Electron Trapping in Positron Driven Wakefields

FACET-II
Facility for Advanced Accelerator Experimental Tests

2023 FACET II User Meeting

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SLAC NATIONAL ACCELERATOR LABORATORY

Stanford University | U.S. DEPARTMENT OF ENERGY

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  - Confirmation of the Signal as Electrons
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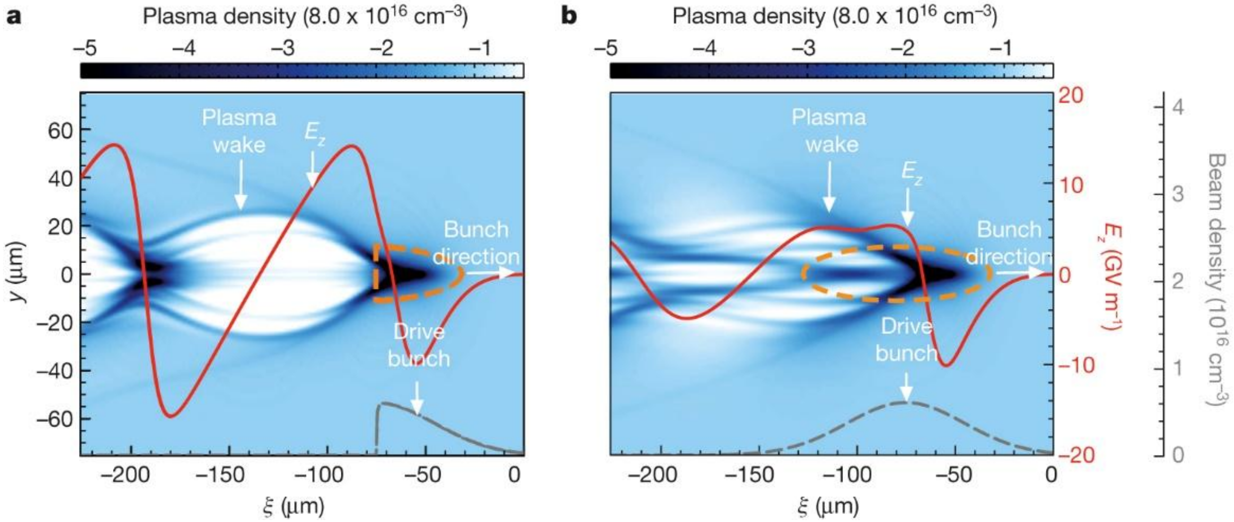
  - Comparison to Experimental Results

Context and Motivation



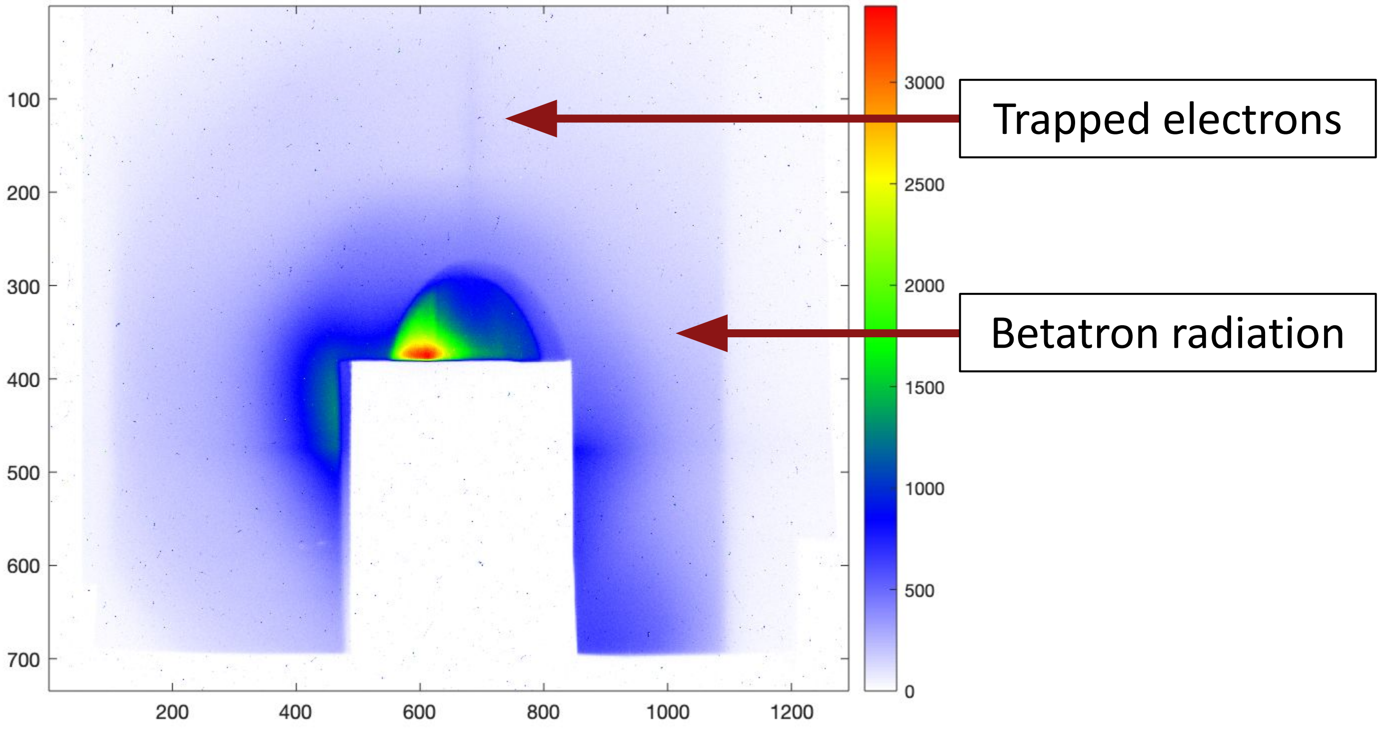
Simulated plasma wakes driven by short and intense positron bunches.[1]

- Plasma wakefield accelerators (PWFA) in high energy physics applications need both electrons and positrons.
- Studying properties of high-gradient wakes driven by positrons can further our understanding and may bring about new possibilities.
- At FACET, we observed acceleration of positrons in a single-bunch positron driven wake.[1]
- During this experiment, we also observed captured and accelerated electrons. It can be useful to understand the conditions where this occurs to control whether it happens in future positron PWFA experiments at FACET II and beyond.

