Bayesian Optimization of Laser-Plasma Accelerators

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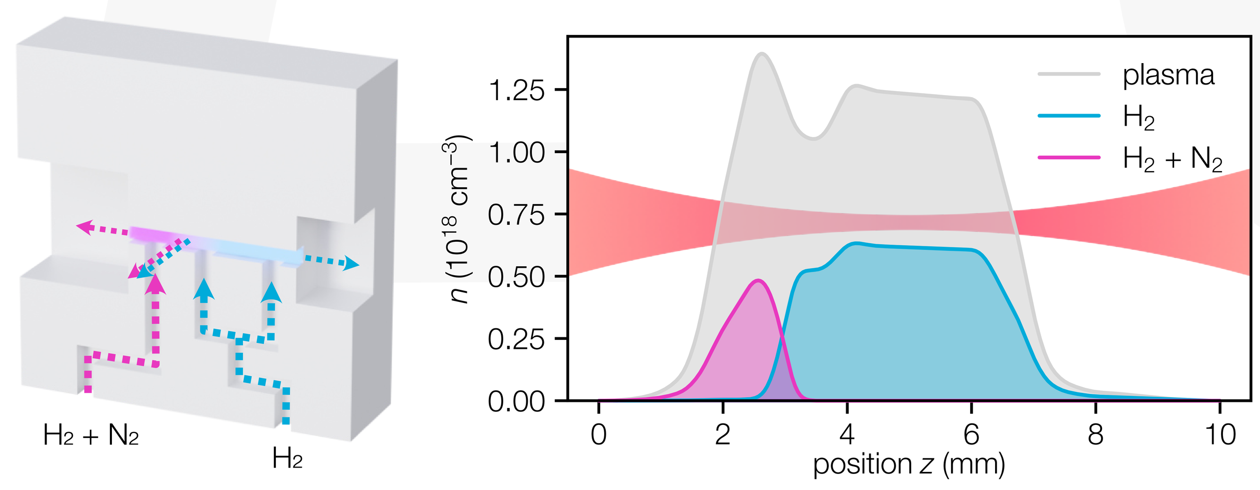
LUX Plasma Source

High quality electron beams from localized ionization Injection



Complex parameter space allows precise tuning of phase space dynamics

- Gas dynamics at vacuum outlet prevents separation of gases from two separate inlets
- Separation of mixed gas for injection and pure Hydrogen for acceleration
- Control over mixing ratio and gas density allows to match beam current to wakefield evolution
- Optimal beam loading conditions when laser, plasma and bunch parameters are matched

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Optimal beam loading in a laser-plasma accelerator
PRL 126, 174801 (2021)

Bayesian Optimization

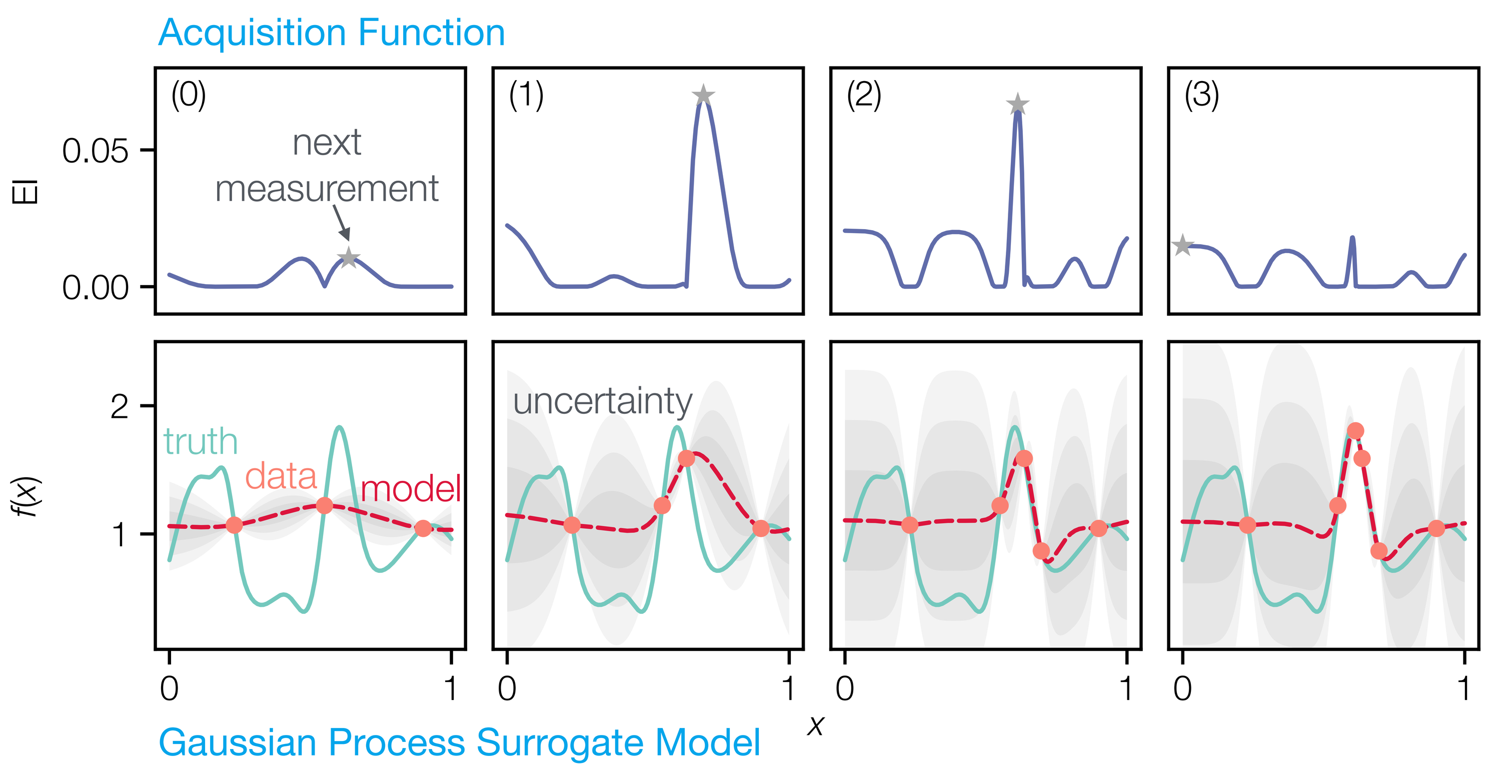
Model based optimization of costly and noisy black-box functions

