High-Current Electron-Transport Studies Using Coherent Transition Radiation (CTR)

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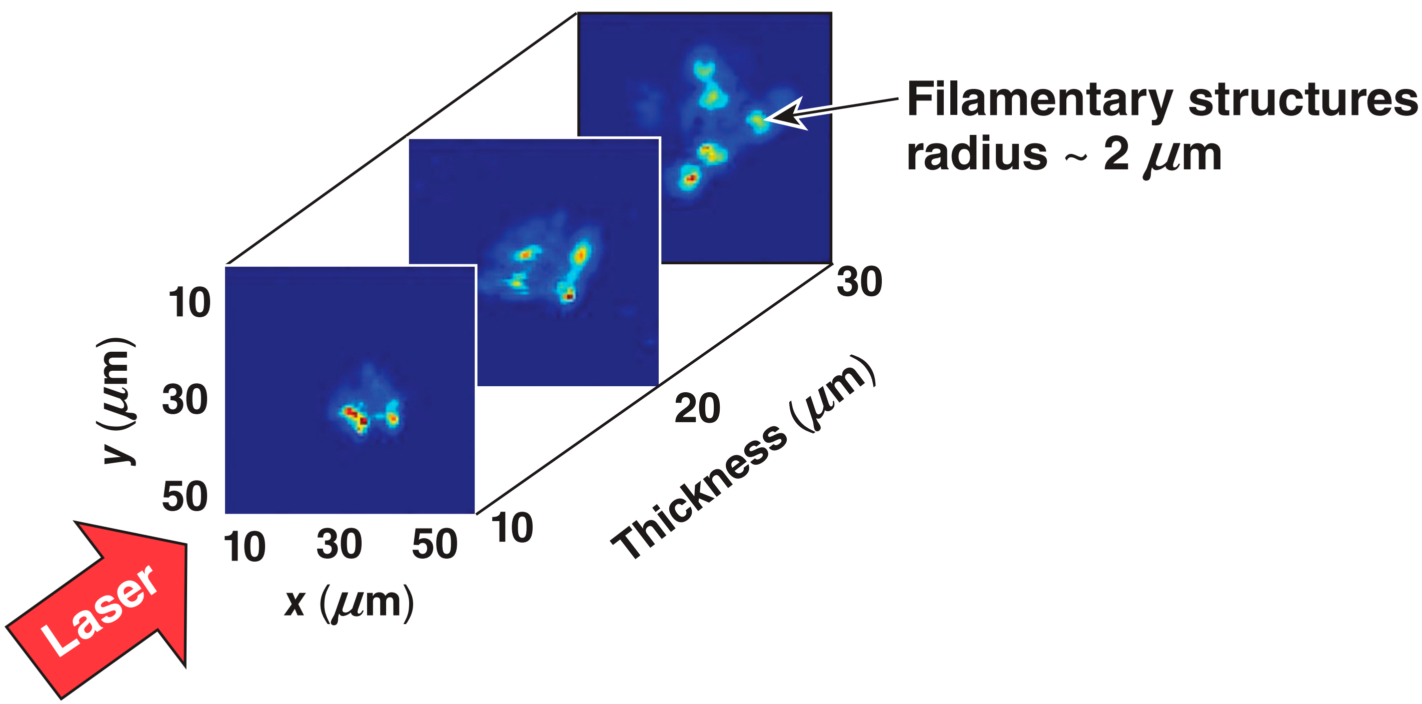
False color-intensity images of the rear side optical emission from laser-illuminated Sn foils



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Summary

Filamentary structures are seen in the coherent transition radiation (CTR) emission pattern

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- Experiments have been conducted with metal targets of varying thicknesses using LLE's Multi-Terawatt (MTW) laser with intensities $\sim 10^{19}$ W/cm^2.
- High-resolution images of the rear-surface emission show the presence of bright small-scale structures with a mean radius of $\sim 2\ \mu$m.
- Simulations suggest that the distribution of CTR is influenced by the presence of self-generated magnetic fields.
- The observed structures account for only a small fraction of the total current.

