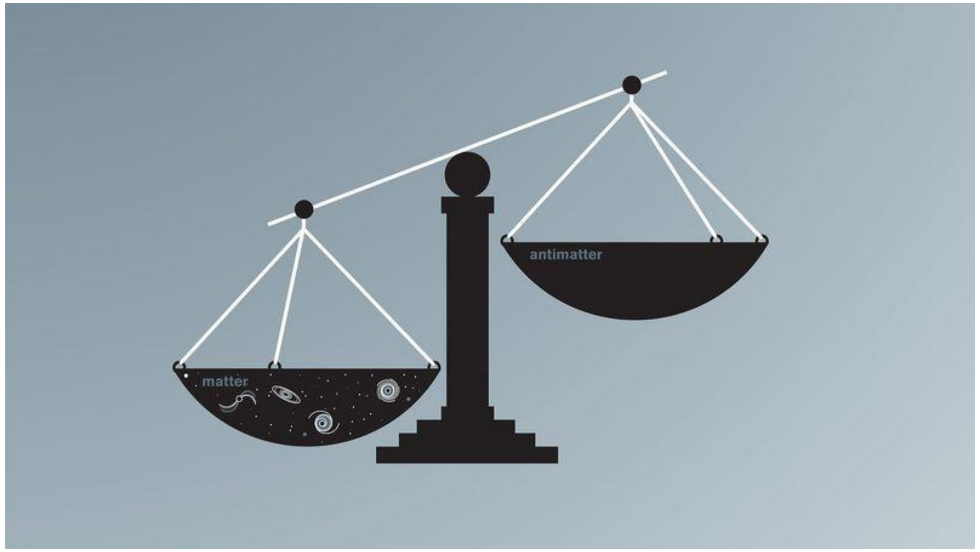
Toward Laser Ablation of Barium Ions

Authors:
Tom Sonius *(S4393503)*

Supervisors:
Dr. Steve Jones
Dr. Lorenz Willmann

Motivation: ALPHA

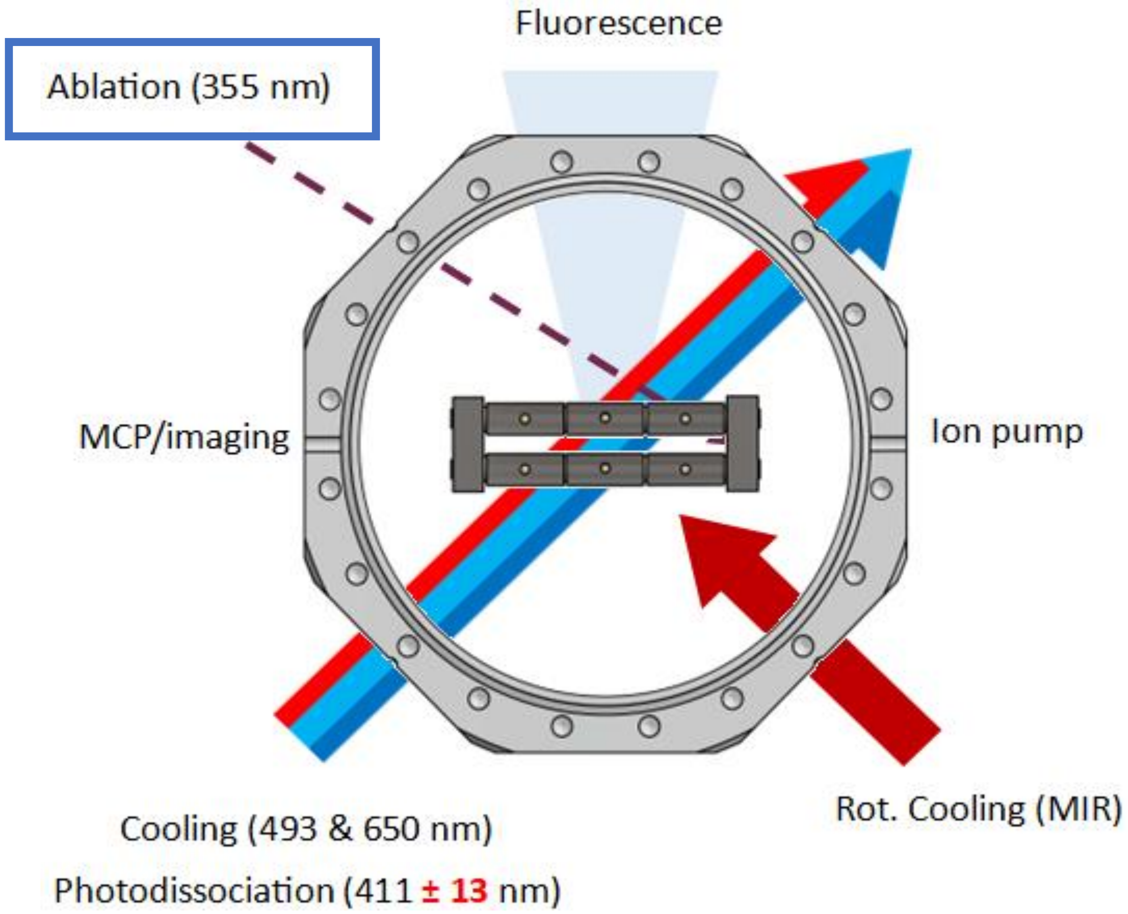
- Why does matter dominate the universe?
- Transition between ground state and first excited state
- Predicted to be the same for hydrogen and anti-hydrogen
- Precision is limited



Y. Nir, “Cp violation,” symmetry magazine, 2005.

Motivation: DiCE

- Compare the two directly
- Laser ablation of BaH_2 => Ba^+ and BaH^+ ions

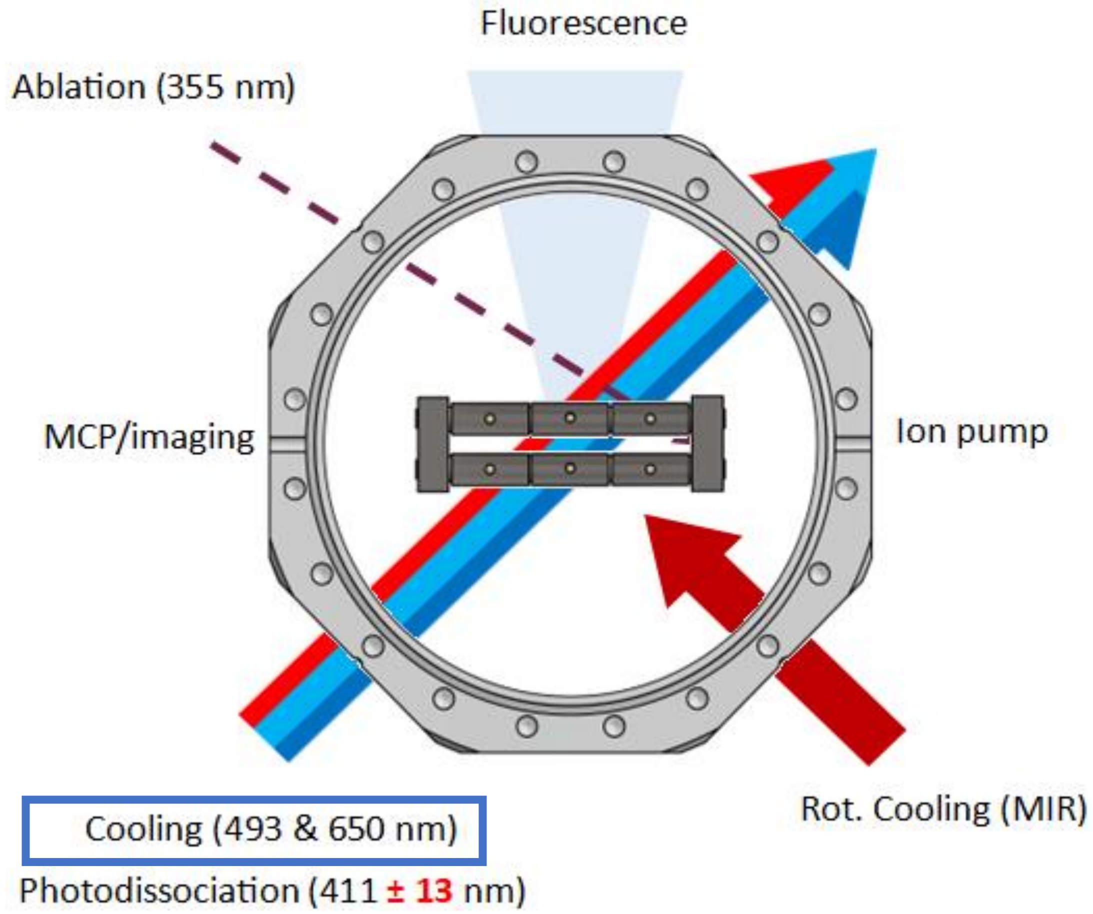


S. A. Jones, "An ion trap source of cold atomic hydrogen via photodissociation of the bah+ molecular ion," New Journal of Physics, vol. 24, no. 2, p. 023 016, 2022, issn: 1367-2630.

Motivation: DiCE

- Compare the two directly

- Laser ablation of BaH_2 => Ba^+ and BaH^+ ions
- Laser cool Ba^+ => sympathethically cool BaH^+



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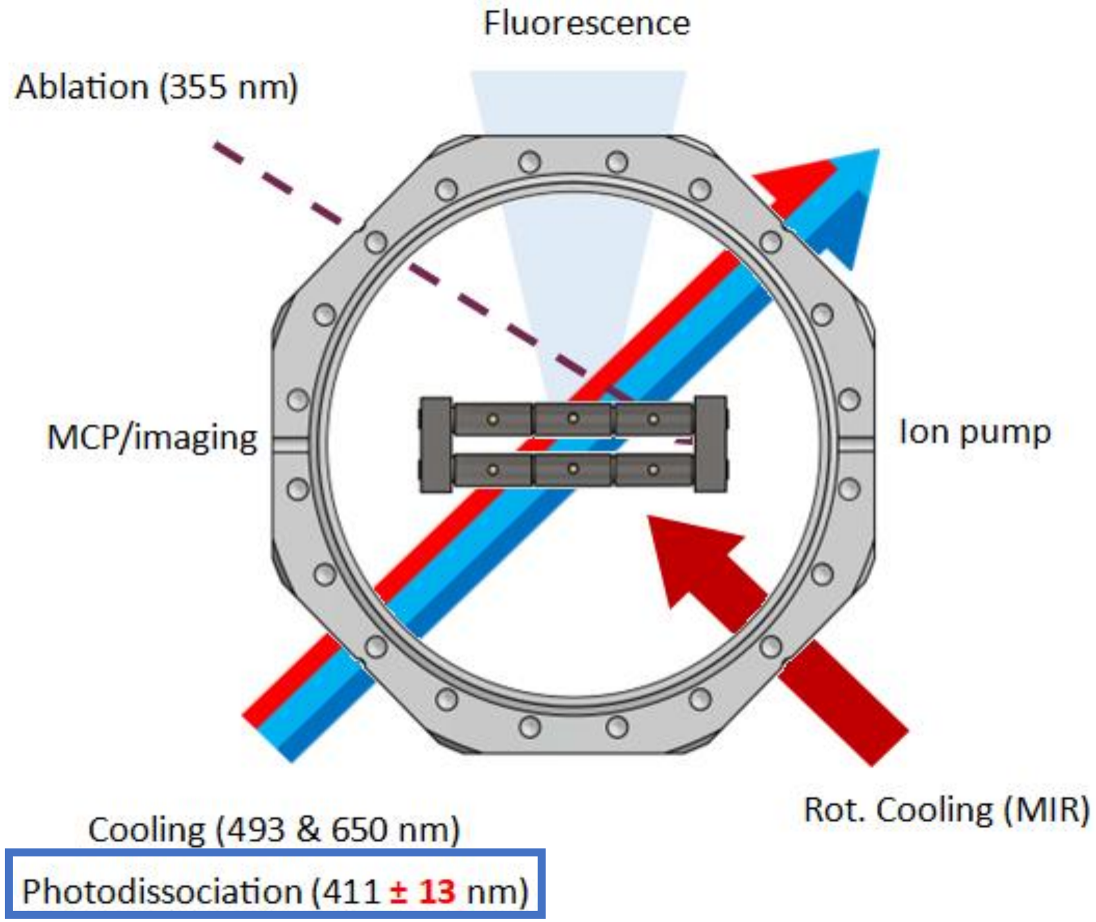
- Photodissociate BaH^+ => cold H



