Statistical analysis of sources of instability on electron beam quality in a laser plasma accelerator

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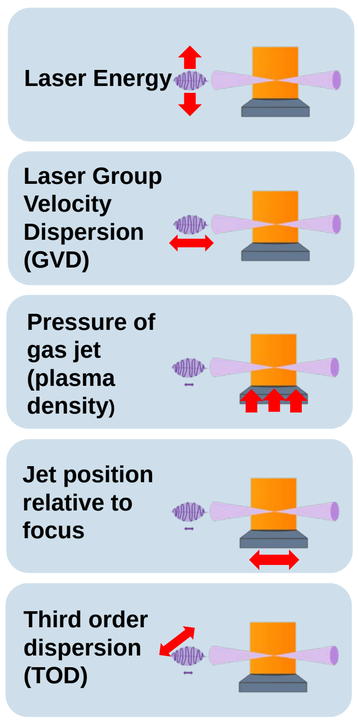
Motivation

- High demand for tunable high-power X-ray sources such as Free Electron Lasers (FEL) for experiments in material sciences, biology and medicine, chemistry, and semiconductor technology
- Laser Plasma Accelerators (LPA) are a compact electron beam source providing low divergence quasi-monoenergetic nano coulomb class electron beams suitable for FEL[1,2] ➡ **proof of concept: COXINEL experiment 2022[3,4]**

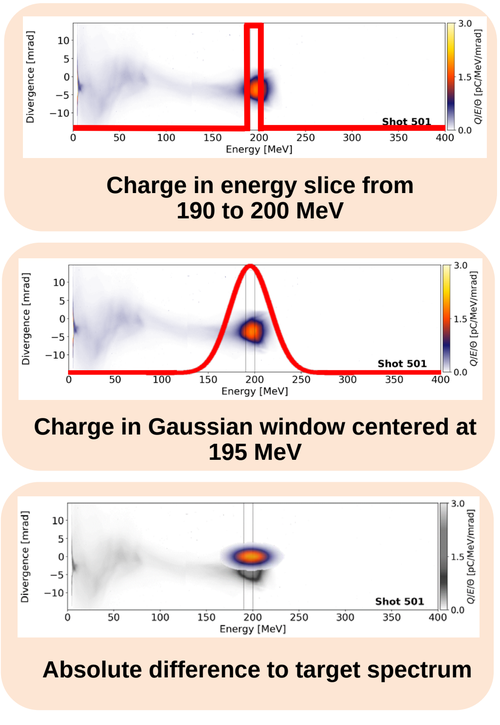
➡ Two requirements for experiment:
  - **Fast optimization of electron beam parameters** for FEL on a daily basis
  - High demands regarding the **stability of electron beam parameters**

