

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

—A Bachelors Defense—

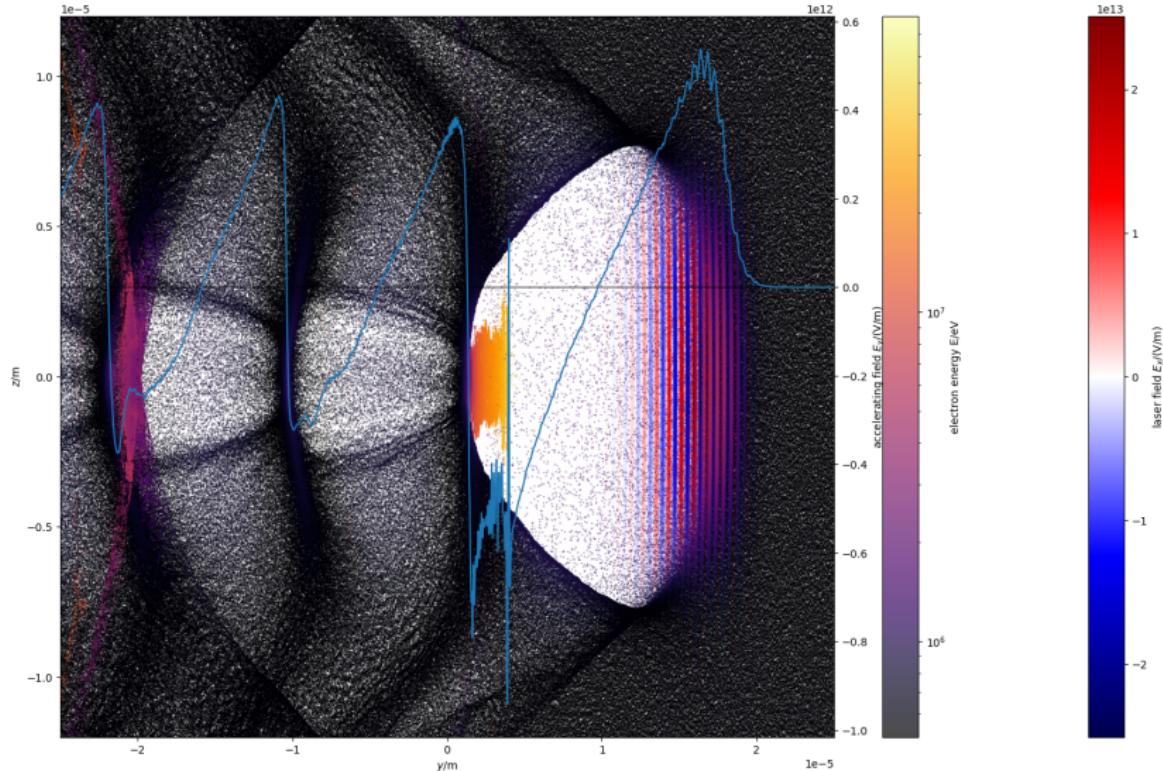
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- 1 Dephasingless Laser WakeField Acceleration (DLWFA)
- 2 Flying focus lasers in Lasy and PICoGPU
- 3 Testing the flying focus lasers
- 4 Conclusion and Outlook
- 5 References

# Laser WakeField Acceleration (LWFA) [1]



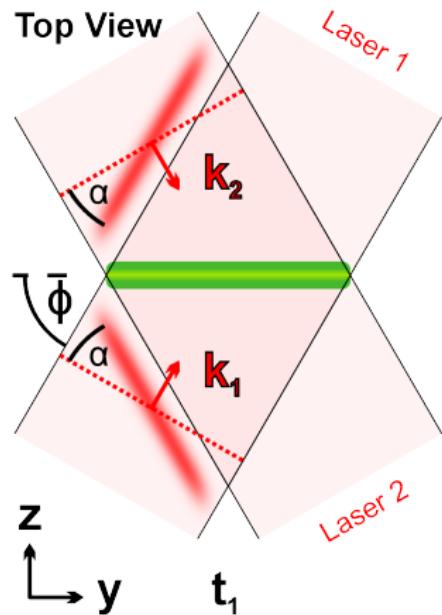
Electric field and electrons in an LWFA simulation.

