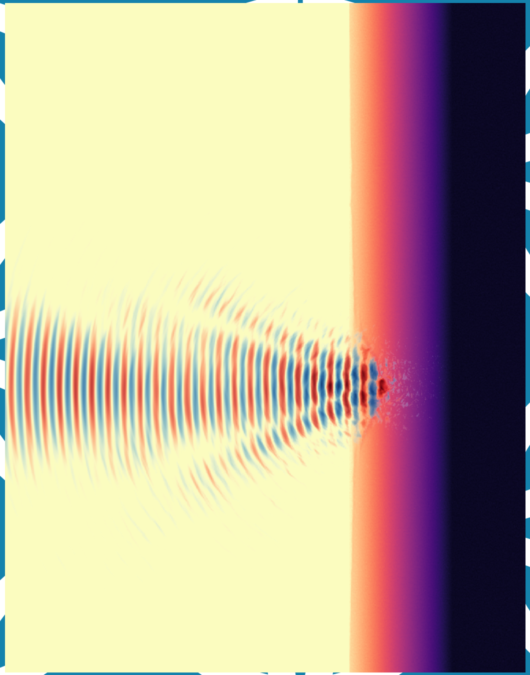
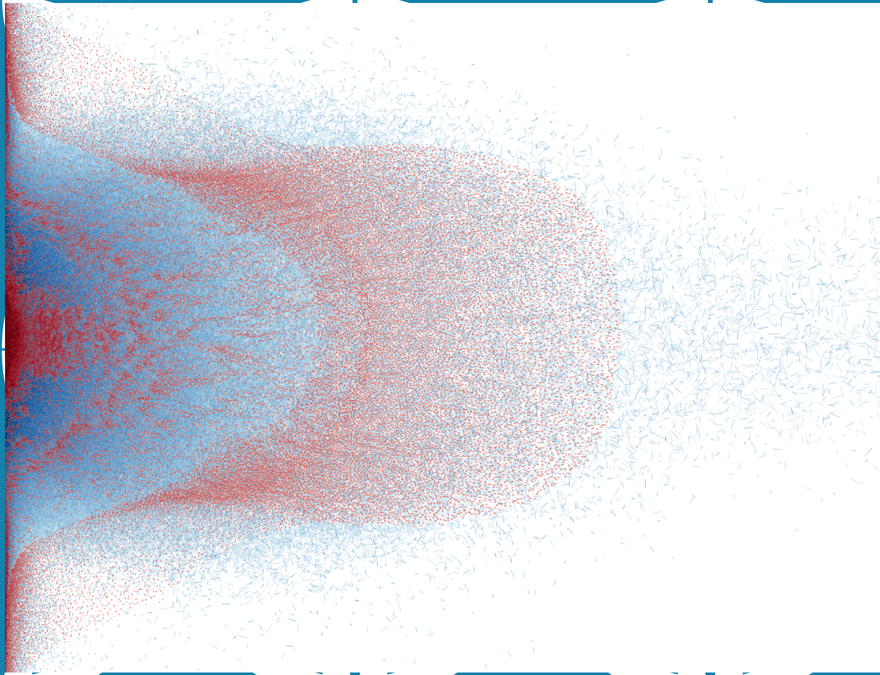
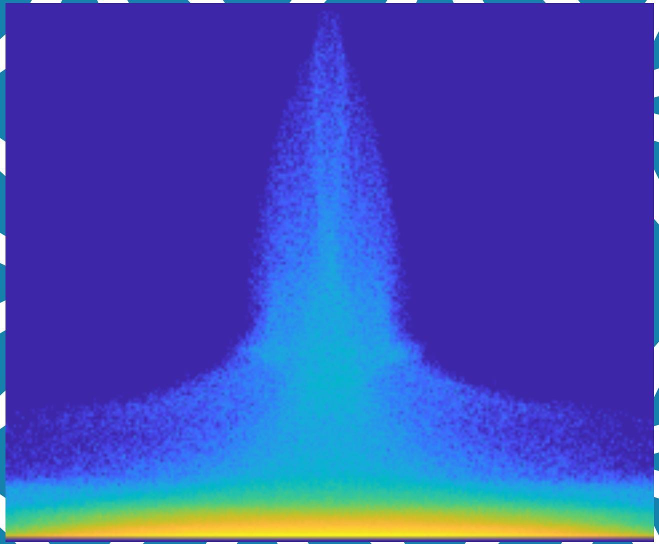


