Bayesian Optimization of Direct-Drive Inertial Confinement Fusion Simulations

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Direct-Drive ICF

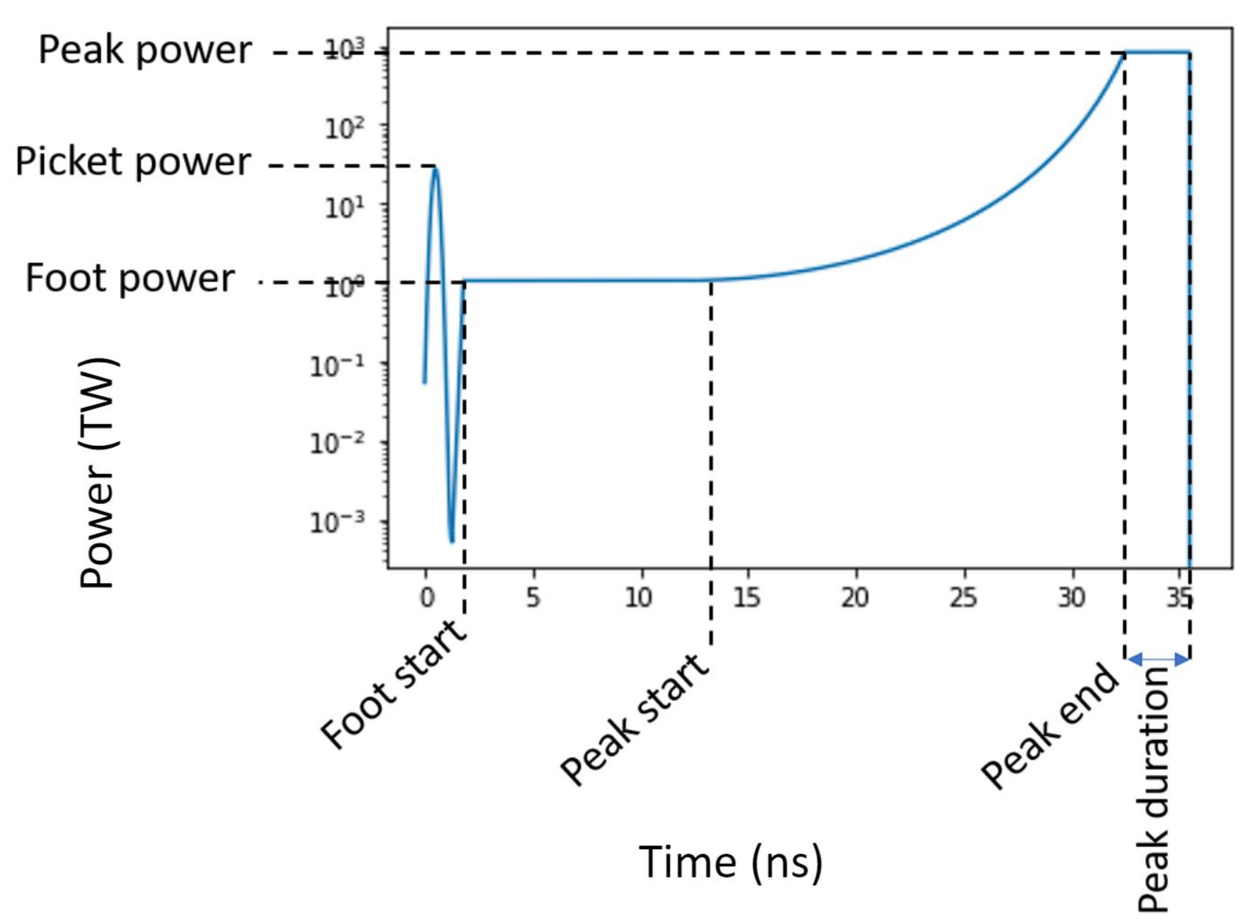


Figure 1: Example of a laser pulse used in Direct-Drive ICF. Main features of the pulse are labeled.

