Designing and Testing Optical Concentrator Targets for High-Intensity Lasers

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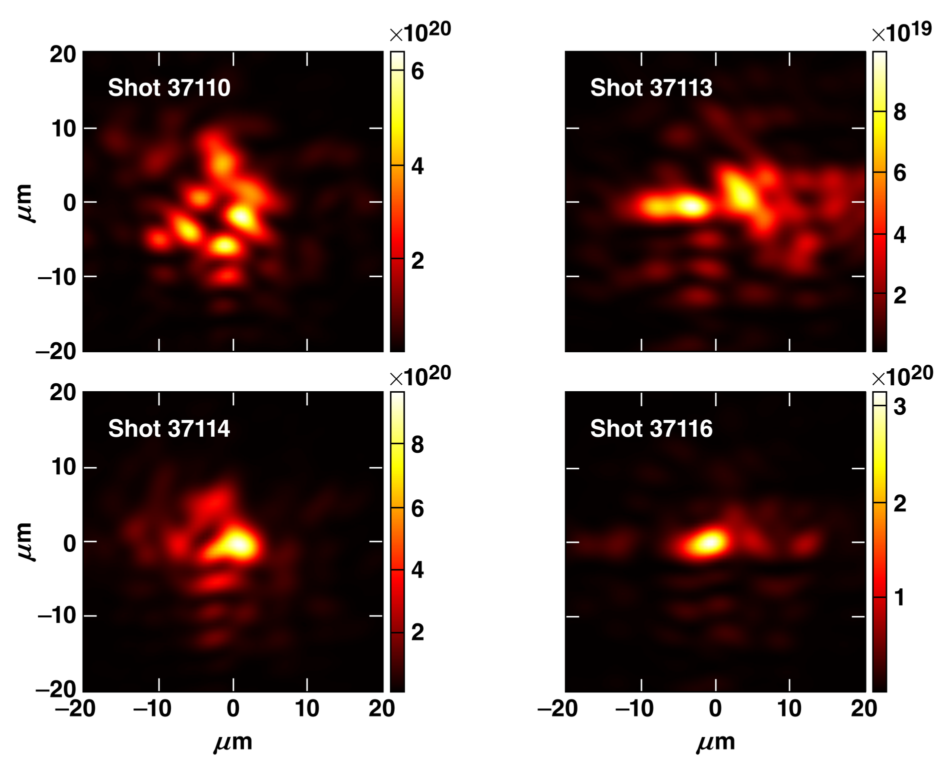
[4]General Atomics

Background

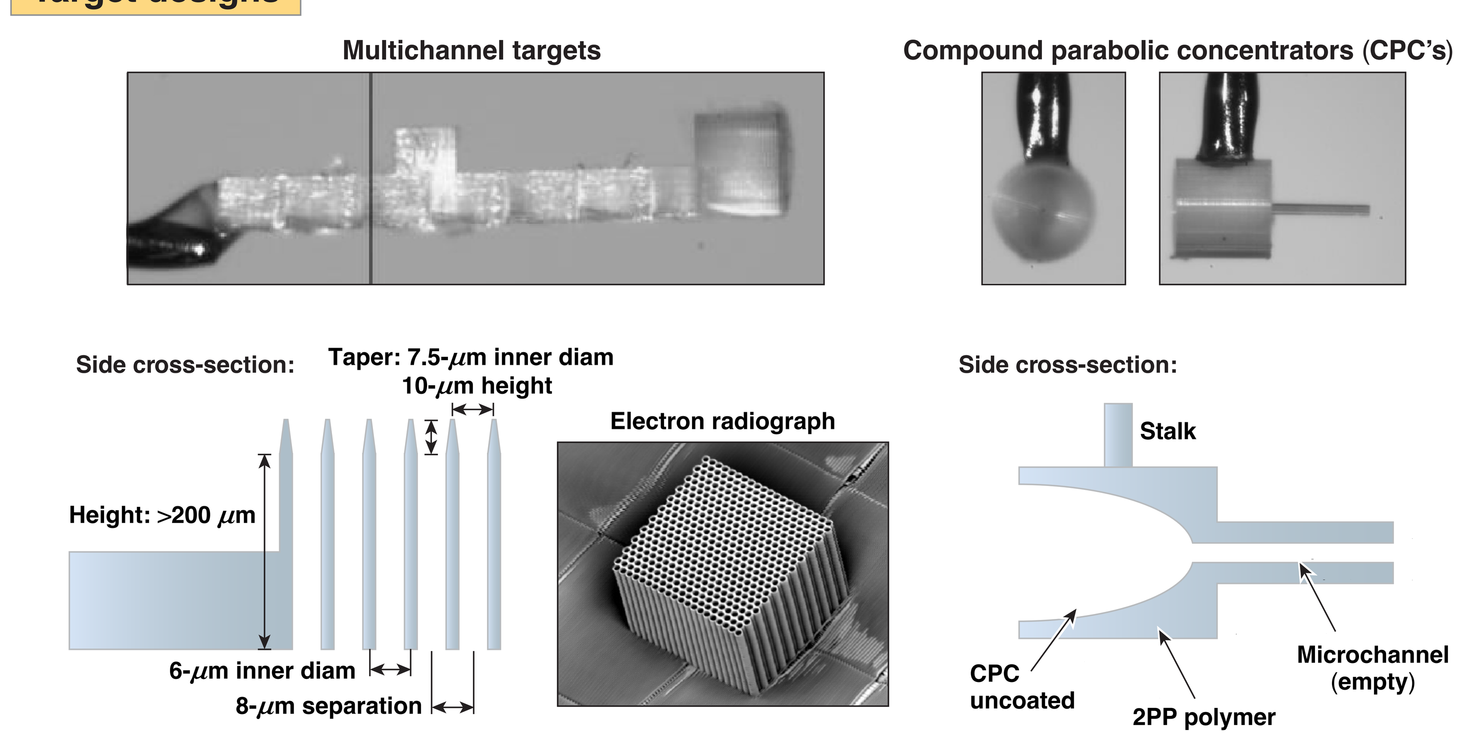
Microchannel experiments

We attempt to send a relativistic laser pulse down a micron-scale tube of overdense material. The tube may be empty or filled with relativistically underdense material. The tube acts as a waveguide through which the laser pulse propagates. During the interaction, energy from the laser pulse is transferred to electrons in the tube, which are accelerated.



