Bayesian optimization of a laser-plasma accelerator

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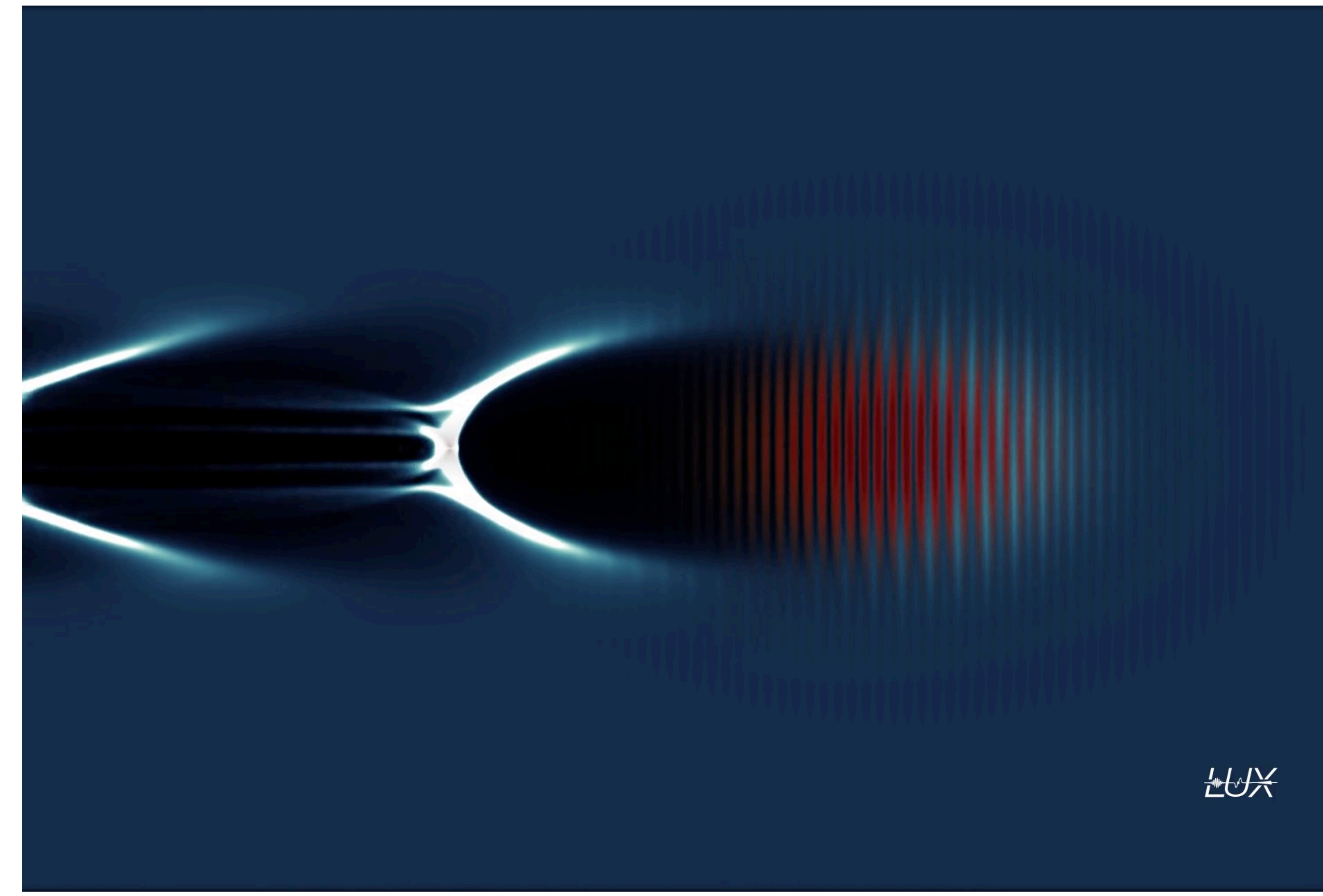
image: DESY, scicomlab