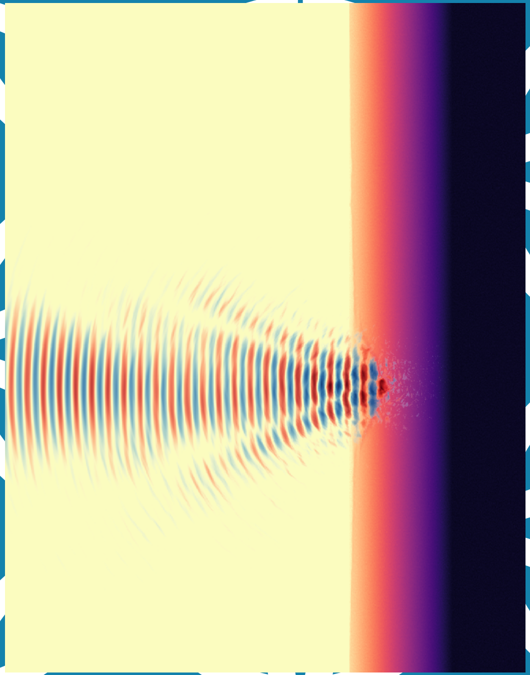


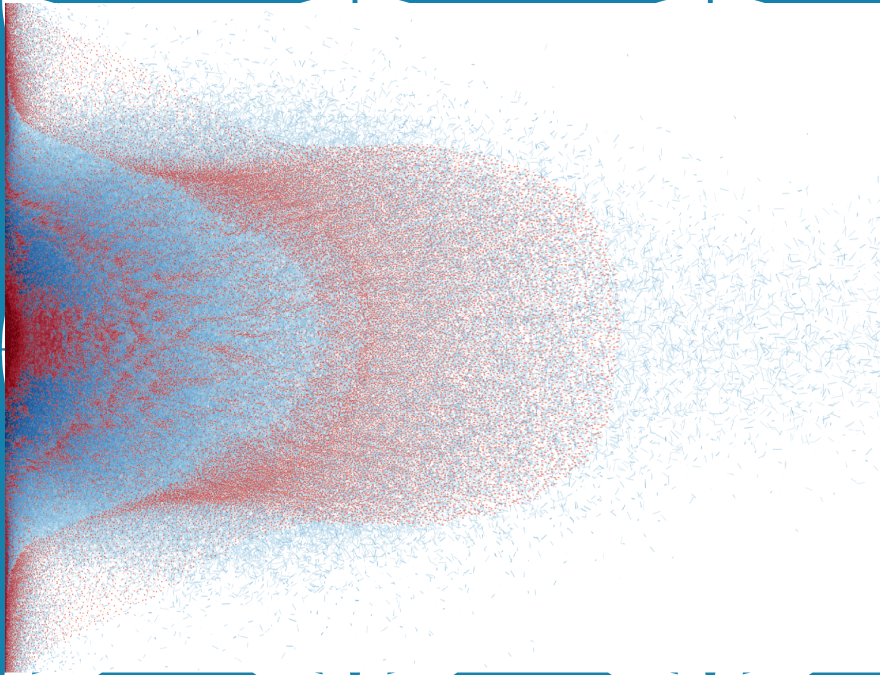


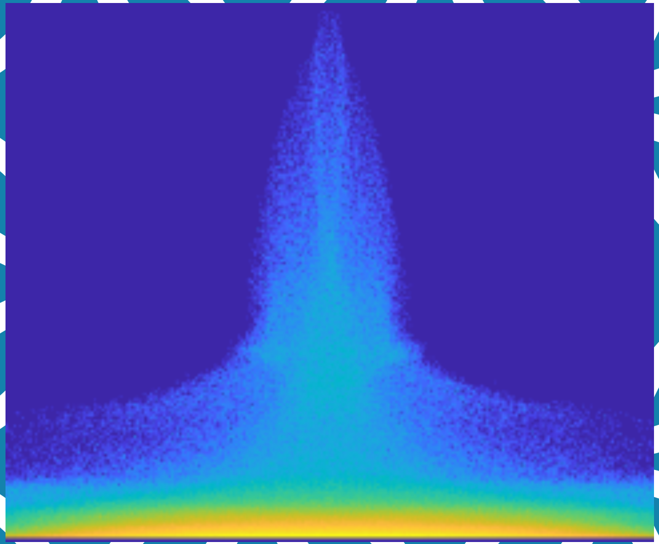
ION ACCELERATION BY RELATIVISTIC-INTENSITY LASERS WITH MAGNETIZED ELECTRON FOCUSING

Kathleen Weichman
and Alexey Arefiev
University of California San Diego

July 17, 2018







WHAT CAN A MAGNETIC FIELD DO FOR LASER-DRIVEN ION ACCELERATION?

Kathleen Weichman
and Alexey Arefiev
University of California San Diego
July 17, 2018

THANK YOU DOE CSGF!

Extra thanks to:

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Aric Hagberg

Gian Luca Delzanno

Alex Arefiev

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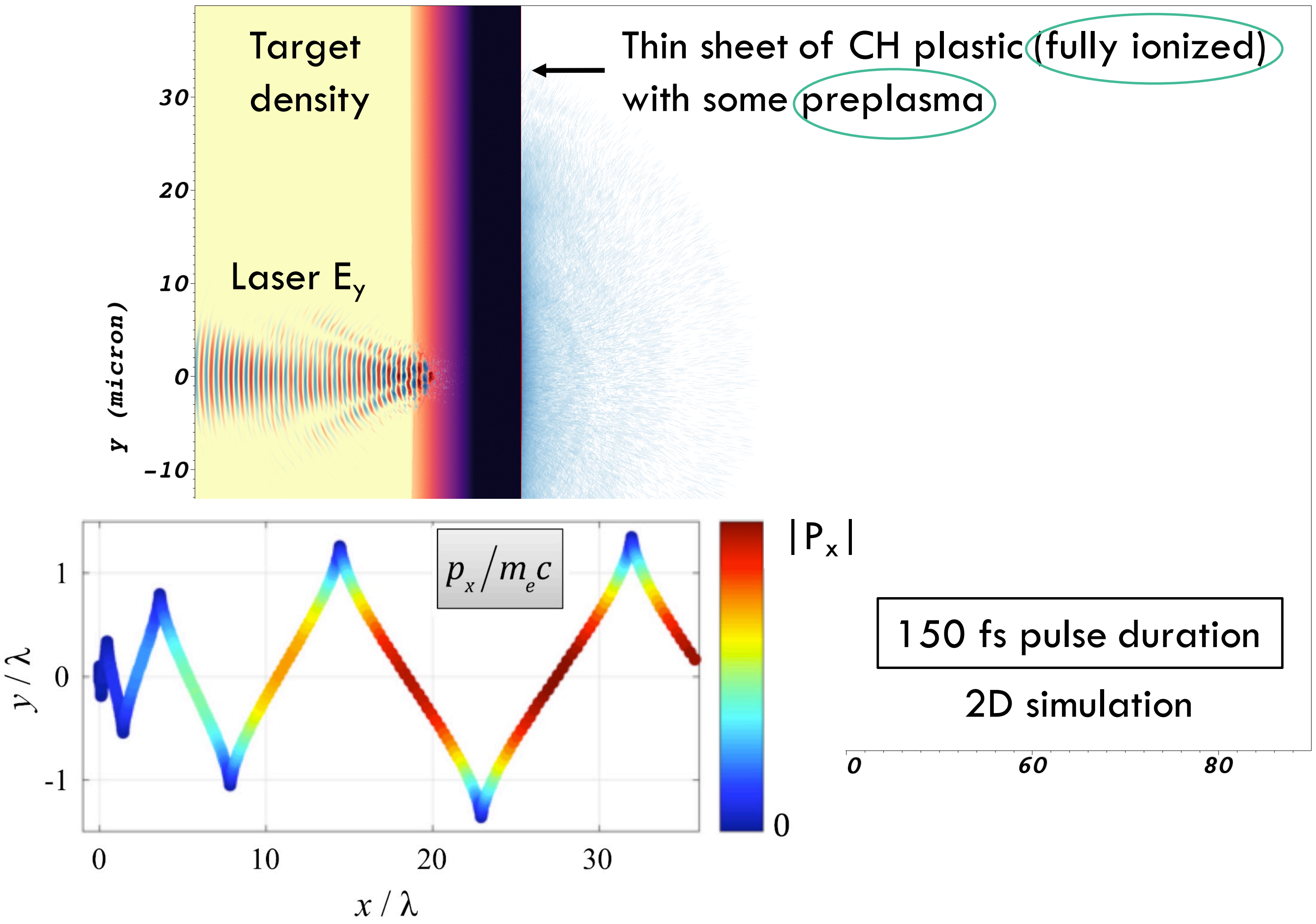
This work used HPC resources of the Texas Advanced Computing Center (TACC) at The University of Texas at Austin and the National Energy Research Scientific Computing Center (NERSC), a U.S. Department of Energy Office of Science User Facility operated under Contract No. DE-AC02-05CH11231.

WHAT IS LASER-DRIVEN ION ACCELERATION?

Step 1
Hit a thin solid target with a relativistically intense, short laser pulse

"Short" = 100 fs – 1 ps

Relativisitic intensity:
An electron starting at rest becomes relativistic within one laser cycle
→ allows p_x (forward momentum)