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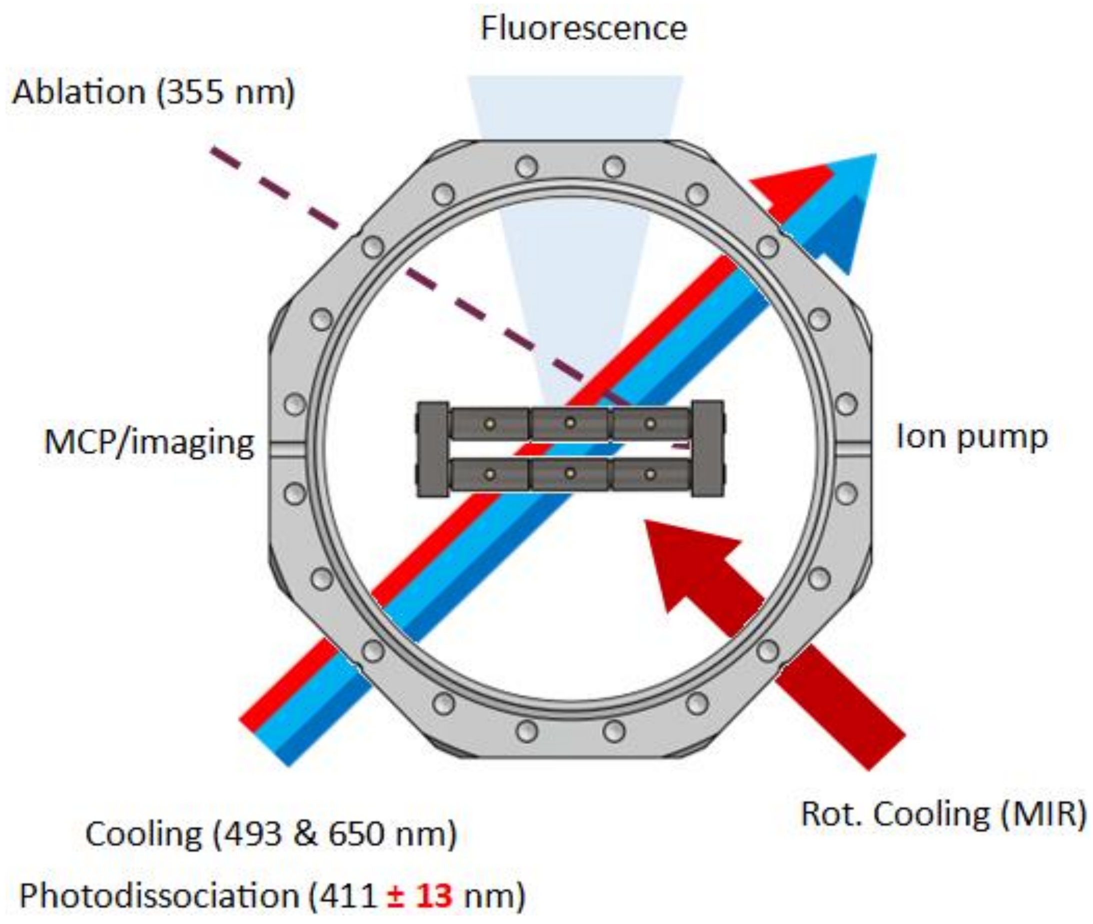

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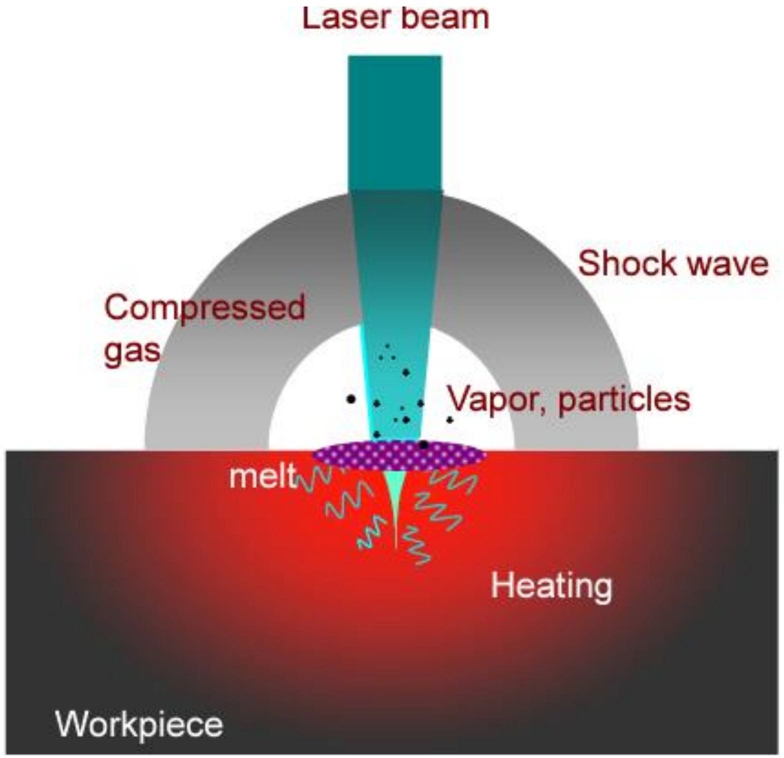
Background: Laser ablation

$$F_{th} \propto \sqrt{t_p T_v^2}$$



E. Rollin, “Barium Ion Extraction and Identification from Laser Induced Fluorescence in Gas for the Enriched Xenon Observatory,” Ph.D. dissertation, Carleton U., 2011.

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Background: Laser ablation

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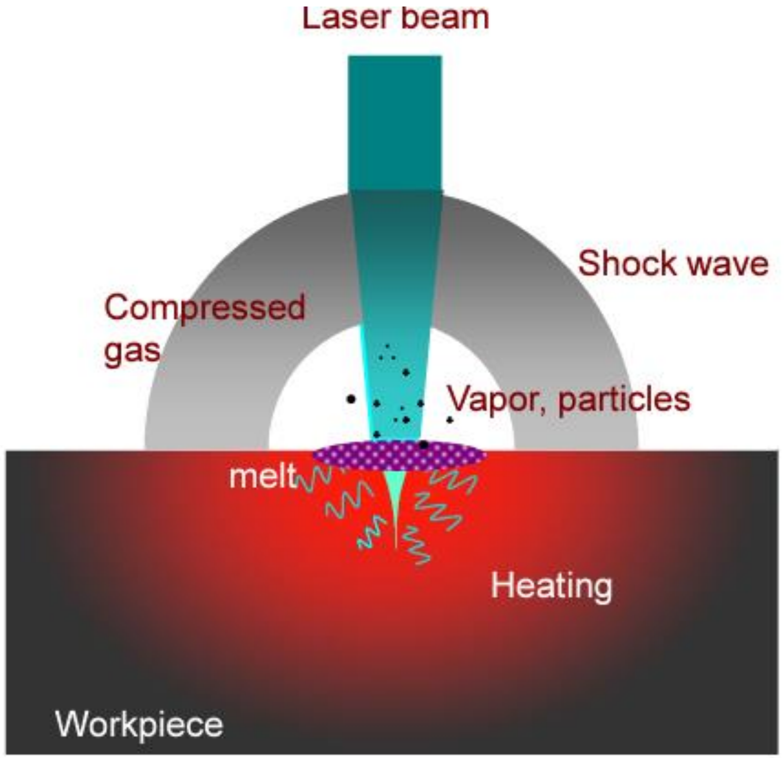
$$F_{th_{Barium}} \approx 0.09\ J/cm^2$$



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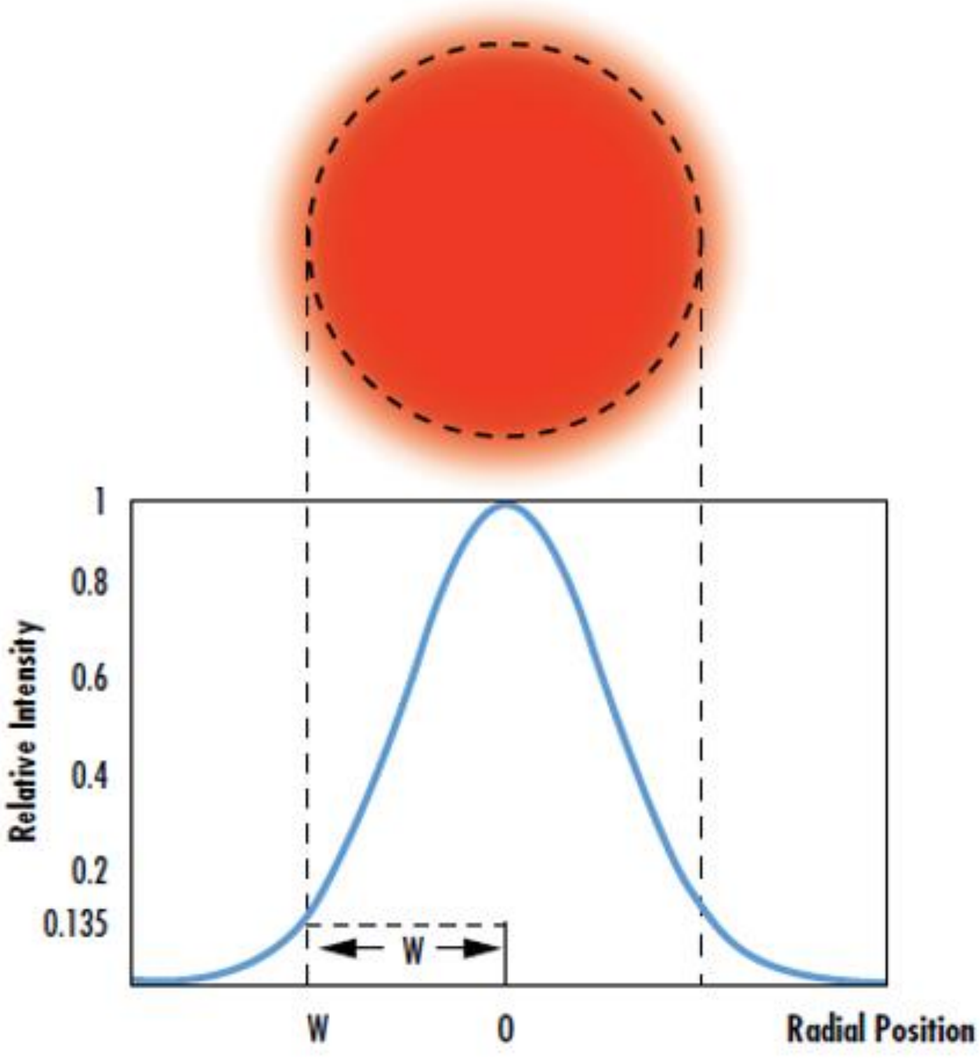
Background: Gaussian beam

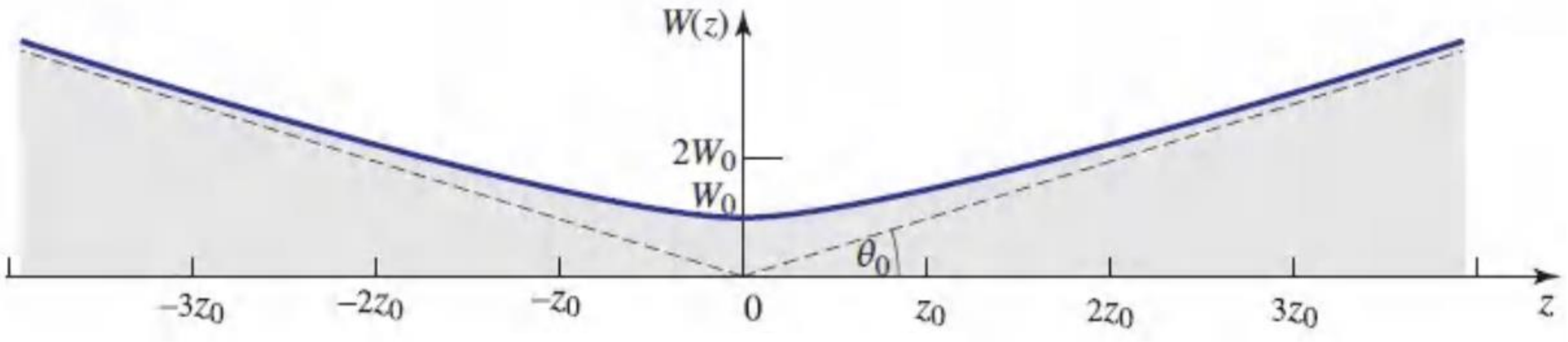


$$I(x,y) = I_0\ exp[-\frac{2(x-x_0)^2}{w^2} - \frac{2(y-y_0)^2}{w^2}]$$

Edmund, Gaussian beam propagation: Edmund optics, c2023.

