# Ion Source Optimization using Bi-Objective Genetic and Matrix-Profile Algorithm

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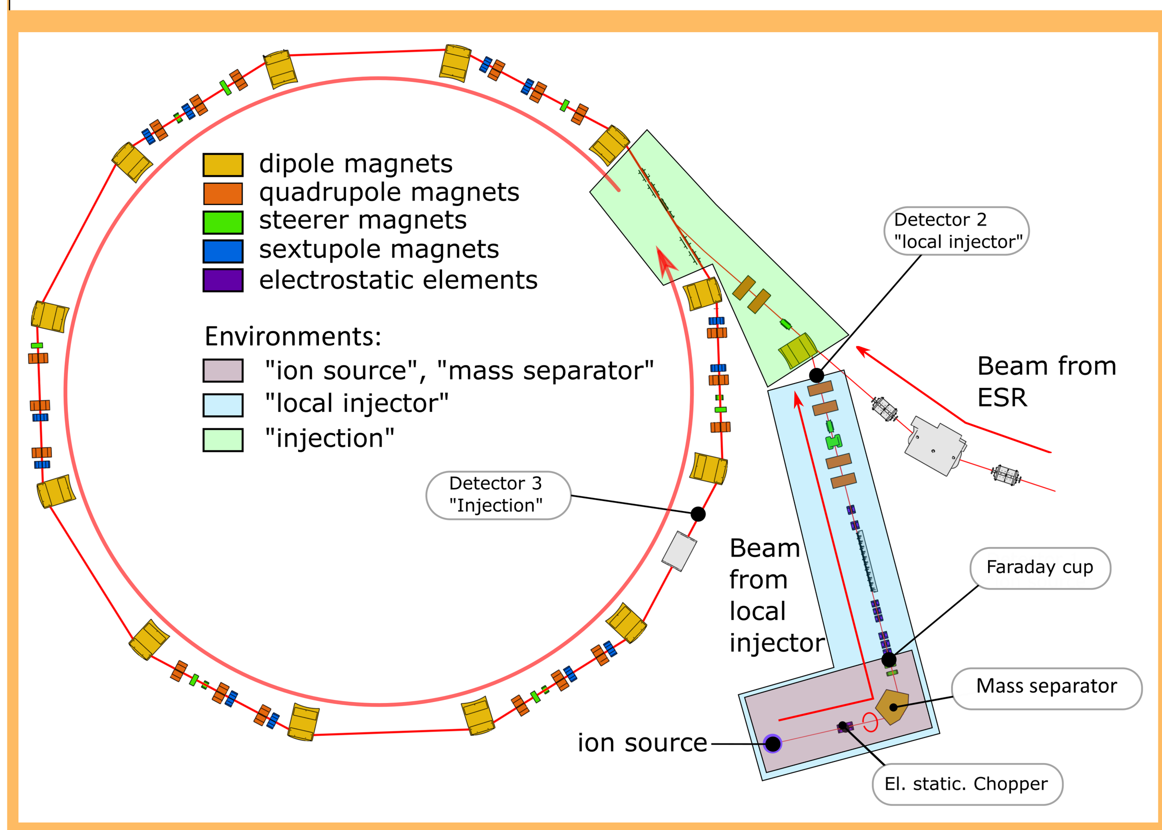
## System Envorinment / Machine




CRYRING@ESR[1]:

FAIR phase 0 ion storage ring for atomic, nuclear and solid state physics experiments in energy range 1.7 keV/u to 10 MeV/u