Arefiev *et al.*, Phys. Plasmas **23**, 056704 (2C

THIS DOES NOT END WELL FOR THE TARGET…

Expanding plasma mess

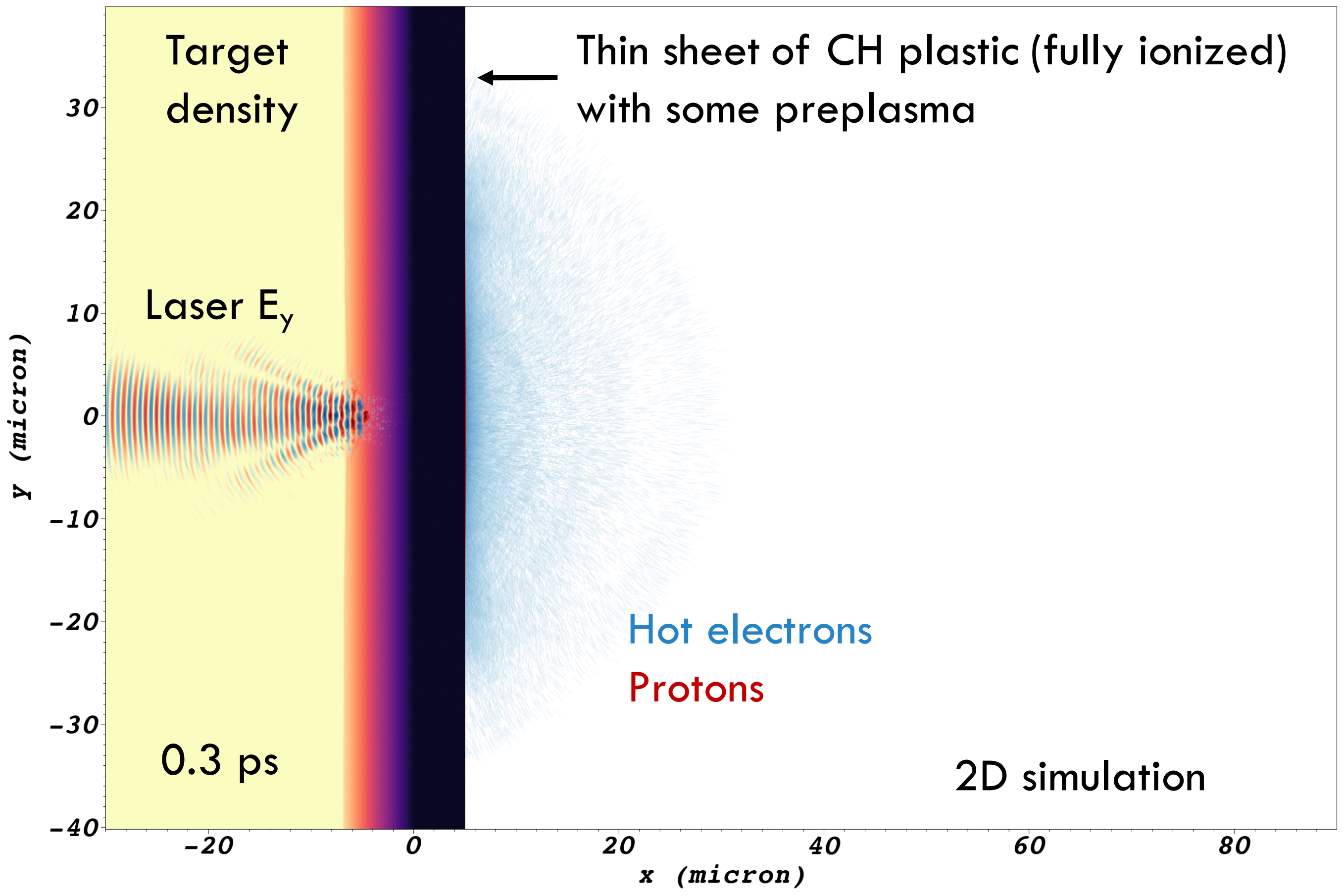
Lots of X-rays, too

Laser plasma physics: getting something done before (or while) your experiment blows up

ION ACCELERATION BY ELECTRON SHEATH

Step 2
Electrons are heated by the laser pulse

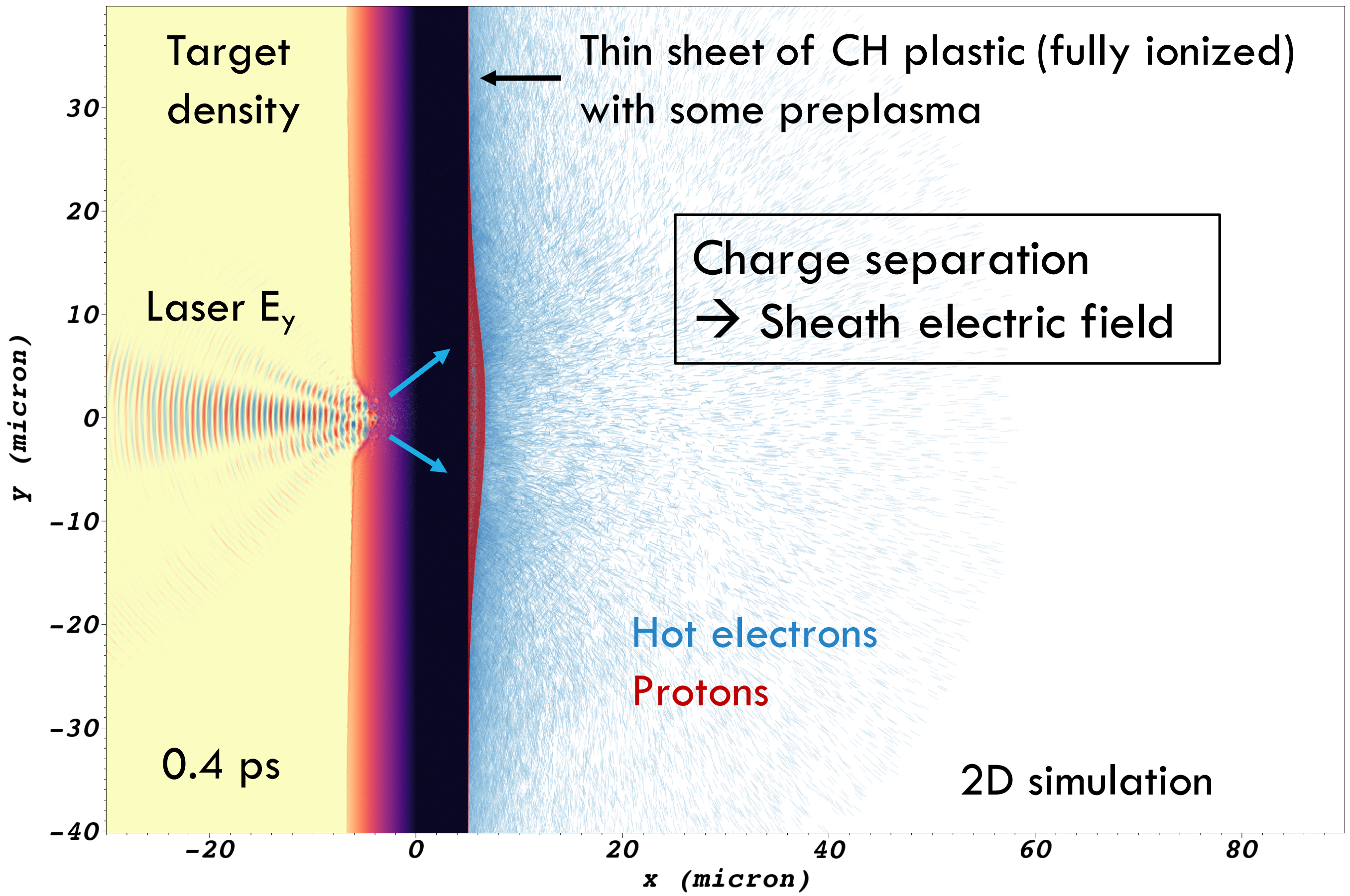
Relativistic intensity → electrons can have forward momentum