Laser-plasma acceleration
State of the art



Advantages

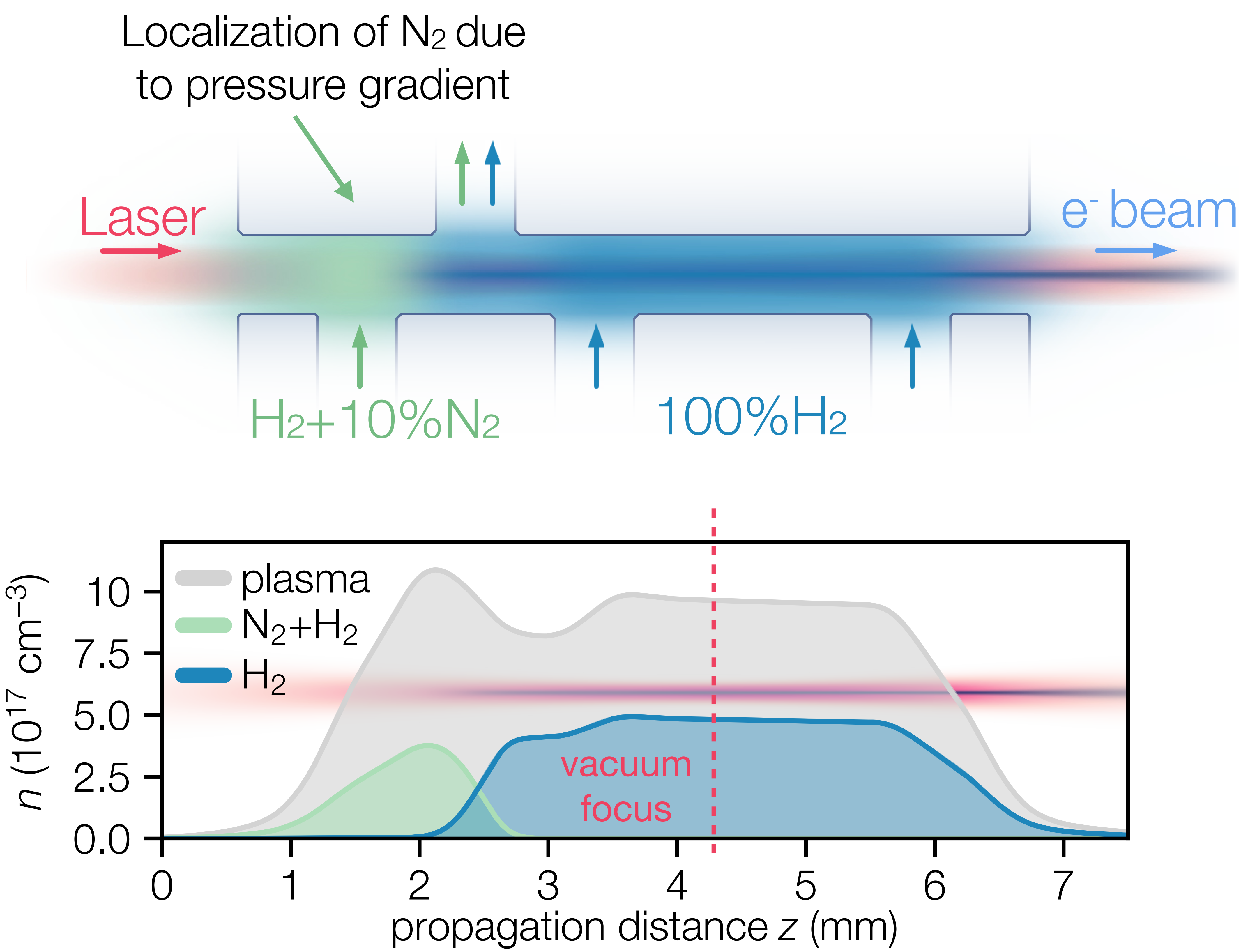
- + 100 GV/m electric fields
- + compact size
- + intrinsic synchronization
- + fs bunch duration
- + pC-nC charges
- + high peak current

