Weekly practice work at the ELI facility

Application of attosecond pulses

Lab Report

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Submitted to:

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Abstract

HHG was done with argon gas where a pulse train of attosecond pulses were produced in XUV spectrum with a wavelength of 1030nm. The experimental setup is described in [1] so here only results will be discussed.

Estimate the peak intensity in the laser focus of the HR GHHG Gas beamline

The parameters for the beam are $\lambda = 1030\ nm$, $\epsilon_n = 1mJ$, $f = 90cm$ and $\tau = 40fs$.To estimate the input beam size w_{in}, a gaussian fit that follows the next equation was used:

$$I(x) = A\ exp\left(-\frac{2(x-x_0)^2}{w_{in}^2}\right) + B \tag{1}$$

The peak intensity can be determined by:

$$I_0 = \frac{2\epsilon_n}{\tau w^2 \pi}\sqrt{\frac{4\ln(2)}{\pi}} \tag{2}$$

with $w = \dfrac{\lambda f}{\pi w_{in}}$. The intensity distribution in the laser focus can be obtained through data analysis of the image recorded as shown in figure 1

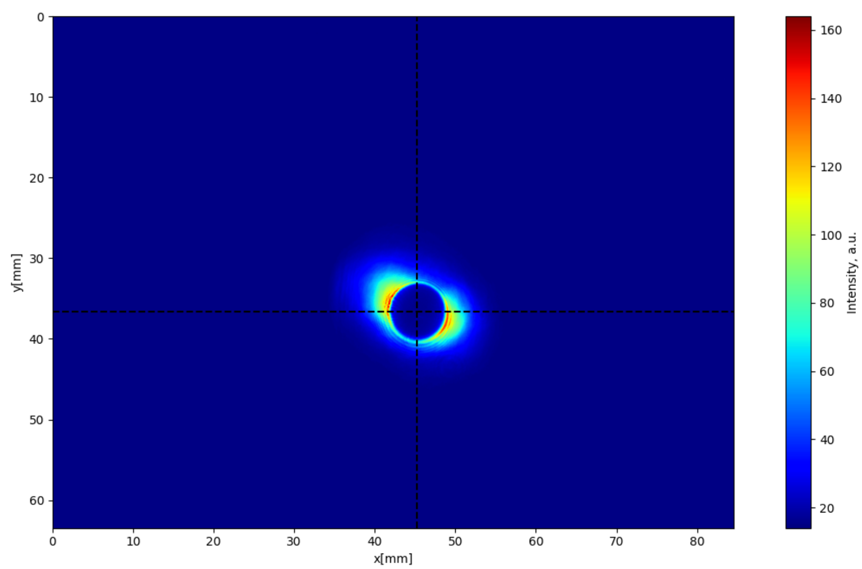


Figure 1: Intensity distribution for the beam

From this, a gaussian profile for the x and y axis was obtained (figure 2a and 2b). Knowing that the diameter of the hole is $7mm$, the value for each pixel in mm can be obtained, so the parameters for the fitting in x are:

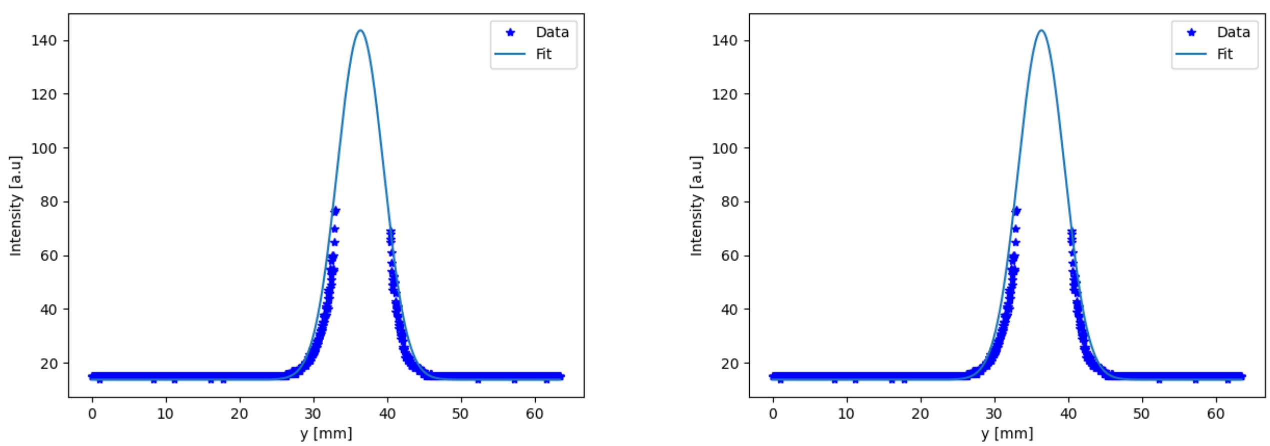
- A = 204.94,

- x_0 = 45.17,
- w_{in}= 6.26,
- B = 15.04,

while in y they are:

- A =129.81,
- x_0 = 36.387,
- w_{in}= 6.26,
- B = 13.74.

From this and equation 2 the intensity is $I_0 = 6.73 \times 10^{14}\ W/cm^2$.



(a) x data

(b) y data

Figure 2: Guassian fitting for x and y data

To determine the energy loss, figure 3 gives the percentage based on the hole of 7mm. For a beam size of around $6\ mm$, the percentage is estimated as 57 %. So the intensity after the loss is $I_0 = 2.89 \times 10^{14}\ W/cm^2$.

Estimate the microscopic cut-off based on the intensities obtained in the previous task and the gas used for generation.

The cut-off energy is given by:

$$E_{cut-off} = I_p + 3.2U_p \tag{3}$$

$$U_p = 9.33 * 10^{-14} \times I\lambda_0^2[\mu m] \tag{4}$$

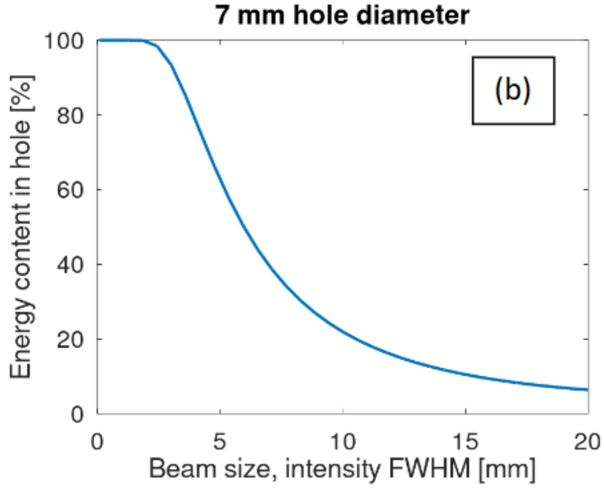


Figure 3: Bean size vs energy loss in the hole

Since the experiment is working with Ar, then $I_p = 15.759\ ev$. Then the cut-off energy is:

$$E_{cut-off} = 228.9 \text{ eV}$$

And considering the losses is:

$$E_{cut-off} = 107.41 \text{ eV}$$

Calibrate the XUV FFS images

HHG spectra was recorded using FFS with and without metallic filter in the beam path. These metallic filters were made of Mg and Te. This can be seen as follows in figures 8, 9 and 10. The spatially integrated harmonic spectrum and spectrally integrated spatial profile can be found for every image recorded[1].

The ratio of the spatially integrated images with filter by those without filter gives the figure 4.

For the theoretical transmittance of Mg and Te, the data was obtained from Henke [2]. Therefore, the calibrated spectrum for Mg is given in figure 5 and for Te in figure 6.

[1]Images 8,9 and 10 can be found in the appendix at the end of the document.