# 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]

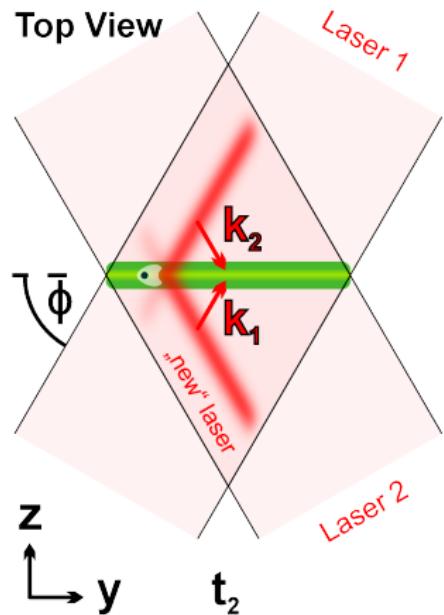


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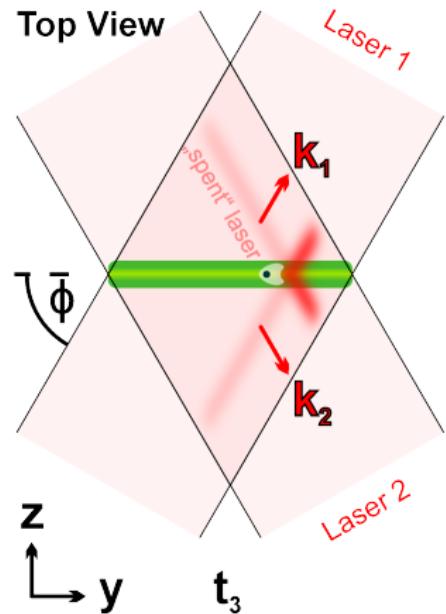


# Flying focus lasers – solving the Problem of Dephasing

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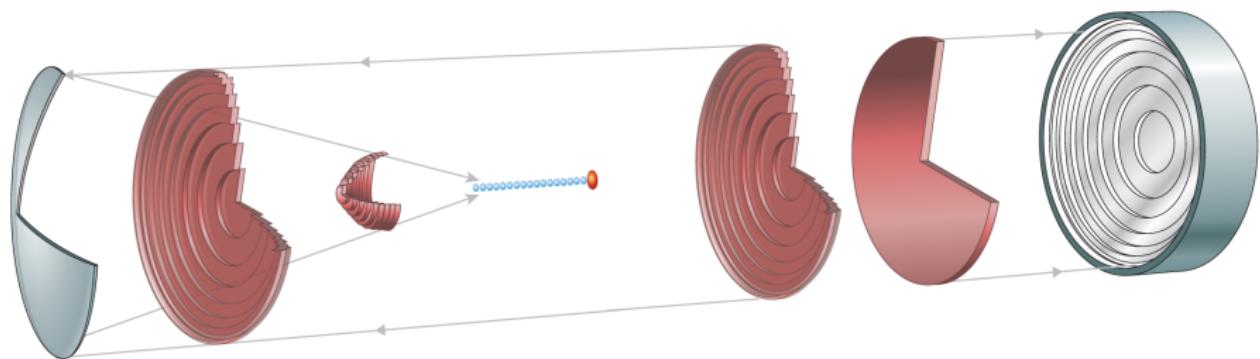
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# Flying focus lasers – solving the Problem of Dephasing

## 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

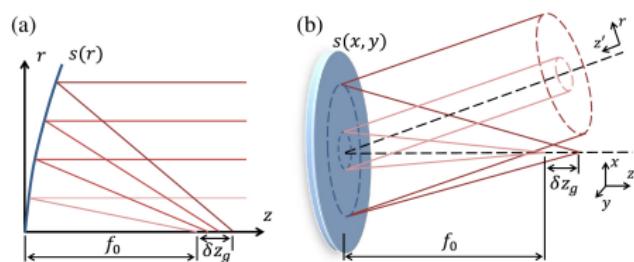
## 2. Axiparabola laser [4]

