

EUROPEAN
PLASMA RESEARCH
ACCELERATOR WITH
EXCELLENCE IN
APPLICATIONS



A novel hybrid-target injector for high-charge laser-driven electron acceleration

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EMR9000 CEA, CNRS, Université Paris-Saclay



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O. Gobert



T. Ceccotti



A. Panchal



D. Trévarin



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Experiments



S. Dobosz Dufrénoy

Theory/simulations



H. Vincenti
(head of
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division)



L. Fedeli



T. Clark

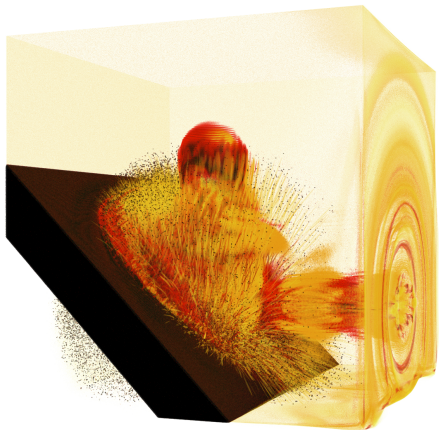


P. Bartoli



G. Robert-Dautun

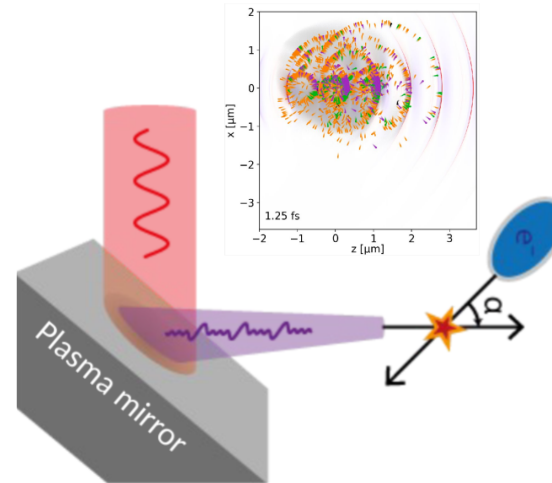
We are interested in several topics
related to relativistic kinetic plasmas



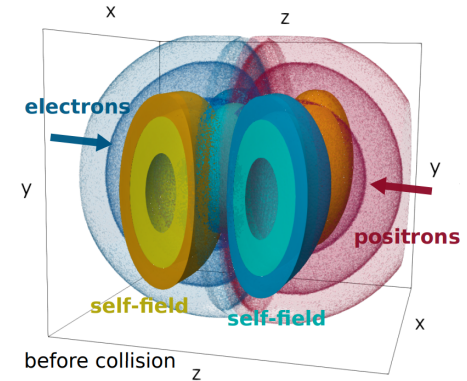
Laser-driven e^-
accelerators



Development of a massively
parallel Particle-In-Cell code

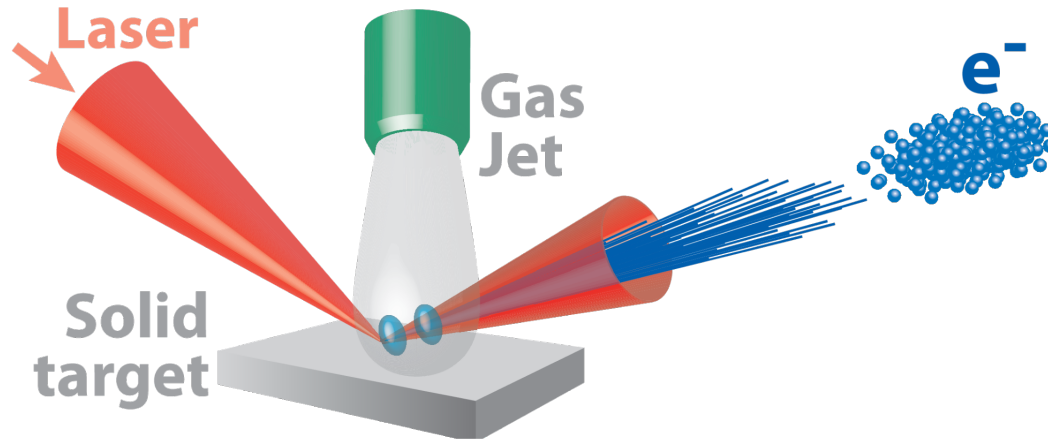


Strong-field QED in ultra-intense
laser-plasma interaction

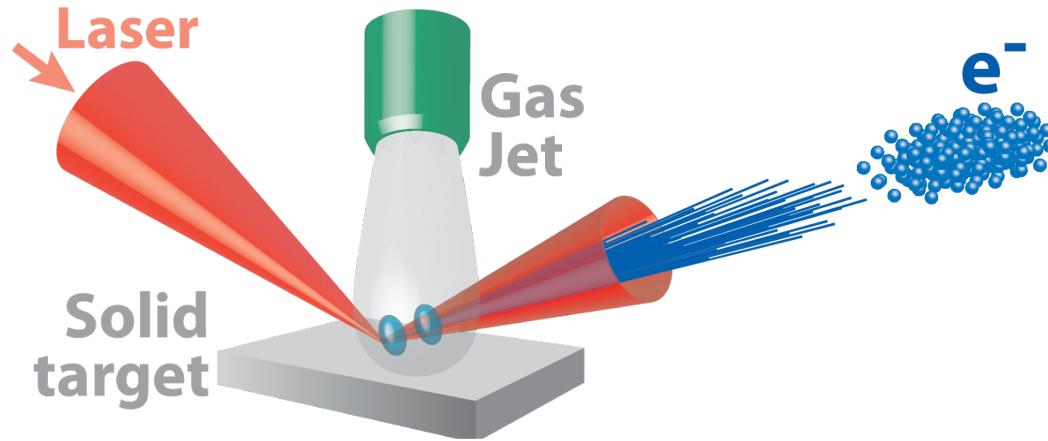


Strong-field QED in
colliders (courtesy of
A.Formenti)

We propose a novel laser-driven
electron acceleration scheme



We propose a novel laser-driven
electron acceleration scheme

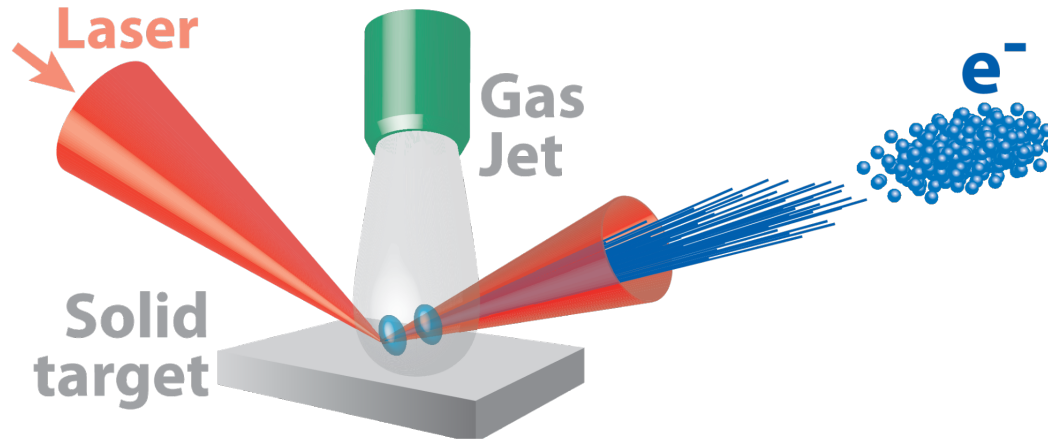


high
quality



high
charge

We propose a novel laser-driven
electron acceleration scheme

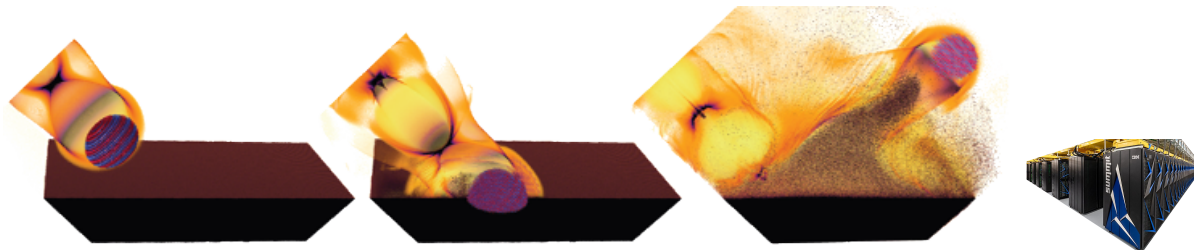


high
quality

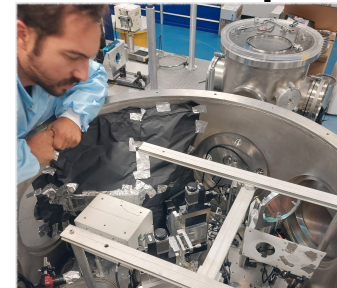


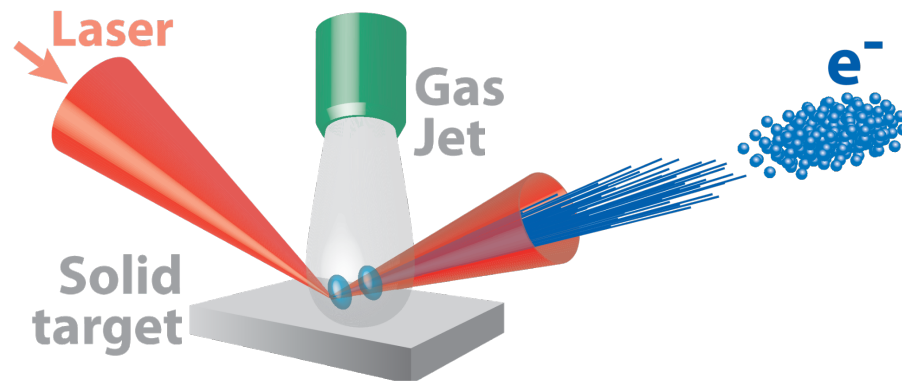
high
charge

validated with large-scale simulations...



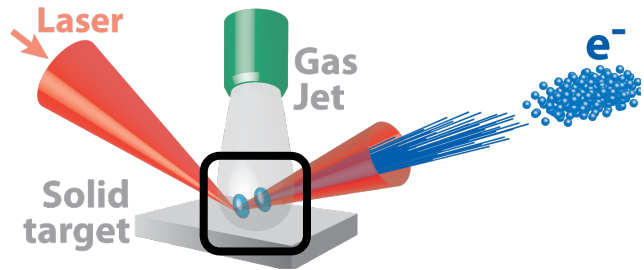
...and experiments



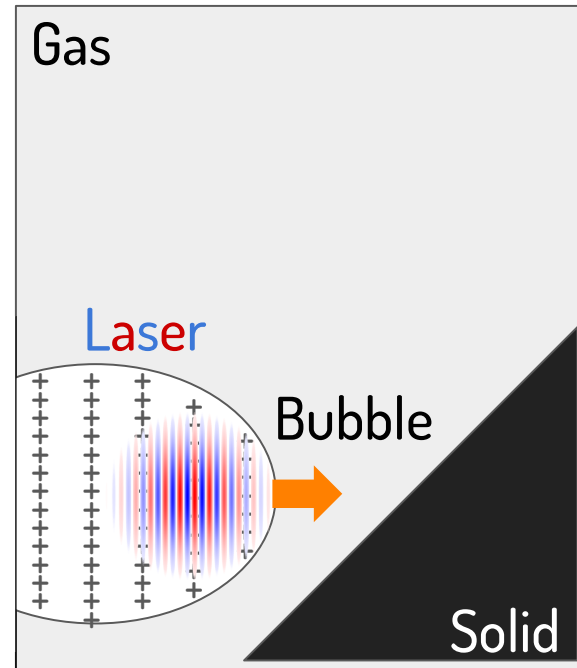
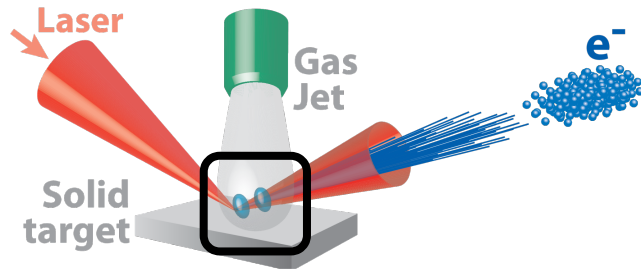


How does this concept work ?

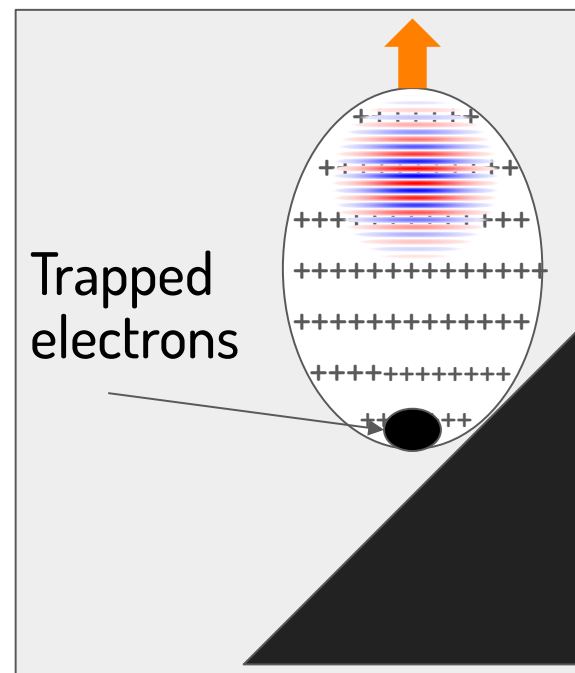
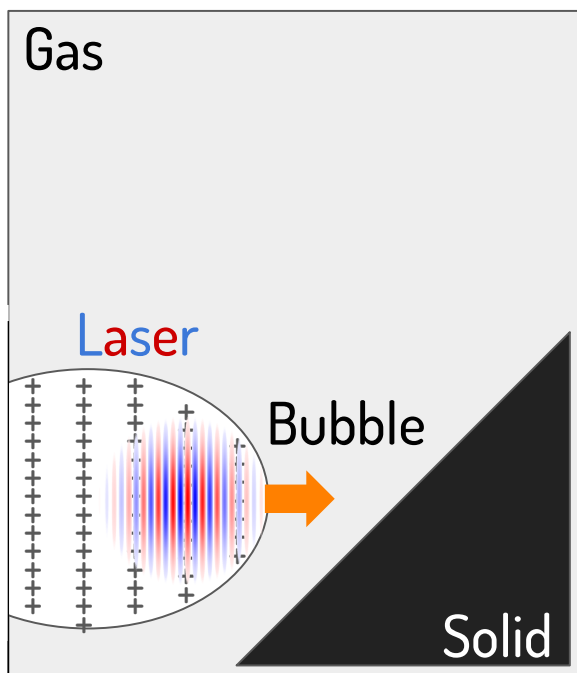
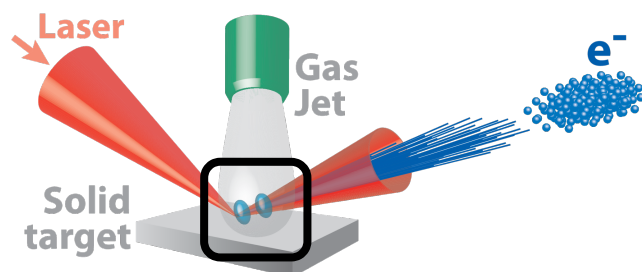
An ultra-short laser beam propagates in a low density gas



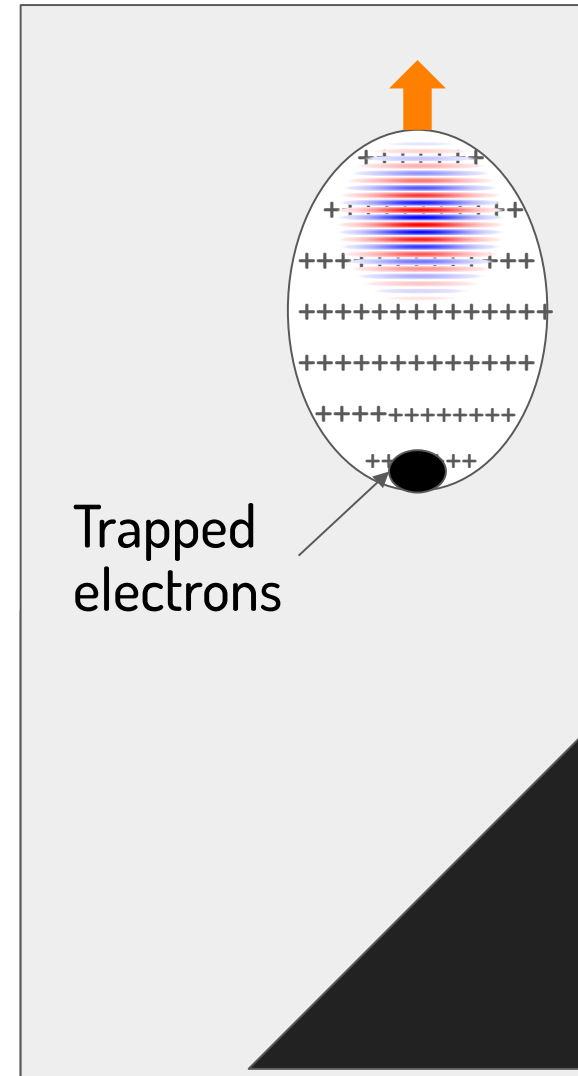
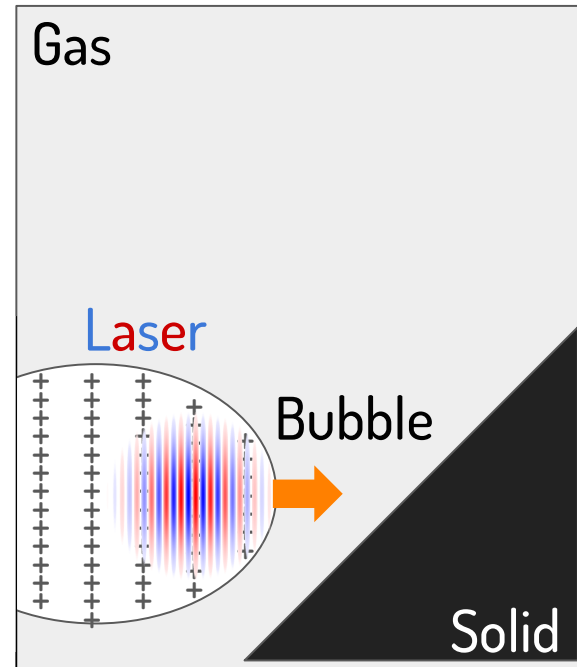
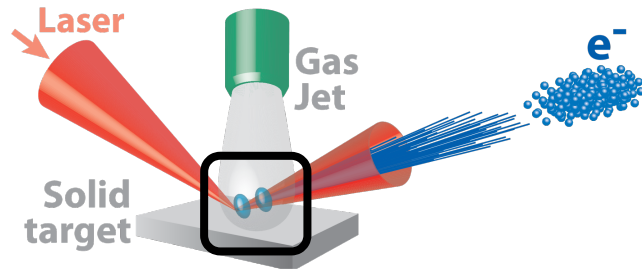
The laser pushes electrons away and generates a positively charged “bubble”