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Collaborators

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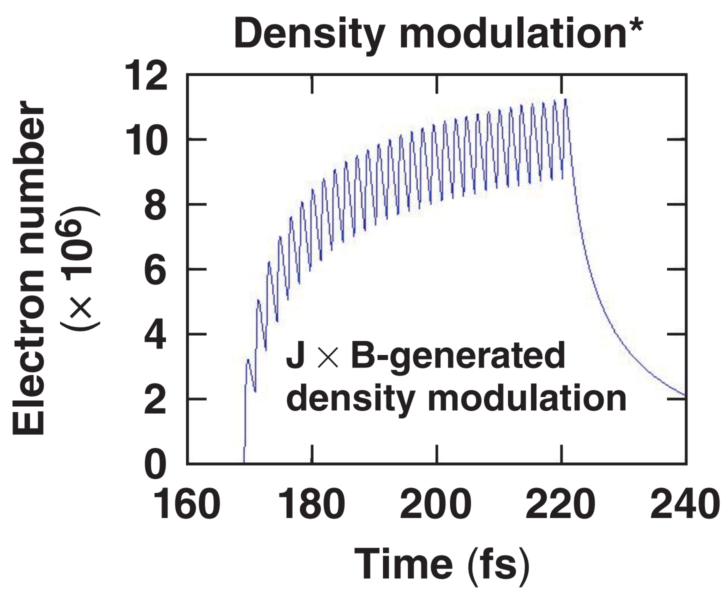
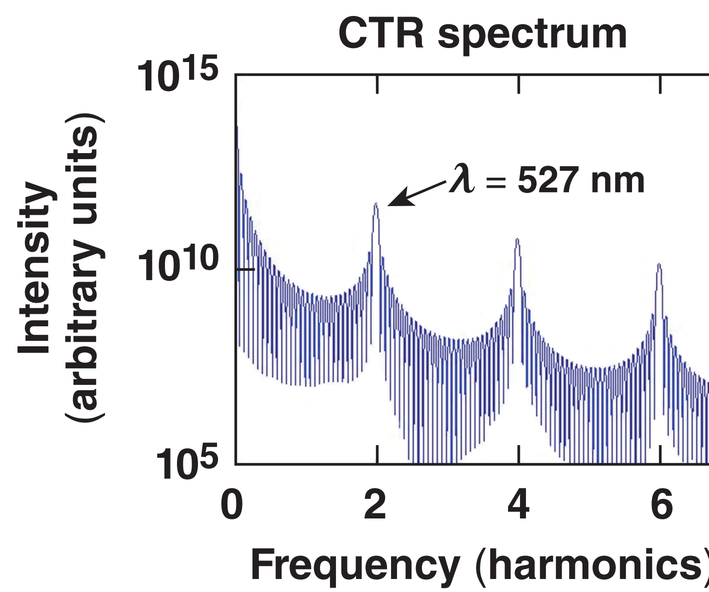
Coherent transition radiation (CTR) provides information on the dynamic properties of relativistic electron beams

- CTR is produced when an electron beam, with a longitudinal density modulation, crosses a refractive index interface such as the rear surface of a solid target.





- The prompt, spectrally narrow signal at 2ω, can be many times brighter than competing emission processes.

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*J. Zheng *et al*., Phys. Plasmas 10, 2994 (2003).

High-resolution (~1.4 μm) imaging of the target's rear surface reveals small-scale structures within the emission region