1. S Corde et al. Nature 524, 442-445 (2015) doi:10.1038/nature14890

Unexpected Electron Acceleration

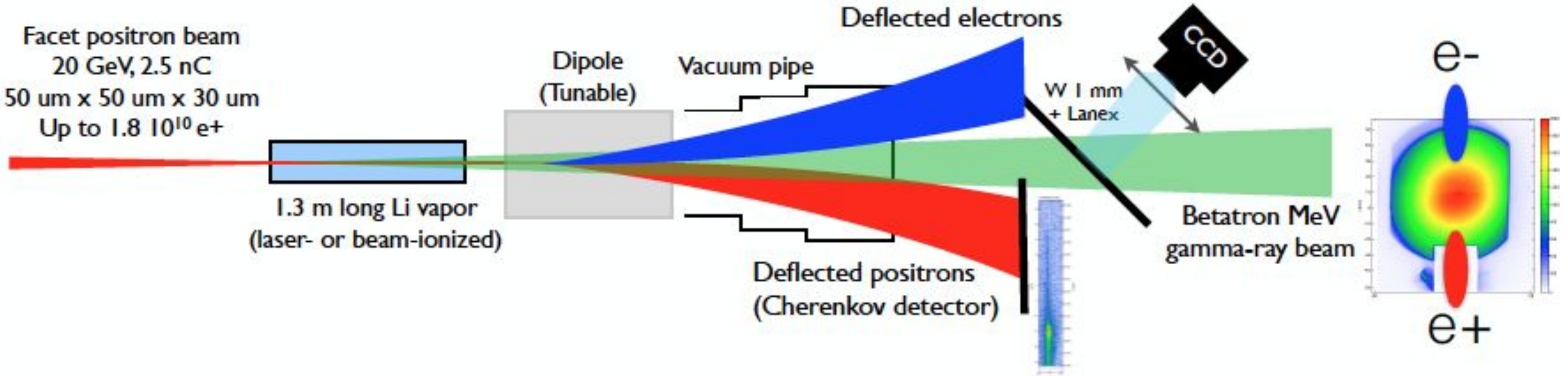
Betatron Radiation Diagnostic Screen



- It was not our intention to capture and accelerate electrons when sending the FACET positron beam into Lithium plasma, but it happened!
- There was no dedicated spectrometer to measure these electrons.
- The electrons appeared on the betatron radiation diagnostic screen downstream of the Cherenkov spectrometer.

Now we will try to understand it.

Experimental Setup



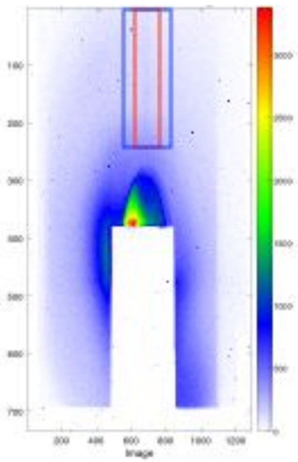
- 1.3 meter-long lithium plasma
- Single bunch positron beam driver
  - positron tail gained energy
  - positron head lost energy
  - plasma electrons captured and gained energy
- The electrons were deflected above the Cherenkov spectrometer, but appeared at the top of the betatron radiation screen. This allows for some makeshift spectrum analysis.

A faint electron signal was visible at the top of the betatron radiation diagnostic.

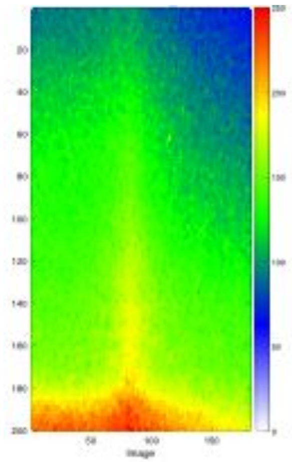
Image: S. Corde, High-gradient Positron-driven Plasma Wakes; AAC 2014

Extracting the Electron Signal

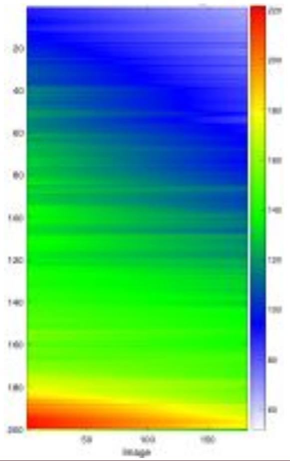
(1)



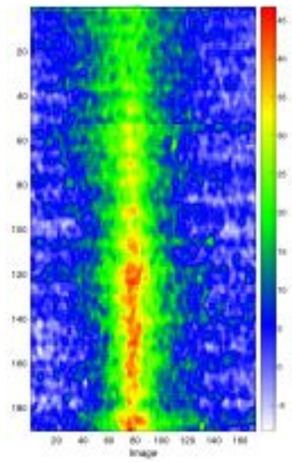
(2)



(3)