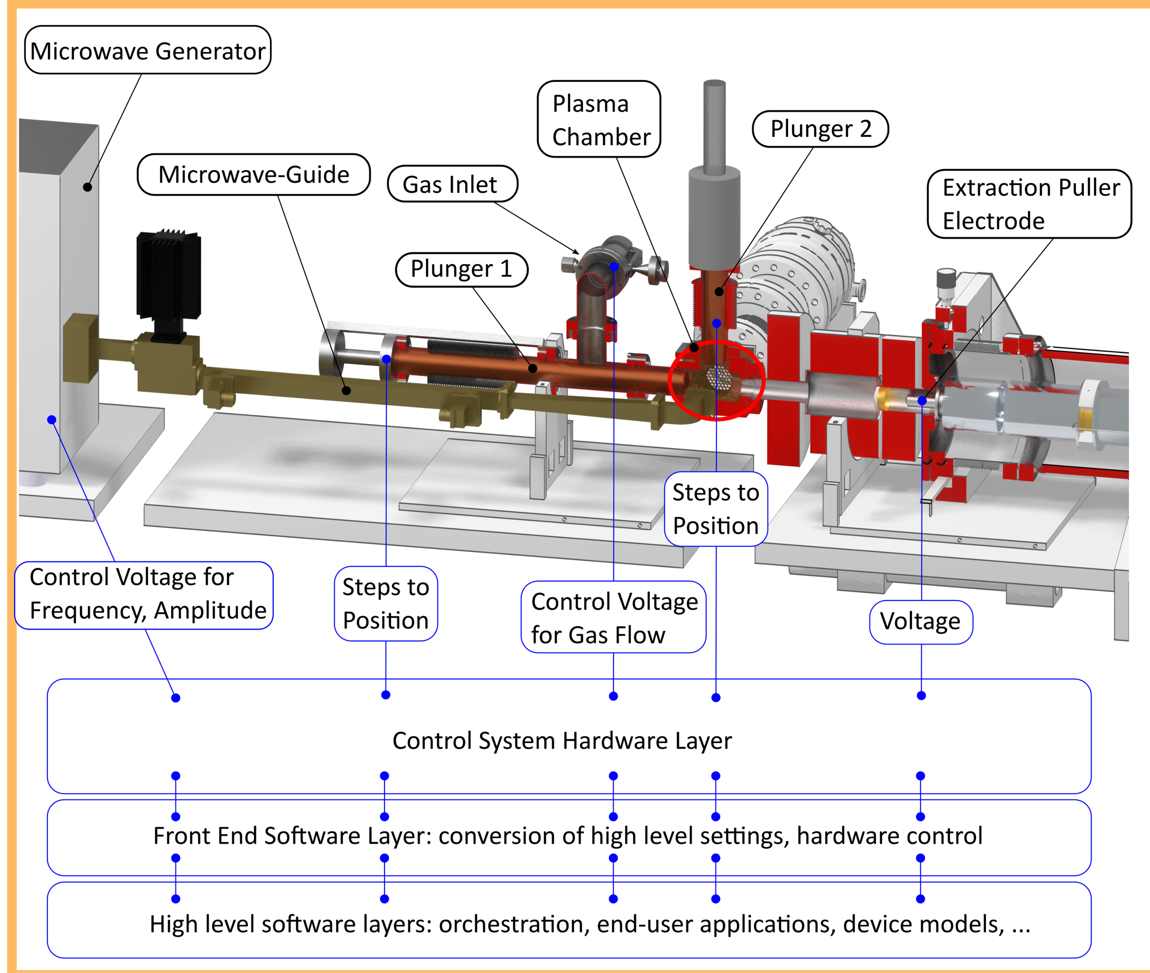
As well test bench for FAIR prototypes and new concepts, esp. Control System related.

[1] Geithner, W., et al. "Status and outlook of the CRYRING@ ESR project." Hyperfine Interactions 238.1 (2017): 13.

Special feature is local ion source and linear accelerator allowing low charge-state operation independent of rest of GSI/FAIR facility.

## ECR Ion Source as Test Environment

Electron Cyclotron Resonance Ion Source (ECRIS)[2] is currently the work-horse for local ion beam production. Establishing stable ion beam operation currently is a manual process taking several hours.




ECRIS control parameters:

- Microwave amplitude
- Microwave frequency
- Gas flow
- Puller electrode voltage
- Plunger 1 position
- Plunger 2 position

Observables from Faraday cup detector:

- Time resolved signal, 10 MHz sampe rate, 13 kSamples
- Mean beam current

[3] Trassl, R., et al. "Development of a 10 GHz "Multi-Mode" ECR, Ion Source for the Production of Multiply Charged Ions from Metallic Elements." Physica Scripta 1999.T80B (1999): 504.

For test we controlled microwave amplitude, mw frequency, gas flow, puller electrode voltage via JAVA optimizer program.