B. Saleh and M. Teich, Fundamentals of Photonics, 3rd Edition. Feb. 2019, isbn: 9781119506874

Background: Gaussian beam



$$w = w_0 \sqrt{1 + \left(\frac{z}{z_0}\right)^2}$$

$$z_0 = \frac{\pi w_0^2}{\lambda}$$

B. Saleh and M. Teich, Fundamentals of Photonics, 3rd Edition. Feb. 2019, isbn: 9781119506874

Goal

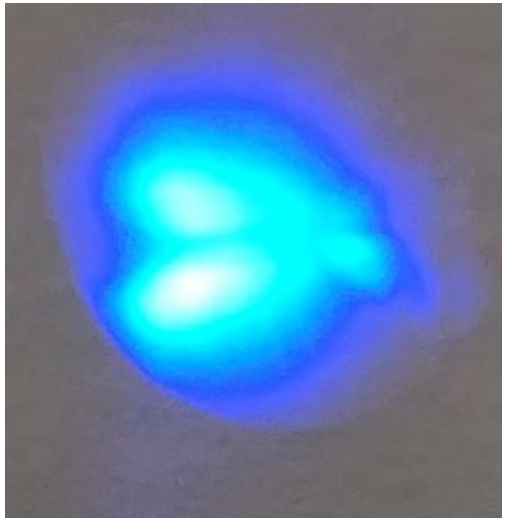
Goals:

- Focus the UV laser to a tight spot
- Approximate the energy needed to ablate barium

To do so:

- Profile the beam
- Construct optical configuration
- Measure the spot size at the focus point

Challenges



$$M^2 = \frac{w_m \cdot \theta_m}{2\lambda/\pi}$$

$$w = w_0 \sqrt{M^2 + M^2\left(\frac{z}{z_0}\right)^2}.$$

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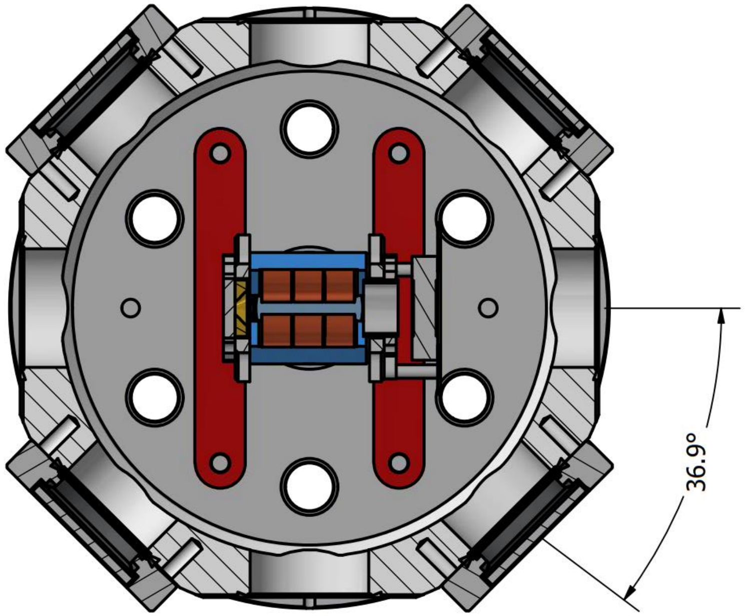
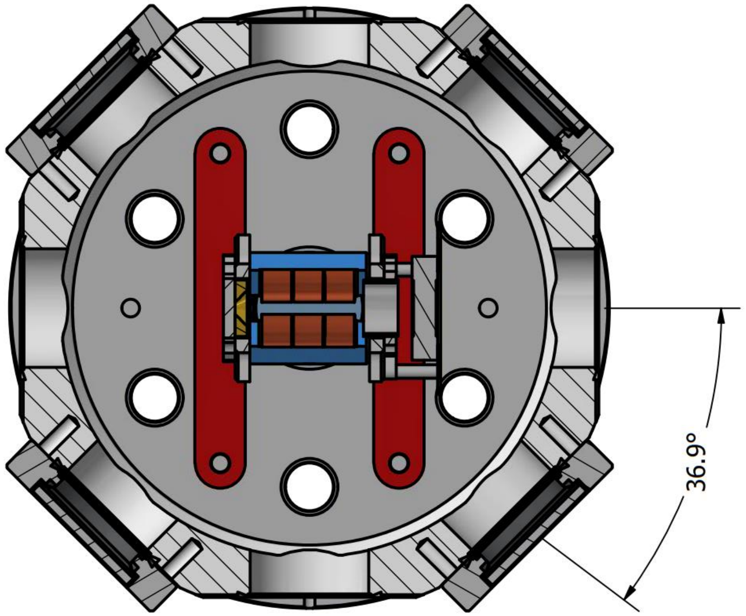
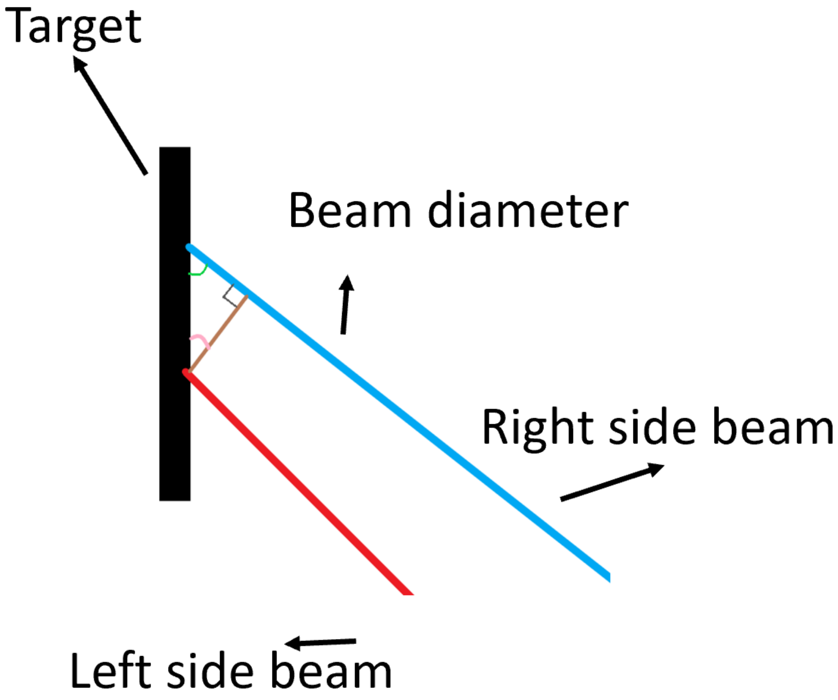
Challenges



