

Generating and testing flying focus laser pulses with Lasy for PICGPU simulations

—A Bachelors Defense—

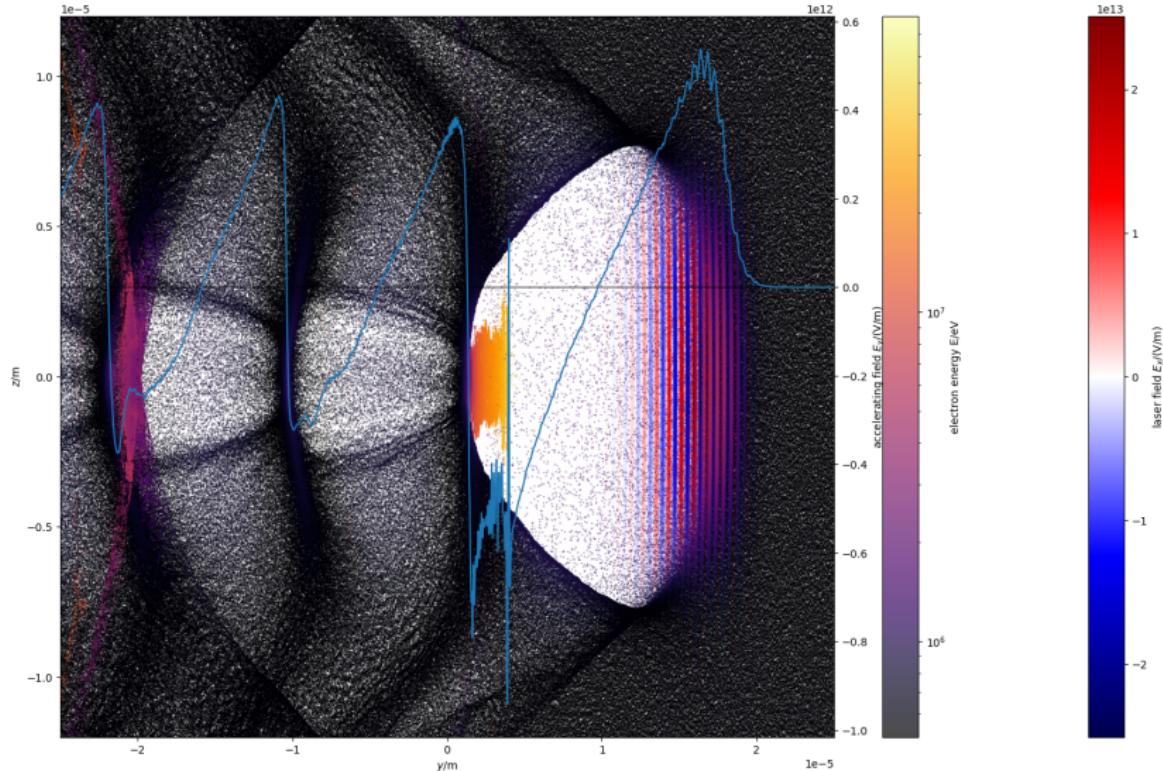
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- 1 Dephasingless Laser WakeField Acceleration (DLWFA)
- 2 Flying focus lasers in Lasy and PICoGPU
- 3 Testing the flying focus lasers
- 4 Conclusion and Outlook
- 5 References

Laser WakeField Acceleration (LWFA) [1]



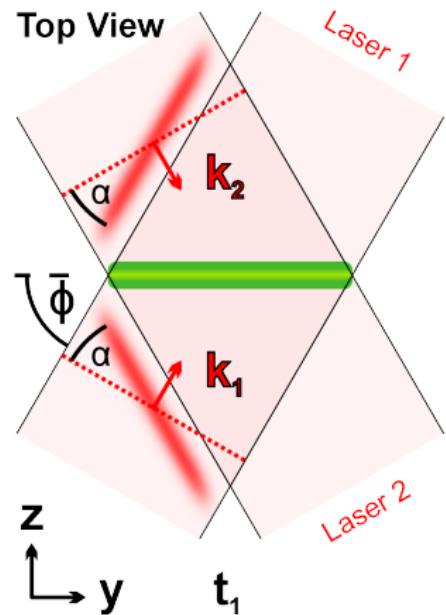
Electric field and electrons in an LWFA simulation.

