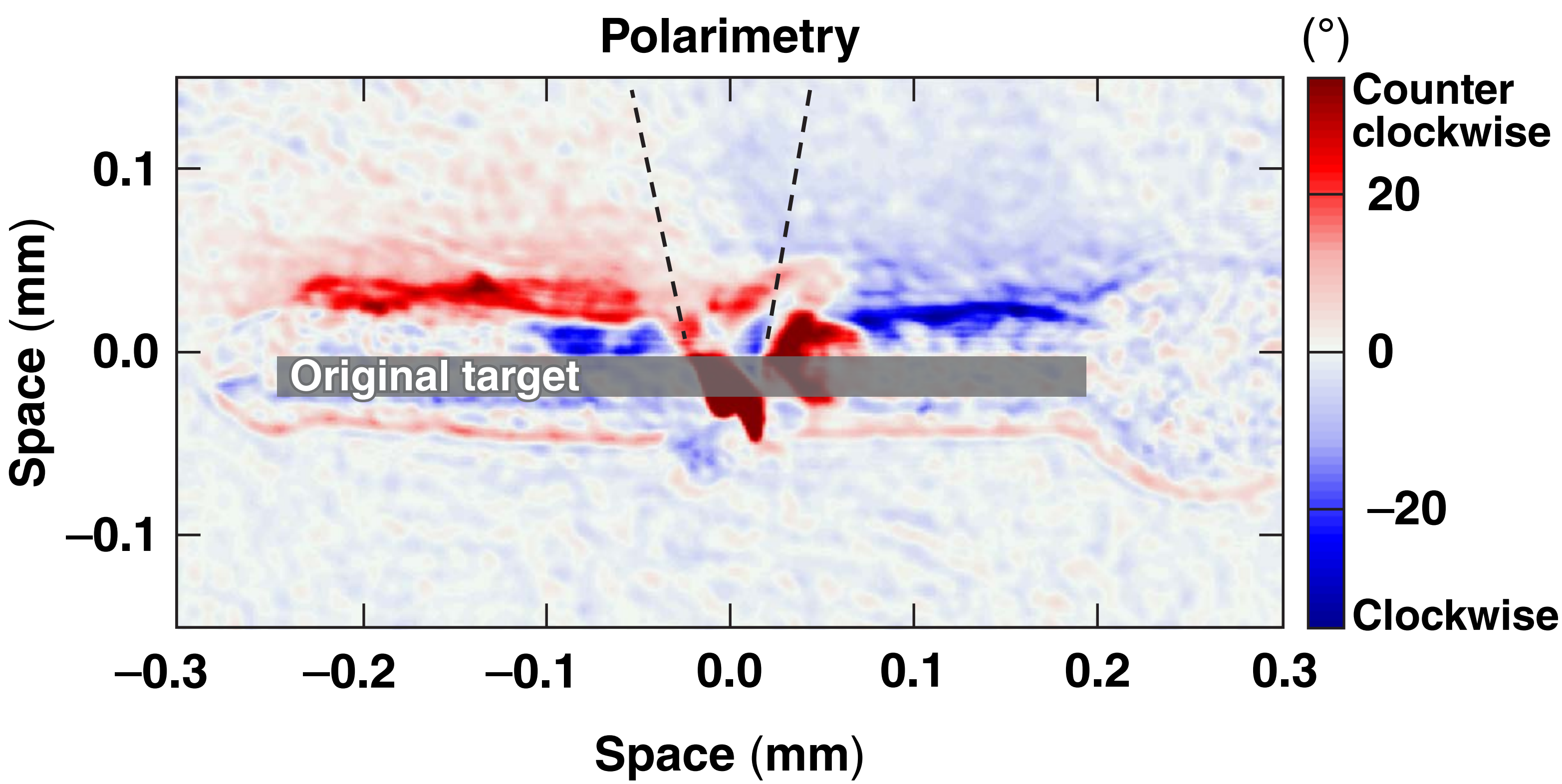
Self-Generated Magnetic Fields in a Laser-Produced Plasma with High-Intensity Beams



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Summary

Toroidal magnetic fields are measured around the focus of the high-power OMEGA EP laser beams

- The 4ω probe diagnostic system was used to study magnetic-field generation in high-power laser–solid target interactions
- Polarimetry* measured the polarization rotation of the probe beam
- Angular filter refractometry (AFR)** measured the plasma density profile

The magnitude of the magnetic field was estimated to be ~8 MG.

