Gigaelectronvolt Acceleration of Captured Electrons in a Positron Beam-Driven Plasma Wakefield Accelerator

Advanced Accelerator Concepts 2022

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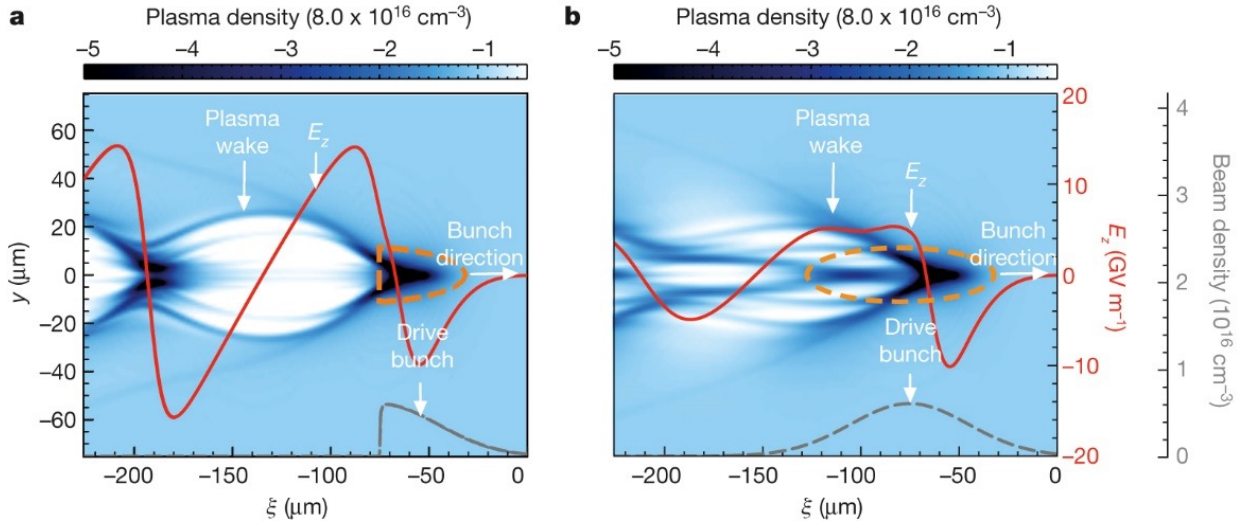
Context and Motivation



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. Understanding why this occurred is useful for future positron PWFA experiments at FACET II and beyond.