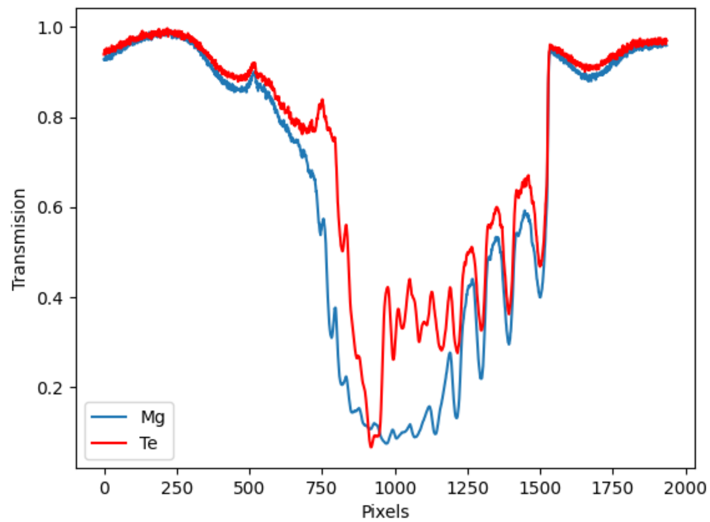


Figure 4: Spatially integrated images of Mg (blue) divided by reference , same for Te (red).

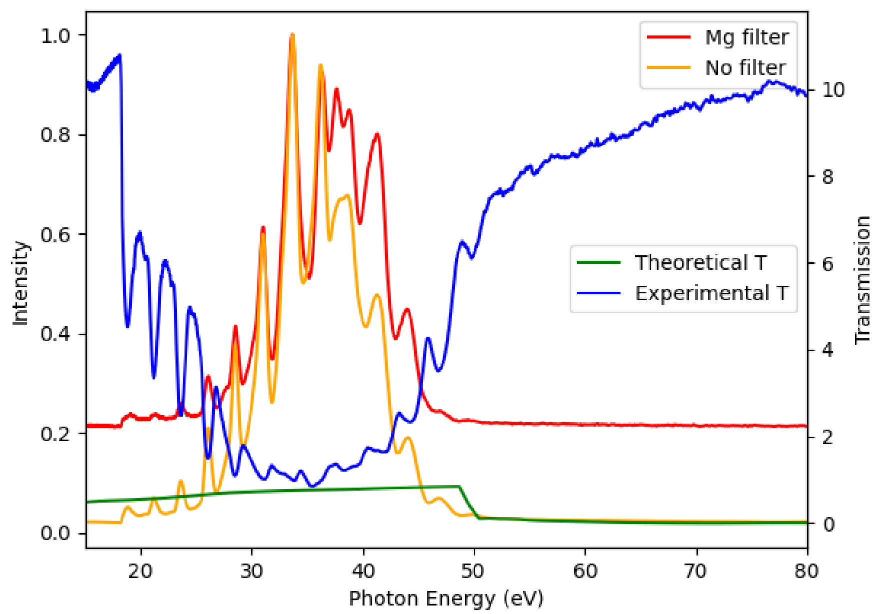


Figure 5: Calibrated XUV spectra for Mg with and without filter. The theoretical and experimental transmission is also shown.

Based on the calibrated XUV spectrum without filter obtained in the previous task, give the macroscopically obtained cut-off.

Based on the previous results, the macroscopic energy cut-off for is 48 eV. The original value calculated previously was of 107.41 eV. This high difference of more than the double can be due to some losses that were not considered in the previous calculation like the interaction of the laser field with different atoms instead of just a single target as it was supposed.

