# MODELING OF LASER DISTRIBUTION AS INPUT FOR SIMULATIONS OF LASER WAKEFIELD ACCELERATION

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## Abstract

In order to accurately simulate laser plasma coupling for PW-class lasers drivers such as Apollon F2 beam, we implemented **a Gerchberg-Saxton-like Algorithm (GSA)** to efficiently fit measured asymmetric laser fluences using bases of orthogonal functions.

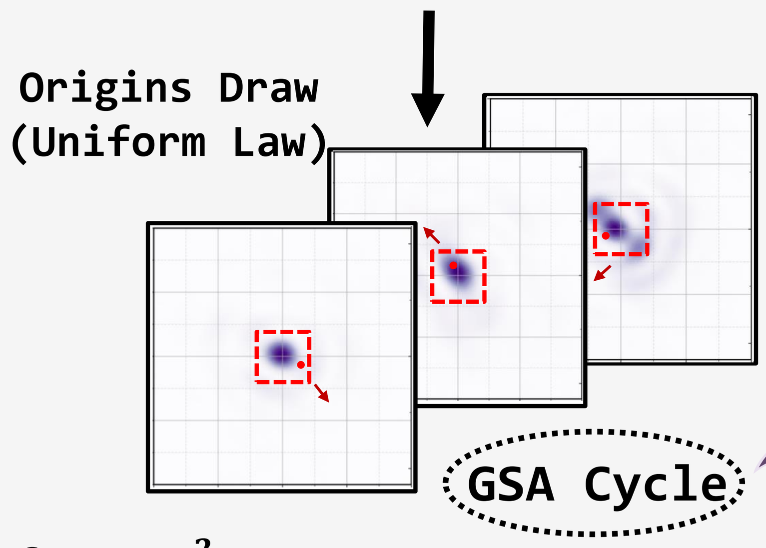
This GSA process allows us to retrieve a 2D phase-map associated to a collection of fluence images measured through laser focus in vacuum by minimising the integrated error on the fit. Due to the high dimensionality of the fit parameter space used within the algorithm, we employed Bayesian Optimisation to retrieve the optimal set of inputs for our fit functions.

## Standard Gradient Descent

Method : Uniform law to draw random set of origins within a narrow space box. If a new minimum is found, the center of the box is shifted.

Structure :

Iteration{i} $(\vec{O}_{x,y,opt}, HG_{m,n,opt}, \chi^2_{min})$

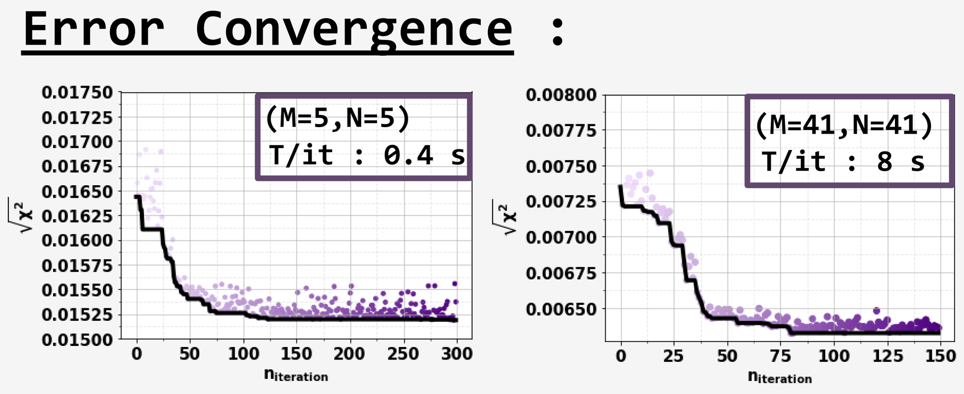



If new $\chi^2_{min}$ : New centers & Box shift

Iteration{i+1} $(\vec{O}_{x,y,opt}, HG_{m,n,opt}, \chi^2_{min})$

Procedure Example : (M=5,N=5) Educated Guess → $\vec{O}_{x,y,EG}$ → (M=41,N=41) Refined Search

Error Convergence :



