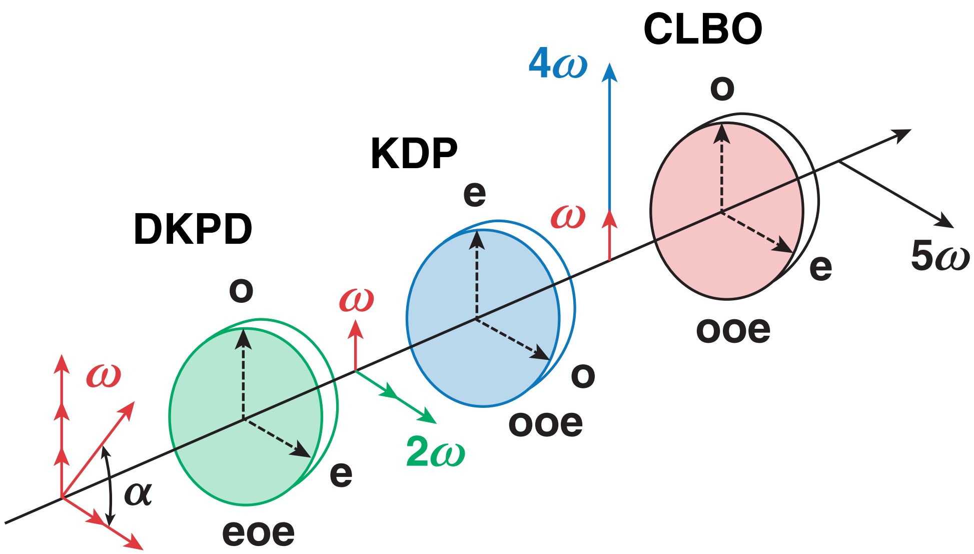
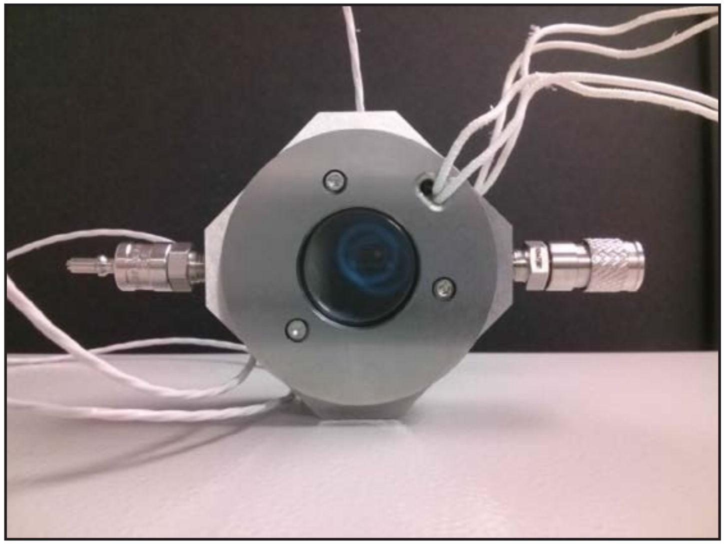
Record Fifth-Harmonic–Generation Efficiency Producing 211-nm Pulses Using Cesium Lithium Borate





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Laboratory for Laser Energetics

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Summary

Cesium lithium borate (CLBO) is a promising option for high-energy coherent-light generation in the UV region

- High-energy coherent-light sources around 200 nm are necessary for diagnosing hot and dense plasmas
- Wide-aperture fifth-harmonic generation (5HG) of Nd:YLF laser radiation has been realized with a cascade of deuterated potassium dihydrogen phosphate (DKDP), potassium dihydrogen phosphate (KDP), and CLBO crystals
  - 275 mJ at 211 nm was reached with a 2.4-ns pulse
  - a conversion efficiency of 25% is the highest reported
- The main limitations are two-photon absorption of fifth-harmonic radiation and a temperature gradient over the CLBO crystal

High-energy, high-efficiency fifth-harmonic generation has been demonstrated with a large-aperture CLBO crystal.

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Collaborators

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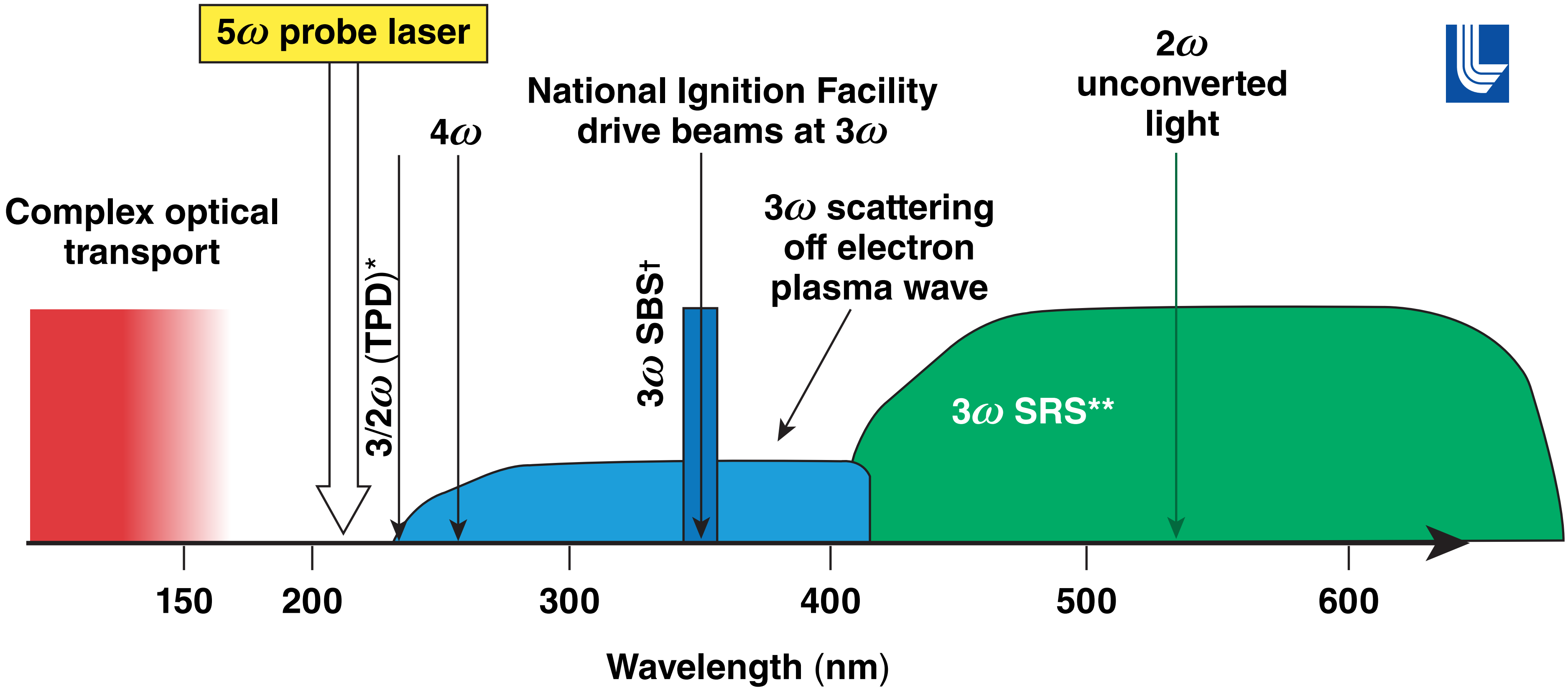
Lawrence Livermore National Laboratory

A 200-nm source is desirable to probe a high-density hot plasma



Frequency conversion of a 100-J, 1053-nm laser to the fifth harmonic is required to produce 10 J at 211 nm.

