Evolution of Masked Electron Bands

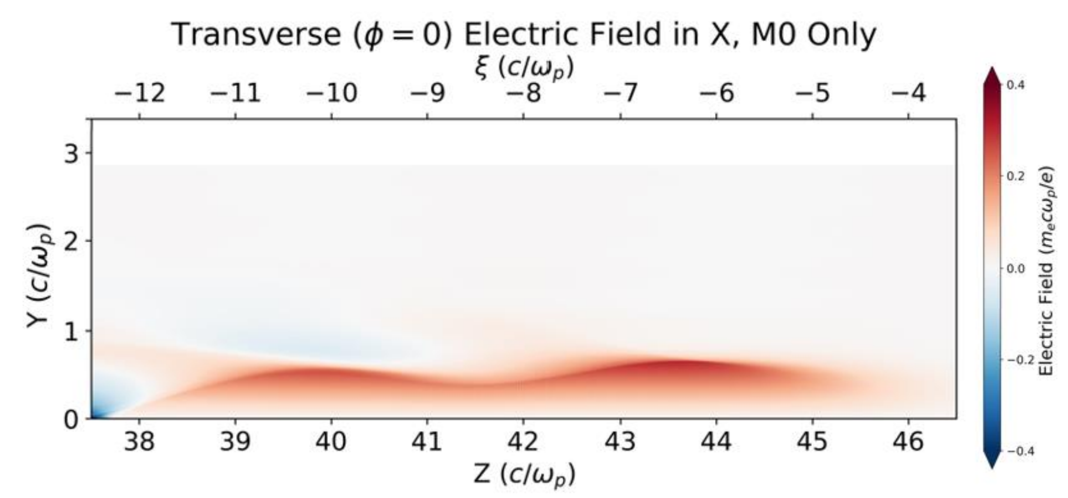
Ashley Lindquist, Nikhil Keer, Navid Vafaei-Najafabadi

Physics REU, Stony Brook University

Abstract

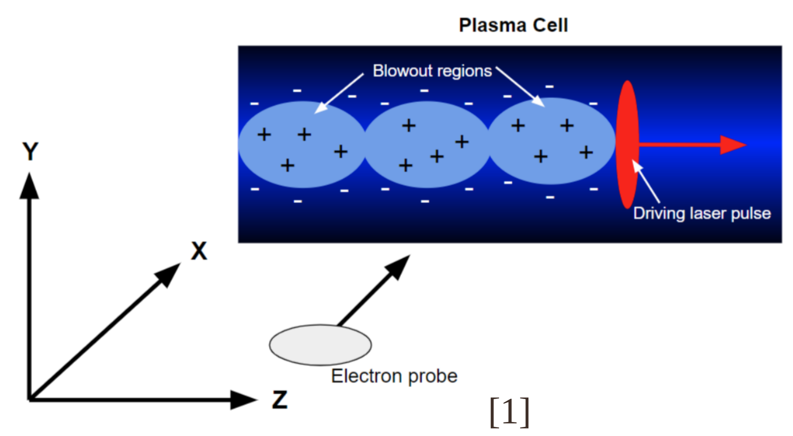
Plasma wakefield accelerators could provide more effective and efficient particle accelerators. By studying the field structure and forces of plasma wakefields we can learn to use them to advance accelerator physics. This work shows simulations of electron probes sent transversely through wakefields to study their structure and optimize experimentation.

Plasma Wakefield



Background

The wakefield is created by sending a laser through the plasma. This creates the bubble structure which moves with the laser pulse. We then send an electron probe transverse to the motion of the blowout region (wakefield).

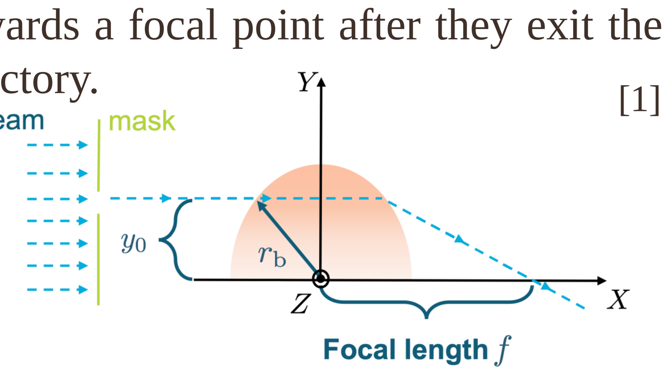


[1]

The plasma wakefield is modeled as a thin lens in the path of the probe electrons. This means that while passing through, the electrons will maintain their initial height and the forces acting on them will send them towards a focal point after they exit the wakefield on a ballistic trajectory.