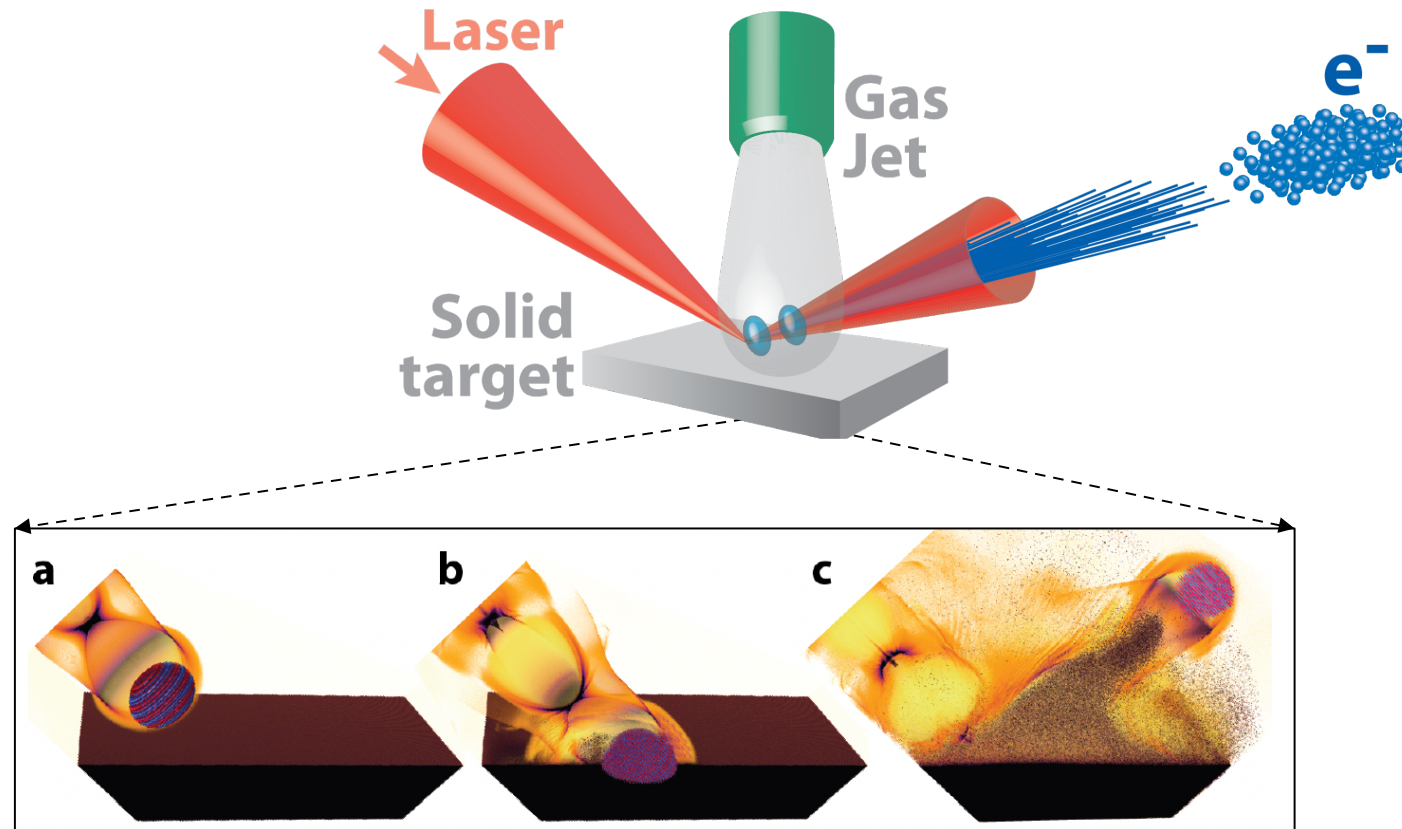
The laser is reflected by the high-density plasma and the bubble traps some of its electrons



The bubble accelerates electrons over few millimeters

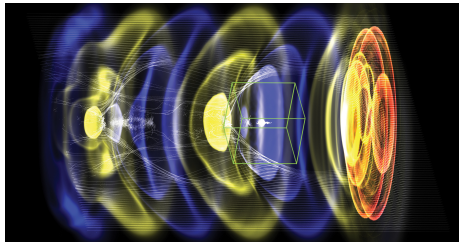


We simulated the hybrid injector concept using the **WarpX** Particle-In-Cell code



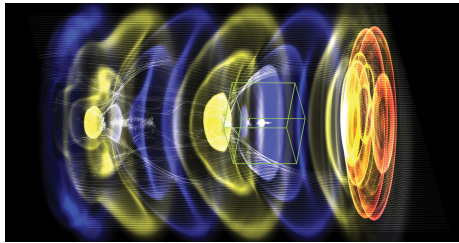
WarpX is an open-source Particle-In-Cell code
for the exascale era.

~100 contributors



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for the exascale era.

~100 contributors



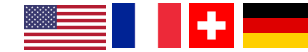
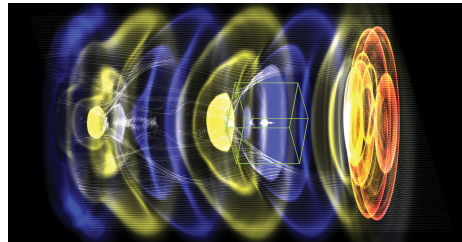
Hosted by HPSF

Open-source & available on Github

Documentation: ecp-warpX.github.io/

WarpX is an open-source Particle-In-Cell code
for the exascale era.

~100 contributors

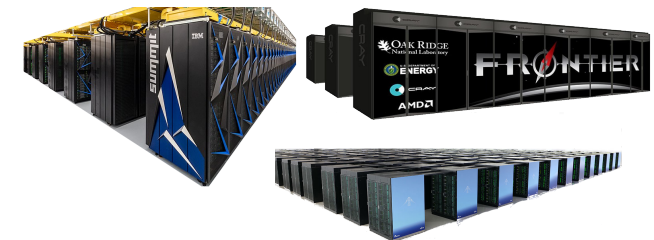


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From your laptop to the largest
supercomputers in the world!



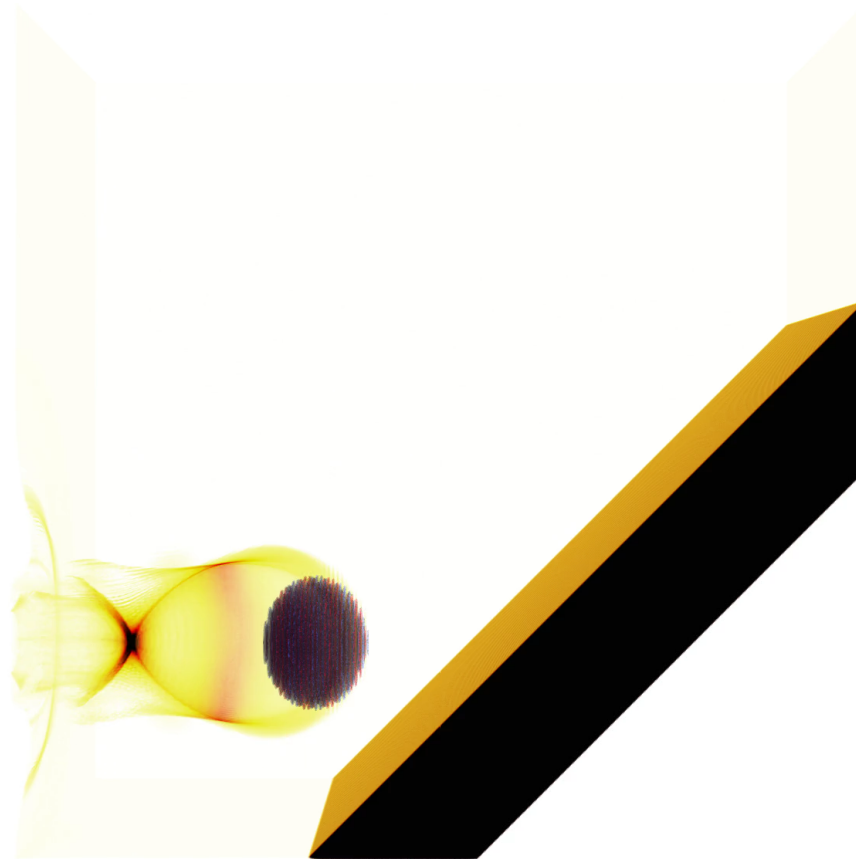
A movie from our 3D simulations



A movie from our 3D simulations



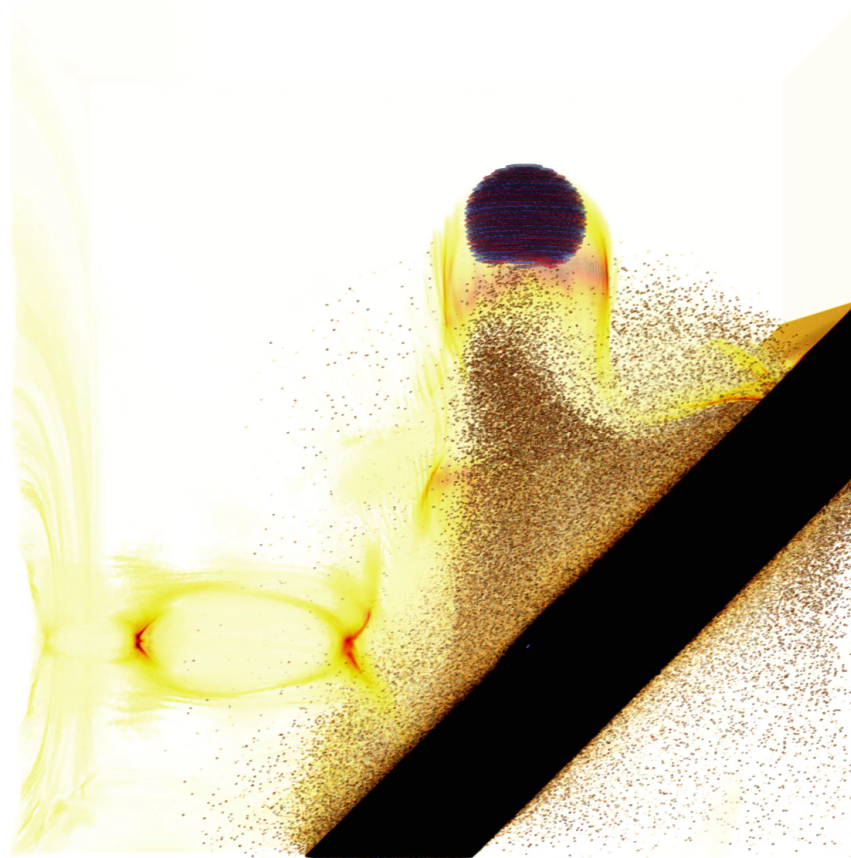
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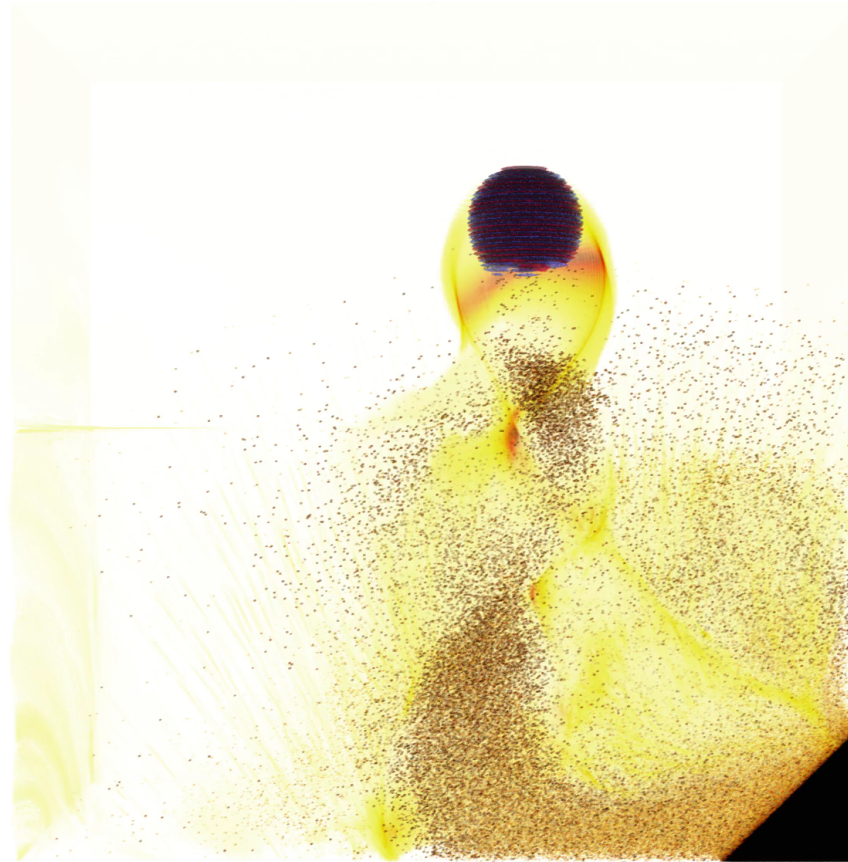
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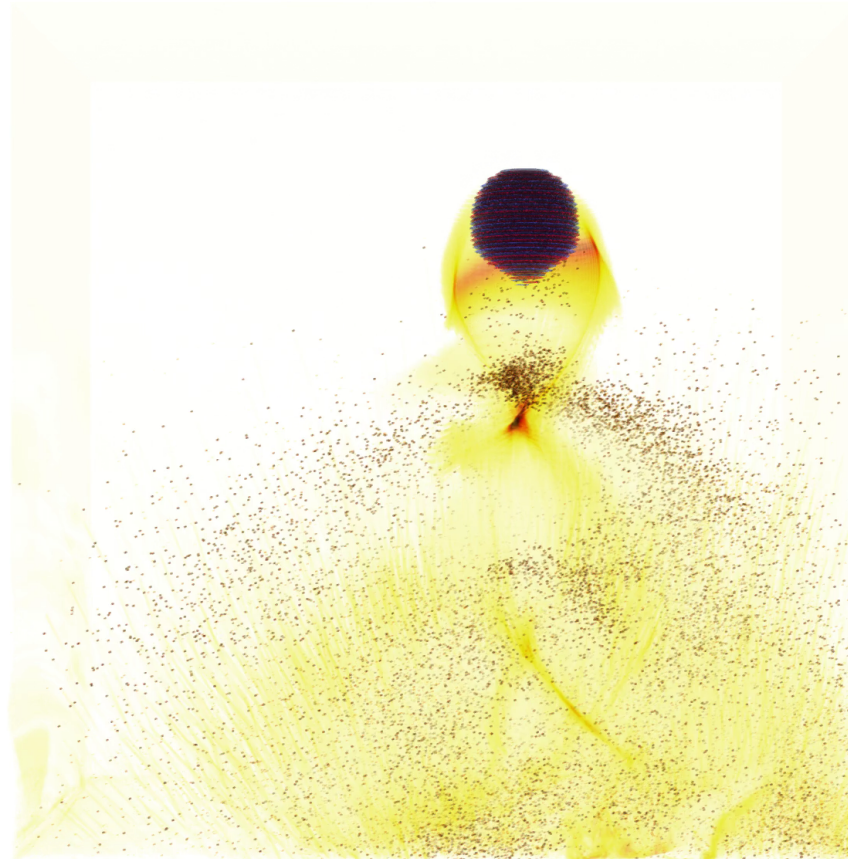
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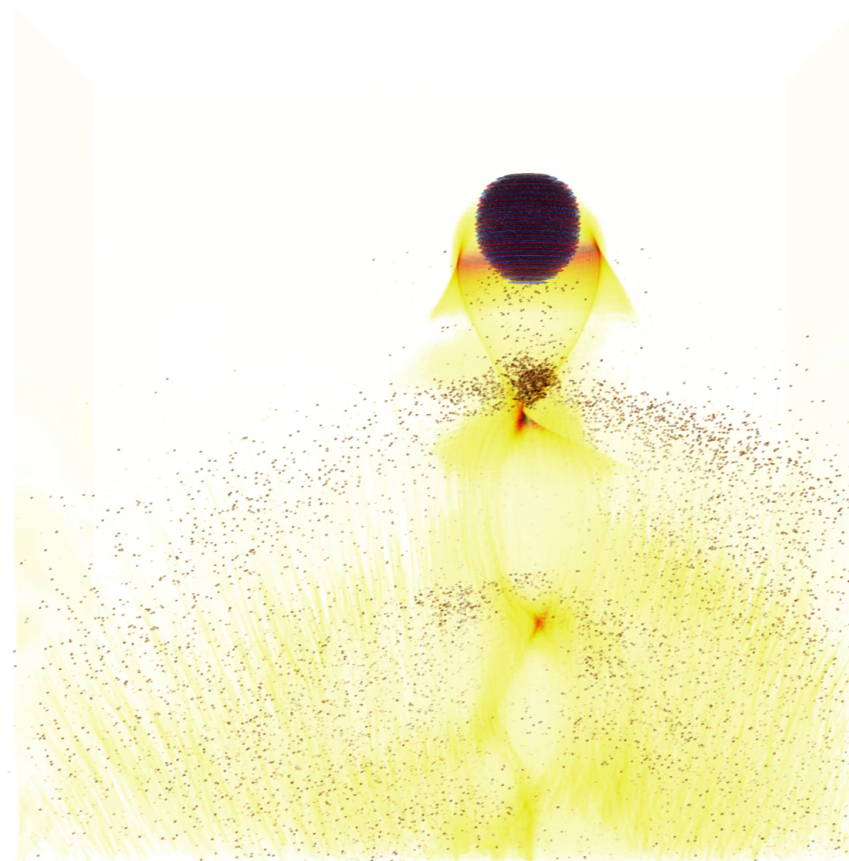
A movie from our 3D simulations



