Fast laser field reconstruction method based on a Gerchberg-Saxton algorithm with mode decomposition

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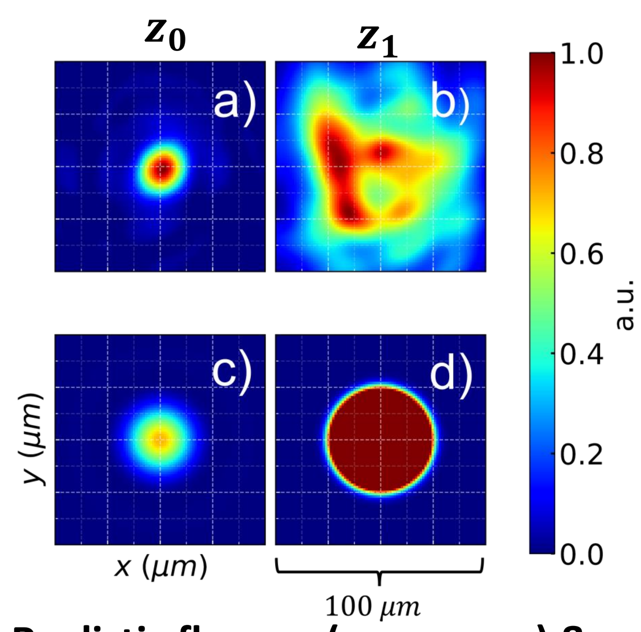
Abstract

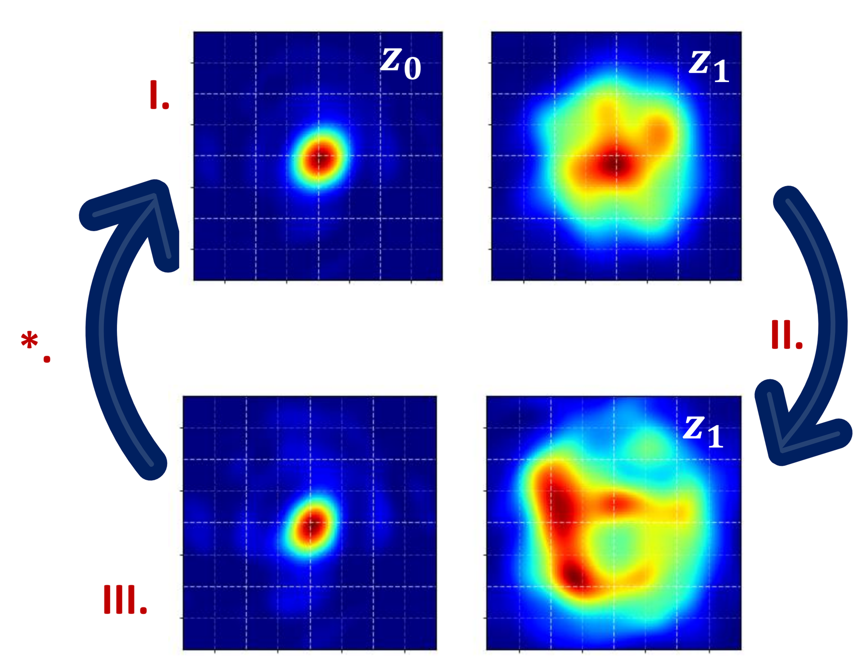
The knowledge of the electric field of high intensity lasers is an important problem when it comes to the study and modeling of its non-linear interaction within a plasma.
A phase-retrieval algorithm, based on the Gerchberg-Saxton method, has been created to characterize with accuracy the spatial component of the spectral phase.

This method, named GSA-MD, uses Hermite-Gauss (HG) modes to reconstruct the laser electric field based on a set of fluence images collected in the focal volume.
The GSA-MD is characterized by its fast execution time (a few seconds), and by its flexibility, as the numerical parameters used to model the electric field can be optimized to decrease the reconstruction error.