- Laser pulse begins with 1-3 low intensity pickets that ablate the surface
  - Creates pressure pulses that send shockwaves to the center compressing the target
- Timing of shocks are important to avoid shock preheating of the fuel
- Laser pulse intensity then increases to peak power which sends a large shockwave that merges with the shock waves from the picket pulse(s)
- In this project peak start, peak end , peak duration and peak power were optimized

Bayesian Optimization

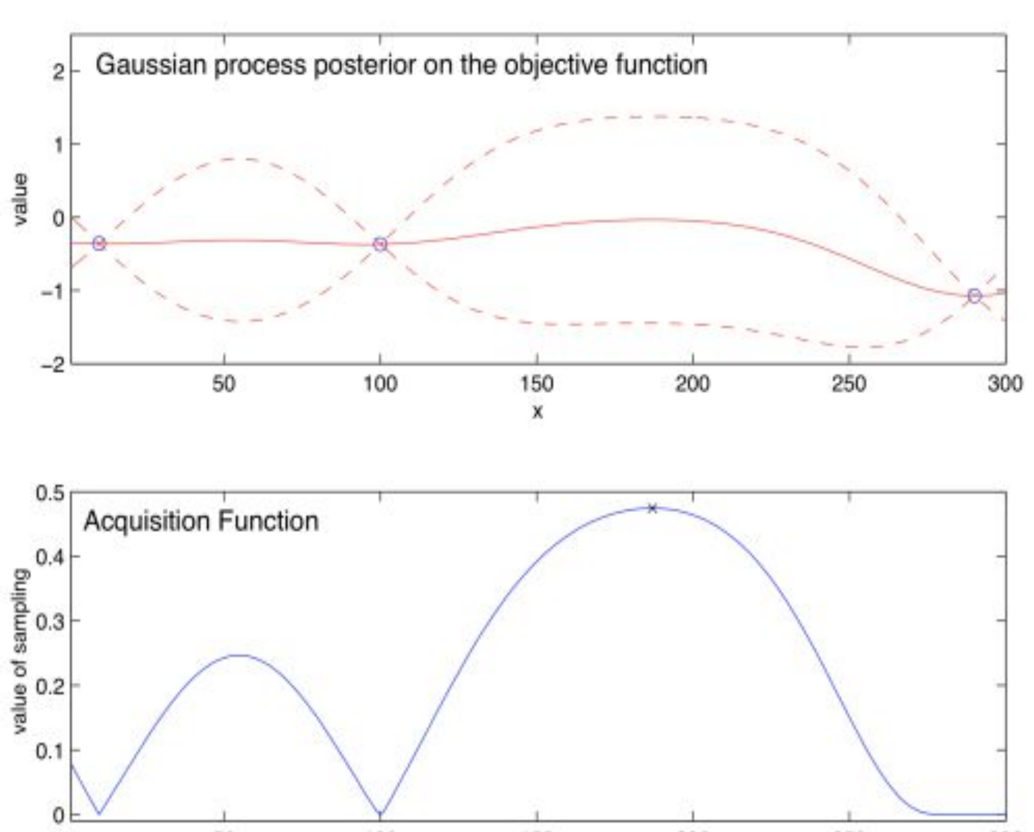


Figure 2: In the top figure the solid red line is the surrogate function given 3 points. The dashed red line are the credible intervals found via Gaussian Process regression.The bottom panel visualizes the acquisition function with the next point to sample marked as x. Image from Frazier, Peter I. "A Tutorial on Bayesian Optimization." *ArXiv.org*, 8 July 2018, https://arxiv.org/abs/1807.02811v1.

$$P(A \mid B) = \frac{P(B \mid A) \cdot P(A)}{P(B)}$$

- Global optimization on BlackBox Functions
  - Meant for 'expensive' functions that are difficult to evaluate
- P(A|B) : Posterior Probability represents the probability of the physics model being correct given the data we've collected
- P(A): Prior Probability represents the prior knowledge, which is how constraints are added
- P(B|A): Likelihood are the chances we would have collected the data we did, if the physics model is correct
- P(B): Evidence is the uncertainty distribution of the data