*A. Davies *et al*., Rev. Sci. Instrum. 85, 11E611 (2014).
**D. Haberberger *et al*., Phys. Plasmas 21, 056304 (2014).

Collaborators

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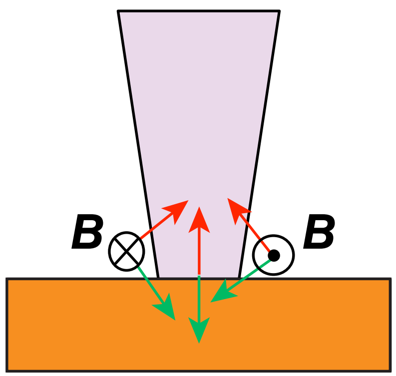
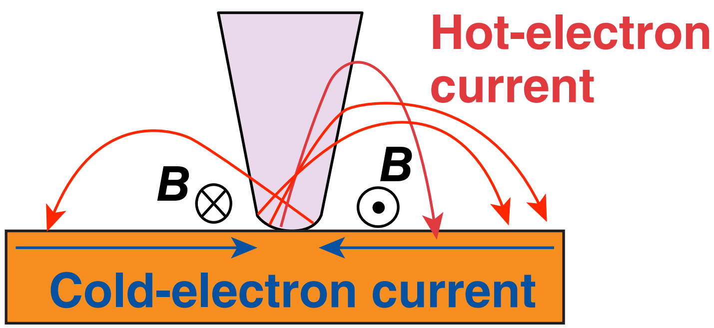
Toroidal megagauss magnetic fields applicable to astrophysical and laser-plasma environments are expected to occur along the surface of a laser-irradiated target

Biermann battery*



$$\partial B/\partial t \sim -\nabla n \times \nabla T$$

Fast-electron current**



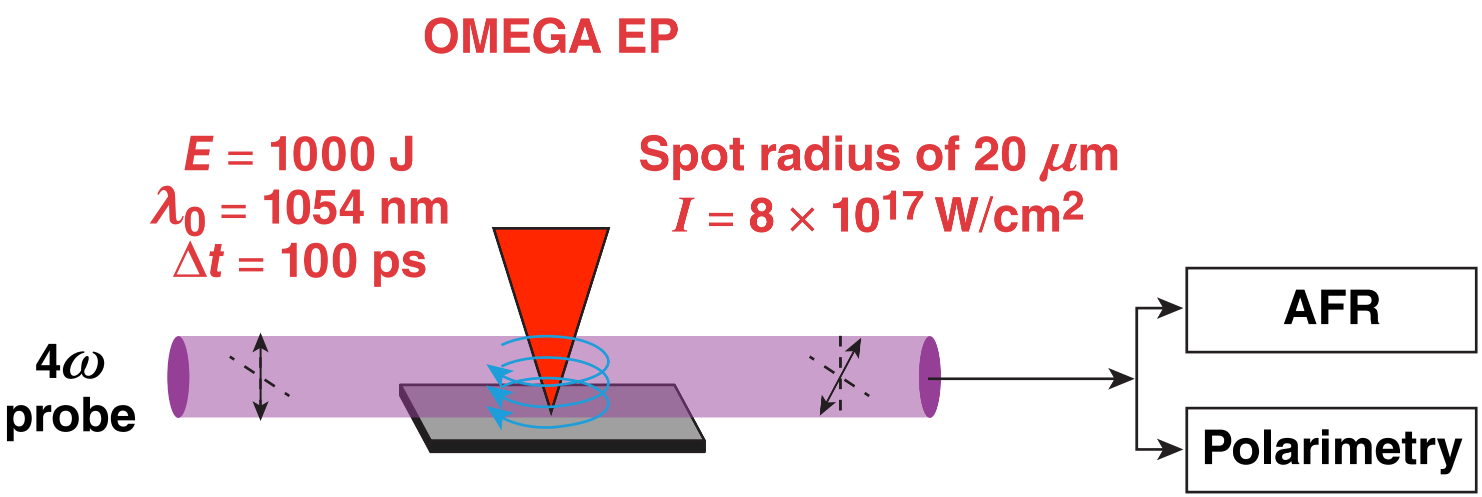
$$\partial B/\partial t \sim \nabla \times J_{hot}$$

Field strength ~ 1 MG to 10 MG

Experimental evidence distinguishing the relative contribution of these mechanisms is limited.