ION ACCELERATION BY ELECTRON SHEATH

Step 2
Electrons are heated by the laser pulse

Step 3
Hot electrons go through the target

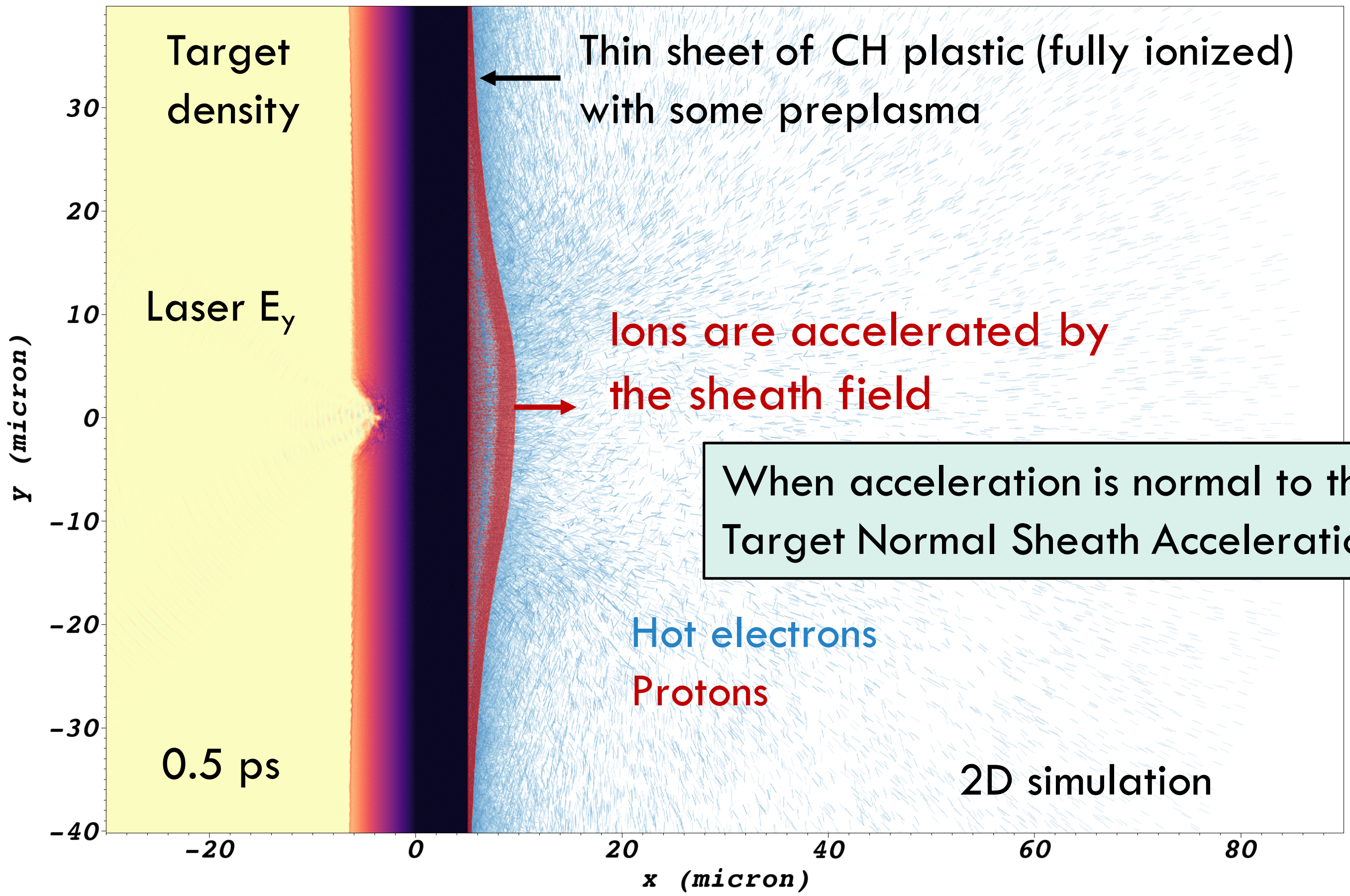


ION ACCELERATION BY ELECTRON SHEATH

Step 2
Electrons are heated by the laser pulse

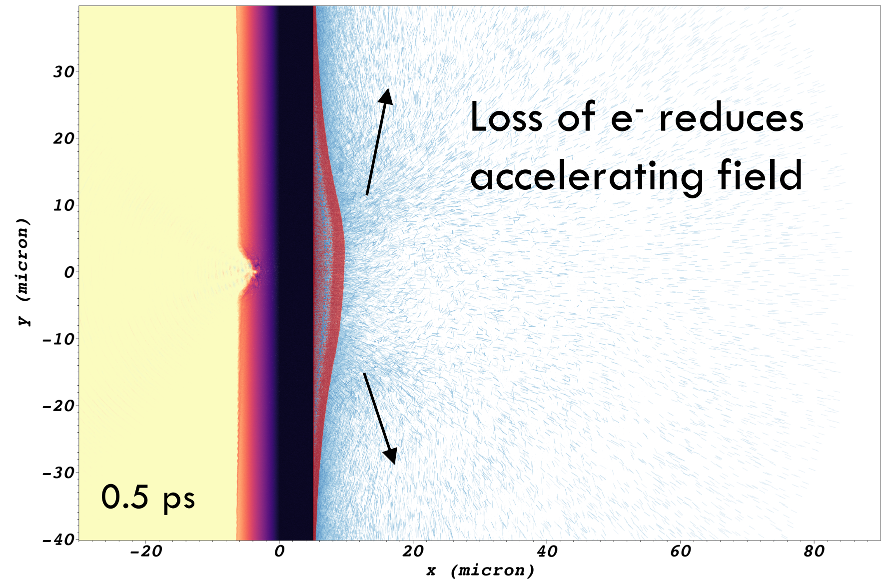
Step 3
Hot electrons go through the target

Step 4
Electrons pull ions out of the rear target surface

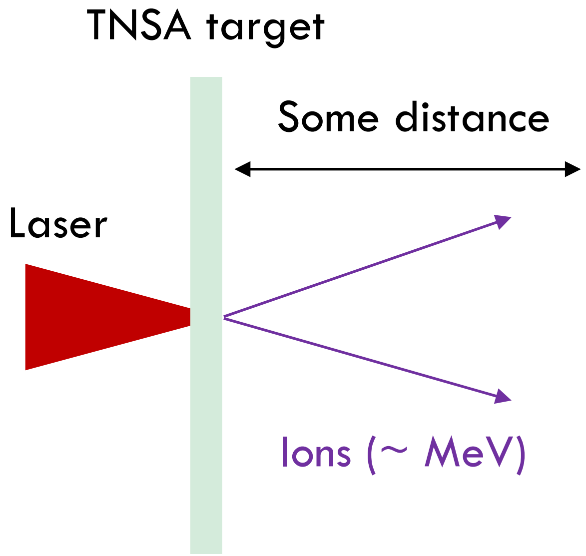


When acceleration is normal to the target: Target Normal Sheath Acceleration (TNSA)

HOT ELECTRONS SPREAD ALONG TARGET SURFACE



Are accelerated ions usable?