One Parameter

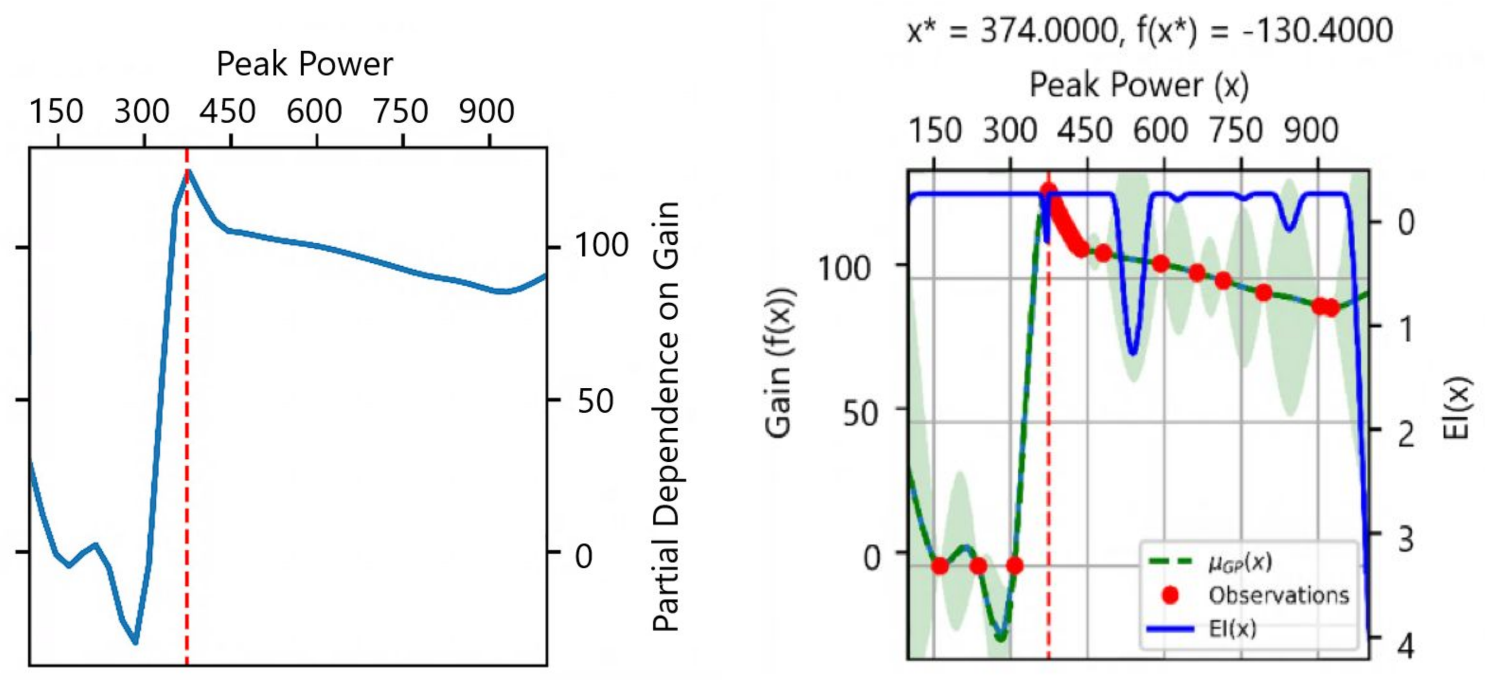