Challenges

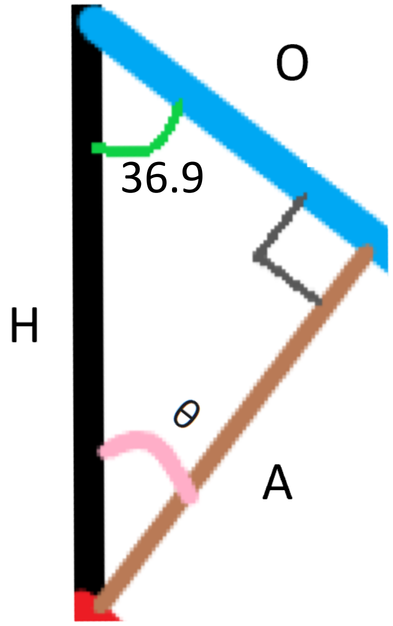



Target

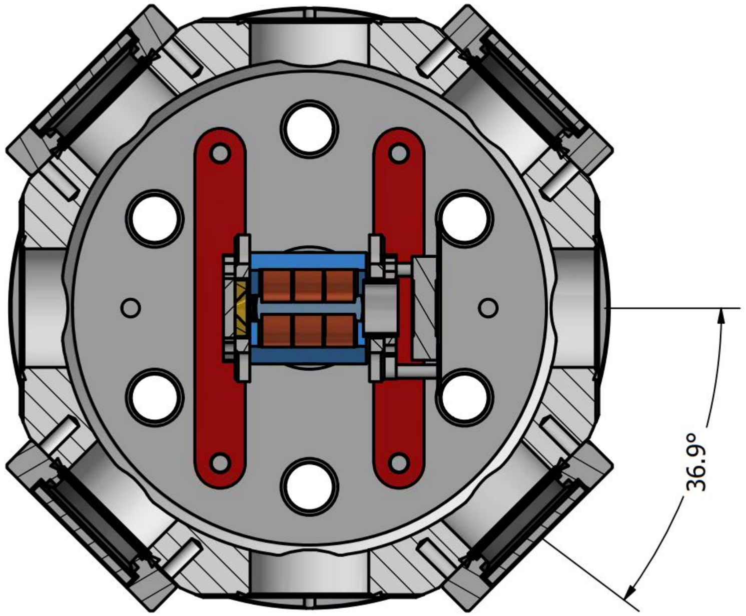
Beam diameter

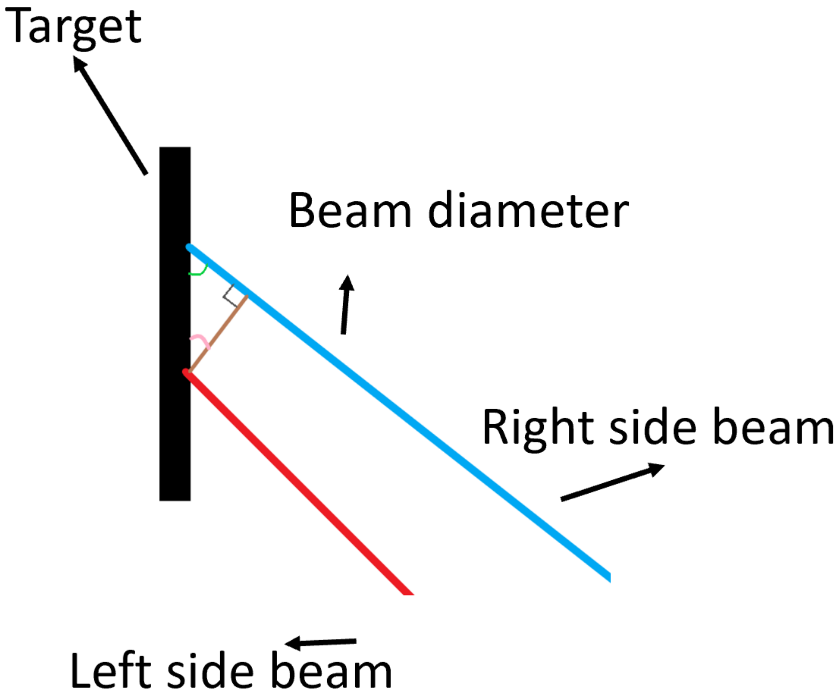
Right side beam

Left side beam



Challenges

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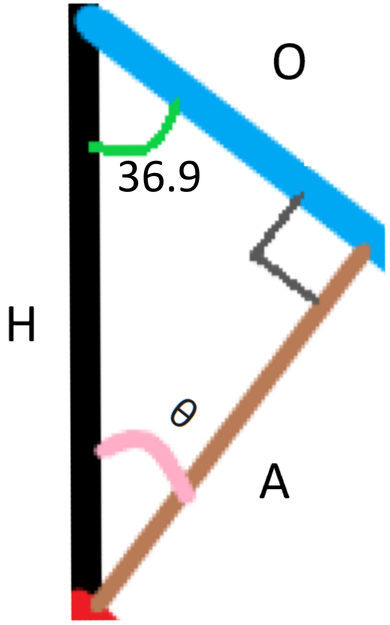
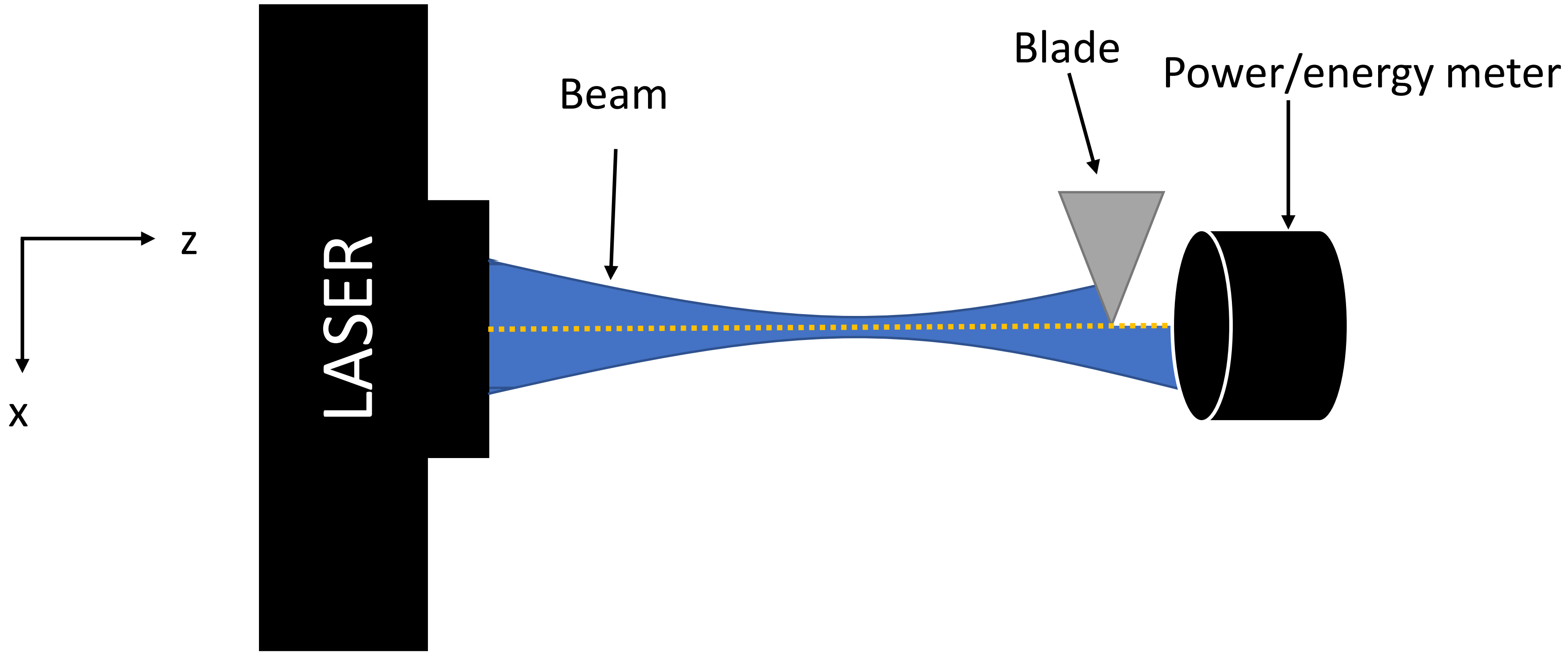
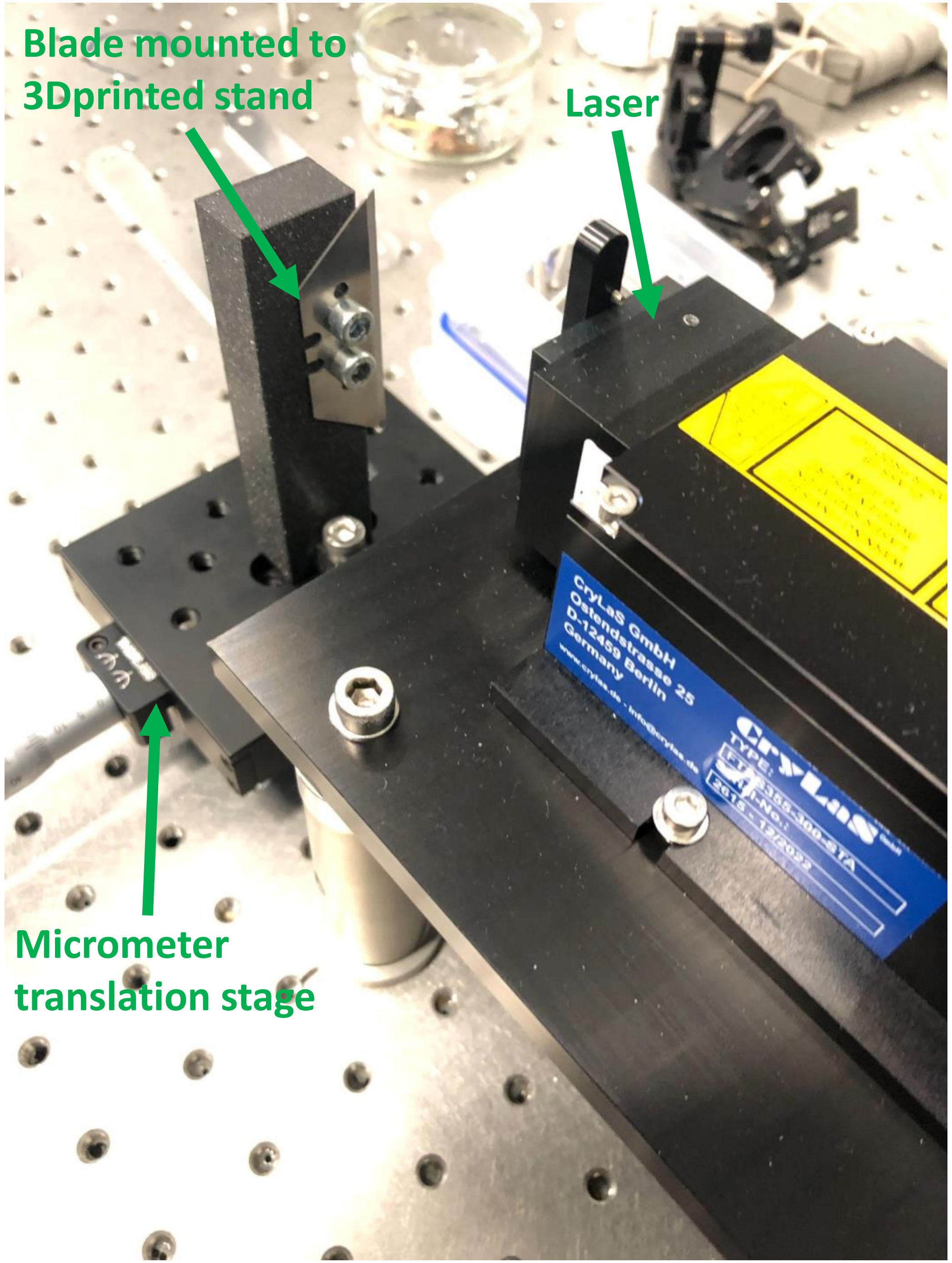


$$H = \frac{A}{cos(\theta)} = \frac{A}{cos(90 - 36.9)} \approx 1.67 \times A$$

Methods: Knife-edge method

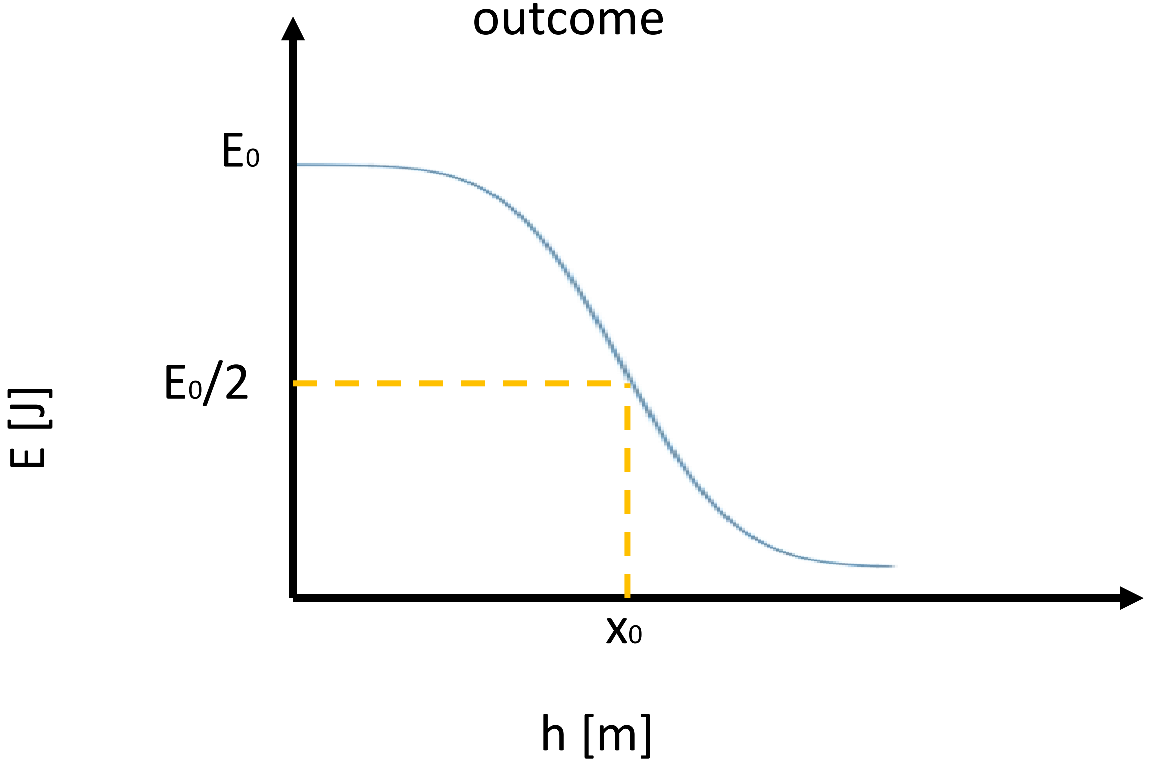


Y. Chiu and J.-H. Pan, “Micro knife-edge optical measurement device in a silicon-on-insulator substrate,” Opt. Express, vol. 15, no. 10, pp. 6367–6373, May 2007.



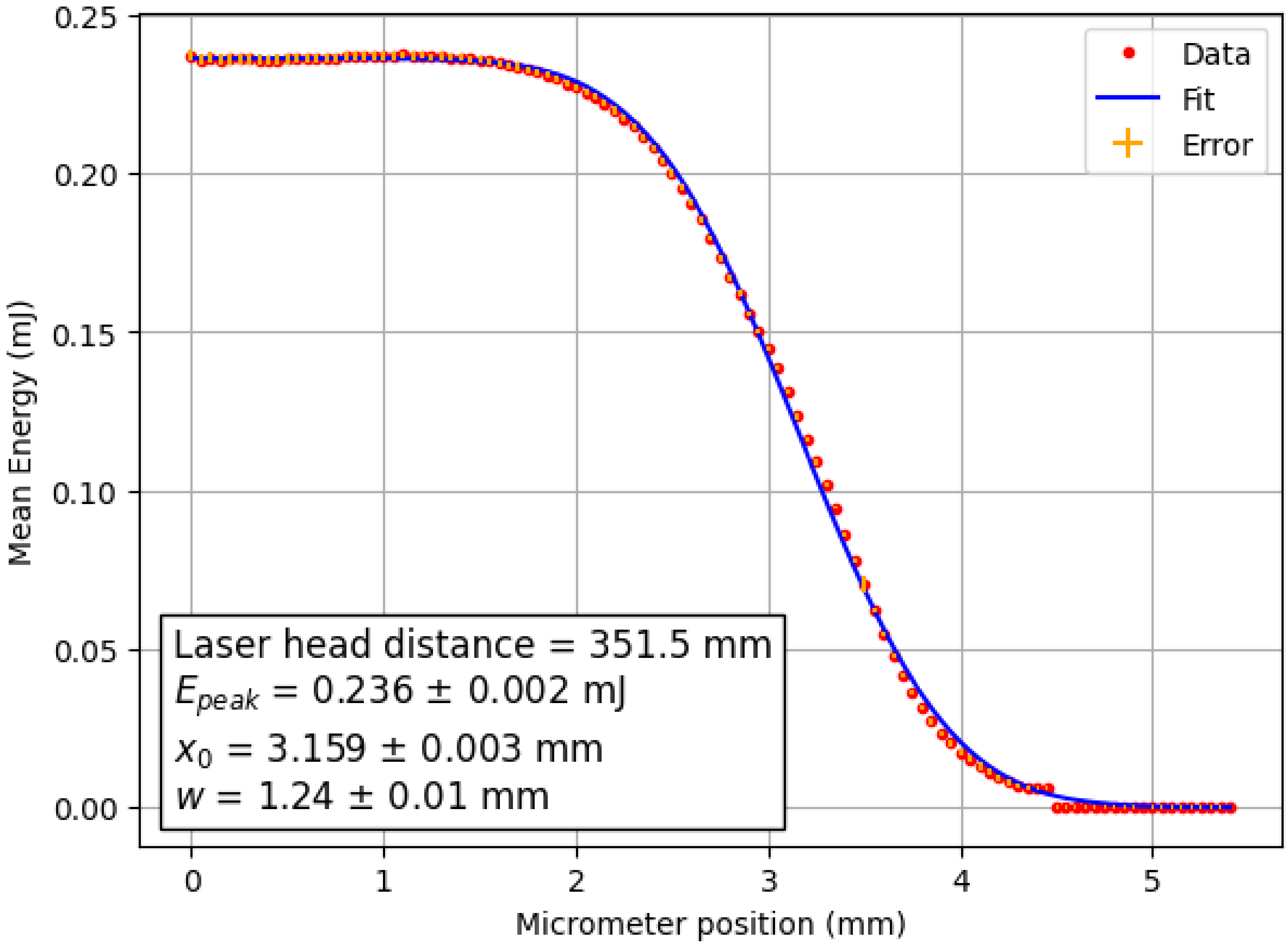
$$P(h) = \frac{P_{peak}}{2}\,\mathrm{erfc}\left(\frac{h - x_0}{\frac{\boxed{w}}{\sqrt{2}}}\right).$$