Experiments relying on accelerated ions (e.g. warm dense matter, fast ignition, proton radiography)

Reduced sheath field → lower ion energies

Electron spread → ion angular divergence

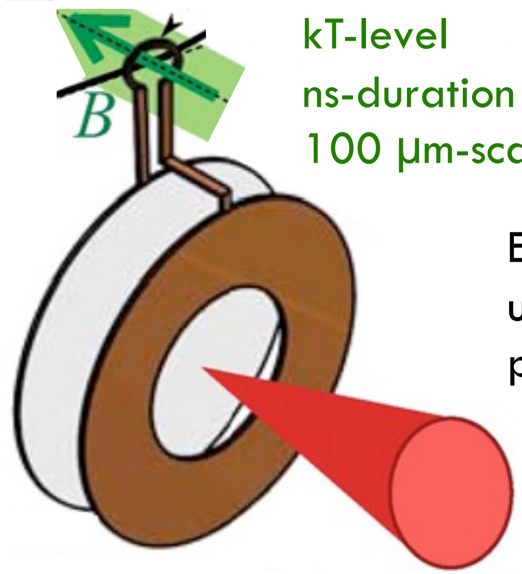
How to prevent electrons from spreading out?
Externally applied magnetic field

WHAT FIELDS ARE NEEDED TO AFFECT ELECTRON MOTION?

Hot electrons should undergo cyclotron motion within a few microns
→ Kilotesla static magnetic fields

Reference points
MRI ~ 1 T
Neutron star ~ 100 kT -10 MT
Laser magnetic field ~ 30 kT

Laser-driven capacitor coil target



kT-level
ns-duration
100 μm-scale

Essentially static and uniform for the purposes of this work

Santos et al. New J. Phys. 17, 083051 (2015)

This is a fundamentally new regime of laser-plasma physics

COMPUTATIONAL DETAILS

EPOCH: open-source particle-in-cell code

2D/3D simulations done at TACC

3D simulation parameters:

Up to 80 um x 10 um x 10 um with 30 cells/um

~10 particles/cell (10^9 numerical particles)

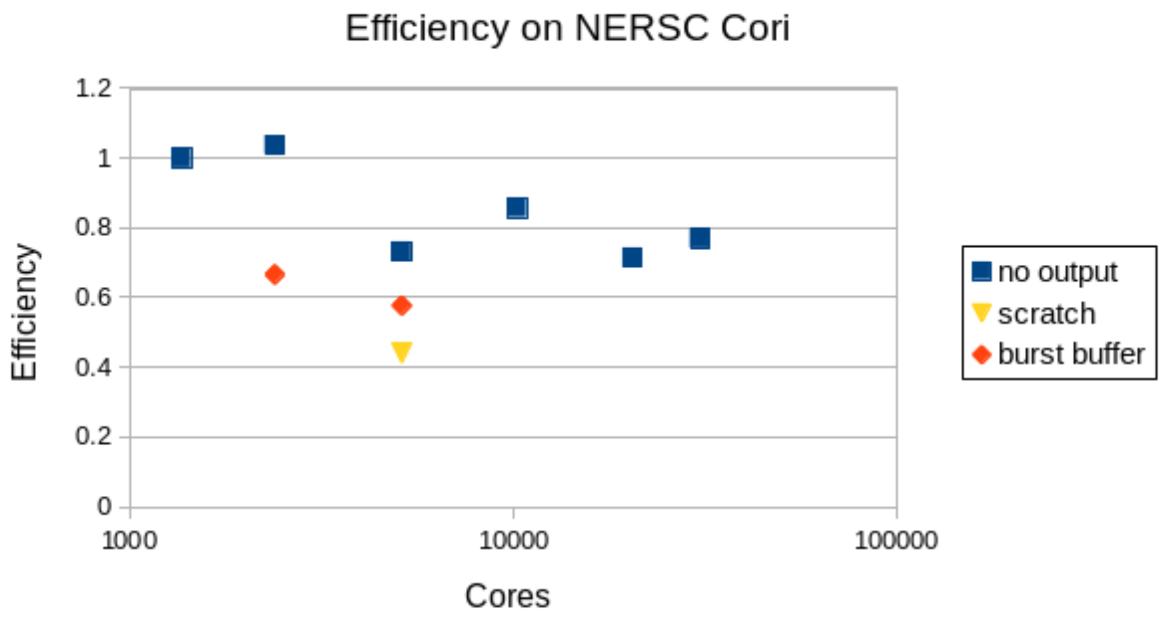
50k to 500k CPU hours (5k to 50k CPU)