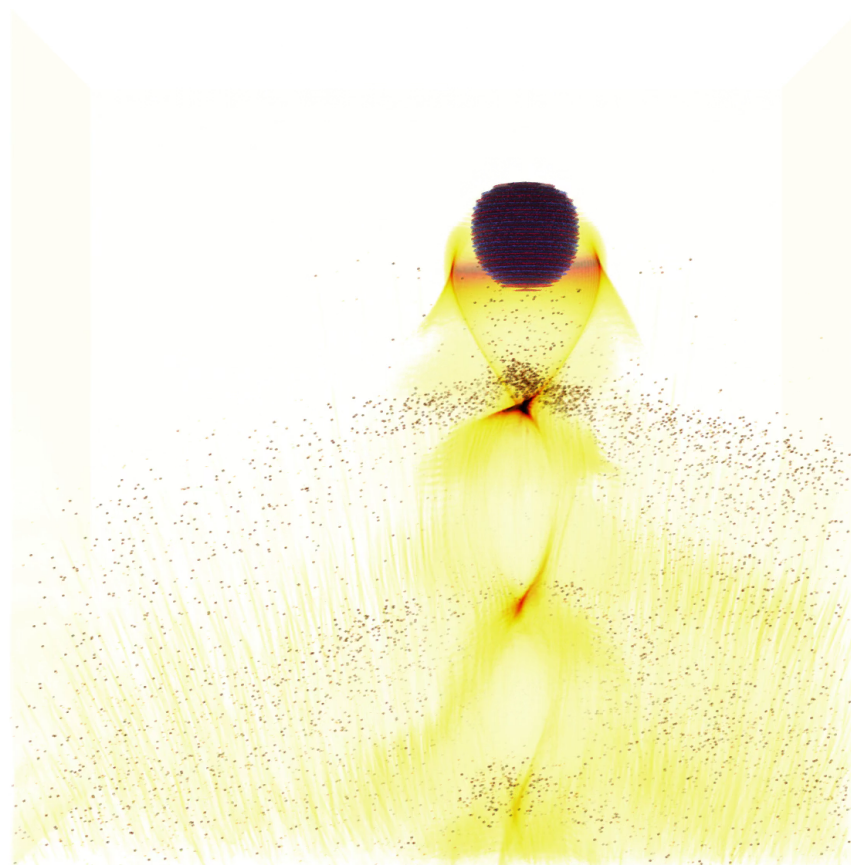
A movie from our 3D simulations



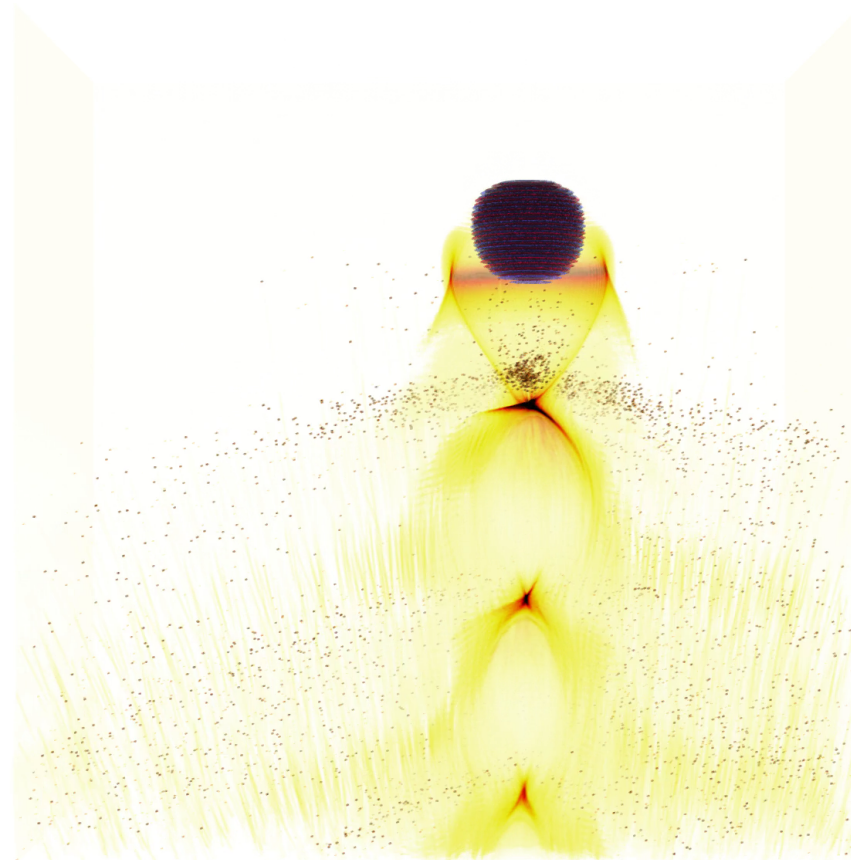
A movie from our 3D simulations



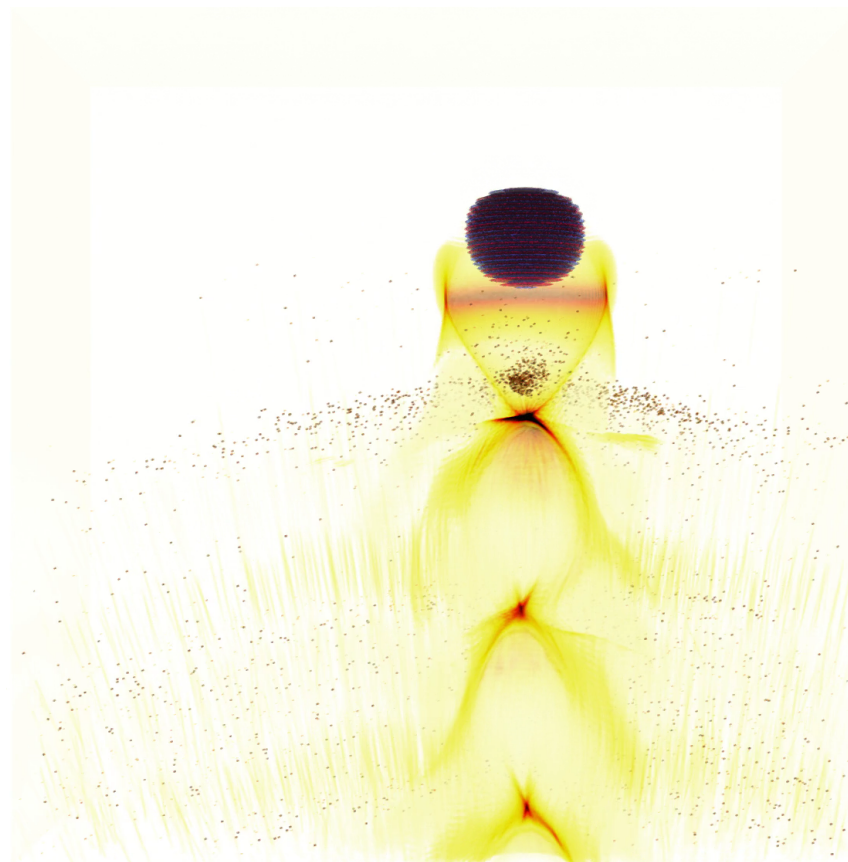
A movie from our 3D simulations



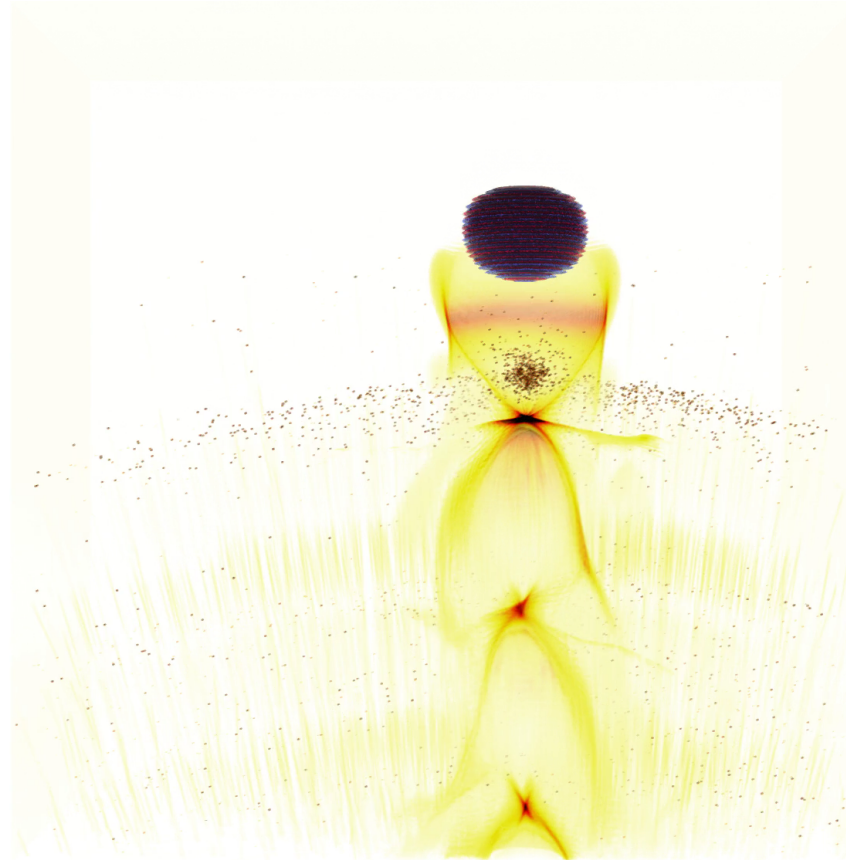
A movie from our 3D simulations



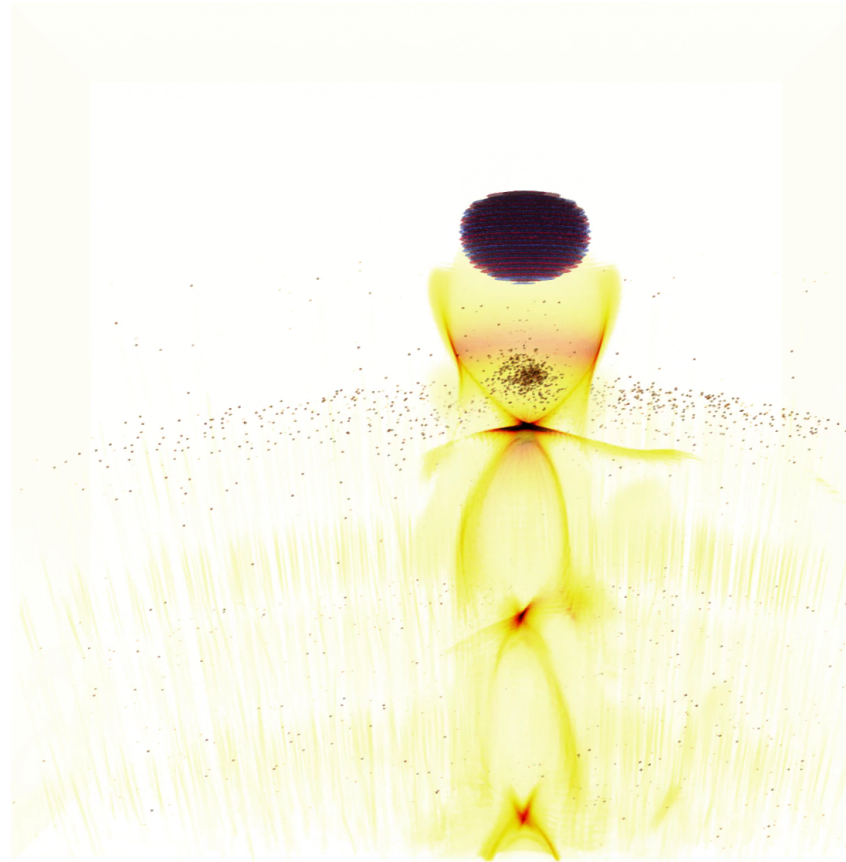
A movie from our 3D simulations



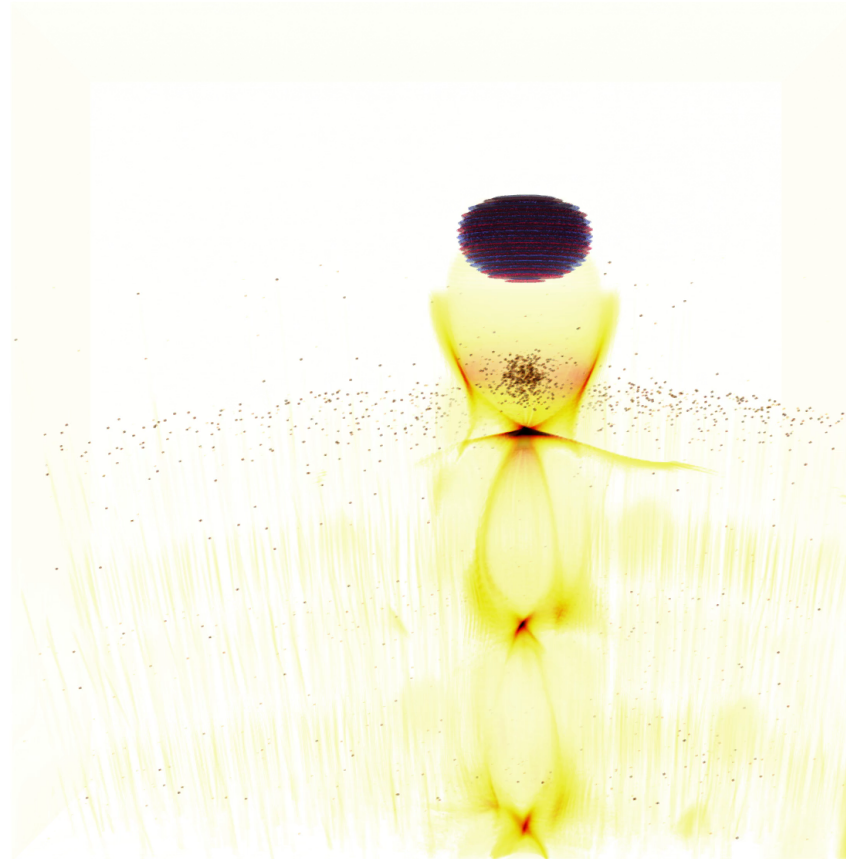
A movie from our 3D simulations



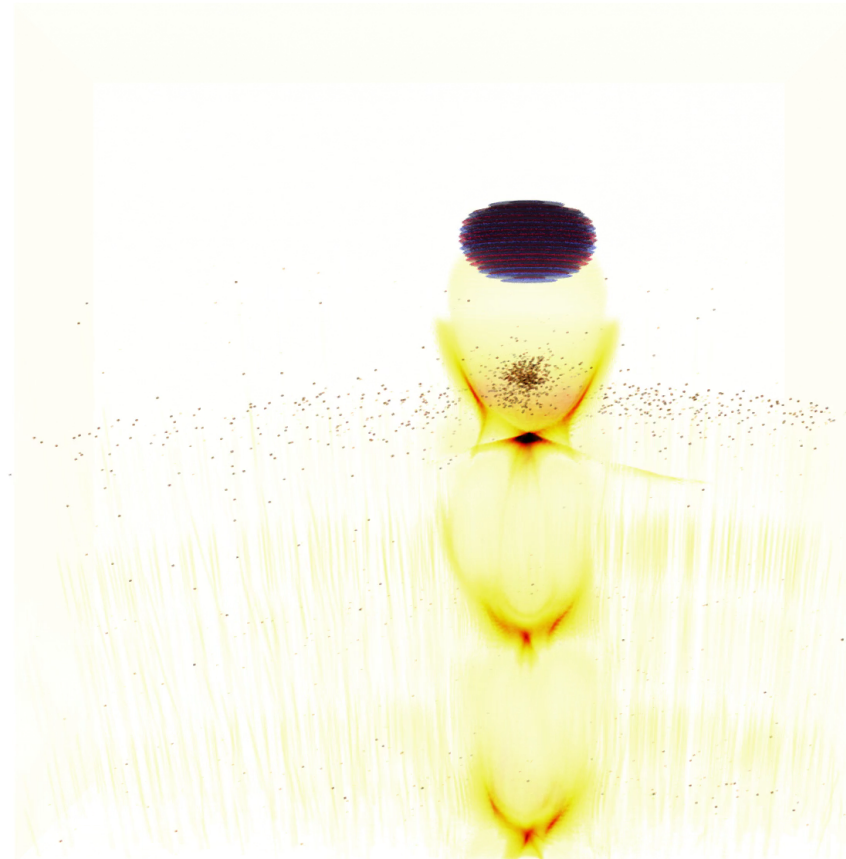
A movie from our 3D simulations



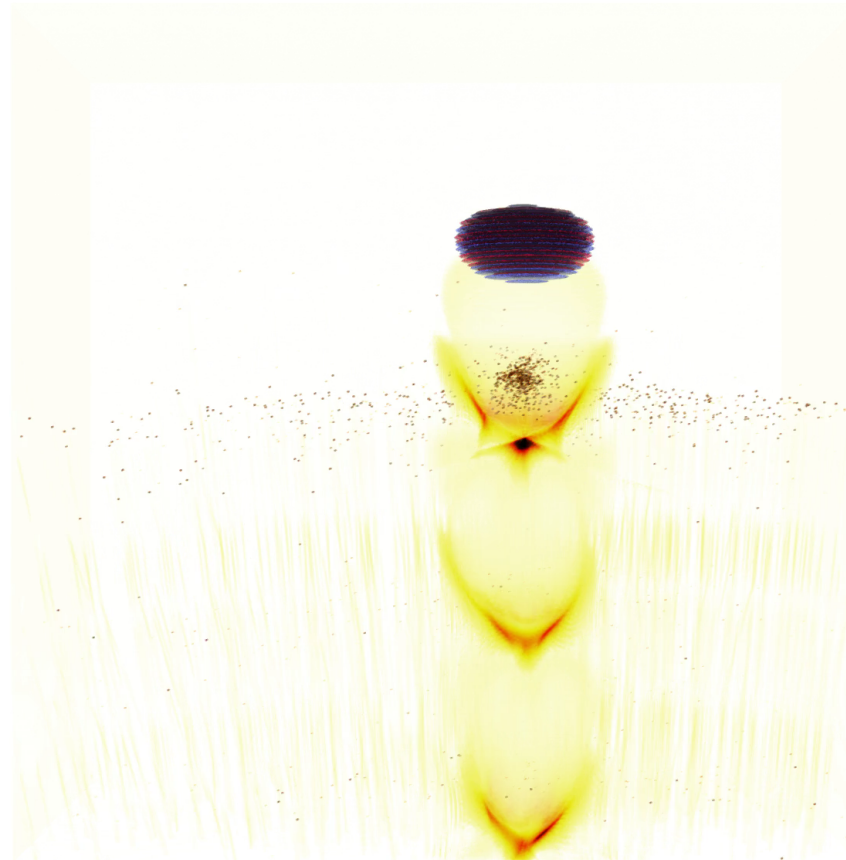
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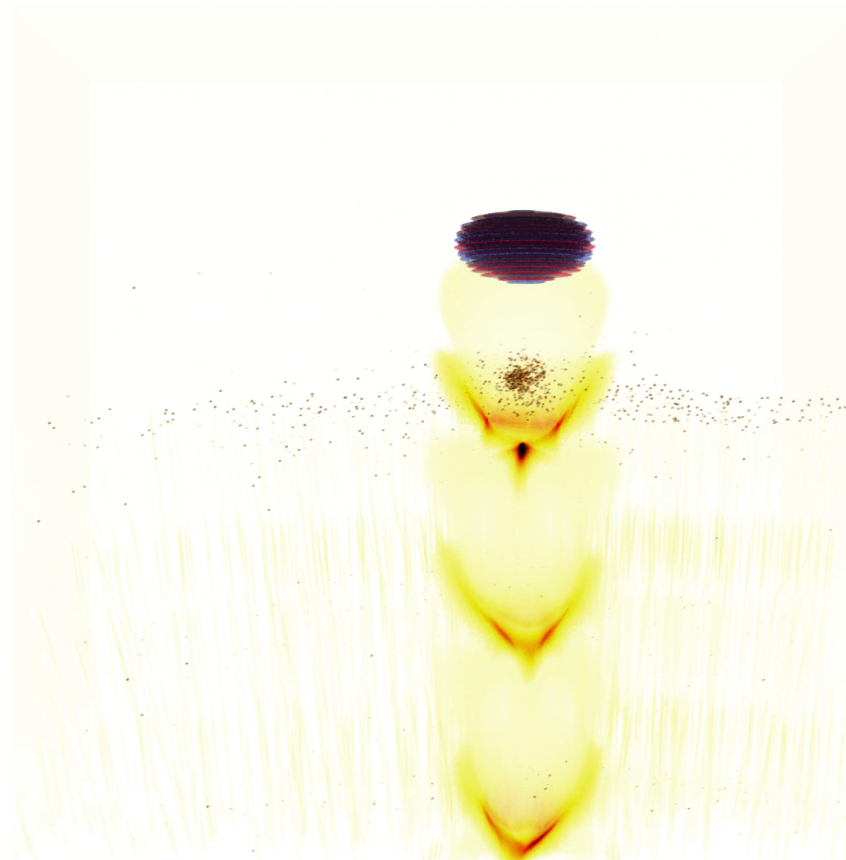
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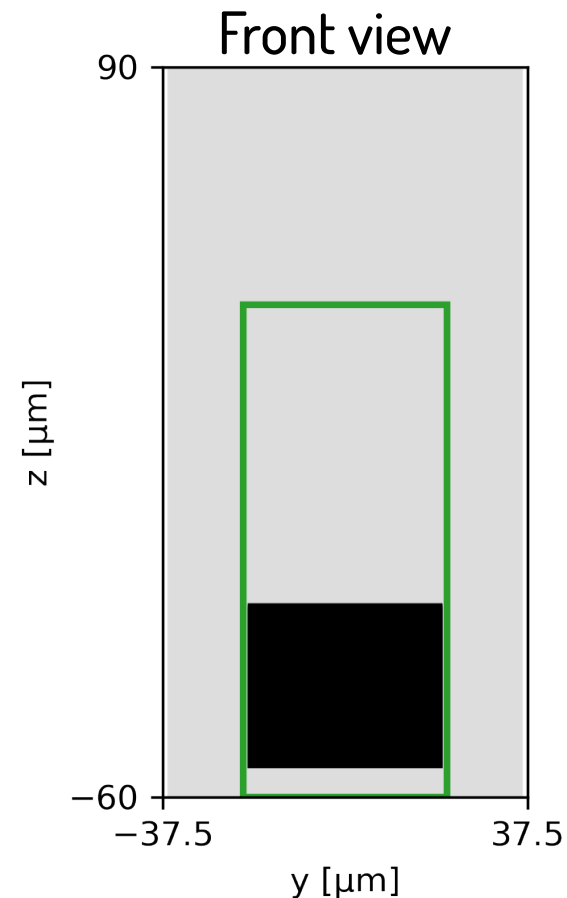
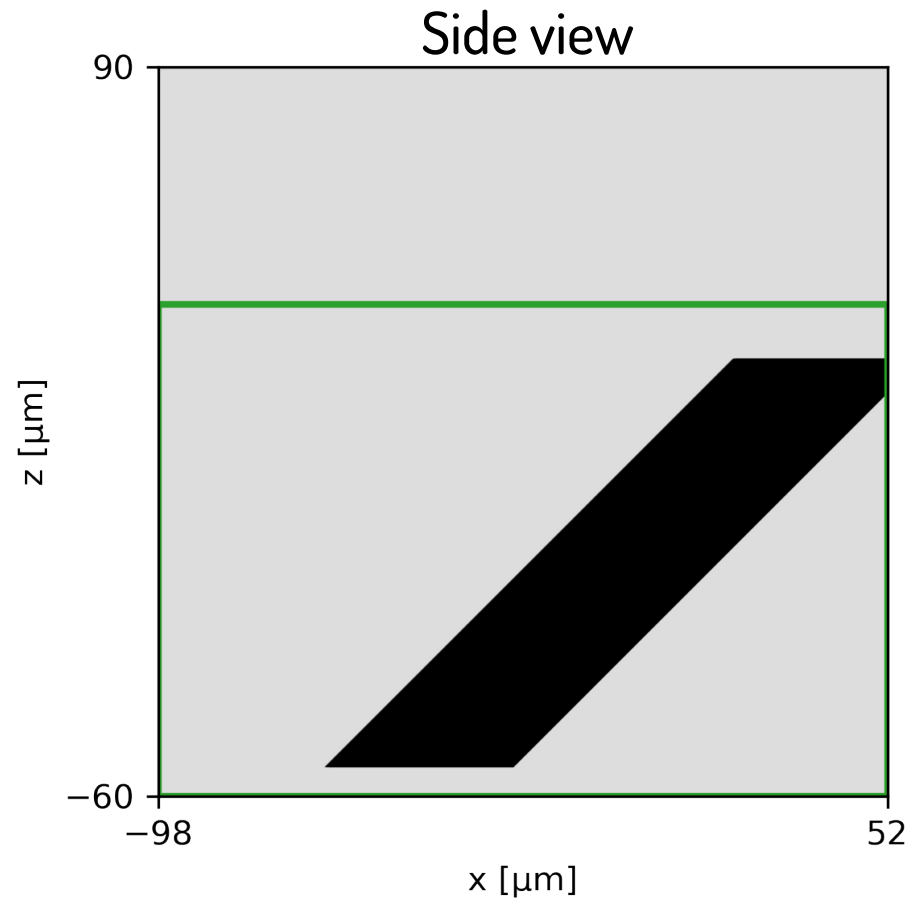
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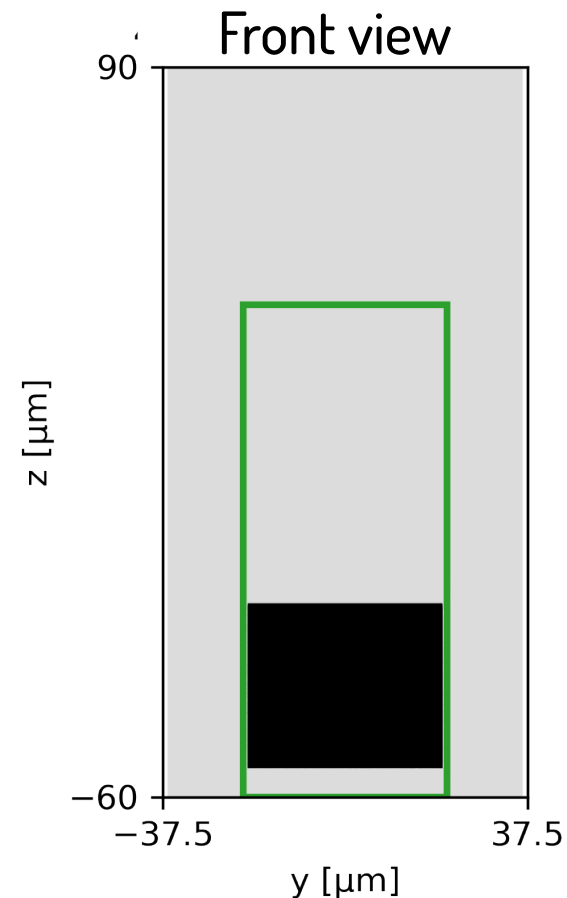
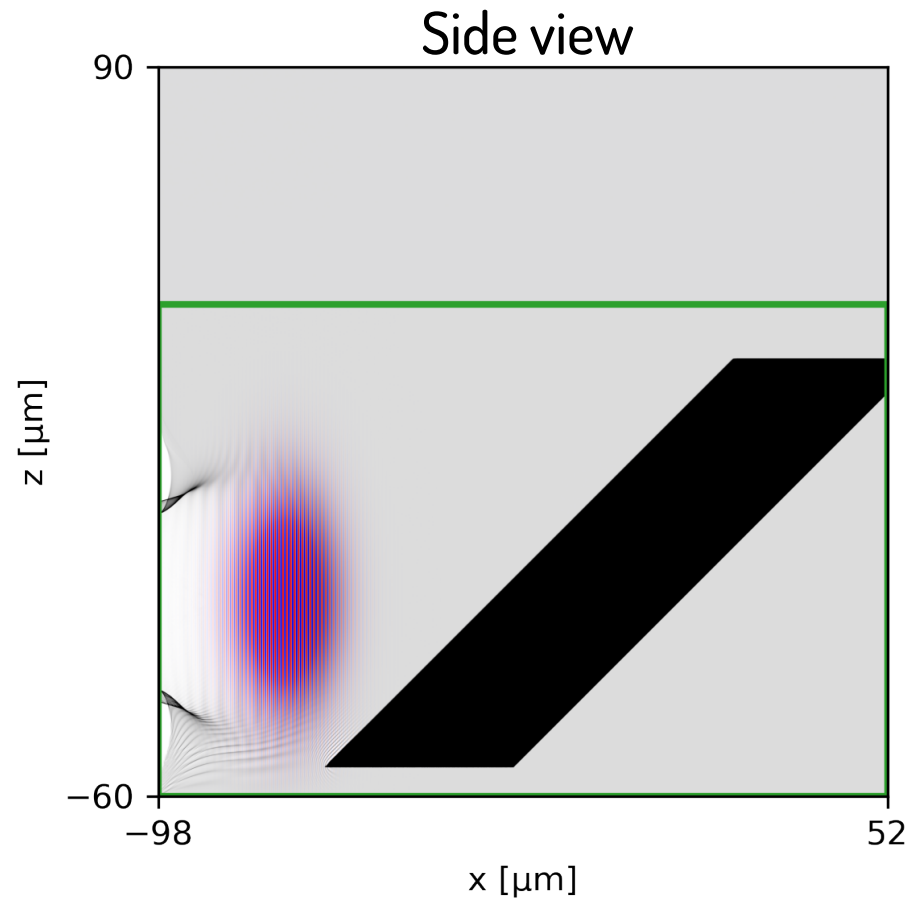


2D slices of our 3D simulations highlight the acceleration process



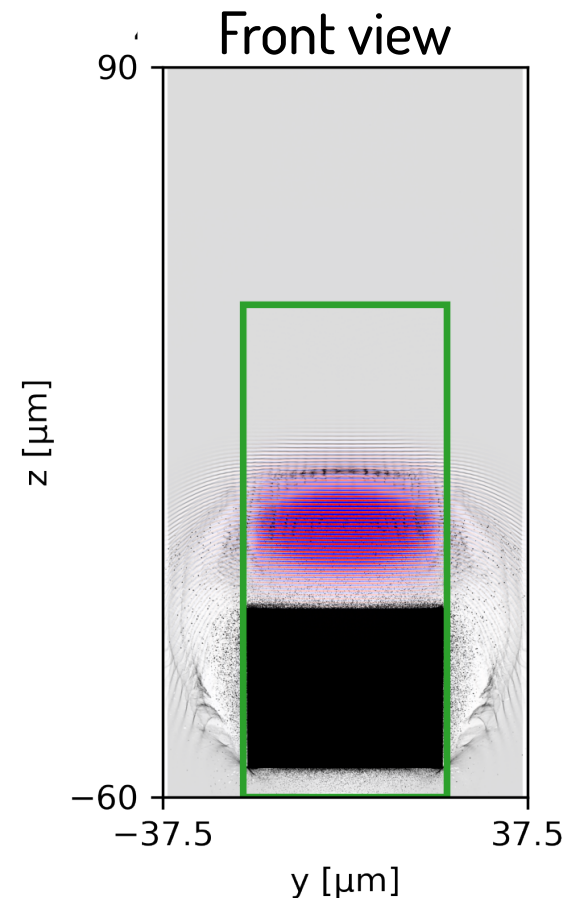
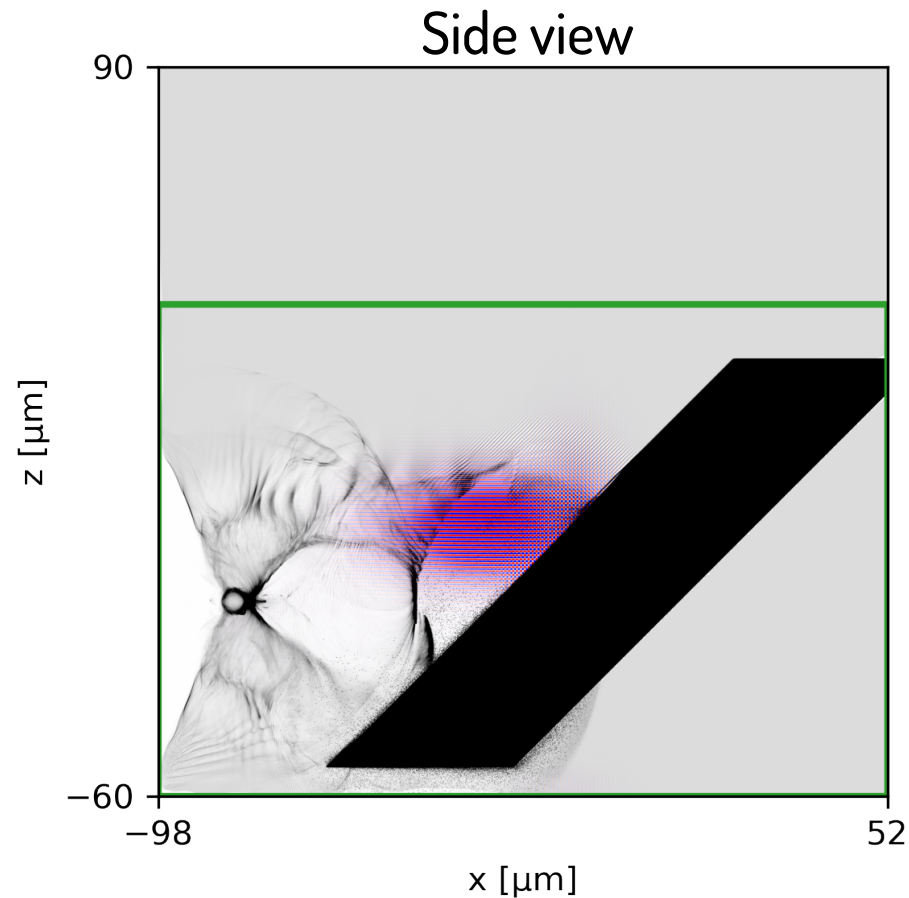
← 3D simulation
on 4096 Summit
nodes