*TPD: two-plasmon decay
**SRS: stimulated Raman scattering
†SBS: stimulated Brillouin scattering

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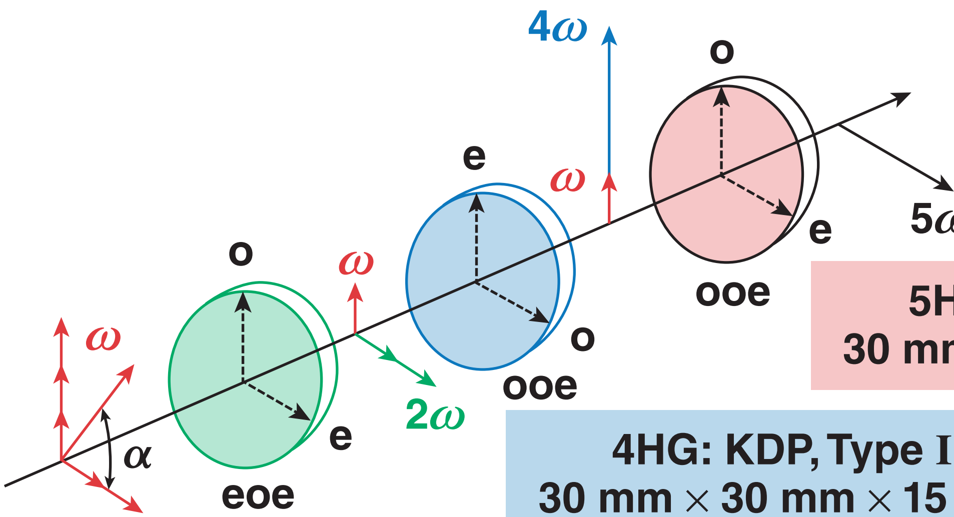
Generating multiple joules at 5ω reduces the crystal options to the KDP group and CLBO

- First 5HG in 1969*
- Wide-aperture, high-efficient 5HG in ammonium dihydrogen phosphate (ADP) at –70°C**
- The CLBO crystal grew to 140 × 110 × 110 mm^3***



5HG: CLBO, Type I, 30 mm diam × 4 mm thick

4HG: KDP, Type I, 30 mm × 30 mm × 15 mm

Second-harmonic generation (SHG): DKDP, Type II, 30 mm × 30 mm × 27 mm

The input polarization angle α was optimized.

o: ordinary
e: extraordinary

*A. G. Akmanov *et al*., J. Exp. Theor. Phys. Lett. 10, 154 (1969).
**I. A. Begishev *et al*., Sov. J. Quantum Electron. 18, 224 (1988);
I. A. Begishev *et al*., J. Appl. Spectrosc. 51, 1218 (1989).
***M. Yoshimura, Y. Mori, and T. Sasaki, Proc. SPIE 3734, 392 (1999).

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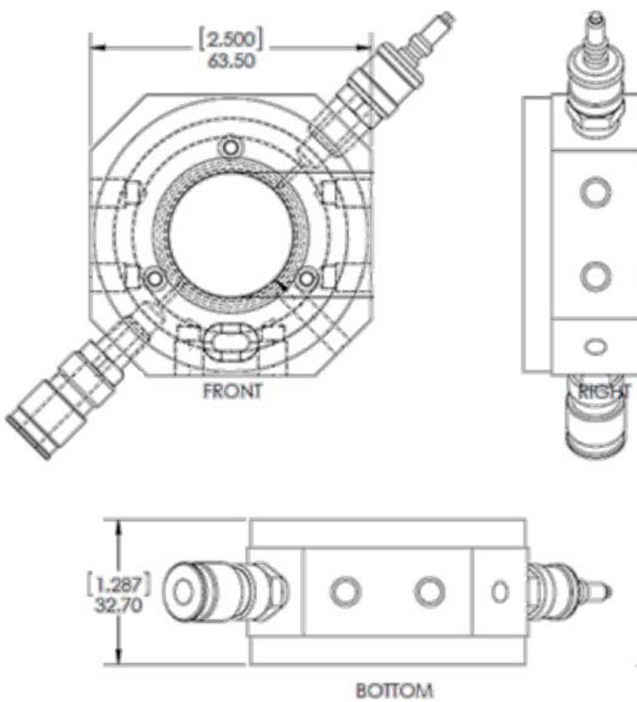
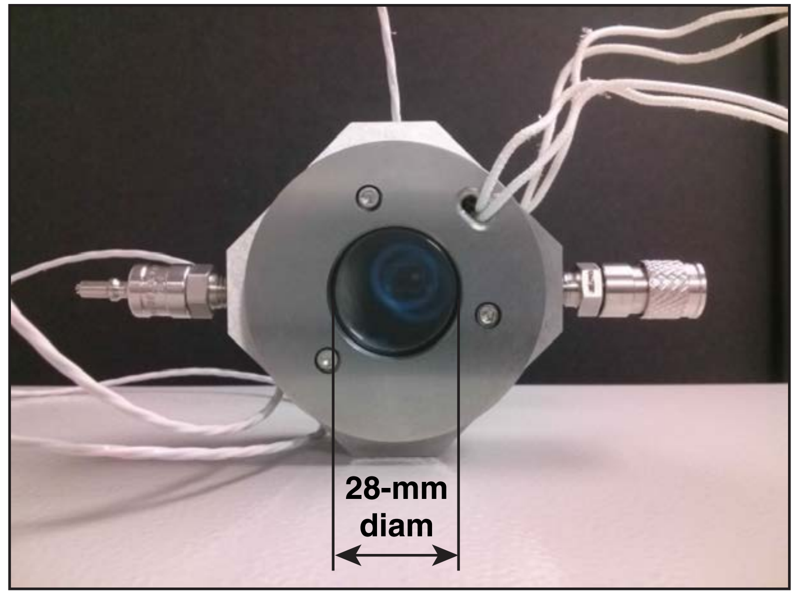
CLBO crystals in ovens were manufactured by Coherent, Inc.





The CLBO crystal is enclosed in an oven with dry nitrogen and held at 120°C to avoid hygroscopic damage to the surfaces.

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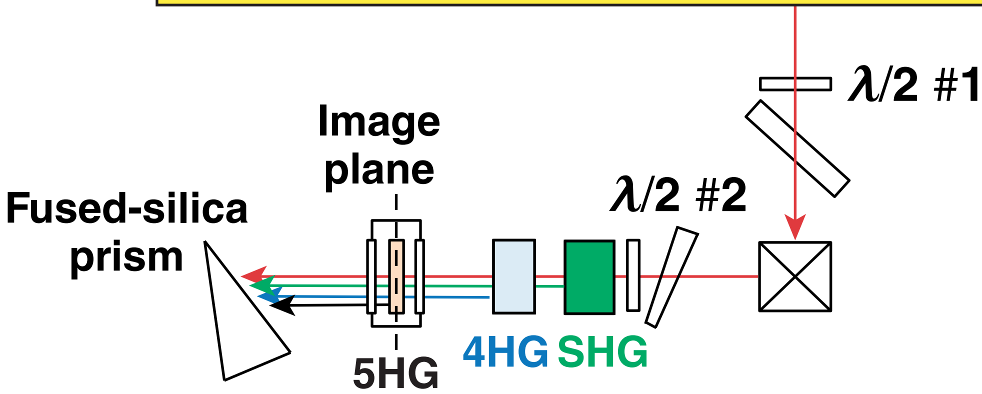
The experiments were performed at LLE using the Multi-Terawatt (MTW) laser

The narrowband mode of the MTW laser: E = 1.5 J (0.5% rms); beam size = 1.1 × 1.1 cm^2; τ = 1 ns to 2.8 ns; I = 1.1 GW/cm^2.



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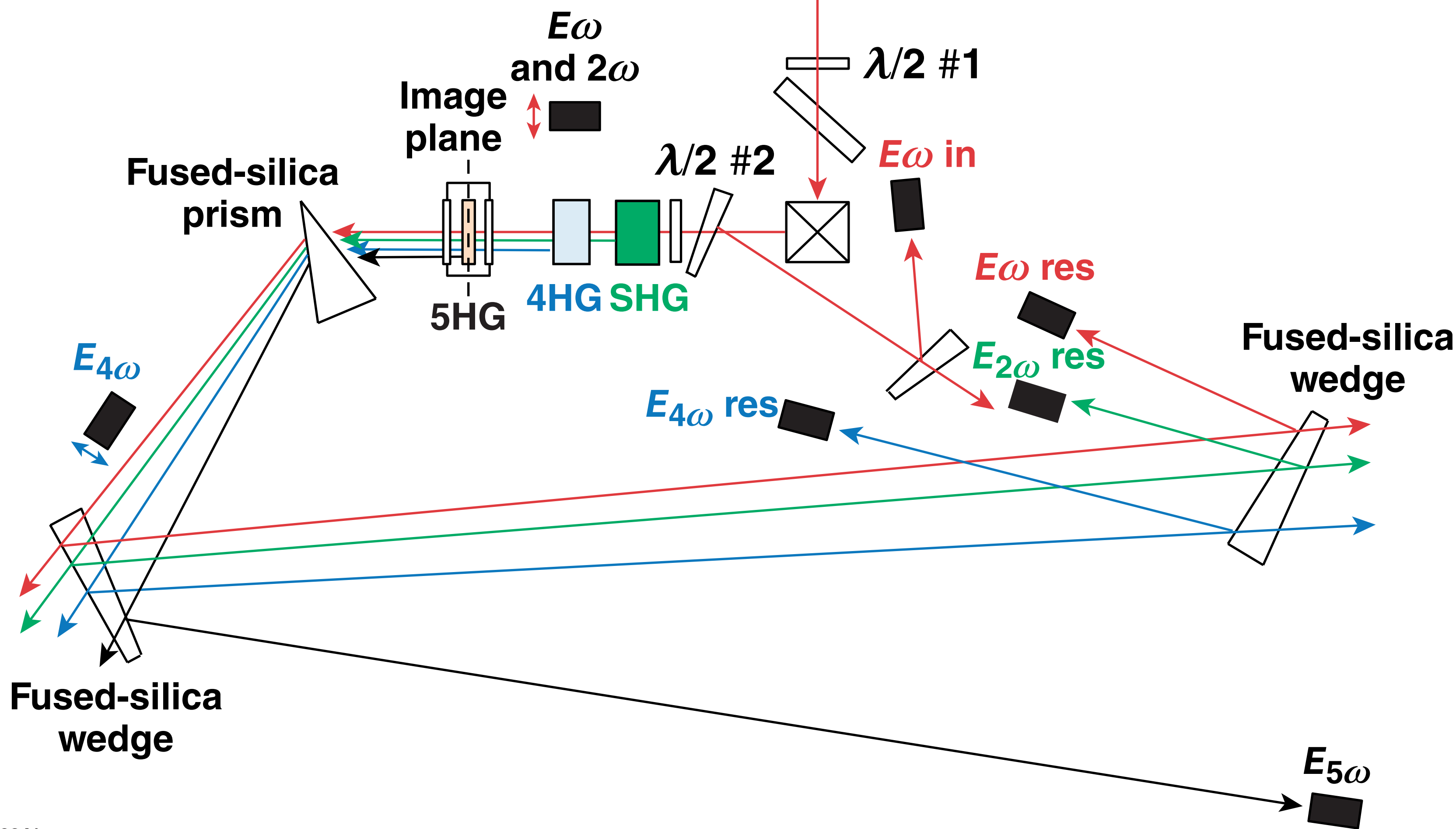