Optimization of electron beam parameters with Bayesian optimization

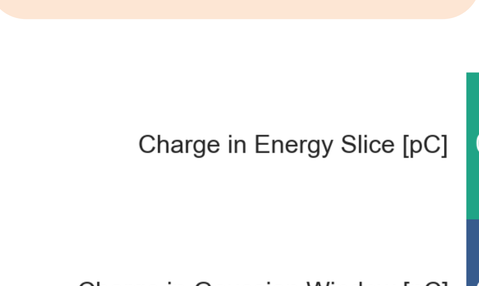
Input parameters



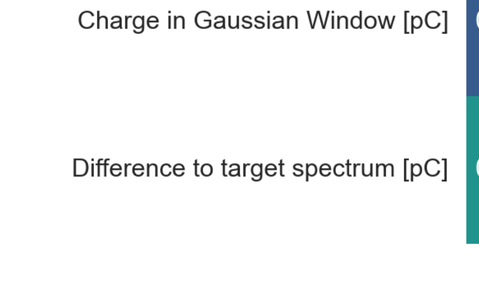
Objective function



Charge in energy slice from 190 to 200 MeV



Charge in Gaussian window centered at 195 MeV



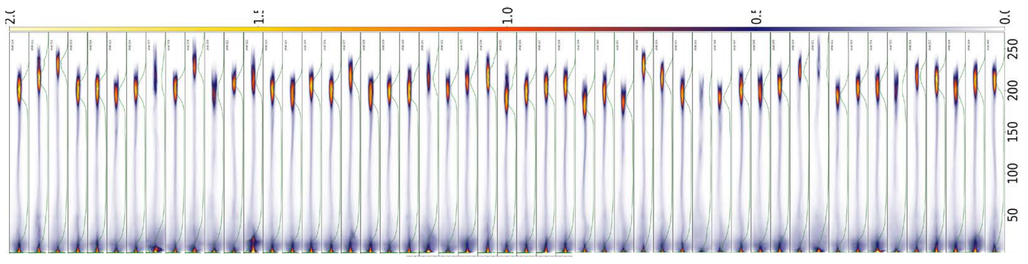
Absolute difference to target spectrum

Parameter space mapping

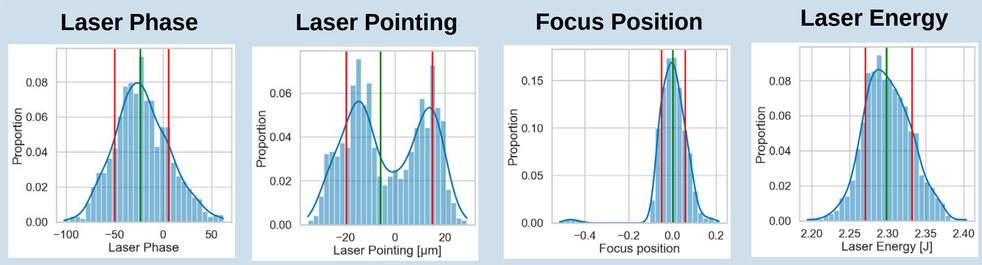
- 2200 shots randomly sampling the parameter space in the following ranges:

Laser energy on target [J]	1.6	2.3
Laser GVD [fs²]	-600	600
Pressure of gas jet [bar]	6	16
Focus position [mm]	-2	2
Laser TOD [fs³]	-20k	20k

Analysis of fluctuations of electron beam parameters

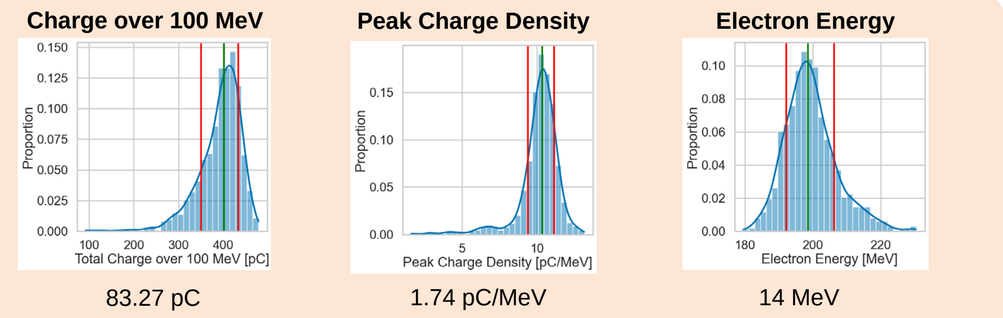


- 1030 consecutive shots over 4,5h
- Observed important fluctuations in input and output parameters