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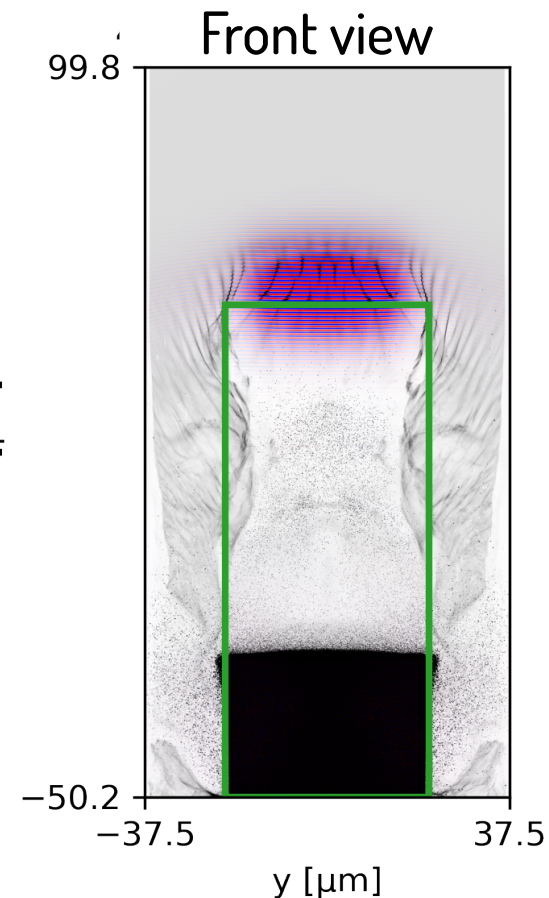
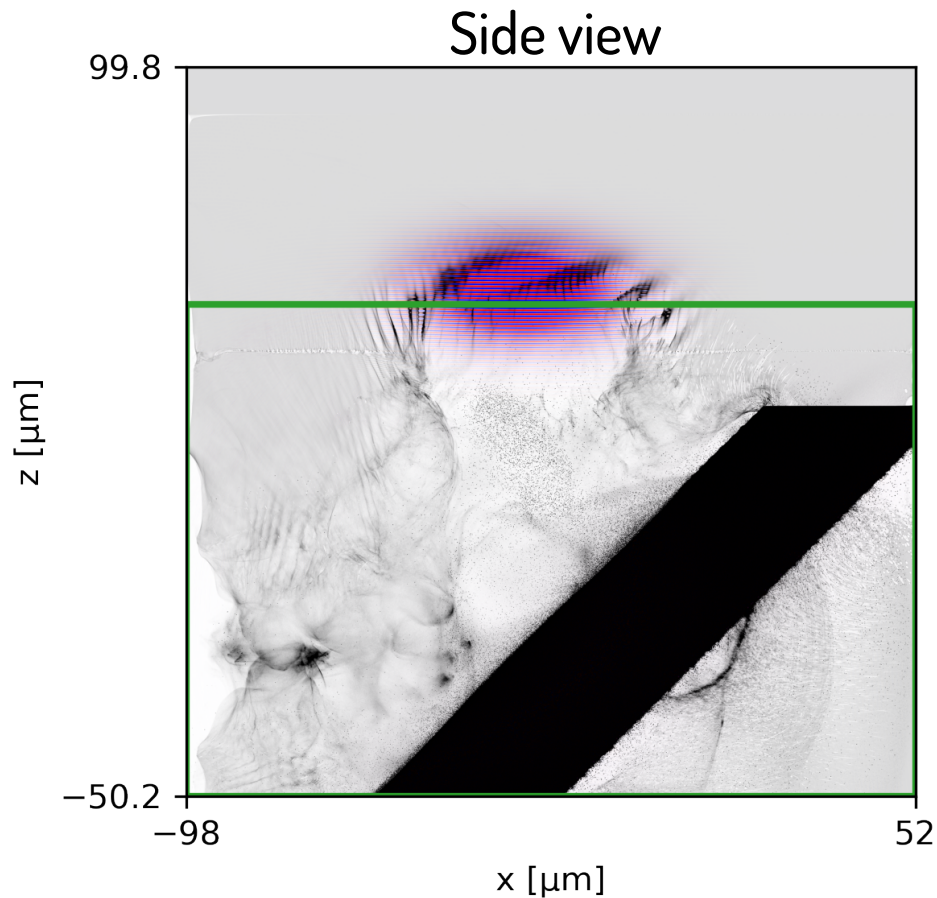
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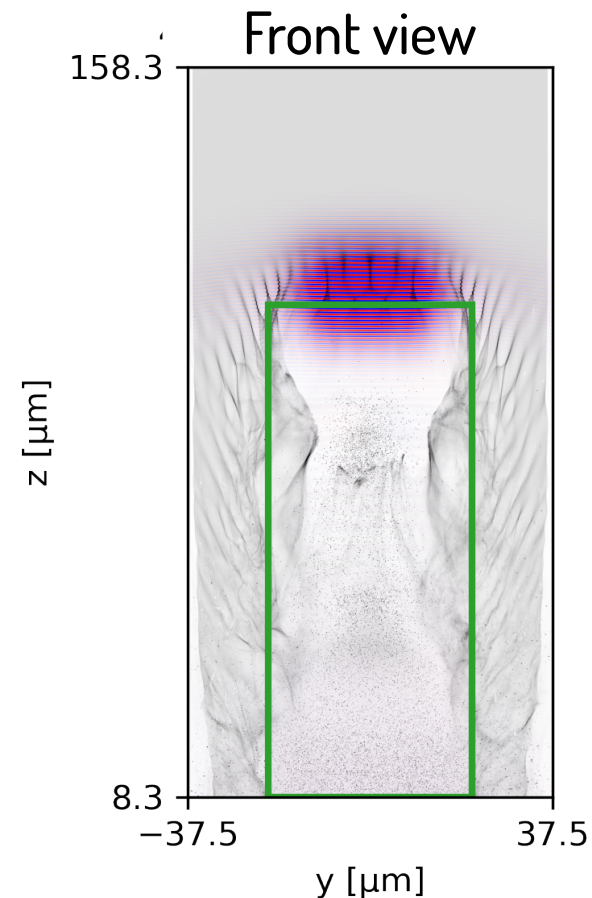
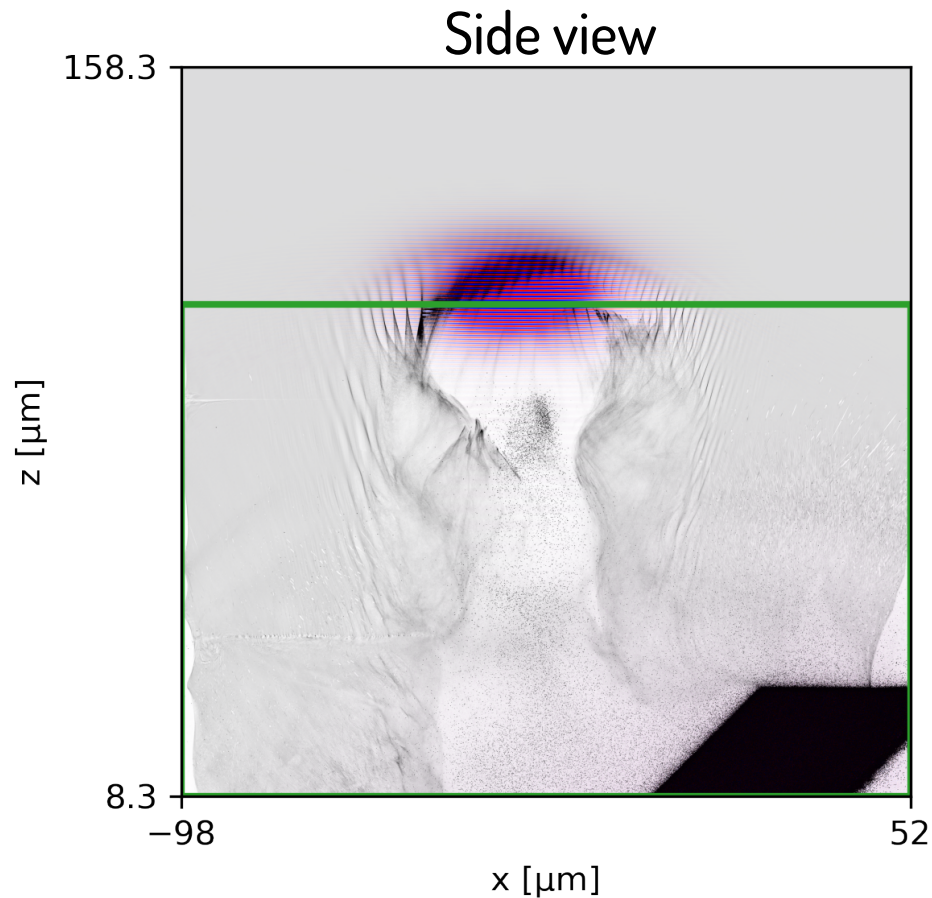
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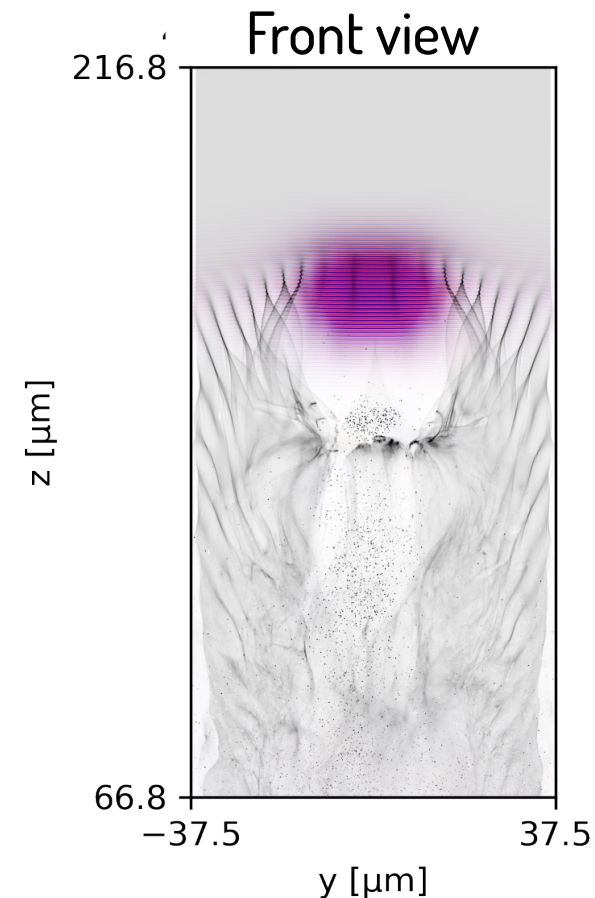
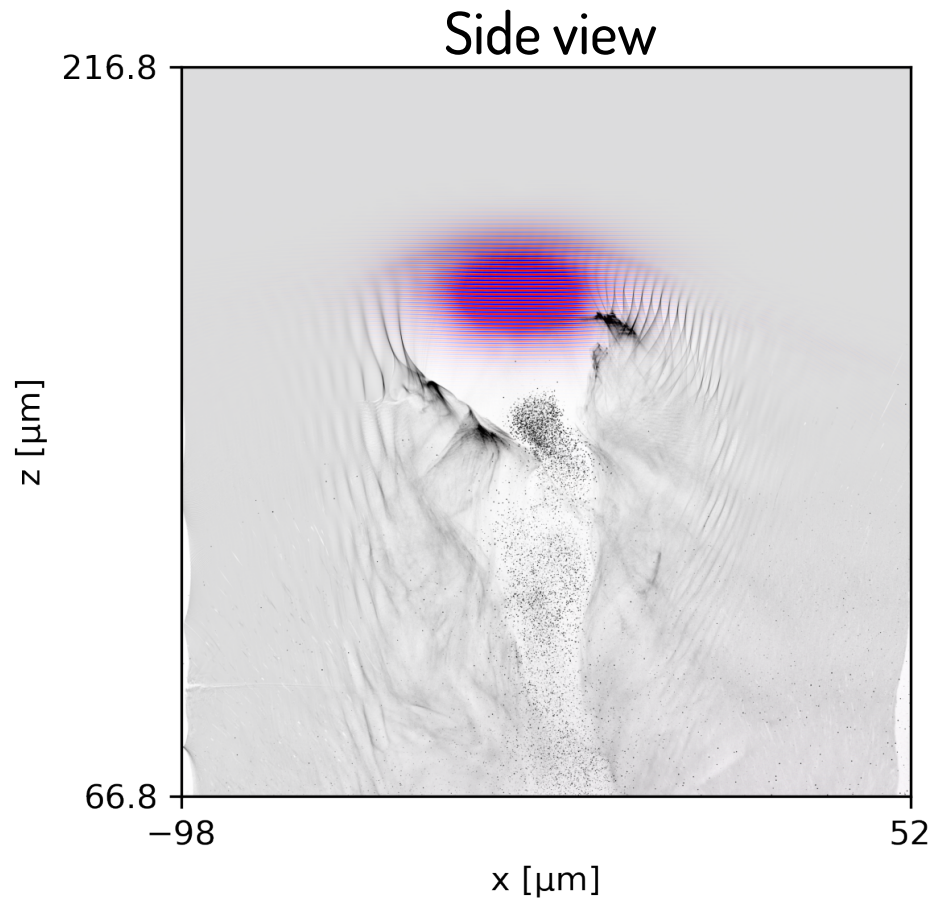
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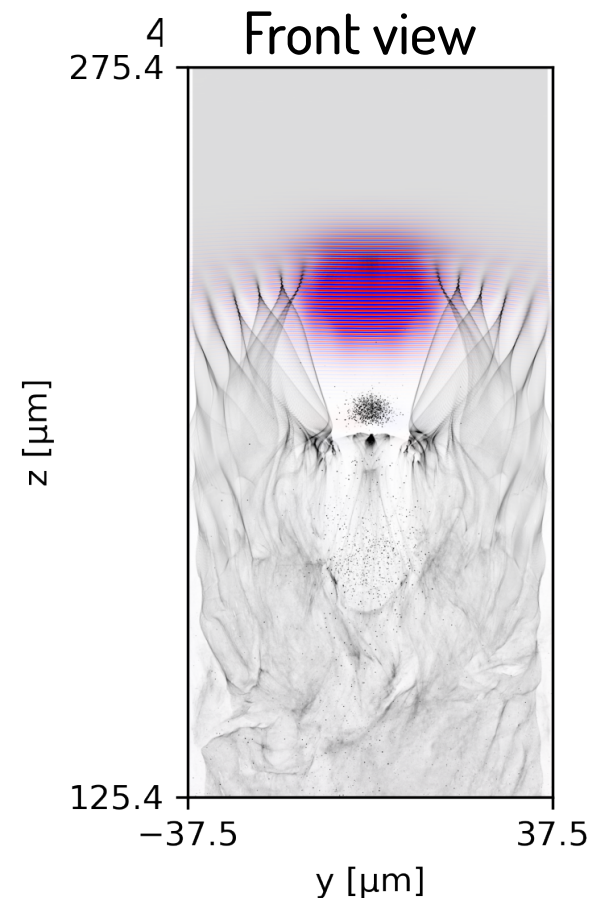
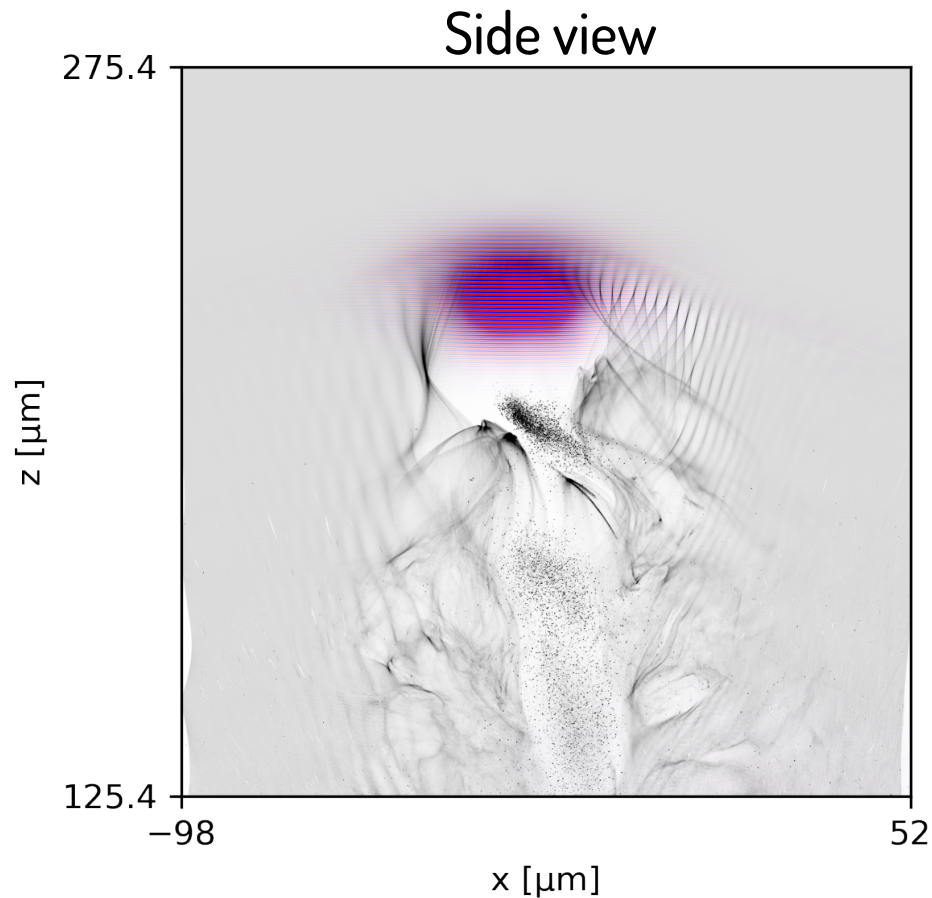
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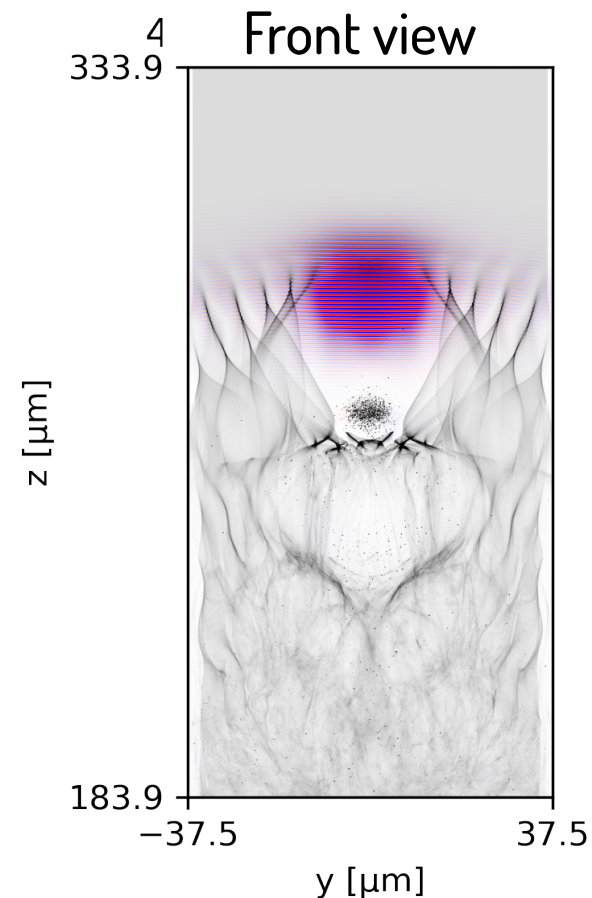
