Measuring Electromagnetic Fields Using Laser-Wakefield-Accelerated Electrons

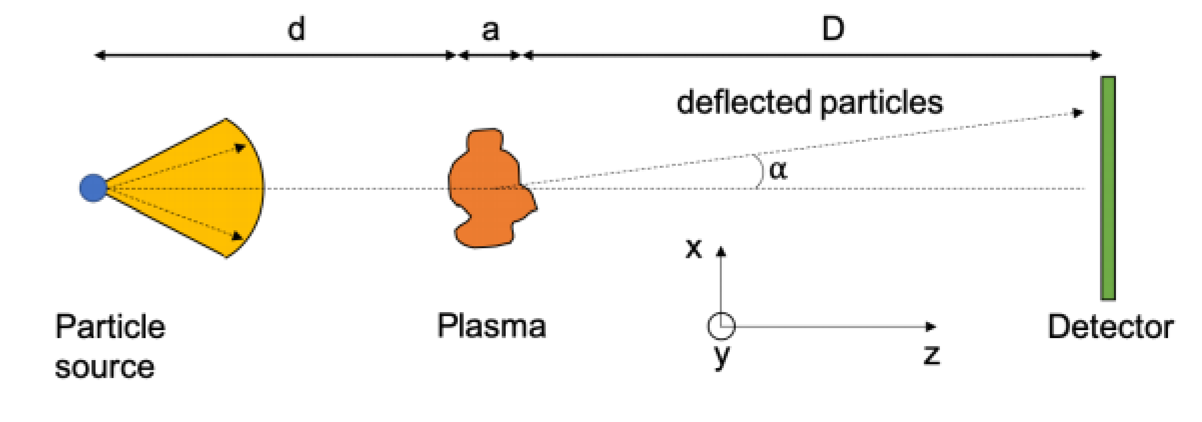
Carlton Kim
Supervised by/in collaboration with Will Fox, Derek Schaeffer, Sophia Malko and Courtney Johnson

Measuring Fields for Plasmas is a Challenge

- Traditional electromagnetic field measurement techniques are insufficient for most laboratory plasmas due to harsh conditions
  - How can a probe be placed in a plasma environment without damaging either the equipment or disrupting the experiment?

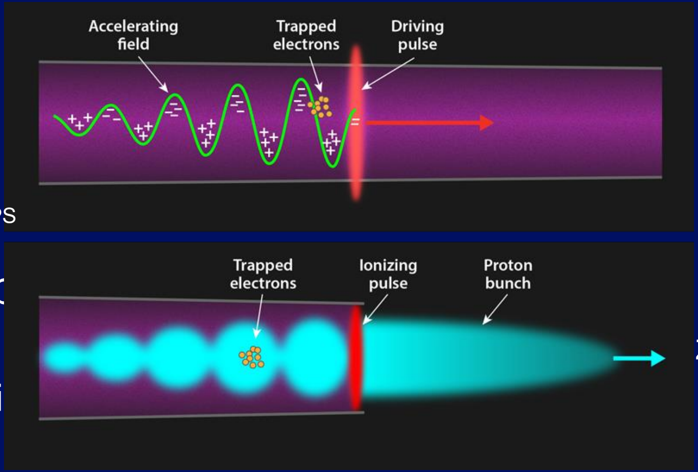
Particle Radiography

- Does not have to be placed into the plasma!



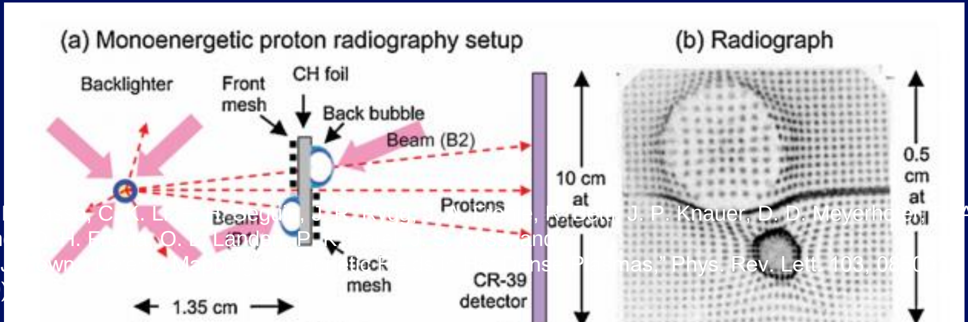
$$\Delta\alpha = \int (\mathbf{E} + \mathbf{v} \times \mathbf{B}) dl$$