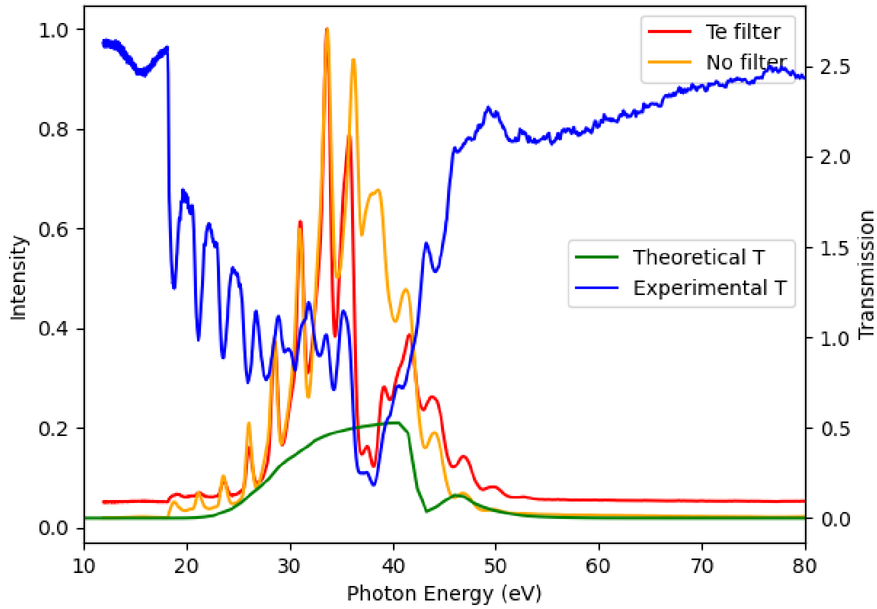


Figure 6: Calibrated XUV spectra for Te with and without filter. The theoretical and experimental transmission is also shown.

Sum the XUV spectrum recorded without filter along the spectral axis

The data for the spectrally integrated spatial profile for the XUV beam is shown in figure 7 with its gaussian fitting. With this, the beam size at the detector plane can be estimated.

The parameters of the fitting are given by:

- A = 4.9×10^5
- x_0 = 16.5
- w_{in} = 5.1
- B = 1.74×10^4

Following the equation

$$\theta_{XUV} = \frac{w_2}{D} \tag{5}$$

$$D = 2.5 \text{ m}$$

From the fit, the value for w_2 is 5.1mm. It means that the divergence for the beam in target area 2 is:

$$\theta_{XUV} = \frac{5.1}{2500}$$

$$= 2.04 \times 10^{-3} \text{ rad}$$

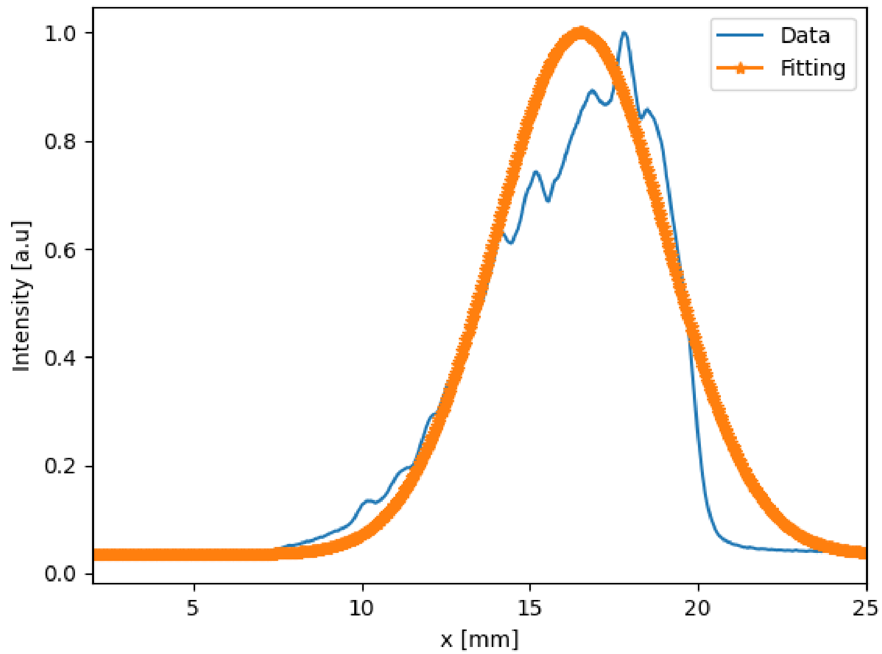


Figure 7: Spectrally integrated profile with a gaussian fit (orange).