Sending a laser pulse down a microscale tube is difficult due to shot-to-shot variability. Although the highest-intensity focus of the OMEGA EP beam (as shown above by the focal-spot diagnostic) can be smaller than 2 μm in radius, speckles in the beam and pointing instability mean that we cannot hit a single microchannel reliably.

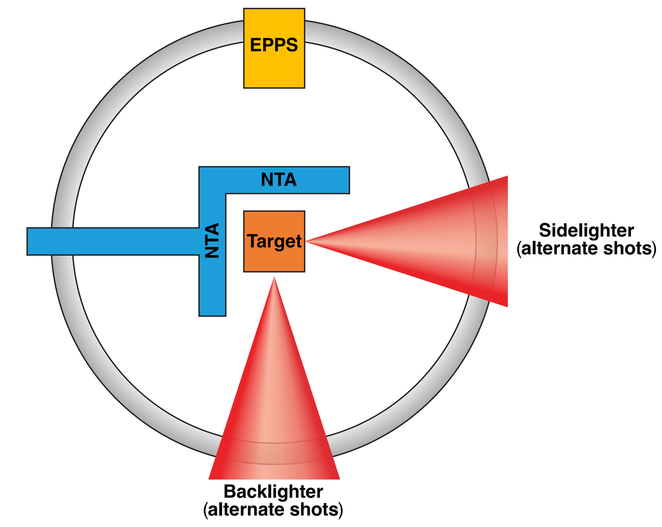
Target designs



We have developed two target designs to increase the efficiency of coupling with a microchannel. Multichannel targets use about 400 microchannels arranged in a close-packed hexagonal array in order to maximize the likelihood of laser light entering one or more channel openings. Compound parabolic concentrator targets use a flared opening to reflect misdirected laser energy into a single channel.

Experimental Results

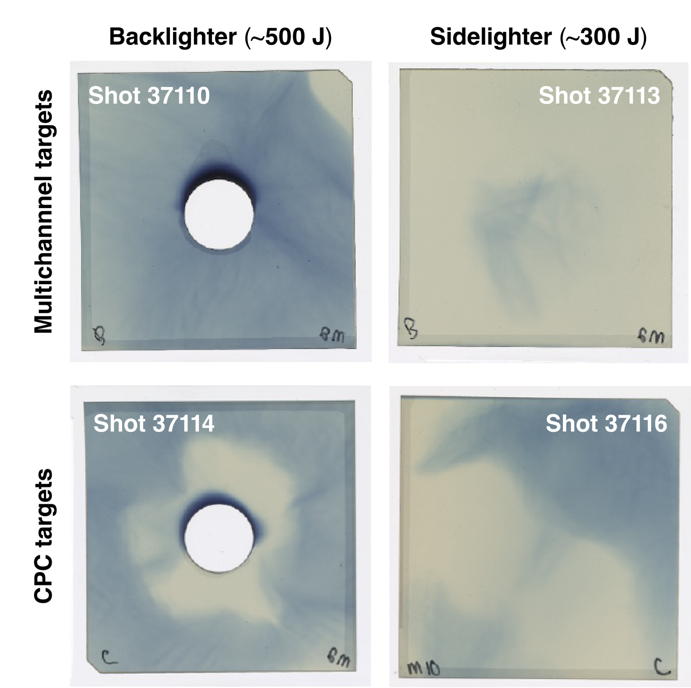
Diagnostic setup



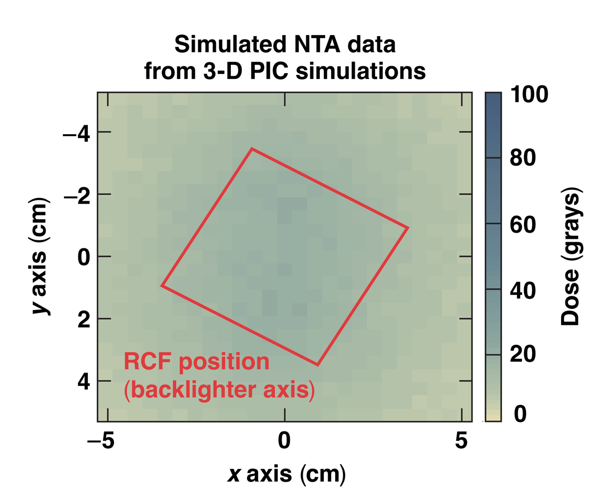
We tested these microchannel targets using the OMEGA EP laser on 15 June 2022. To maximize the amount of data gathered, we alternated shots on the backlighter and sidelighter beams.

EPPS: electron–proton–positron spectrometer
NTA: near-target arm

Radiochromic films from the NTA diagnostic



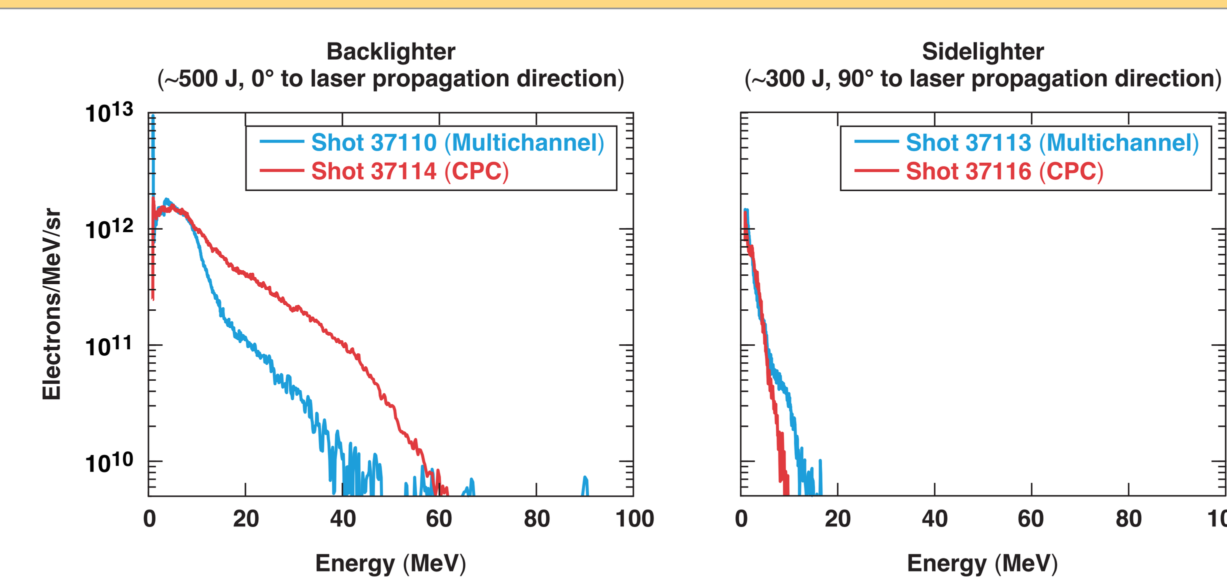
Radiochromic films from the NTA diagnostic are held 9.1 cm away from the microchannel outlet in the direction of laser propagation. The radiation produced by the microchannel interaction was filtered with 1.1 cm of Teflon, which eliminates electrons below 4 MeV. Thus, these films show that the angular distribution of emitted electrons above 4 MeV was significantly different for multichannel and CPC targets.