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

Experimental Setup

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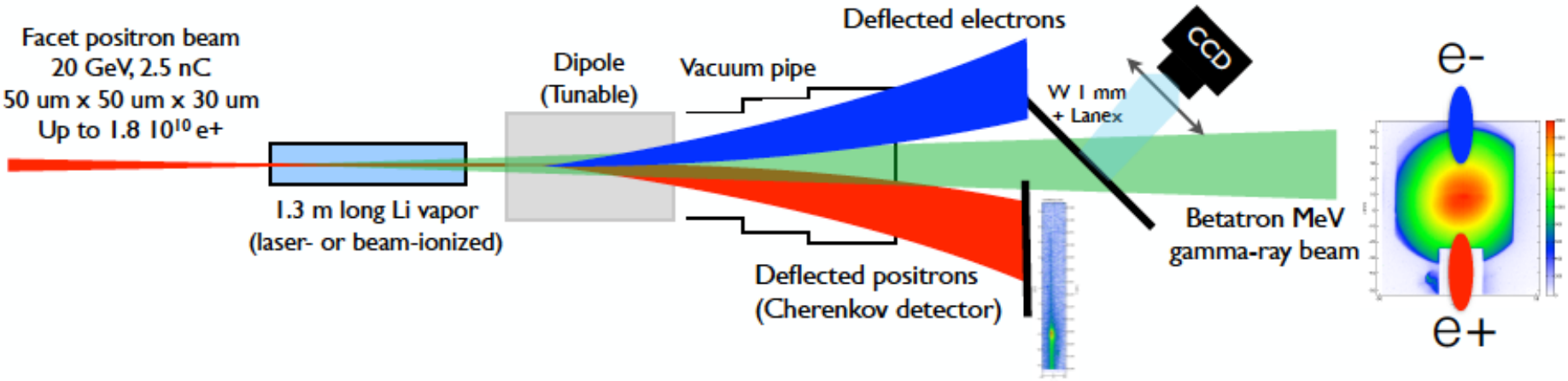
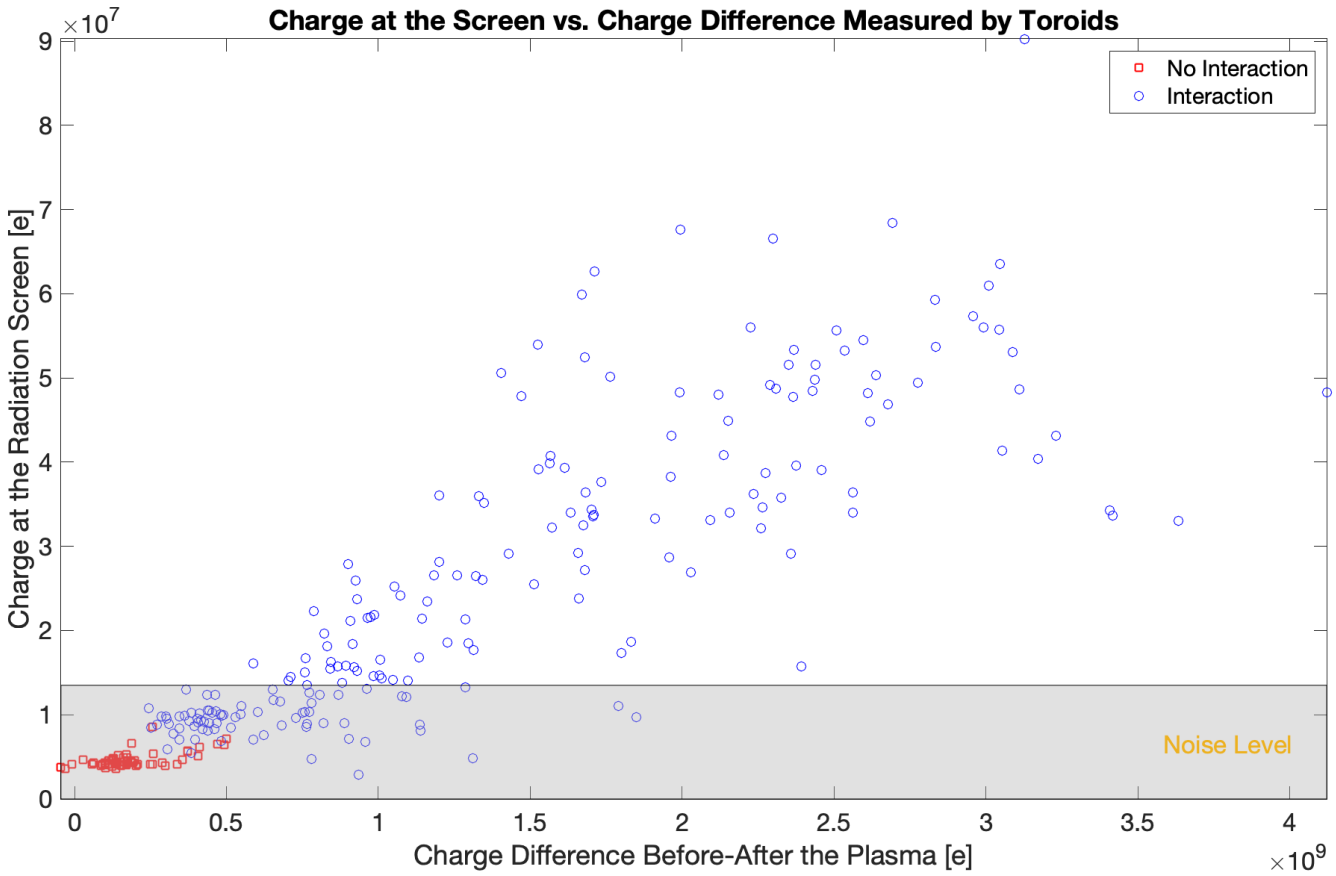


- 1.3 meter long lithium plasma oven
- Single bunch positron beam driver
  - positron tail gained energy
  - positron head lost energy
  - plasma electrons captured and gained energy
- The electrons were deflected above the spectrometer screen, but appeared at the top of the betatron radiation screen.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