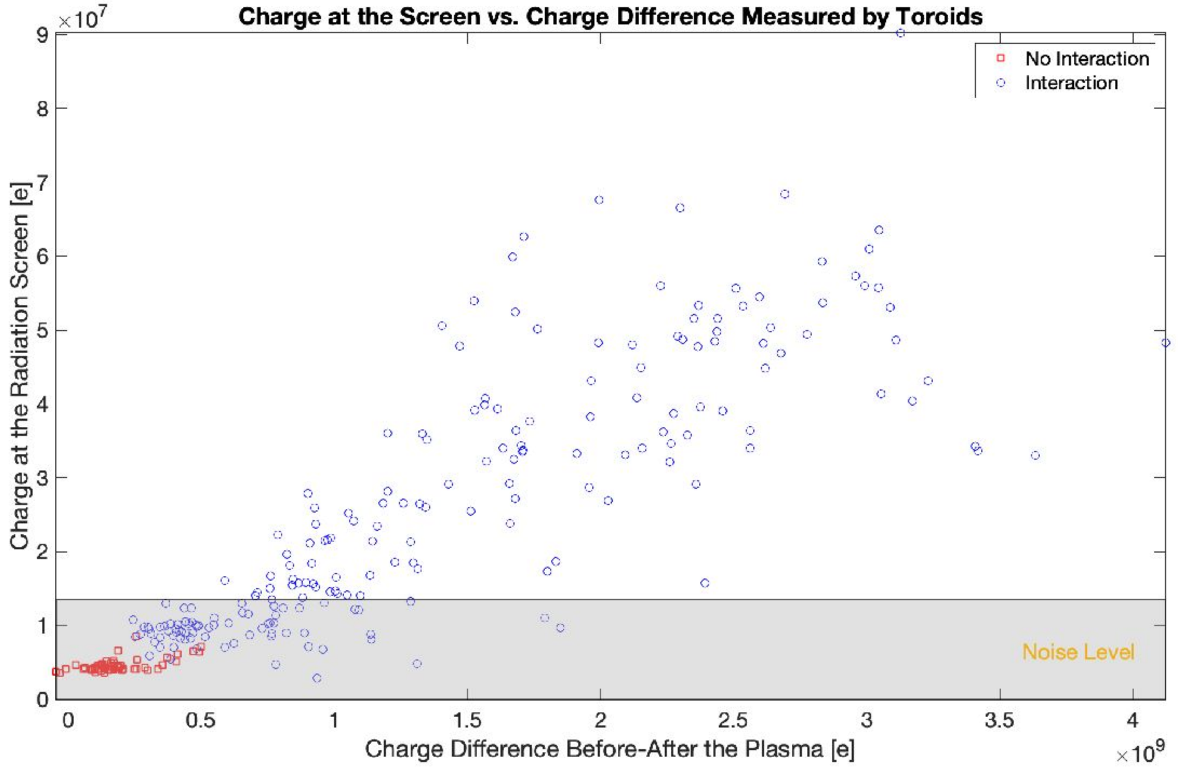
(4)



1) Raw image of the screen with the region of interest (ROI) highlighted in the red rectangle. The blue box shows the border used to create the background.
2) Zoomed in image of the ROI.
3) The variation in the background is assumed to be linear in the horizontal direction. With this assumption, we can create a background image using the blue border in (1).
4) Resulting image when (3) is subtracted from (2).
5) Not pictured—further processing can be done, such as a gaussian blur filter to smooth out the signal.

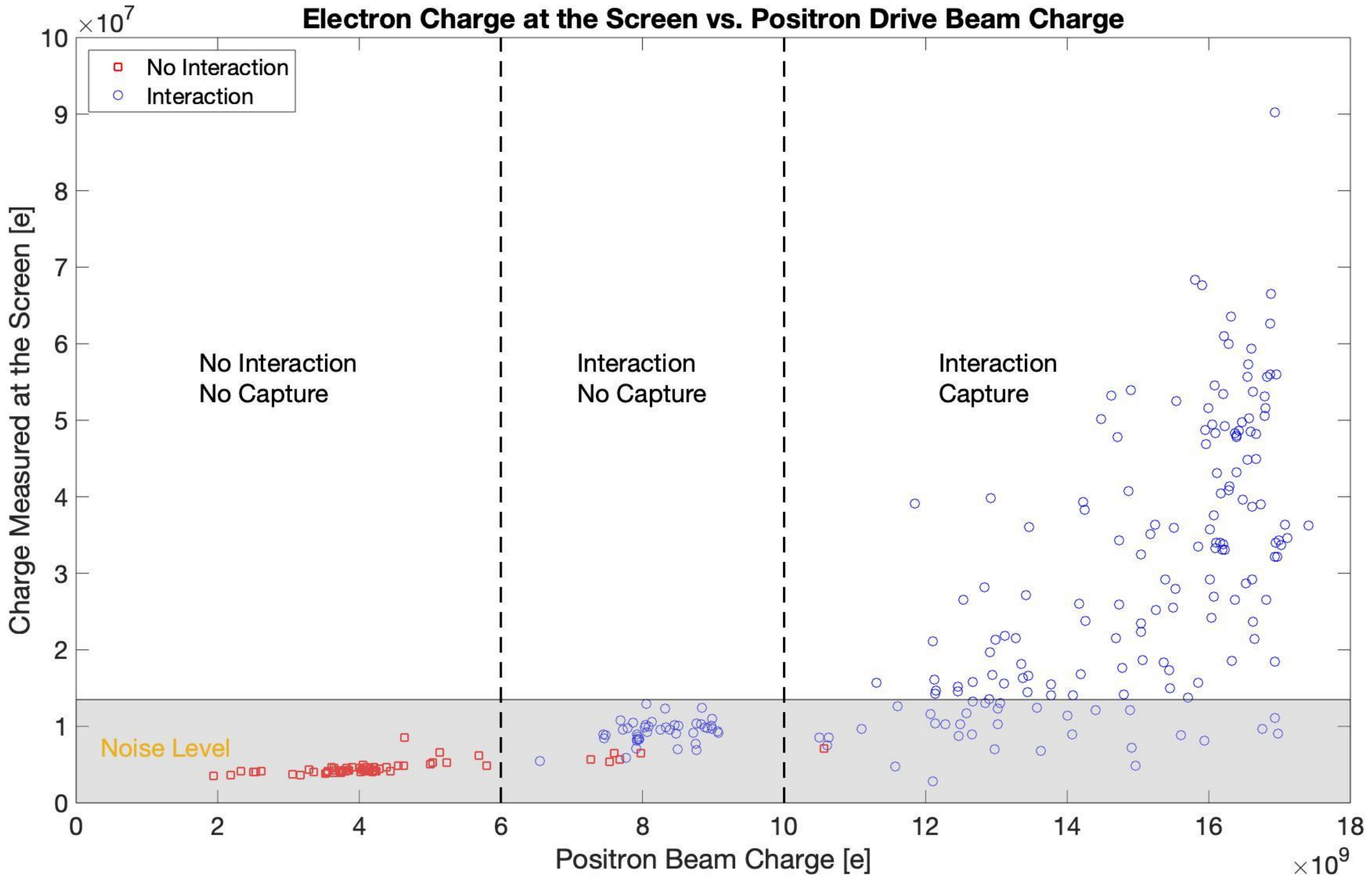
Extracting the electron signal requires creating a makeshift background image.