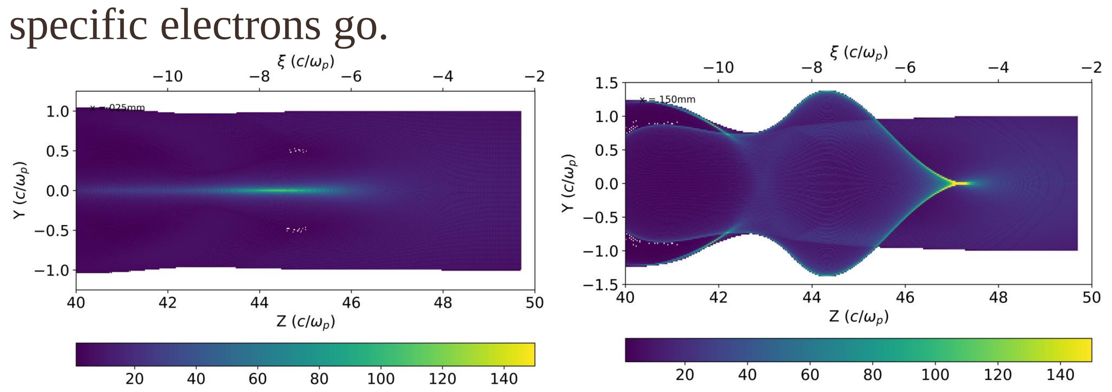
$$f = \frac{p^2}{2\gamma m F_{\perp max}} \cdot \left(1 - \left(\frac{y_0}{r_b}\right)^2\right)^{-1/2}$$

Focal length   Depth of field



[1]

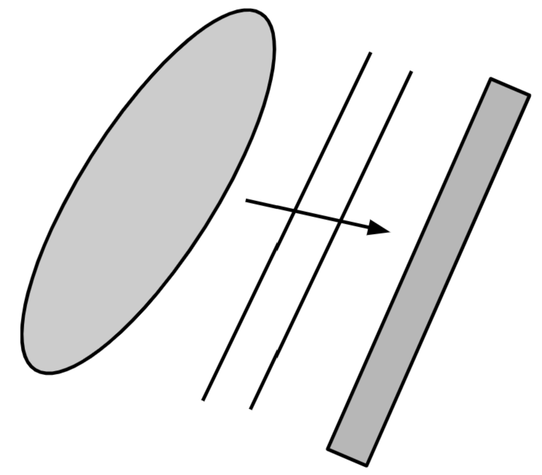
One issue with this is that electrons that enter the wakefield in different positions experience different focusing forces. Because electrons cross paths, it is useful to use masks to see where specific electrons go.