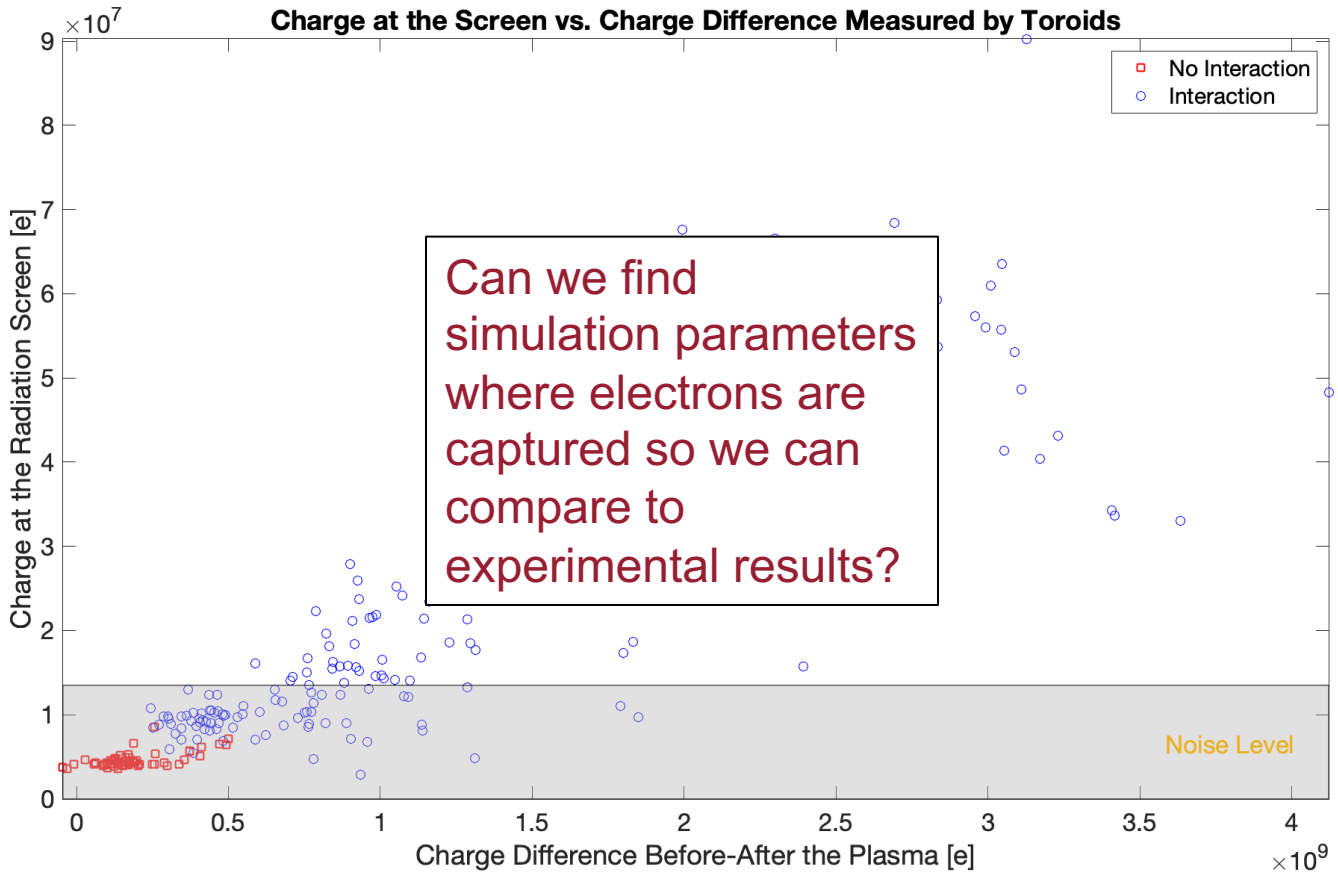
Image: S. Corde, High-gradient Positron-driven Plasma Wakes; AAC 2014

Confirming the Electron Signal



- 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.

Confirming the Signal as Electrons



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

- 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.

Osiris parameters