File sizes up to 30 GB

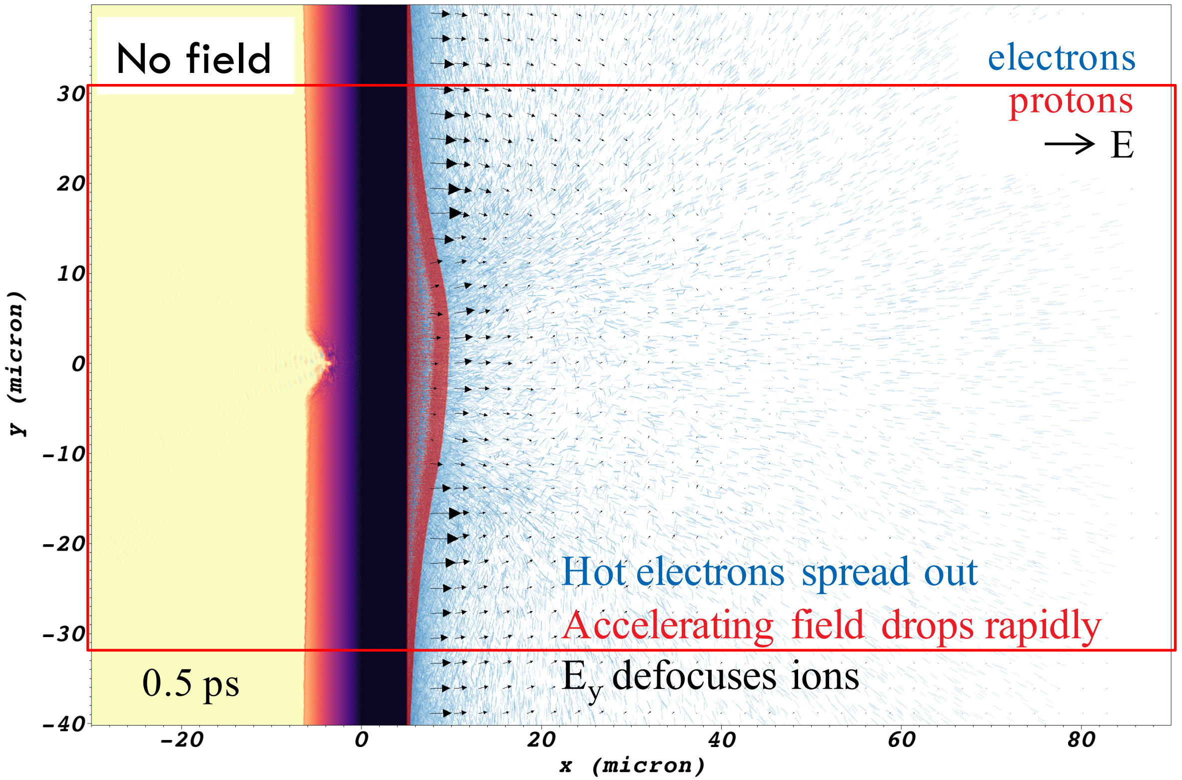
3D simulation results are preliminary

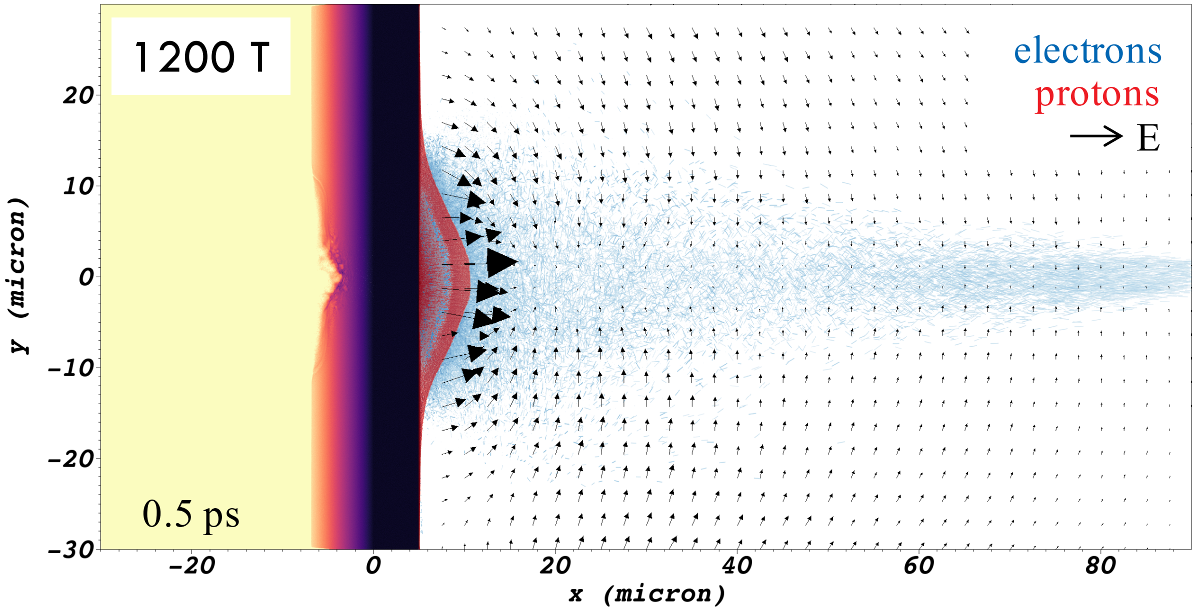
Future work will be done at NERSC, to allow increased problem size

Scaling for representative 3D laser-plasma problem



THE PROMISE OF ADDING A MAGNETIC FIELD





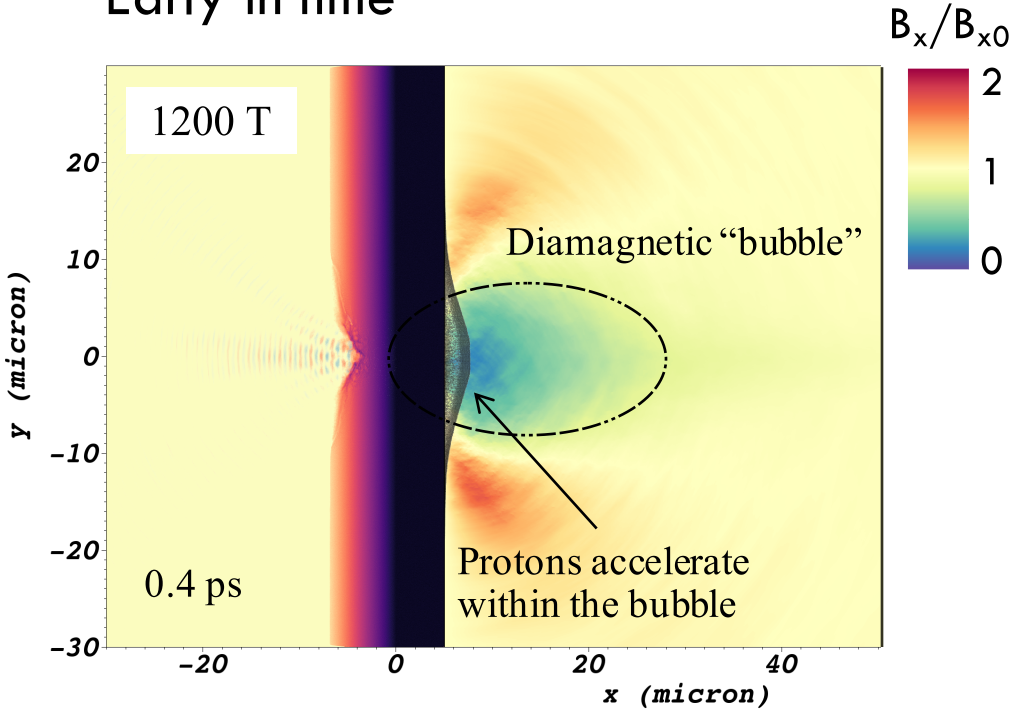
Hot electron expansion is reduced

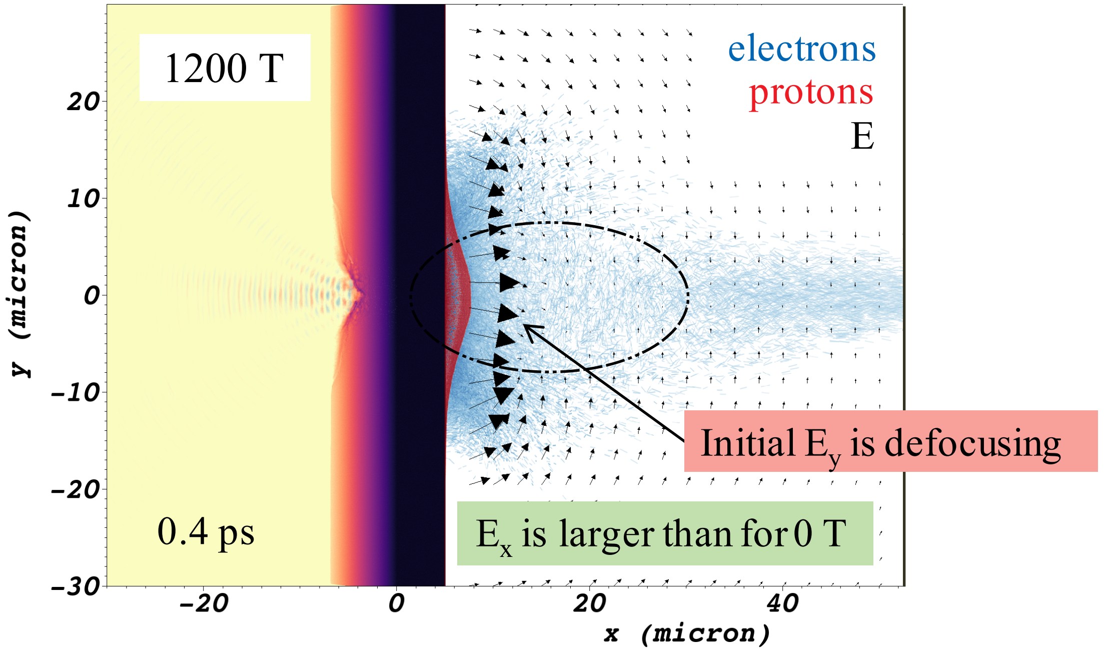
Accelerating field is better maintained

Potentially focusing E_y structure

DOES MAGNETIZED ELECTRON SHEATH ACCELERATION PRODUCE USABLE IONS?