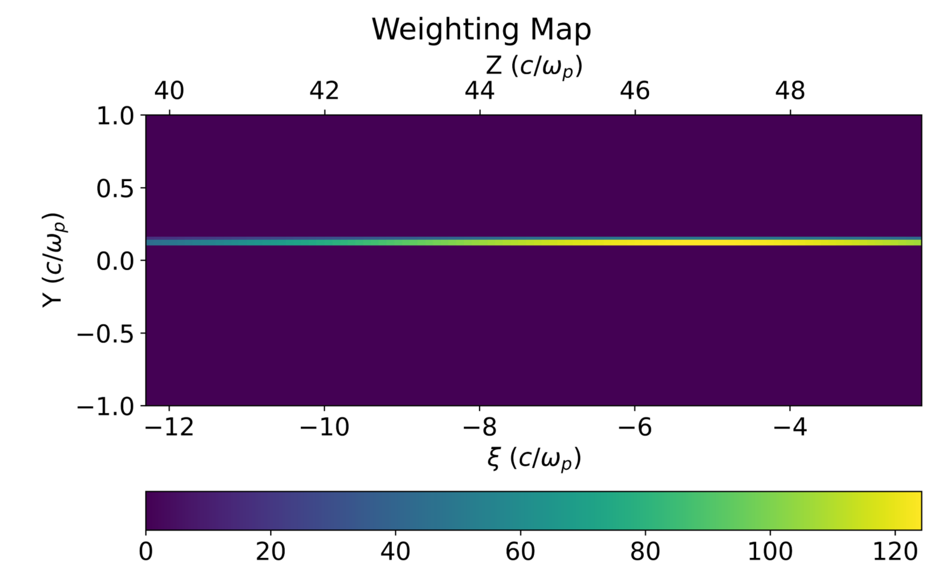


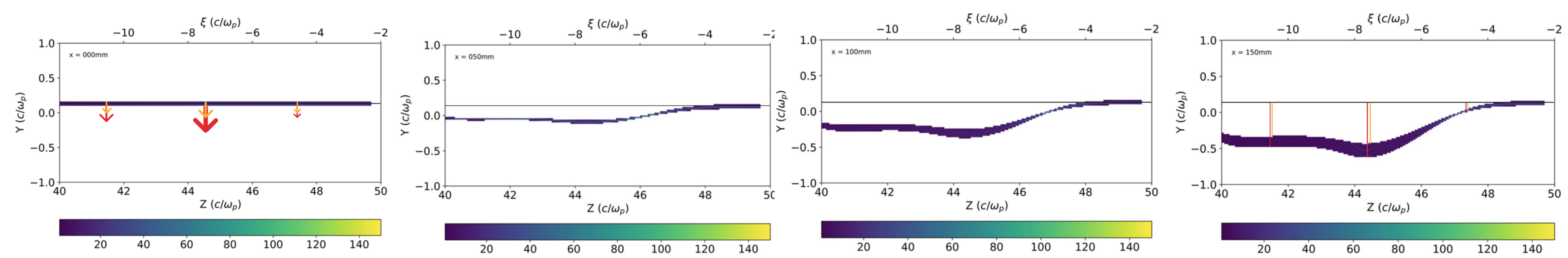
Simulation images of a full probe at distances x=25mm and 75mm behind the wakefield. The position with the highest density, later corresponding to the fastest expanding slice, is the position with the strongest focusing (~Z= 44.5)

Electron Bands

Experimentally, electron bands are created by sending the probe through an opening in a mask. The parts of the probe that make it through are the band. In QuEP, the bands are made by weighting all electrons not in the 'opening of the mask' zero.







Thin Bands:

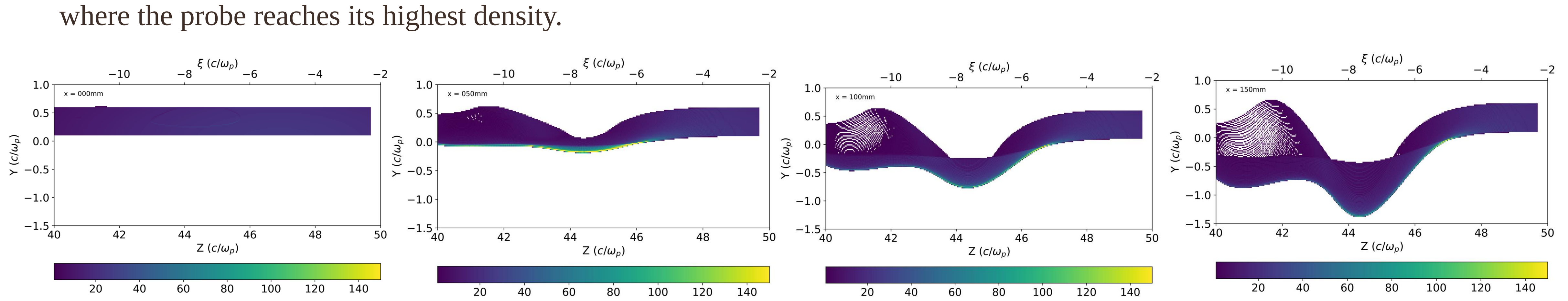
By limiting the probe into bands of electrons the change in width of the probe can be seen. This change occurs because of the different amounts of force the electrons experience while inside the wakefield. In the first graph the arrows are drawn by size to indicate the amount of force the parts of the band are experiencing. The most force in the middle bottom, second on the left, and the least force on the right. This can be determined by how much the electrons were displaced in the final graph. The band changes in thickness because of the different force on the top and bottom. In the middle, the bottom of the band experienced significantly more force than the top, so it moved much further than the top did, widening the band.