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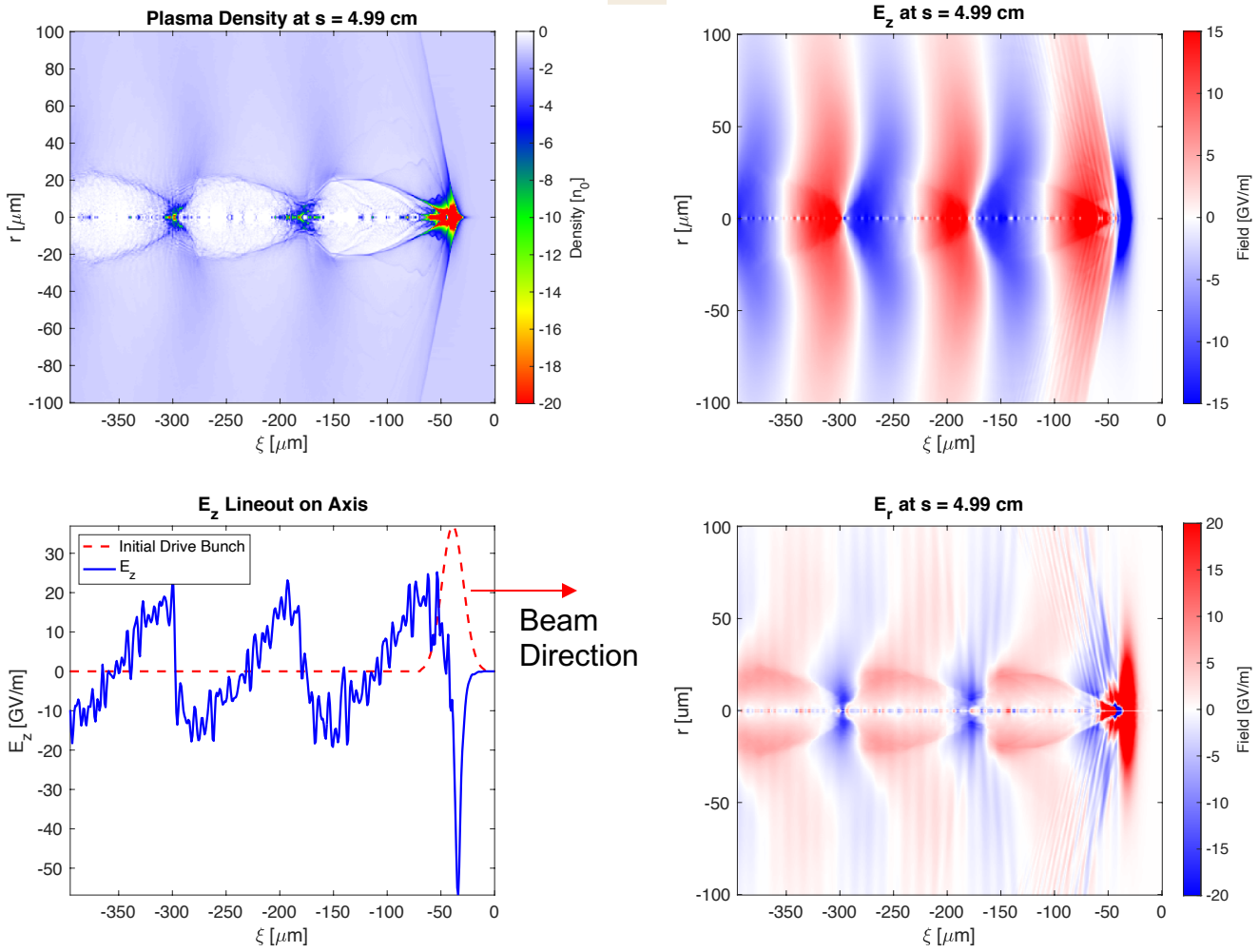
Parameter	Value
Particle type	positrons
Pre-ionized?	yes
Helium Buffer?	no
# of particles	1.8E10
σ_z	10 μm
σ_r	4 μm
Peak Current	34.49 kA
Grid size	720 x 400 cells
Cell size	0.05 k_p^{-1} x 0.025 k_p^{-1}
n_0	8E16 cm^{-3}
Particles per cell (each species)	4 x 4