### ■ 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



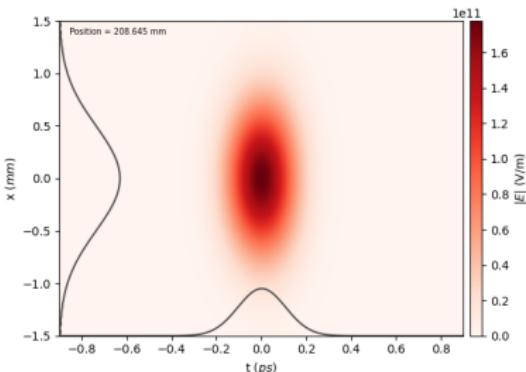
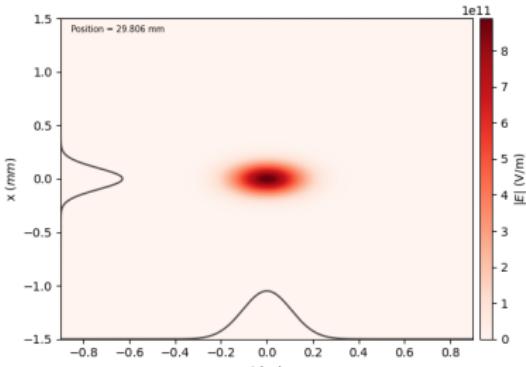
Axiparabola functionality. Image taken from Smartsev et al [5].

# 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

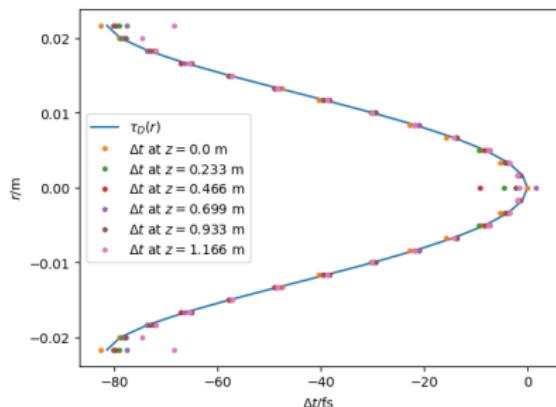
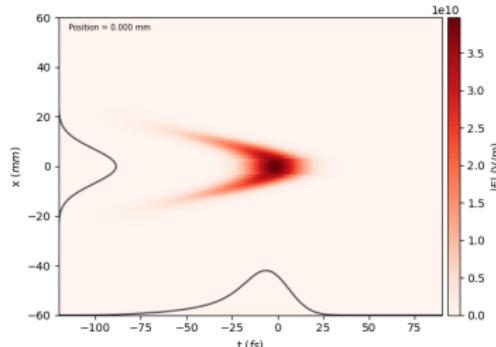
Images: Example of a Gaussian pulse being propagated by Lasy. Top: generated at the focus, Bottom: 6  $z_R$  after the focus.