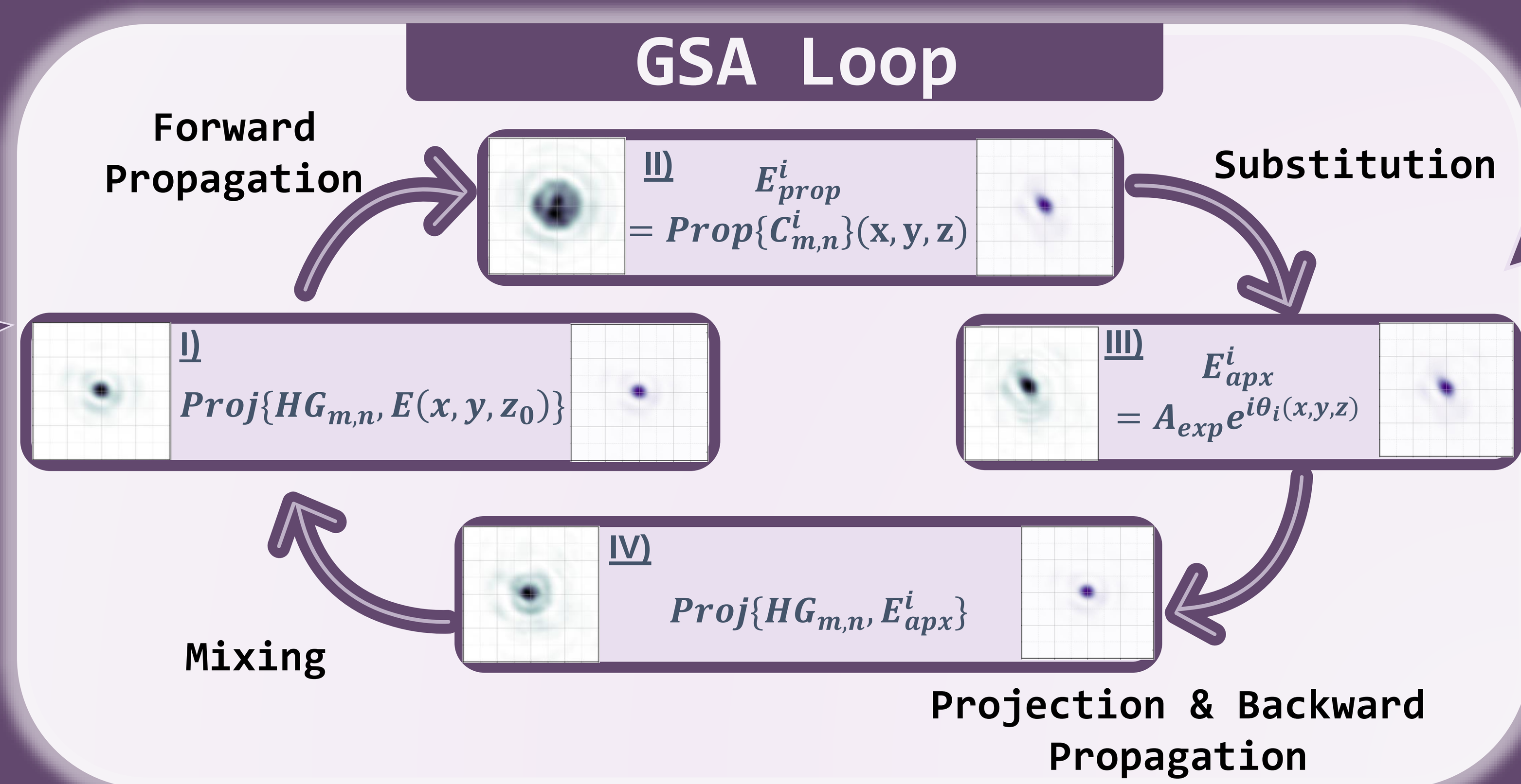

## Comparison of Fit Methods

Multiple shots are necessary to measure the fluence through the focal volume. The laser beam fluctuates from shot to shot. Measured images are fitted with an ensemble of Hermite-Gauss functions. The origins of the Hermite-Gauss ensemble is matched to measured data by minimising the integrated error between measured and fitted fluence:

$$\chi^2 = \sum_{z_i}\sum_{x,y}\left(\Phi_{fit}(x,y,z_i) - \Phi_{exp}(x,y,z_i)\right)^2$$

$\chi^2$ is minimised within each GSA cycle. Providing the starting origins with a quick educated guess allows faster convergence.