Radiography Methods



Florian Grüner, “Shooting Ahead with Wakefield Acceleration,” APS (2019), physics.aps.org/articles/v12/19

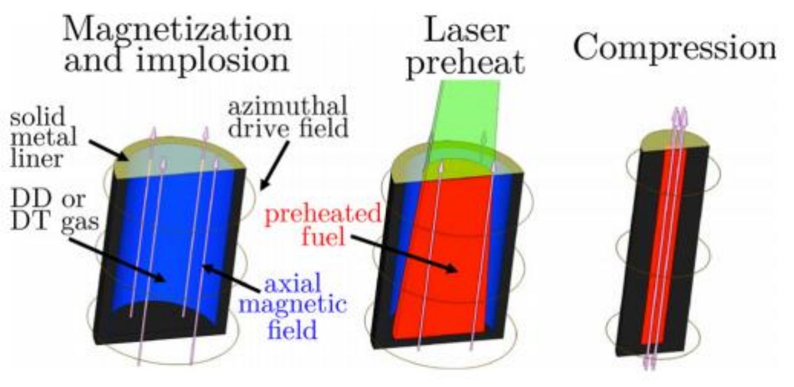
- Current radiography methods utilize p
  - Protons generated through irradiating thin ... zing the result of the implosion of a Deuterium Heli
  - In the 3-60 MeV range of energy
- Electrons radiography is a newer concept being tested
  - Electrons are produced through laser-wakefield acceleration
  - Laser-wakefield acceleration is when a laser is driven through a plasma. A “wake” is created that creates a force which accelerates electrons in the direction of the beam.
  - Measured to be beyond 1 GeV



R. D. ... C. ... J. P. Knauer, D. D. Meyerhofer ... A.
Amen... O. L. Land...
R. P. J... Phys. Rev. Lett. 103, 08...
(2009)

