Characterizing Magnetic and Electric Fields from Laser-Driven Coils Using Axial Proton Probing

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Laser-driven coils can deliver a highly localized magnetic field without using conventional pulsed-power devices

- Axial proton probing clearly distinguishes magnetic and electric fields
- Experiments on OMEGA EP demonstrate the generation of a 60-T field at the center of the coil loop
- Axial radiographs can only be reproduced with a combination of electric and magnetic fields
Collaborators

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Laser-driven coils rely on a laser to eject electrons from a target, causing a current to be drawn from any connected source.
Transverse proton probing of laser-driven coils leaves a lot of room for interpretation

- The primary, axial magnetic field is probed with a transverse proton beam, but so is the radial electric field
- In previous proton-probing experiments the protons were completely expelled from a region around the coils
- The radial component of the magnetic field is also significant and causes rotation of a mesh fiducial, distinguishing it from the radial electric field

Axial proton probing separates magnetic and electric fields and provides information on plasma conditions inside the coil.
Experimental setup for axial proton probing of double- and single-plate, laser-driven coils on OMEGA EP

Double plate

1.25 kJ
1 ns at 3ω

Reference mesh

Protons to film pack

Single plate

OMEGA EP short pulse
0.7 ps, 300 to 450 J
Double-plate shots showed no evidence of a magnetic field at 1 ns

- Charge buildup is clearly seen at the center of the coil
- Deflection is not consistent with a magnetic field
- Plasma appears to have filled the gap between the plates or wires causing a “short circuit”

20-MeV proton probe corresponding to 1.1 ns after the start of the long pulse
Proton tracing with specified current and charge distributions was used to analyze the results.

\[ Q_{-} = -1 \times 10^{12} \]
\[ Q_{+} = 1 \times 10^{12} \]
\[ Q_{\text{ring-}} = -1 \times 10^{12} \]
\[ Q_{\text{ring+}} = 1 \times 10^{12} \]
\[ Q_{\text{center}} = -0.5 \times 10^{11} \]

No current

Radiographs in the double-plate case can be duplicated with only charge.
Comparing synthetic and experimental radiographs at two proton energies help separate B and E component contributions.

20-MeV protons

40-MeV protons
Comparing synthetic and experimental radiographs at two proton energies help separate B and E component contributions.

Simulated protons overlaid with measurement

- 20-MeV protons
- 40-MeV protons
Comparing synthetic and experimental radiographs at two proton energies help separate B and E component contributions

Simulated protons overlaid with measurement

20-MeV protons

40-MeV protons
Single-plate results indicate an axial magnetic field of ~60 T

- Distinctly different features are seen with single-plate shots; mesh stretching and twisting instead of focusing
- Mesh twisting near the parallel wires is most likely caused by magnetic fields

20-MeV proton probe corresponding to 1.1 ns after the start of the long pulse
The features can only be duplicated with both current and charge with the current localized at the edge of an electron sheath.

\[ Q_{\text{ring}^+} = 3 \times 10^{12} \]

\[ Q_{\text{ring}^-} = -2 \times 10^{12} \]

\[ Q_+ = 0.6 \times 10^{12} \]

\[ Q_- = -1 \times 10^{12} \]

\[ Q_{\text{units}} = \text{number of charges} \]

\[ I = 71.6 \text{ kA creates a 60-T B field at the center} \]
A combination of E and B fields reproduces both 20- and 40-MeV films with only minor discrepancies

20-MeV protons

Simulated

Measurement

40-MeV protons

Simulated

Measurement
A combination of magnetic and electric fields reproduces both 20-
and 40-MeV films with only minor discrepancies

20-MeV protons

40-MeV protons
A combination of magnetic and electric fields reproduces both 20- and 40-MeV films with only minor discrepancies.
Laser-driven coils can deliver a highly localized magnetic field without using conventional pulsed-power devices

Summary/Conclusions

- Axial proton probing clearly distinguishes magnetic and electric fields
- Experiments on OMEGA EP demonstrate the generation of a 60-T field at the center of the coil loop
- Axial radiographs can only be reproduced with a combination of electric and magnetic fields

Future experiments will work toward developing ways to model laser-driven coils and quantify mesh displacement.
Axial radiographs can only be reproduced with a combination of electric and magnetic fields.
A combination of E and B fields reproduces both the 20 and 40 MeV films with only minor discrepancies.
Transverse proton probing has difficulties distinguishing a magnetic field from electric field.
The radial component of a magnetic field rotates axial probing protons; electric field focuses/defocuses protons.
Protons initial incidence angle and first deflection breaks symmetry of radial magnetic field

Protons from a point source incident at an angle along X