GSA-MD [1]



Realistic fluence (upper row) &
Flattened Gauss approximation (lower row)



2-planes GSA-MD cycle

$$\chi^2 = \sum_{k=0}^{N_{images}-1} \frac{\sqrt{\sum_{i_x,i_y}^{N_{pix_x},N_{pix_y}} \left(F_{exp}(x,y,z_k) - F_{fit}(x,y,z_k)\right)^2}}{N_{images} \sum_{i_x,i_y}^{N_{pix_x},N_{pix_y}} F_{exp}(x,y,z_k)}$$

I. Electric field is decomposed in HG sum and propagated

II. Complex phase is extracted and applied to measured amplitude

III. HG coefficients are updated (possible mixing)

***.** Monitoring of χ^2 for possible stoppage criterion

Origin Tuning

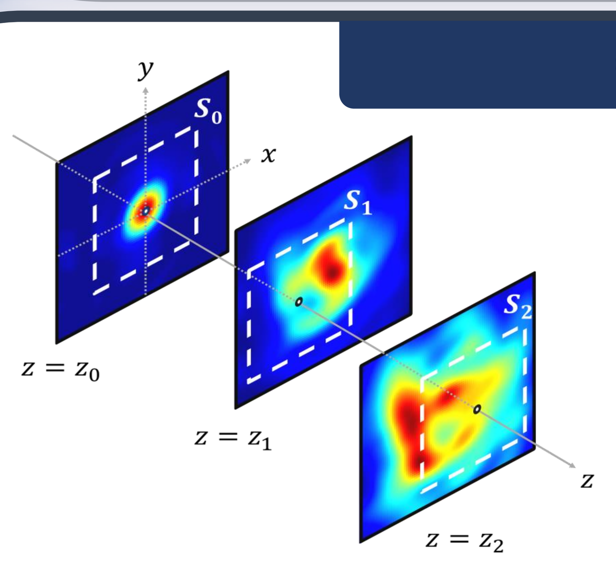
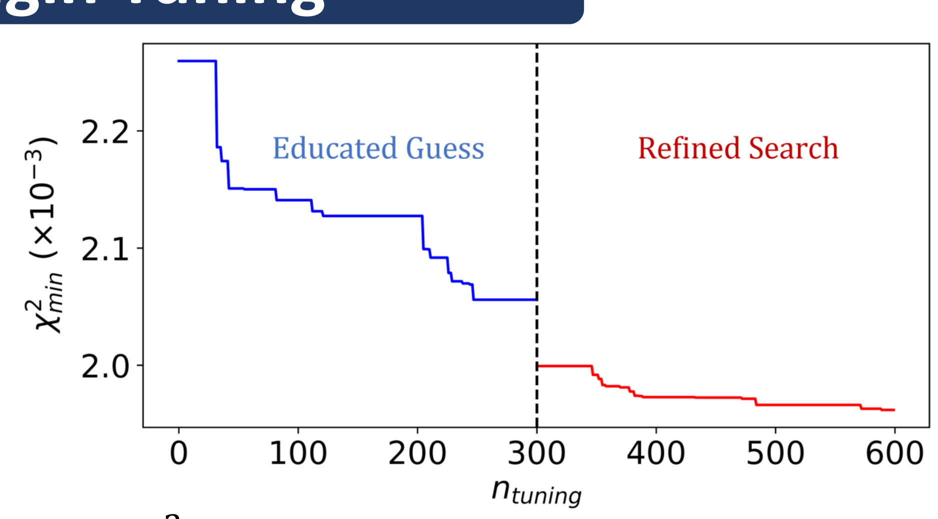