We ran a 3-D PIC simulation of a laser with the same parameters as an OMEGA EP short-pulse beam entering a 40-μm channel filled with a 1 n_c density foam with 100-n_c density walls. We show a plot of the fluence of electrons above 3.5 MeV produced by this interaction, projected onto a plane 9 cm away from target chamber center for comparison with our NTA data. The size of an NTA film pack is shown in red.

RCF: radiochromic film
PIC: particle-in-cell

Electron spectra measured by the electron–proton–positron spectrometer (EPPS) [1]



For backlighter and sidelighter shots, respectively, the EPPS was positioned at 0° and 90° relative to the axis of laser propagation. The results indicate that relative to the multichannel targets, the CPC targets produced more energetic electrons in the forward direction, but fewer energetic electrons orthogonal to laser propagation. This suggests that the CPC targets accelerate electrons more effectively.

Concentrator Designs

Original concentrator design

CPC's were originally designed for collecting diffuse Cherenkov radiation into a detector [1]. Any photon that enters the top of the CPC at an angle of θ or less will be reflected off the walls until it exits the aperture of radius r at the bottom of the CPC. CPC's have been used previously with high-intensity lasers [2], but a CPC may not be optimal for the problem of guiding a focused laser beam into a microchannel.

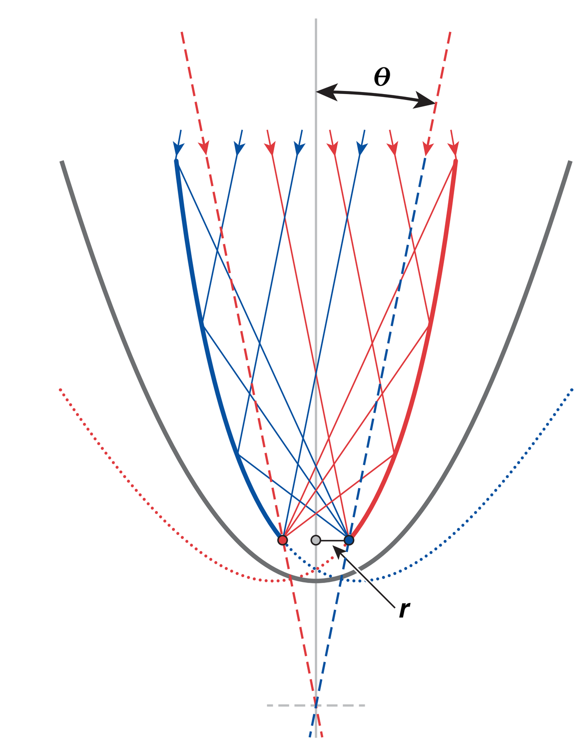
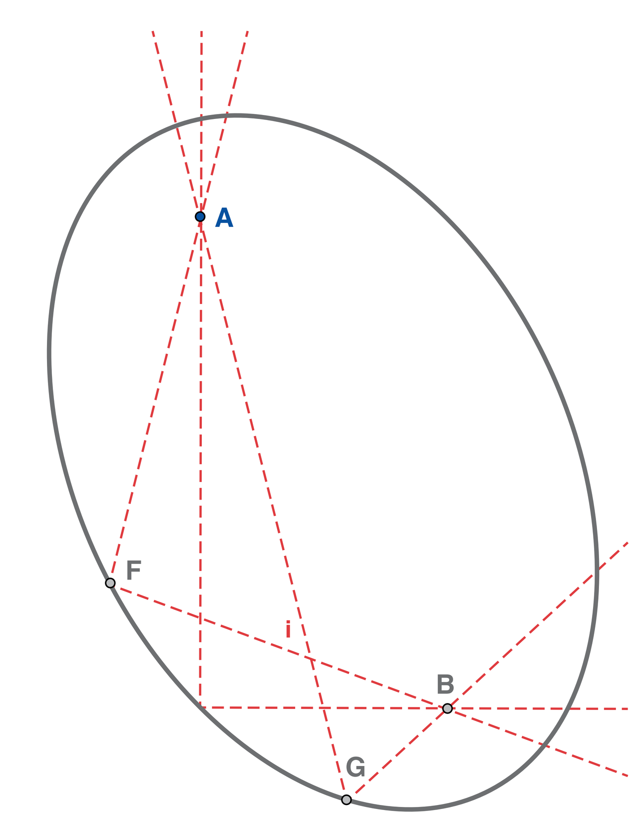


Figure from MacPhee *et al.* [3]



Elliptical concentrator design

An alternative design we are considering is an elliptical concentrator, shown at left. If we hit one focus of the ellipse with our laser (shown here as an *f*/2 laser hitting Point A), the beam will be reimaged to the other focus of the ellipse (Point B). By changing the eccentricity of the ellipse and the angle at which we hit the first focus, we can change the beam direction and magnification at the second focus. Demagnifying the laser spot reduces both the spot size and the pointing variation.

Summary

We have studied the performance of both multichannel and CPC microchannel targets in experiments on OMEGA EP. We observed that the CPC targets produced greater numbers of electrons, higher energy electrons, and different angular distributions of electrons as compared to the multichannel targets. New concentrator designs, including elliptical concentrator targets, will be tested on experiments on OMEGA EP in April 2023.