Challenges

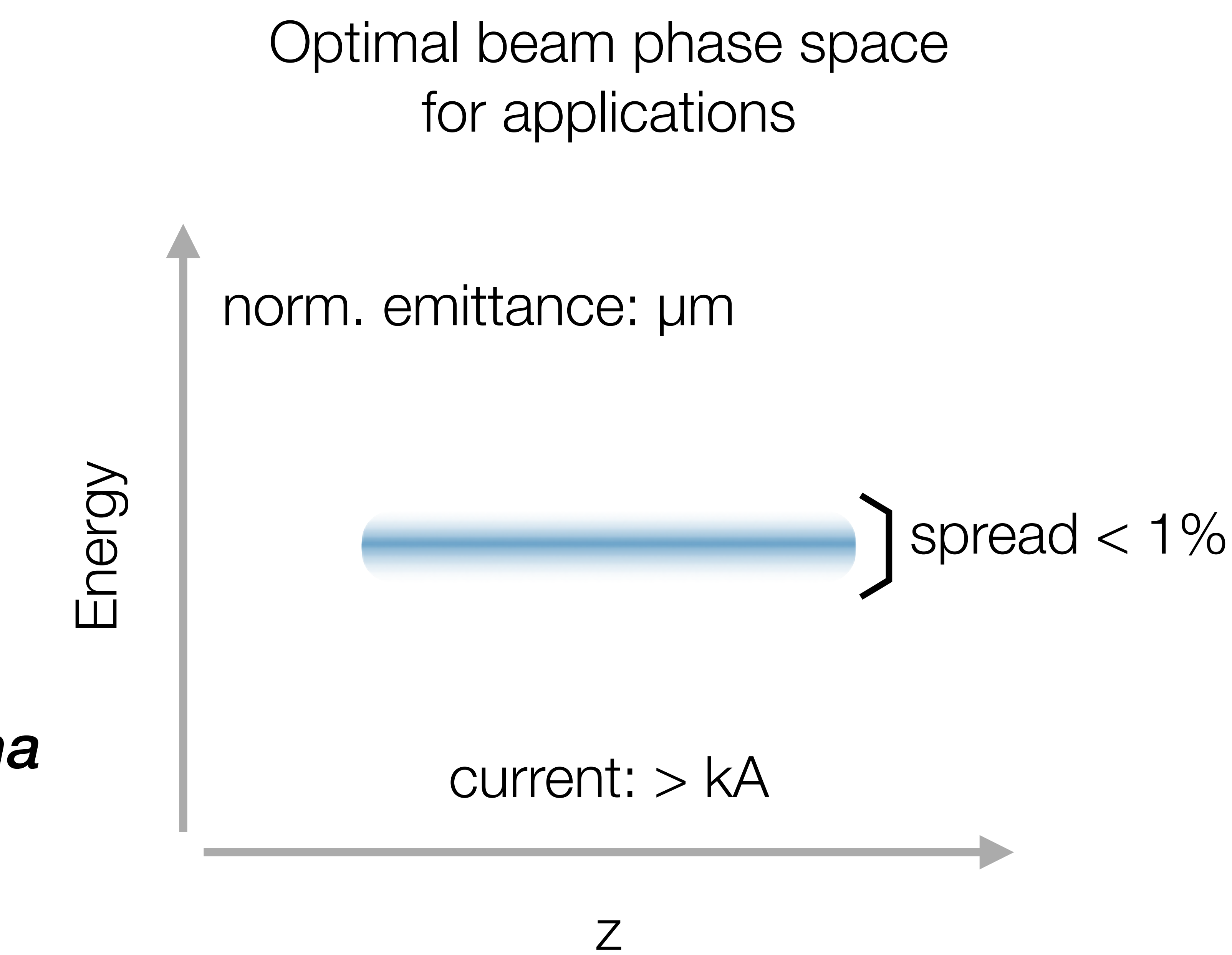
- beam quality
- increased stability
- kHz repetition rates