# 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 of delay  $\tau_D(r)$

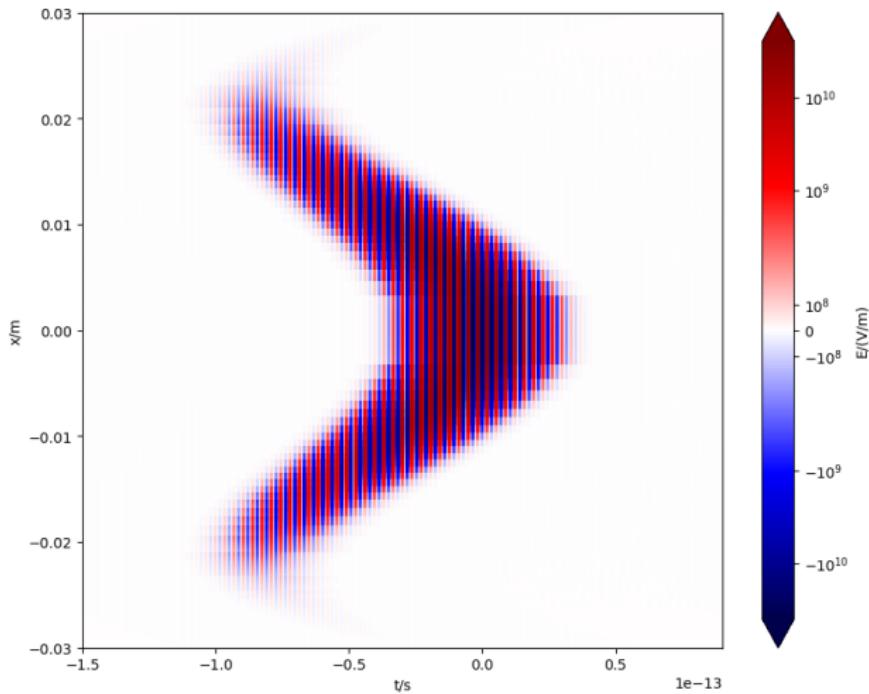


Images: A Gaussian pulse after interacting with the RGD.

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)



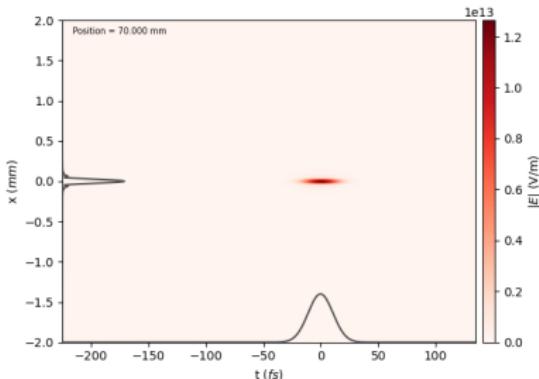
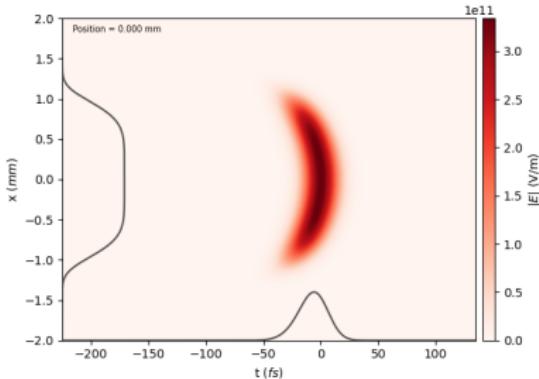
The electric field of the laser after interacting with the RGD.