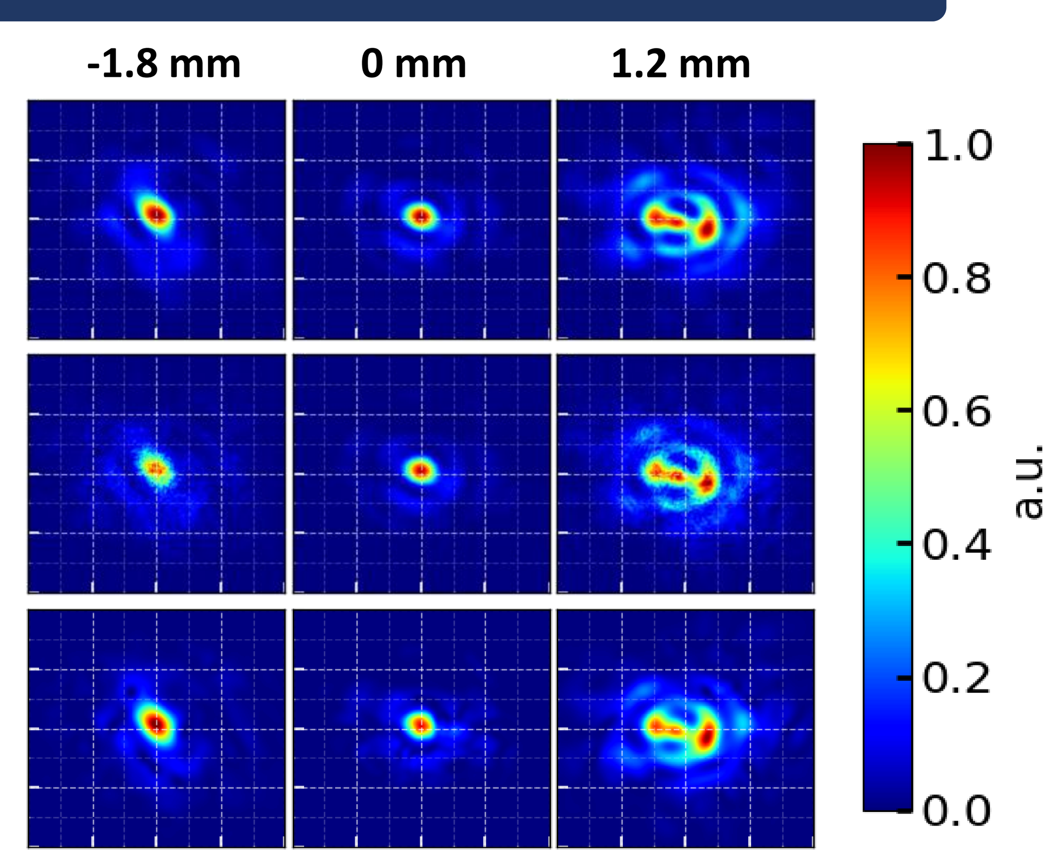
Illustration of the HG Origin Tuning



χ^2 minimization through Origin Tuning

- χ^2 fluctuates with the HG modes origins
- The Origin Tuning procedures optimizes χ^2 in two phases
- Over several iterations, this leads to a significant error decrease