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The experiments were performed at LLE using the Multi-Terawatt (MTW) laser

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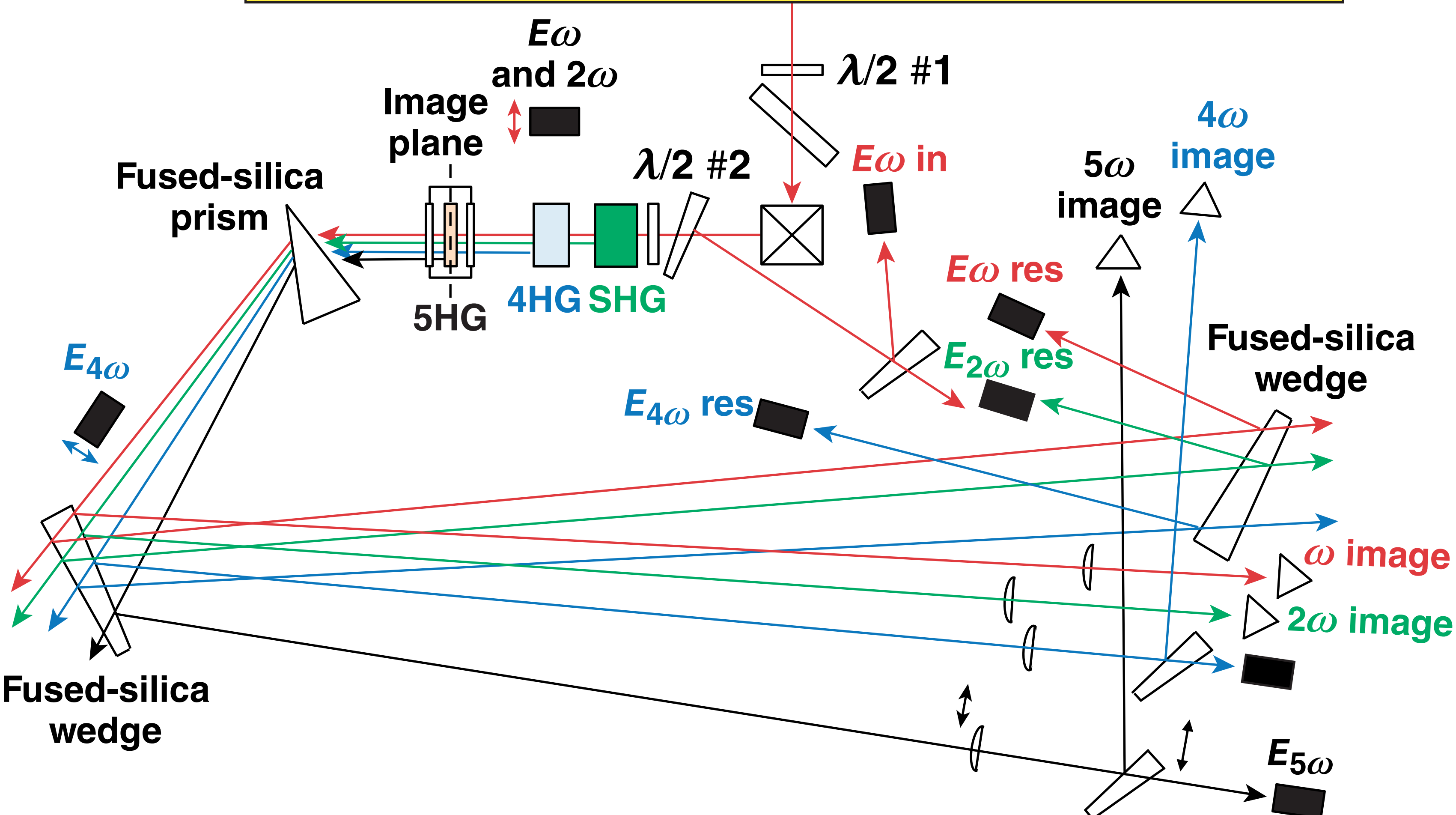

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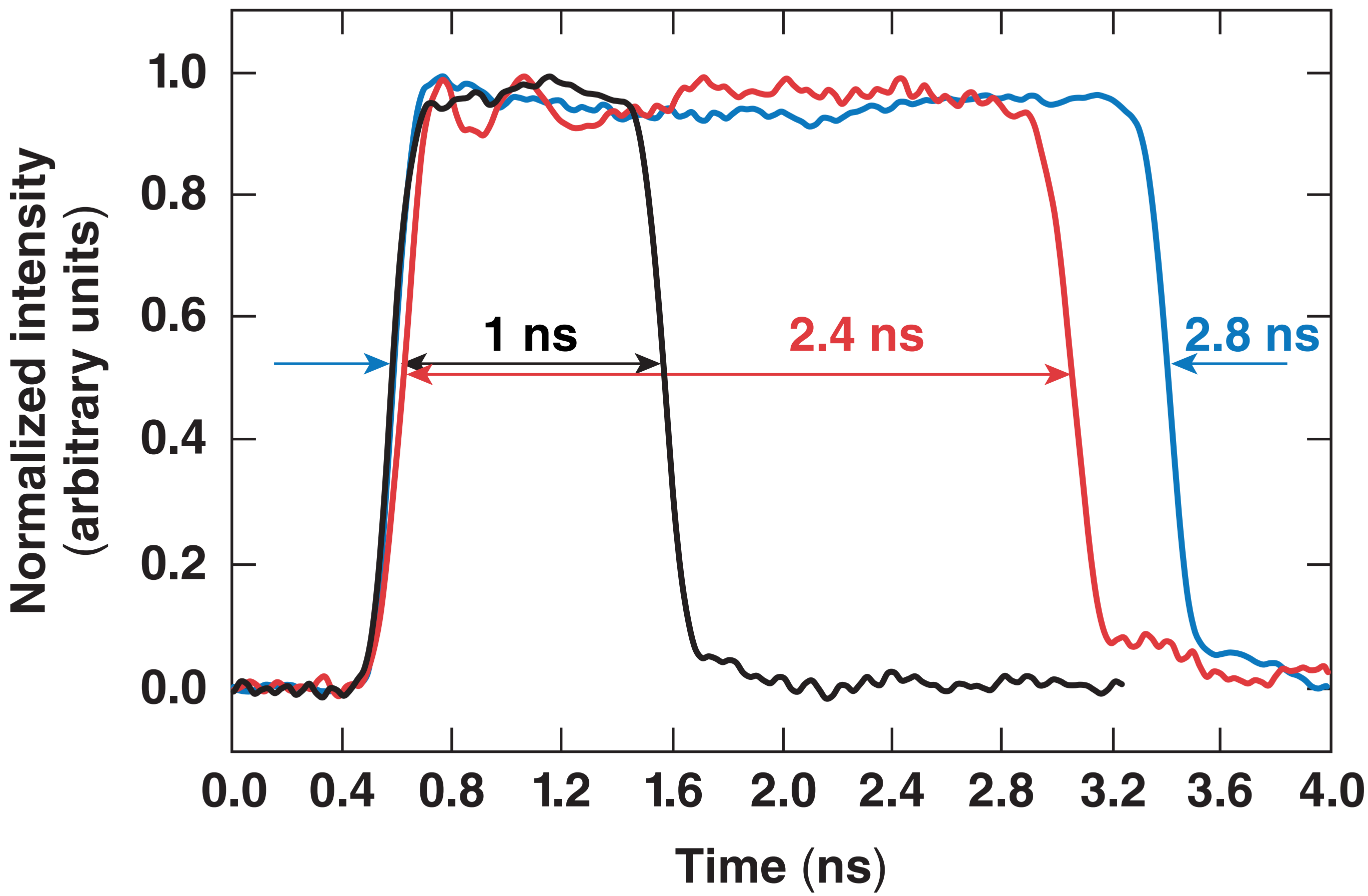
The 5HG was performed with various flattop pulses