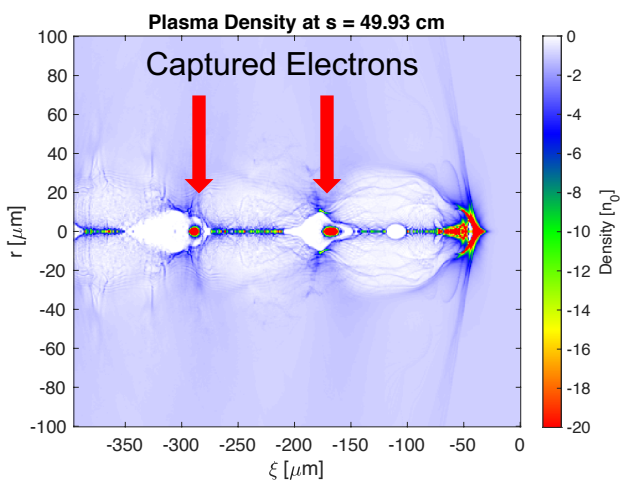
- After trial and error these are the parameters that produced results that resembled the experiment.

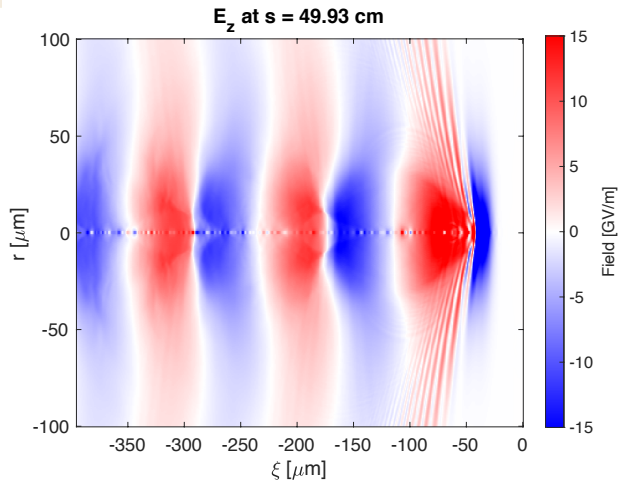
Simulation output after 5cm

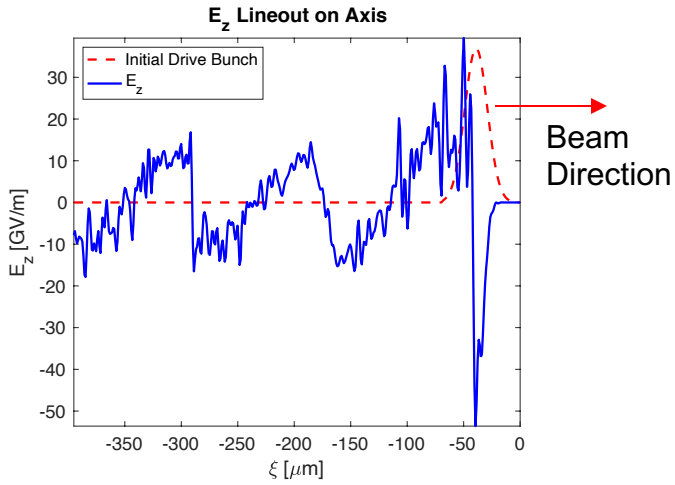


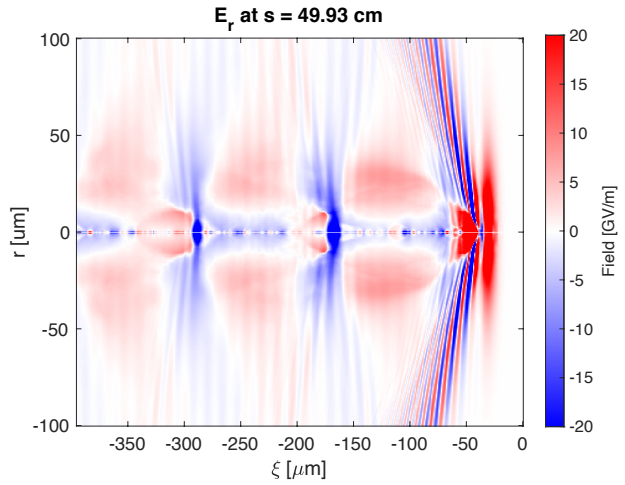
- Suck-in regime: positron-driven non-linear wake.
- Some electrons end up on axis complicating the fields.