## Optimizer Algorithm: JENETICS Java Library

JENETICS[3] provides Genetic Algorithm, Evolutionary Algorithm, Genetic Programming, and Multi-objective Optimization as JAVA library. Accelerator settings parameters and value ranges are treated as "genes", collected into a "chromosome". Optimization objectives are the "fitness" of an "individual" given by its "phenotype" (one set of settings parameter values).

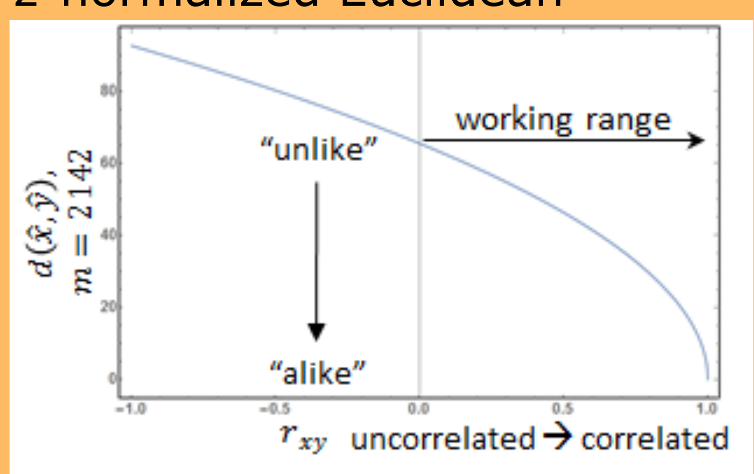
In multi-objective mode, JENETICS allows to optimize N setting parameters to the Pareto-front optimum of M goal parameters.

[3] Wilhelmstötter, F.: Jenetics advanced genetic algorithm, online http://jenetics.io

## Motiv and Dischord Detection: Matrix-Profile Python Library

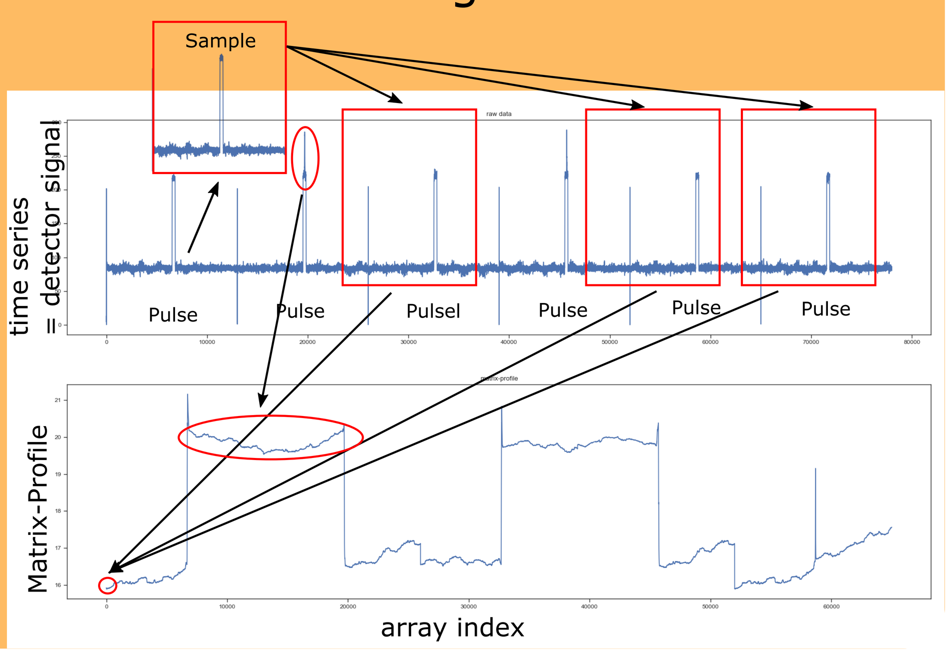
matrixprofile[4] provides a Python library for data mining of time series data for trend and anomaly detection by z-normalized Euclidean distance

$$d(\hat{x},\hat{y}) = \sqrt{2m\Big(1 - \underbrace{\frac{\sum_{i=1}^{m} x_i y_i - m\mu_x\mu_y}{m\sigma_x\sigma_y}}_{\text{correlation coefficient } r_{xy} \in [-1,1]}\Big)}$$