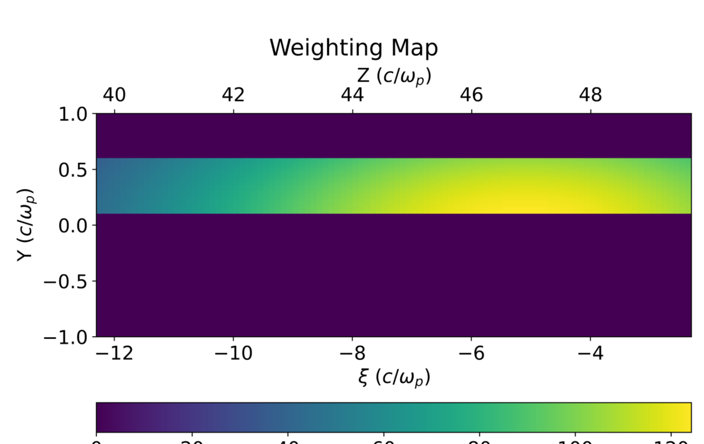
Thick Bands:

While thin bands of electrons may be more useful for measuring changes in width, the evolution of thick bands can also be very visually interesting. As seen in the graph in the abstract, the wakefield only spans up to about Y= 0.5 meaning that anything outside of that won't experience strong focusing forces.

Comparison:

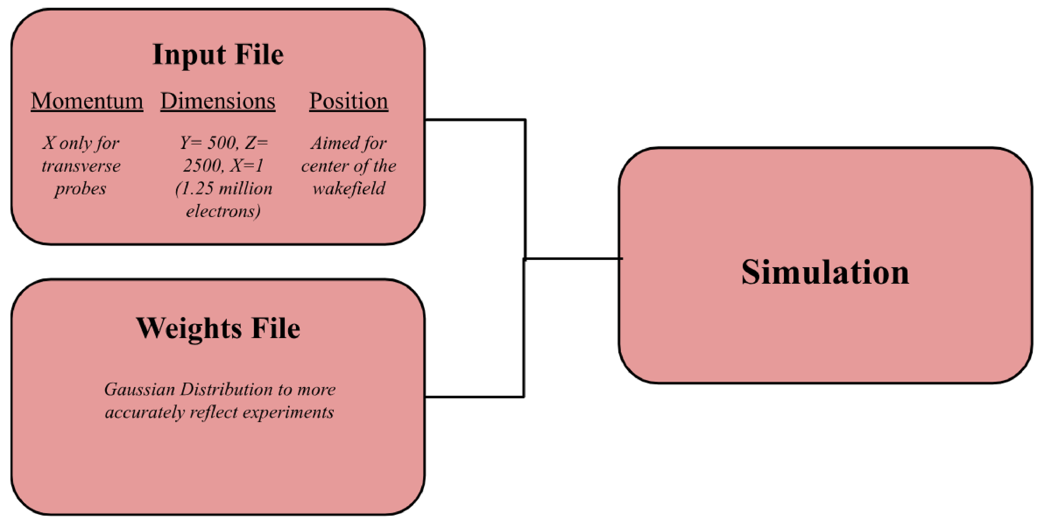
In the graphs shown below a mask open between Y= 0.1 to Y= 0.6 was run through QuEP. Both this and the thin band graph had their opening start at Y= 0.1 but in the thick band graph the lowest point almost reaches Y= -1.5 while Y= -0.75 is about the lowest point for the thin band. This shows that there is a point above the range of the thin band that experiences the most focusing force in the wakefield. In the X= 150 mm step around Z= 47 is another interesting connection between all the band graphs. For the thin band this is where the band reaches its minimum width. In the other graphs this seems to be the point where the probe reaches its highest density.