Electrons Have Advantages Over Protons

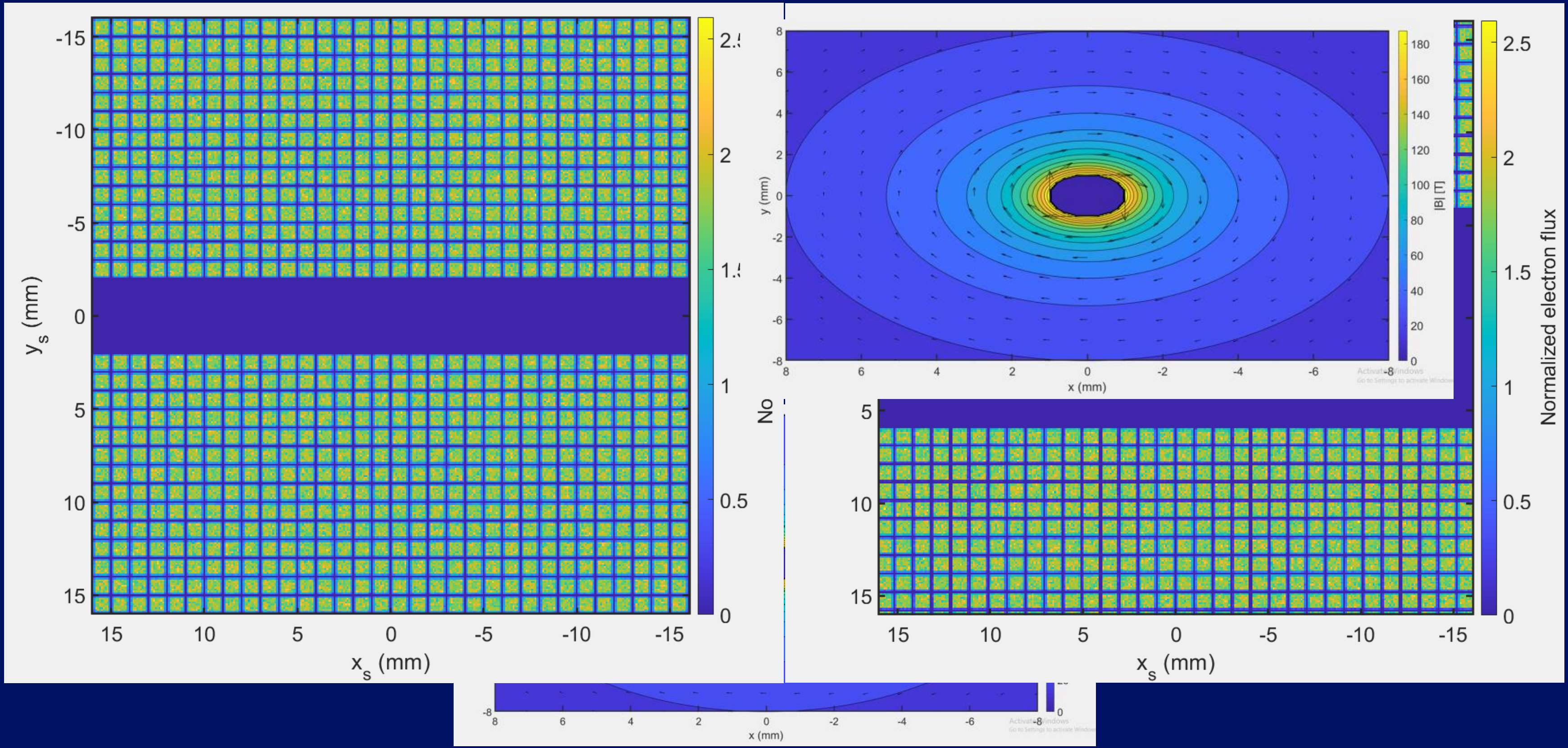
- Electrons can probe into HEDP’s with higher magnetic field
- Electrons can penetrate thicker material filters around the target plasma
- Electrons have high spatial and temporal resolution
- Laser required for sending out the electrons is compact
- Useful for laboratory setups like Mag-LIF (magnetized liner inertial fusion)



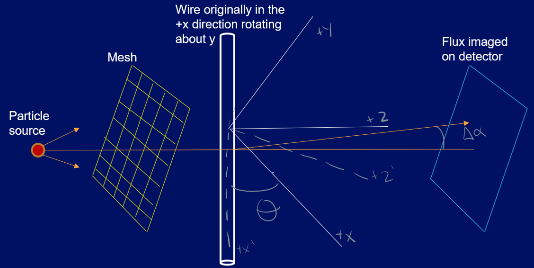
Sefkow et al, “Design of magnetized liner inertial fusion experiments using the Z facility,” AIP Physics of Plasmas 21, 072711 (2014)