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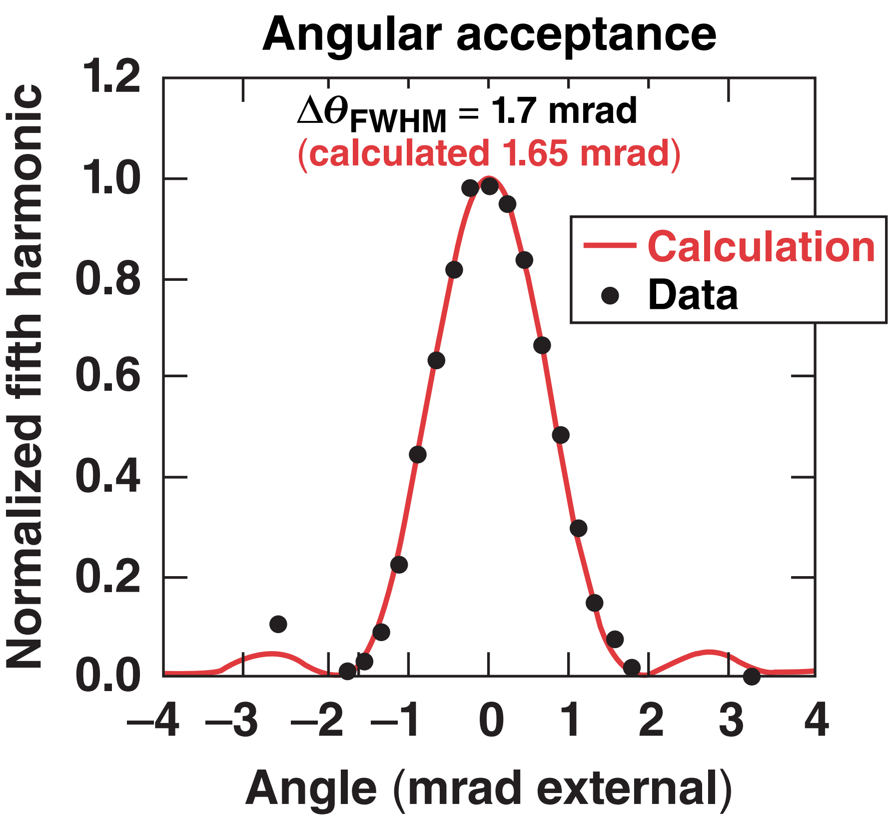
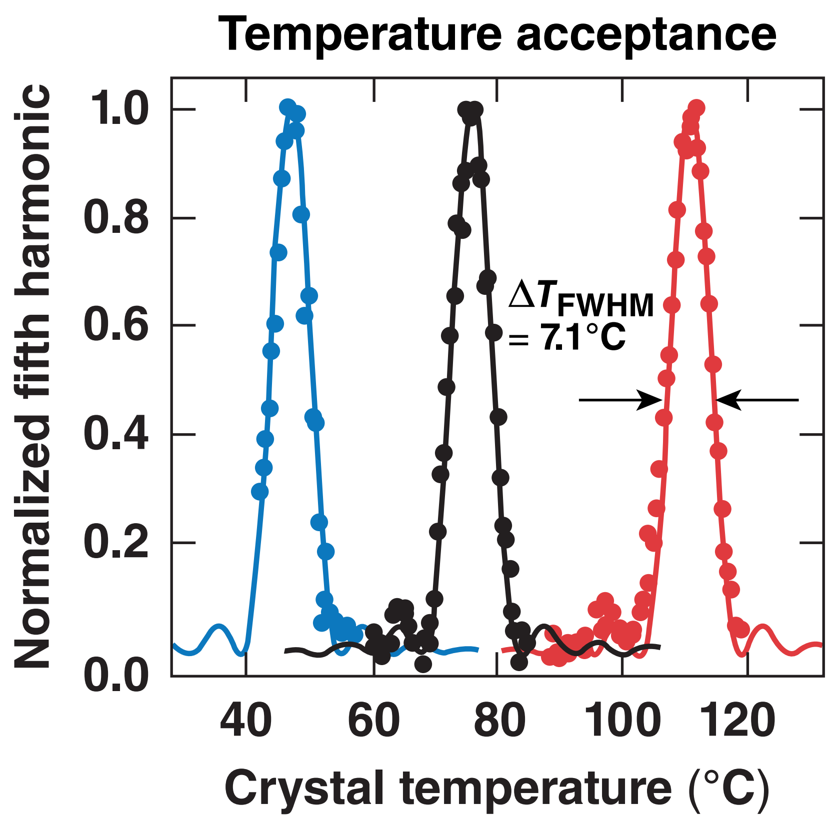
Measured angular and temperature acceptances of 5ω agree with simulations





- 4-mm long CLBO

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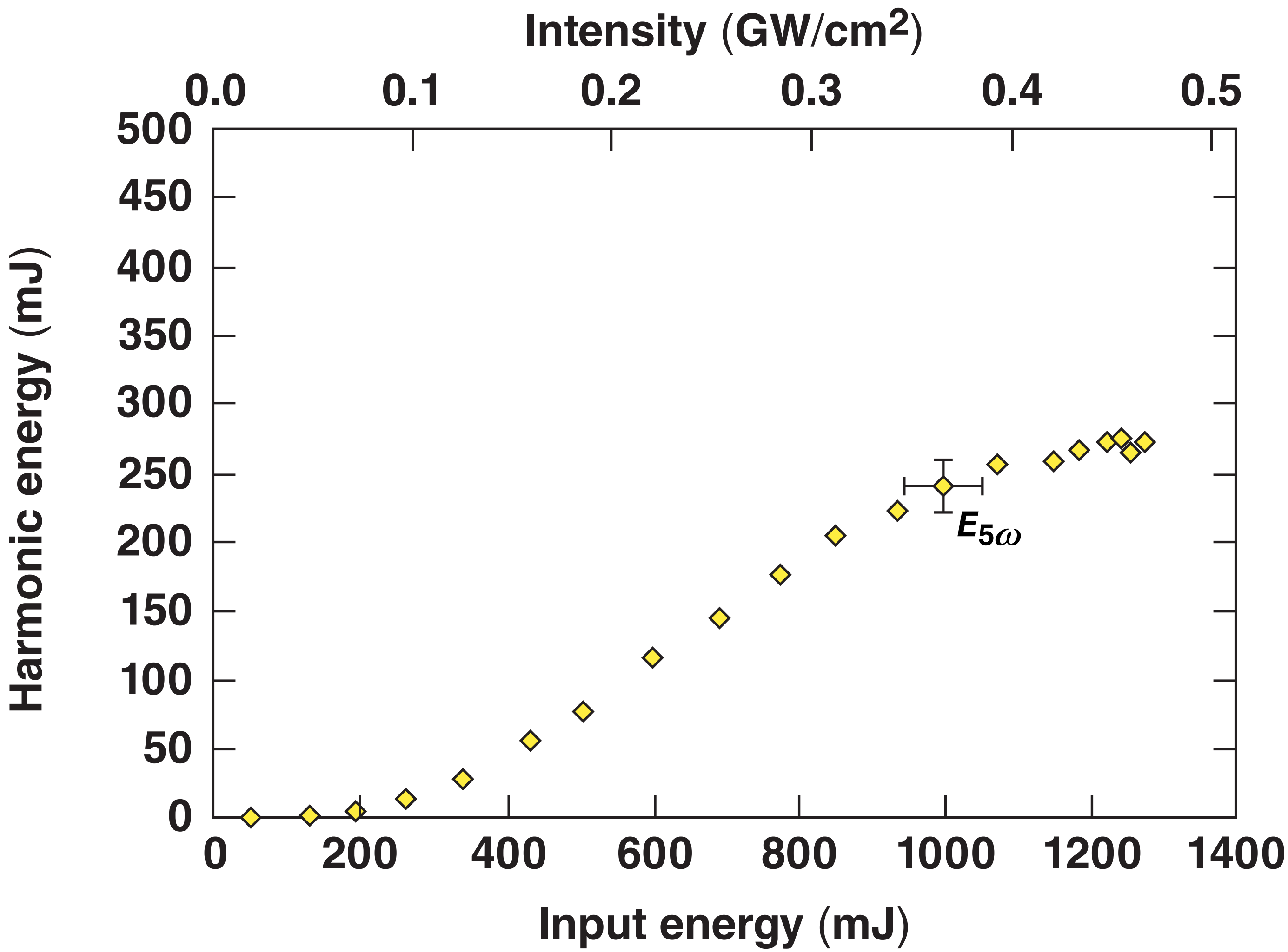
The maximum fifth-harmonic energy of 275 mJ was reached with a 2.4-ns pulse