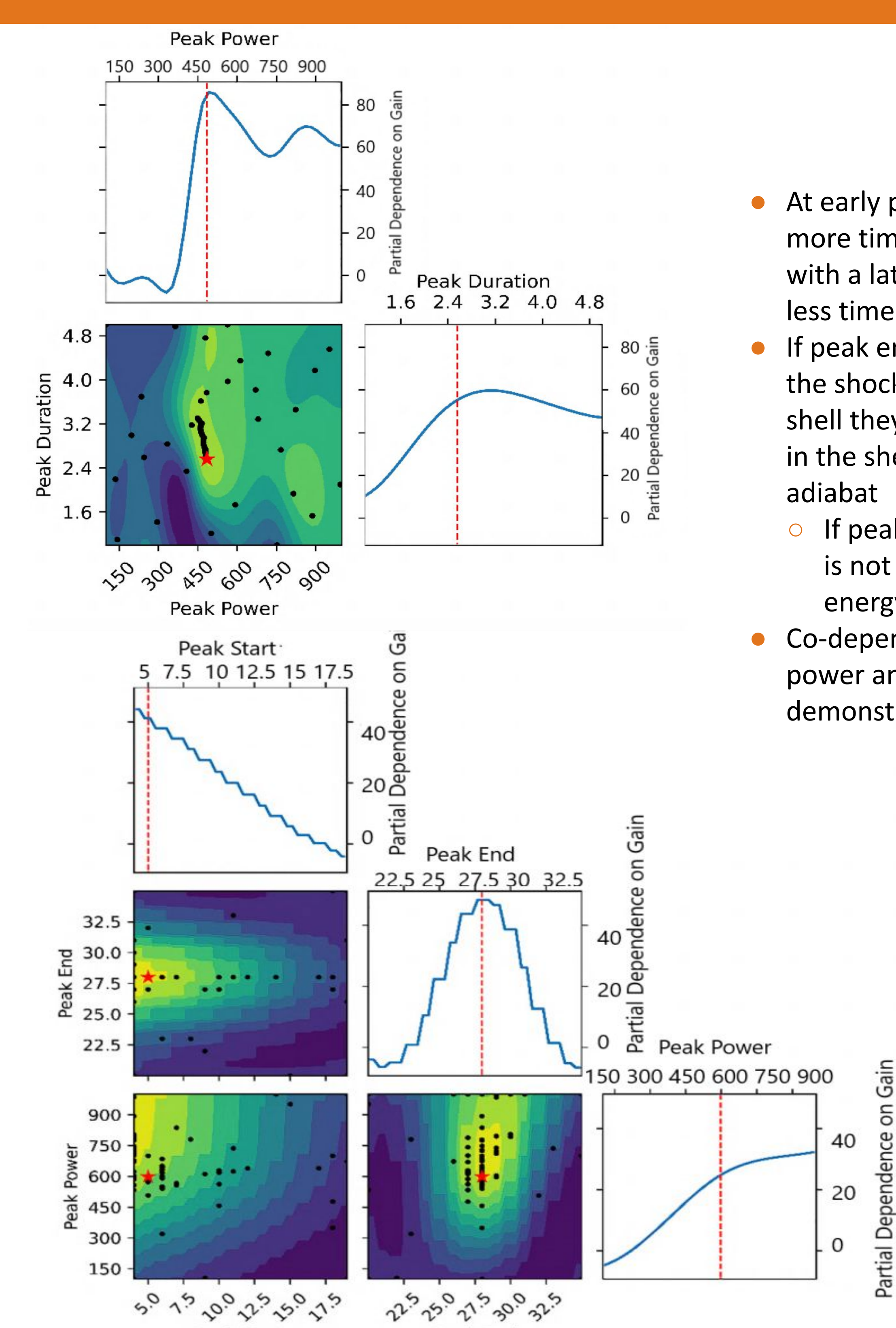