Expected energy vs distance outcome



M. Rosete, “Position sensing of a gaussian beam with a power meter and a knife edge,” Revista Mexicana de Fisica, vol. 39, pp. 484–492, Jan. 1993

Results: Profiling



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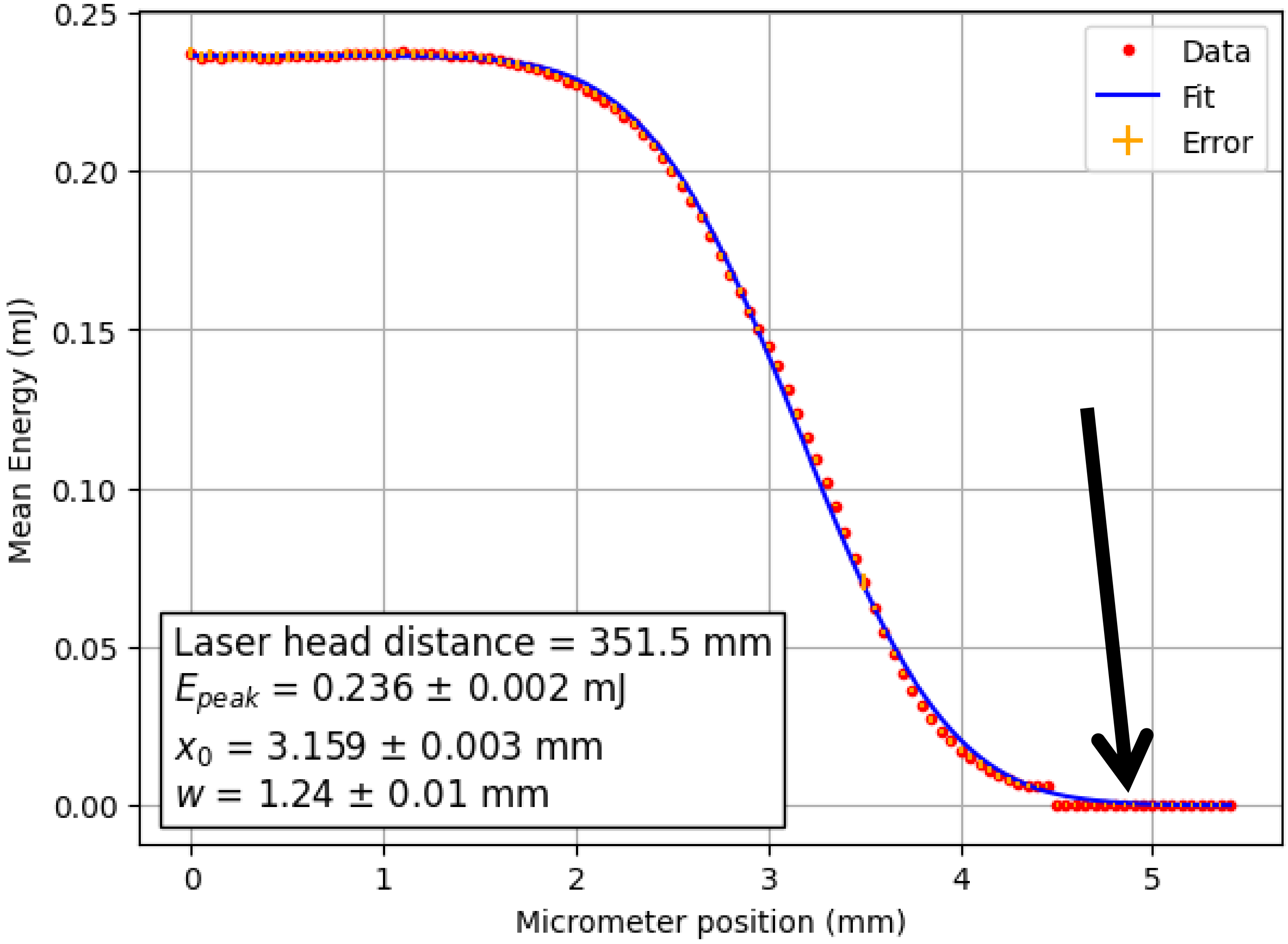

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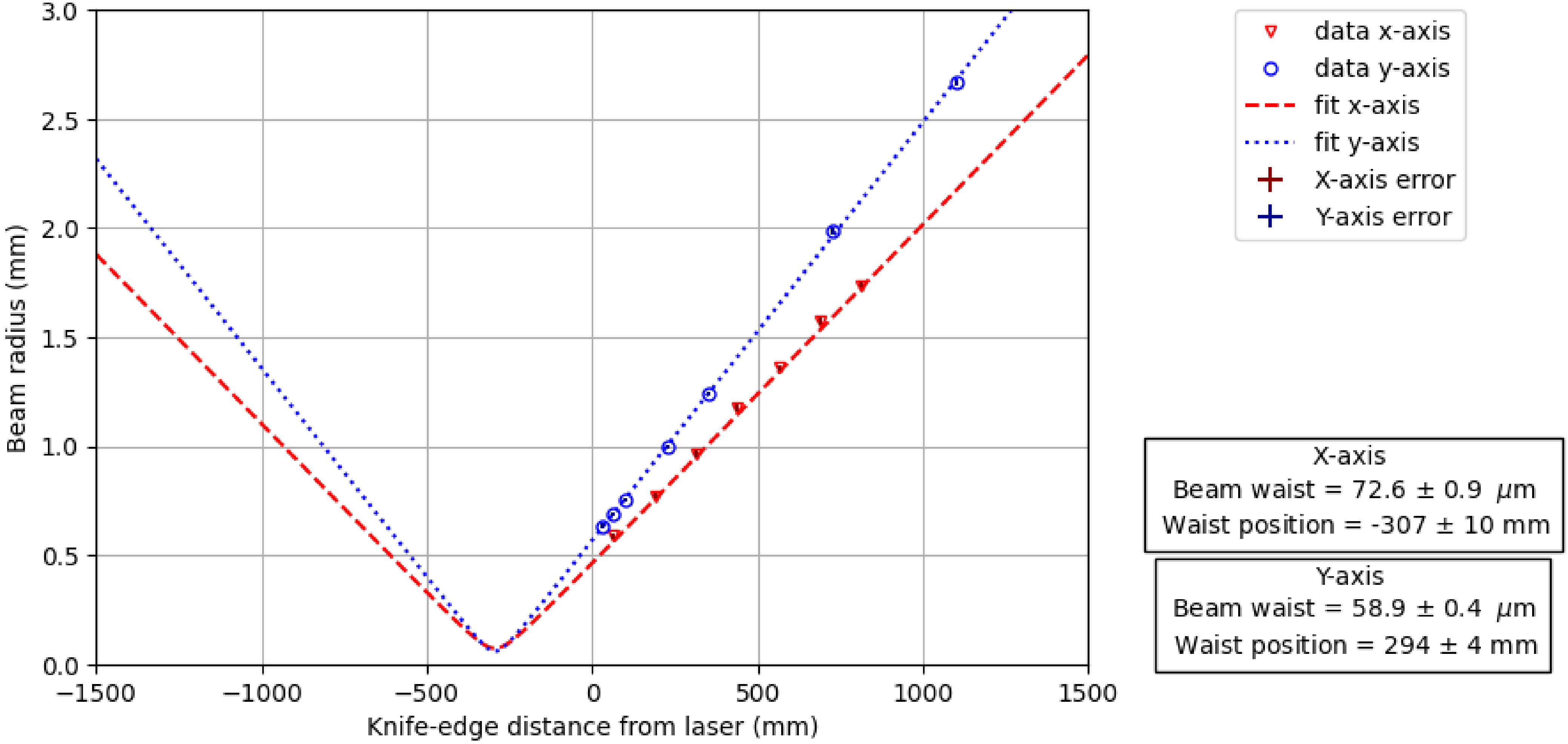
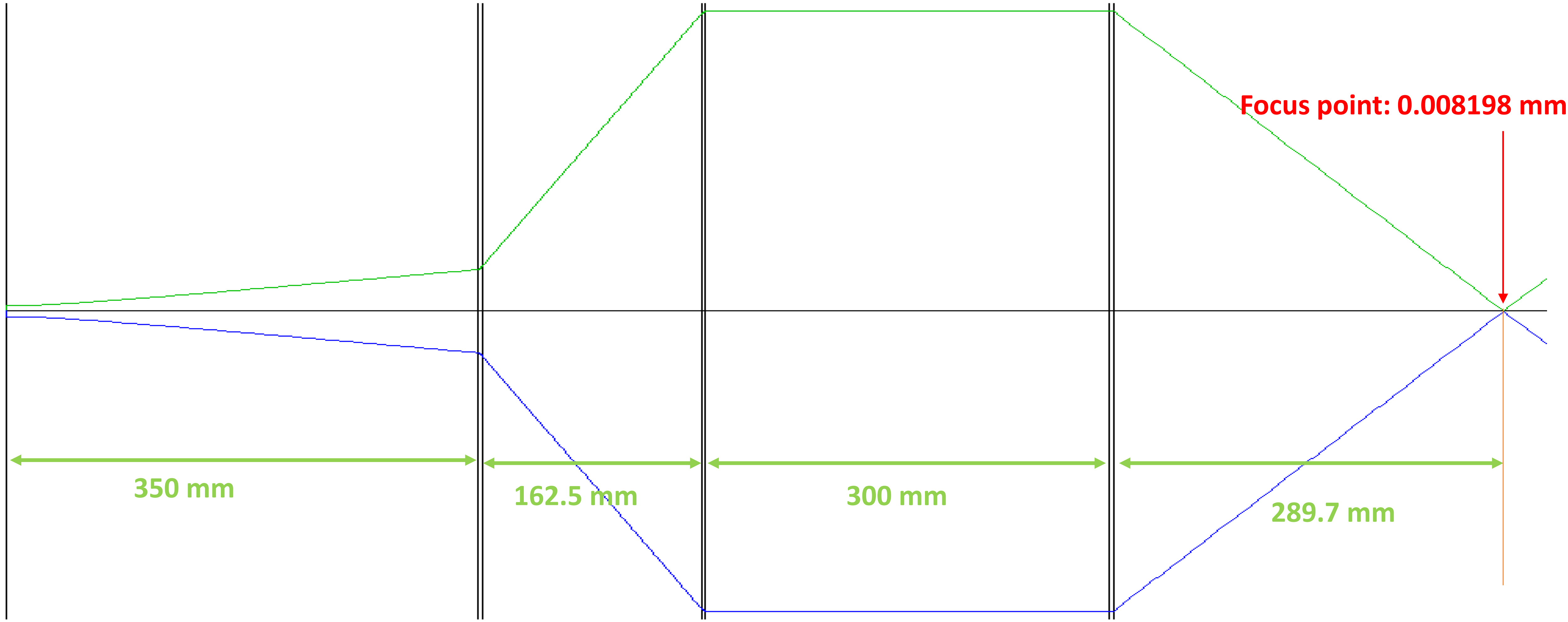