## GSA Loop

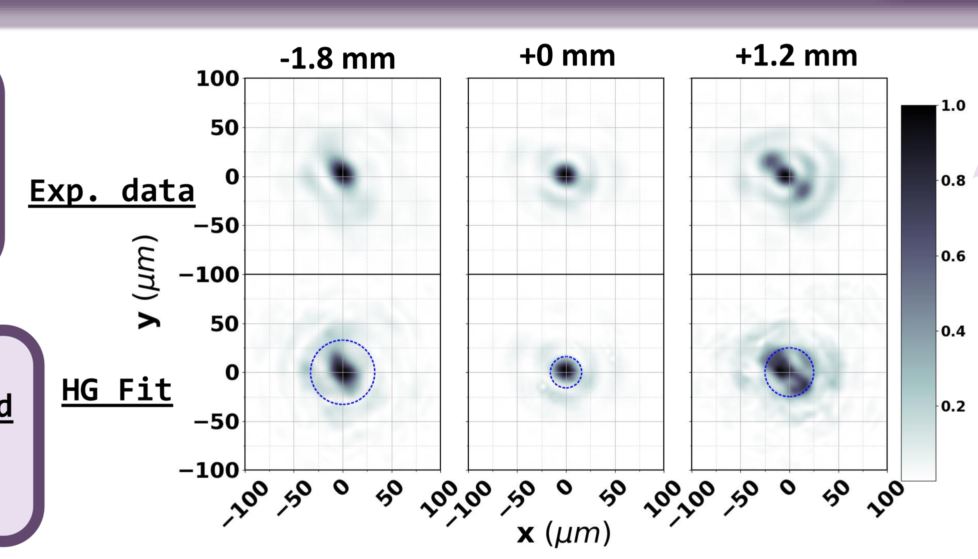



**Exp. Parameters**

$E_l = 5\,J$
$\tau_l = 25\,fs$
$w_0 = 16\,\mu m$

**Numerical Parameters**

Bayesian Optimisation method
(M=41,N=41)
$w_{fit} = 20\,\mu m$

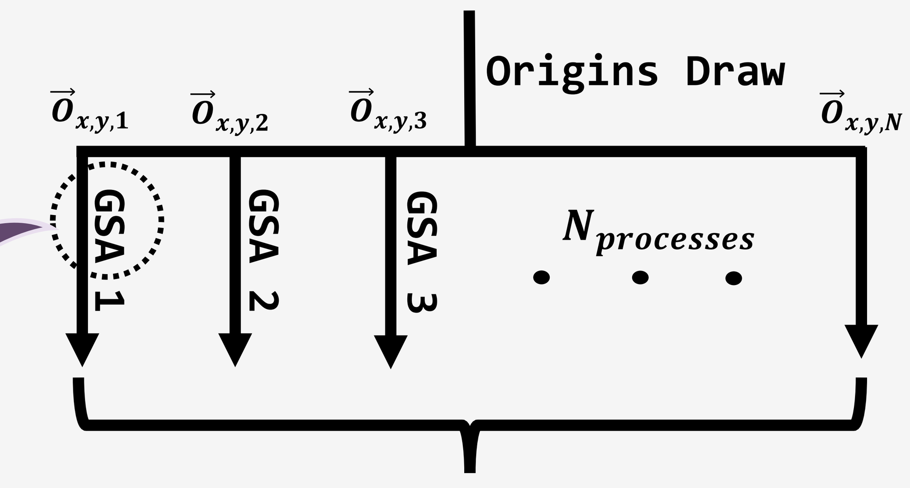



## Bayesian Optimisation

Method : Bayesian optimisation using a Gaussian kernel & parallel sequences of measurements.
Each set of measurements is used to enhance the accuracy of the $\chi^2$ model.

Structure :

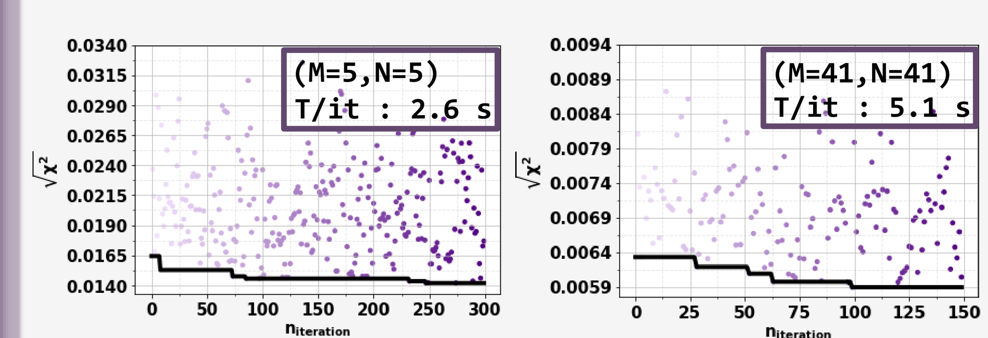
(Optimiser{i}, $\vec{O}_{x,y,opt}, HG_{m,n,opt}, \chi^2_{min}$)