Figure 3: On the left the surrogate function for a 30 call run with one parameter. On the right the red dots are the samples observed during optimization. The green line is the surrogate function for peak power. The blue line is the acquisition function. The y-axis represents the gain.

- At less than 300 Terawatts there is not enough KE coupled to the shell, so the target is unable to reach ignition conditions
- At 400 Terawatts ignition conditions are met
- At higher powers there are greater implosion velocities which leads to lower mass assemblies

Two and Three Parameters



- At early peak starts there is more time to accelerate and with a late peak start there is less time to accelerate
- If peak end is too early when the shocks break out of the shell they collide with shocks in the shell and increase the adiabat
  - If peak end is too late there is not efficient coupling of energy in the hotspot
- Co-dependence of peak power and peak start demonstrated in contour plots

Figure 4 and 5: Diagonals show the partial dependence of a single parameter on the surrogate function. Below the diagonals are contour plots showing the partial dependence of two parameters on the surrogate function. Black dots are the points that were evaluated and the red star is the predicted minimum.

Four Parameters

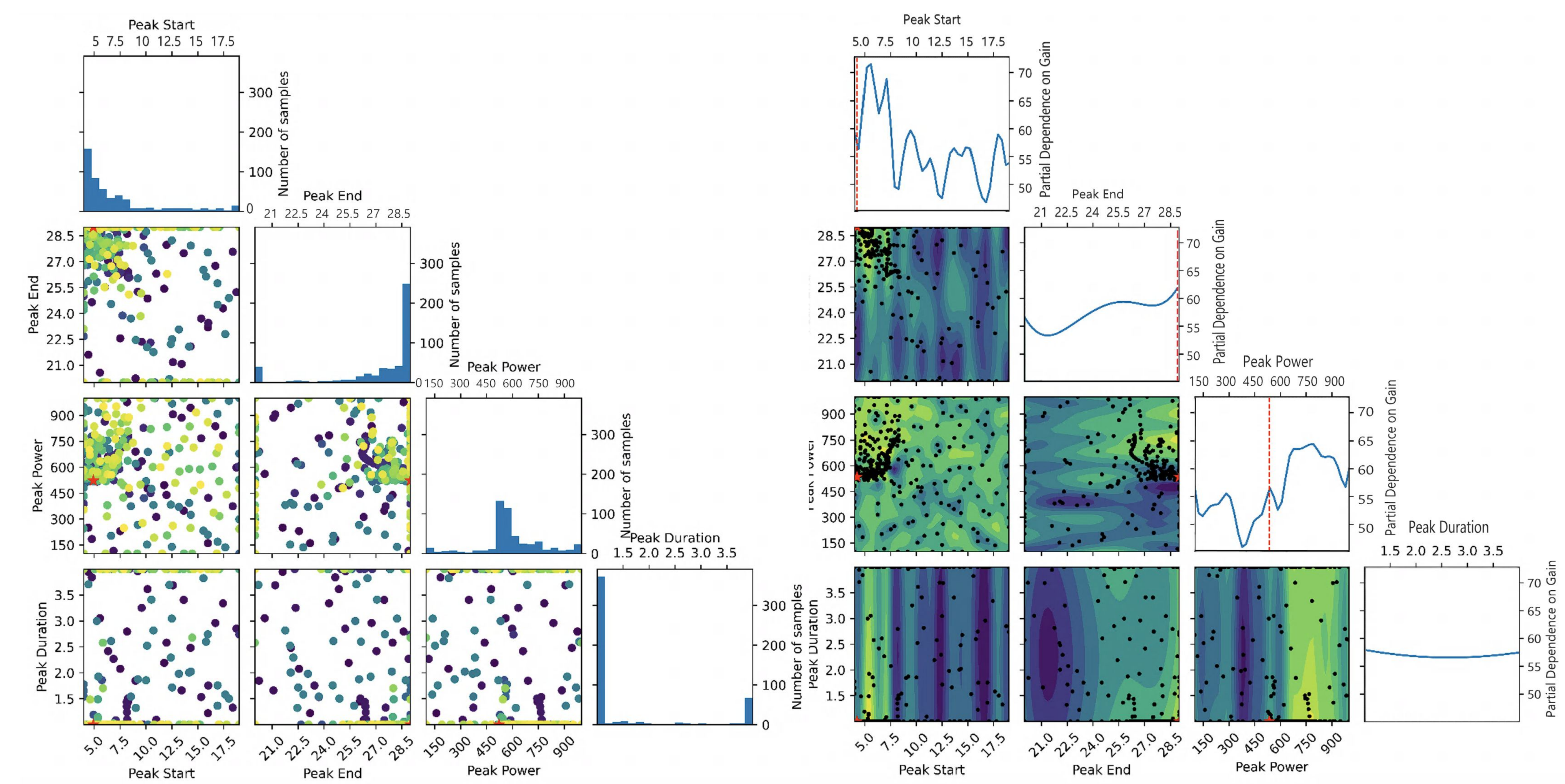


Figure 5 and 6: Four parameter run for 500 calls.In scatter plots dark purple are the first samples explored and yellow are the last. In the contour plots yellow is the highest gain, 160, to dark purple, the lowest ghain, 0.