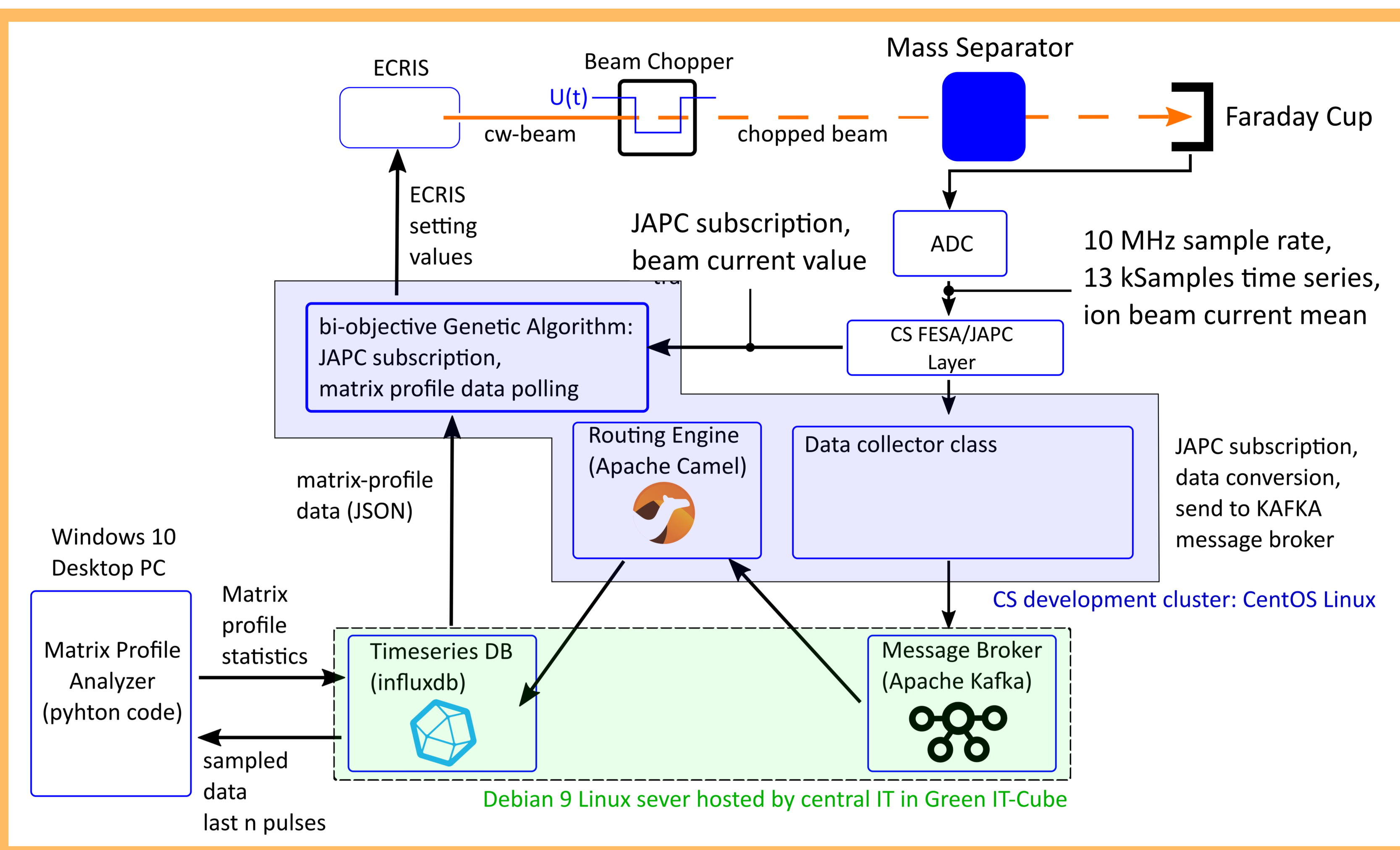

of all subsamples of size m of given time series of length l with all l-m subsets of size m of the series:

Output of the computation is array of minimal values of d(x,y) for each subset providing information if subsamples have similar patterns (low d-value) in the series or if the subsamples are uncorrelated (high d-value).