Tuning beam parameters

High quality beams for FEL experiments



optimize laser and plasma conditions

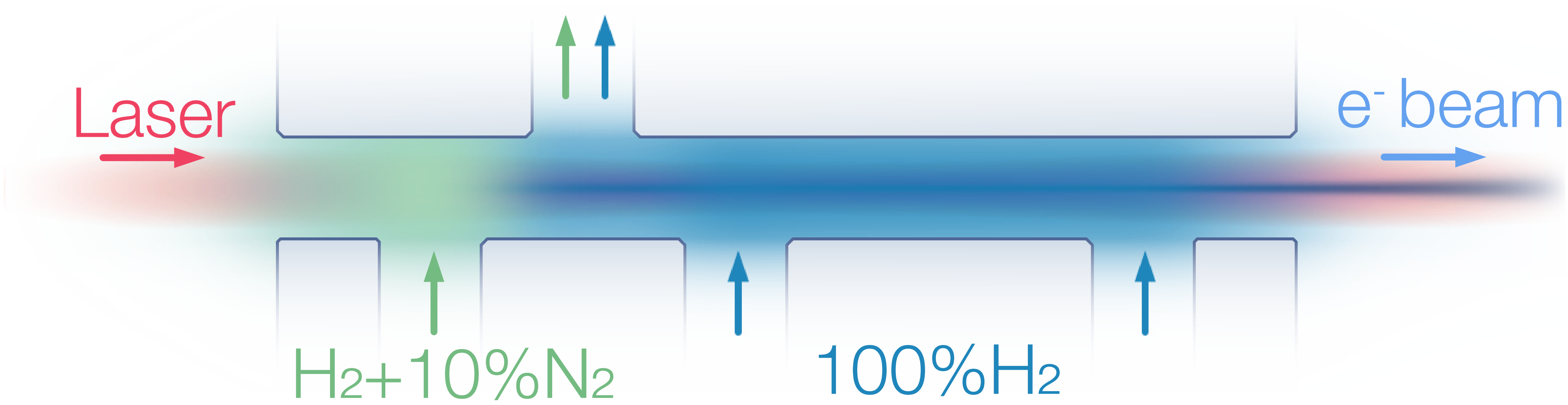


M. Kirchen et al.,
Optimal beam loading in a laser-plasma accelerator
PRL 126, 174801 (2021)

Finding the optimum

Curse of dimensionality

Just scan it?



Focus position: *target length 5 mm / 0.05 mm = 100x*

Doping: *0 to 100 % / 1 % = 100x*

Gas density: *0.5×10^{18} to 1×10^{18} cm^{-3}/0.05×10^{18} cm^{-3}= 10x*

Laser energy: *2 J to 3 J / 0.1 J= 10x*

1 000 000 measurements
@ 1 Hz → 11.5 days or
years worth of computing budget for simulations

Finding the optimum

Requirements

- Expensive PIC simulation
- Low repetition rate in experiments
- Slow machine controls

- Unstable experimental condition
- Jitter

- Unknown function
- Potential local optima

few evaluations / measurement

noise resistent

global optimization

Finding the optimum

Requirements

Young, energetic LPA (5) seeks mature optimization algorithm for adventurous exploration of costly and noisy data. ☎+49 40 8998-0

- Expensive PIC simulation
- Low repetition rate in experiments
- Slow machine
- …ondition
- Jitter
- Potential local optima

few eva… measu…

…optimization

Efficient Global Optimization of Expensive Black-Box Functions

DONALD R. JONES[1], MATTHIAS SCHONLAU[2,⋆] and WILLIAM J. WELCH[3,⋆⋆]

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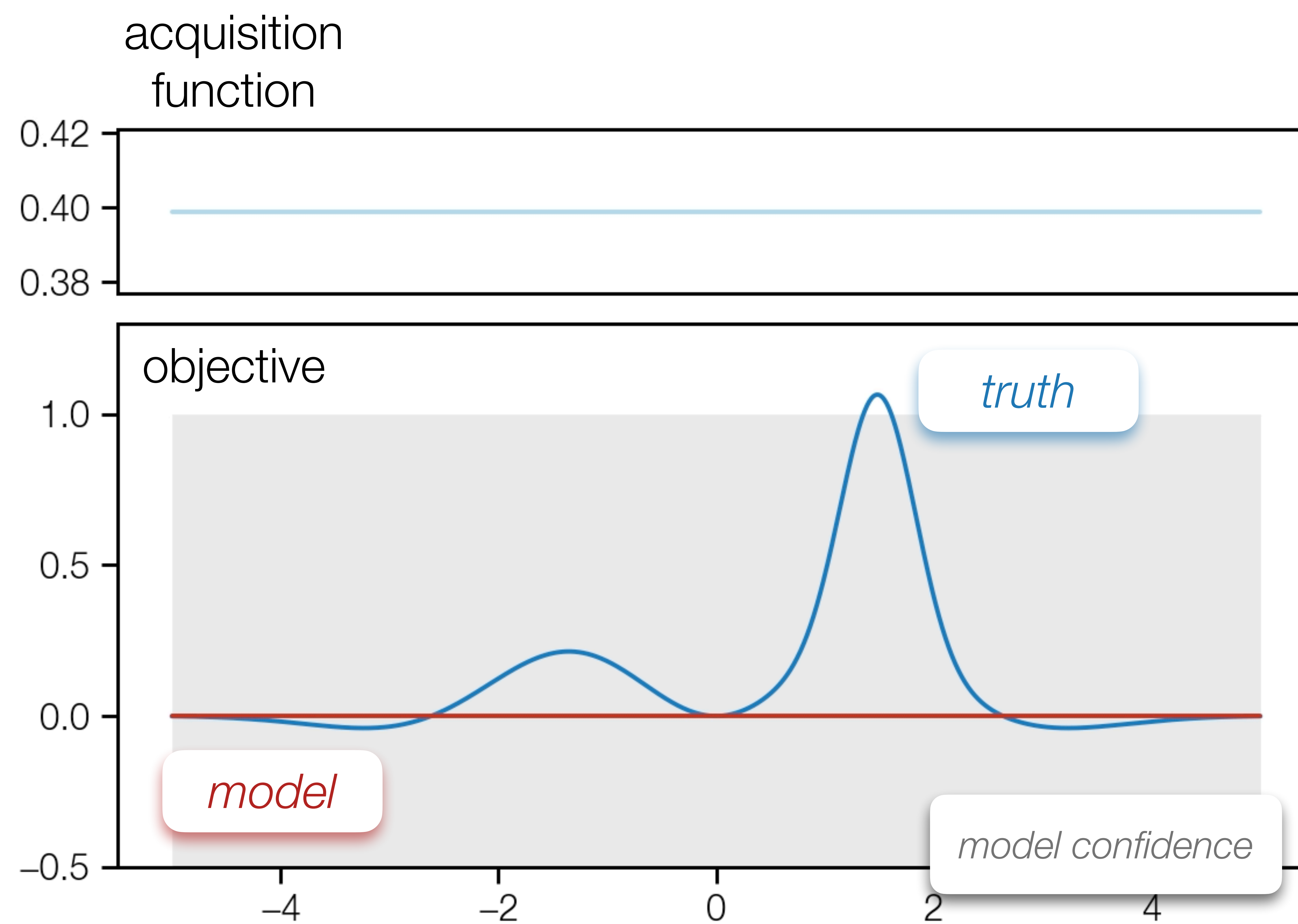
Bayesian optimization
Basic concepts