Confirmation of the Signal as Electrons



- We compare the charge difference before – after the plasma to the signal at the radiation screen to confirm that they are electrons.
- The charge at the screen is lower than the charge difference because not all electrons are captured by the screen. Additionally, there is a loss of positron charge.

Charge scan for the positron drive beam



- Plasma interaction is determined by the presence of betatron radiation
- By scanning the positron beam charge we could isolate three different scenarios:
  - No interaction/no capture
  - Interaction/no capture
  - Interaction/capture

The threshold for electron capture was ~1E10 positrons.

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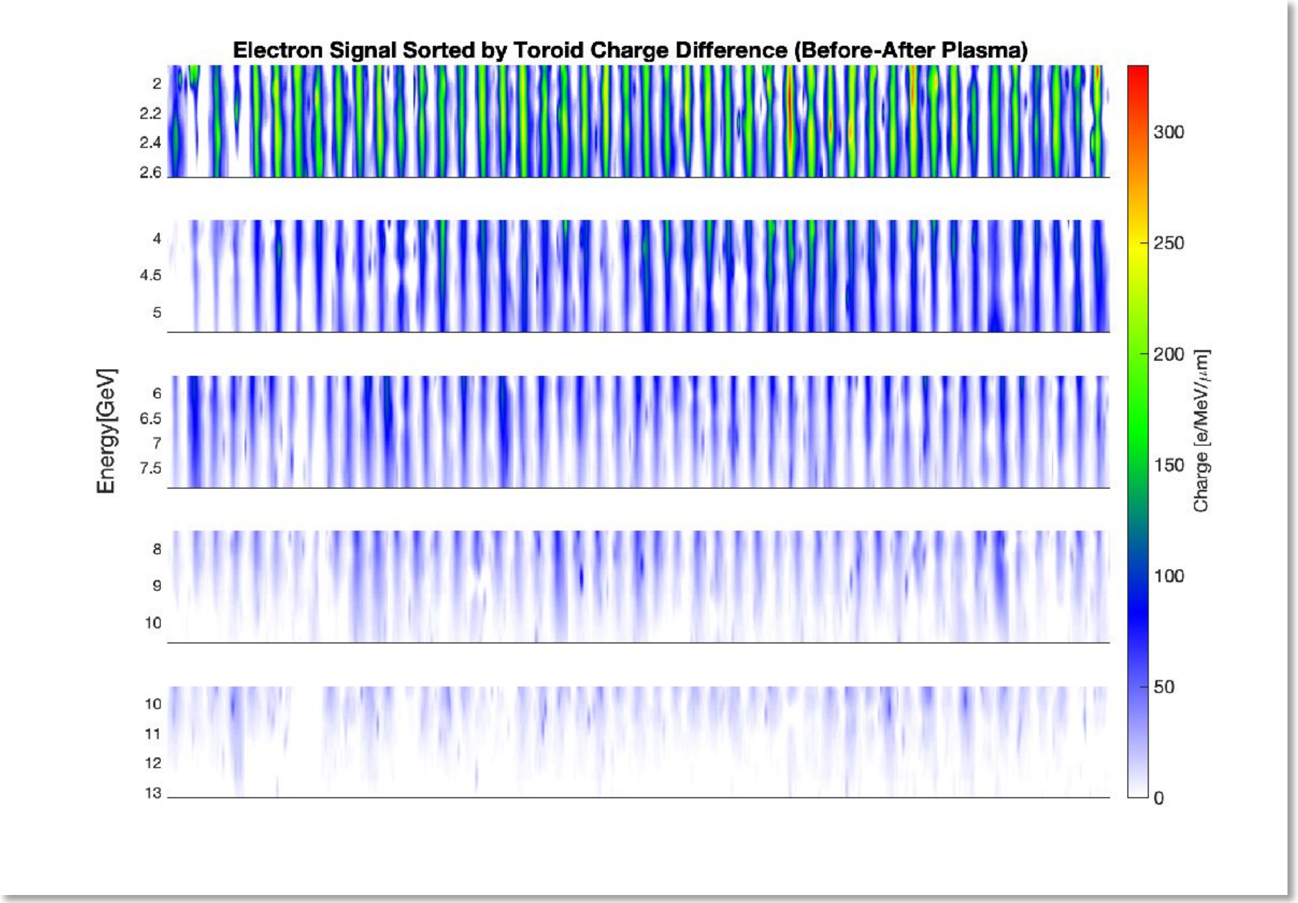
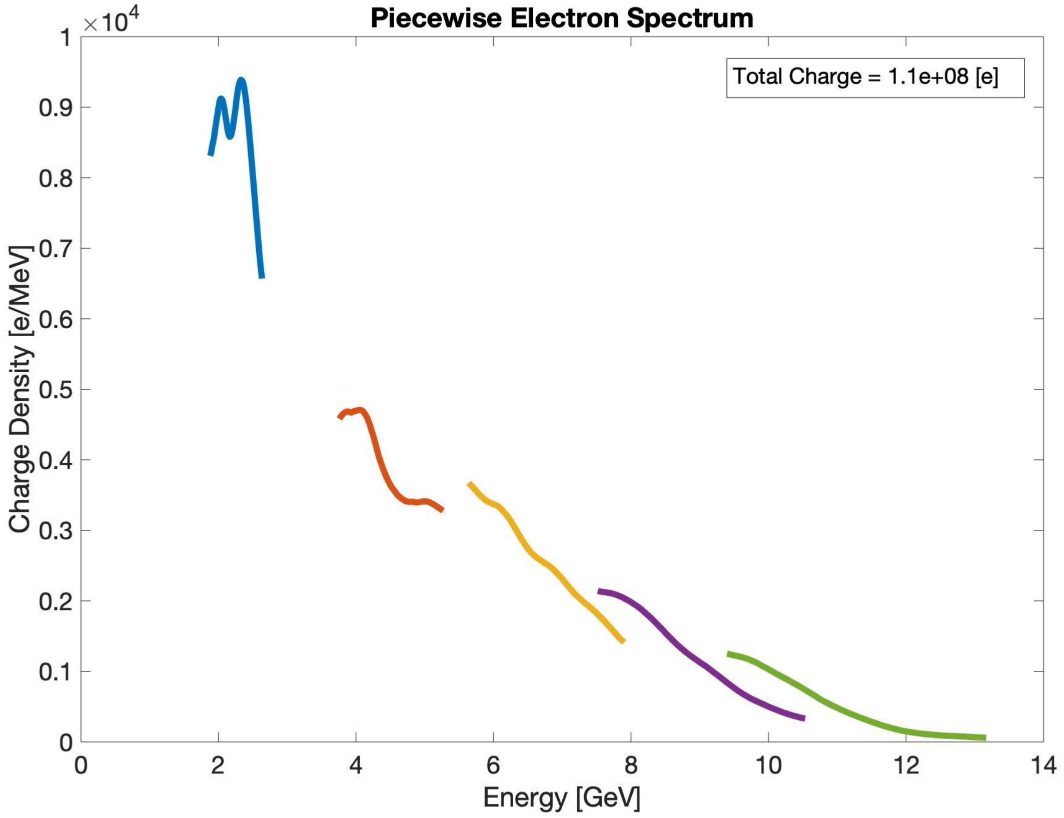
Electron Spectrum



