Bayesian tuning of the Compact Muon Beam Line for the Mu3e experiment

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Introduction

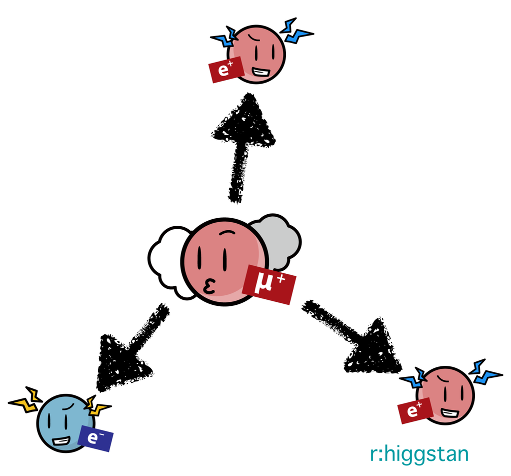
The HIMB[1, 2] project aims to increase the intensity of two muon beamlines at PSI by two orders of magnitude up to 10^{10} μ^+/s. To reach such high-quality tunes during commissioning, a novel tuning strategy is required, due to the large aberrations introduced by the employment of solenoidal elements along the HIMB beamlines.

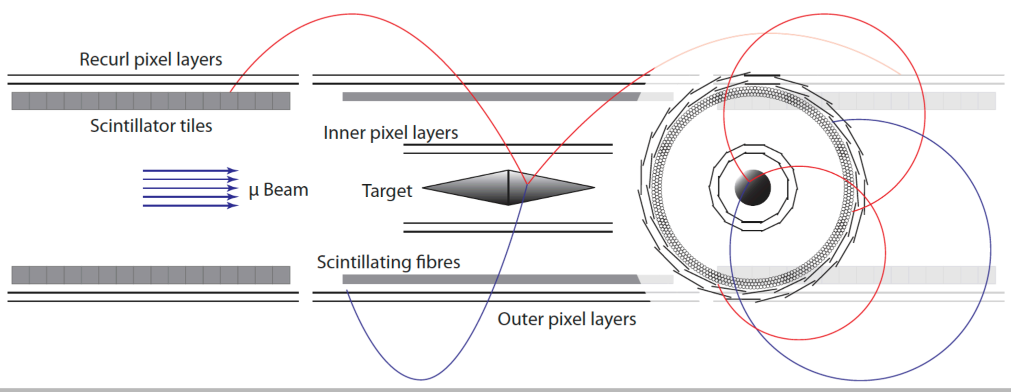
We present here the preliminary tests carried out in December 2023 at the Compact Muon Beam Line (CMBL) at PSI, serving the Mu3e[3] experiment.

The Mu3e experiment

The Mu3e experiment aims to measure the charged Lepton Flavor violating decay $\mu^+ \rightarrow e^+ e^- e^+$:

- Phase I: SES of 10^{-15} at 90 % C.L., ~10^8 μ^+/s (CMBL).
- Phase II: SES of 10^{-16} at 90 % C.L., > 10^9 μ^+/s (HIMB).