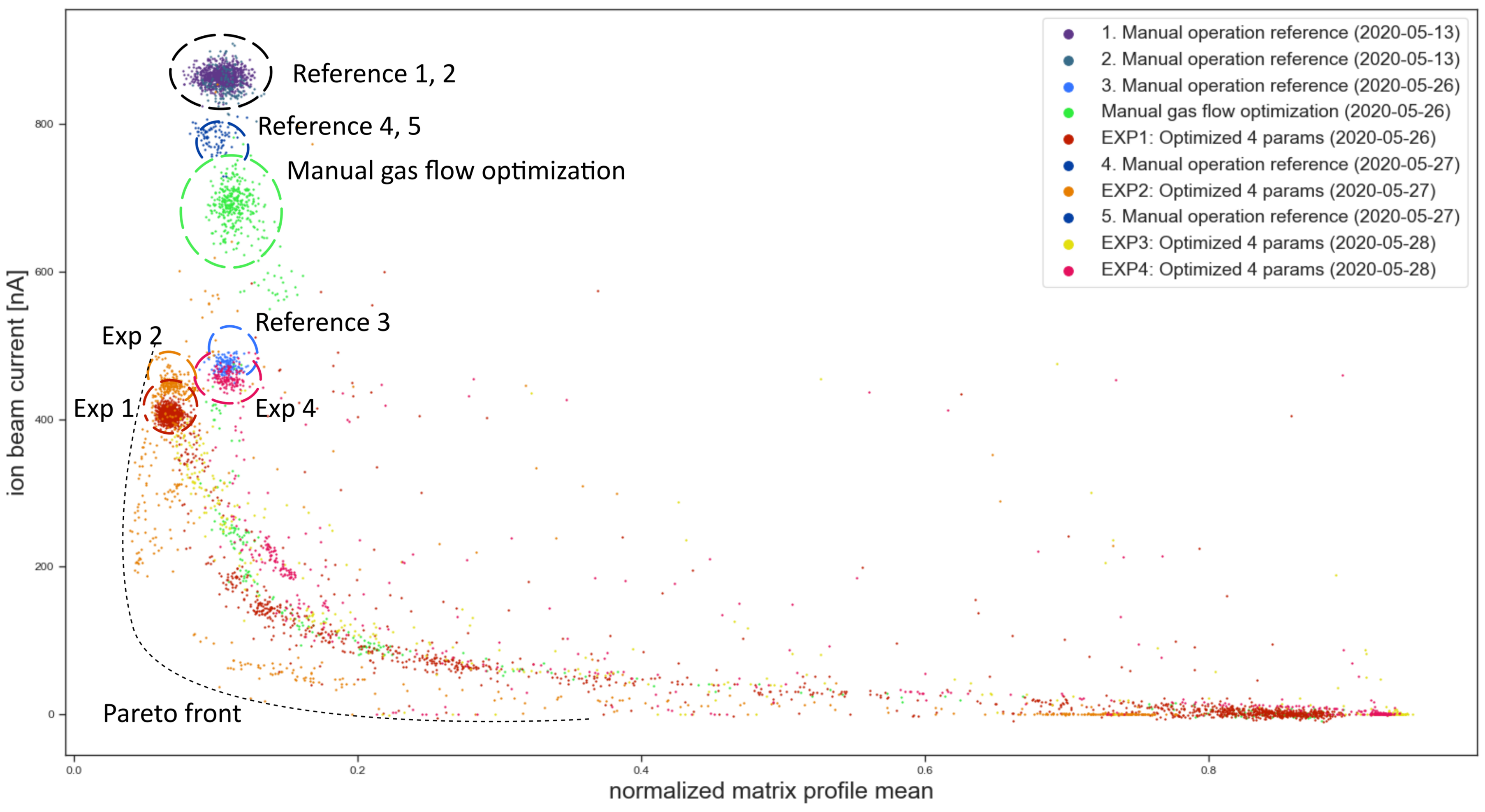

[4] Van Benschoten, Andrew H., et al. "MPA: a novel cross-language API for time series analysis." Journal of Open Source Software 5.49 (2020): 2179.