Flying focus lasers – solving the Problem of Dephasing

1. TWEAC [3]

- Traveling-Wave Electron ACcelerator
- Uses two laser pulses with tilted pulse fronts
- The tilt controls the velocity of the overlapping region

Image: TWEAC setup using two laser pulses. Image taken from Debus [2]

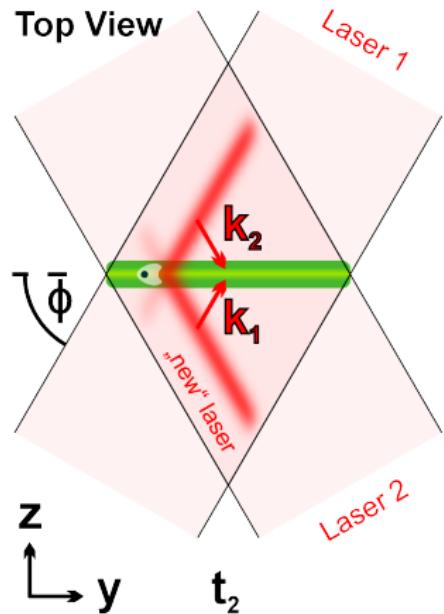


Flying focus lasers – solving the Problem of Dephasing

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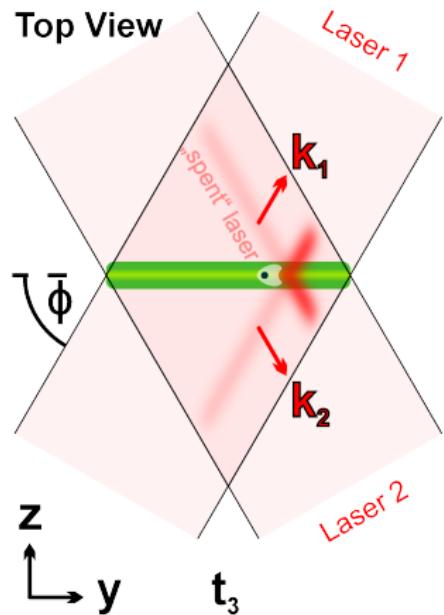


Flying focus lasers – solving the Problem of Dephasing

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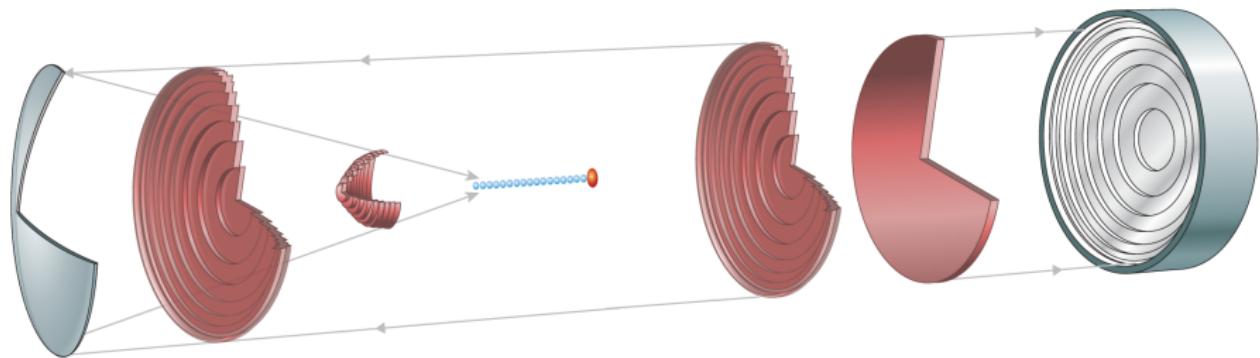
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Flying focus lasers – solving the Problem of Dephasing

2. Axiparabola laser [4]



The flying focus setup. Two optical elements: The Axiparabola (left) and the Radial Group Delay echelon (RGD) (right). Image taken from Palastro et al [4].