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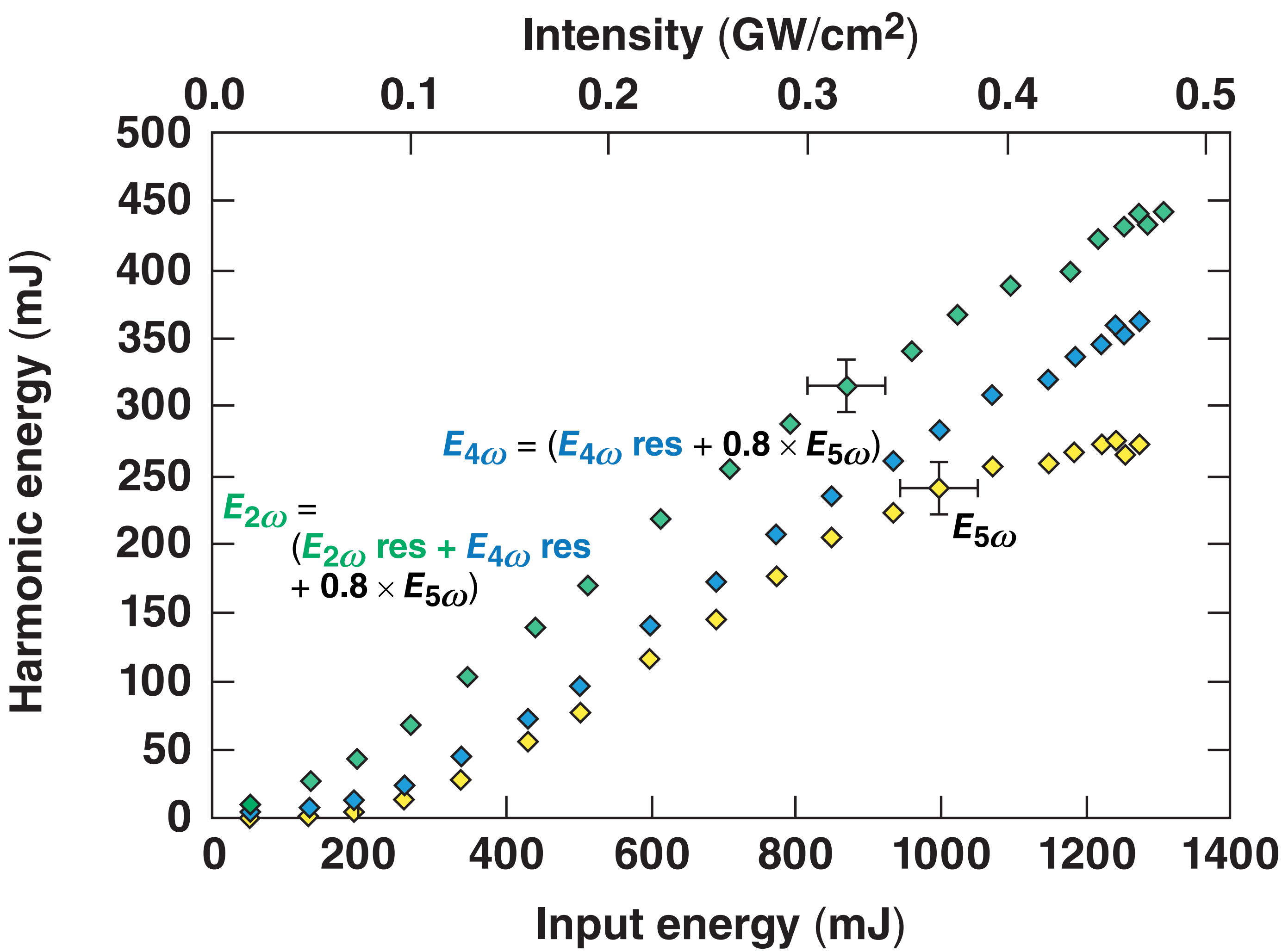
The maximum fifth-harmonic energy of 275 mJ was reached with a 2.4-ns pulse



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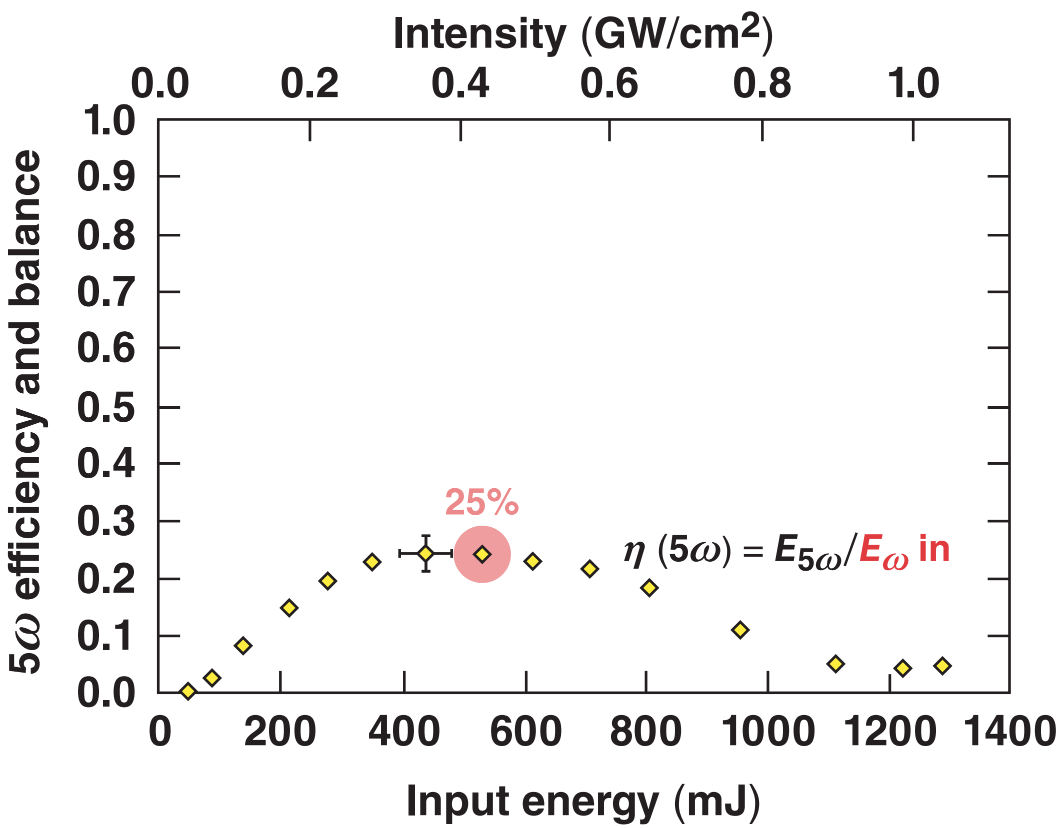
The maximum 5ω conversion efficiency was reached with a 1-ns pulse



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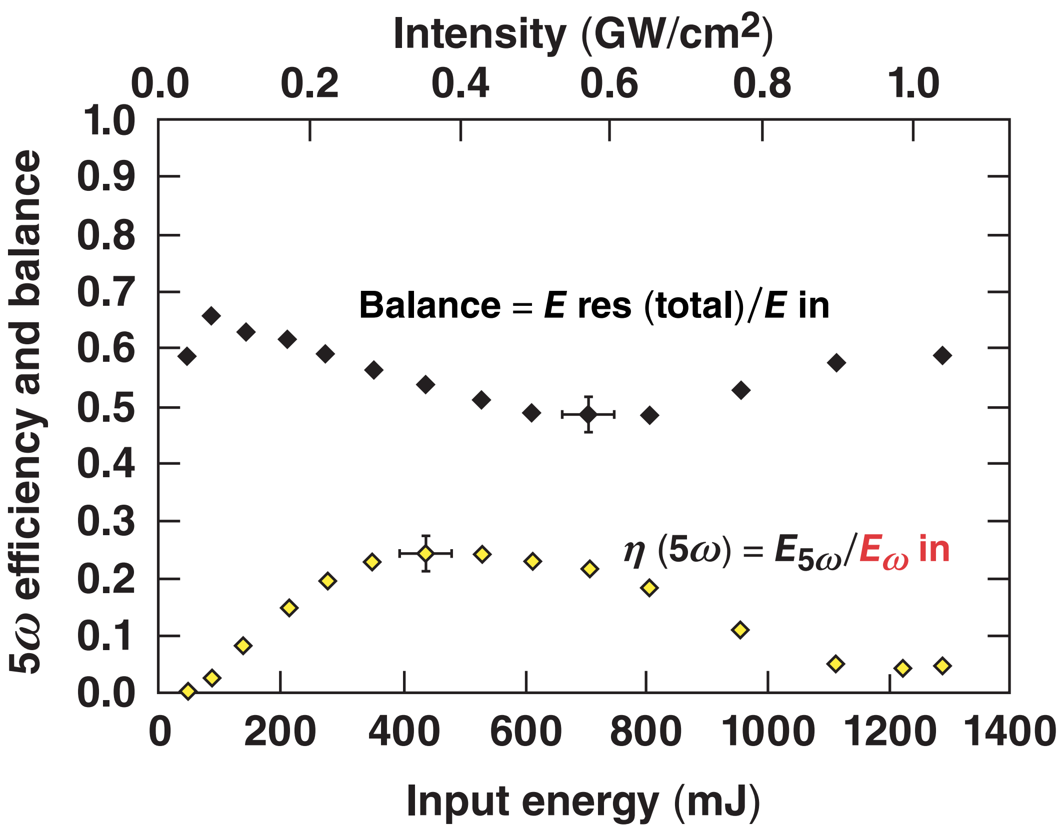
The maximum 5ω conversion efficiency was reached with a 1-ns pulse



- $FR^*_{5\omega} = E_{5\omega}/E$ res (total) = 50% (max).
- $FR_{4\omega > 5\omega}$ = 70% (max).