*J. A. Stamper *et al*., Phys. Rev. Lett. 26, 1012 (1971).
**Y. Sakagami *et al*., Phys. Rev. Lett. 42, 839 (1979); J. J. Thomson, C. E. Max, and K. Estabrook, Phys. Rev. Lett. 35, 663 (1975).

Experiments were designed to measure the magnetic fields generated around the focus of the high-power laser pulse for a variety of configurations

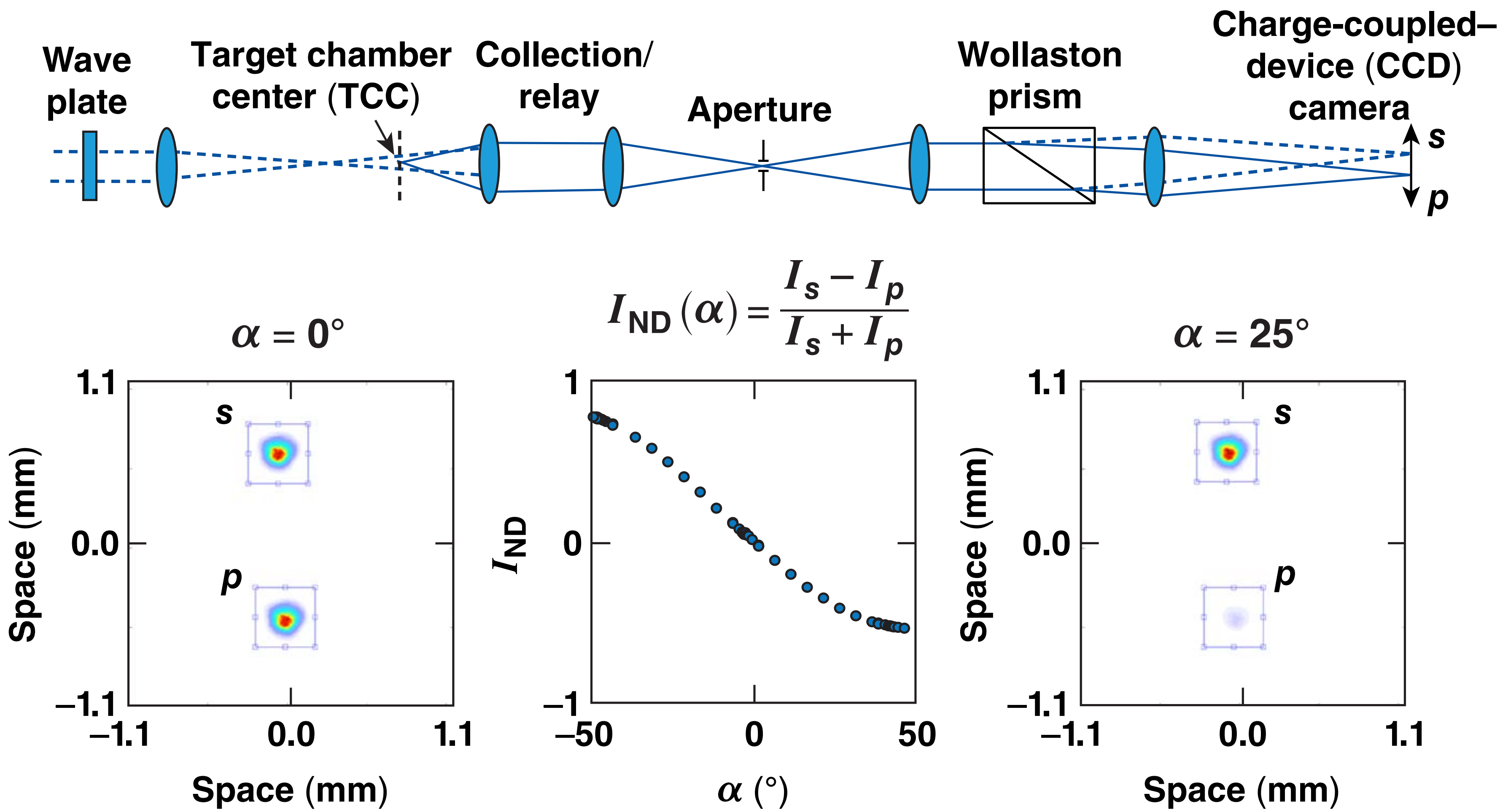


Faraday effect: $\Delta\theta = \frac{e}{2m_e c} \int_{-\infty}^{\infty} \frac{n_e}{n_c} B \cdot d\ell$

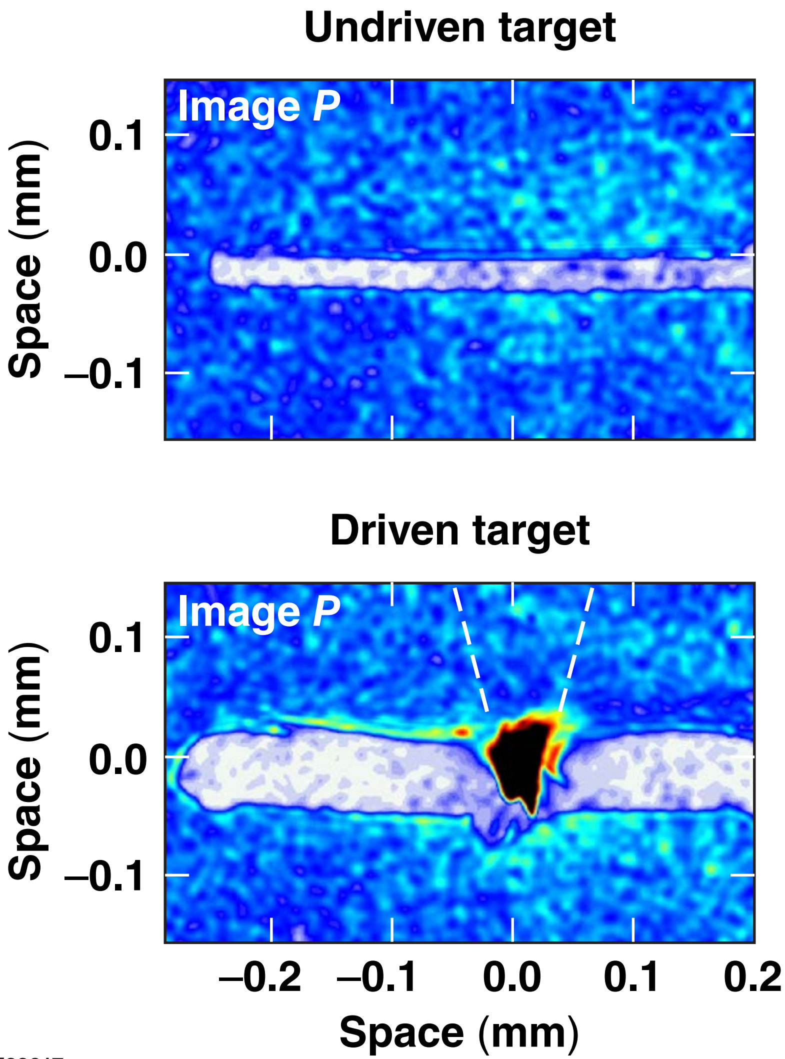
n_e: AFR
$\Delta\theta$: polarimetry

The magnetic field can be calculated from the Faraday effect equation by measuring polarization rotation $\Delta\theta$ and plasma density n_e.