Use-case

- Evaluations (PIC simulation, experiment, …) are expensive
- Problem is not convex (local optima)
- Observations are noisy

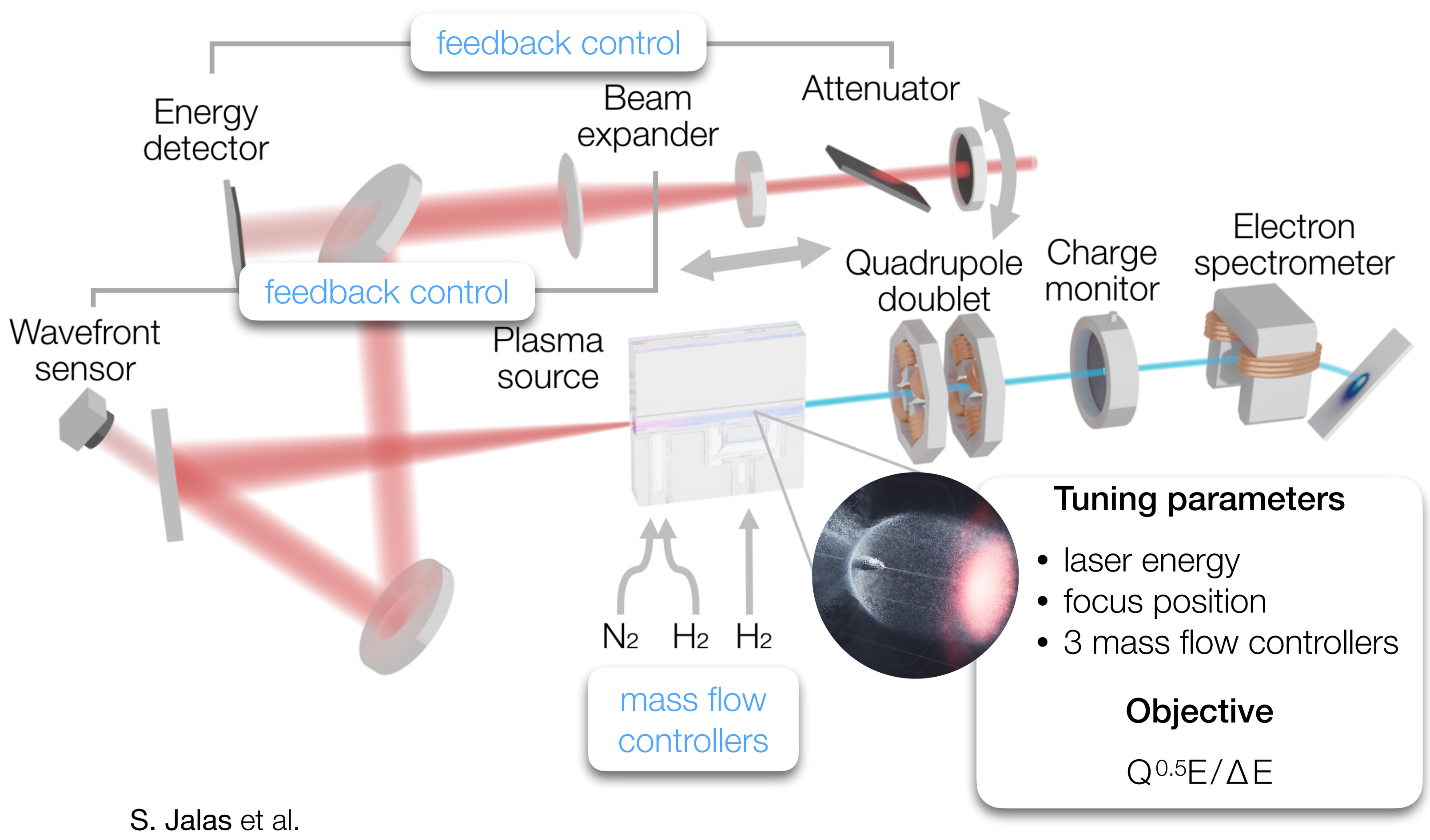
Concept

- Approximate problem with cheap surrogate model
- Define acquisition function from model predictions and uncertainties
  - Quantifies value of potential measurement in finding the global maximum
- Evaluate real problem with parameters that give largest acquisition function value



Experimental Results

Autonomous optimization of the LUX accelerator to sub-percent energy spread



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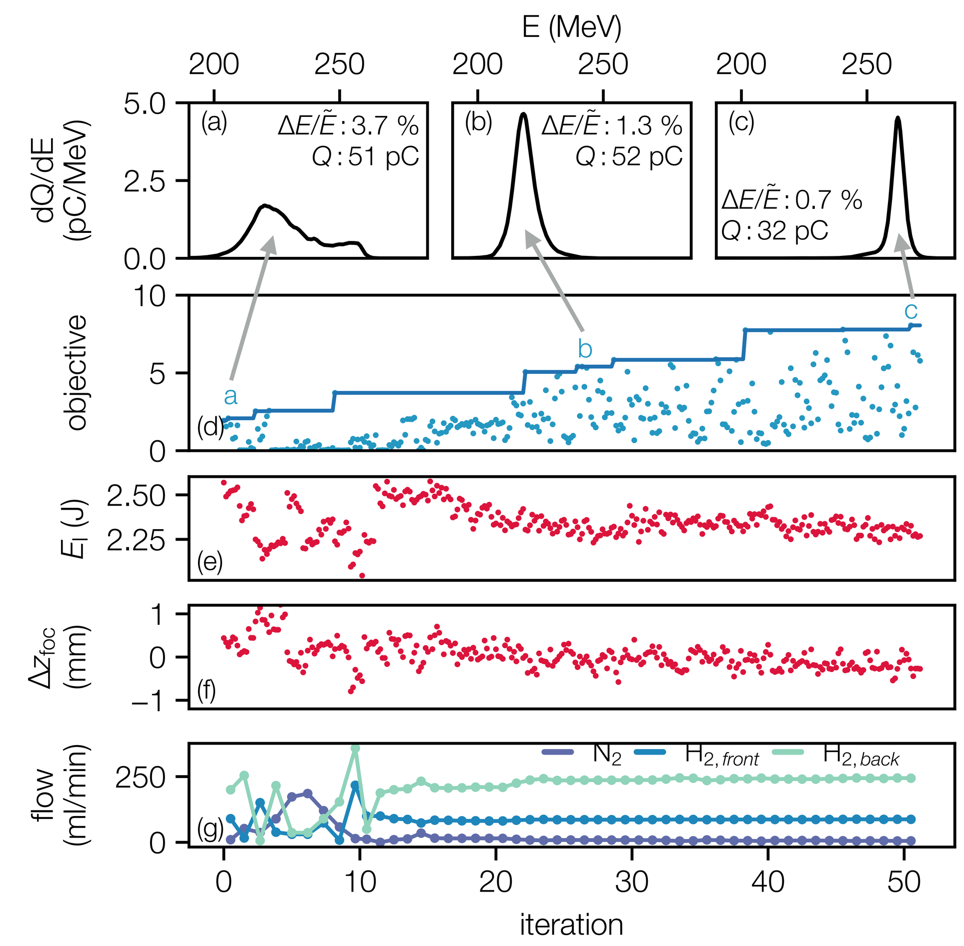
Bayesian optimization of energy spread and beam charge

- Complex input parameter space ▸ more than 10^6 combinations for required scan resolution
- Need to find setup that provides minimal energy spread and high charge

LPA optimization with noisy online beam measurements

- Train surrogate model with single shot data
- Tune machine with feedback controlled actuators
- Start with random machine settings
- Accelerator autonomously searches and finds set-point that gives **sub-percent energy spread.**



Autonomous optimization of the energy spread and charge at LUX.

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