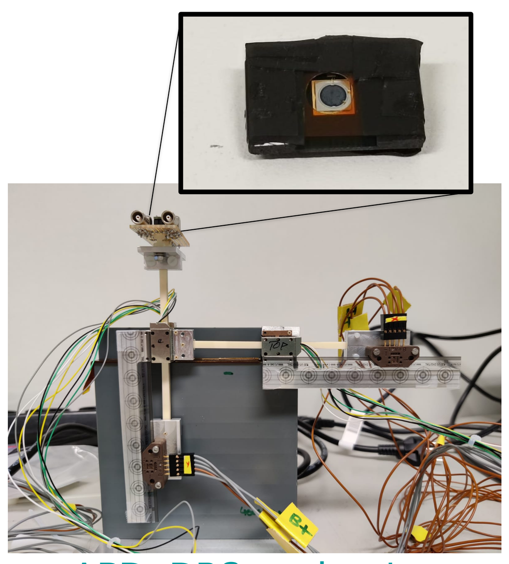




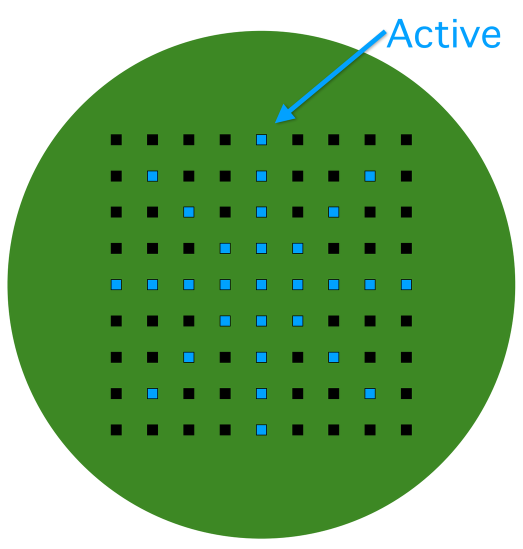
Beam monitor set-up

Two beam monitors were used in this study:

- Avalanche Photo-Diode on piezoelectric motor stage: performs sequentially the point-by-point(1.5 mm radius) scan of the beam spot;
- MatriX: 9×9 matrix of plastic scintillators (2 mm side) read by SiPMs. Only a subset of the grid was used to minimize the DAQ size.



APD, DRS evaluation board[4] read-out



MatriX, WaveDream[5] read-out

Both detectors are controlled with a MIDAS[6] front-end.

References