Build surrogate model
Gaussian process regression

Acquisition function describes potential of next evaluation

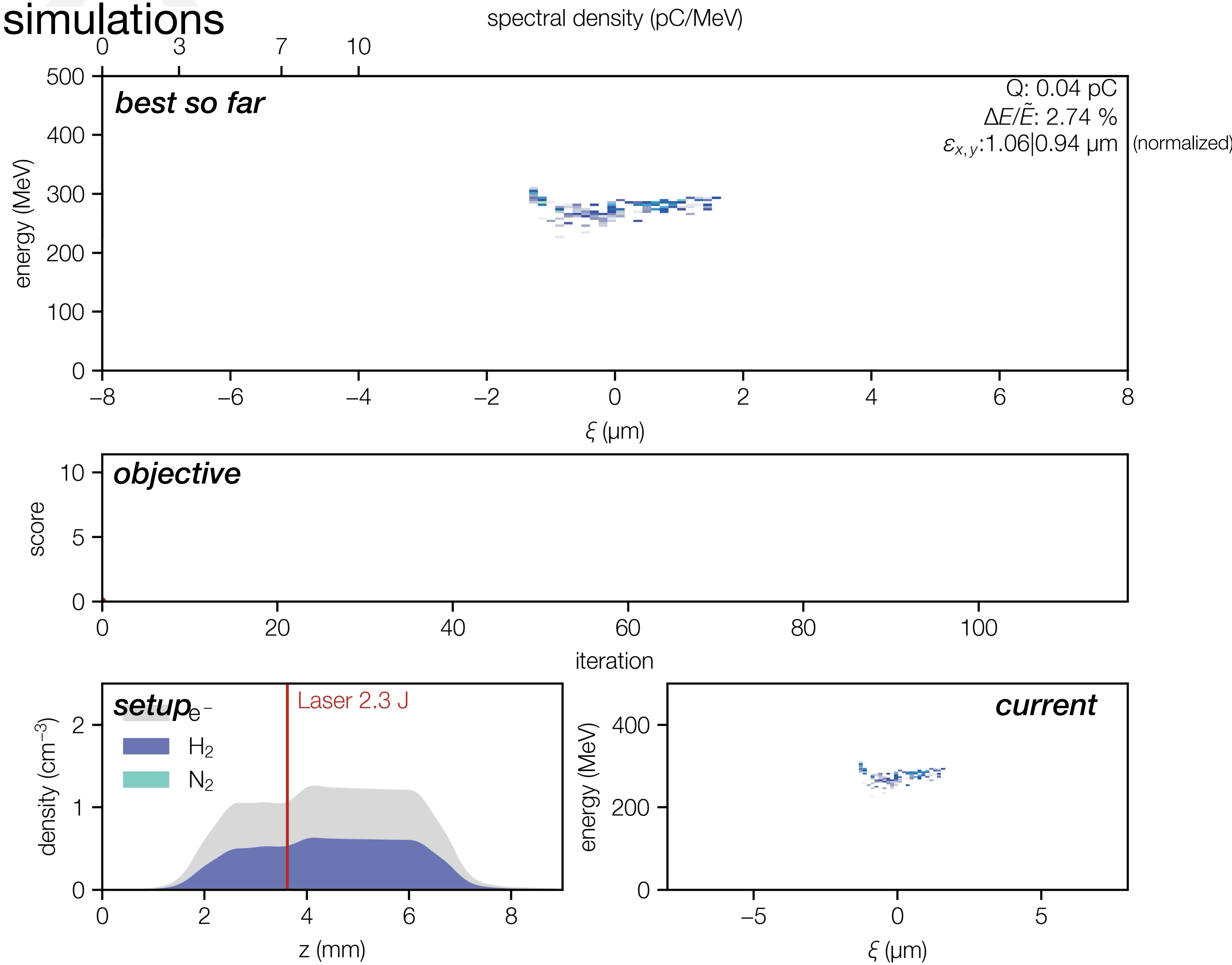
Perform evaluation where acquisition function is largest