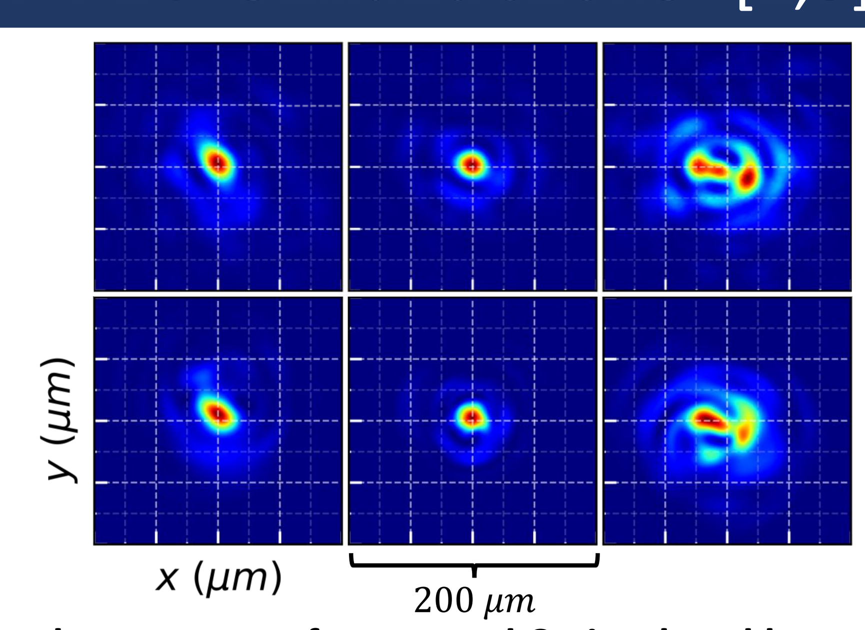
Comparison to a GSA without MD



Parameter	GSA	GSA-MD ($N_{m,n} = 40$, without origin tuning)	GSA-MD ($N_{m,n} = 40$, with origin tuning)
N_{iter}	50	50	50
Total time	3.8 s	13.6 s	1h15 min
χ^2 ($\times 10^{-3}$)	2.50	2.28	1.61
χ^2_0 ($\times 10^{-3}$)	1.94	2.76	1.98
χ^2_1 ($\times 10^{-3}$)	3.89	2.48	1.52
χ^2_2 ($\times 10^{-3}$)	1.67	1.60	1.35

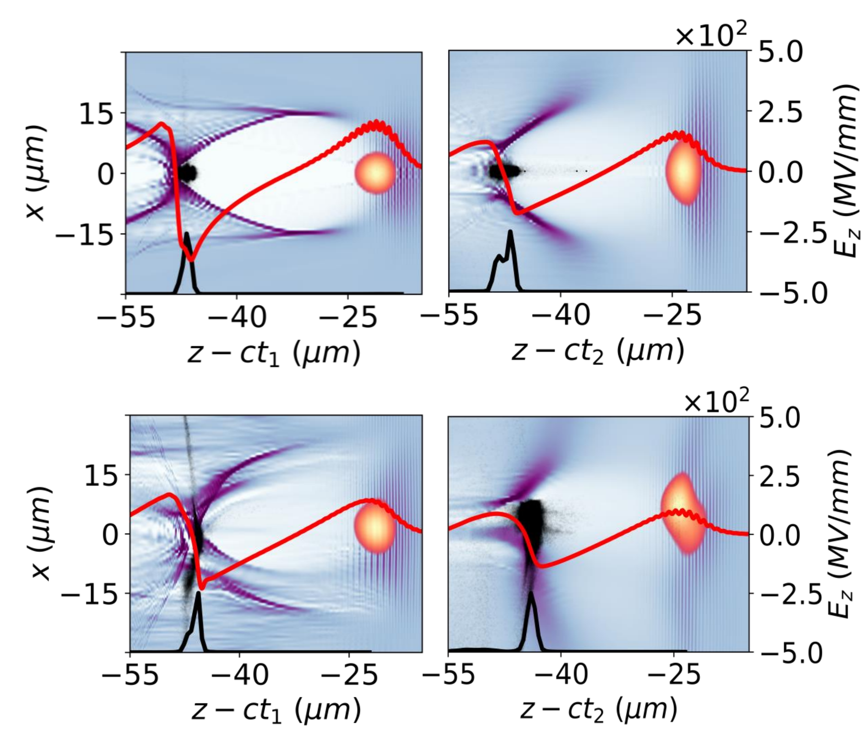
- GSA-MD performs on the same time-scale
- The reconstruction is smoother and less noisy

Application : Laser asymmetry impact in PIC simulations [2,3]