- The screen did not capture all the captured electrons in a single shot.
- To view different energy ranges of the electrons, the spectrometer dipole was scanned.
- Each row represents a different dipole setting, i.e. energy range.
- Each column in each row represents a single shot.

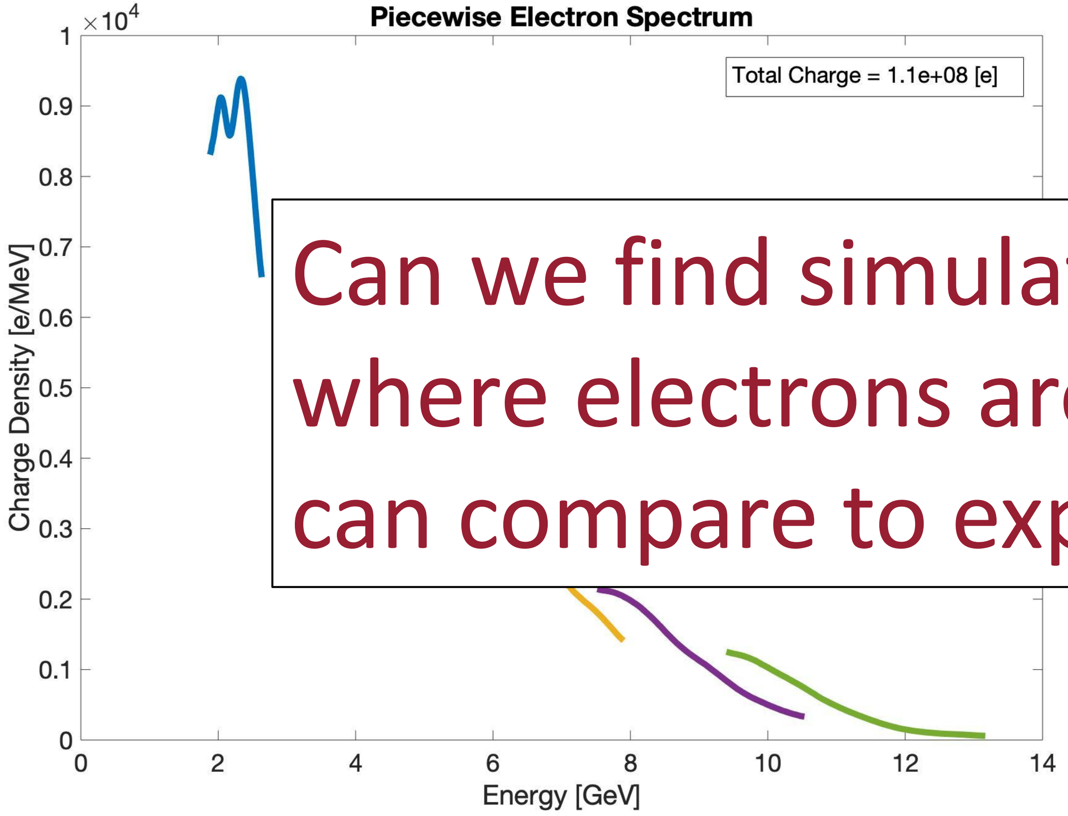
Electron Spectrum



- Pieces were obtained by averaging the shots at each dipole setting
- The spectrum is missing information due to a lack of data; however, the general structure of the spectrum is clear.

The electrons span a broad range of energy up to 13 GeV.

Electron Spectrum



Can we find simulation parameters where electrons are captured so we can compare to experimental results?

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The electrons span a broad range of energy up to 13 GeV.

Osiris Simulation Parameters

Parameter	Value
Particle type	positrons
Pre-ionized?	yes
Helium Buffer?	no
# of particles	1.8E10
σ_z	10 µm
σ_r	4 µm
Peak Current	34.49 kA
Grid size	720 x 400 cells
Cell size	0.05 k_p^{-1} x 0.025 k_p^{-1}
n_0	8E16 cm^{-3}
Particles per cell	4 x 4

- 2D cylindrical Osiris simulation
- After scanning input beam parameters, these were the simulation parameters we found to best reproduce the experimental data.

Simulation parameters that produce results similar to the experiment.

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- 2D cylindrical Osiris simulation
- After scanning input beam parameters, these were the simulation parameters we found to best reproduce the experimental data.
- The experiment measured larger values for the beam size, but these values for σ_z and σ_r are needed to match simulation to experiment.

Simulation parameters that produce results similar to the experiment.

