Design of Experiments to Study Relativistically Transparent Magnetic Filaments Using OMEGA EP

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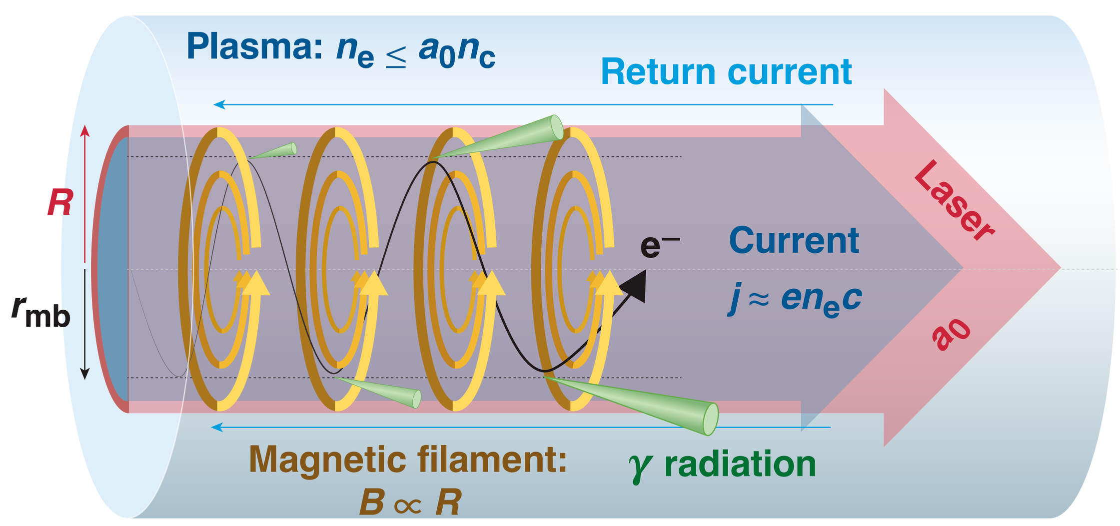
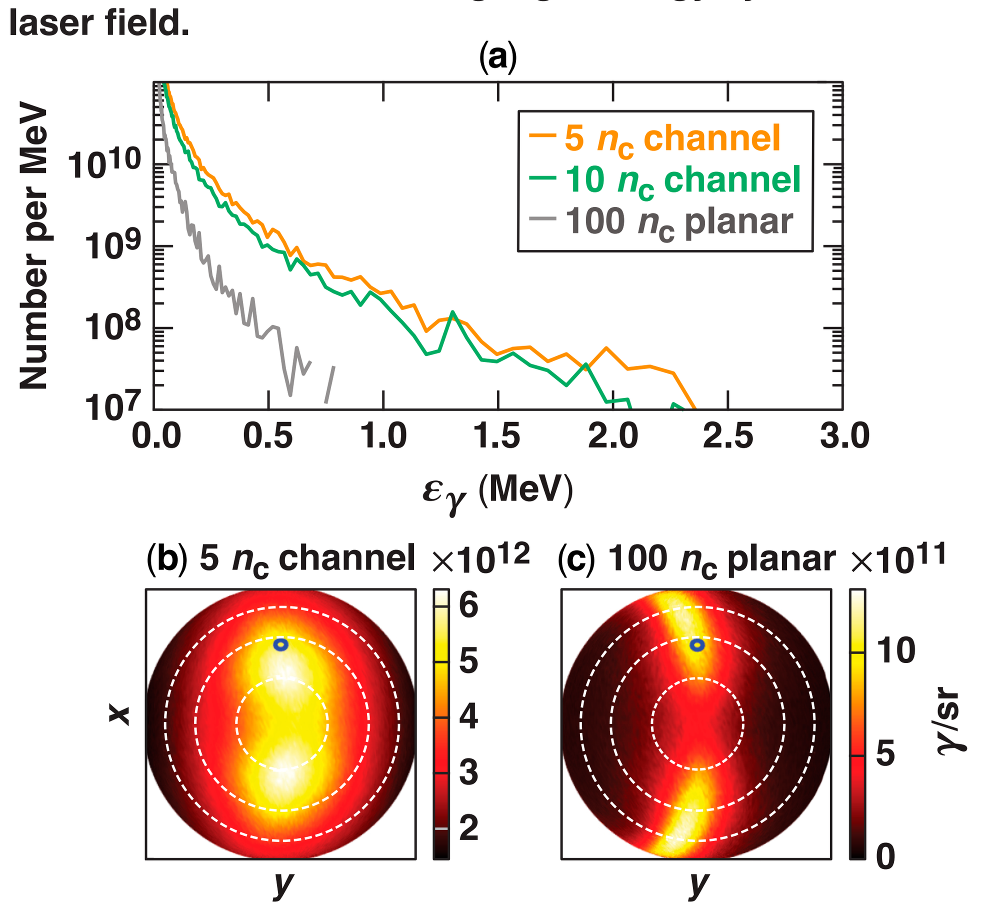
Introduction