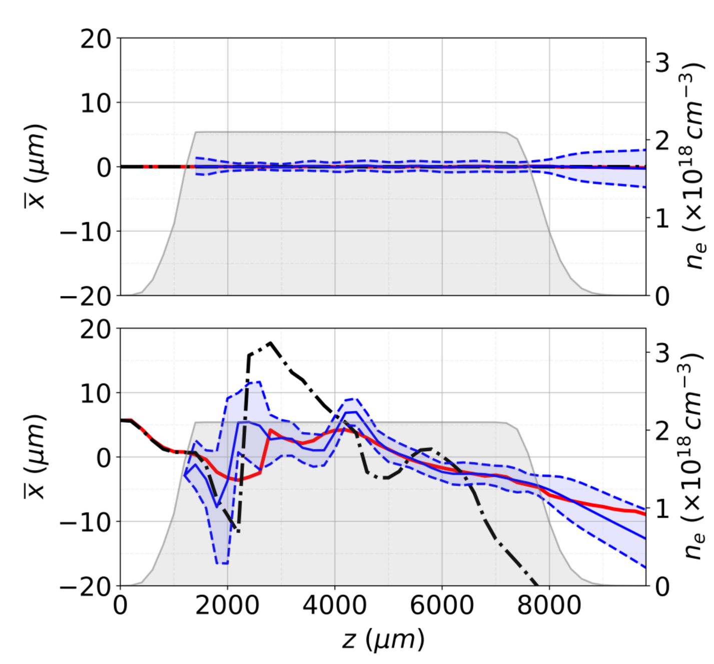


Fluence map of measured & simulated laser

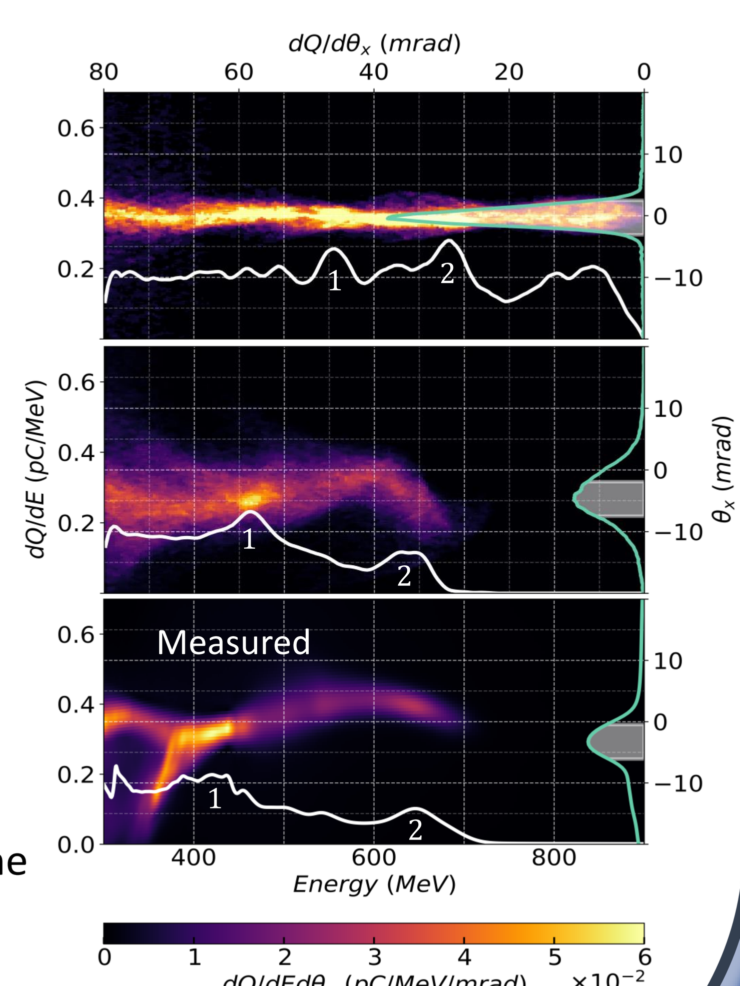
- GSA-MD output is used as input for PIC simulations
- Laser asymmetry leads to centroid fluctuation
- Electrons bunch characteristics are impeded



Plasma cavity at 2 iterations



Evolution of the laser & bunch centroid



Output bunch spectra

- We acknowledge the resources and assistance of the computing center MesoLUM managed by ISMO (UMR8214) and LPGP (UMR8578), University Paris-Saclay (France)

Conclusion

The GSA-MD is a fast and flexible algorithm which allows the reconstruction of the electric field via an Hermite-Gaussian decomposition. Its tunability resides the many numerical parameters of the algorithm (number of modes, numerical waist, input phase…), and it can be executed in a few seconds.
It has also been proven that an additional procedure of Origin Tuning of the Hermite-Gauss origins can lead to a significant diminution of the error.

[1] *I. Moulanier et al., Physics of Plasmas 30*, 053109 (2023)
[2] *I. Moulanier et al., JOSA B* 40, Issue 9, pp. 2450 - 2461 (2023)
[3] *L. T. Dickson et al., Physical Review Accelerators and Beams 25*, 101301 (2022)

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