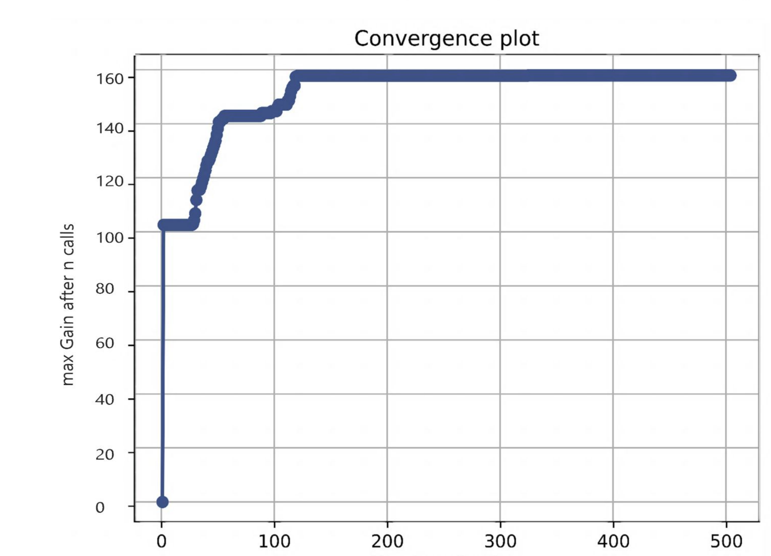
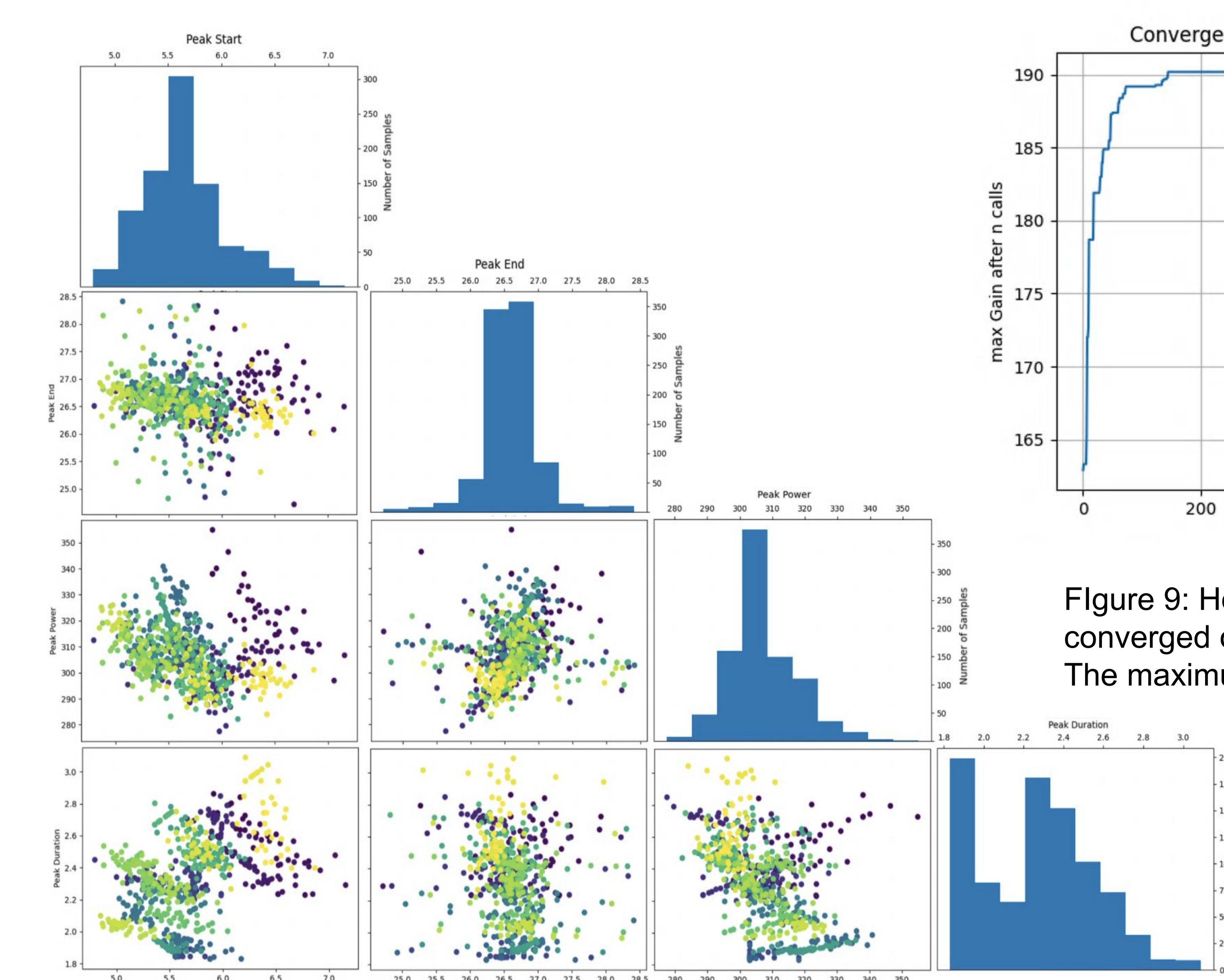