In relativistically transparent interactions, intense lasers can drive relativistic currents and azimuthal magnetic filaments in classically overdense plasmas. We designed experiments to study the efficiency of electron acceleration and x-ray production by relativistically transparent magnetic filaments in near-critical-density, foam-filled microchannel targets. We predict that by varying the density of the target, the characteristic energy and number of radiated photons can be controlled.

Background



Qualitative picture of magnetic filamentation. A laser drives a current in a relativistically transparent plasma. This current generates a return current outside the laser radius. The coaxial currents generate a strong azimuthal magnetic field. Electrons that would normally be deflected by the laser can be trapped by the azimuthal magnetic field and rapidly accelerated while also emitting high-energy synchrotron radiation as they oscillate in the laser field.



(a) Spectrum of photons generated in particle-in-cell (PIC) simulations: 6-μm-ID channels filled with 5× critical density (orange curve) and 10× critical density plasma (green curve); and planar targets with 100× critical density plasma (blue curve). [(b),(c)] Angular distribution of radiated photons with energy above 10 keV for the (b) 5× critical density-filled channel and (c) 100× critical density planar target. Note that the color scales differ by a factor of approximately ~5. The blue circle is the direction of the detector in simulations. The white dashed circles are angles of 20°, 40°, 60° from the laser axis.

References

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[4] H. Chen *et al.*, Rev. Sci. Instrum. 79, 10E533 (2008).
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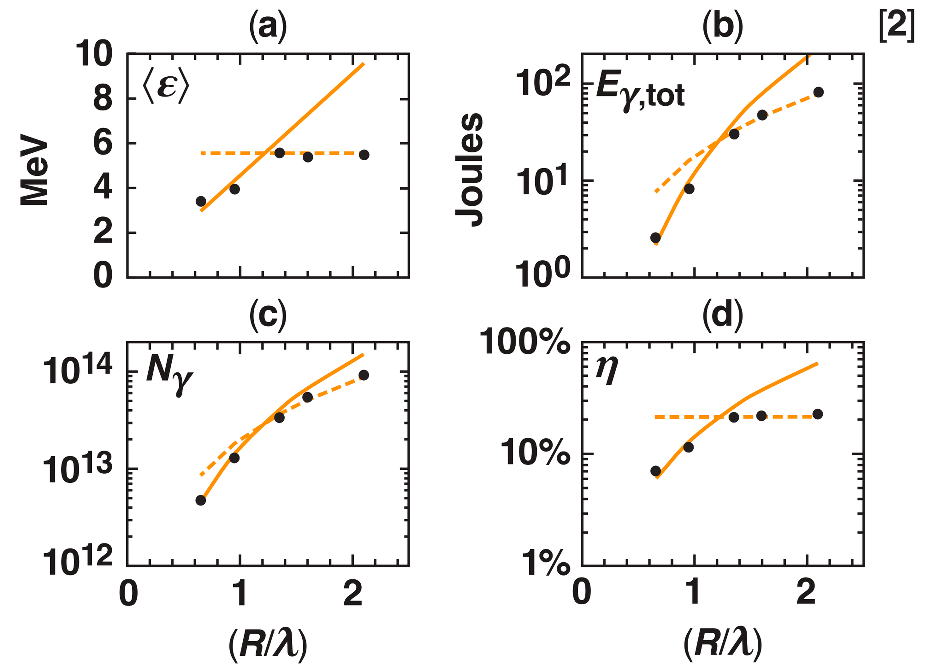
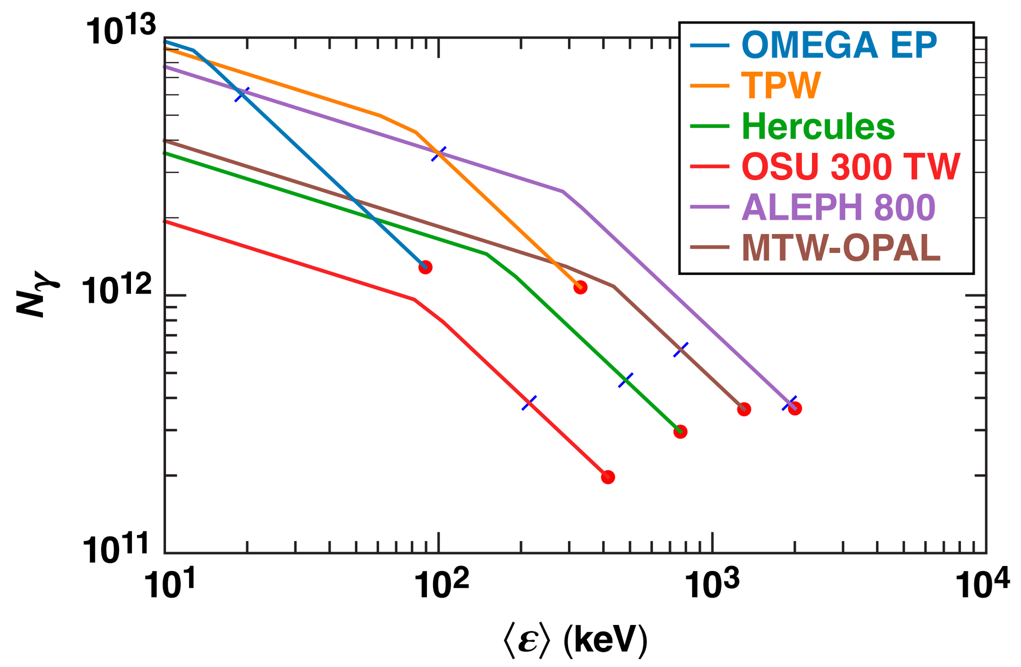
Theory