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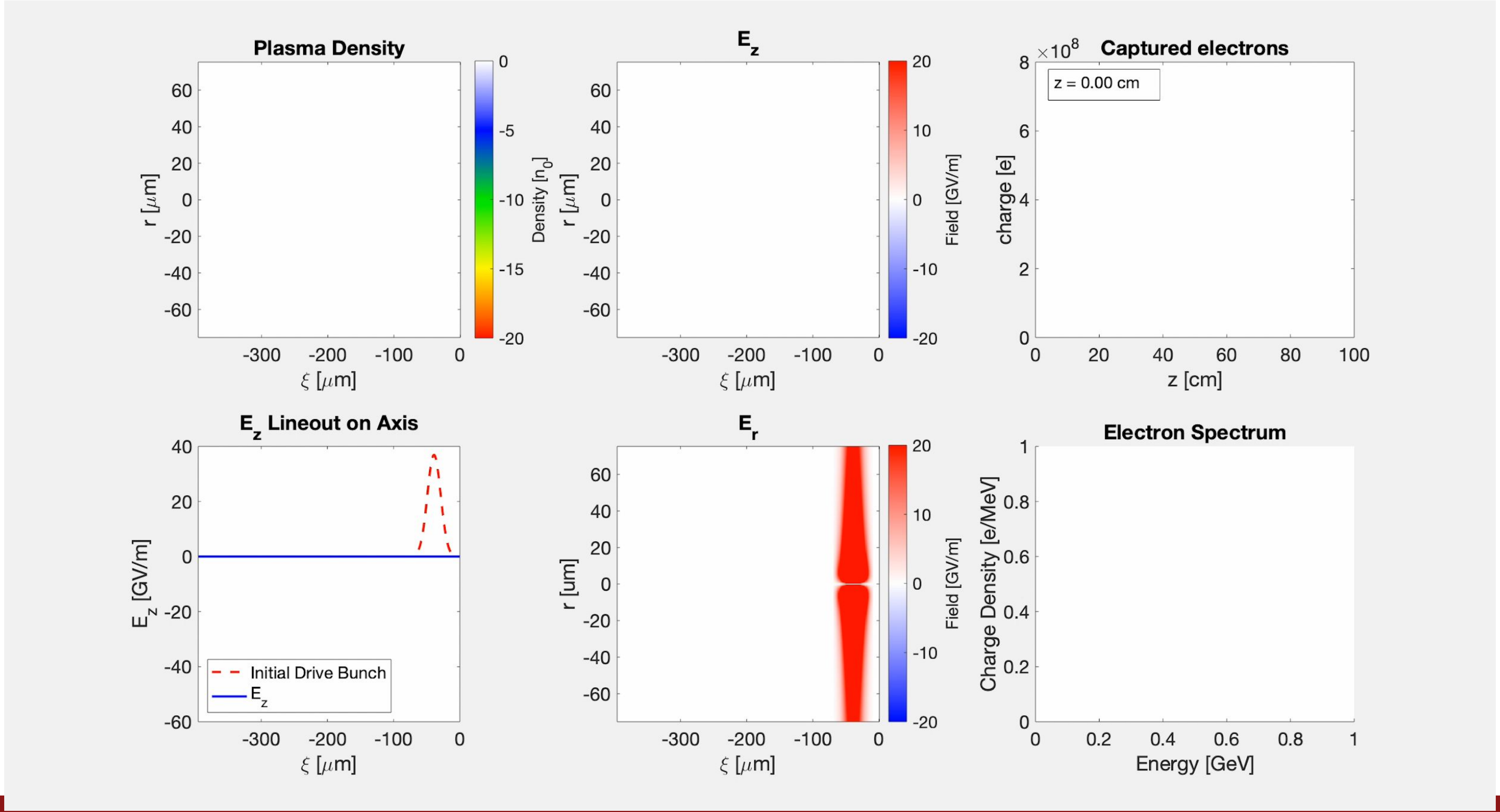
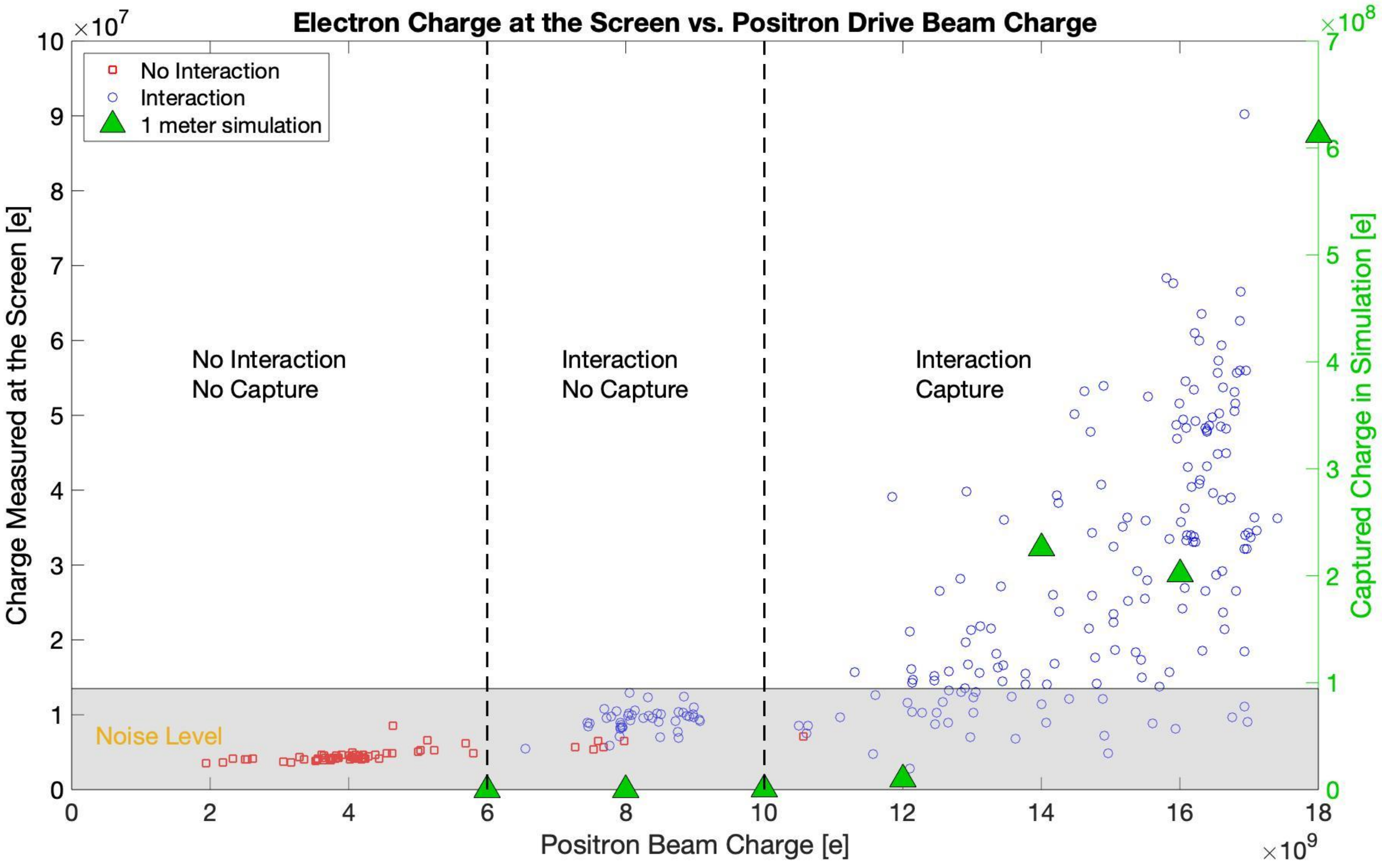
1 Meter Long Simulation