X-axis
Beam waist = 72.6 ± 0.9 μm
Waist position = -307 ± 10 mm

Y-axis
Beam waist = 58.9 ± 0.4 μm
Waist position = 294 ± 4 mm

Results: Simulations



Beam waist: 0.072 mm

Lens 1 arrive: 0.55 mm

Lens 2 exit: 3.996 mm

Lens 3 arrive: 3.994 mm

Focus point: 0.008198 mm

350 mm

162.5 mm

300 mm

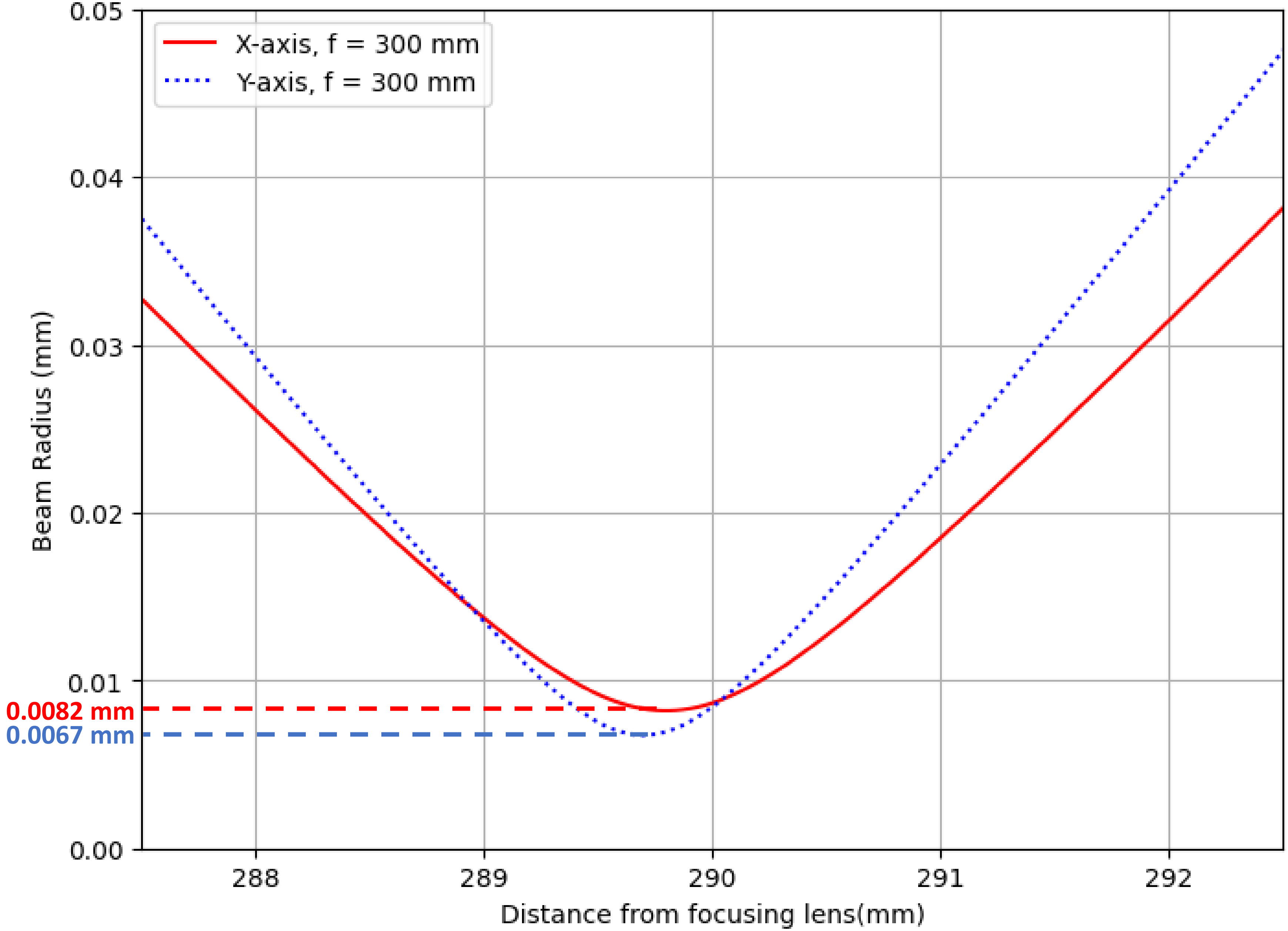
289.7 mm

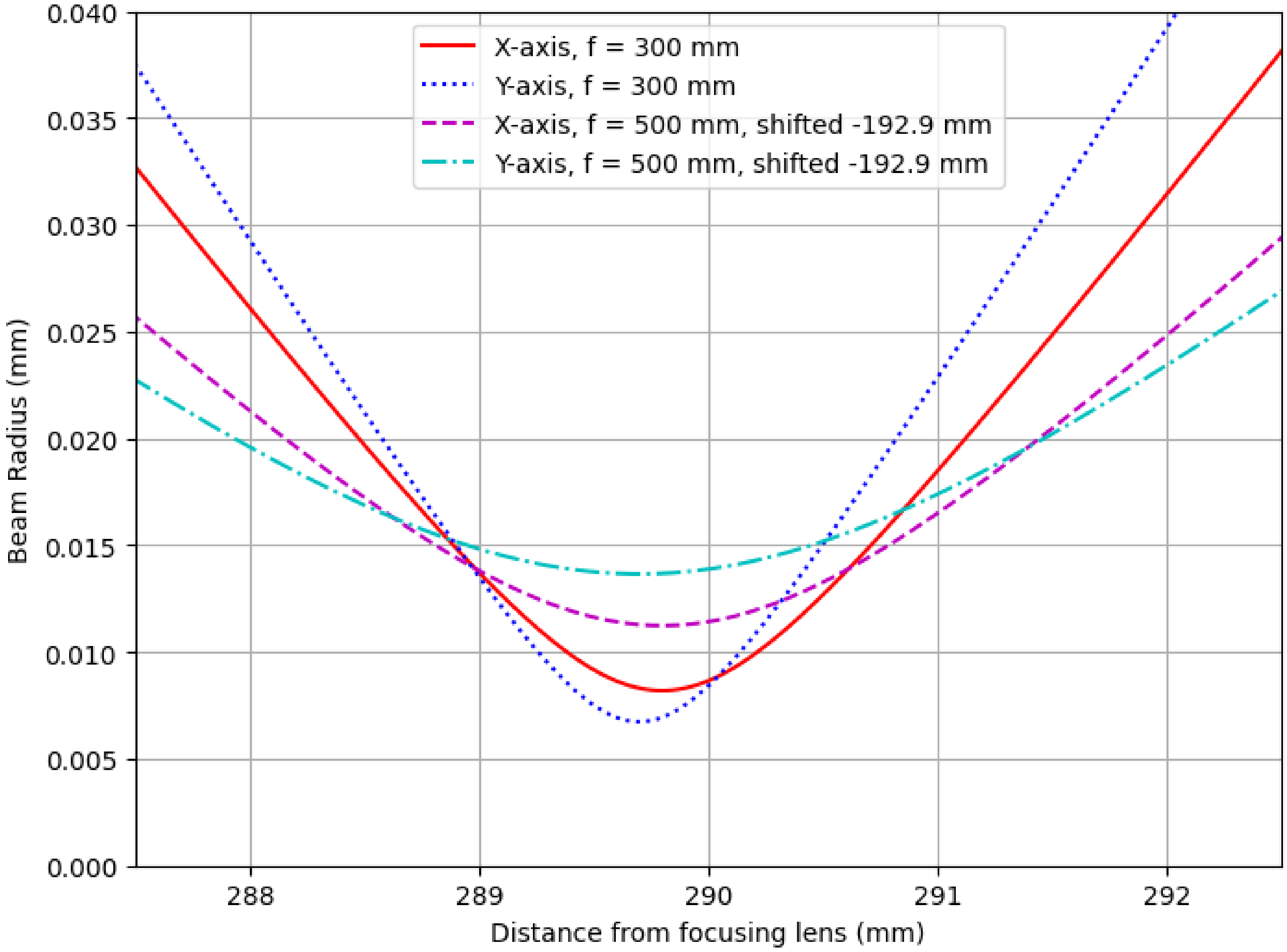
f = -30 mm

f = 200 mm

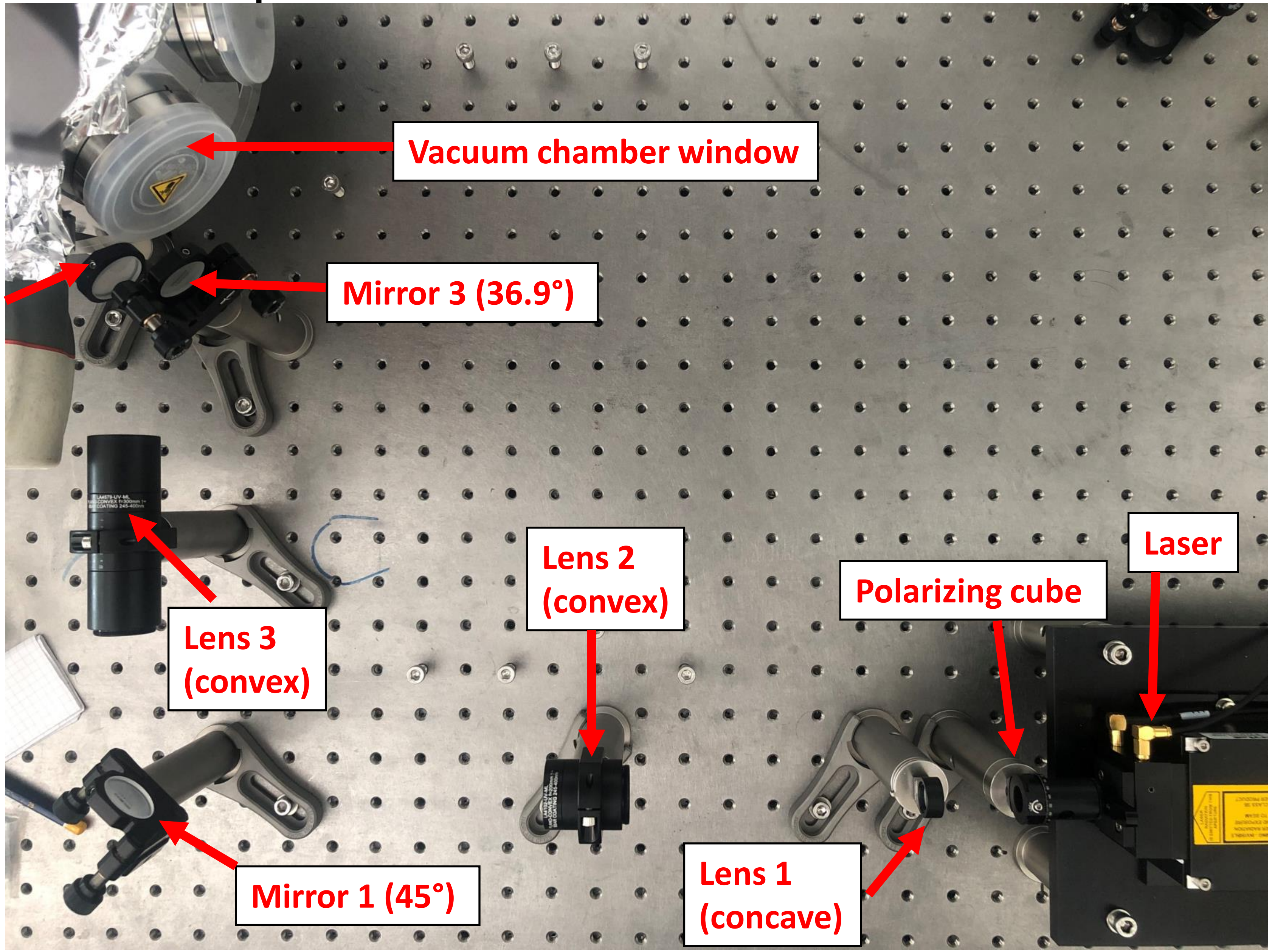
f = 300 mm

Results: Simulations




X-axis, f = 300 mm
Y-axis, f = 300 mm
X-axis, f = 500 mm, shifted -192.9 mm
Y-axis, f = 500 mm, shifted -192.9 mm
Beam Radius (mm)
0.000
0.005
0.010
0.015
0.020
0.025
0.030
0.035
0.040
288
289
290
291
292
Distance from focusing lens (mm)

Results: Beam path



Vacuum chamber window

Mirror 2 (45°)

Mirror 3 (36.9°)

Lens 3
(convex)

Lens 2
(convex)