Acknowledgements

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References

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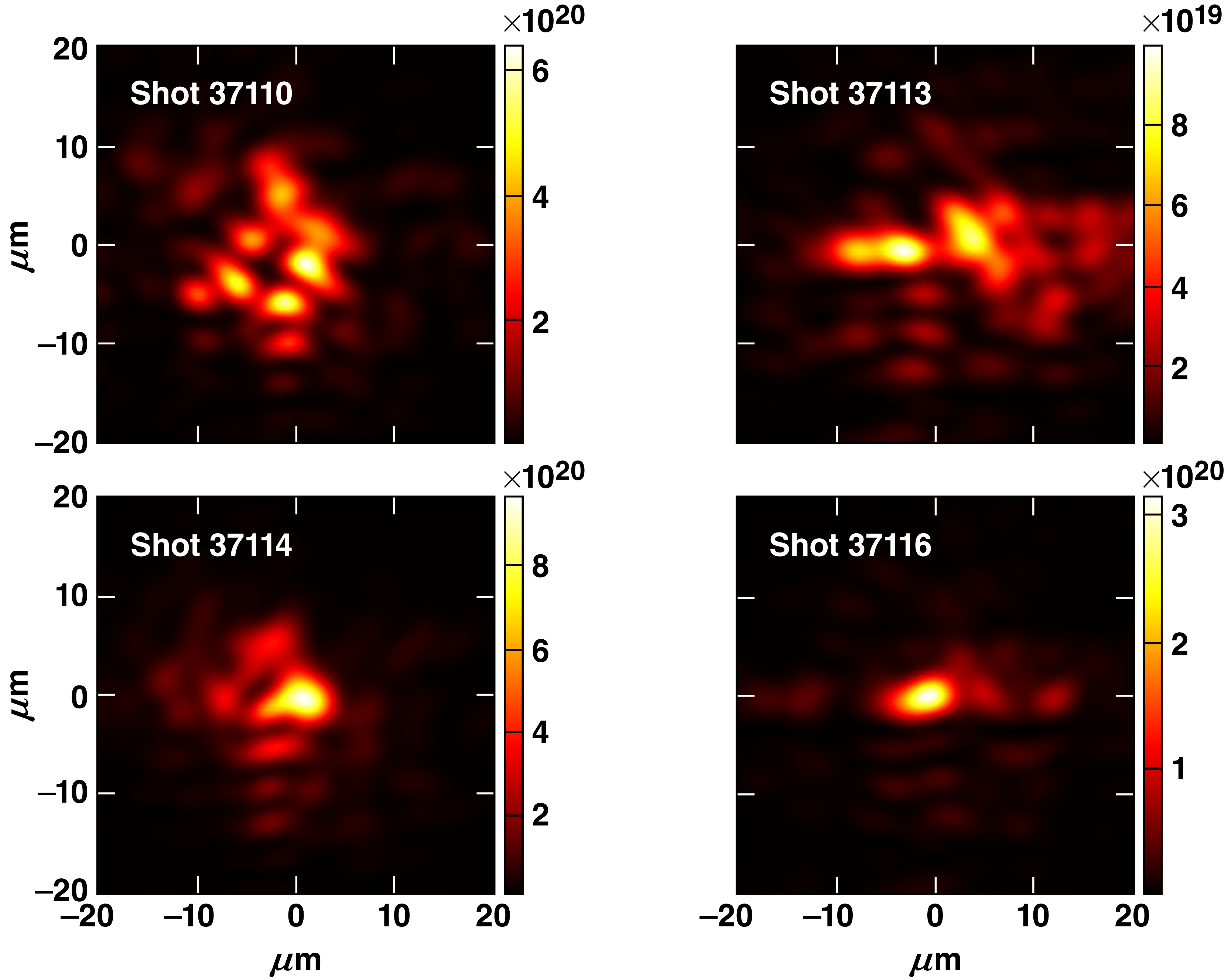

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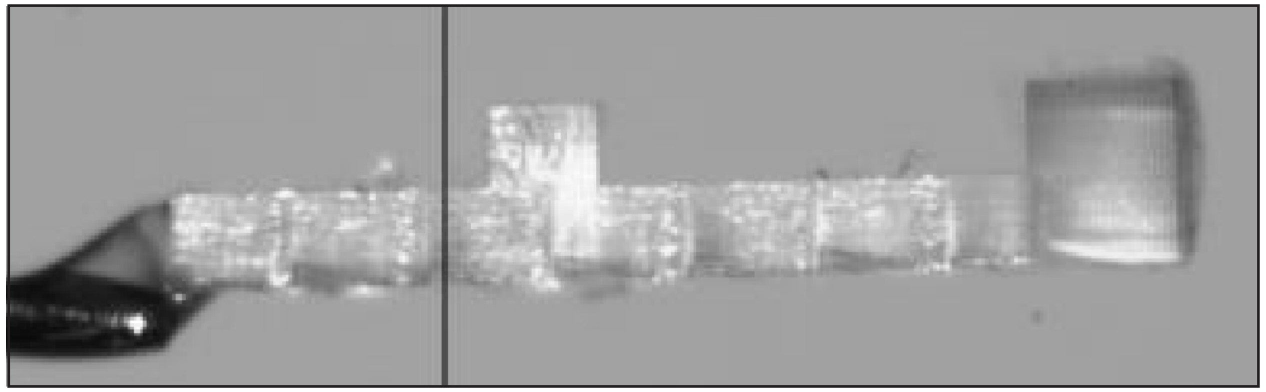
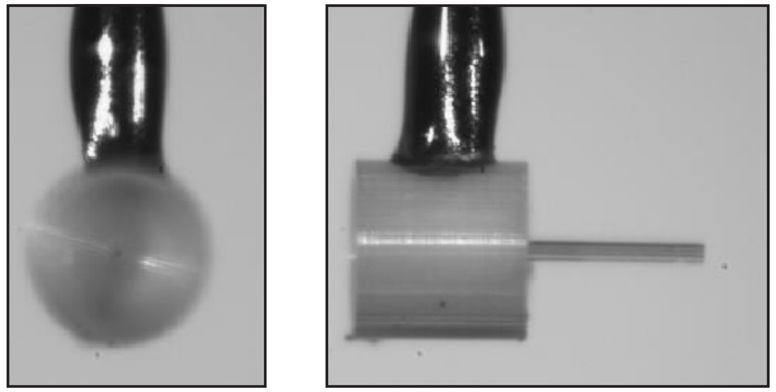
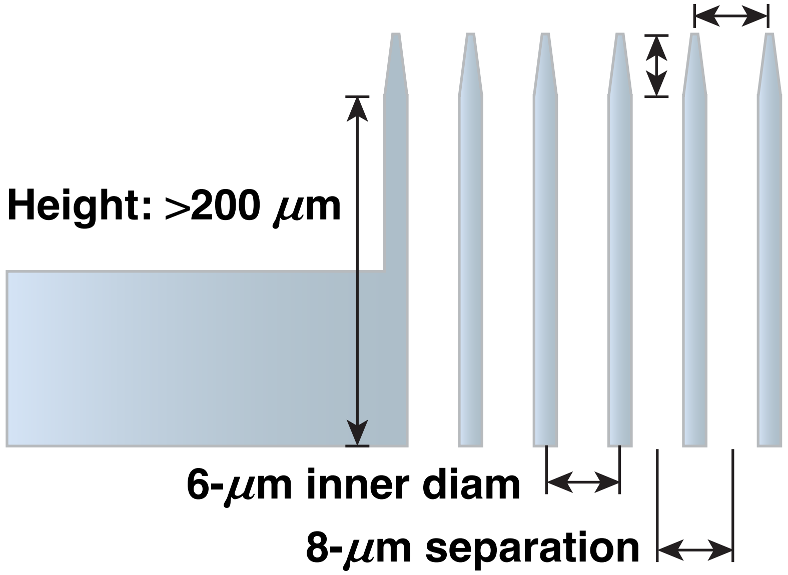