[1] R. Eichler et al., PSI Bericht, Report No.: 2022-01 (2022)

[2] G. Dal Maso et al., EPJ Web of Conferences 282, 01012 (2023)

[3] K.Arndt et al., Nucl. Instrum. Methods Phys. Res. Sect. A: Vol. 1014 (2021) 165679

[4] S. Ritt, et al. Application of the DRS chip for fast waveform digitizing. Nucl. Instrum. Meth. Section A 623 (2010) 486

[4] Galli L., et al. A highly integrated trigger and data acquisition system. Nucl. Instrum. Meth. Section A 936 (2019) 399–400

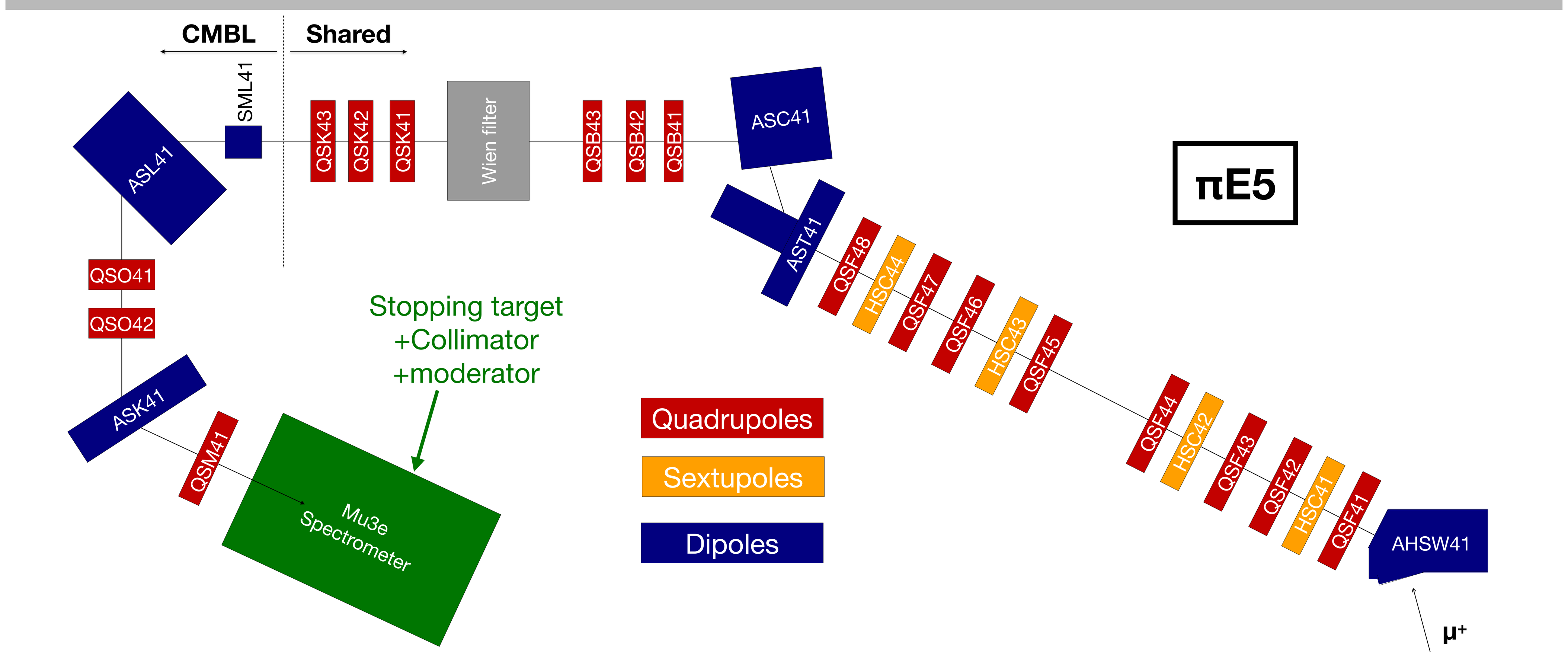
[6] S Ritt, P Amaudruz, K Olchanski - Proc. ieee 10th real time conf, 1997