Estimate the beam divergence θ_{XUV} of the XUV beam originating from the gas cell using the description in Section 2.3. Consider that reimaging happens two times from the gas cell to the FFS detection plane!

The XUV beam size in the gas cell w_{XUV} and the reimaged beam size in target area one relate to each other by: [1]

$$N_1 = \frac{w_1}{w_{XUV}} \tag{6}$$

the divergence of the beam is inversely proportional to the beam waist, so the divergence angles θ of the original and reimaged beams are related to each other by: [1]

$$N_1 = \frac{\theta_{XUV1}}{\theta_1} \tag{7}$$

The magnification for the toroidal mirror is then:

$$N_2 = \frac{\theta_1}{\theta_{XUV2}} \tag{8}$$

Since the magnification for the toroidal mirror (N_2) is 1 and for the ellipsoidal mirror is (N_1) 0.4, then divergence of the beam originated from the gas cell, mixing equations 7 and 8, is:

$$\theta_{XUV1} = N_1 N_2 \theta_{XUV2}$$

$$= 0.4 \times 0.00204 \text{ rad}$$

$$= 8.16 \times 10^{-4} \text{ rad}$$

Estimate the divergence of the IR beam using eq. (8) using the input beam size w_{in} in Task 11 and the focal length of the focusing optics. How do the divergences of the XUV and IR fields relate to each other? Does it fit the theoretical prediction?

From equation 5, the divergence for IR using the value of w_{in} calculated in the beginning and the focal length is:

$$\theta_{IR} = \frac{w_{in}}{f}$$

$$= 6.95 * 10^{-3}$$

And so the relation between the divergence of the XUV and IR is:

$$\frac{\theta_{IR}}{\theta_{XUV1}} = \frac{6.95 * 10^{-3}}{8.16 * 10^{-4}} = 8.51$$

which shows that the divergence of the IR beam is ≈ 9 times greater than the XUV one.

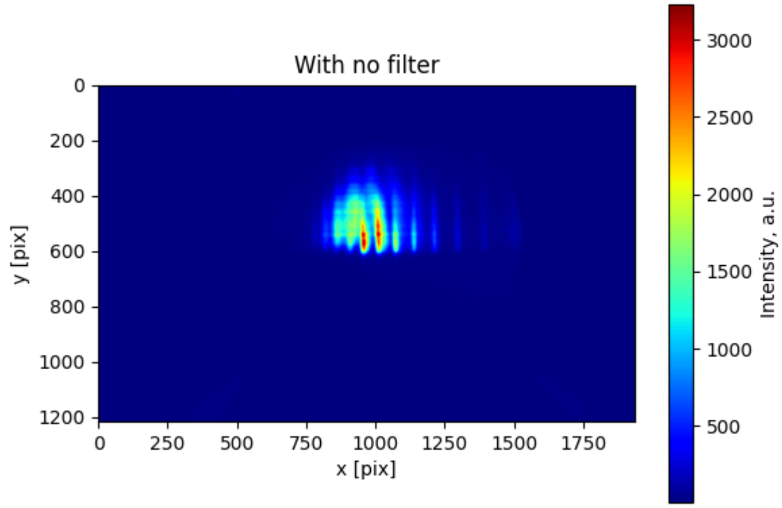
Since the prediction says that $\theta_{XUV} < \theta_{IR}$, then the result showed above follows the theoretical prediction.