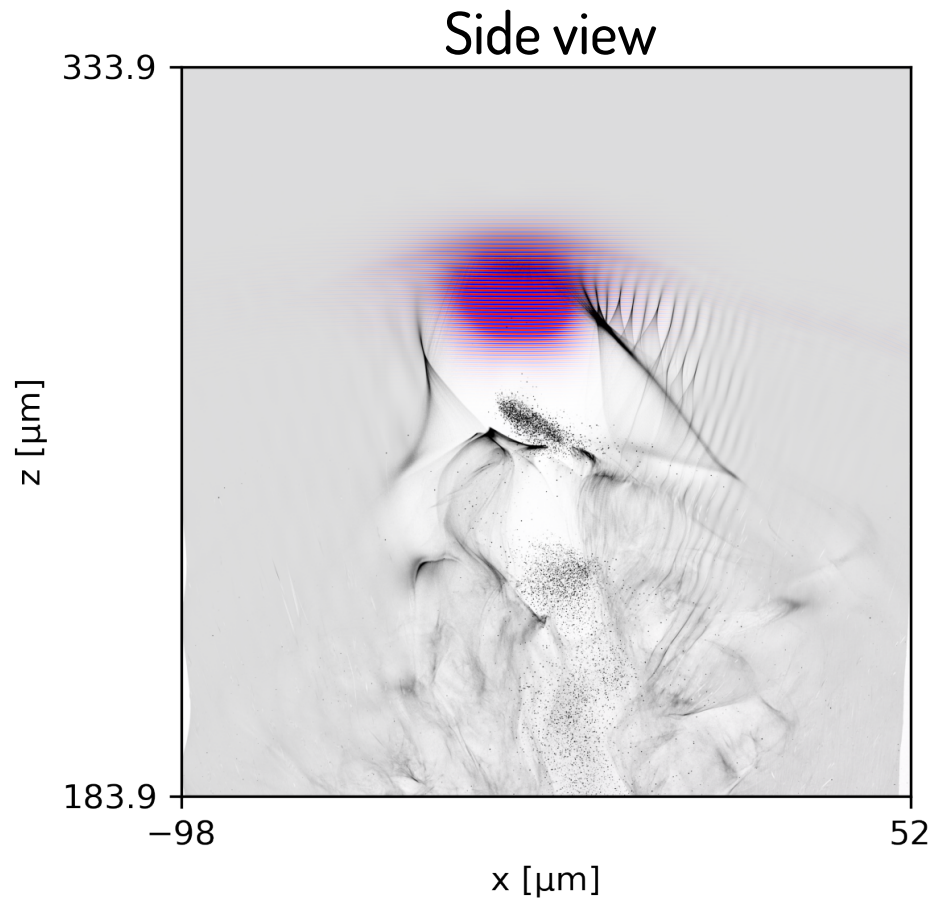
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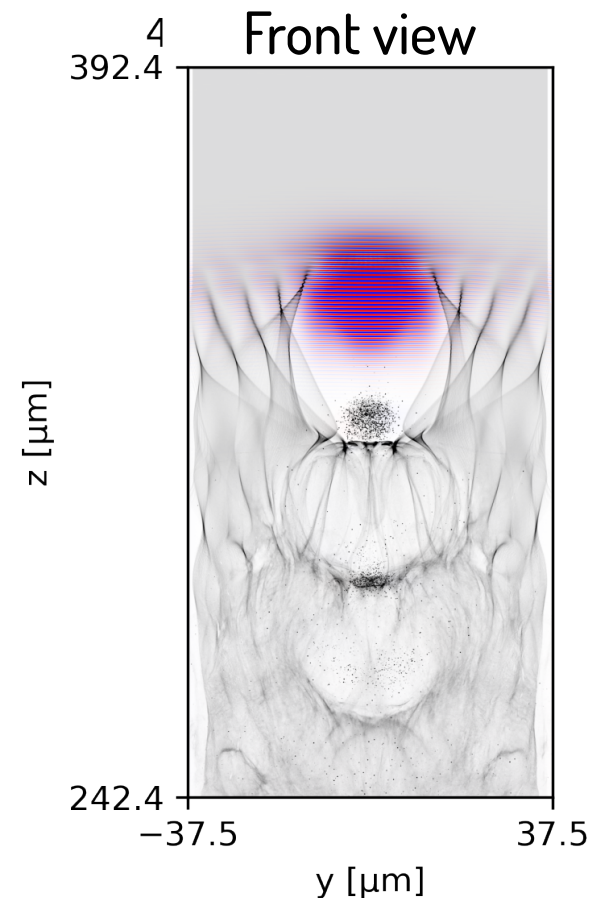
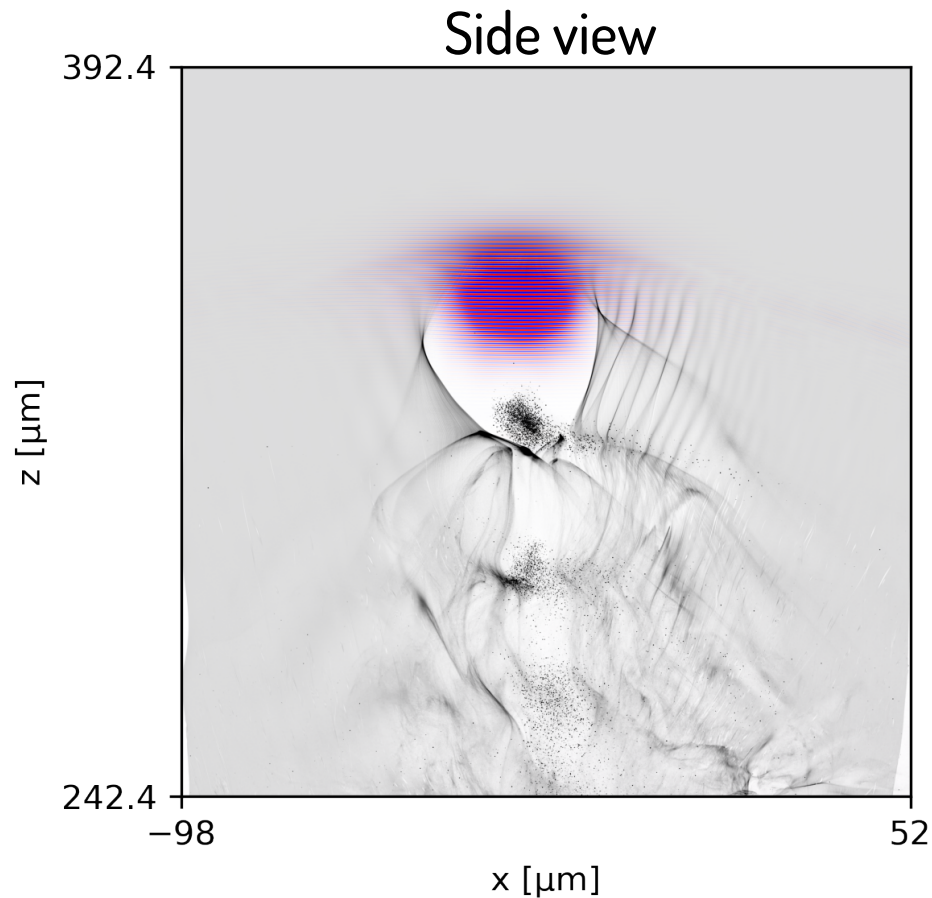
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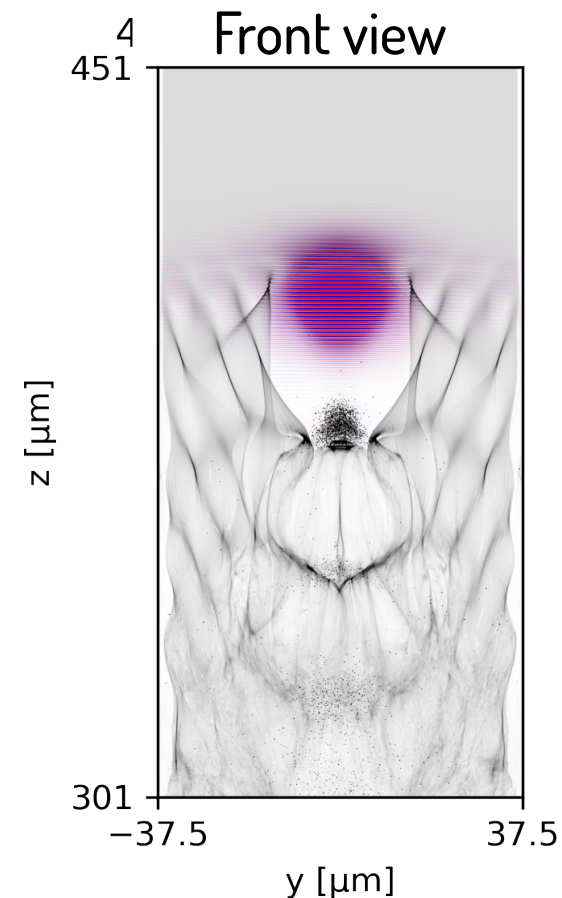
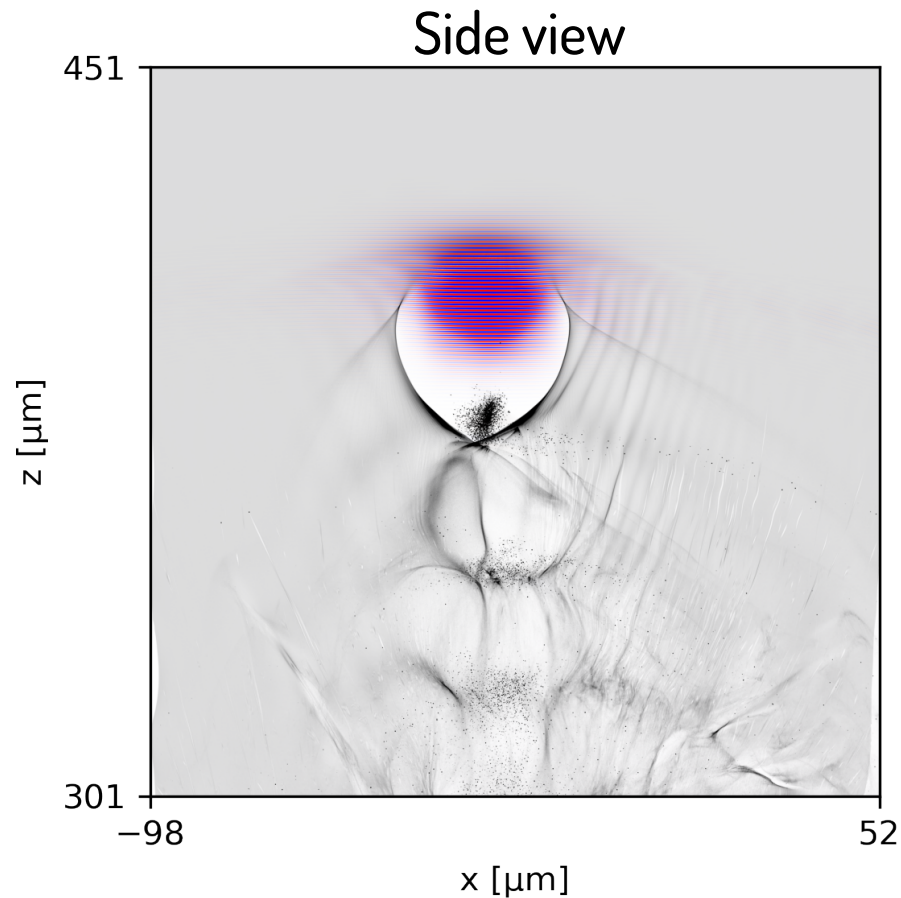
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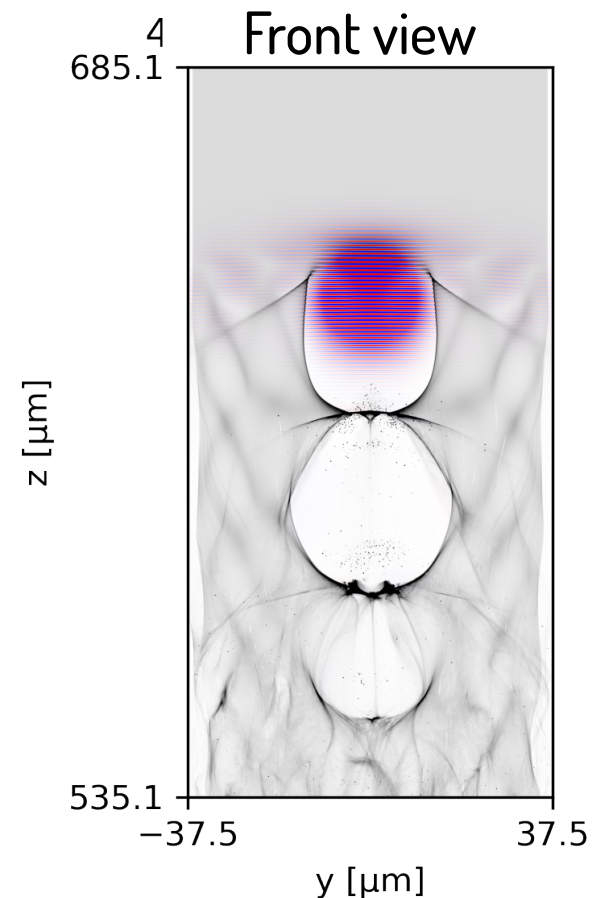
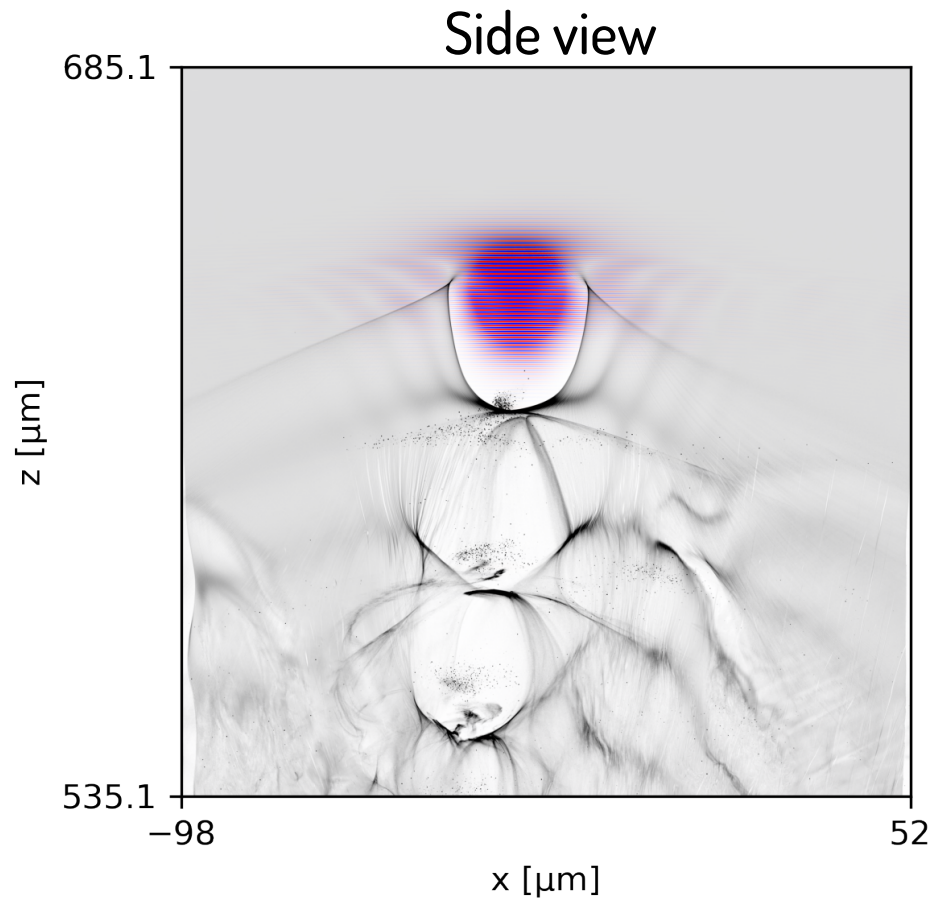
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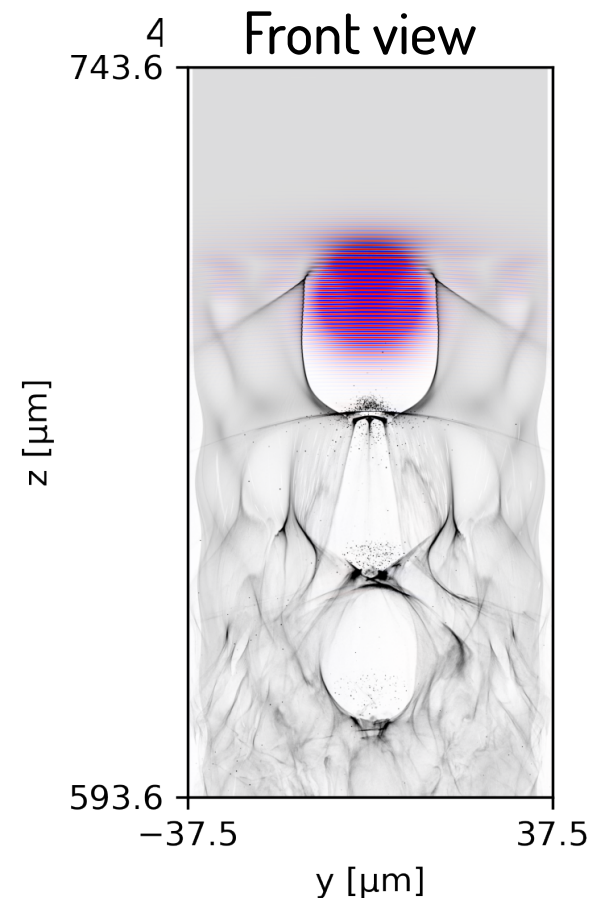
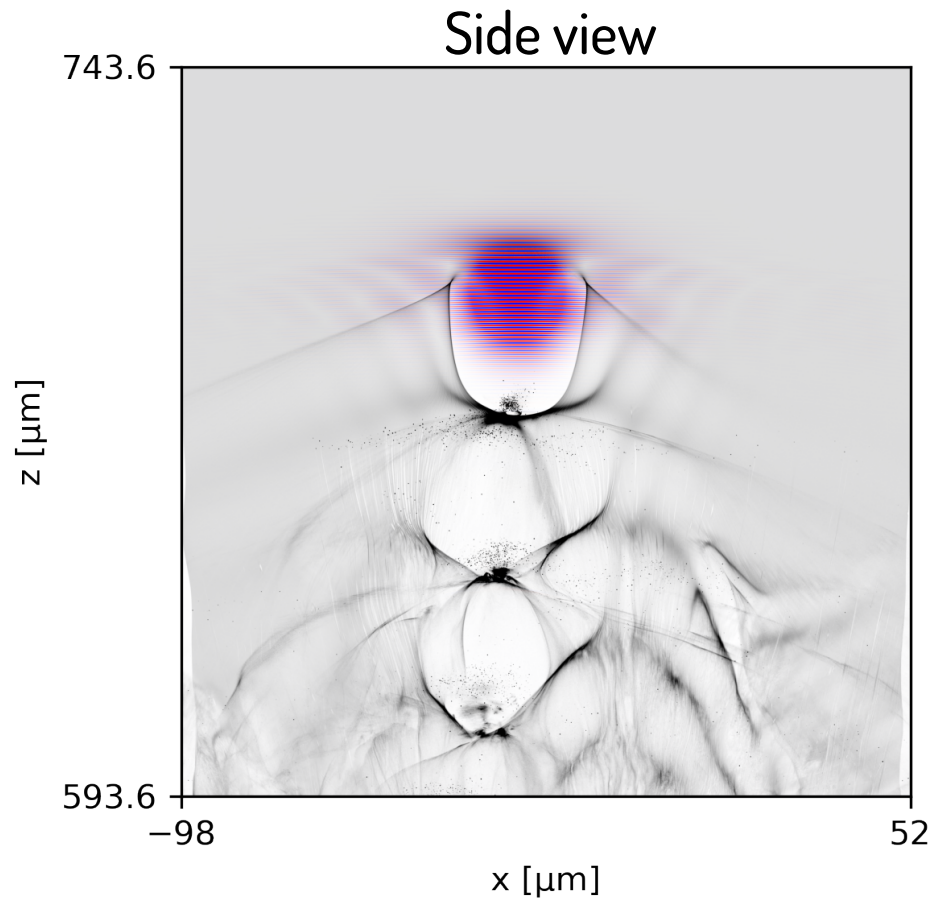