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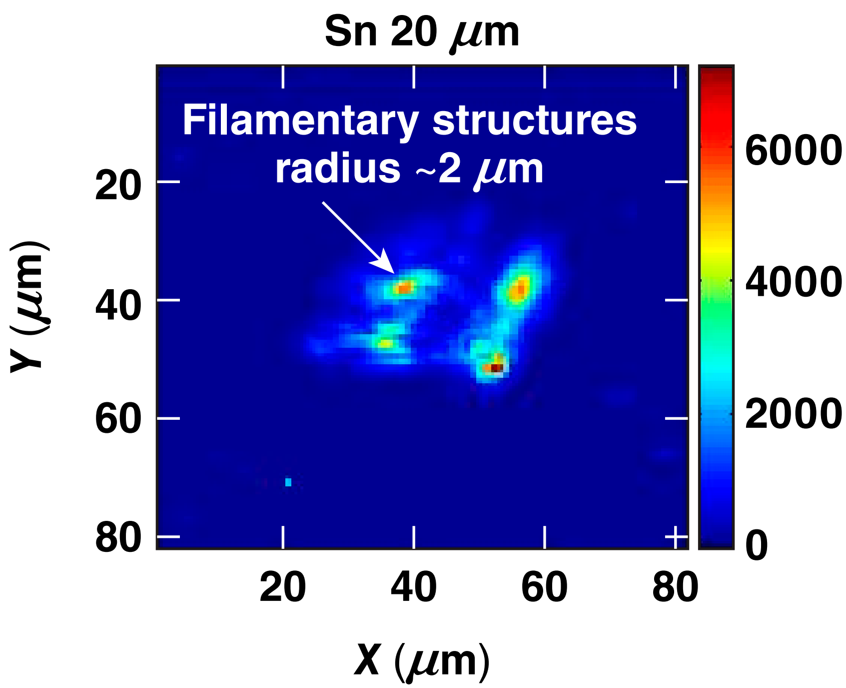
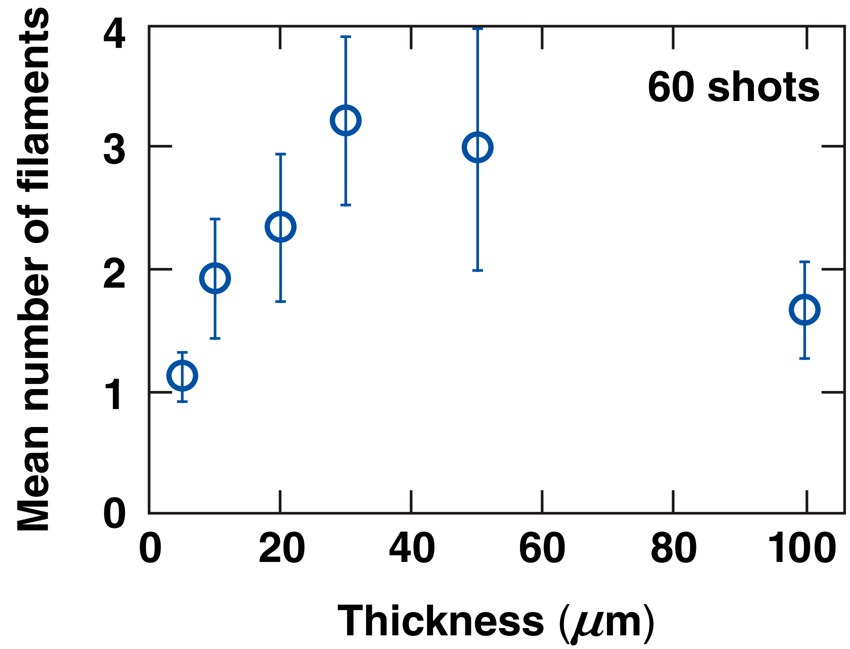
E_{Laser} ~5J, Δt_{Laser} ~ 500 fs, I = 10^{19} W/cm^2, normal incidence





- The structures are suggestive of electron-beam filamentation.
- An average of three filaments are identified per shot.
- The mean radii, at 50% of the maximum amplitude, is ~2.0 μm.

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Estimates suggest the observed structures account for only ~2% of the total current

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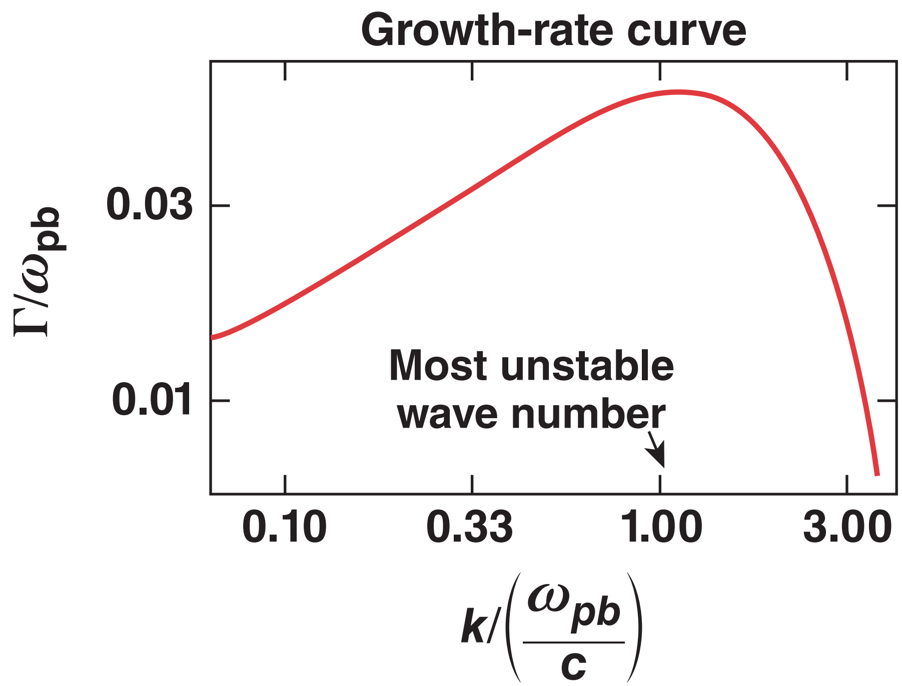
- An estimate of the filament current is obtained by assuming the filament size is determined by the most unstable wave number of the resistive filamentation instability.[1]
- Equating the most unstable wave number to the size of experimentally observed structures specifies c/ω_{pb} and the corresponding beam electron density.