We have developed analytic scaling laws to predict quantities related to the photon spectrum produced by magnetic filaments: (a) average energy per photon $\langle\varepsilon\rangle$, (b) total photon energy $E_{(\gamma,tot)}$, (c) total number of photons N_γ, and (d) efficiency η. Here, we have fit the scaling laws (orange curves) to the results of a 3-D PIC simulation [2] with $a_0 = 190$ (black points).

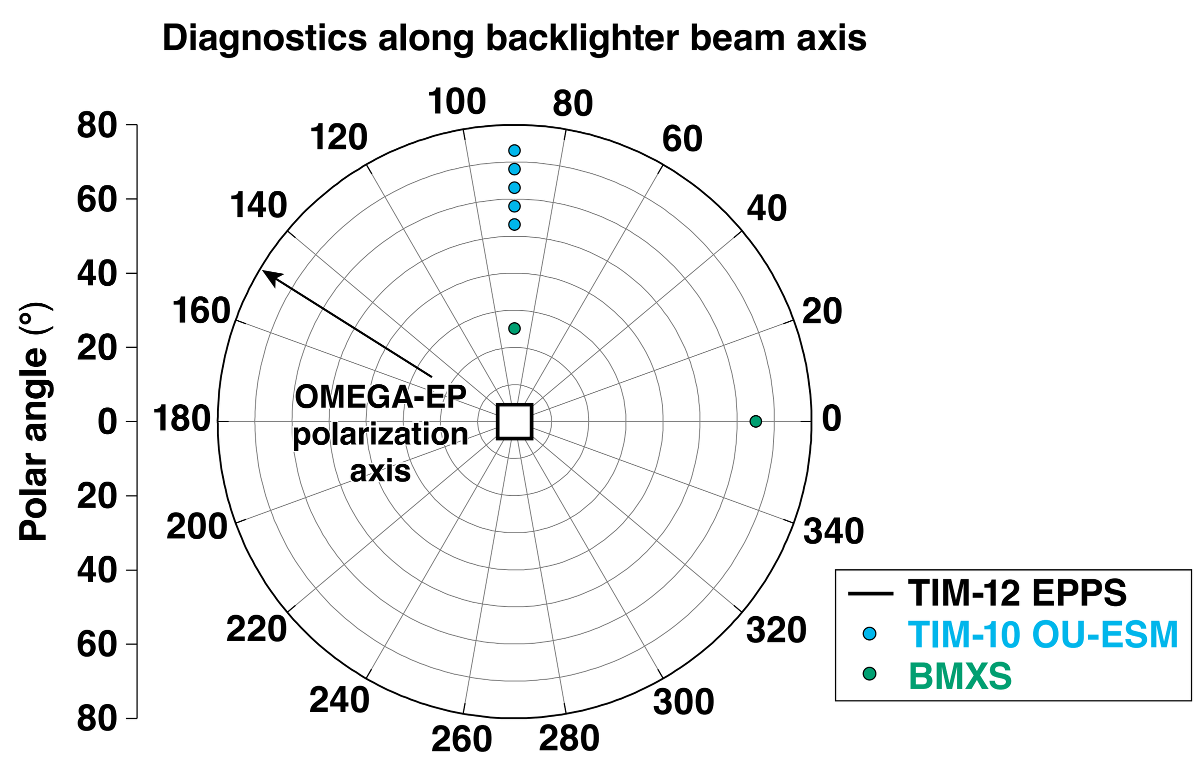


Laser name	Normalized intensity	Focal spot radius (μm)	Pulse length (fs)	Wavelength (nm)
OMEGA EP	21*	1.5*	700	1054
Texas Petawatt	30*	2.0	140	1057
Hercules	37	1.5	30	815
OSU 300 TW	30	1.5	30	815
ALEPH 800	54	1.2	30	800
MTW-OPAL	43*	2*	15*	910*

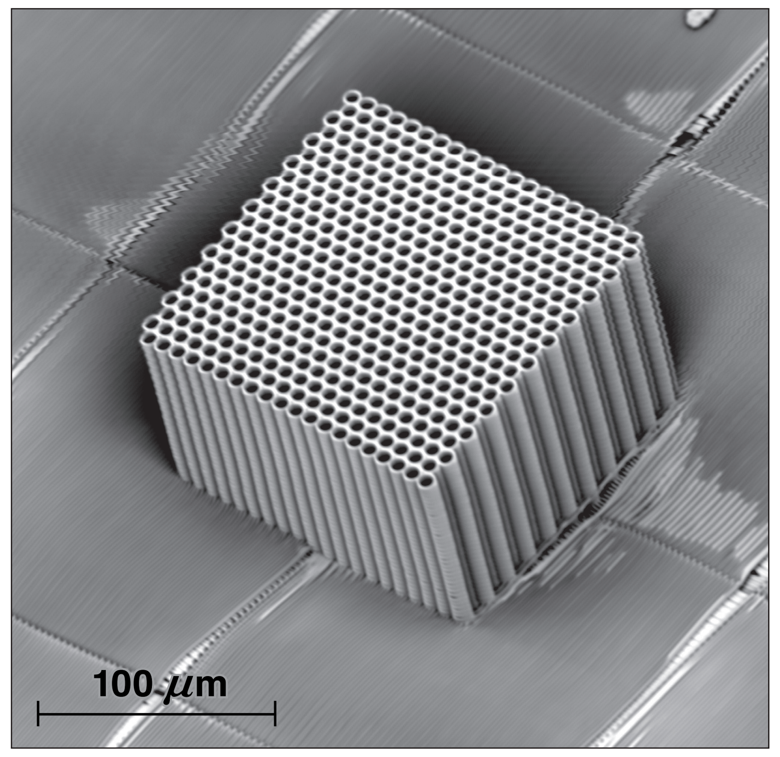
Laser parameters used in this plot are shown in the table. Parameters obtained independently noted by an asterisk. All other parameters derived from specifications given on lasernetus.org.

Based on our analytic scaling laws, we have predicted characteristics of the achievable photon spectra for various laser systems. Each line is a parametric plot of total number of photons N_γ versus average energy per photon $\langle\varepsilon\rangle$ as functions of target density. Target density decreases from left to right on this plot. The theoretical minimum density for magnetic filamentation was proposed by Gong *et. al.* [3] (red points). The blue bars are the minimum solid density currently achievable experimentally.

Experimental design



Proposed arrangement of diagnostics for experiments on OMEGA EP planned for 11/17/2021. Electron–proton–positron spectrometer (EPPS) [4] with front image plate (black line). Two bremsstrahlung MeV x-ray spectrometers (BMXS) [5] (green points). Osaka University electron spectrometer (OU-ESM) [6] with five spectrometry channels (blue points). An additional EPPS with front image plate will be deployed on the sidelighter beam axis so that shots can be alternated between the backlighter and sidelighter.



Microchannel targets printed by A. Haid using two-photon polymerization. When filled with relativistically transparent foam, these overdense microchannels act as guides for magnetic filaments. This prevents hosing instability, which alters the direction of the emitted photons and electrons. Microchannels are hex packed to maximize the chances of the laser striking foam, an improvement over previous experiments.

Main conclusions

There are three main points we wish to emphasize

1. We will experimentally test whether relativistically transparent microchannels can produce wide-spectrum x rays as predicted.
2. Theoretically, the characteristics of the photon spectrum can be adjusted by varying the density of the target and the intensity of the laser.
3. Probing the high-energy x-ray limit will require higher-intensity lasers and/or lower-density (potentially gas-filled) targets.

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