Refine model with new knowledge



Bayesian optimization

Particle-in-cell simulations



$$\sqrt{Q}\tilde{E}/\Delta E$$

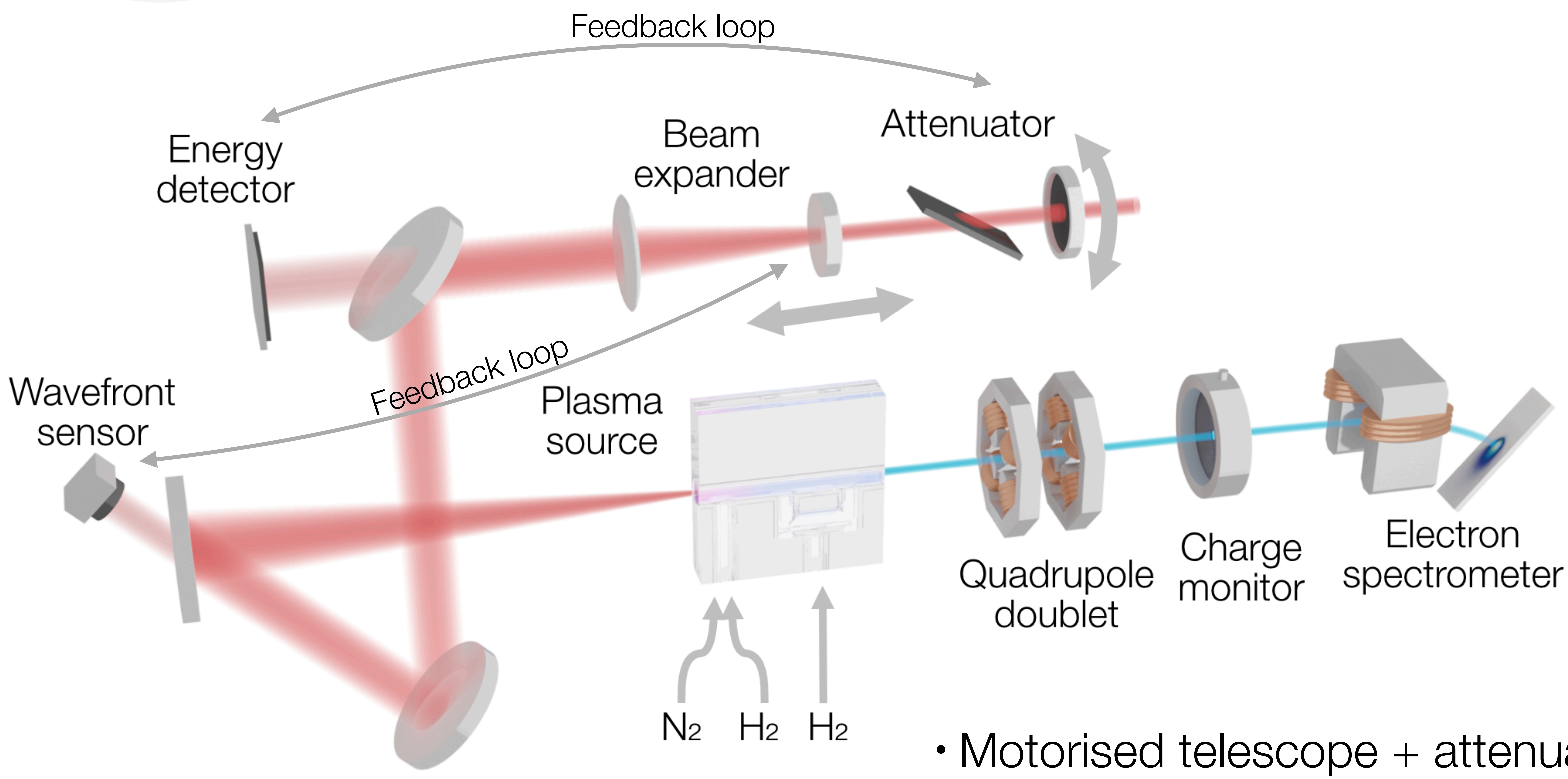
objective function

- charge
- energy
- energy spread

FBPIC simulations

Experimental setup

LUX laser-plasma accelerator