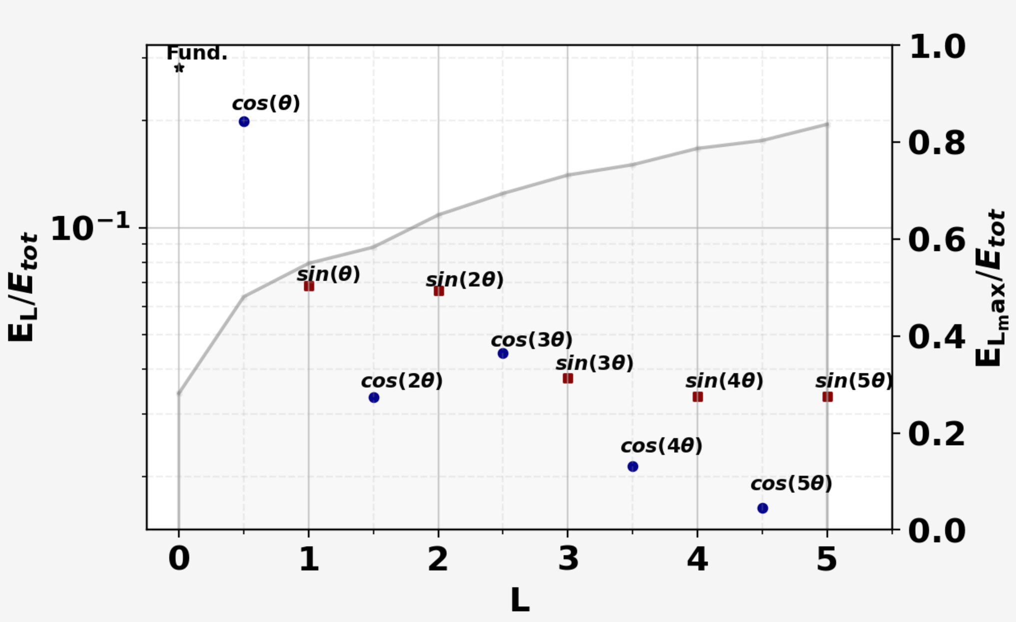

(Optimiser{i+1}, $\vec{O}_{x,y,opt}, HG_{m,n,opt}, \chi^2_{min}$)

Procedure Example : (M=5,N=5) Educated Guess → $\vec{O}_{x,y,EG}$ → (M=41,N=41) Refined Search

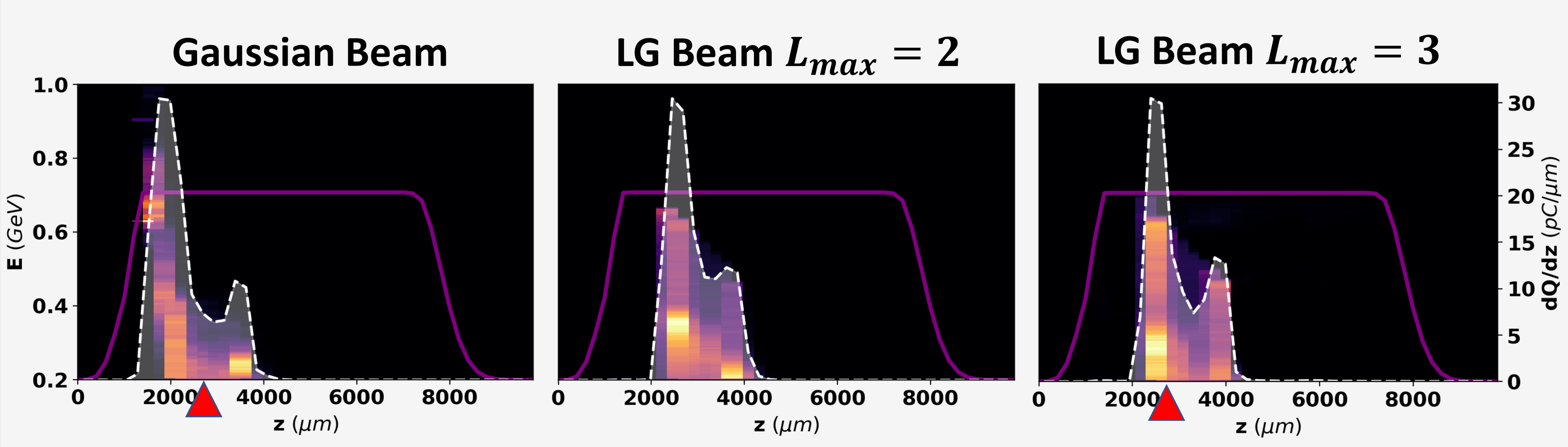
Error Convergence (3 procs):