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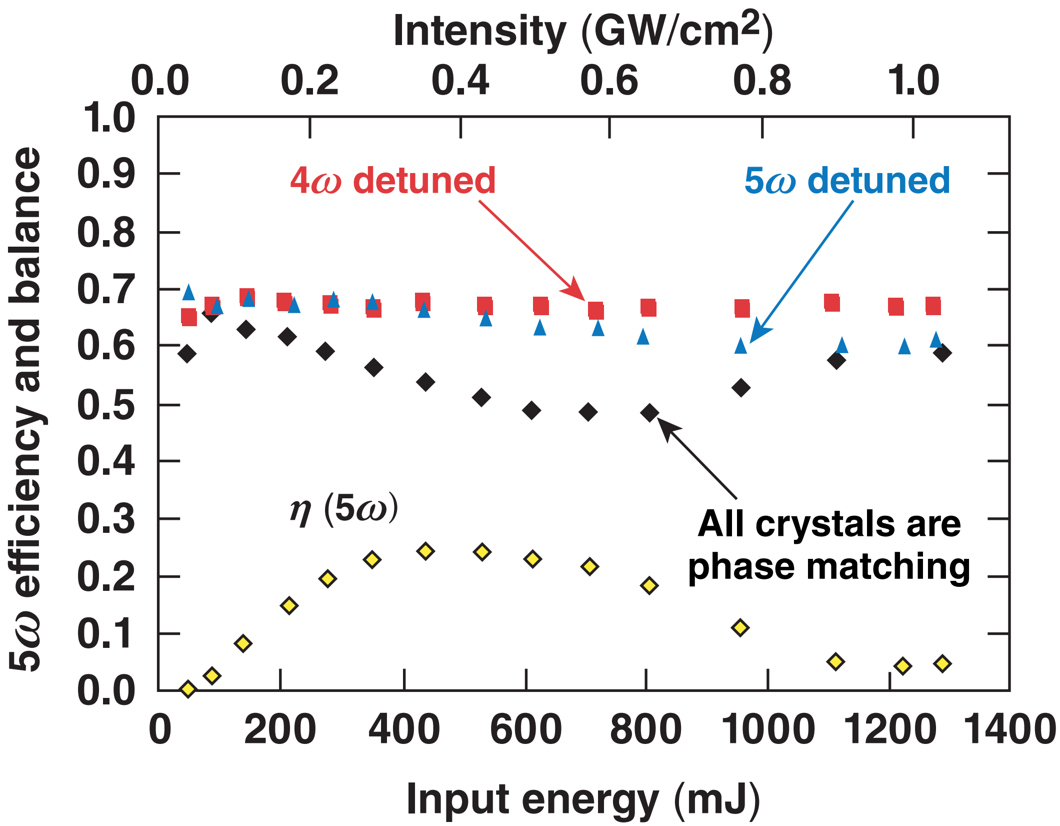
*FR: fraction

Two-photon absorption is the main fundamental limit for 5ω generation in CLBO

τ = 1 ns



- The energy balance (◆) is decreased significantly by two-photon absorption.
- Two-photon absorption of (4ω + 4ω) is relatively low.

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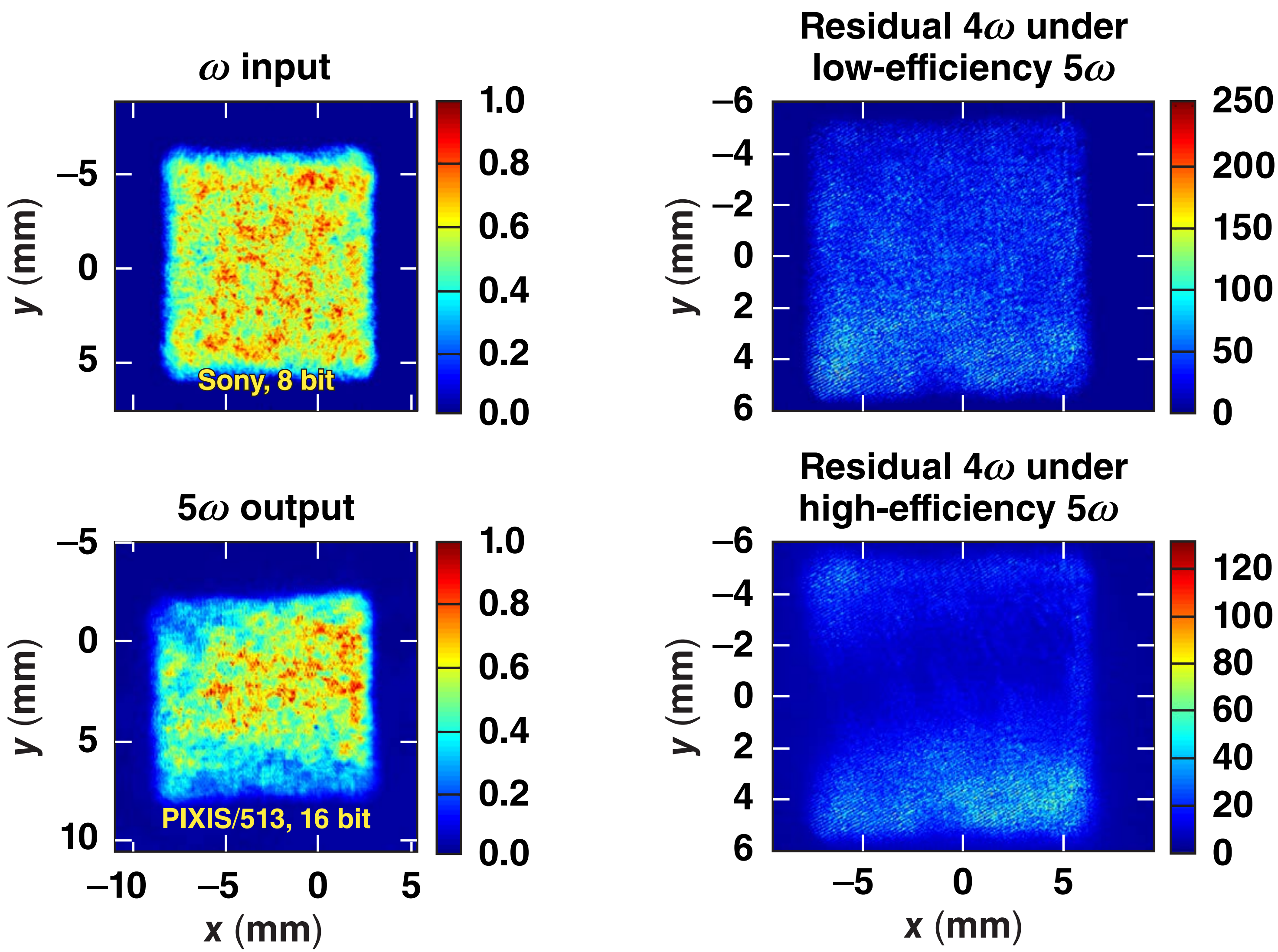
Higher conversion efficiency would be possible if the 5ω phase matching was uniform over the crystal