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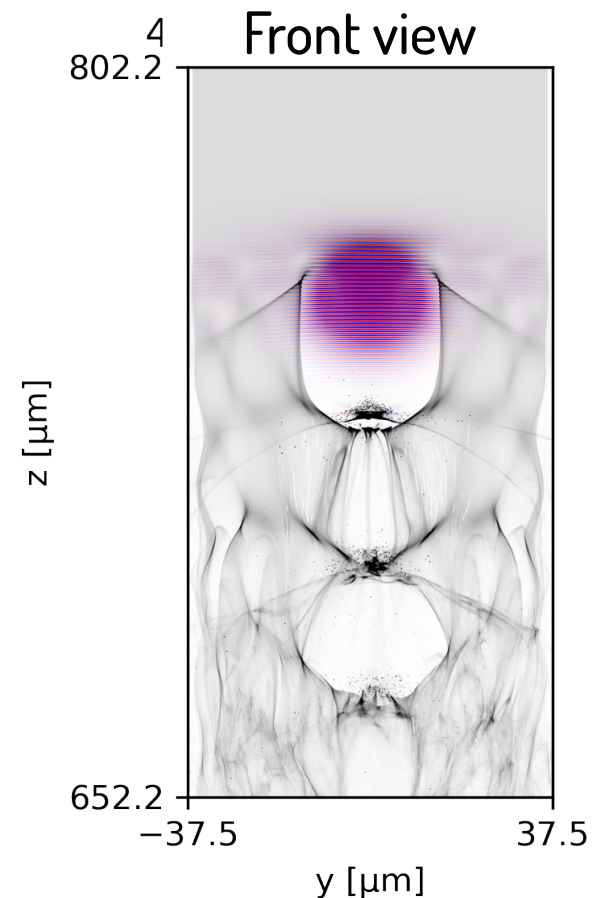
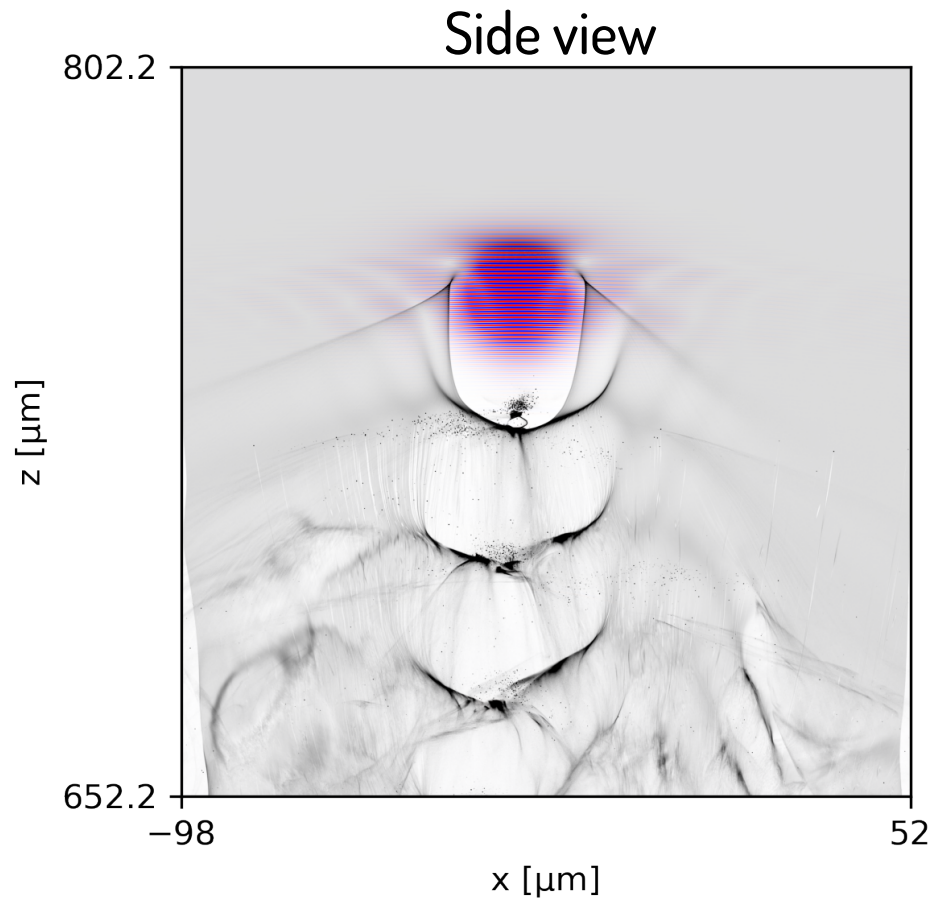
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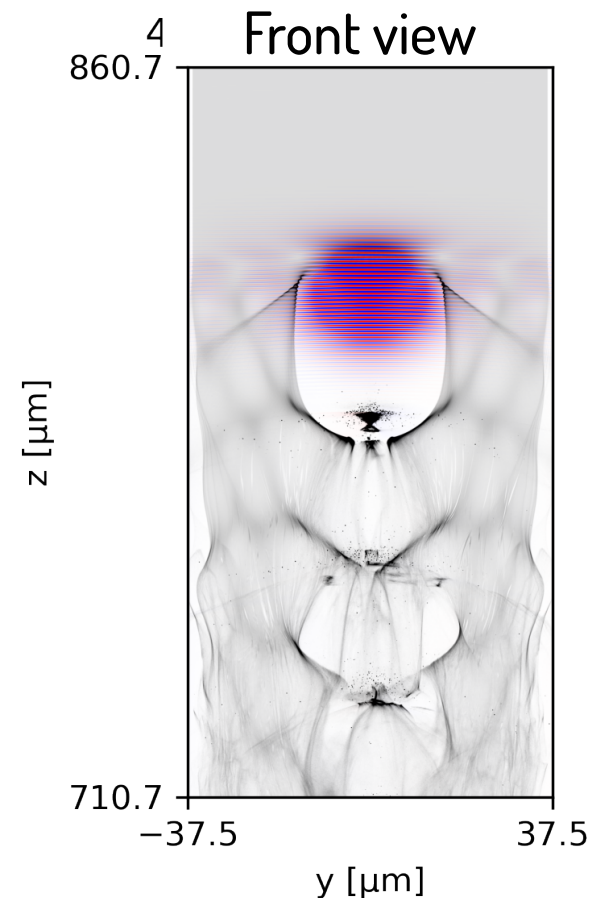
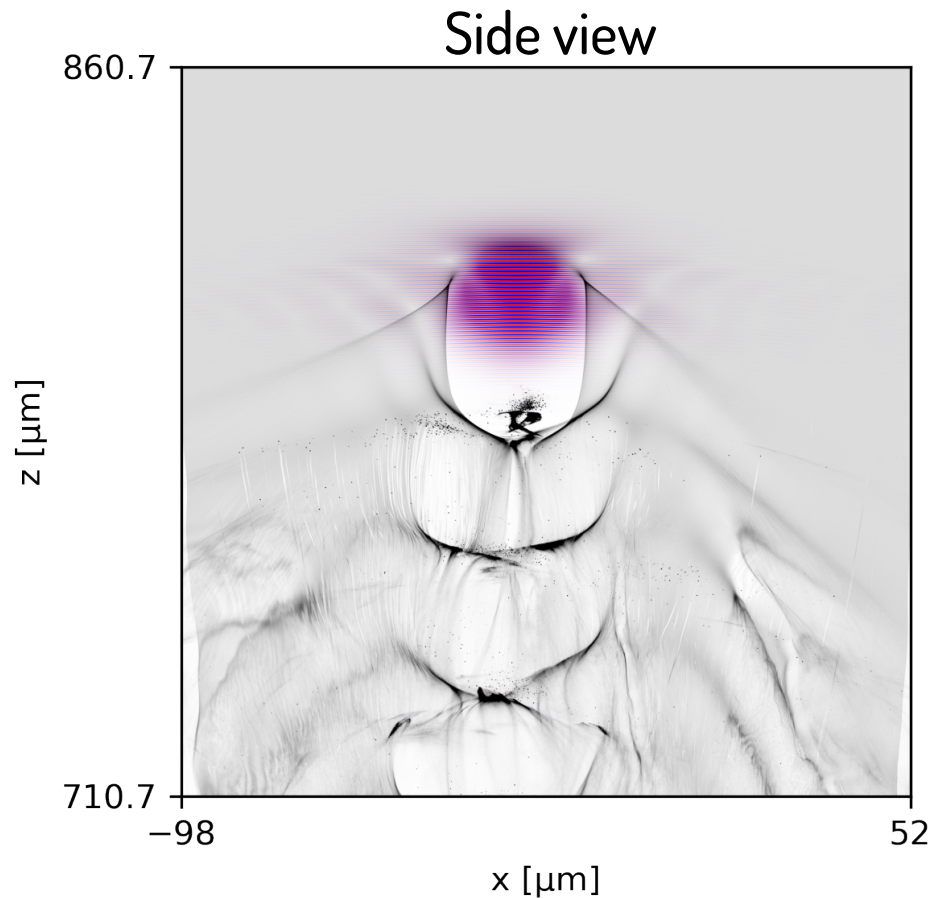
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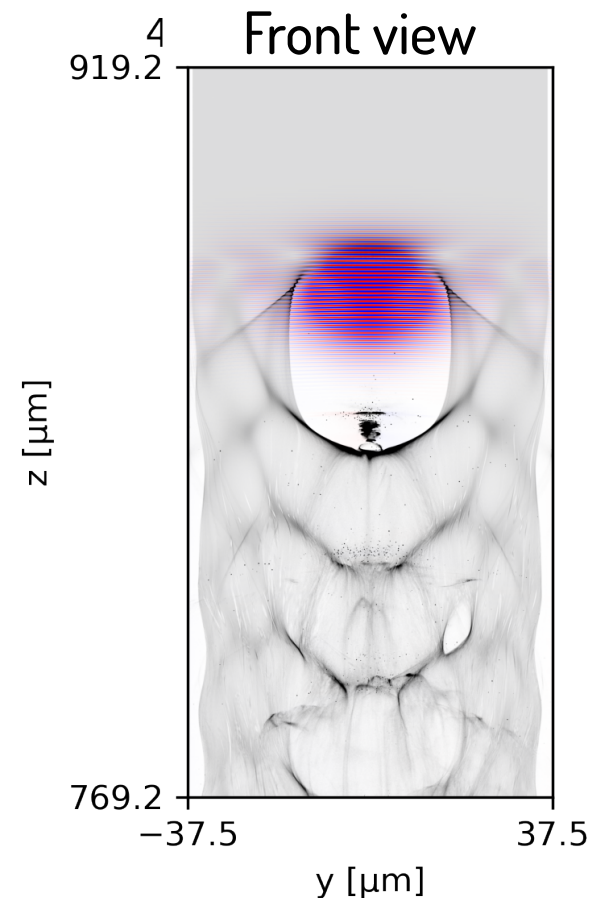
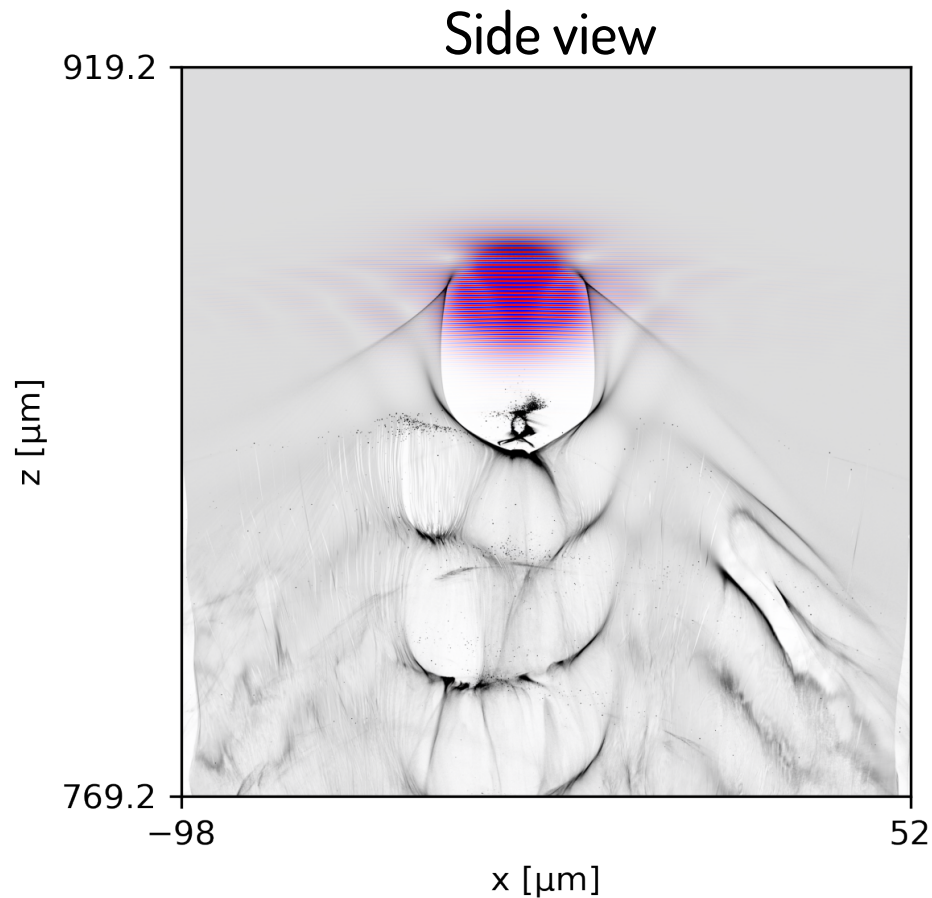
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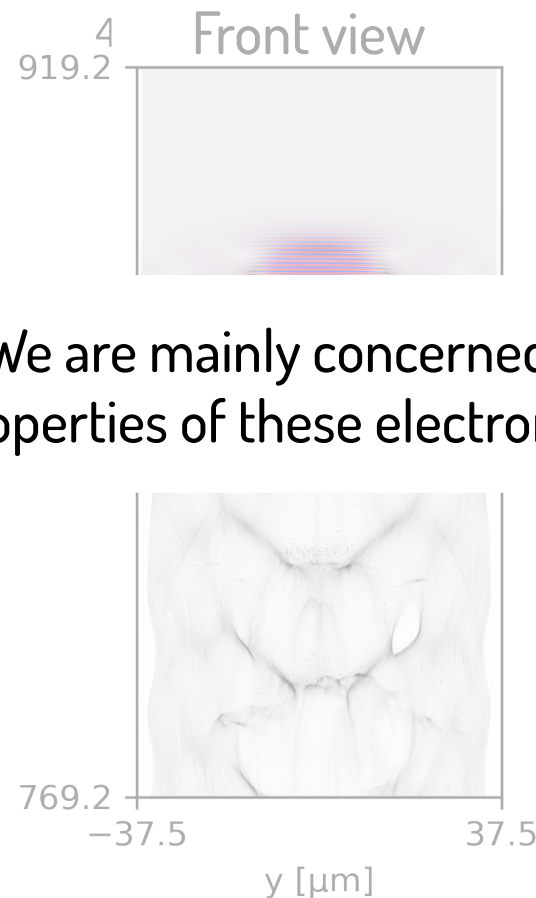
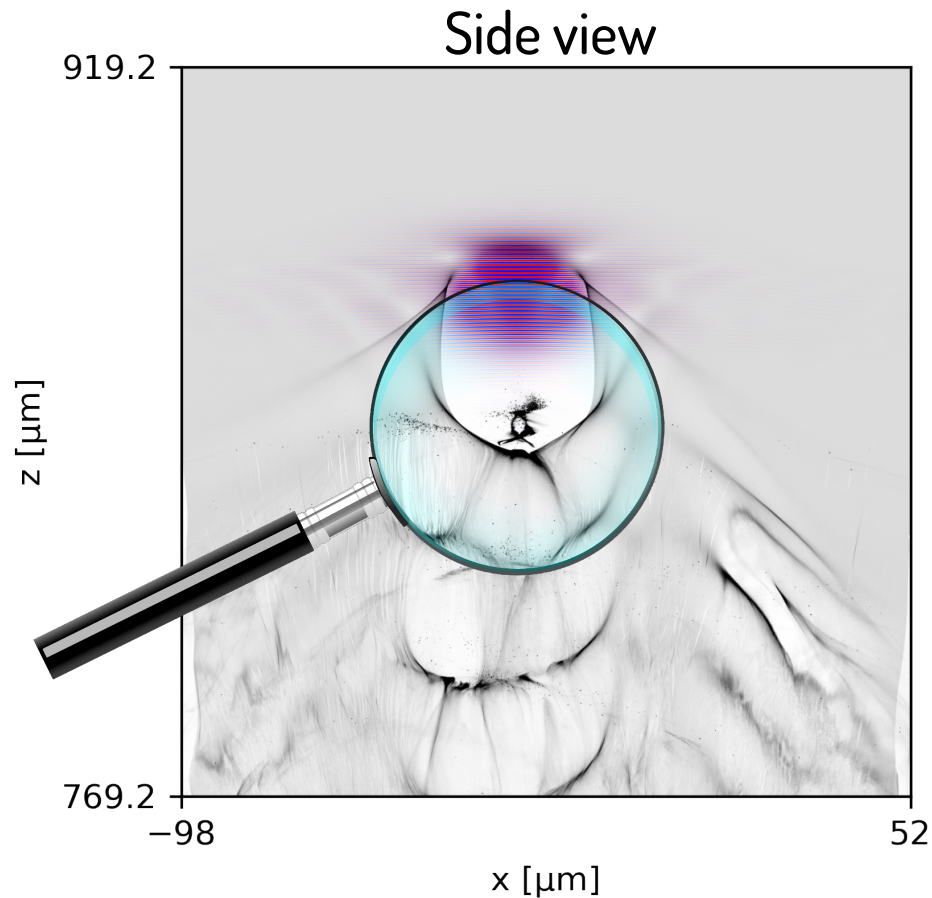
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2D slices of our 3D simulations highlight the acceleration process