- For the 1-MeV electrons, the filament current is ~24 kA.
- The total current, for a laser-to-electron energy-conversion efficiency of 20%,[2] is estimated to be ~1.4 MA.

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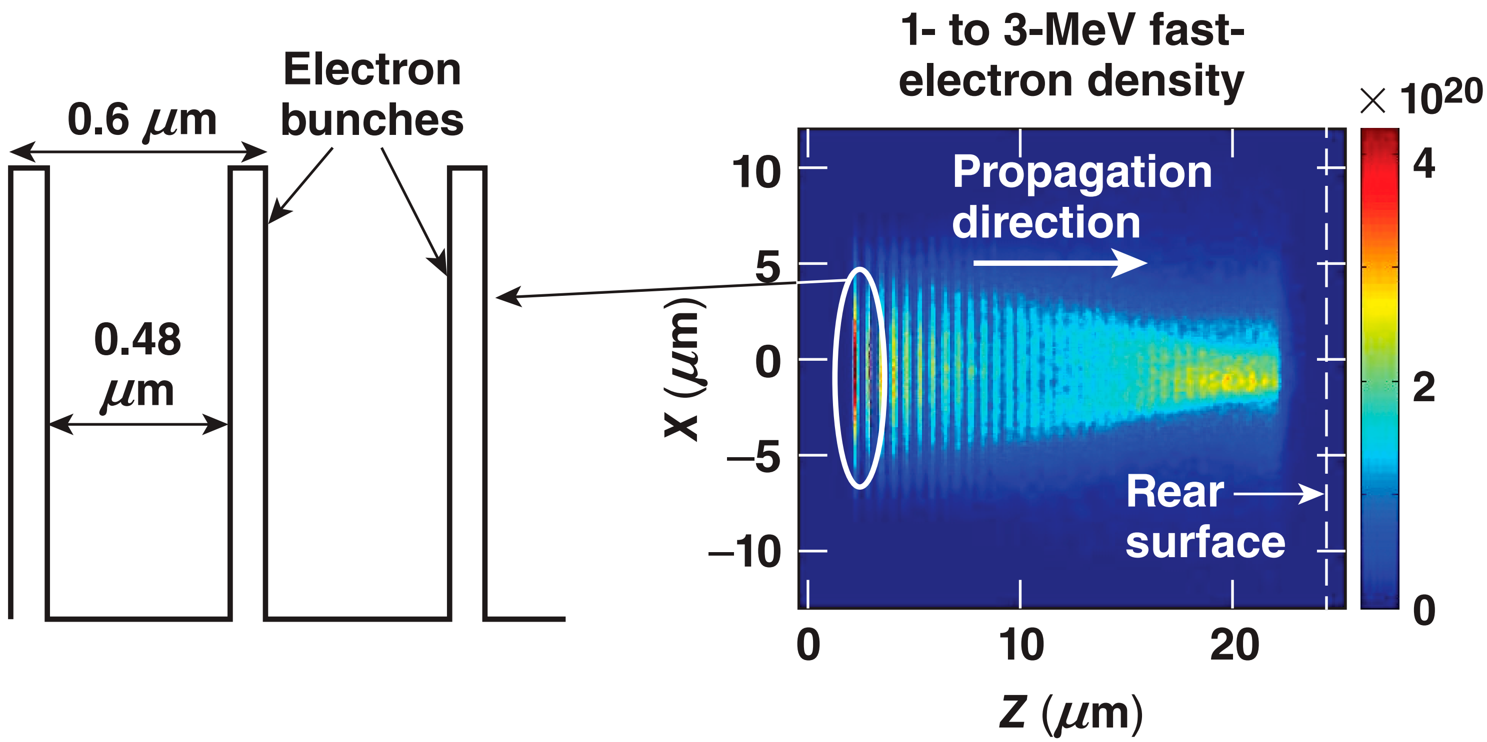
[1] L. Gremillet, G. Baonnaud, and F. Amiranoff, Phys. Plasmas 9, 941 (2002).
[2] P. M. Nilson *et al*., Phys. Plasmas 15, 056308 (2008).