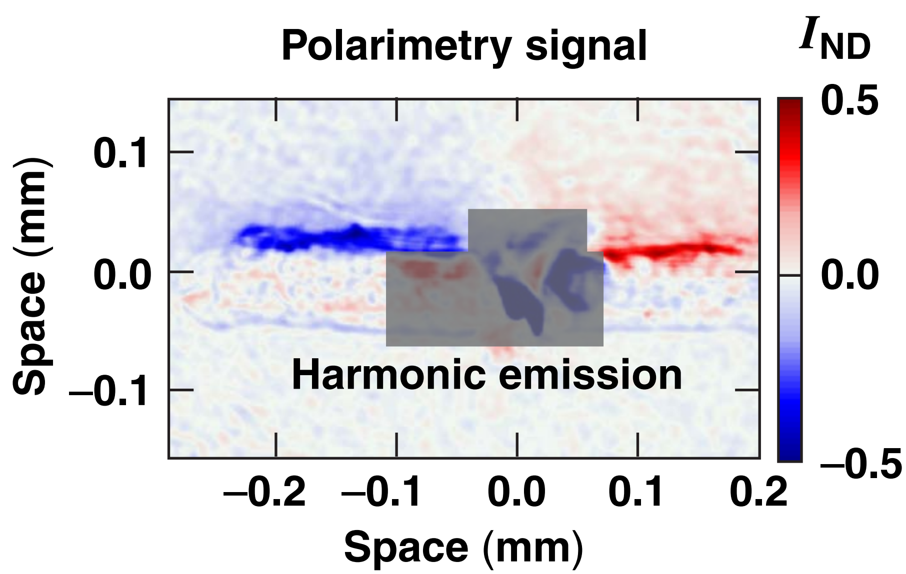
A $\lambda/2$ wave plate was used to rotate the polarization in a controllable manner to calibrate the polarimetry diagnostic



Equal and opposite polarimetry signals were observed on the sides of the laser focus, indicating toroidal magnetic fields

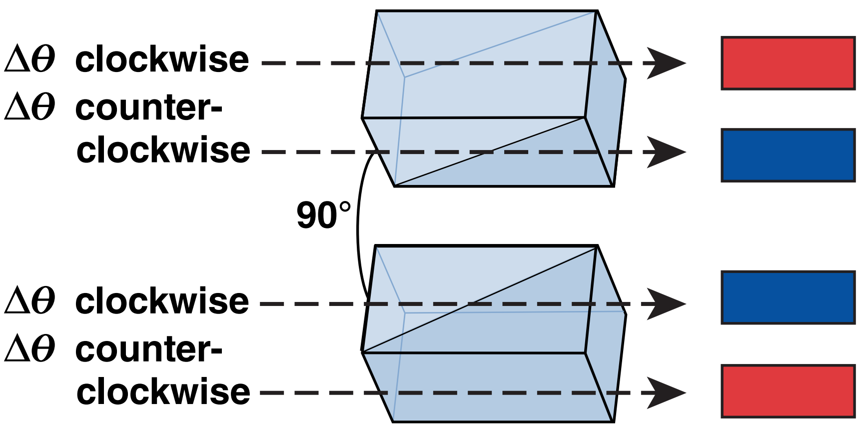


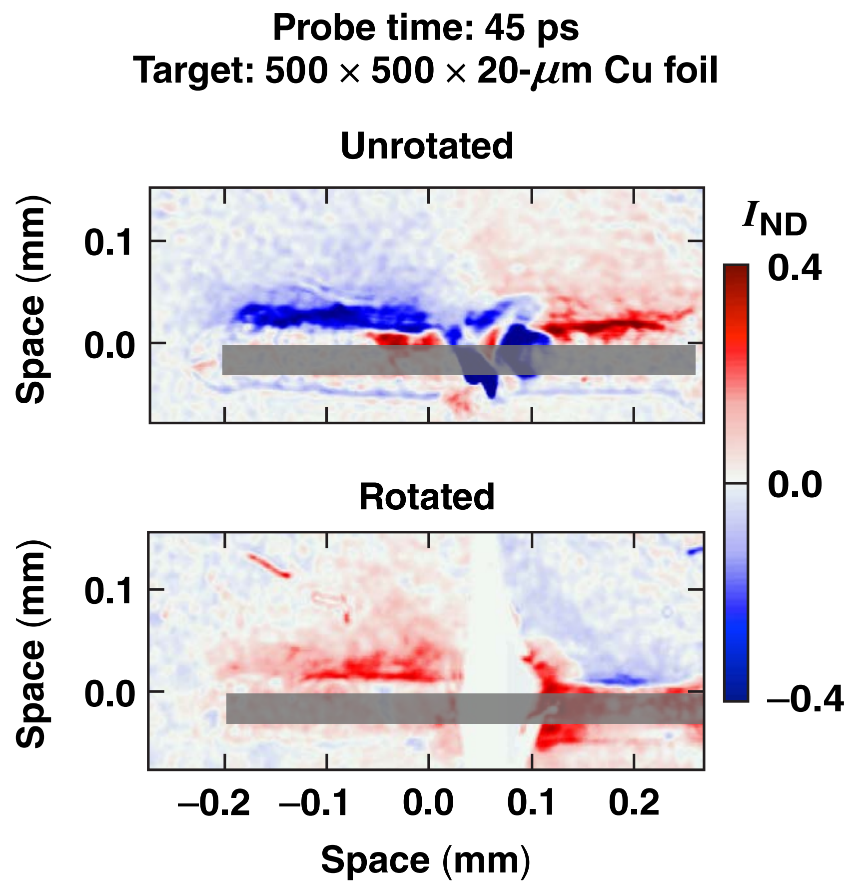
$$I_{\mathrm{ND}}(\alpha) = \frac{I_s - I_p}{I_s + I_p}$$