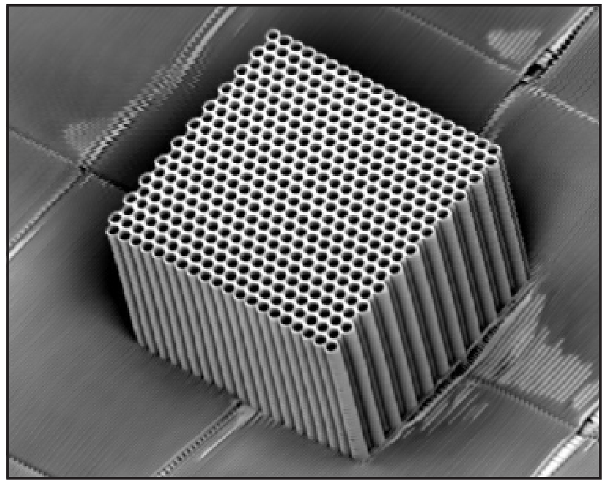
Compound parabolic concentrators (CPC's)



Side cross-section:



Electron radiograph



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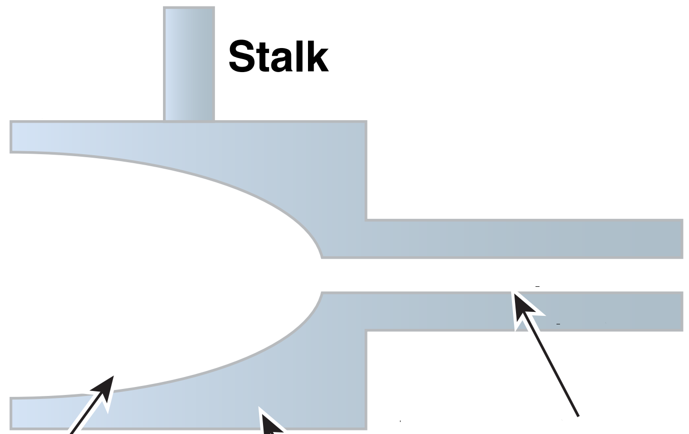

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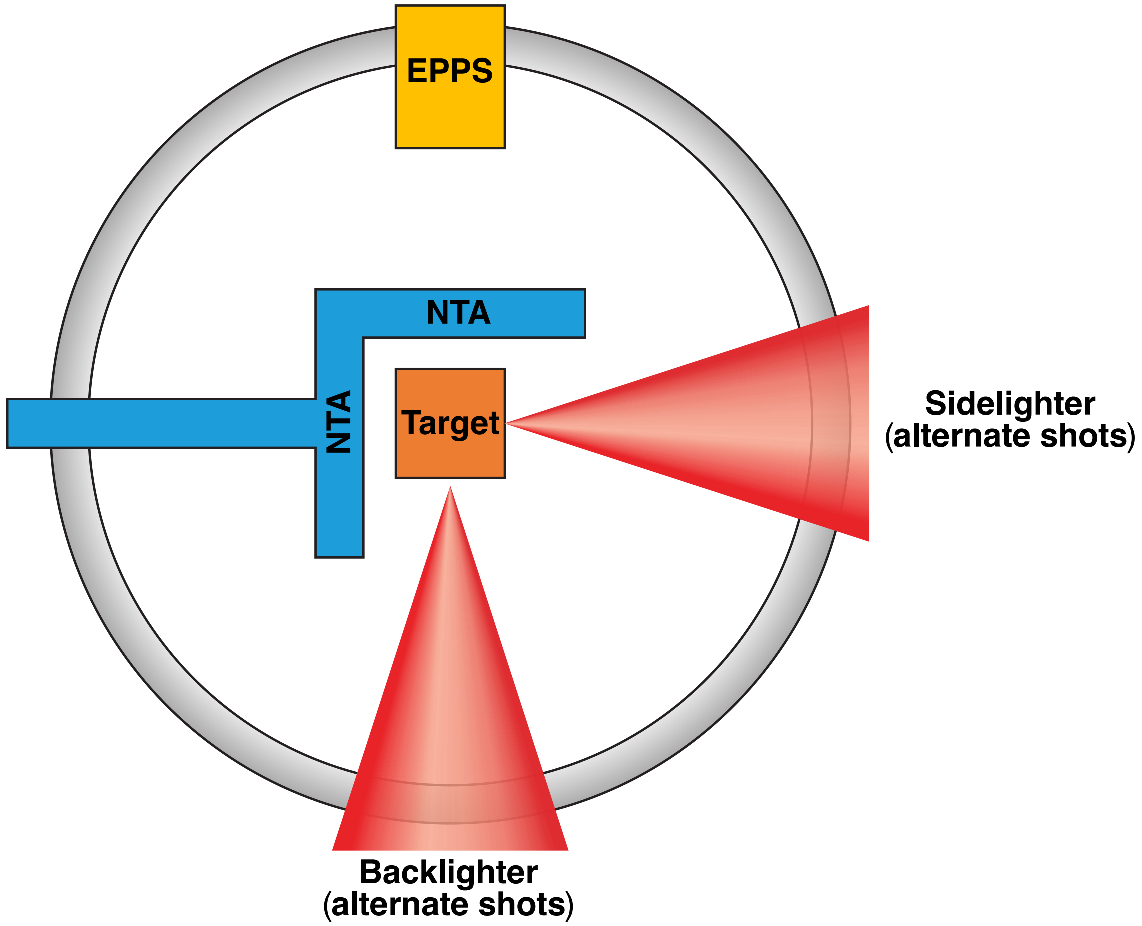