Simulation output after 50cm



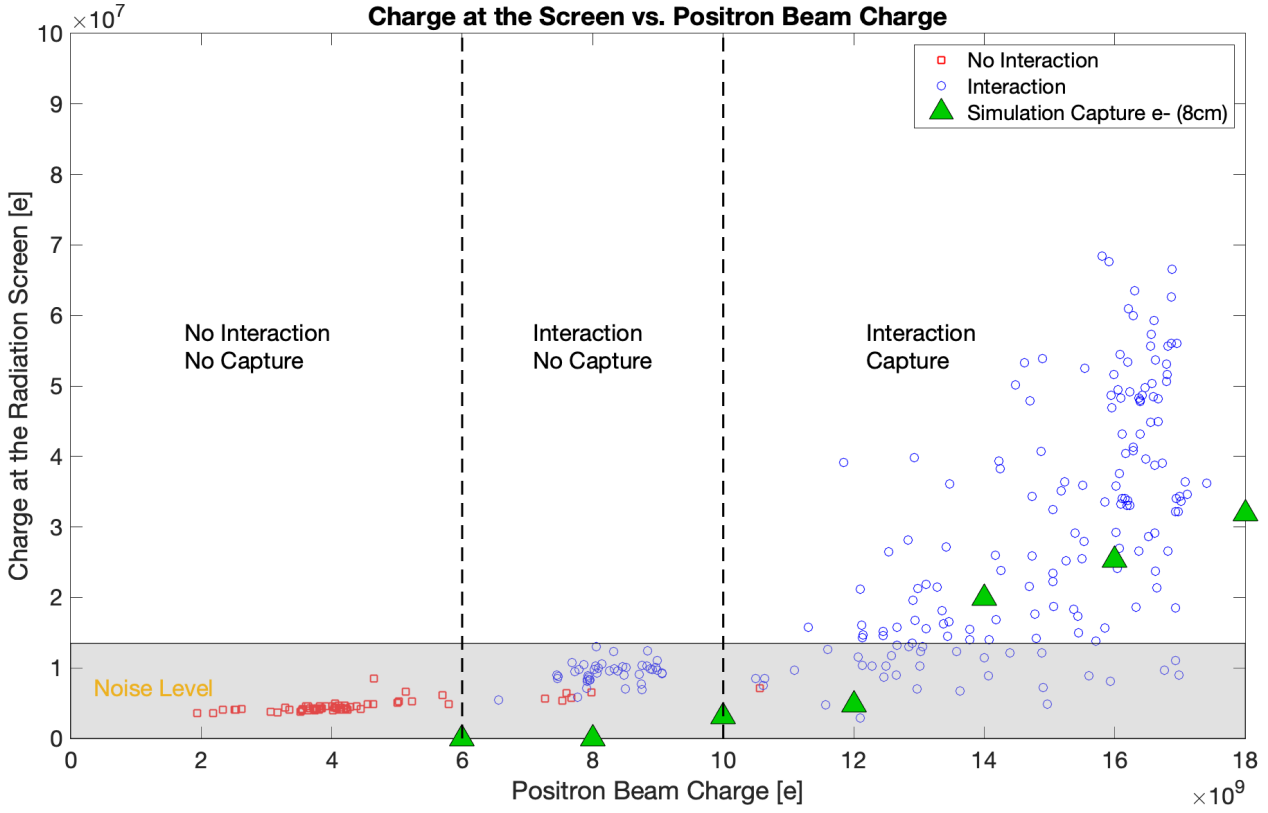






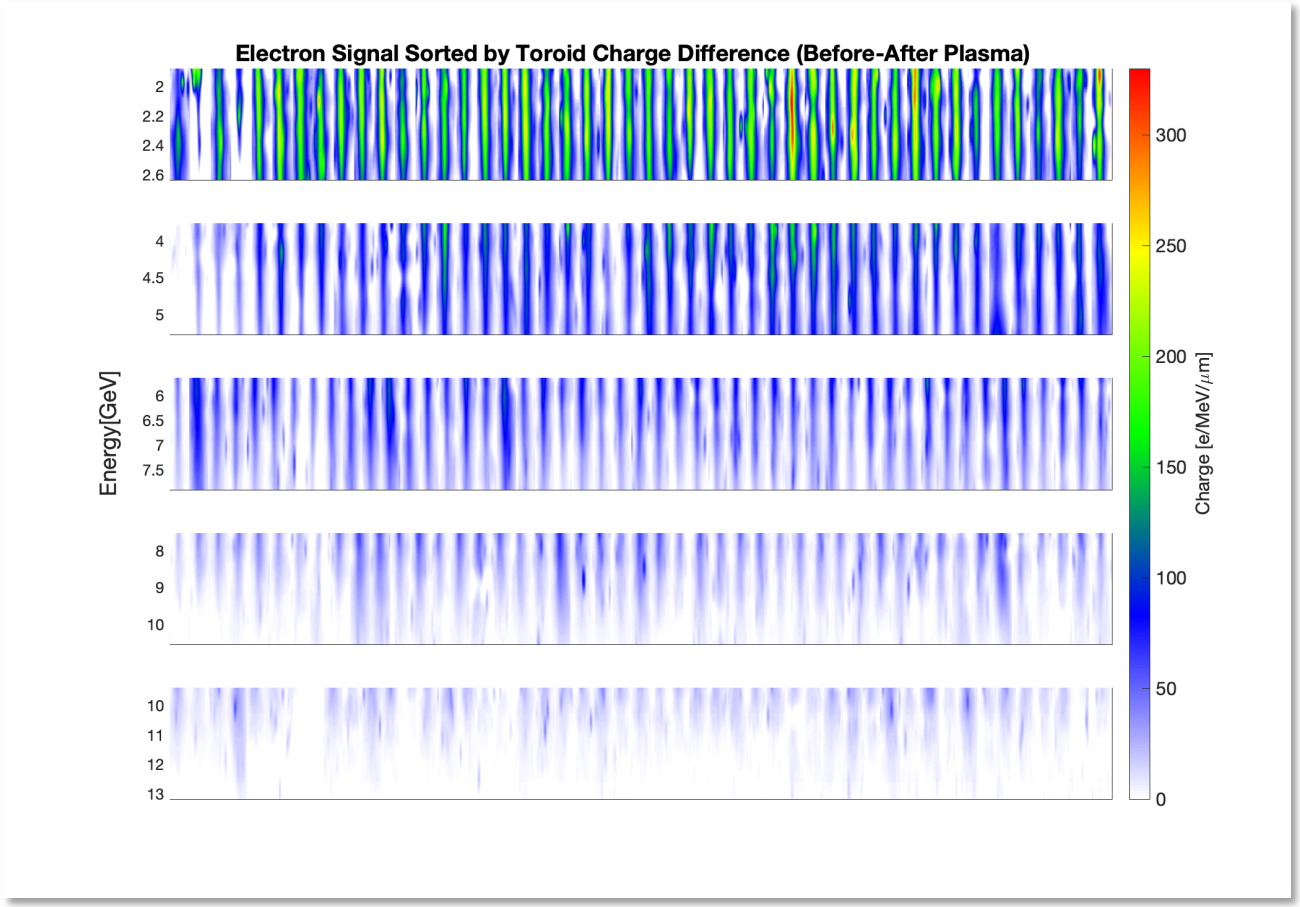
- Electrons have been captured and accelerated, and even cause a miniature blowout with the surrounding plasma electrons.
- Complicated evolution of the plasma density and fields.

Electron Capture Threshold with Varying Positron Beam Charge



- By scanning the positron beam charge we could isolate three different scenarios.
- The capture threshold is the same in experiment and simulation!
- Note that each simulation ran for 8 cm only.

Electron Signal at Different Energies



- Since all the electrons could not be captured in a single shot, the spectrometer dipole was scanned to get a more complete picture.
- We observed accelerated captured electrons up to 13 GeV.