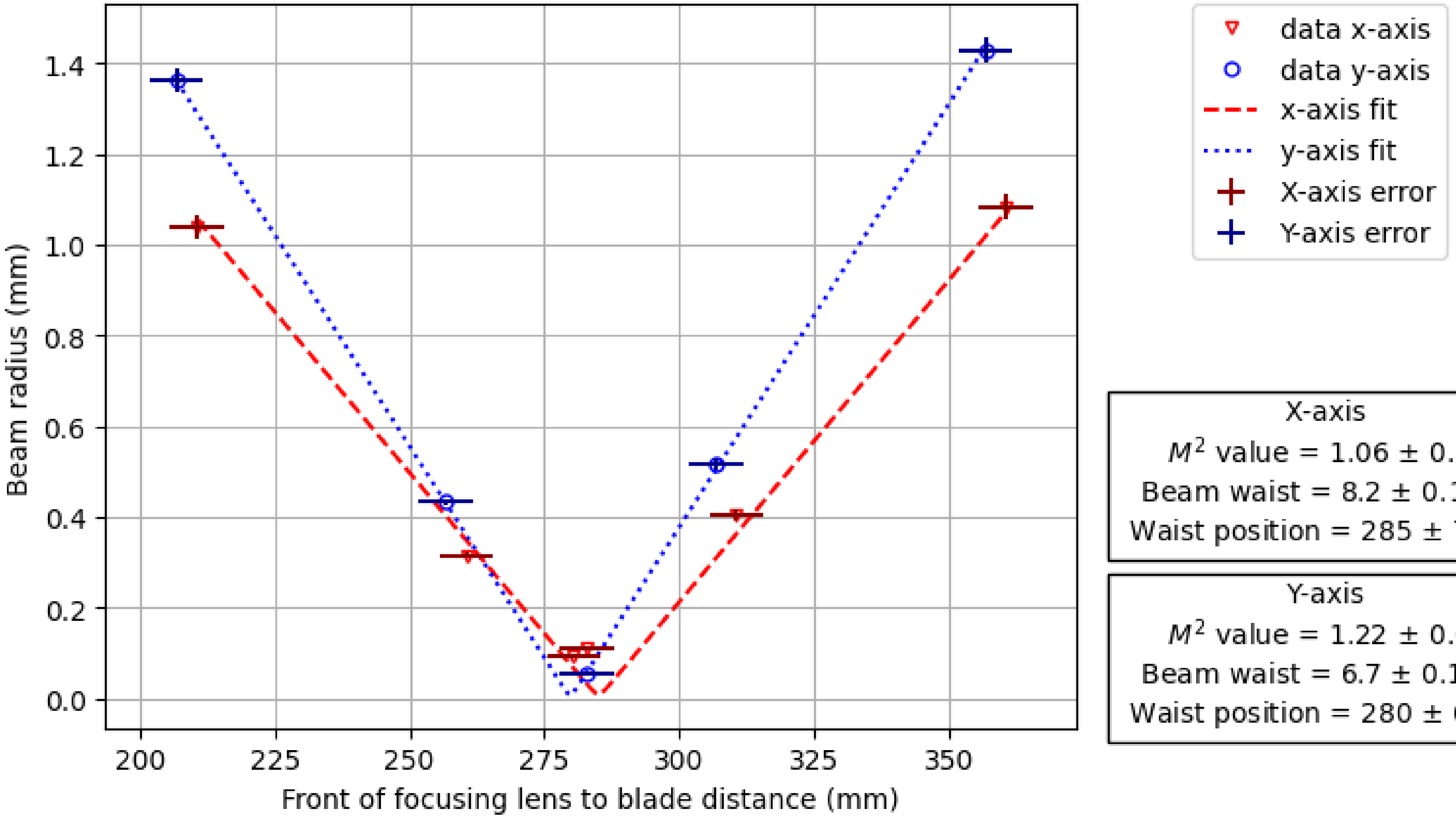
Polarizing cube

Laser

Mirror 1 (45°)

Lens 1
(concave)

Results: Focus



X-axis

M^2 value = 1.06 ± 0.04

Beam waist = 8.2 ± 0.1 μm

Waist position = 285 ± 7 mm

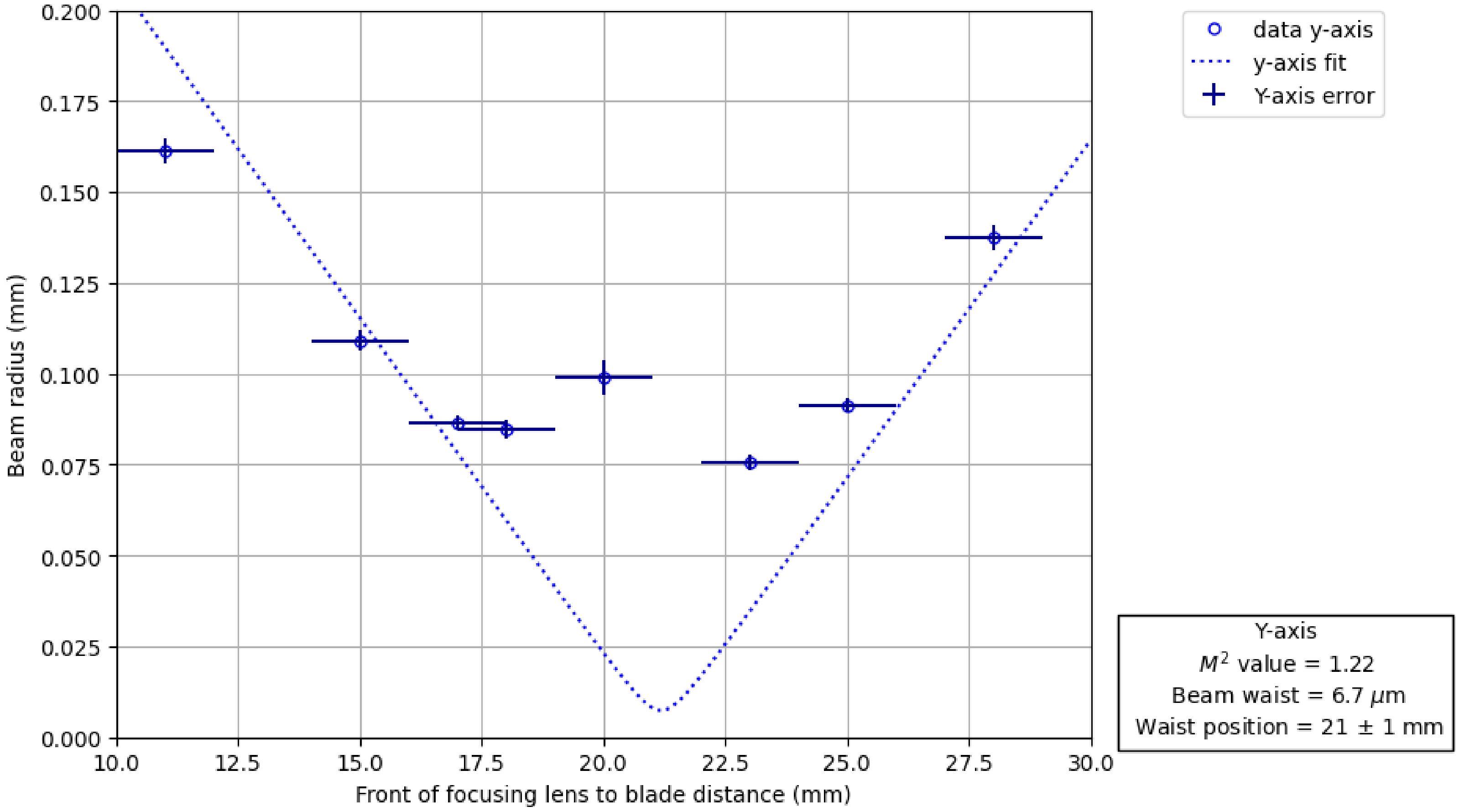
Y-axis

M^2 value = 1.22 ± 0.01

Beam waist = 6.7 ± 0.1 μm

Waist position = 280 ± 6 mm

Results: Focus



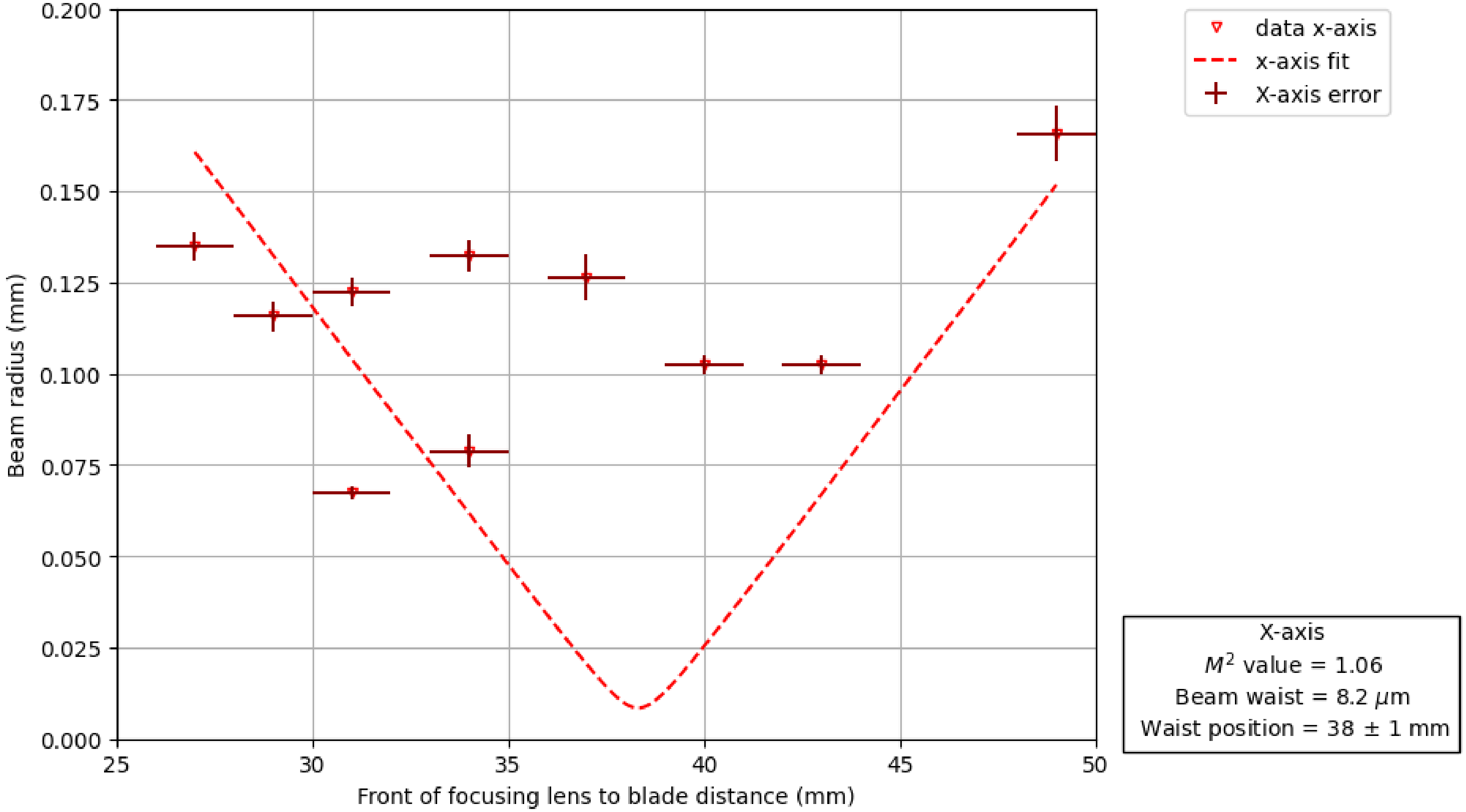
Y-axis

M^2 value = 1.22

Beam waist = 6.7 μm

Waist position = 21 ± 1 mm

Results: Focus



Conclusion

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$$E_{th} \approx 0.00042 \times 0.09 \approx 37\ \mu J$$

Outlook

Measure the focused spot size more precisely:

Outlook

Measure the focused spot size more precisely:

- Lower the energy

Outlook

Measure the focused spot size more precisely:

- Lower the energy
- Reduce pulse frequency

Outlook

Measure the focused spot size more precisely:

- Lower the energy
- Reduce pulse frequency
- Switch blade material

Acknowledgements

Steve

Nikos

Sam

Joel

Bart

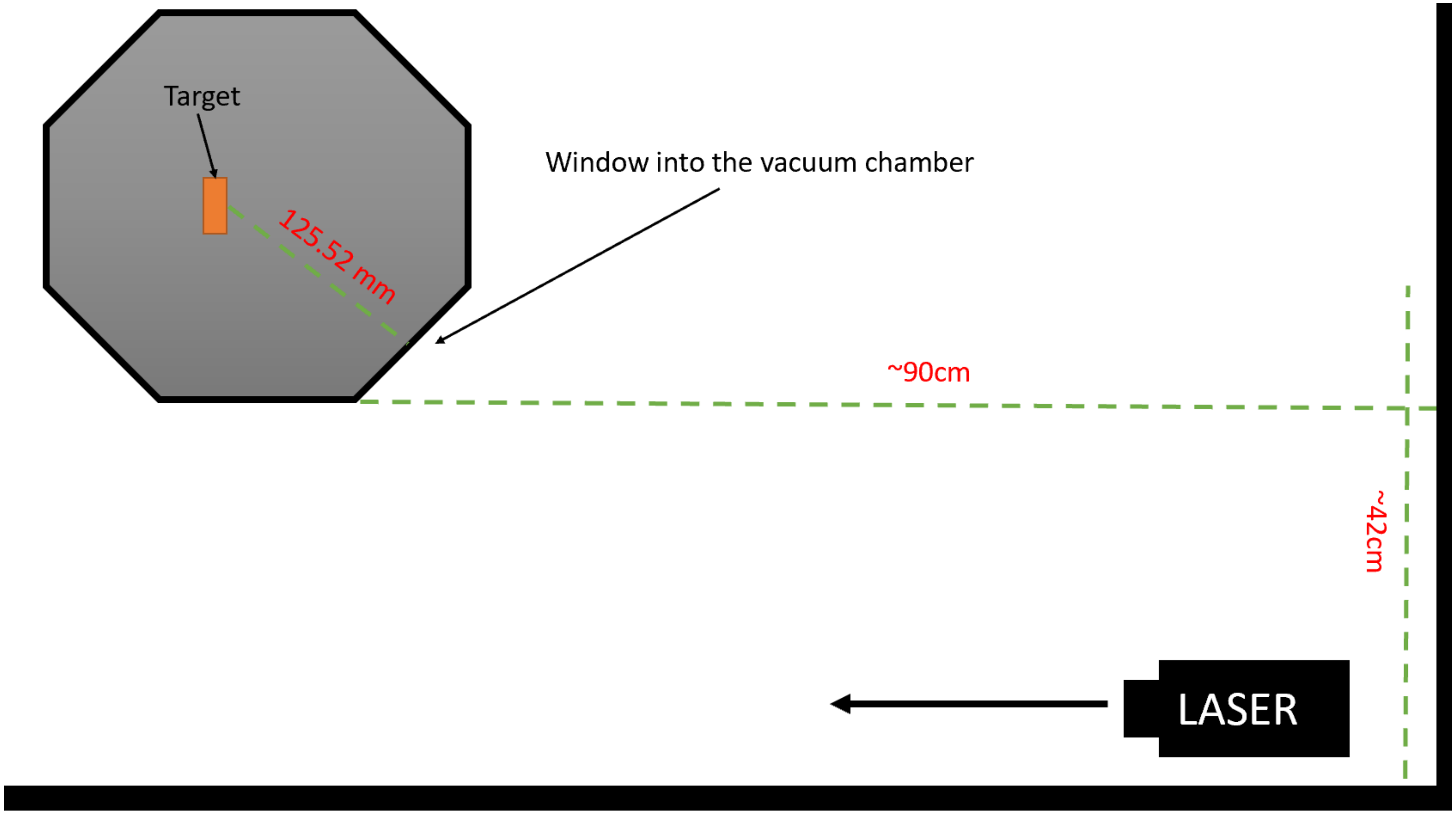
Backup slides:

$$2r_x = 2w_x \times 1.67$$
$$2r_x = 2 \times 0.01 \times 1.67 = 0.0334$$

$$A = \pi \times r_x \times r_y$$
$$A = \pi \times 0.0167 \times 0.008 \approx 0.00042 \ cm^2$$

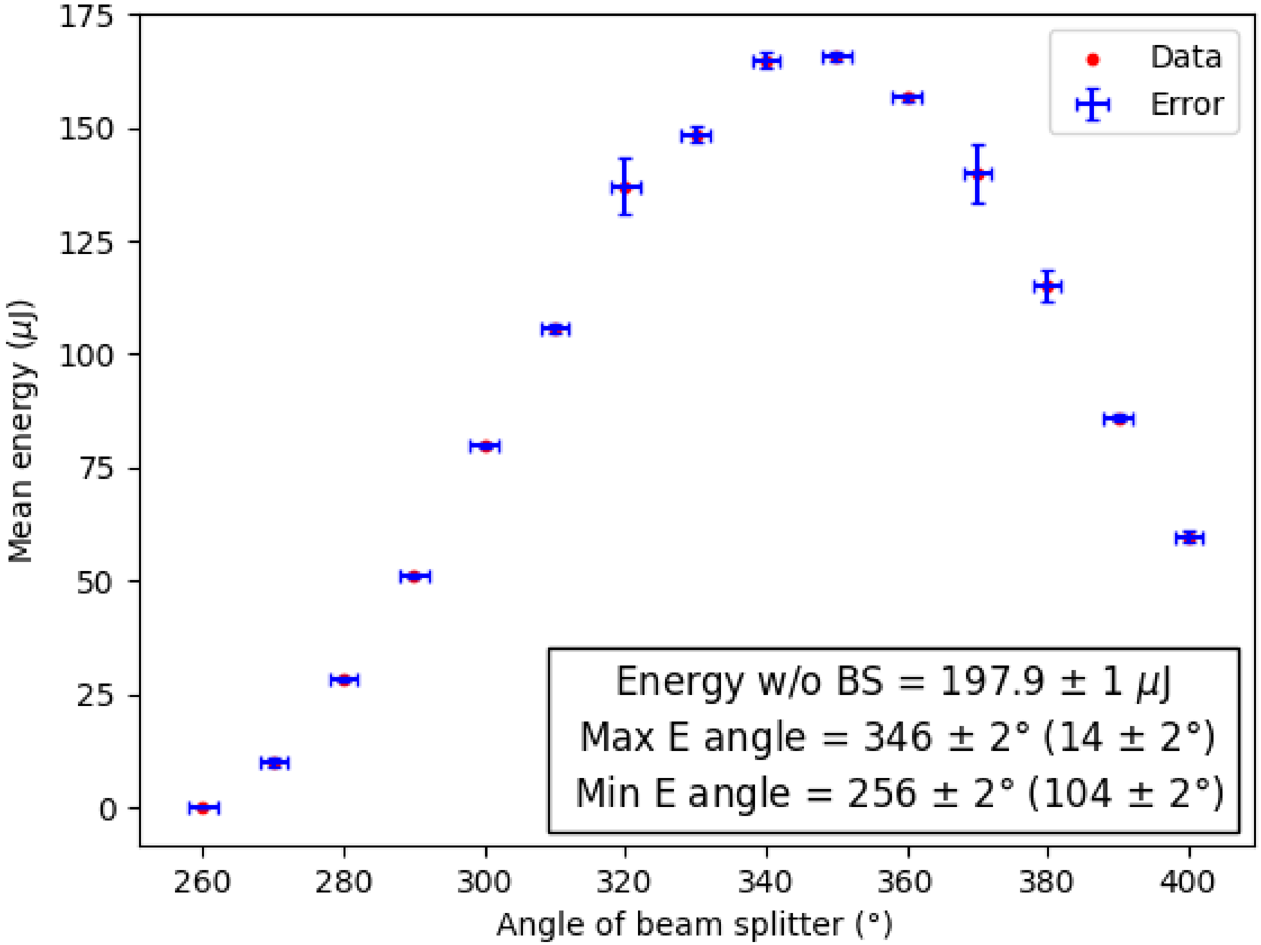
$$F_{th_{Barium}} \approx 0.09 \ J/cm^2$$
$$E_{th} \approx 0.00042 \times 0.09 \approx 37 \ \mu J$$

Methods: Optics path

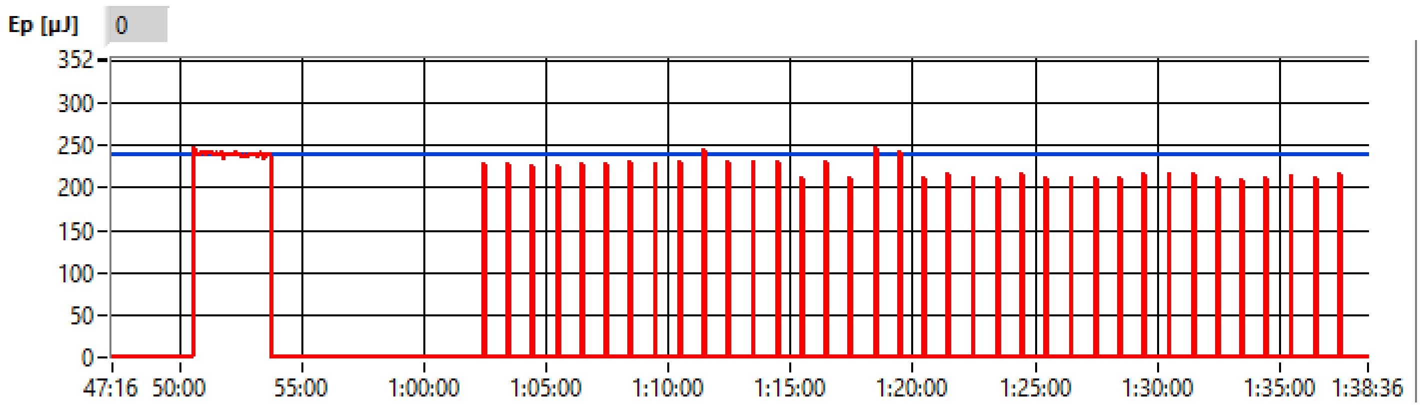


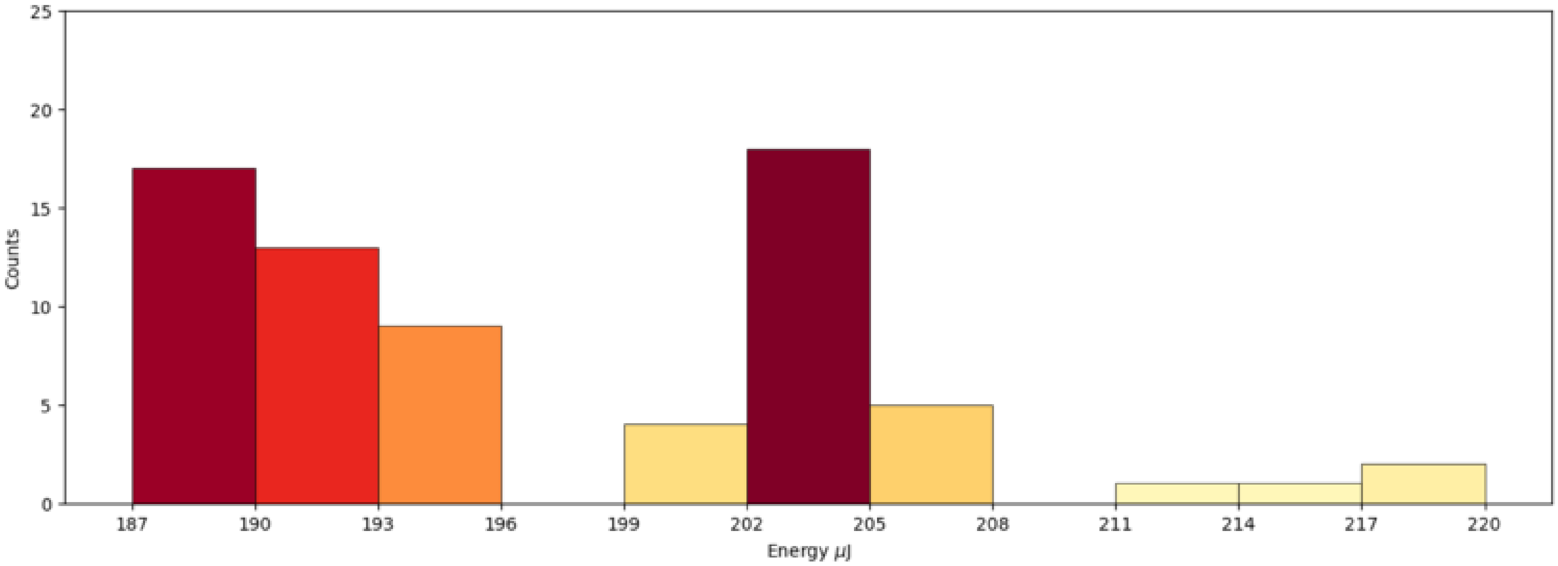
$$F_{th} = \frac{\sqrt{\chi t_v \rho C_p T_v^2}}{(1-R)}$$

Where χ is the thermal conductivity, t_v is the time taken to reach the vaporization threshold temperature, ρ is the target density, C_p is the specific heat, T_v is the temperature reached, and R is the reflectivity of the material [11]. An estimate of the threshold fluence for barium can then be found by setting T_v to be the vaporization temperature of barium, and assuming the t_v to be the pulse duration [11].



Energy w/o BS = 197.9 ± 1 μJ
Max E angle = 346 ± 2° (14 ± 2°)
Min E angle = 256 ± 2° (104 ± 2°)


Ep [µJ]
0
352
300
250
200
150
100
50
0
47:16
50:00
55:00
1:00:00
1:05:00
1:10:00
1:15:00
1:20:00
1:25:00
1:30:00
1:35:00
1:38:36


25
20
15
10
5
0
Counts
187
190
193
196
199
202
205
208
211
214
217
220
Energy µJ