# Implementing the flying focus

## 2. The Axiparabola

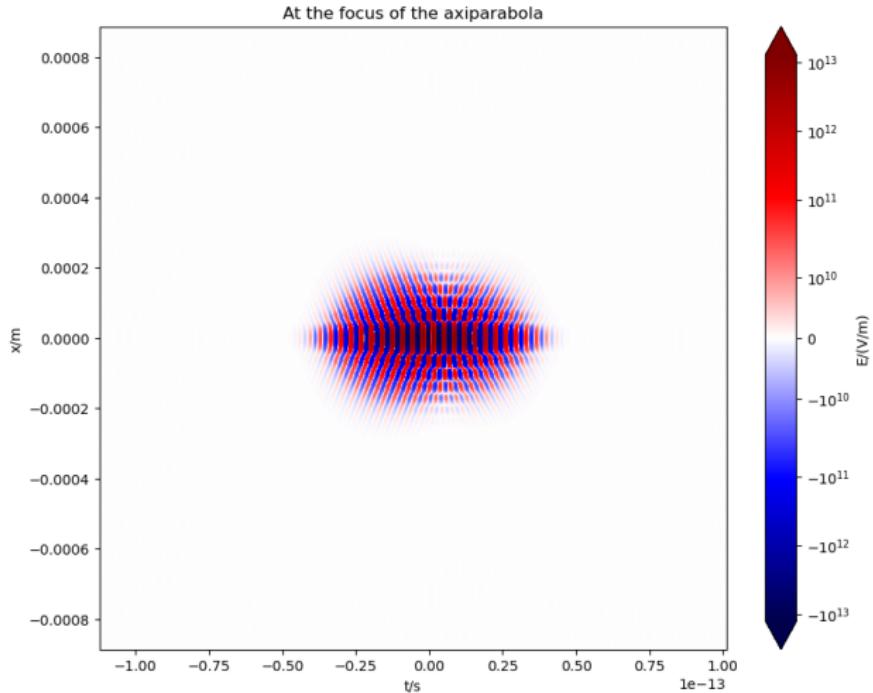
- Included in Lasy
- Following Smartsev et al [5]
- Focusing laser pulse in the focus region
- Also implemented an axiparabola following Ambat et al [6]
  - Very small differences

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

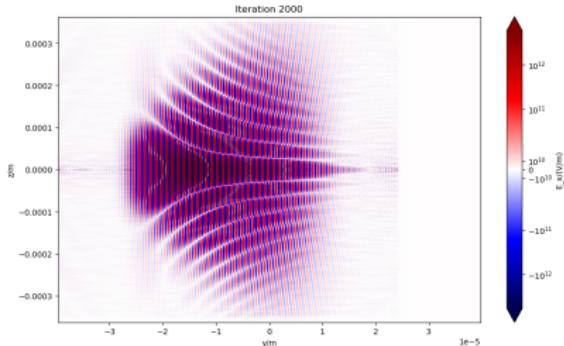
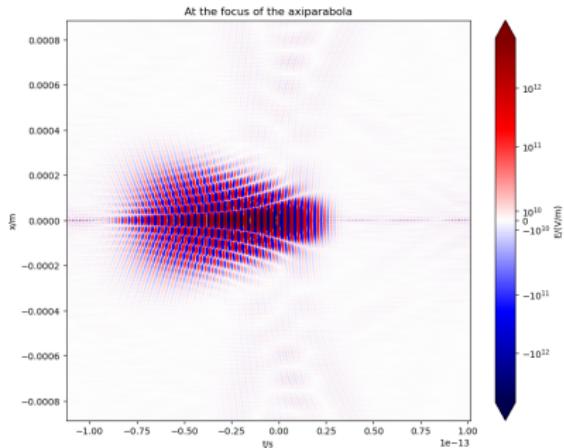
## 2. The Axiparabola



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

# Importing to PIConGPU

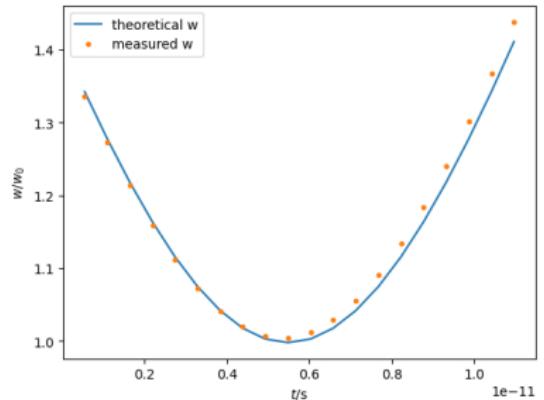
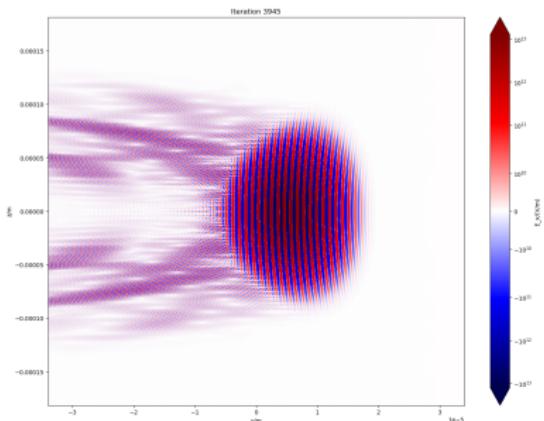
- New module `full_field`
- Generates full electric field and saves it using openPMD-api
- `incidentField` method  
FromOpenPMDPulse [8] imports the field into PIConGPU



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 PIConGPU simulation.