Flying focus lasers – solving the Problem of Dephasing

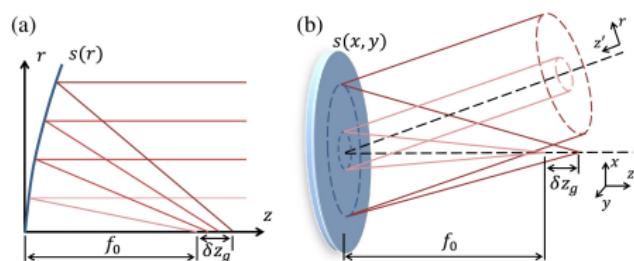
2. Axiparabola laser [4]

■ Axiparabola [5]:

- Near-parabolic mirror
- Focuses light onto a line – the focus region
 - Light at radius r is focused at $f(r) = f_0 + \delta \left(\frac{r}{R} \right)^2$

■ Radial Group Delay echelon (RGD) [6][4]:

- Stepped concentric mirror rings
- Shape follows some function $\tau_D(r)$
- controls the timing of the axiparabola focus



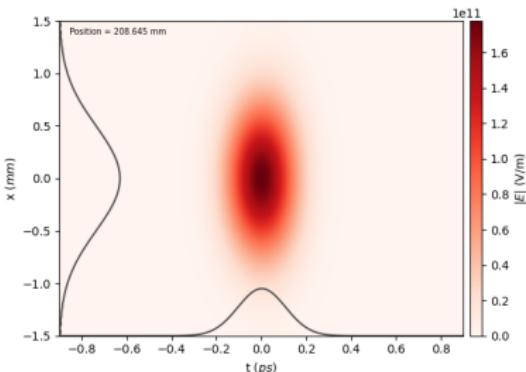
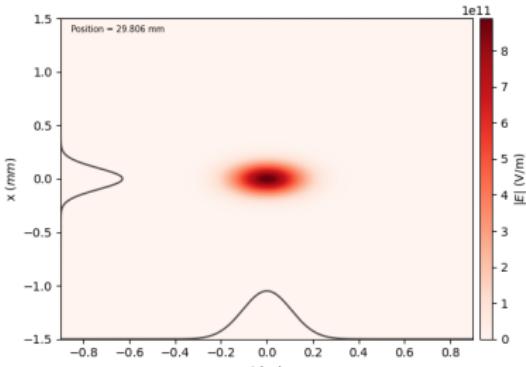
Axiparabola functionality. Image taken from Smartsev et al [5].

Lasy [7]

A python library

- A python library for simulating Laser pulses in a vacuum
- Uses complex envelope of the laser field
- Uses angular spectrum propagation
- Can use cylindrical coordinates for memory and CPU time efficiency
- Offers a range of optical elements