The connection between unstable filaments and the CTR emission is investigated using two-dimensional *LSP*[1] simulations

- A thermal distribution of electrons, with $T_{hot} \sim 1.2$ MeV, is periodically injected into an Al slab, producing an electron beam with a comb structure.



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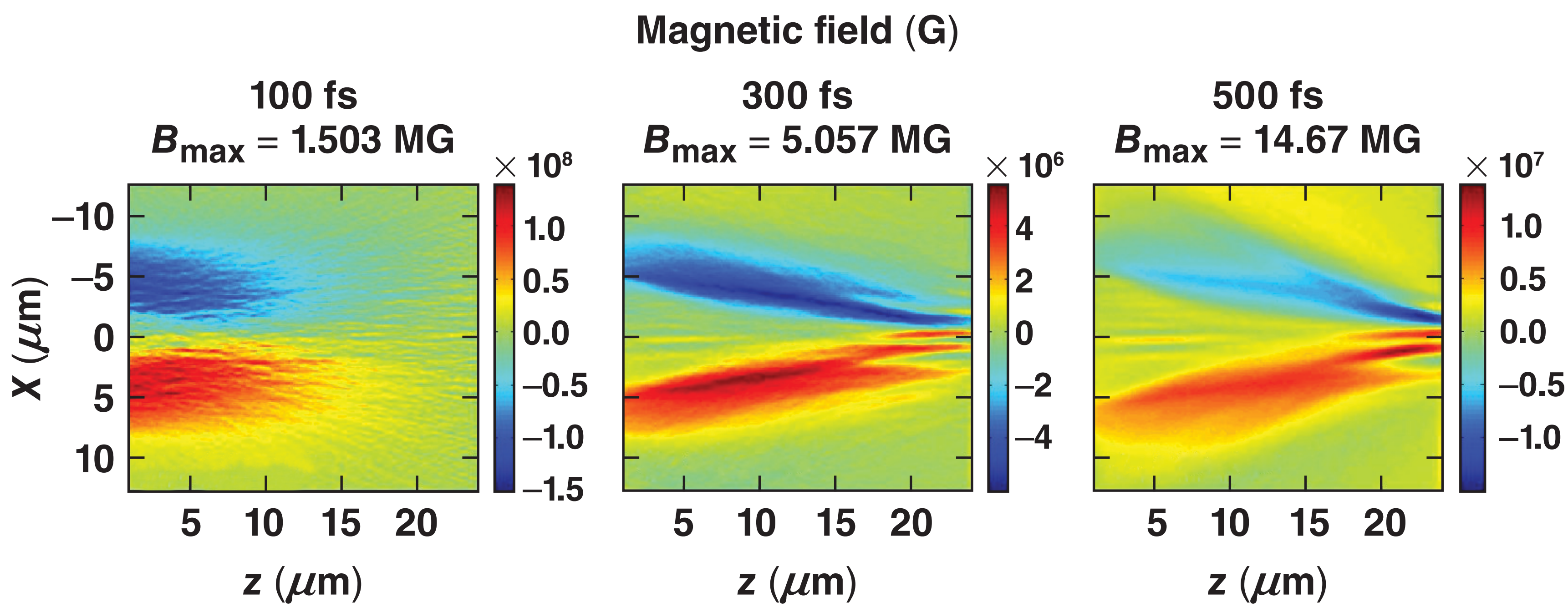
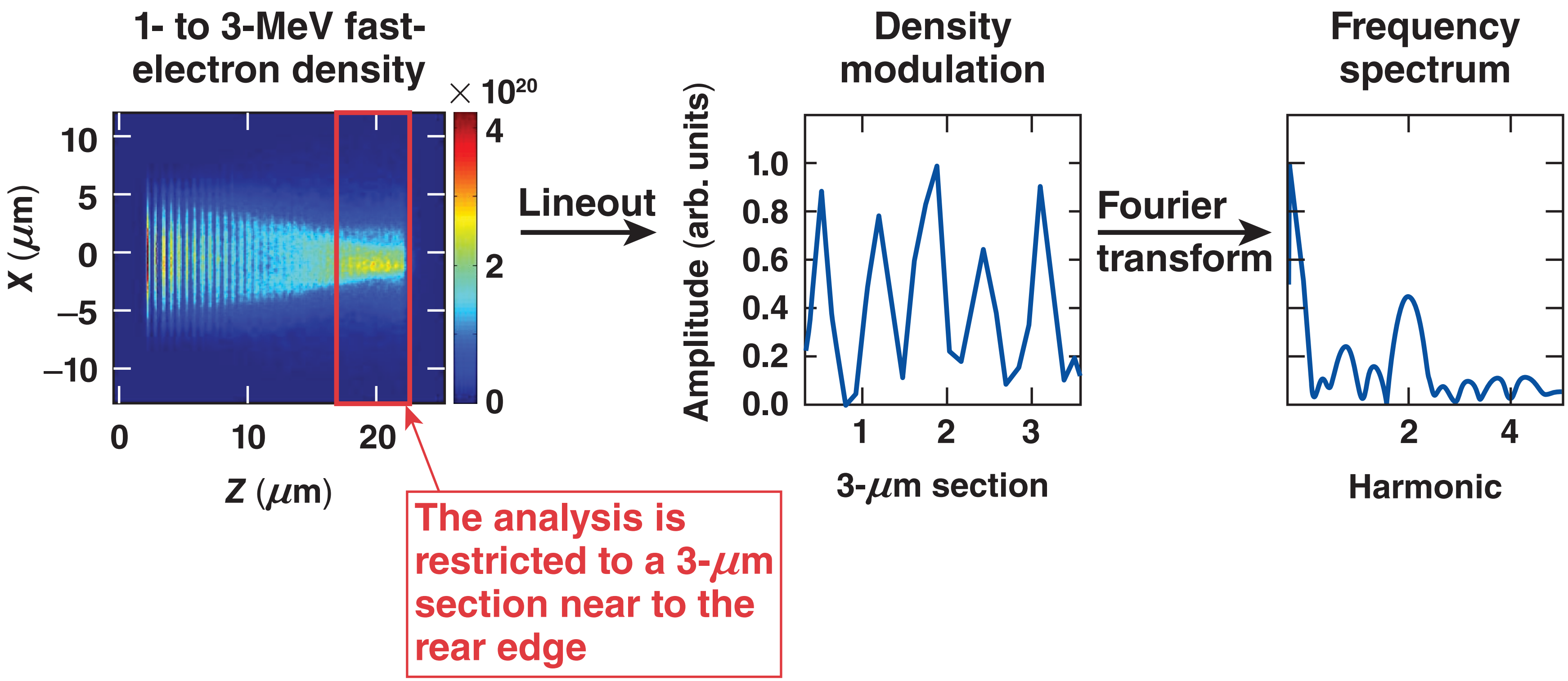
[1]D. Welch *et al.*, Nucl. Instrum. Methods Phys. Res. A 464, 134 (2001).