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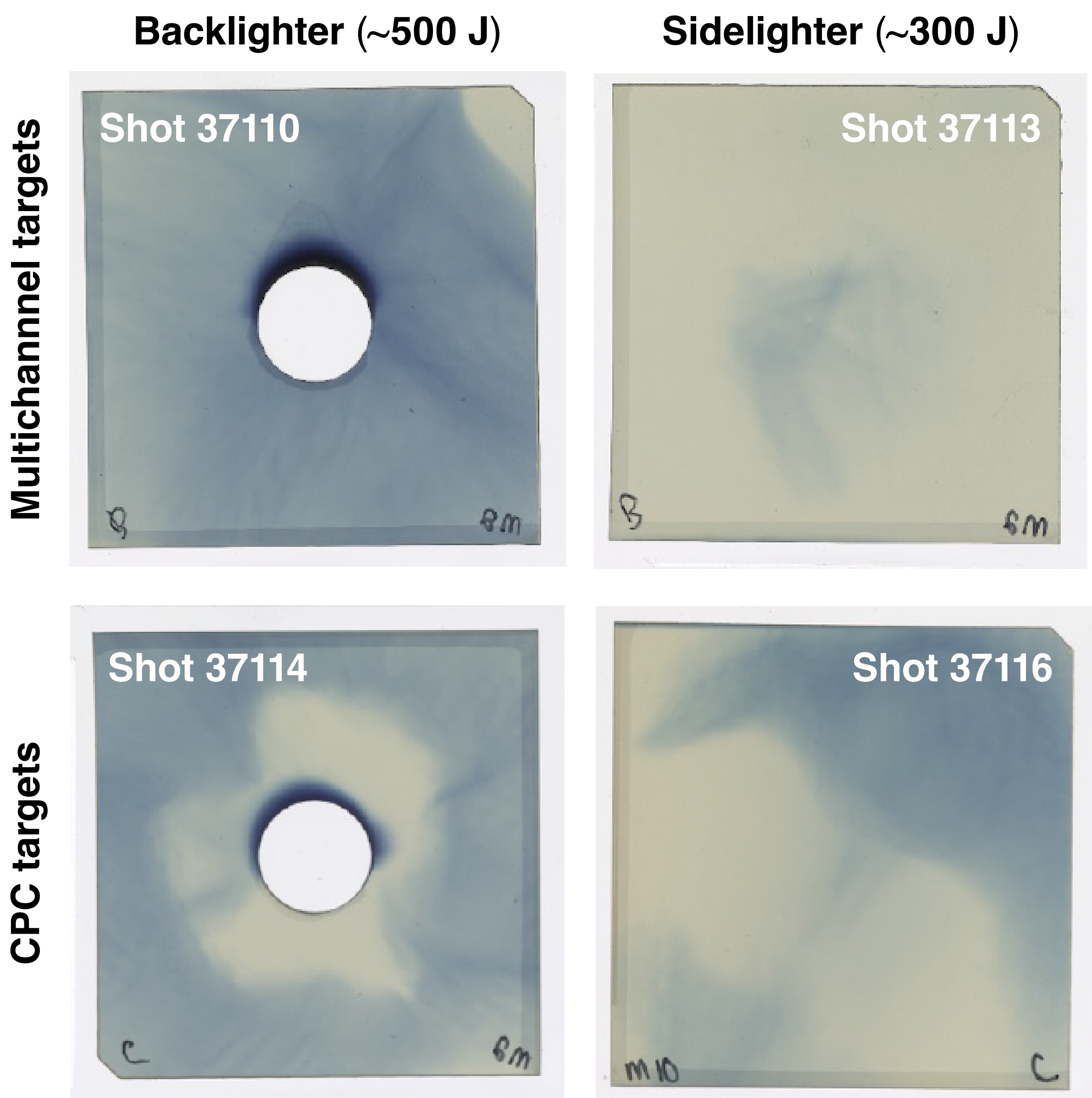

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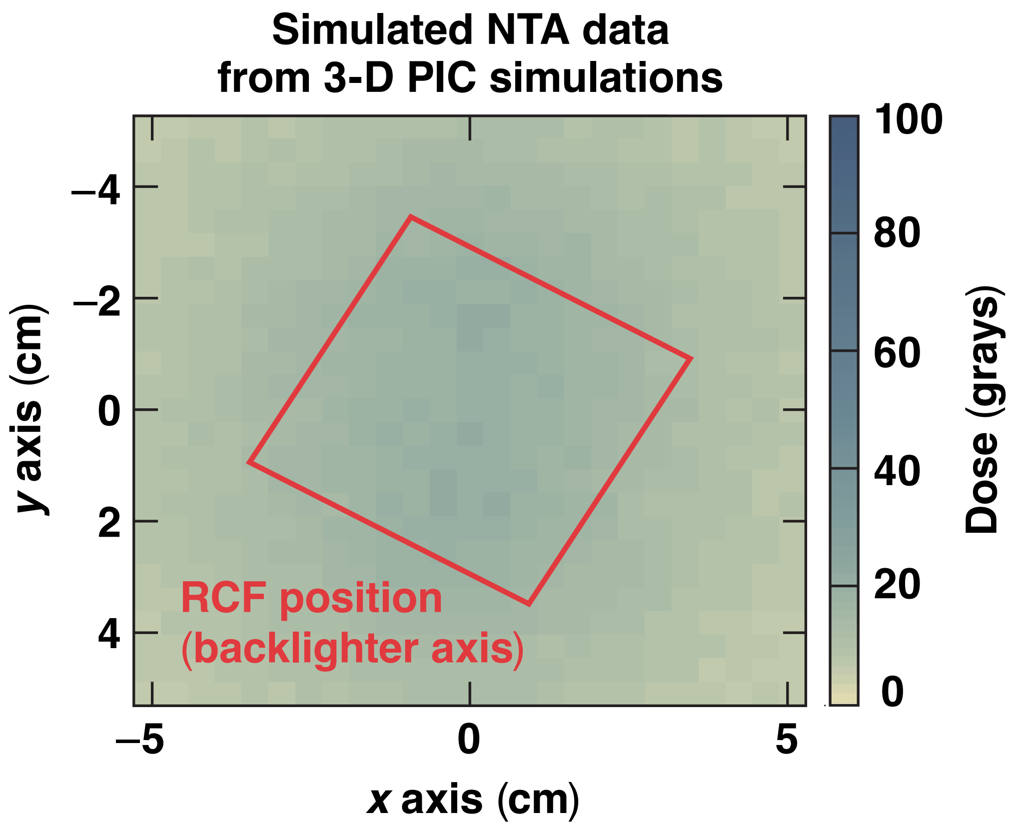