E23617

Rotating the Wollaston prisms by 90° tests if the observed signal is caused by polarization rotation

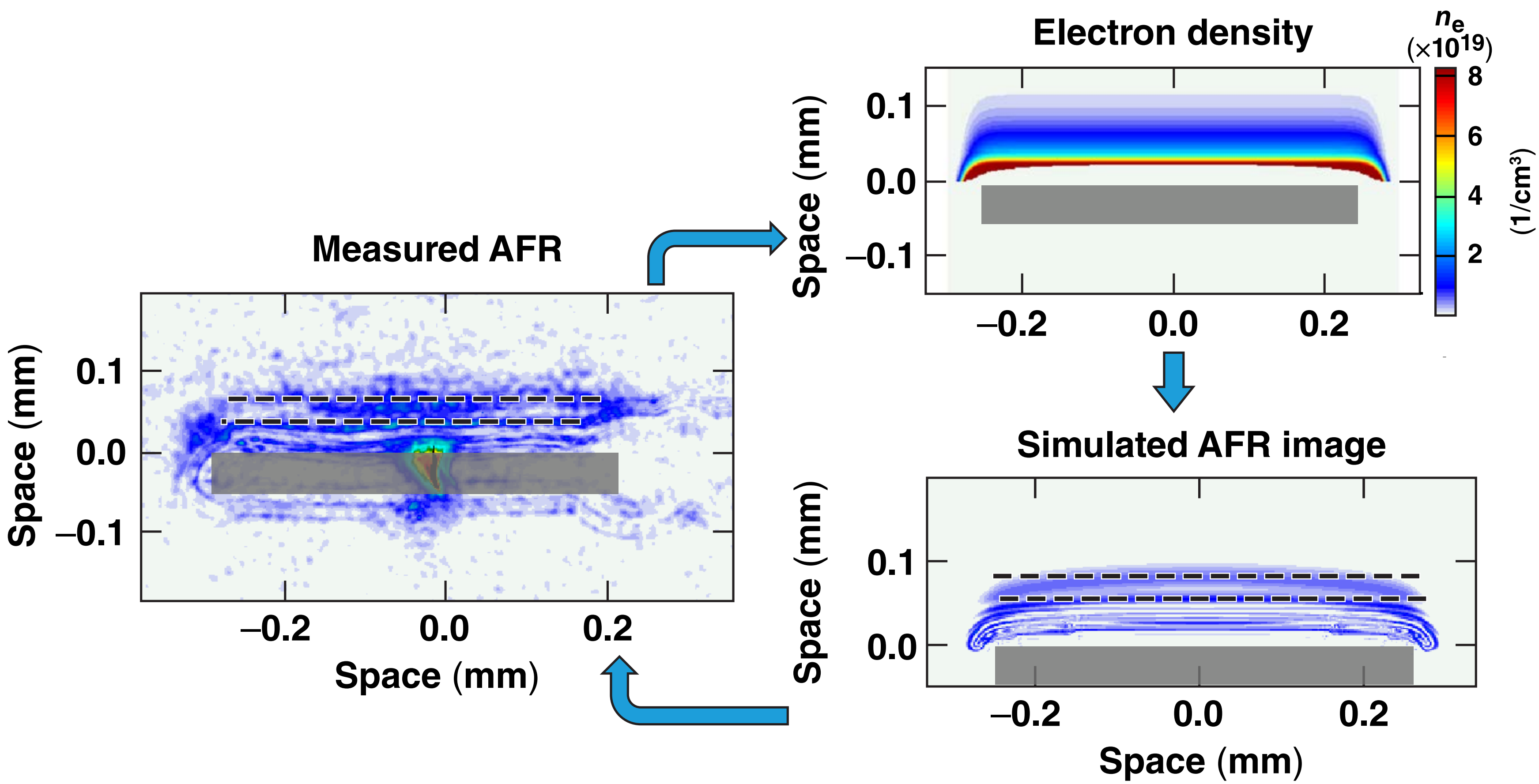




This test confirms that the observed signals are from polarization rotation.

E23618