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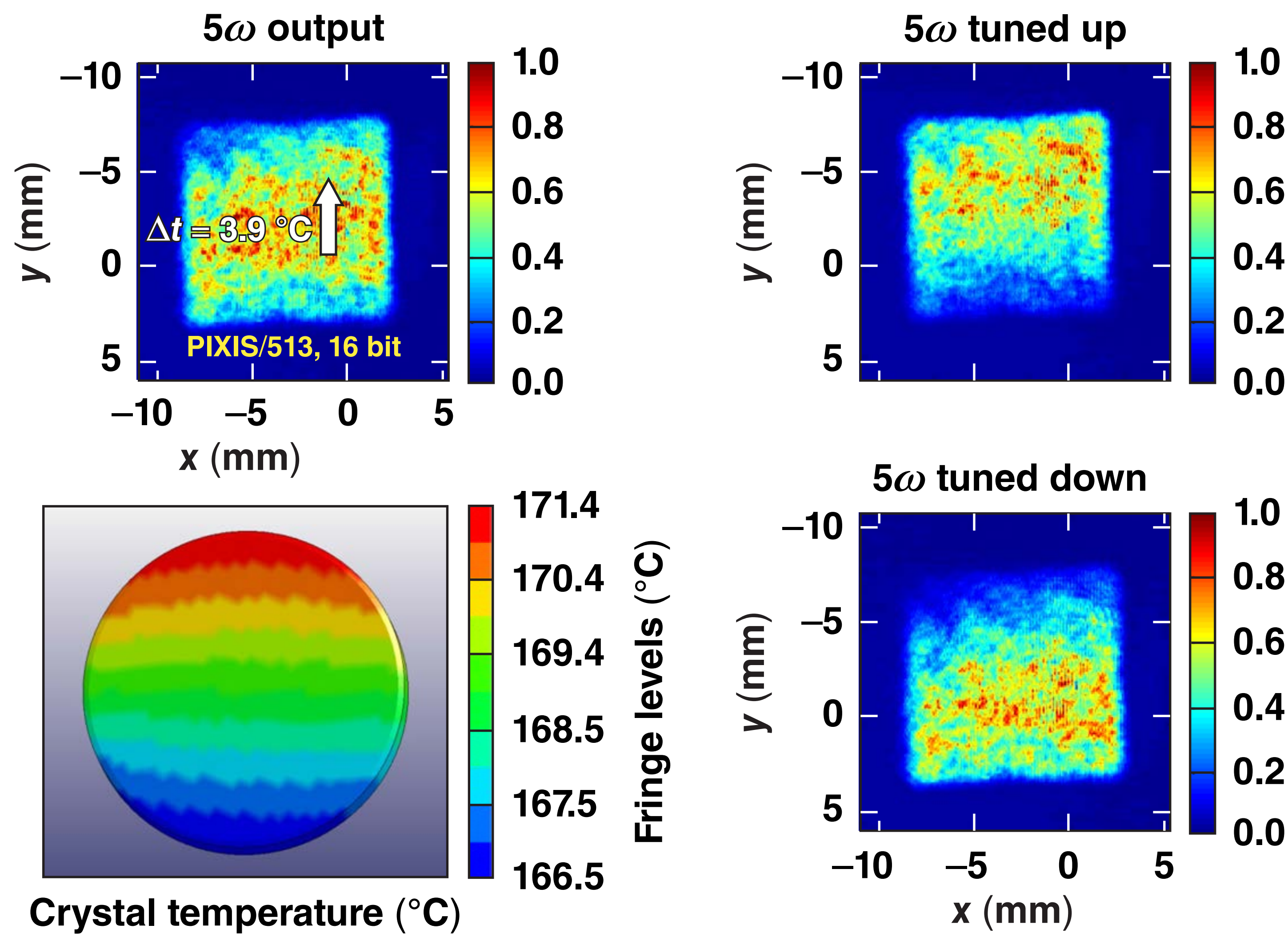
The 5ω beam nonuniformity comes from a temperature gradient over the CLBO crystal



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Summary/Conclusions

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UR LLE

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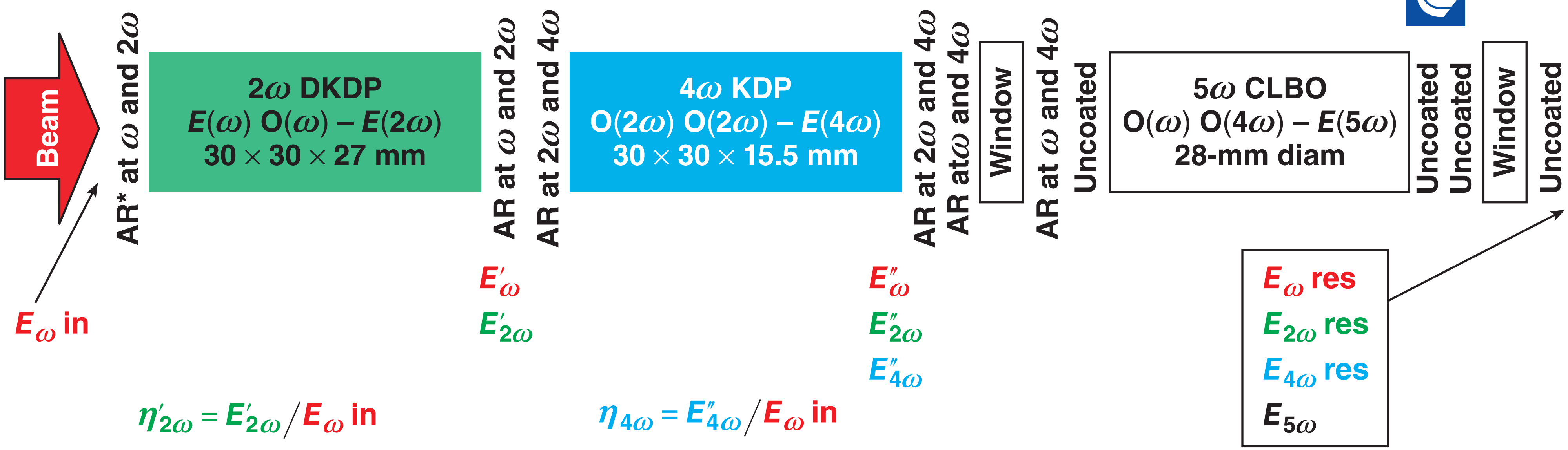
Fifth-harmonic generation has been realized in a cascade frequency conversion



$\eta'_{2\omega} = E'_{2\omega} / E_\omega \text{ in}$

$\eta_{4\omega} = E''_{4\omega} / E_\omega \text{ in}$

$\text{FR}'_{2\omega} = E'_{2\omega} / (E'_{2\omega} + E'_\omega)$

$\text{FR}''_{2\omega > 4\omega} = E''_{4\omega} / (E''_{4\omega} + E''_{2\omega})$

$\eta_{5\omega} = E_{5\omega} / E_\omega \text{ in}$

$E \text{ res (total)} = E_\omega \text{ res} + E_{2\omega} \text{ res} + E_{4\omega} \text{ res} + E_{5\omega}$

$\text{FR}_{5\omega} = E_{5\omega} / E \text{ res (total)}$

$\text{FR}_{2\omega} = (E_{2\omega} \text{ res} + E_{4\omega} \text{ res} + 0.8 \times E_{5\omega}) / E \text{ res (total)}$

$\text{FR}_{4\omega > 5\omega} = E_{5\omega} / (1.25 \times E_{4\omega} + E_{5\omega})$

$\text{FR}_{2\omega > 4\omega} = (E_{4\omega} \text{ res} + 0.8 \times E_{5\omega}) / (E_{2\omega} \text{ res} + E_{4\omega} \text{ res} + 0.8 \times E_{5\omega})$

FR means "fraction"

$\text{Balance} = (E_\omega \text{ res} + E_{2\omega} \text{ res} + E_{4\omega} \text{ res} + E_{5\omega}) / E_\omega \text{ in} = E \text{ res (total)} / E_\omega \text{ in}$

*AR: antireflection coating

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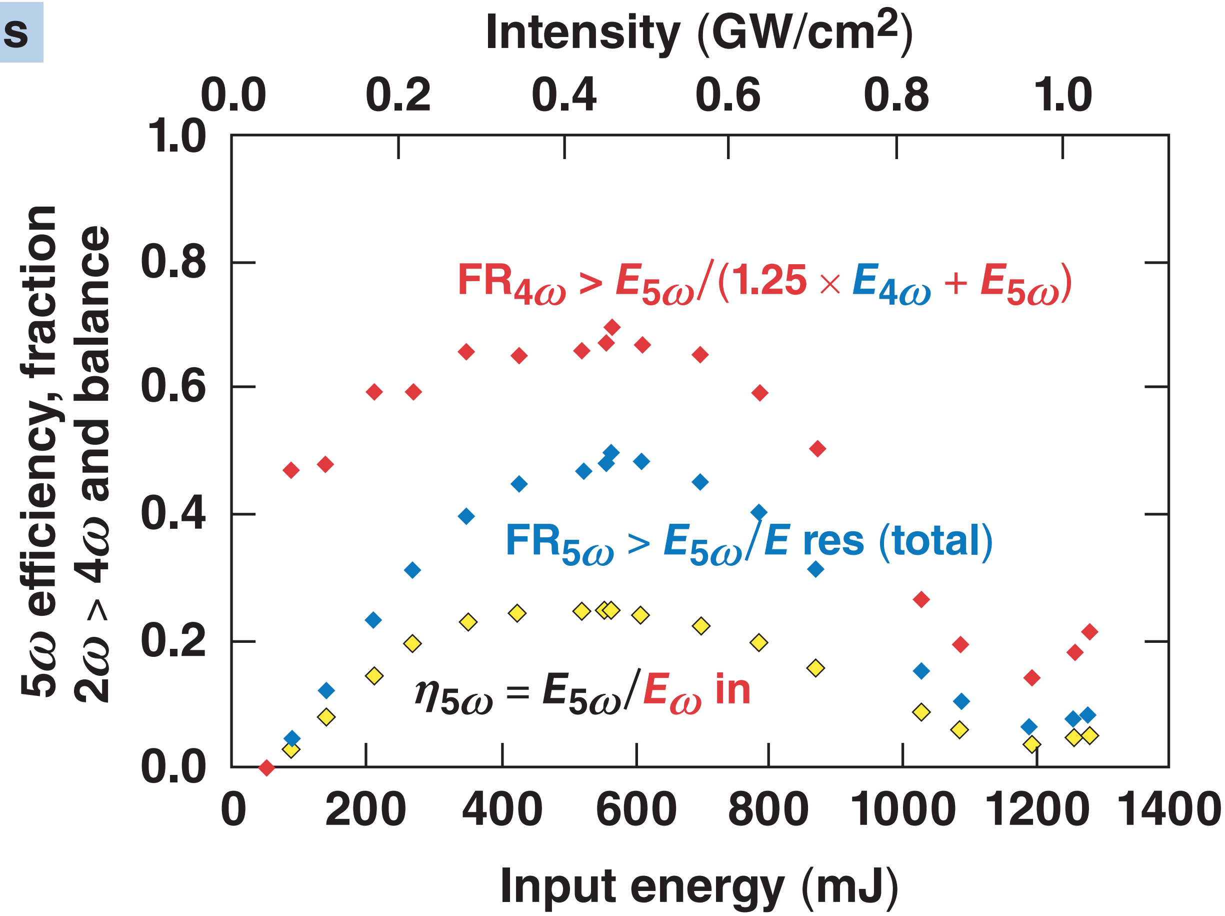
How efficient is the fifth-harmonic–generation process?