## Energy distribution on higher modes

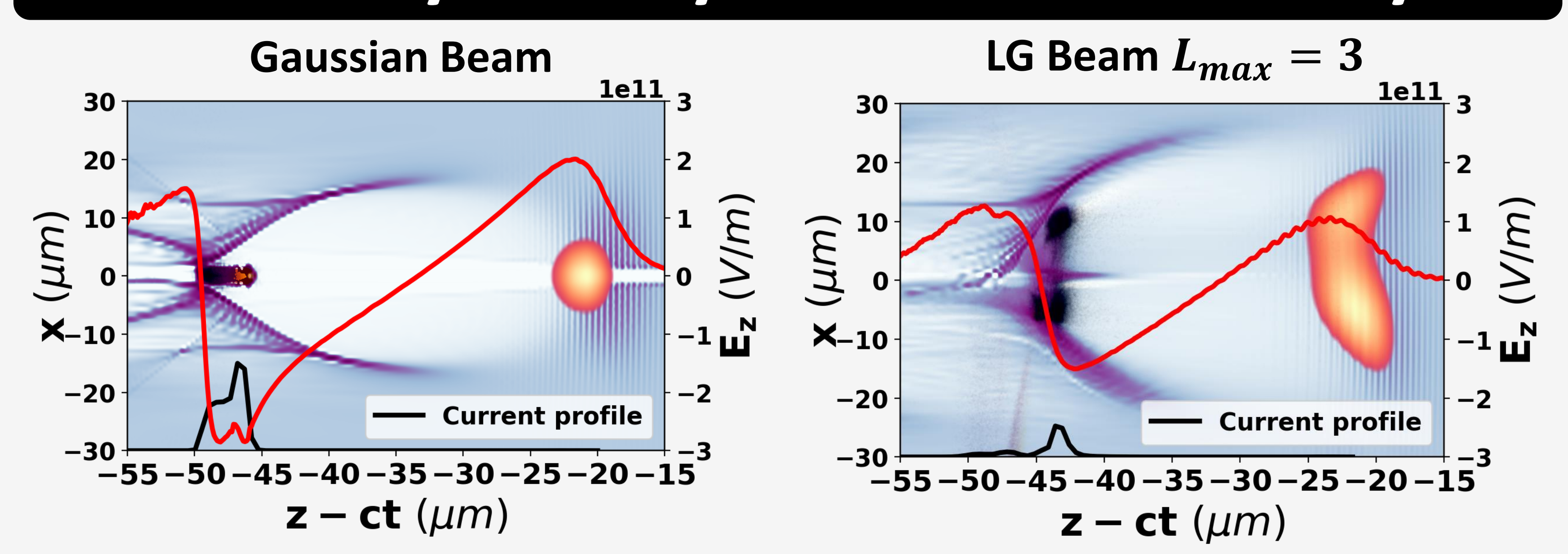



A large portion of the Laguerre-Gauss numerical fitted energy is dispersed in non-symmetrical modes.
The transverse description of the laser greatly impacts the injection physics which occurs only in above-thresholds domains.




Accelerating fields and relativistic self-focusing are stronger for symmetrical beams, which explains why the injected charge gradually declines for beams including a larger number of modes (up to 48% difference).
The inclusion of non-symmetrical modes delays the injection threshold by $0.5 \times z_R$ and is responsible for a drop of 20 % in maximum electron bunch energy.

## Loss of Symmetry in the Plasma Cavity




▶ Plasma cavity at $z_{sim} = 2600\,\mu m$

Non-linear effects such as relativistic self-focusing greatly impact the shape and energy transfer efficiency of the accelerating structure for non symmetric laser transverse distribution.

## Conclusion

We established a Gerchberg-Saxton-like method to retrieve & reconstruct realistically the complex electric field from a collection of laser fluence images measured in vacuum. The accuracy of this method is maximised through a looped optimisation method, which has also been improved using Bayesian Optimisation. The implementation of such a driver profile into FBPIC simulations shows strong correlations of laser spatial features & electrons acceleration dynamics allowing for more accurate simulation results.

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