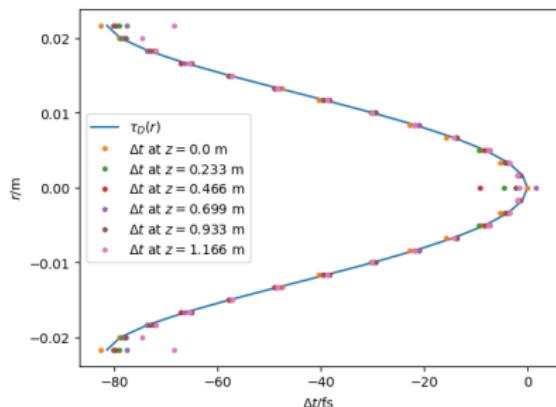
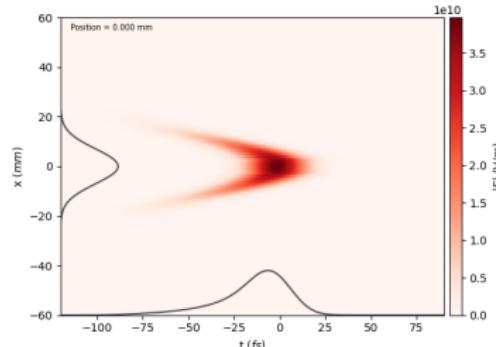
Images: Example of a Gaussian pulse being propagated by Lasy. Top: generated at the focus, Bottom: 6 z_R after the focus.



Implementing the flying focus

1. The Radial Group delay echelon (RGD)

- Implemented from scratch as Lasy optical element
- Following the description by Ambat et al [6]
- Shapes the pulse temporally without focusing or defocussing
- Can generate any radially symmetric shape $\tau_D(r)$

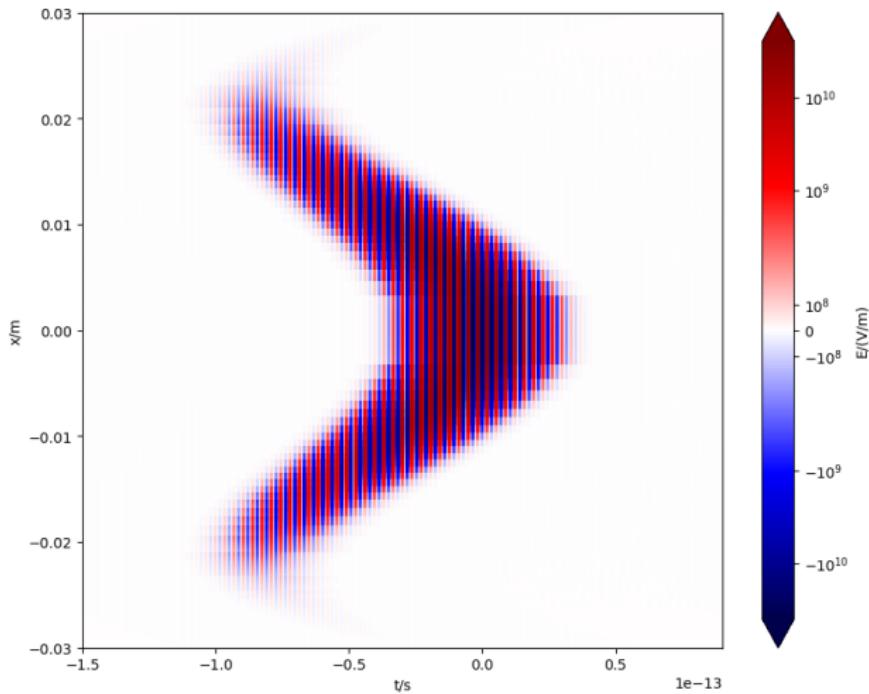


Images: A Gaussian pulse after interacting with the RGD.

Top: field envelope, Bottom: Test results. even after long distances the shape still holds.