References

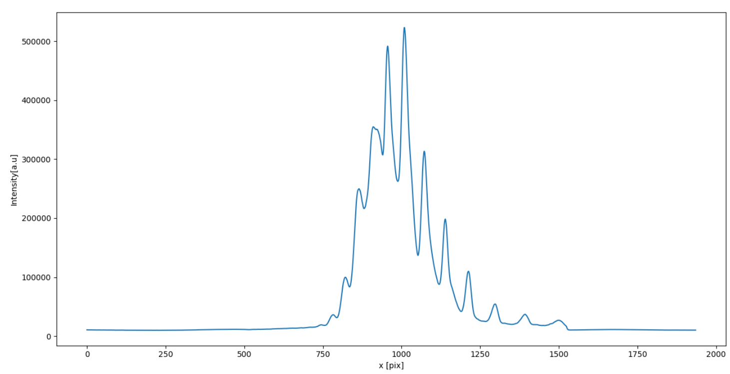
[1] *Balázs, M.* (2022). Applications of attosecond pulses

[2] *Henke.* Filter Transmission. Obtained from: https://henke.lbl.gov/optical_constants/filter2.html

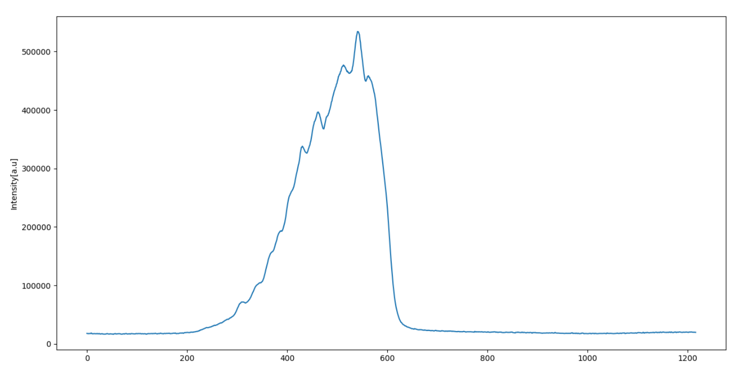
Appendix



(a) No filter

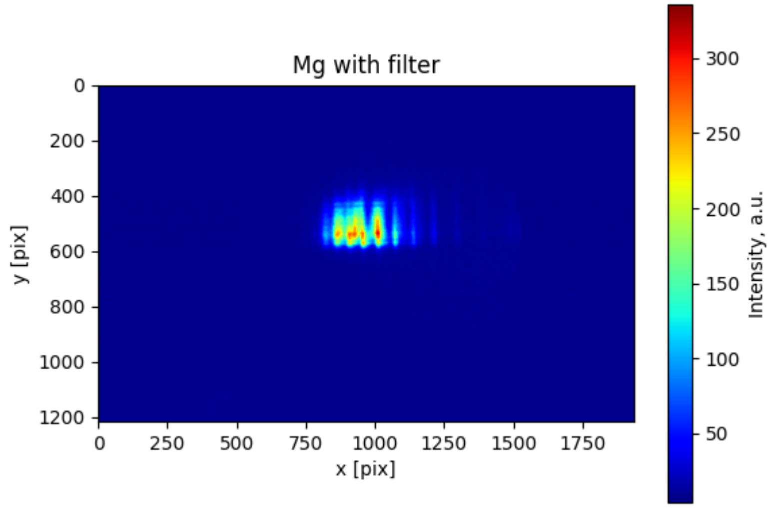


(b) Spatially integrated harmonic spectrum

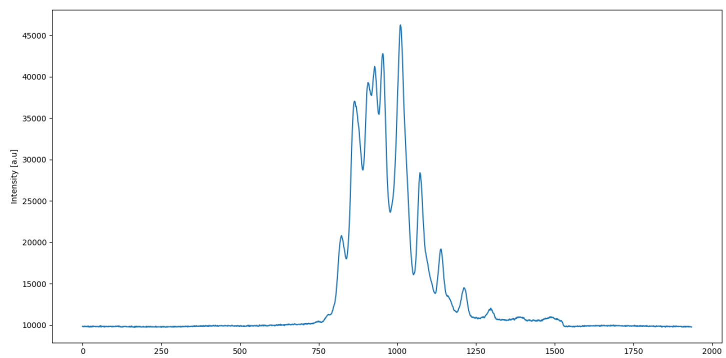


(c) Spectrally integrated spatial profile

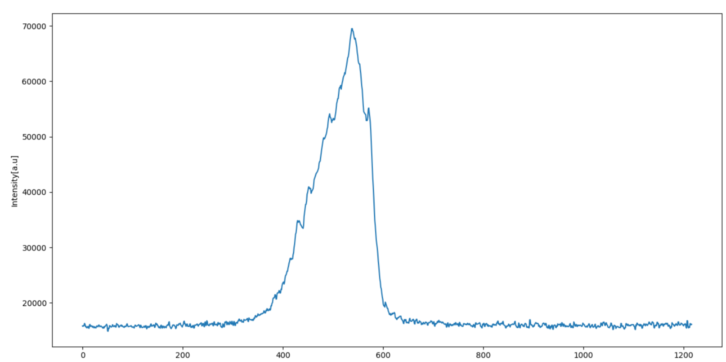