Electron Spectrum

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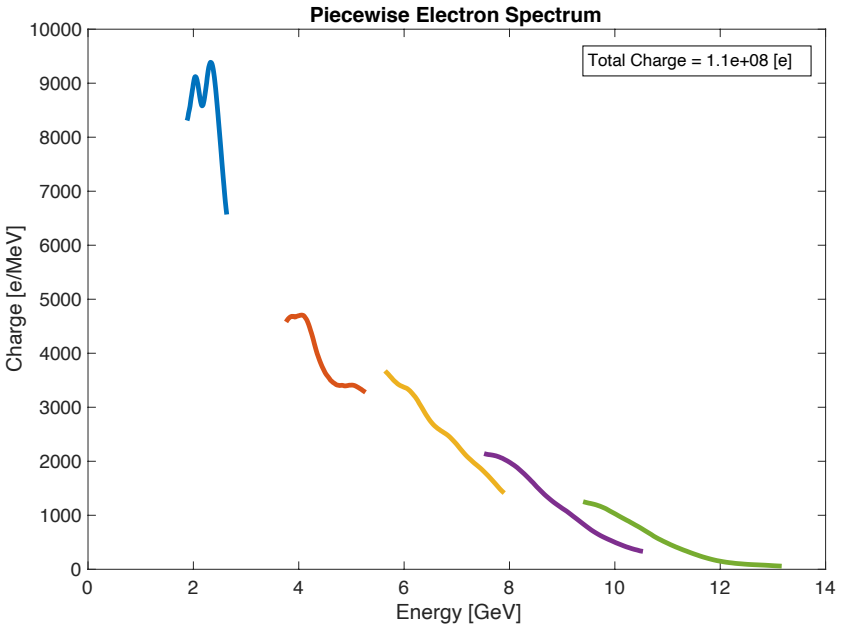
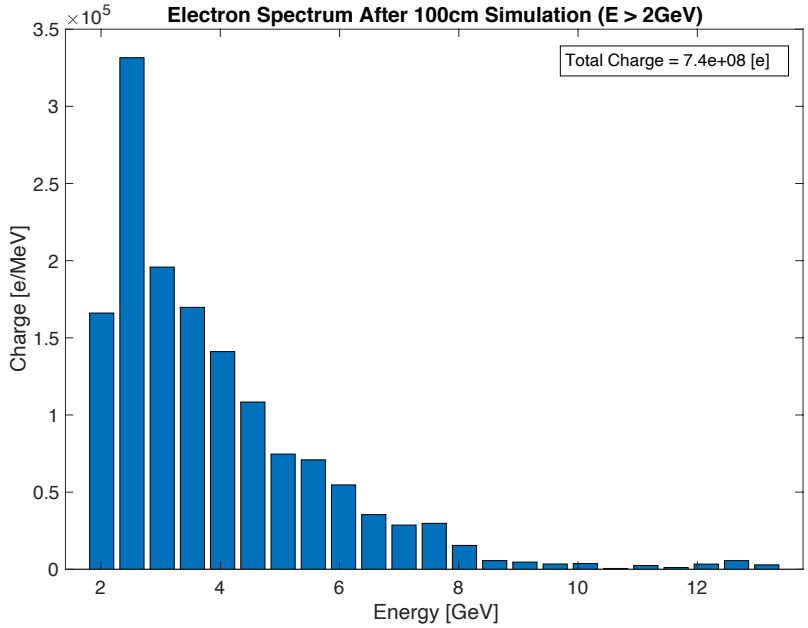
Experiment:

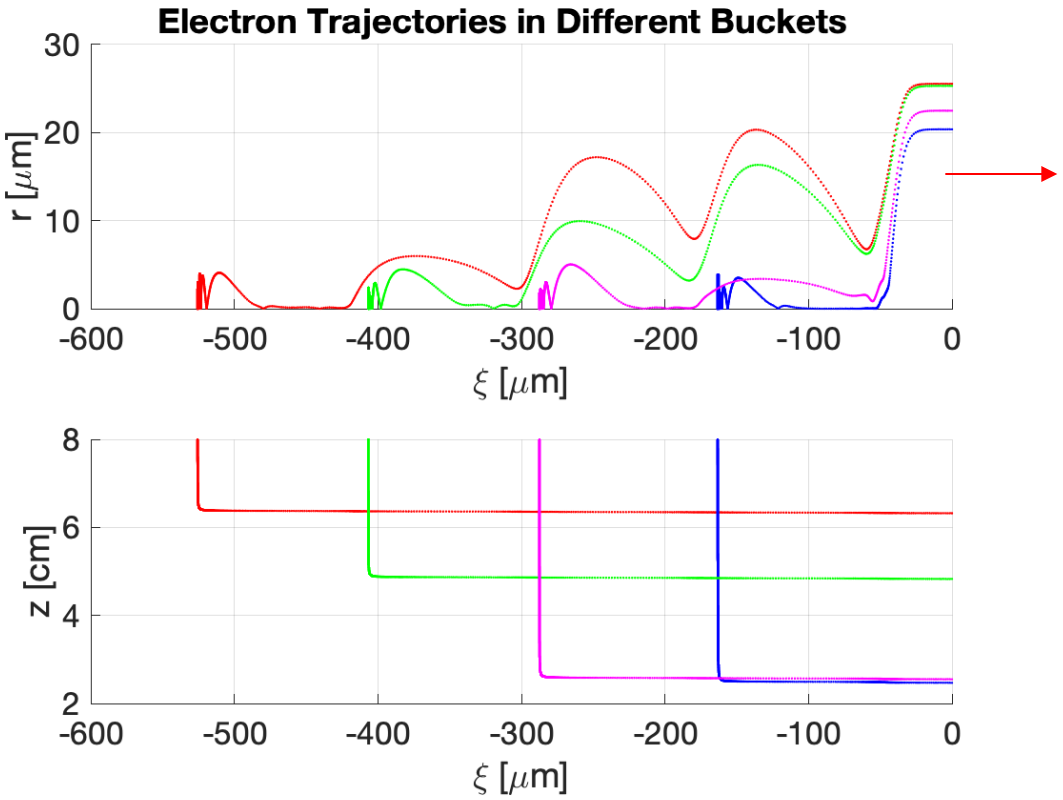


Simulation:



- Piecewise spectrum using the average from each dipole setting
  - Broad electron spectrum up to ~13 GeV.
- The total charge is similar in magnitude and the spectra have a similar shape.