Implementing the flying focus

1. The Radial Group delay echelon (RGD)



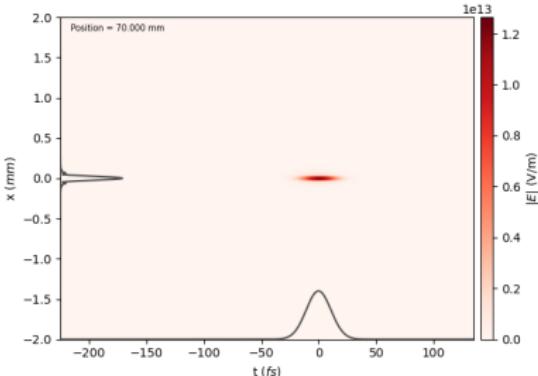
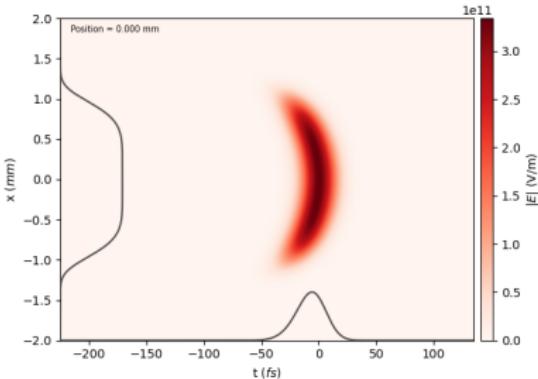
The electric field of the laser after interacting with the RGD.

Implementing the flying focus

2. The Axiparabola

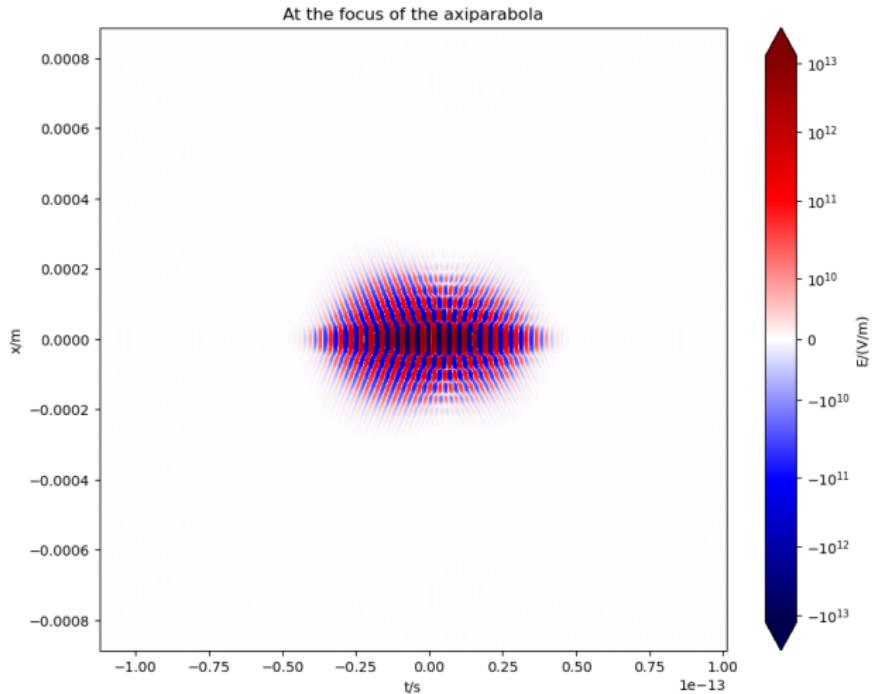
- Included in Lasy
- Following Smartsev et al [5]
- ?

Images: A super-Gaussian laser pulse after reflecting off the axiparabola. Top: in the near field, Bottom: in the far field at the beginning of the focus region.