# Testing the method

- Test with Gaussian laser pulse and parabolic mirror
- Some artifacts are visible
  - Problem of the incidentField method  
→ See [9]
- Test successful



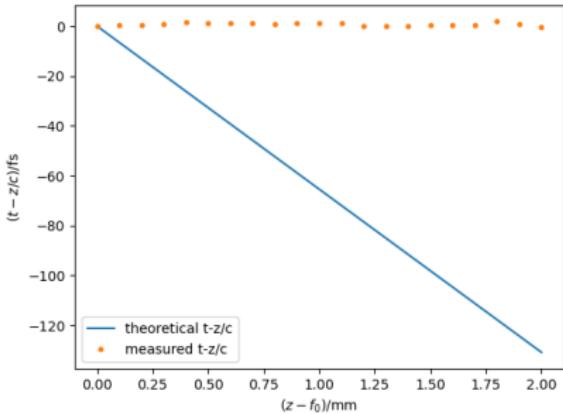
Images: Top: Electric field of the Gaussian laser pulse  $z_R$  before the focus as imported into a PICongPU simulation,  
Bottom: The beam waist  $w$  of the pulse over time,  
compared to theory.

# Testing the flying focus laser

## First results

- It dont work
- I want it to though
- hmmm

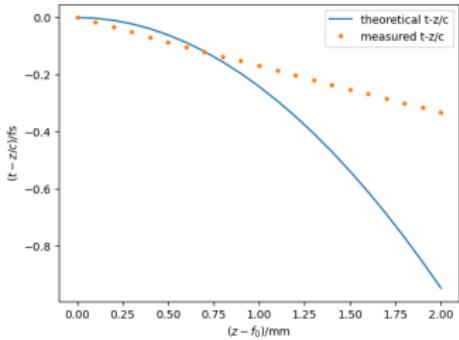
Images: Top: ?, Bottom: ?.



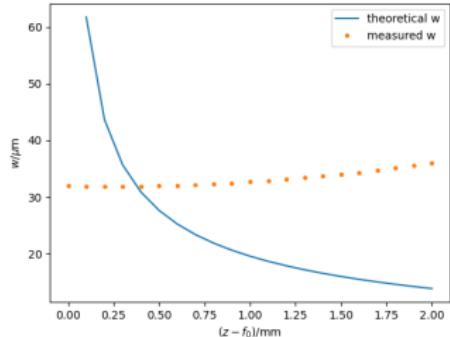
# Testing the flying focus laser

Axiparabola only

- With only the axiparabola differences appear already  
→ Here must be the problem...



Images: Comparing measurements from a Lasy simulation with theoretical values using Ambat et al [6]. Top: Arrival time  $t - z/c$ , Bottom: Beam waist  $w$ .



# Testing the flying focus laser

More test?



Images:

# Conclusion

## Remaining Possible reasons for failure

- The Axiparabola
  - The shape could be wrong
- The Propagation
  - Possibly the Lasy propagation gives incorrect/incomplete results
- The Findings in the other papers
  - Maybe the Axiparabola does not work at all
  - Maybe it works in a different manner

# Outlook

- Lasyl lasers available in PICoGPU
- LWFA with new laser setups possible
- Some problems still need resolving
- Hic sunt dracones

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Klaus Steiniger.

Issue 5269 todo in laser refactoring.

[https://github.com/ComputationalRadiationPhysics/picongpu/  
issues/5269](https://github.com/ComputationalRadiationPhysics/picongpu/issues/5269).

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