Figure 8: No filter images without metallic filter



(a) Mg filtered

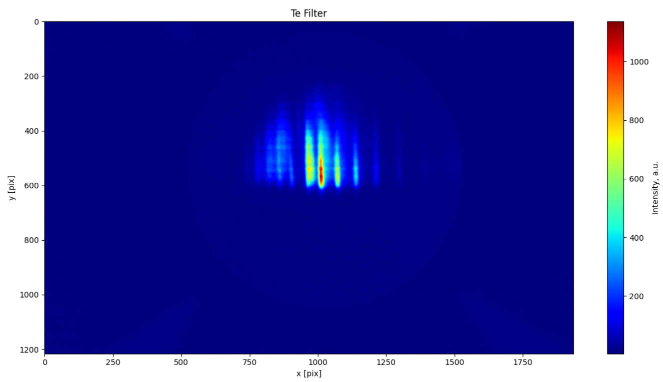


(b) Spatially integrated harmonic spectrum

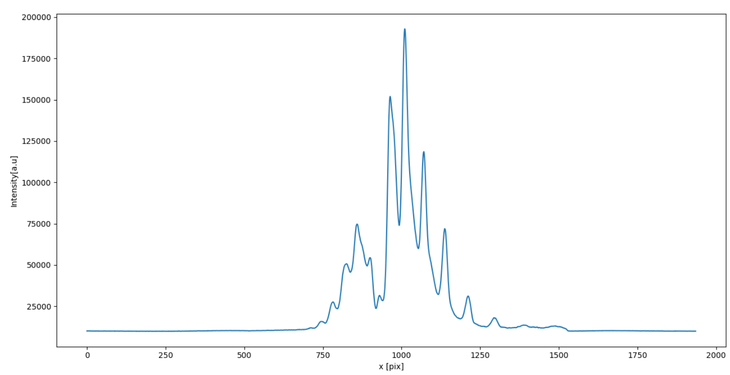


(c) Spectrally integrated spatial profile

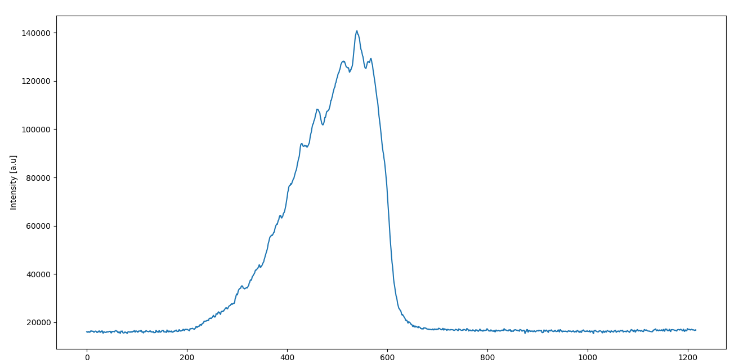
Figure 9: Filter images of Mg with a metallic filter



(a) Te filtered



(b) Spatially integrated harmonic spectrum



(c) Spectrally integrated spatial profile

Figure 10: Filter images of Te with a metallic filter