## Integration into FAIR Control System




1. Digitized, 10 MHz time resolved signals from current transformer are accessible via FAIR CS JAPC-layer (JAPC: Java API for Parameter Control)
2. Data collector class picks up data from JAPC and converts to Apache AVRO formatted message sent to Apache Kafka broker
2b. Optimizer program building on Jenetics JAVA library picks up JPAC provided beam current as one objective of optimization. Code waits for Matrix-Profile data.
3. Apache Camel routing engine picks up data from Kafka and sends it to InfluxDB
4. Python code employing Matrix-Profile library fetches last N (typically 5) time resolved signal data sets and calculates Matrix-Profile and related statistics. Statistics data is sent to influxDB.
5. Optimizer program fetches latest Matrix-Profile data set, uses Matrix-Profile mean as second optimization goal.
6. Calculate new ion source control values and send to hardware.

## Feasibility Test Results



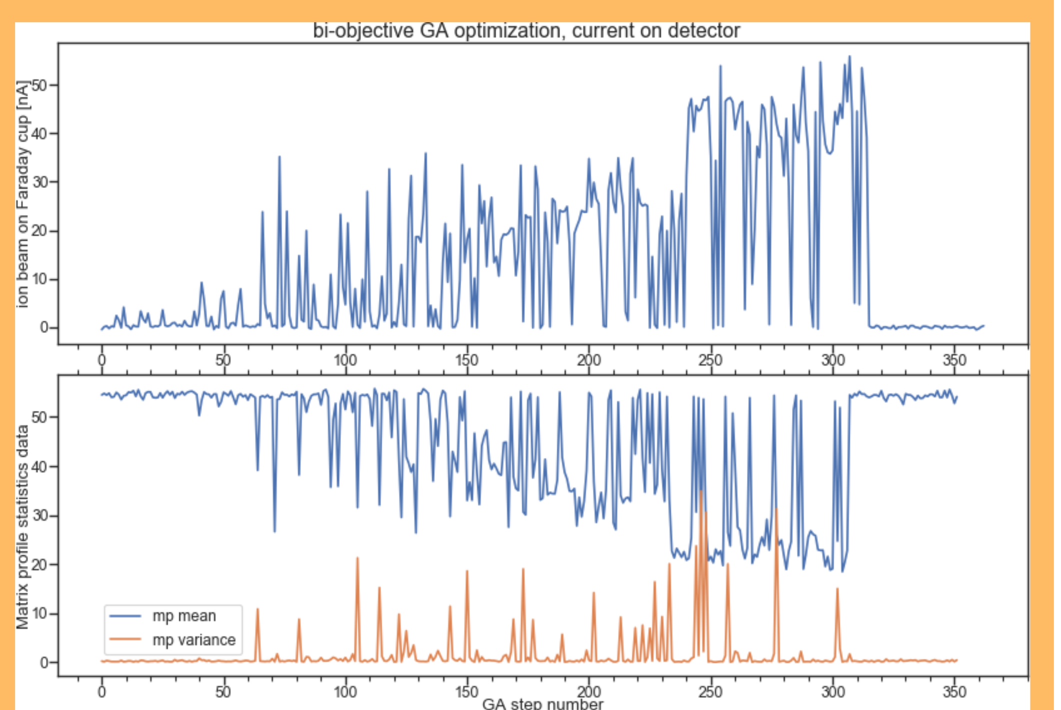

Plotting ion beam current against normalized mean of Matrix-Profile of 5 consecutive ion source spills exhibits the Pareto-front; trade-off between stable ion source operation (= low Matrix-Prof. values) and ion beam intensity.

Optimization experiments were performed using different settings for control parameters, Genetic Algorithm settings and signal processing. Above plot shows that optimizer reached intermediate results compared to reference values.

GA optimizer reached optimized state within 300 to 600 optimizer steps.

Optimizer cycle time between two step was in the order of 10 seconds in our test environment, going through steps 1 to 6 above.

Ion source spill frequency is in the order of 1 Hz.




We conclude that it is feasible to use the tested technology stack for automated ion source tuning. The performance of this automated approach tentatively seems to be compatible with manual operation, even more as current results are biased by ion-source end-of-lifecycle degradation calling for experiments with better boundary conditions.