Charge scan for the positron drive beam



The threshold for electron capture in simulation agrees with the experiment.

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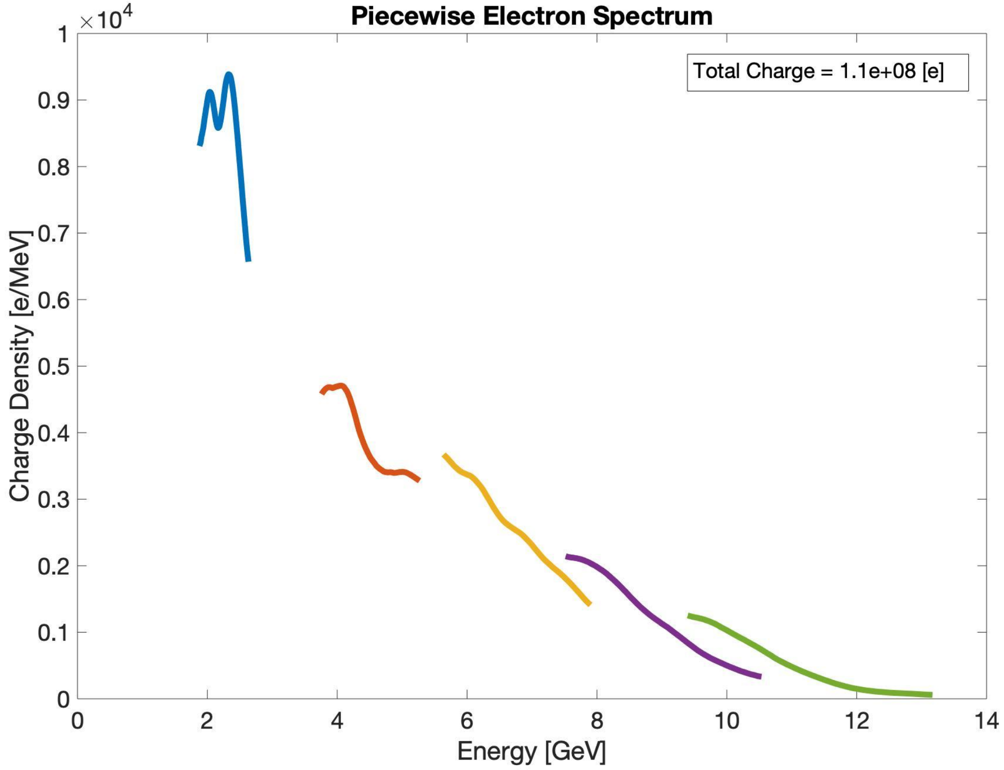
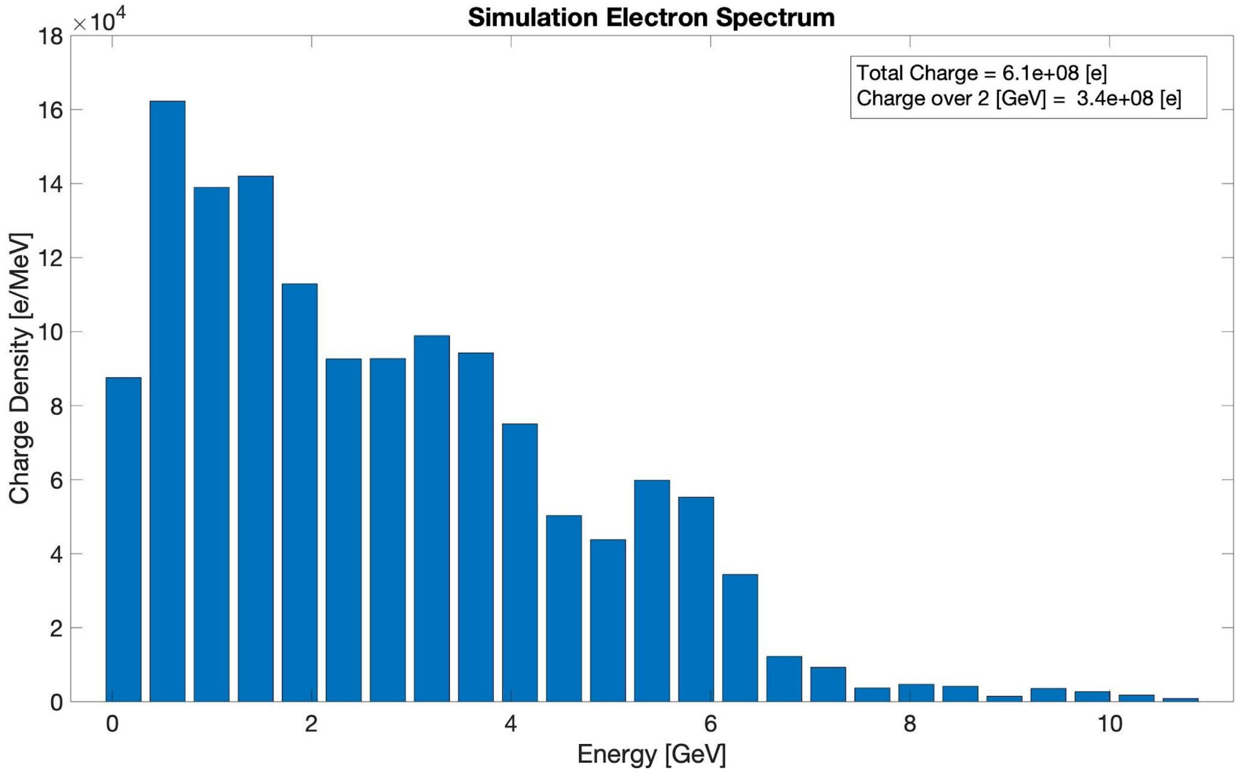
Electron Spectrum