A dc magnetic field grows in time with the maximum strength occurring in the vicinity of the target's rear edge



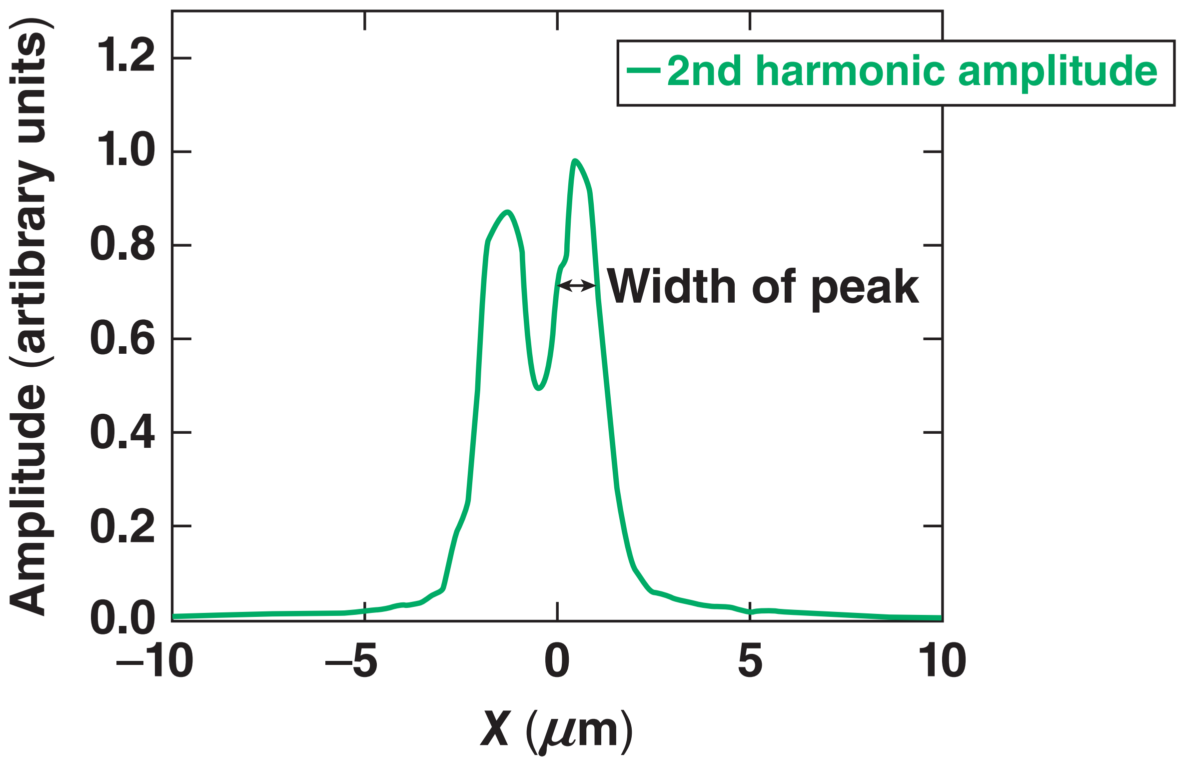
- The magnetic fields converge toward the rear edge of the target.
- Through their influence on the fast-electron trajectories, the magnetic fields affect the distribution of CTR at the rear edge.