$\tau = 1$ ns



Half the optical output energy is at 5ω.

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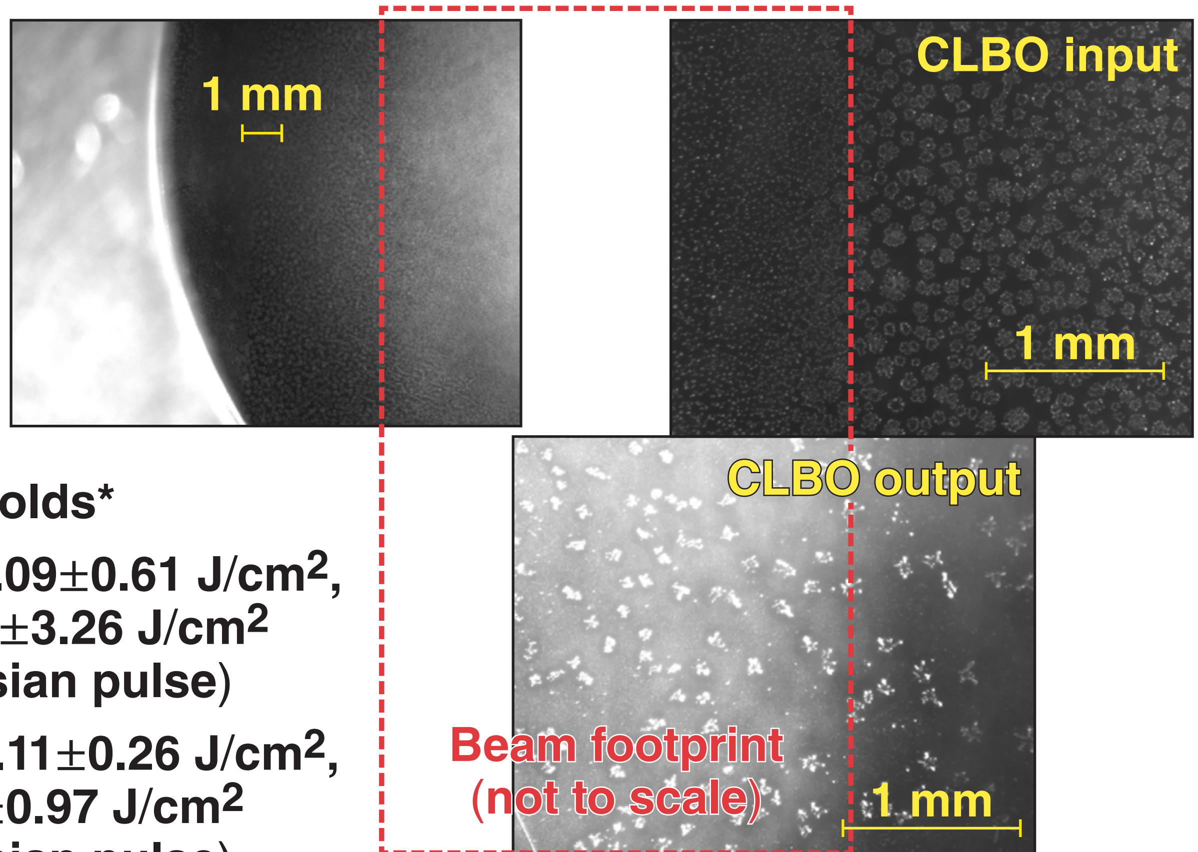
Damages have been found on both input and output surfaces of CLBO, even in the area not exposed by the laser beam



Damage thresholds*

- ω: 1-on-1: 12.09±0.61 J/cm^2, *N*-on-1: 16.36±3.26 J/cm^2 (1.4-ns Gaussian pulse)
- 2ω: 1-on-1: 5.11±0.26 J/cm^2, *N*-on-1: 8.87±0.97 J/cm^2 (1.2-ns Gaussian pulse)

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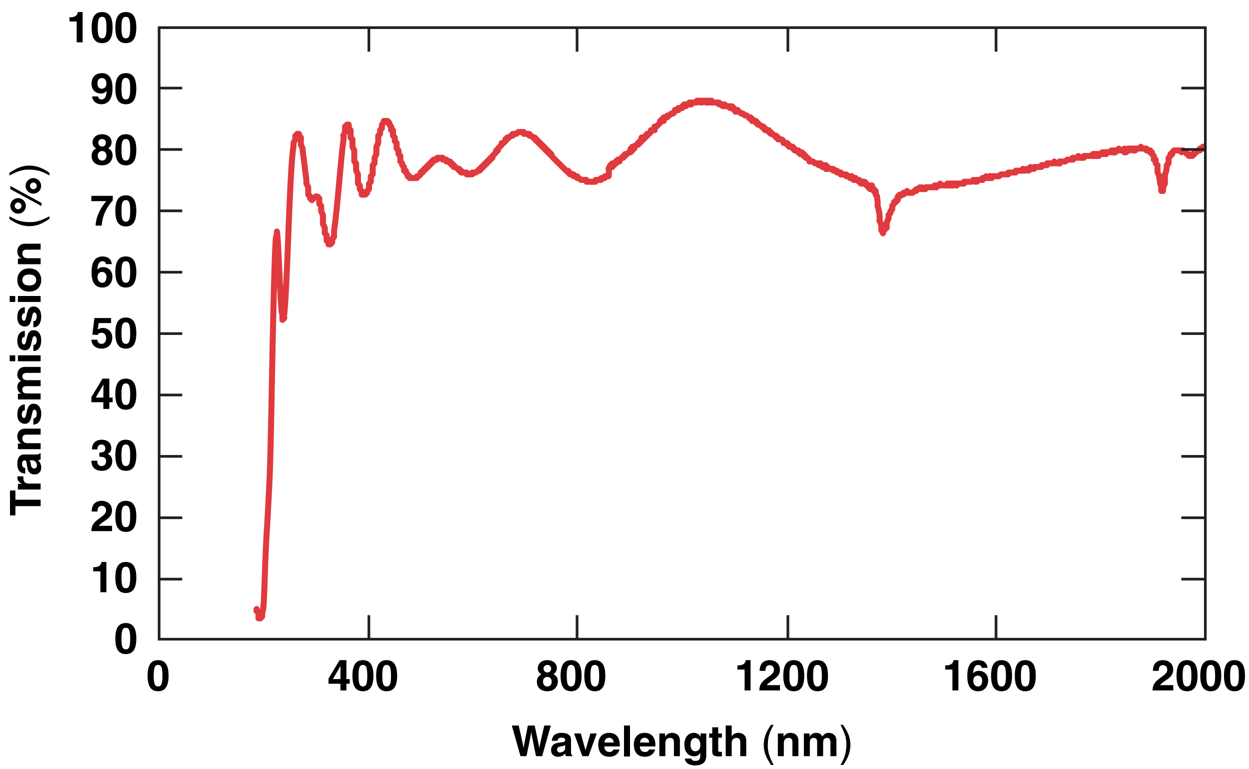
*A. A. Kozlov and S Papernov, tested in the LLE Damage Test Laboratory (2016).

The transmission response of the CLBO oven assembly



The CLBO oven input window is AR coated for 1ω and 4ω; the crystal and output window are uncoated.

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