The electron density can be inferred from AFR by simulating the AFR signal for a given density profile

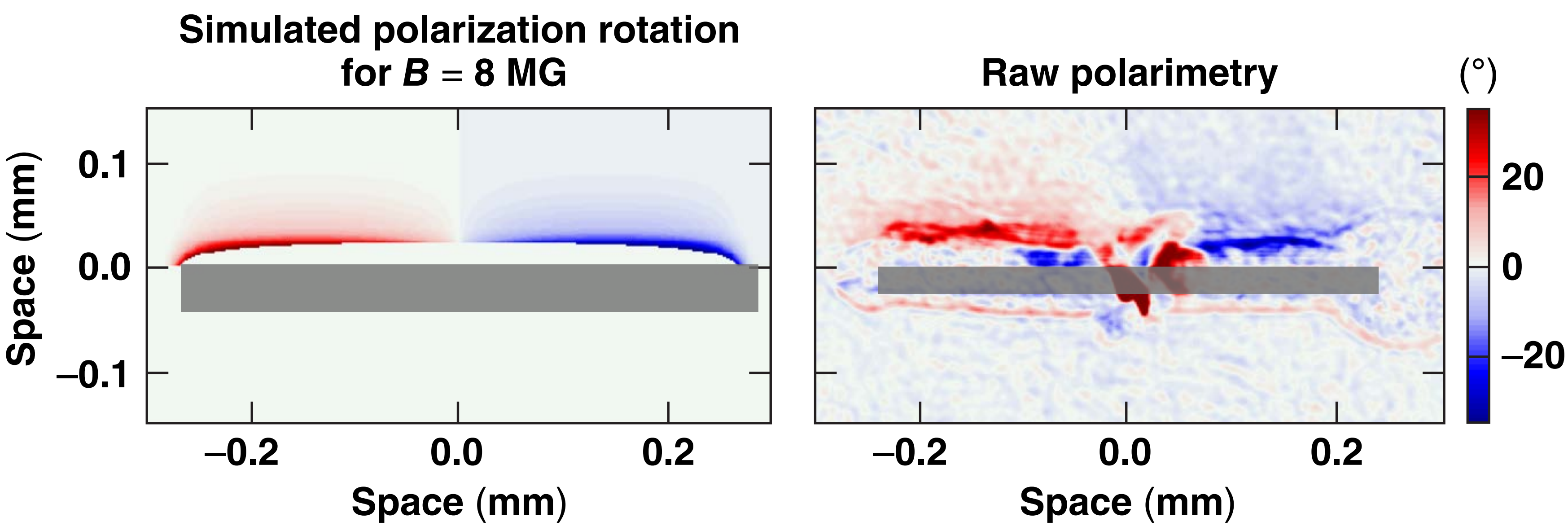


By matching the bands' distances from the original target surface, the coronal density profile can be obtained.