- Motorised telescope + attenuator for laser control
- 3 channel Mass Flow Control for target setup
- High resolution electron diagnostic
- Fully incorporated in DOOCS control system

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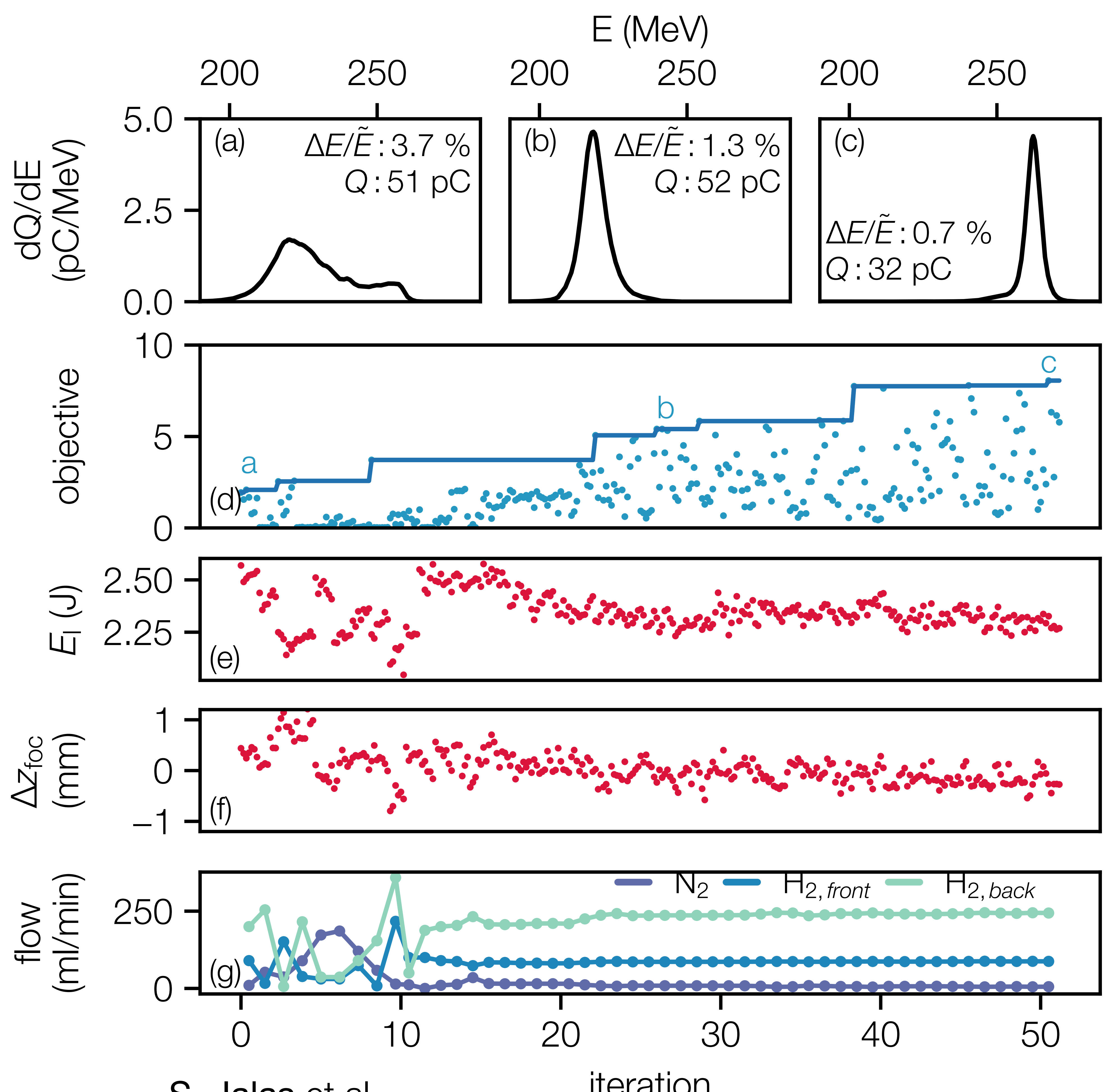
Bayesian optimization