Fourier analysis of the electron-density modulation is used to predict the spatial distribution of CTR



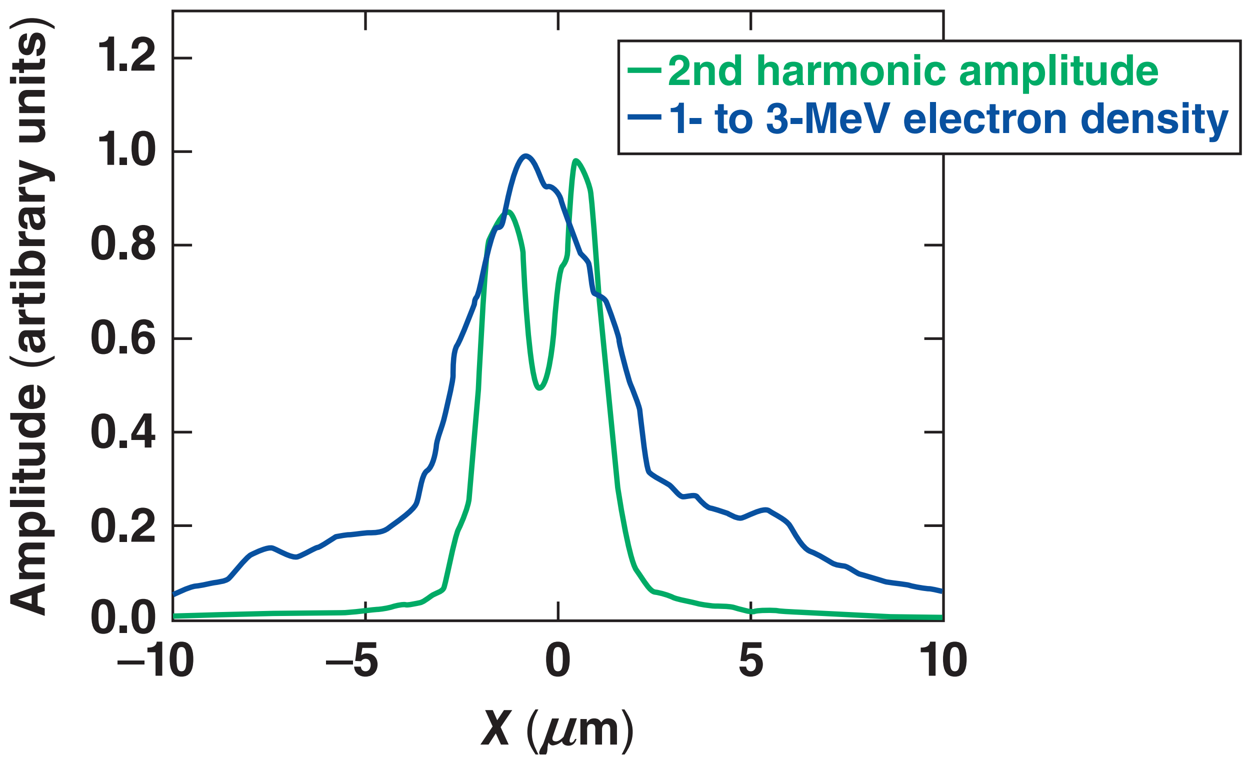
- The amplitude at the laser second harmonic is extracted and plotted as a function of the transverse coordinate.