Simulation

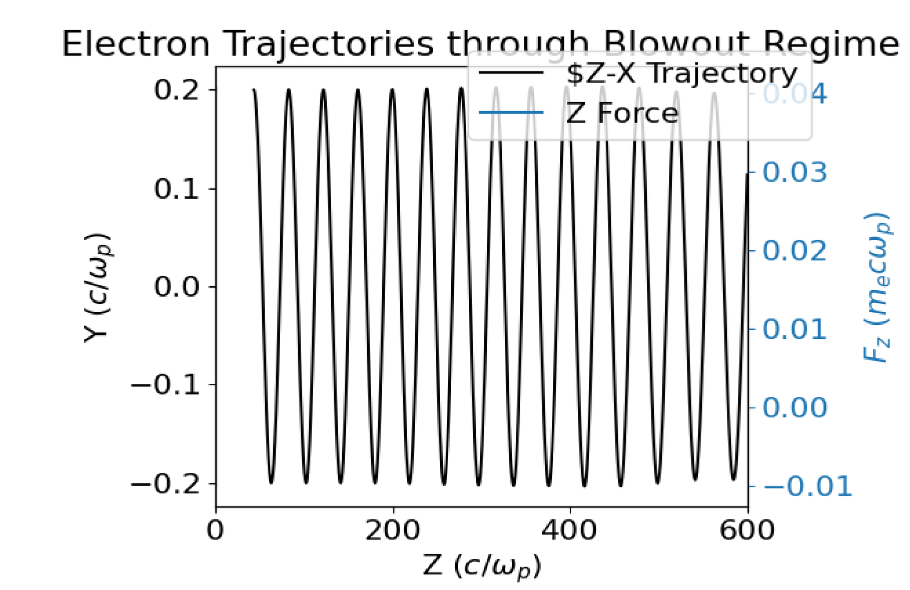
The results after running a job on QuEP simulate what would happen if you placed a screen at different X distances after the electrons left the wakefield. If done in fine enough increments this can create an animation of how the probe changes.



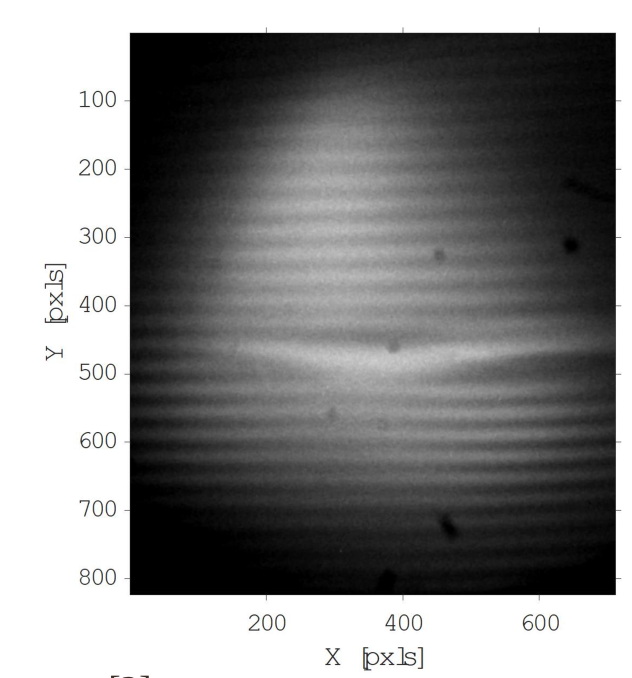
Documentation

While running simulations on QuEP doesn't generally involve writing code it can be difficult to navigate without background in coding. To make getting started on QuEP easier for future students a 'User Manual' has been drafted. By putting this on the GitHub with the main code this should speed up the learning curve of work using the simulations.

The sections instructions have been written for Seawulf use and the Betatron Test. Seawulf is a computing cluster at Stony Brook that can run the millions of particle code necessary for creating accurate simulations. The Betatron Test is to send a single particle longitudinally into the wakefield in order to see it exhibit betatron motion. (For more information on longitudinal probing see Nikhil Keer's poster)



Future Work



[2]

Moving forward a diagnostic of distinguishing between thin and thick band graphs could be created. This would work with the applications in the lab at Brookhaven National Laboratory to help better set up experiments. It would also be beneficial to continue with an analytical model of predicting the results of bands both in the simulation and the experiment.

Acknowledgements

The authors would like to thank Evan Trommer for all his help, Marisa Petrusky for her thesis, and the previous QuEP writers. This material is based on work supported by the NSF under Grant No. PHY-2243856 and PHY-1852143

Citations

[1[M. Petrusky, "Picturing Plasma: Studying the simulated transverse probing of laser wakefield accelerators", Bachelor's Thesis, Stony Brook University, Stony Brook, NY (2021); https://cpb-us-e1.wpmucdn.com/you.stonybrook.edu/dist/a/2056/files/2021/05/Marisa-Petrusky-PHY-WRTD.pdf

[2] V.N. Litvinenko, N. Vafaei-Najafabadi, R. Samulyak, July 2024, *Direct Measurements of Fields and Radiation in the Self-Modulated Plasma Wakefield Regime*, [PowerPoint slides], Brookhaven National Laboratory, https://indico.bnl.gov/event/9698/contributions/43925/attachments/31848/50445/ATF_23dUsersMeeting_Petrushina.pdf