[7] J. B. Mockus and L. J. Mockus., Journal of Optimization Theory and Applications 70.1 (1991), pp. 157–172. issn: 1573-2878

[8] T. Akiba et al., Proceedings of the 25th ACM SIGKDD. 2019, pp 2623–2631

[9] Dalesio L. R. et al., Nucl. Instrum. Meth. Section A 352 (1994) 179-184

The Compact Muon Beam Line



The πE5 area delivers the highest continuous muon beam rates to particle physics experiments. Due to the presence of permanently installed equipment in the downstream part of the experimental area, an additional section of the beamline has been added to couple the muon beam into the Mu3e experiment, the Compact Muon Beam Line.

The commissioning was finalized at the end of 2023, with 7.5×10^7 μ^+/s on the Mu3e stopping target with moderator and collimator.

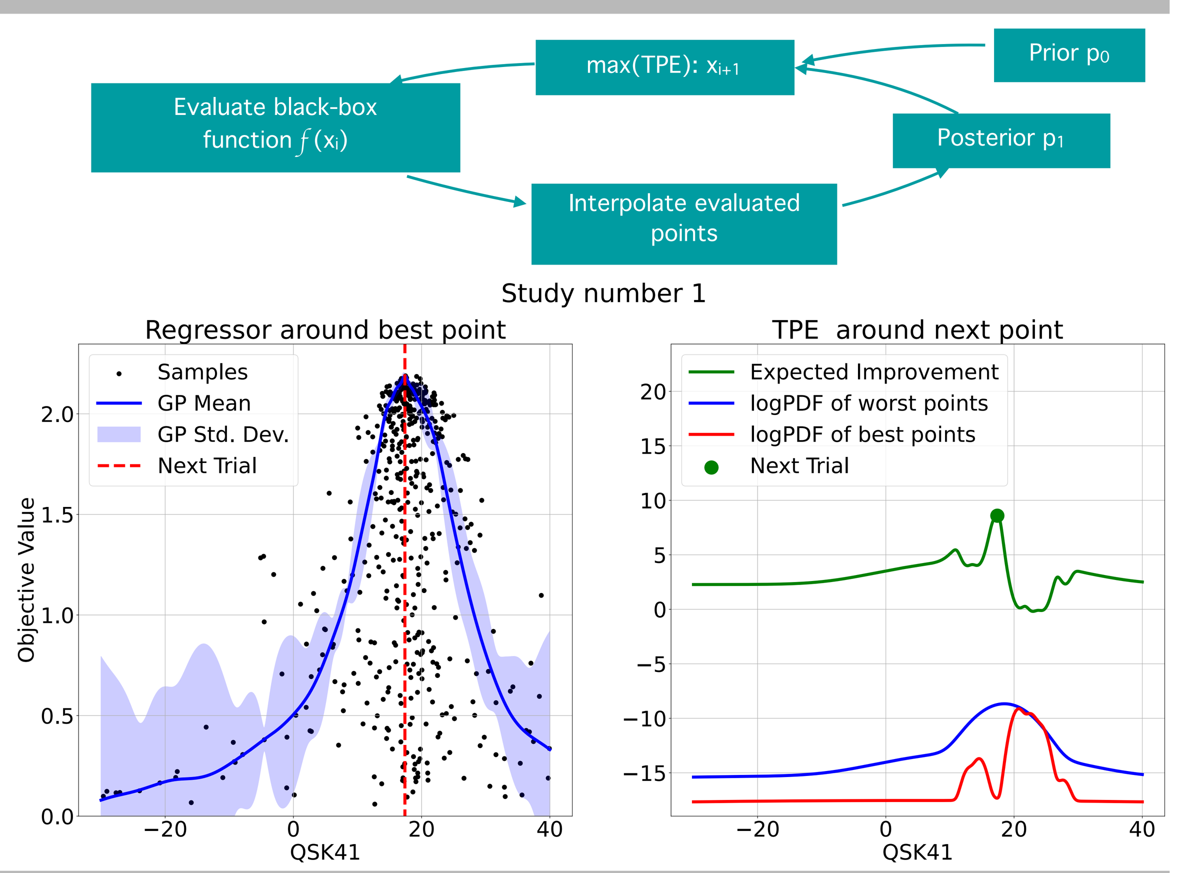
Bayesian optimization

Bayesian optimization[7] is a class of global optimization strategies of black-box functions, which are expensive to evaluate, with a probabilistic approach:

- define prior;
- maximize chances to improve maximum to sample the next point (Tree-structured Parzen estimator from the optuna[8] python package here);
- define posterior and repeat.

Here, the parameters are the excitation currents of the beamline magnets and the evaluation of the function is the measurement.

A python front-end sends the beamline settings through EPICS[9] and reads the trigger rates of the detector.



Preliminary results and outlook

A first test was carried out in December 2023 during the CMBL commissioning. The optimization front-end has been run unsupervised and compared to the usual optimization strategy from a human operator: scan excitation currents sequentially. Tests could be carried out only during dead time, when no operator was available for tuning.

	Free parameters	Optimization	Figure of merit	Detector	Measuring point	N. Iterations	Total time	Final rate	Optimization objective
1	QSK	Bayes	Rate on axis	APD	QSM 41	500	35 min.	1.8×10^8 μ^+/s	2.2×10^5
2	QSK/O/M/HSC	Bayes	Rate on axis	APD	QSM 41	500	70 min.	1.2×10^8 μ^+/s	2.3×10^5
3	All	Operator	Rate on axis	APD	QSM 41	-	2 days	1.8×10^8 μ^+/s	2.2×10^5
4	QSK/O/M/HSC	Bayes	Rate on axis	APD	Mu3e*	800	3 hours	1.0×10^8 μ^+/s	5.7×10^5
5	QSK/O/M/HSC	Bayes	Total rate	MatriX	Mu3e*	240**	1 hour	7.6×10^7 μ^+/s	-
6	All	Operator	Rate on axis	APD	Mu3e*	-	1 week	1.0×10^8 μ^+/s	5.8×10^5

*: without final collimator/moderator, **: not enough time to converge

The optimization can also use 2D scans with either the APD or MatriX:

- multiple figures of merit (rate/beam spot)
- phase space extraction
- simulation input
- parameter importance

Further dedicated tests are planned in 2024 in different experimental areas at PSI focusing on full-rate measurements and multiple figures of merit.