For the 1- to 3-MeV fast electrons, two transversely separated peaks appear in the amplitude of the second harmonic



- The spatial width of the harmonic peaks is ~1.1 μm (FWHM).

The transverse modulation does not appear in the 1- to 3-MeV fast-electron density



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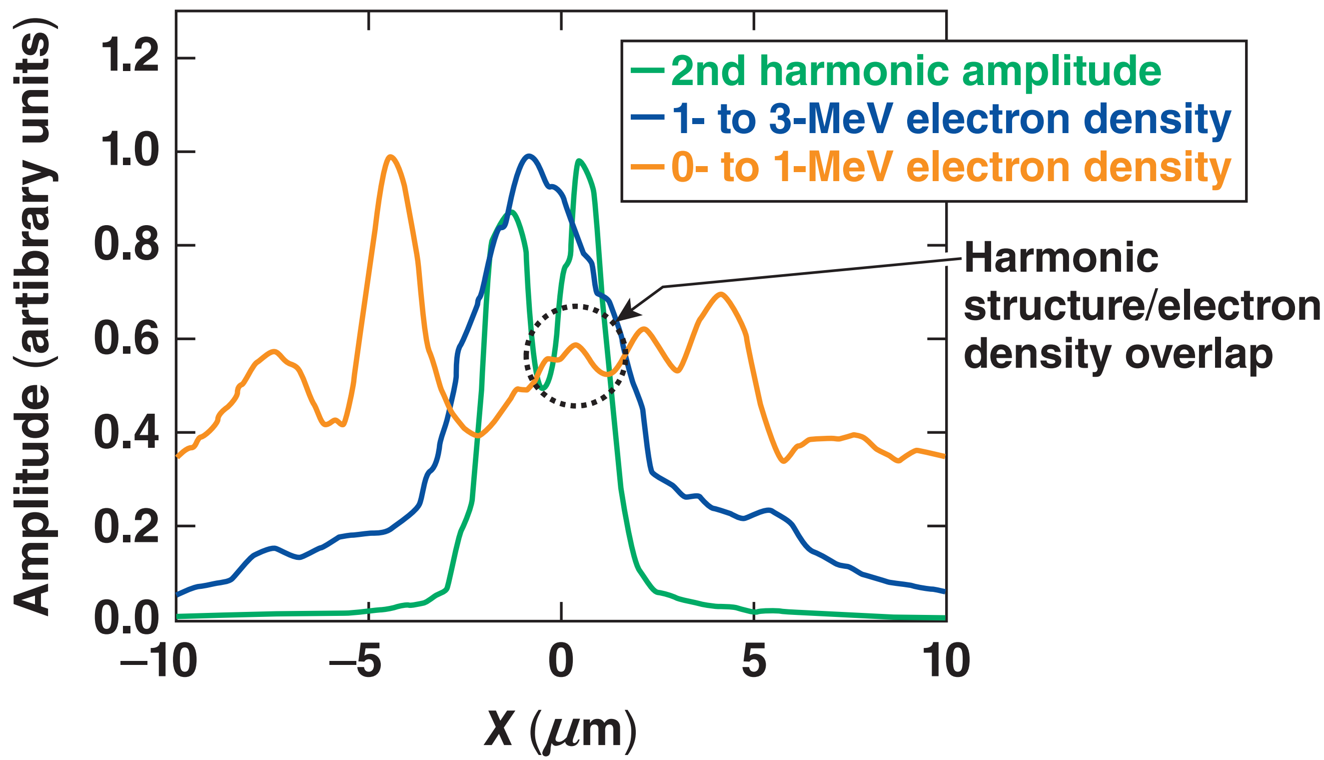
The predicted transverse distribution of CTR does not match the transverse distribution of the fast-electron density



- The 0- to 1-MeV electrons account for ~70% of the total fast-electron population.
- Based on the spatial overlap of the harmonic peaks with the fast-electron density, each peak covers a section of the electron beam, corresponding to ~3% of the total population.

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Summary/Conclusions

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