E23619

The approximate magnetic field is calculated using the polarization rotation and electron density

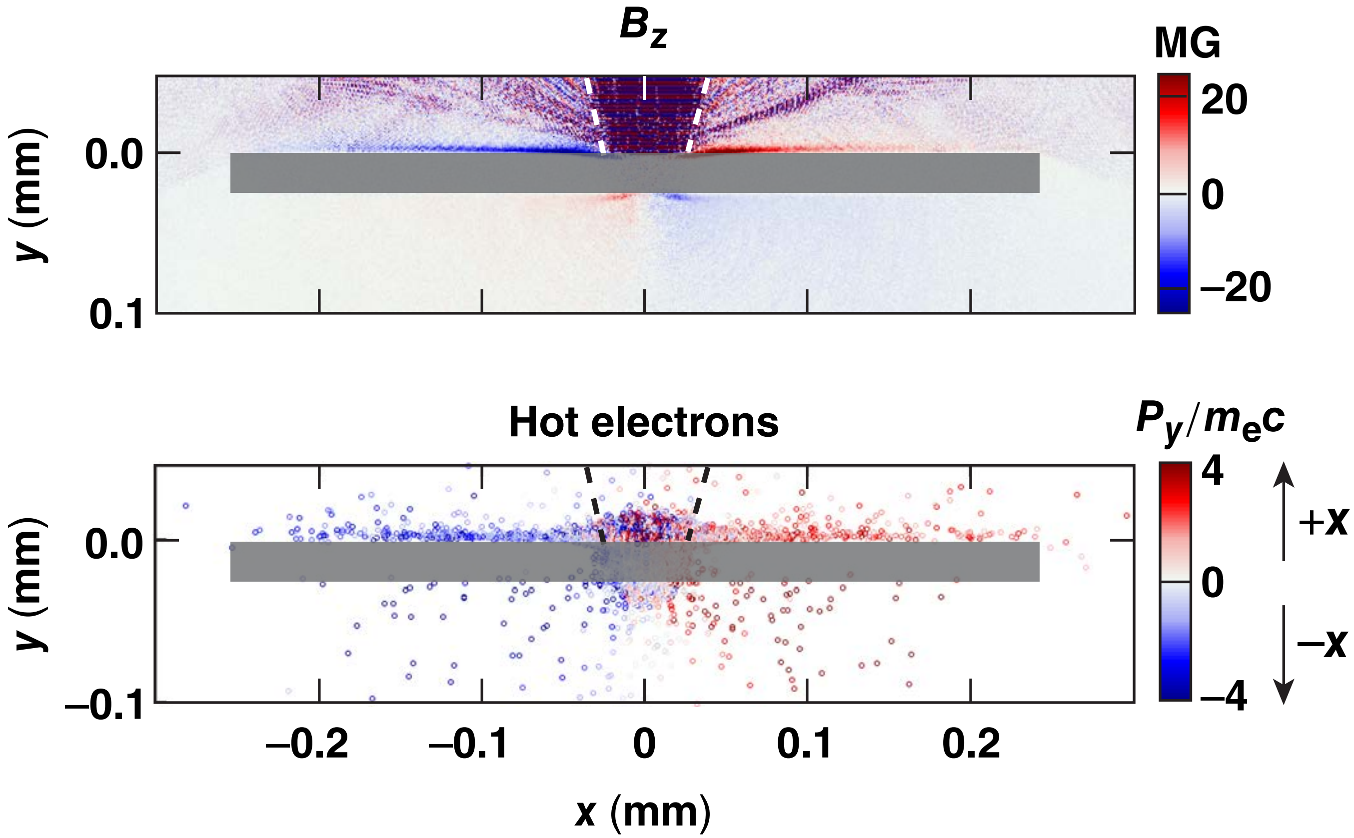
$$\Delta\theta = \frac{e}{2m_e c}\int_{-\infty}^{\infty}\frac{n_e}{n_c}B\cdot d\ell$$



Our results are consistent with a toroidal magnetic-field magnitude of ~8 MG.

E23620

OSIRIS particle-in-cell (PIC) simulations show the generation of magnetic fields of similar magnitude and extent to experimental data



Tracking hot electrons in PIC simulations suggest that the fountain effect could be responsible for the toroidal B field.

E23621

Toroidal magnetic fields are measured around the focus of the high-power OMEGA EP laser beams

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