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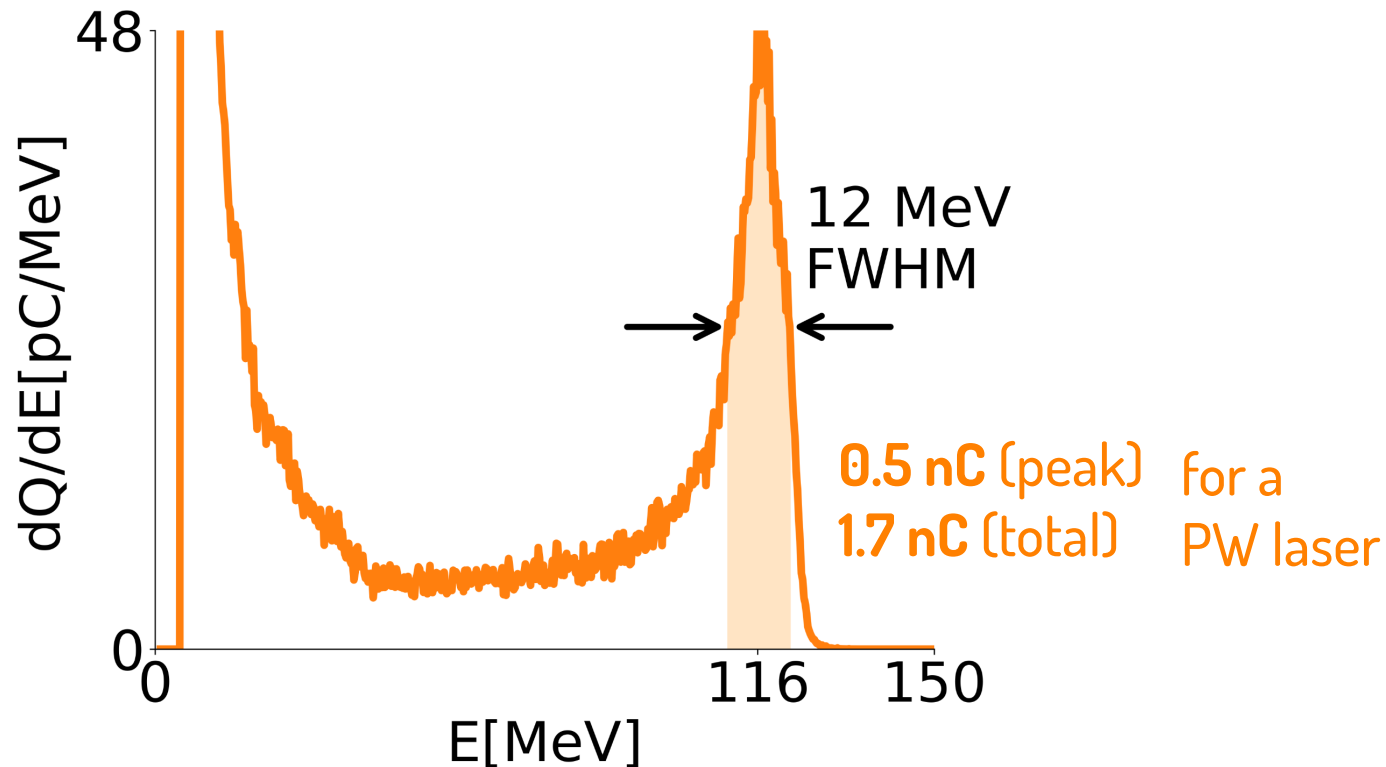