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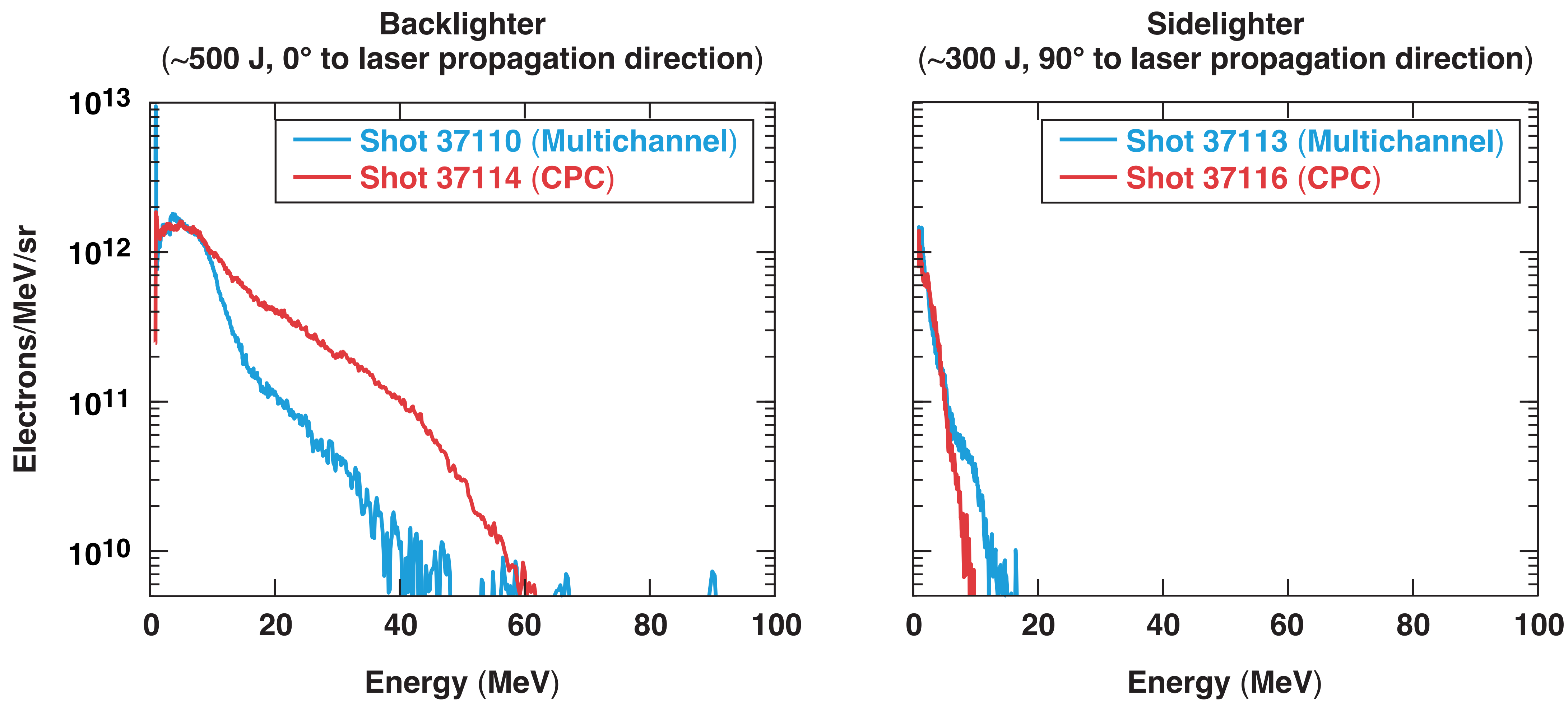