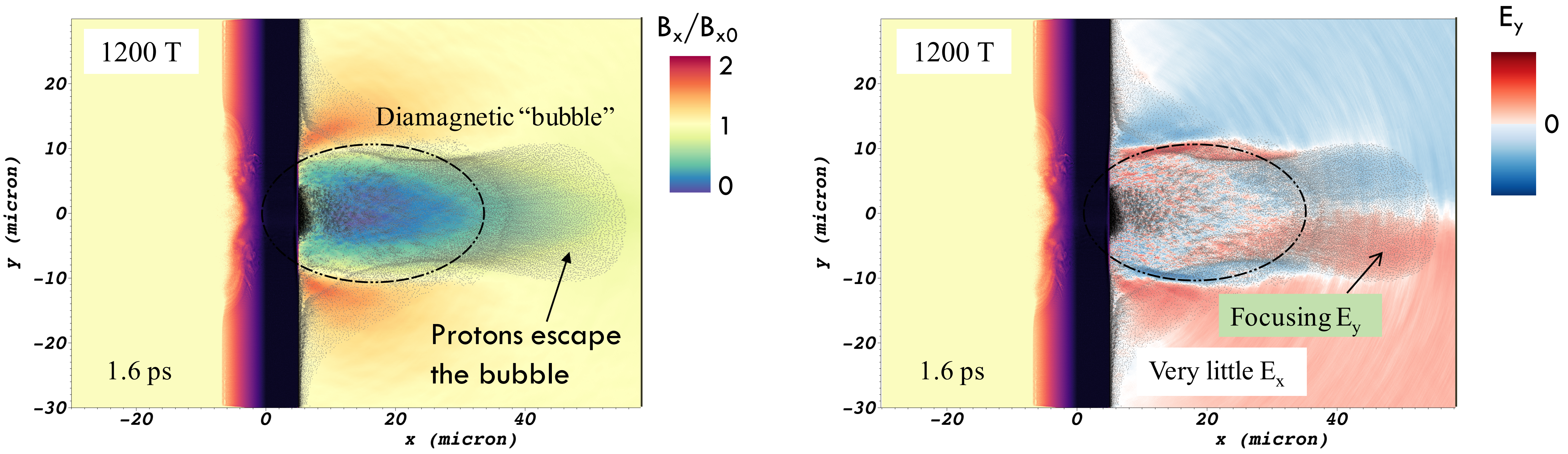
Early in time





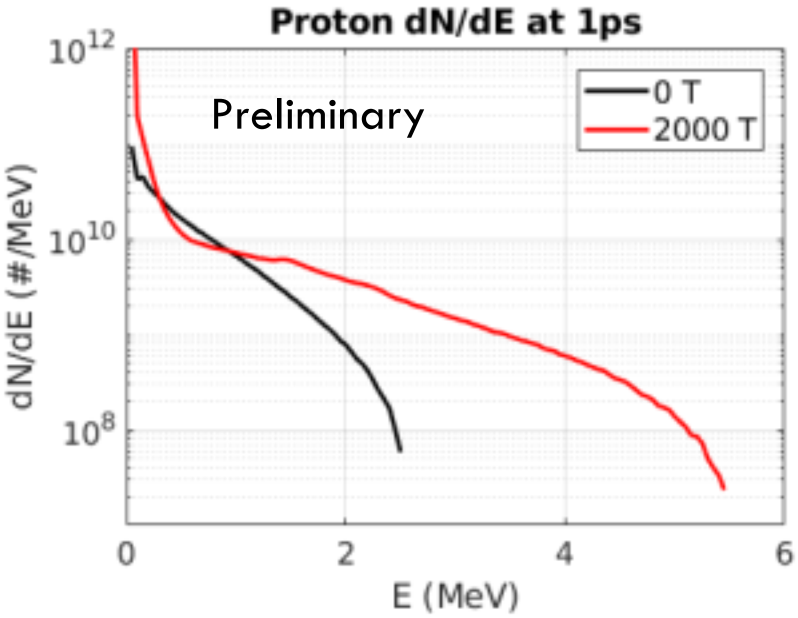
After the initial acceleration, ions have a large (~5°) angular divergence!

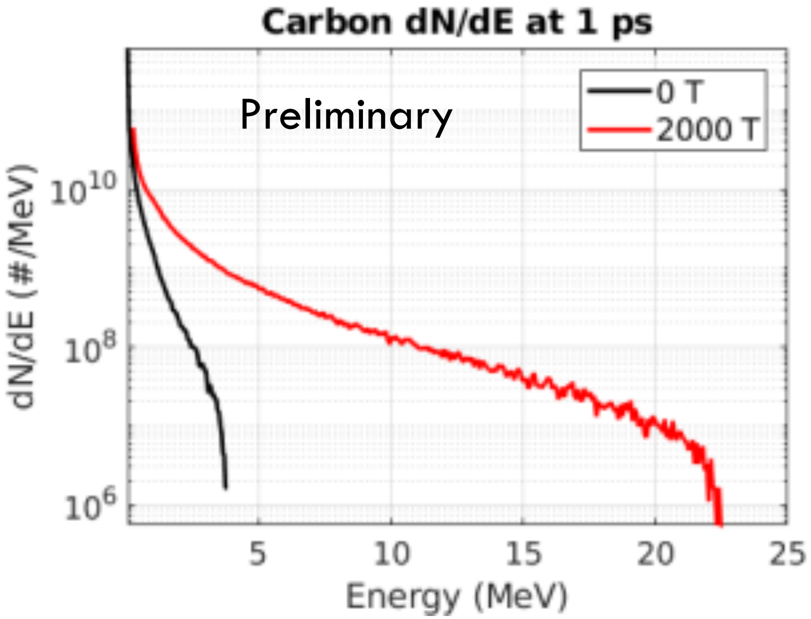
LATER, IONS SEE A FOCUSING FIELD — GOOD FOR TRANSPORT



Ions are pulled back towards the axis, eventually forming an ion beam

PRELIMINARY 3D RESULT: INCREASED ION ENERGY





Are these ions usable?

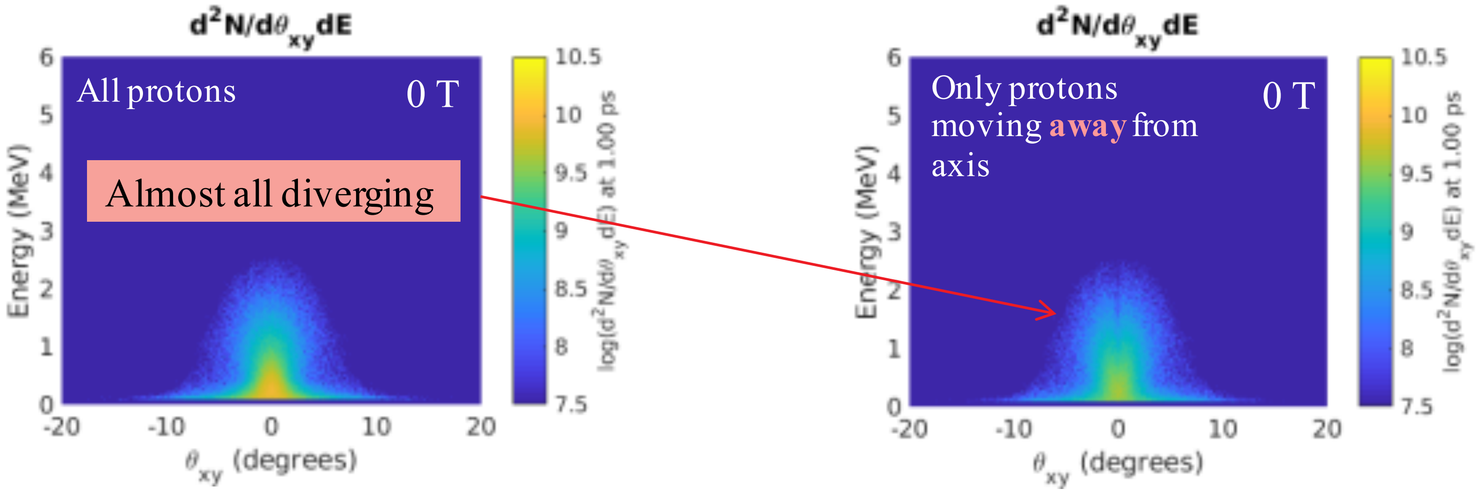
ARE HIGH ENERGY IONS DIVERGING FROM THE AXIS?