Implementing the flying focus

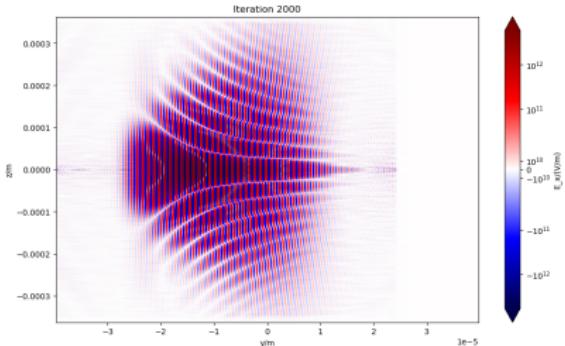
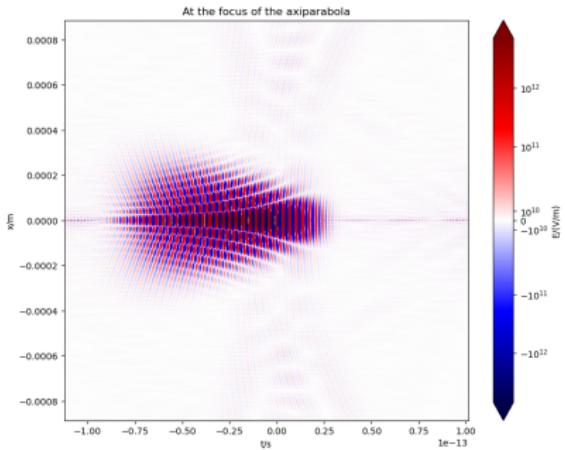
2. The Axiparabola



The electric field of the laser at the beginning of the focus region of the axiparabola.

Importing to PICoGPU

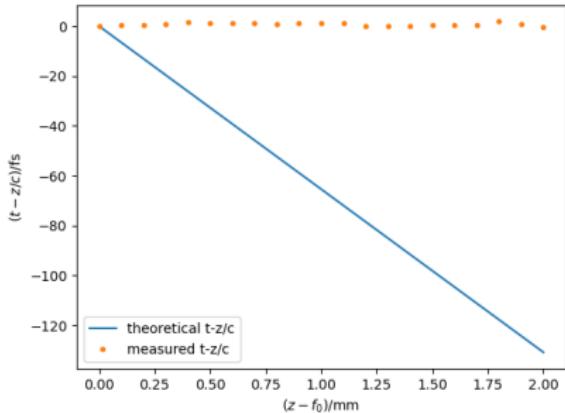
- New module `full_field`
- Generates full electric field and saves it using openPMD-api
-



Images: Top: Electric field of the complete flying focus laser at the beginning of the focus region, Bottom: That same electric field entering the simulation window of a PICoGPU simulation.

Testing the flying focus laser

First results



Testing the flying focus laser

Test

Conclusion

Remaining Possible reasons for failure

- The Axiparabola
- The Propagation
- The Findings in the other papers

Outlook

?

- Easy lasers available in PICoGPU

→ ...

- LWFA with new laser setups
possible

References (I)

-  T Tajima and JM Dawson.
Laser electron-accelerator.
Physical Review Letters, 43(4), 1979.
-  Alexander Debus.
Traveling-wave electron accelerators.
AAC 2022 conference talk: <https://www.aac2022.org/>.
-  Alexander Debus, Richard Pausch, Axel Huebl, Klaus Steiniger, Rene Widera, Thomas E. Cowan, Ulrich Schramm, and Michael Bussmann.
Circumventing the dephasing and depletion limits of laser-wakefield acceleration.
Physical Review X, 9, 2019.
-  J. P. Palastro, J. L. Shaw, P. Franke, D. Ramsey, T. T. Simpson, and D. H. Froula.
Dephasingless laser wakefield acceleration.
Phys. Rev. Letters, 124, 2020.

References (II)



Slava Smartsev, Clement Caizergues, Kosta Oubrerie, Julien Gautier, Jean-Philippe Goddet, Amar Tafzi, Kim Ta Phuoc, Victor Malka, and Cedric Thaury.

Axiparabola: a long-focal-depth, high-resolution mirror for broadband high-intensity lasers.

Optics Letters, 44, 2019.



M. V. Ambat, J. L. Shaw, J. J. Pigeon, K. G. Miller, T. T. Simpson, D. H. Froula, and J. P. Palastro.

Programmable-trajectory ultrafast flying focus pulses.

Optics Express, 31(19), 2023.



Lasy 0.6.2 documentation.

<https://lasydoc.readthedocs.io/en/latest>.

Accessed october 2025.