High quality electron beams



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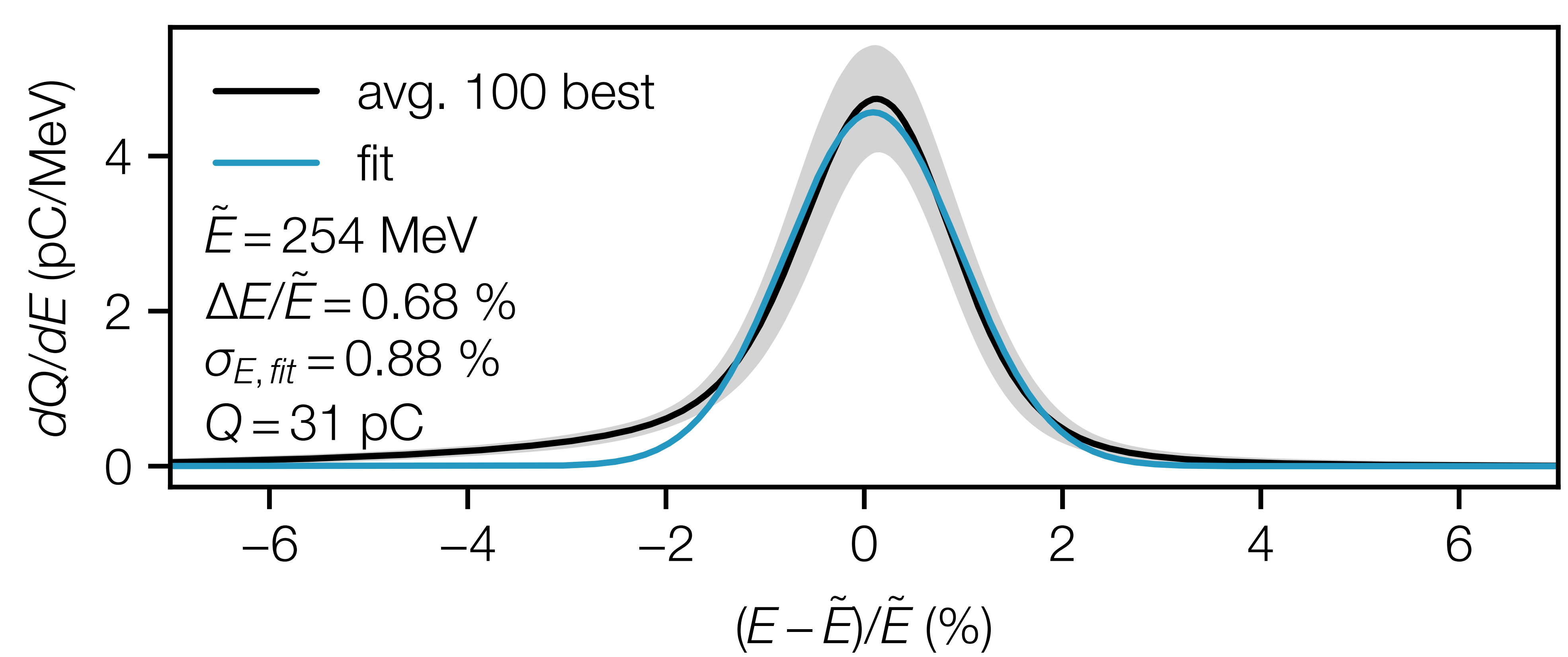
Random start-point → sub percent energy spread beams

No human input

Statistics of 100 best from 2500 shot at optimum



Summary

- Machine learning based optimization of a laser-plasma accelerator
- Combined workflow for optimizing simulations + experiment
- Showed reliable generation of **sub percent energy spread** electron beams
- Single-shot accurate surrogate model for future feedback and virtual diagnostics

For more details see our recent publications:

PHYSICAL REVIEW LETTERS **126,** 104801 (2021)

Bayesian Optimization of a Laser-Plasma Accelerator

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Optimal Beam Loading in a Laser-Plasma Accelerator

Manuel Kirchen,[1,*] Sören Jalas,[1] Philipp Messner,[2,1] Paul Winkler,[3,1] Timo Eichner,[1] Lars Hübner,[3,1] Thomas Hülsenbusch,[3,1] Laurids Jeppe,[1] Trupen Parikh,[3] Matthias Schnepp,[1] and Andreas R. Maier[3,1]