The electron spectrum shape and energy range in simulation agrees with the experiment.

Conclusions

- We can roughly reproduce the electron capture experimental results in simulation
  - Electron capture threshold above 1E10 positrons.
  - Similar electron spectrum shape and magnitude of charge.
- Simulations show electrons are captured over multiple buckets.
- Although the simulation input beam parameters are smaller than the experimental beam at FACET, they are within the capabilities of FACET-II.
  - It is important to understand the conditions where capture occurs to control (or at least be aware of) whether it happens in future positron PWFA experiments at FACET II and beyond.

Collaborators

- University of Oslo: Erik Adli
- Beijing Normal University: Weiming An
- SLAC National Accelerator Laboratory: Christine Clarke, Joel Frederico, Spencer Gessner, Selina Green, Mark Hogan, Nathan Lipkowitz, Tor Raubenheimer, Dieter Walz, Vitaly Yakimenko, Gerald Yocky
- University of California, Los Angeles: Christopher Clayton, Thamine Dalichaouch, Chandrashekhar J. Joshi, Kenneth Marsh, Warren Mori
- CERN: Jean-Pierre Delahaye
- Ecole Polytechnique: Sebastien Corde
- University of Colorado Boulder: Michael Litos
- Tsinghua University: Wei Lu
- Paul Scherrer Institute: Margaux Schmeltz
- Stony Brook University: Navid Vafaei-Najafabadi

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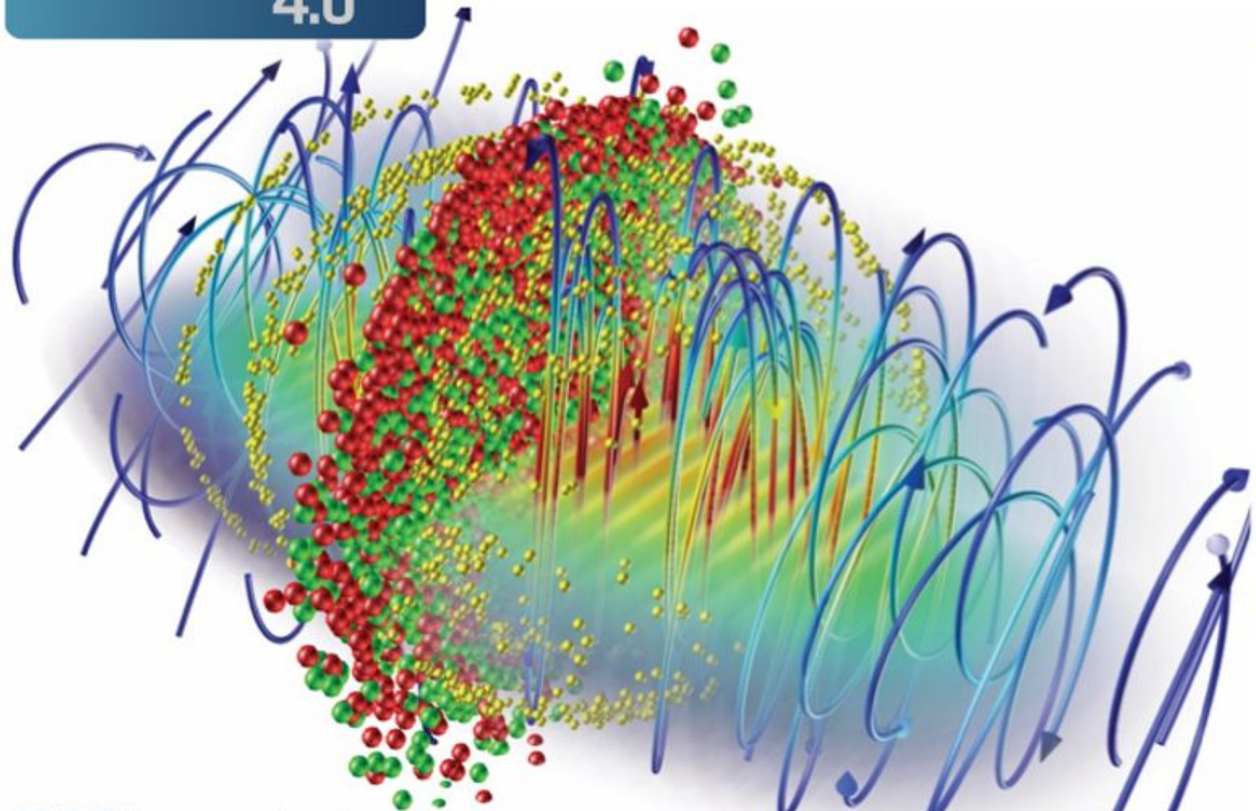
Committed to open science



OSIRIS framework

- Massively Parallel, Fully Relativistic Particle-in-Cell Code
- Parallel scalability to 2 M cores
- Explicit SSE / AVX / QPX / Xeon Phi / CUDA support
- Extended simulation/physics models

Open-access model

- 40+ research groups worldwide are using OSIRIS
- 300+ publications in leading scientific journals
- Large developer and user community
- Detailed documentation and sample inputs files available

Using OSIRIS 4.0

- The code can be used freely by research institutions after signing an MoU
- Find out more at:

http://epp.tecnico.ulisboa.pt/osiris

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Thank you!