Electron Trajectories



- Electrons with in a small initial radius interval have a chance of becoming captured.
- The electrons ultimately end up on axis before capture.

Conclusions

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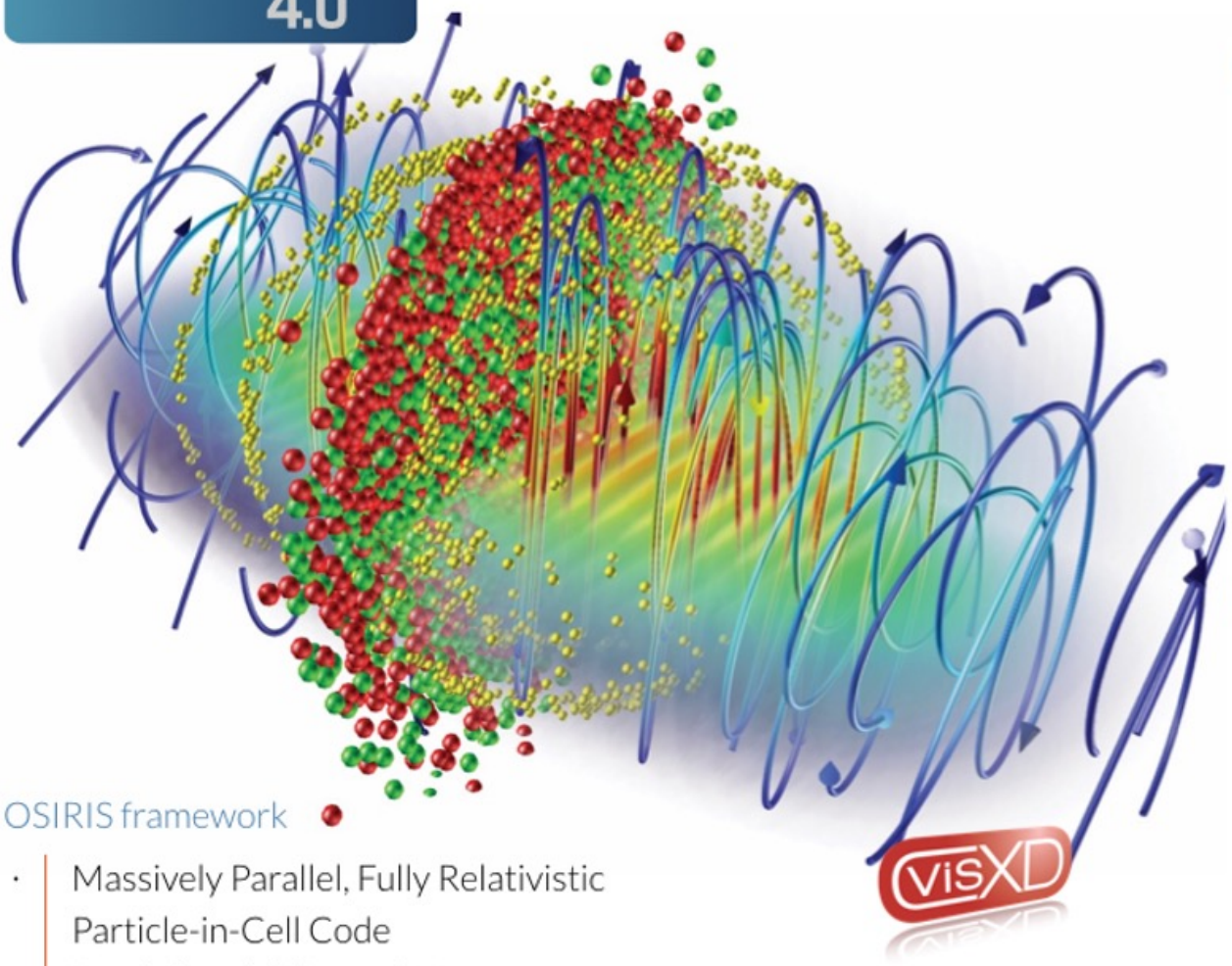
- We can roughly reproduce the experimental results in simulation
  - Electron capture threshold at 10^{10} positrons.
  - Similar electron spectrum shape and magnitude of charge.
- Simulations show electrons are captured over multiple buckets.
- Simulations also show the evolution of the wake and plasma density is quite complicated.
- This is an interesting case and understanding it could be useful for future positron PWFA experiments.

Osiris 4.0

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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Thanks!