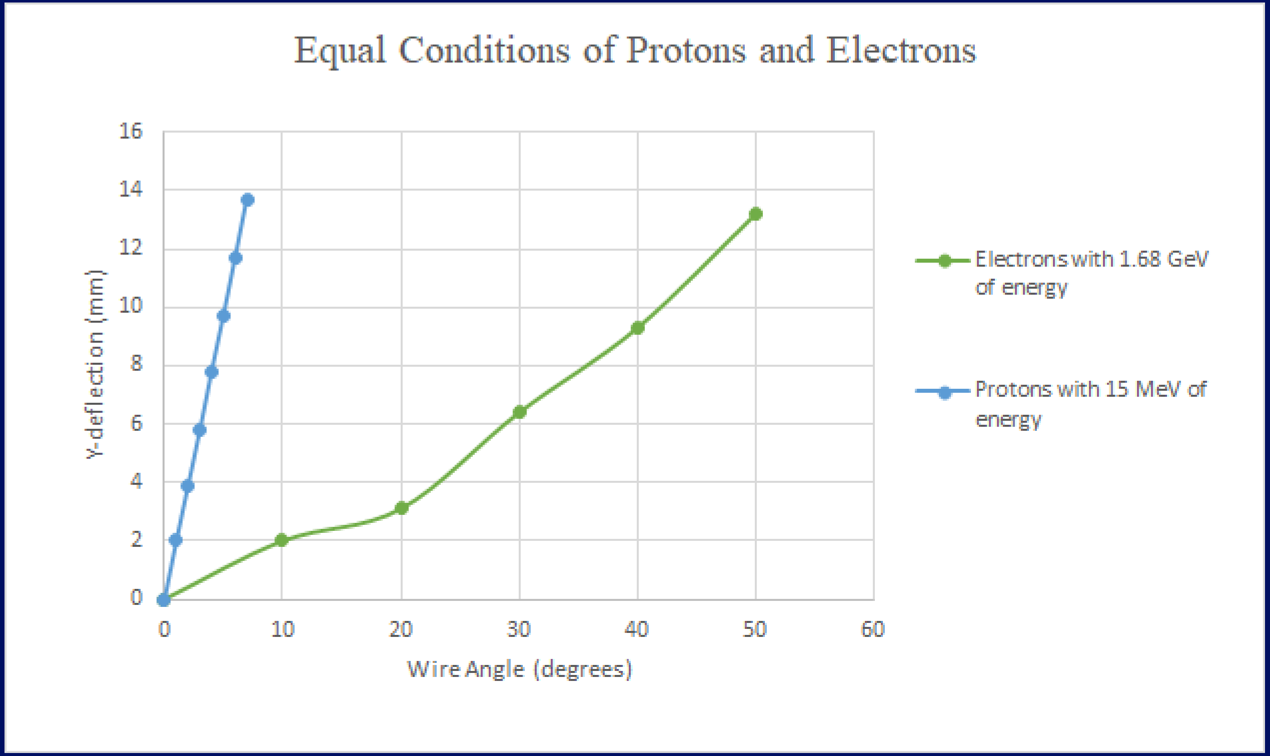
Modeling an Infinite-Length Wire

Set-up of 1 MA Current Through Wire



Much Less Deflection With Electrons





What This Means and What Comes Next

- Electrons are able to resist deflection caused by higher levels of electromagnetic fields
- Electrons seem to have a higher threshold of magnetic field strength which they can measure
- Further modeling needs to be done to account for more complex interactions of the wire (such as wire deflection)
- Eventually, we can use wakefield accelerated electron-based radiography setups in actual experiments

Thank you!

References

R. D. Petrasso, C. K. Li, F. H. Seguin, J. R. Rygg, J. A. Frenje, R. Betti, J. P. Knauer, D. D. Meyerhofer, P. A. Amendt, D. H. Froula, O. L. Landen, P. K. Patel, J. S. Ross, and R. P. J. Town, “Lorentz Mapping of Magnetic Fields in Hot Dense Plasmas,” Phys. Rev. Lett. 103, 085001 (2009).

Florian Grüner, “Shooting Ahead with Wakefield Acceleration,” APS (2019), physics.aps.org/articles/v12/19

Sefkow et al, “Design of magnetized liner inertial fusion experiments using the Z facility,” AIP Physics of Plasmas 21, 072711 (2014)

N. L. Kugland, D. D. Ryutov, C. Plechaty, J. S. Ross, and H. S. Park, “Invited Article: Relation between electric and magnetic field structures and their proton-beam images,” Review of Scientific Instruments 83, 101301 (2012).

Key Equations Used in Code

ϕ=angle of the position in space

$\Delta\alpha$=angle of deflection

$$\mathrm{B}_\phi = \frac{\mu I}{(2\pi r)}$$

$$B_x = -\frac{\mu I}{(2\pi r)} sin(\theta) sin(\phi)$$

$$B_y = \frac{\mu I}{(2\pi r)} sin(\theta) cos(\phi) - \frac{\mu I}{(2\pi r)} cos(\theta) sin(\phi)$$

$$B_z = \frac{\mu I}{(2\pi r)} cos(\theta) sin(\phi)$$

$$\Delta\alpha = \int (\mathbf{E} + \mathbf{v} \times \mathbf{B}) dl$$

$$\Delta\alpha \propto \int B dl$$

$$x = x_0 + \frac{x_0}{l} L + \alpha_x L$$

$$y = y_0 + \frac{y_0}{l} L + \alpha_y L$$