55.6 | 34 µm | 0.10 mm | 61 mJ

Input parameter fluctuations

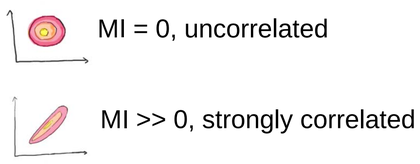


83.27 pC | 1.74 pC/MeV | 14 MeV

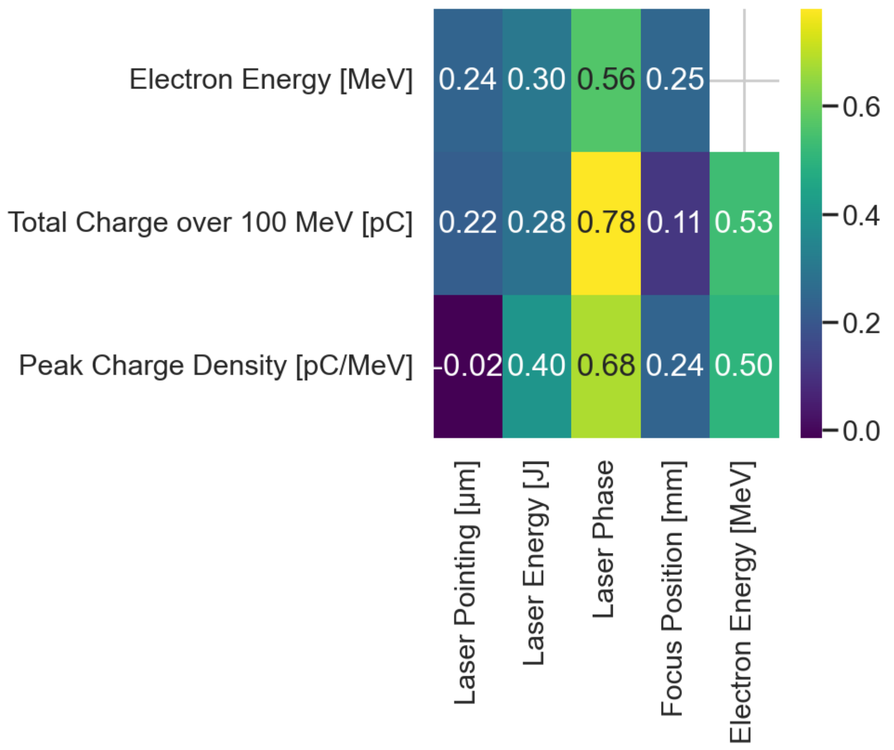
Output parameter fluctuations

Investigation of correlations

- Use Mutual Information (MI) to estimate strength of correlation between parameters

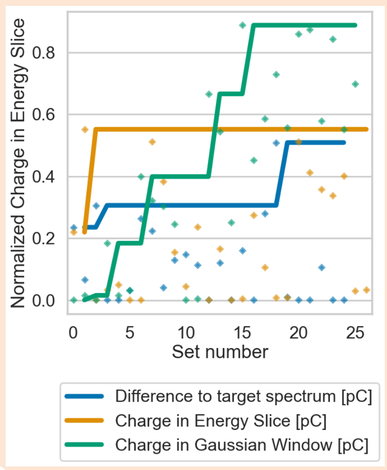


Investigation of correlations using Mutual Information

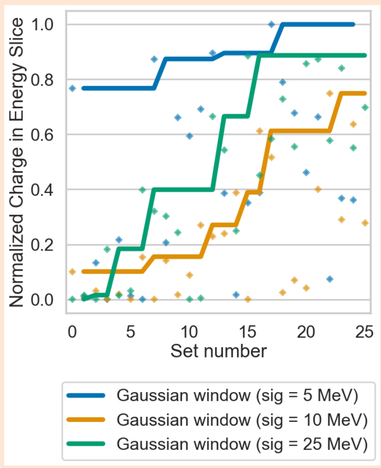


Hyperparameter tuning

Type of objective function



Size of Gaussian window



- Let each model optimize for 200 shots (init: 5 random sets)
- Evaluate model regarding accuracy and optimization speed

Conclusion

- Mutual Information is a powerful tool to estimate the strength of correlations between input and output parameters
- In our system, the fluctuations of the spectral phase have the biggest impact on electron beam quality

References

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Questions?
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