← We are mainly concerned with the properties of these electrons

it

Our simulations shows that we can accelerate a substantial amount of charge with high quality

After ~1mm
(acceleration still in progress)

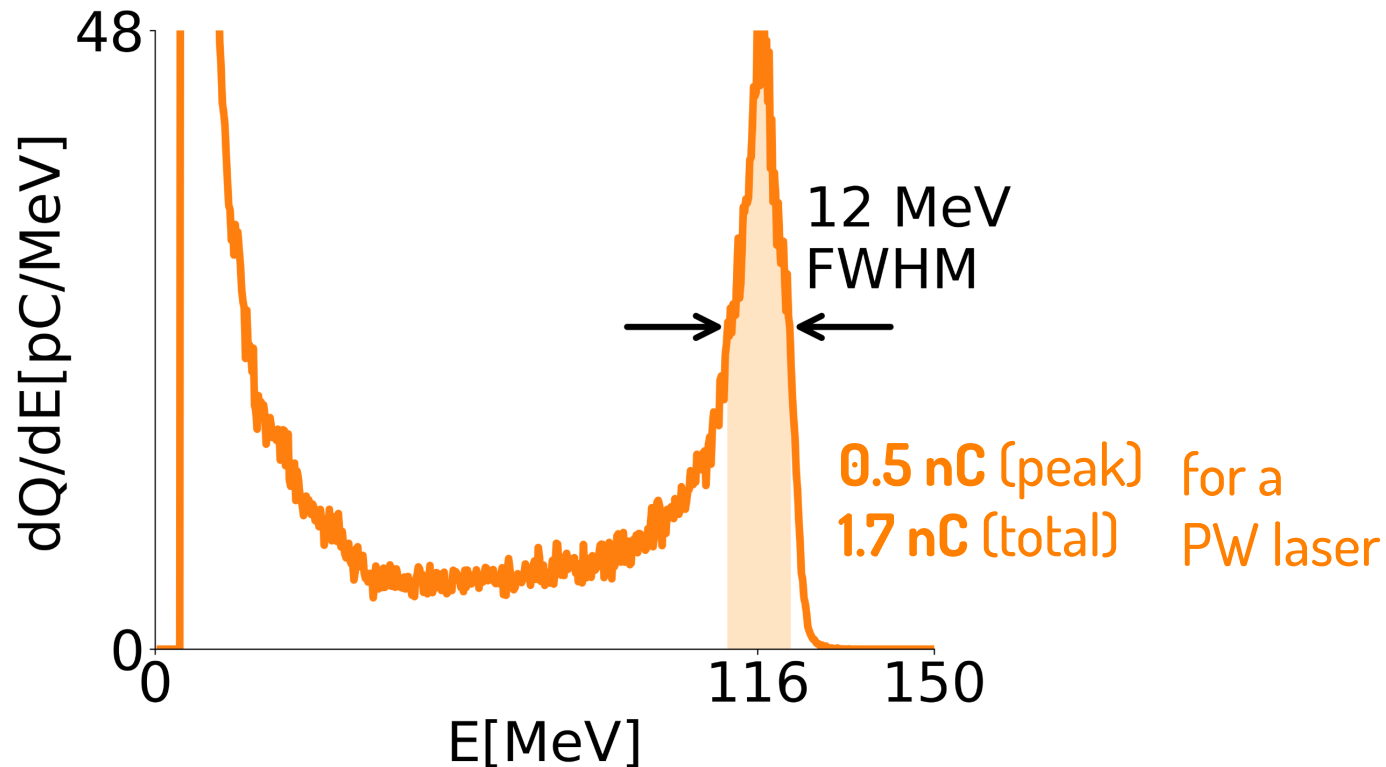


Production runs on
Frontier, Fugaku and Summit



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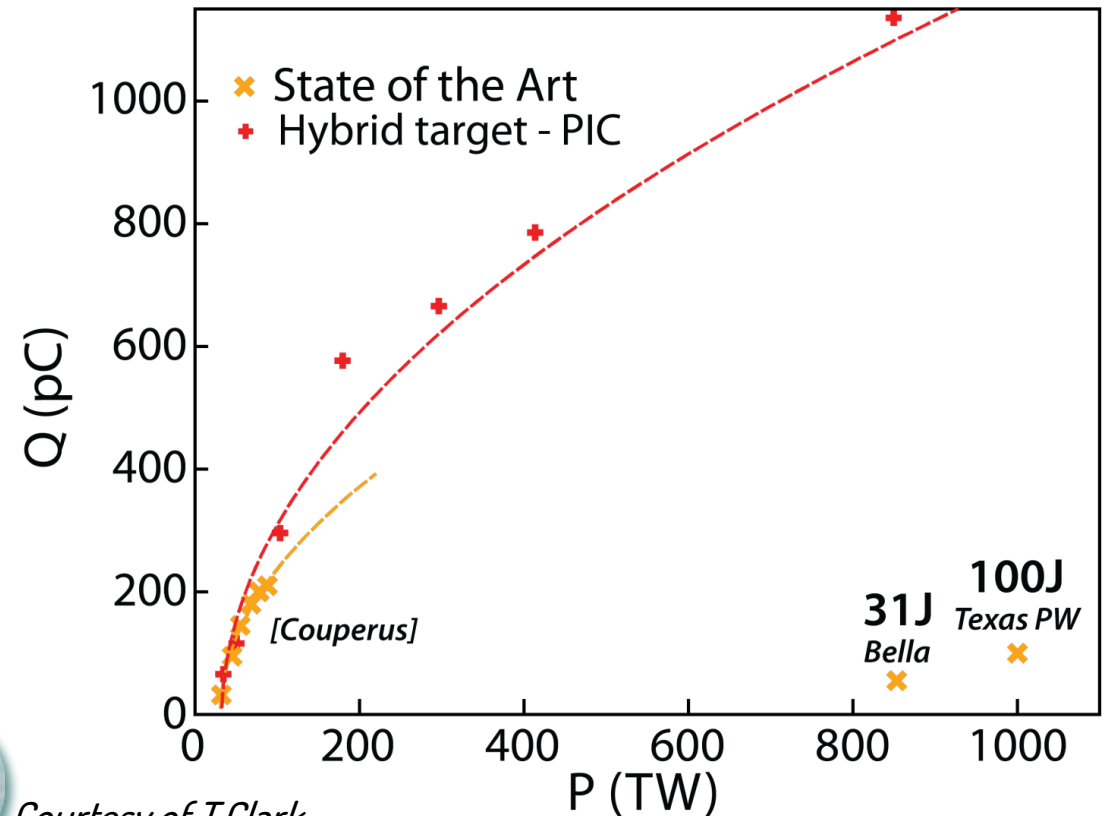
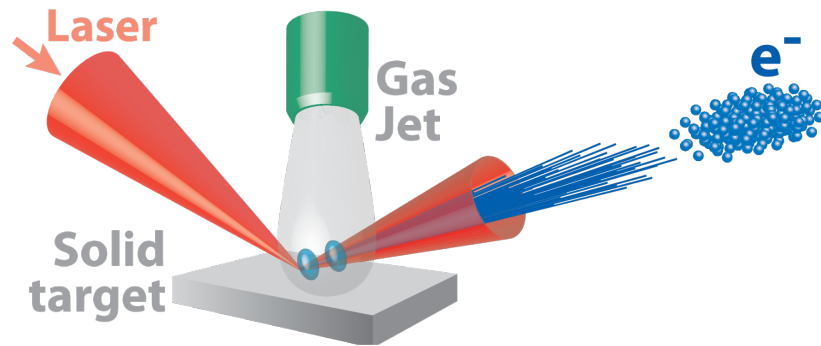


Production runs on
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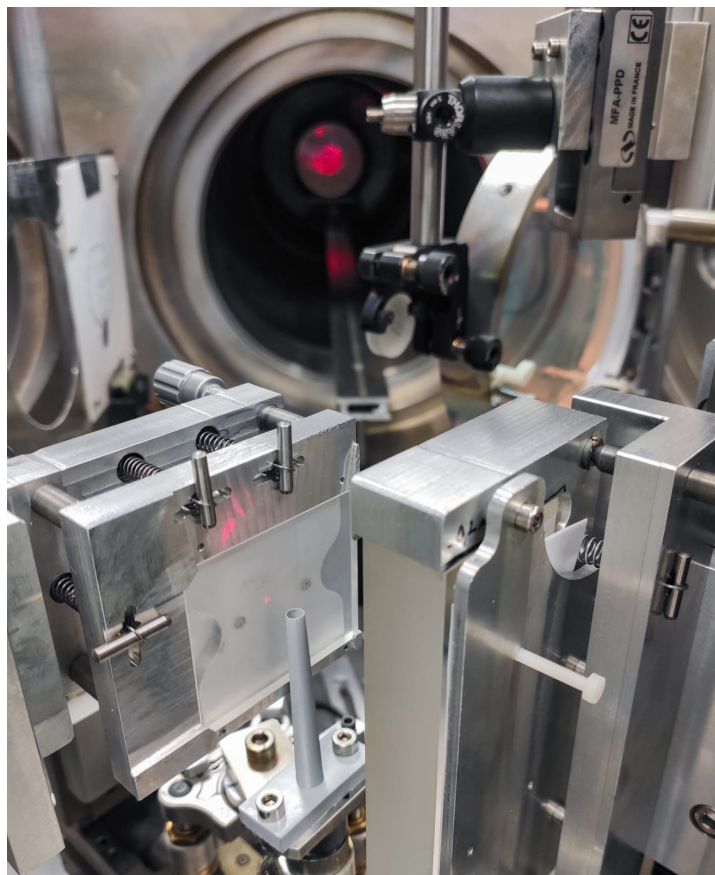
SC22 Gordon Bell prize in 2022!

2D PIC simulations suggest that the hybrid injector should allow for high accelerated charges also at high-energies



Courtesy of T.Clark

Exascale simulations informed the design of the experimental validation of our concept



A. Leblanc



T. Clark

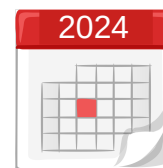
Three experimental campaigns
between 2022 and 2024



10 TW laser



40 TW laser

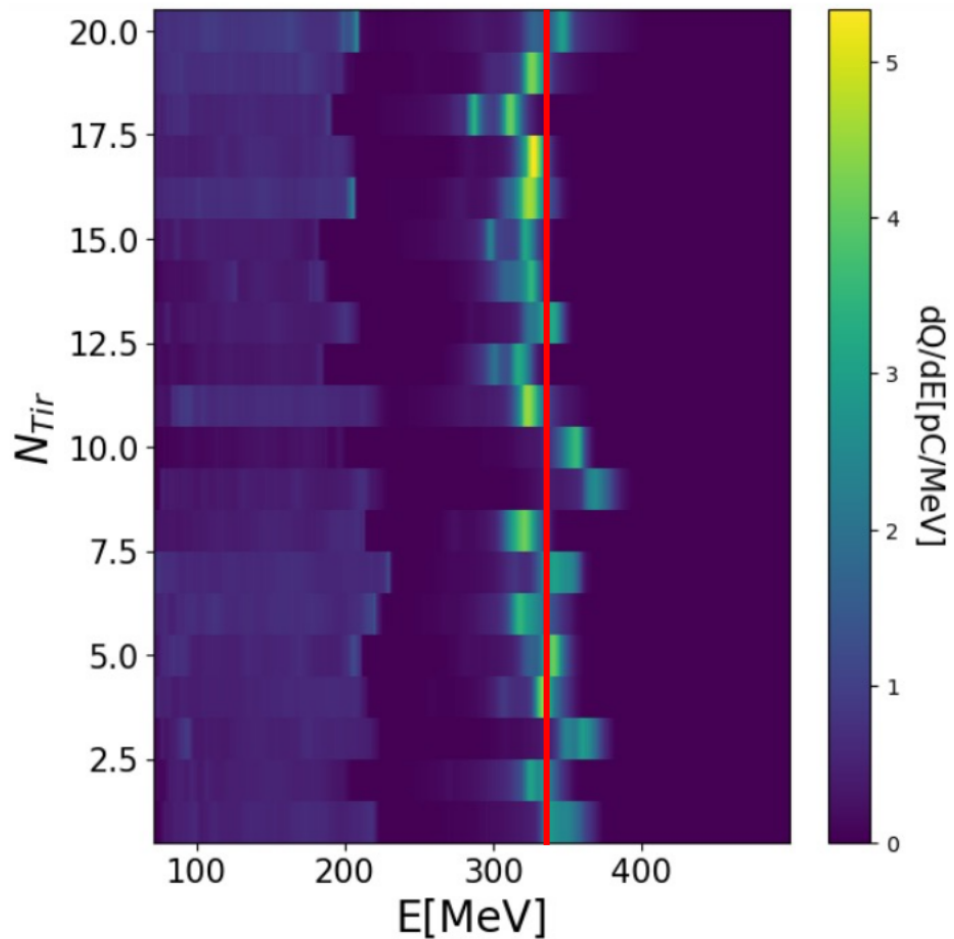


300 TW laser

In our experiments we observed
a very good shot-to-shot stability

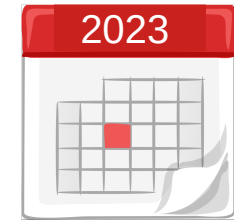


40 TW

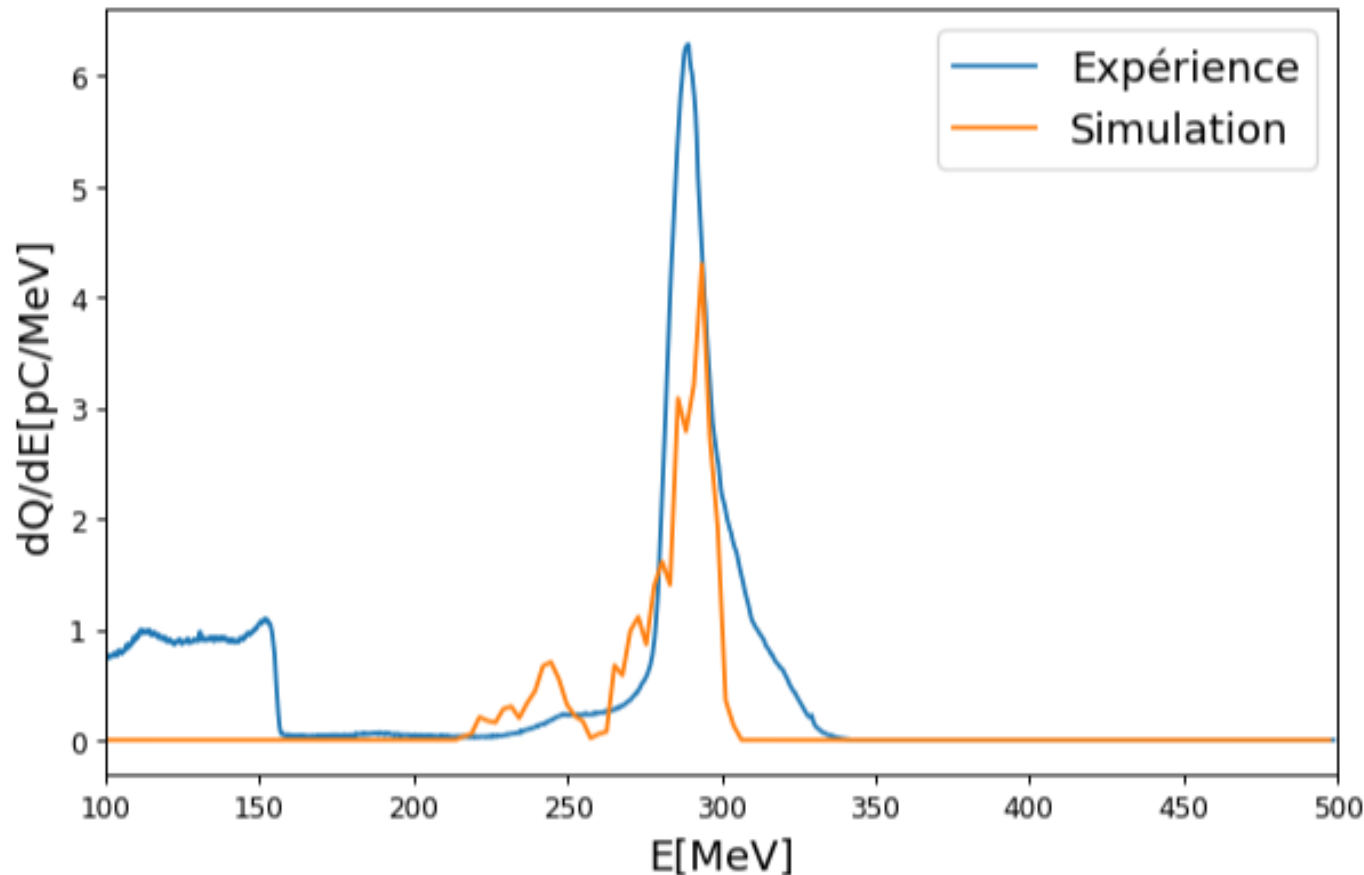


← Electron energy spectra for
20 consecutive shots

Experiments also show very good quality of the accelerated electrons (in agreement with PIC simulations)



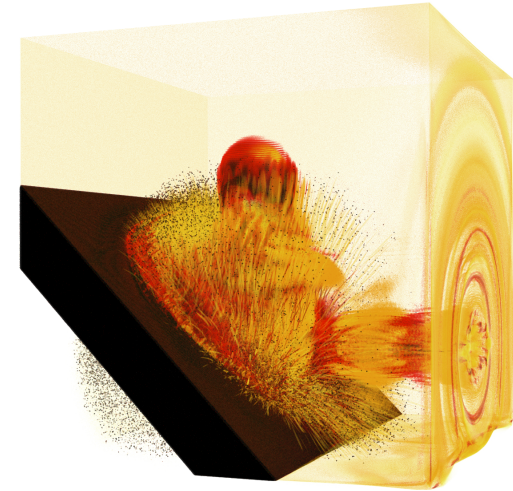
IoA
40 TW



Conclusions

The hybrid target injector is a promising concept to enable high-charge, high-quality LWFA sources like those envisaged for EUPRAXIA

We have validated this concept by means of large-scale PIC simulations and experimental campaigns in 2 facilities.



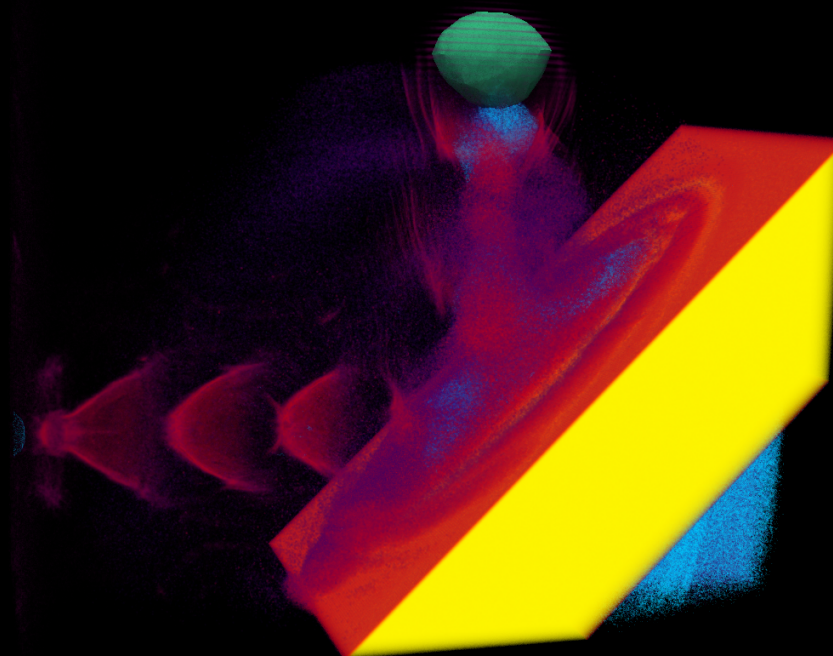
Perspectives

New campaigns foreseen by end-of 2024 / early 2025 at CEA (UHI100)

A paper is currently in preparation (submission expected by the end of 2024)

A new radiation module is being added to WarpX to study X-ray emission with the hybrid injector

A speedup of the simulation of the acceleration phase is envisaged via coupling with **LASY** and **HIPACE++**



Thanks for your attention!
Grazie per l'attenzione!

The End