Spectra of energy and momentum angle with x-axis

No field:

Peak proton energy ~ 2.5 MeV

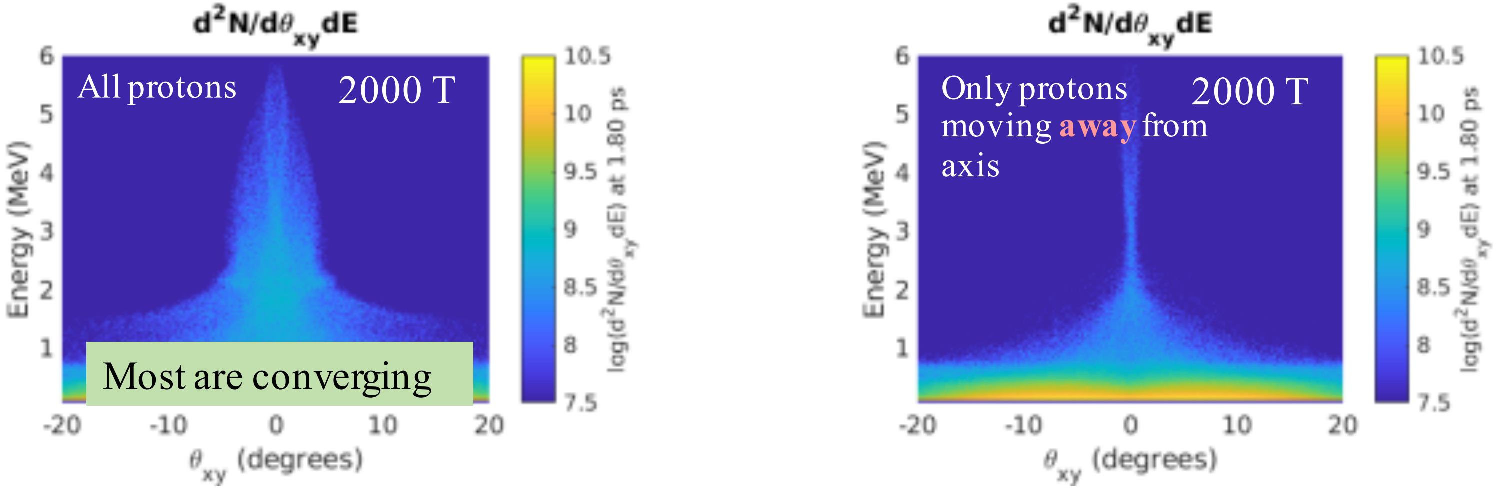
Protons have momentum away from the axis



2000 T:

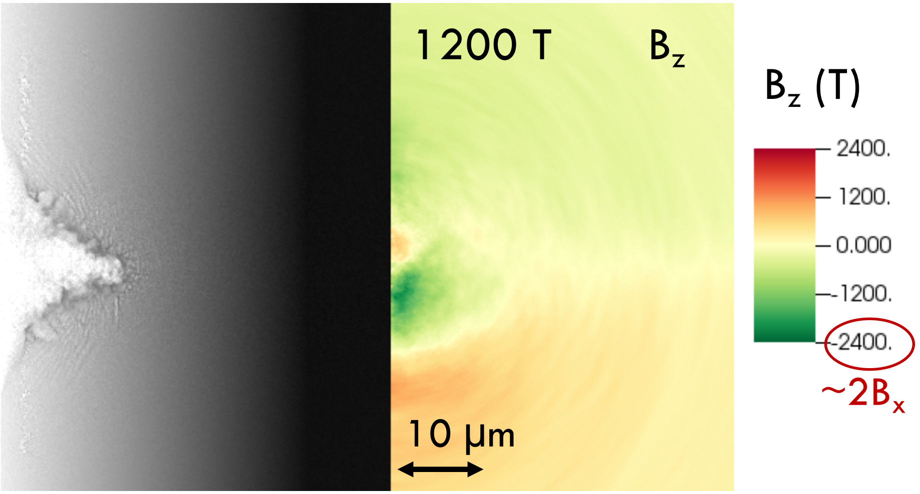
Peak proton energy ~ 5.5 MeV

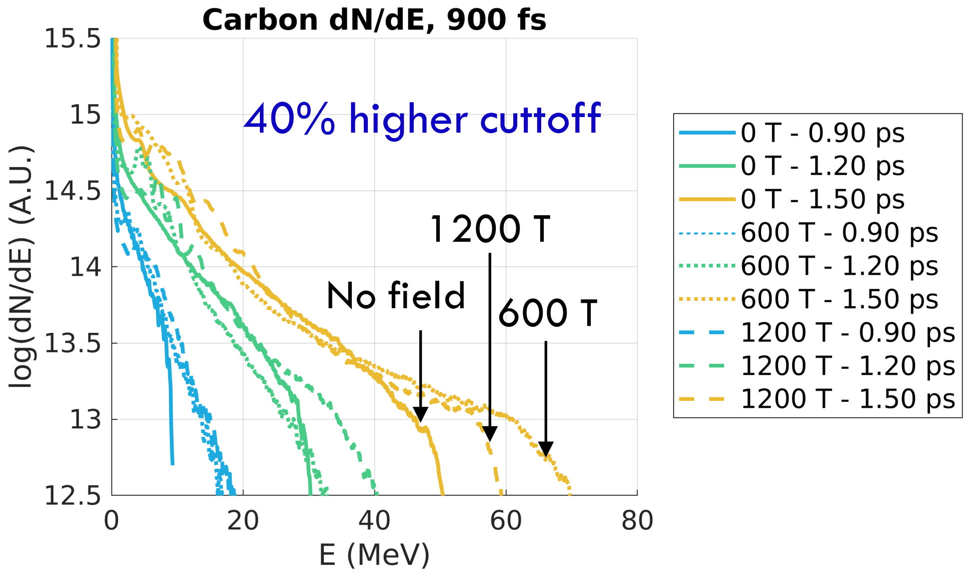
Protons have momentum towards the axis



APPLICATION TO 900 FS PULSE DURATION – "OPTIMUM" FIELD EXISTS

B_x	Energy in > 5 MeV protons (A.U.)
No field	1
600 T	1.3
1200 T	0.6





Is the self-generated azimuthal field a problem?

* 2D simulation, different plasma conditions than previous work

MAGNETIZED ELECTRON SHEATH ACCELERATION

Hot electron spread successfully limited

Two-stage process:

1) acceleration within bubble

2) focusing and beam formation following escape from bubble

Possible results: higher ion energies; lower divergence; formation of true ion beams of multiple species

Work is ongoing to understand the source of the performance optimum for longer pulse duration