},\vec{\delta})$ and $\mathcal{M}_y(\vec{z},\vec{\delta})$, or alternatively, the beam spot obtained by applying the transfer map
- Minimisation is done numerically using *COSY INFINITY*'s Levenberg-Marquardt or simulated annealing optimiser

Agreement of COSY INFINITY and G4beamline models



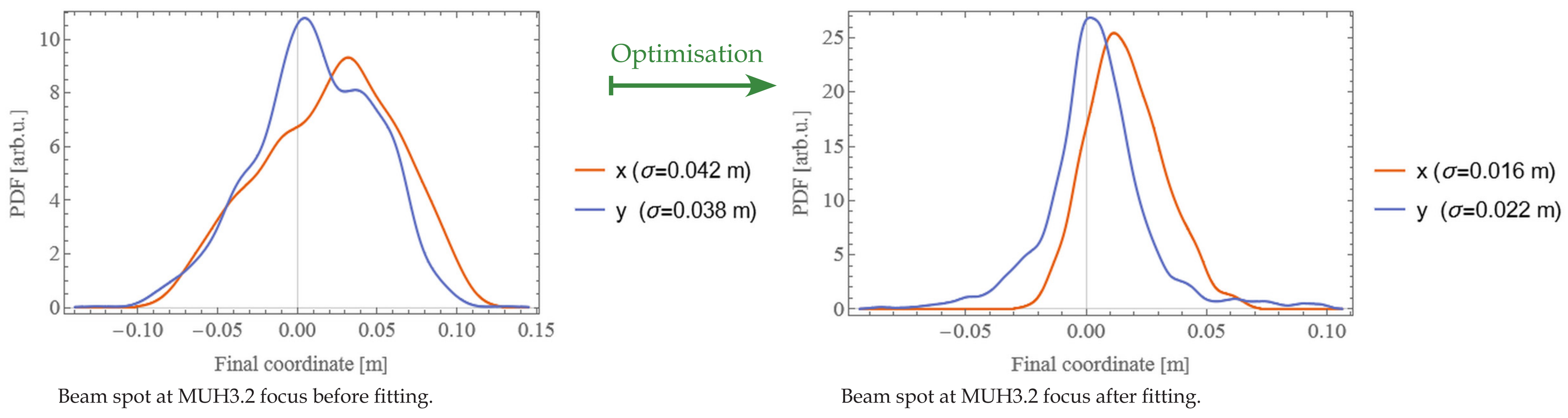
- We obtained good agreement between the *COSY INFINITY* and *G4beamline* models for final focus modelling
- For example, for an MUH3.2 final focus model with the last two quadrupole tuplets and a simple representation of the dipole magnet ASS31 between them, we obtained the differences of $\sigma(\Delta x) = 1.7$ mm and $\sigma(\Delta x) = 3.4$ mm for final beam coordinates, which are acceptable

Transfer map of the ASS31 septum magnet



- We calculated a field map of the ASS31 septum magnet, which switches the beam between the MUH3.2 and MUH3.3 branches, using *COMSOL*
- We obtained a transfer map of ASS31 from its field map for use in transfer map–based optimisations

Optimisation of the MUH3.2 final focus



Beam spot at MUH3.2 focus before fitting. Beam spot at MUH3.2 focus after fitting.

- The goal for the beam spots in the MUH3 beamline is $\sigma_{x,y} \lesssim 20$ mm
- We performed an optimisation of the MUH3.2 branch's final focus using transfer maps, obtaining $\sigma_x = 16$ mm and $\sigma_y = 22$ mm
  - This optimisation used 7th order transfer maps but not system knobs
  - The optimisation program with system knobs currently uses 2nd order transfer maps but will be revised to use higher orders
  - Only the last quadrupole triplet was used in this optimisation
- HIMB beamline optimisation using transfer maps completes in seconds to hours, depending on the method, while optimisation using *G4beamline* can take hours or days

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