Figure 7: How quickly the optimizer converged on the maximum gain found in the entire run. The maximum gain found was 160.

Nelder-Mead Optimizer



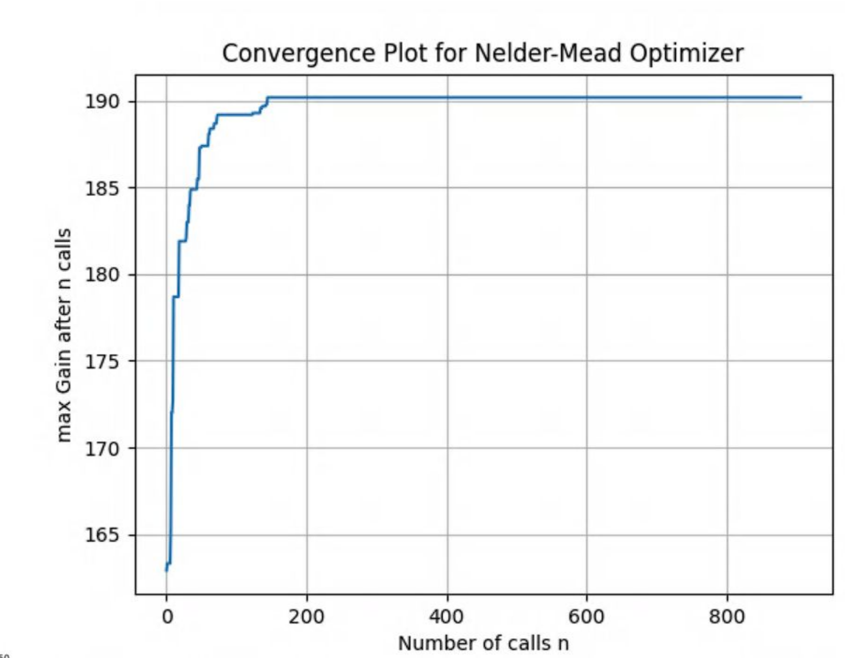


FIgure 9: How quickly the optimizer converged on the maximum gain found. The maximum gain found was 190

Figure 8: Four parameter run in 905 calls. Performed with Nelder-Mead and basin hopping optimization . .In scatter plots dark purple are the first samples explored and yellow are the last.