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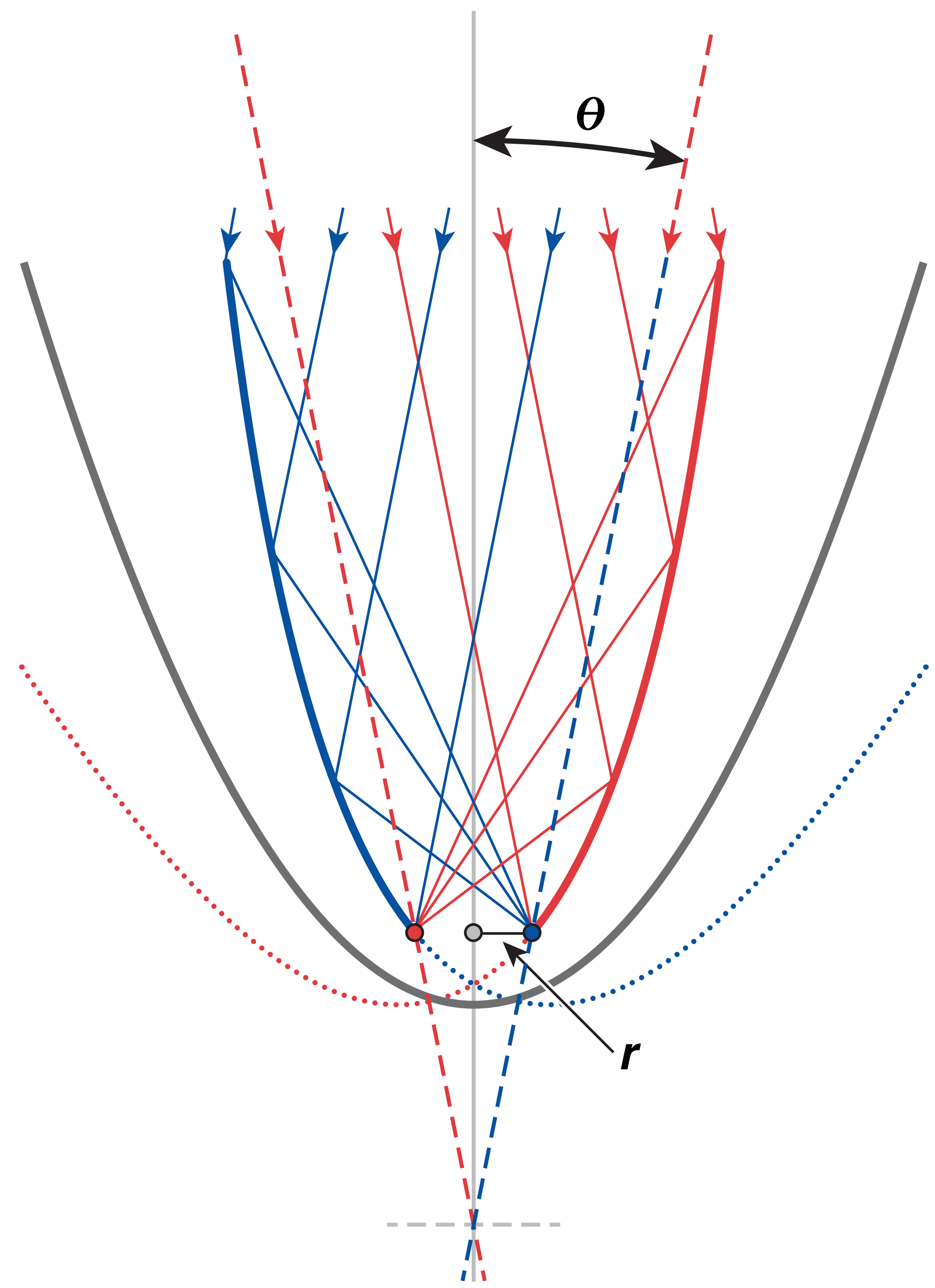

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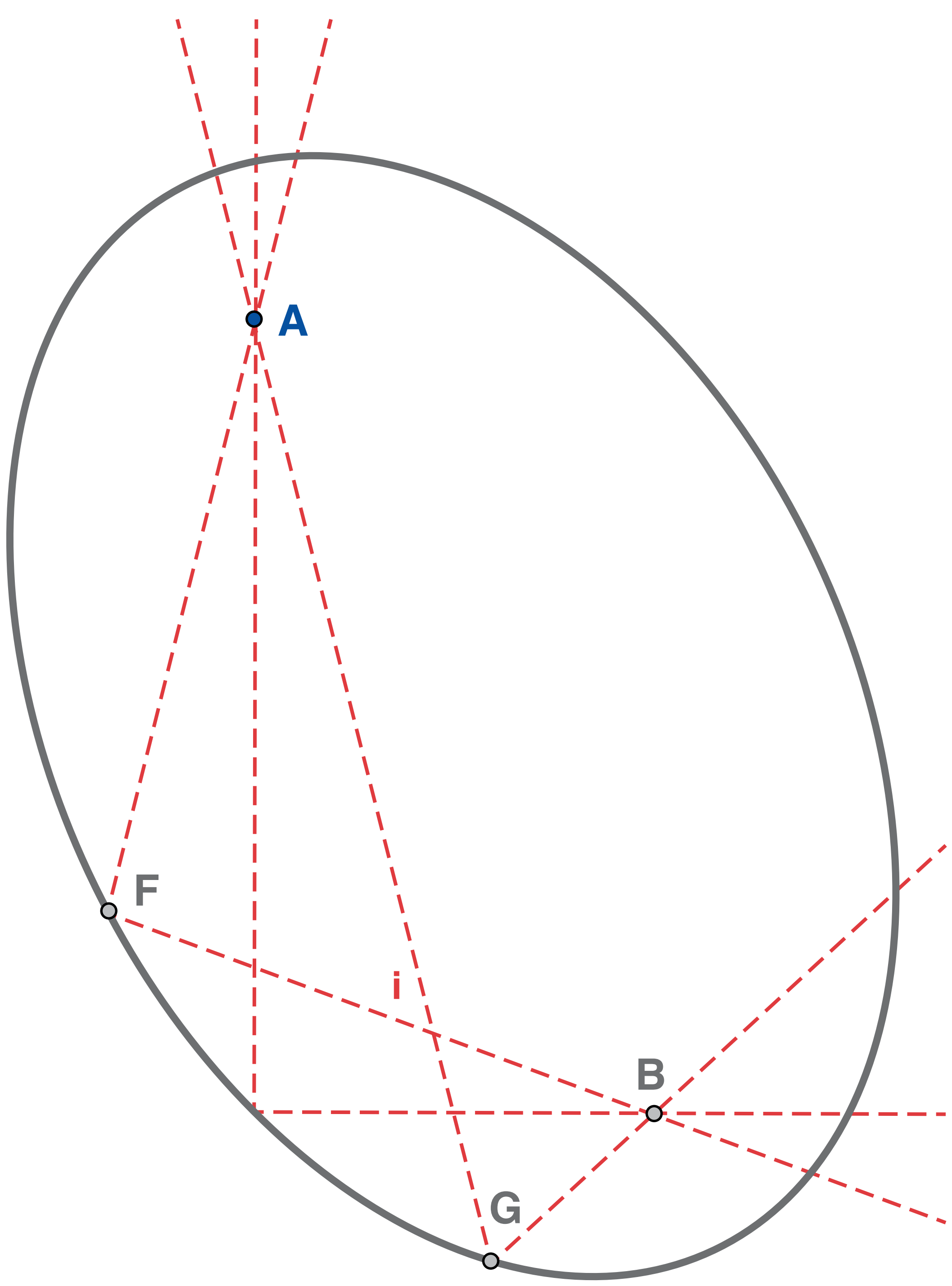

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