

# CWレーザー加熱されたチタン薄膜を用いた 高強度レーザー駆動酸素イオン加速

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# Acknowledgment

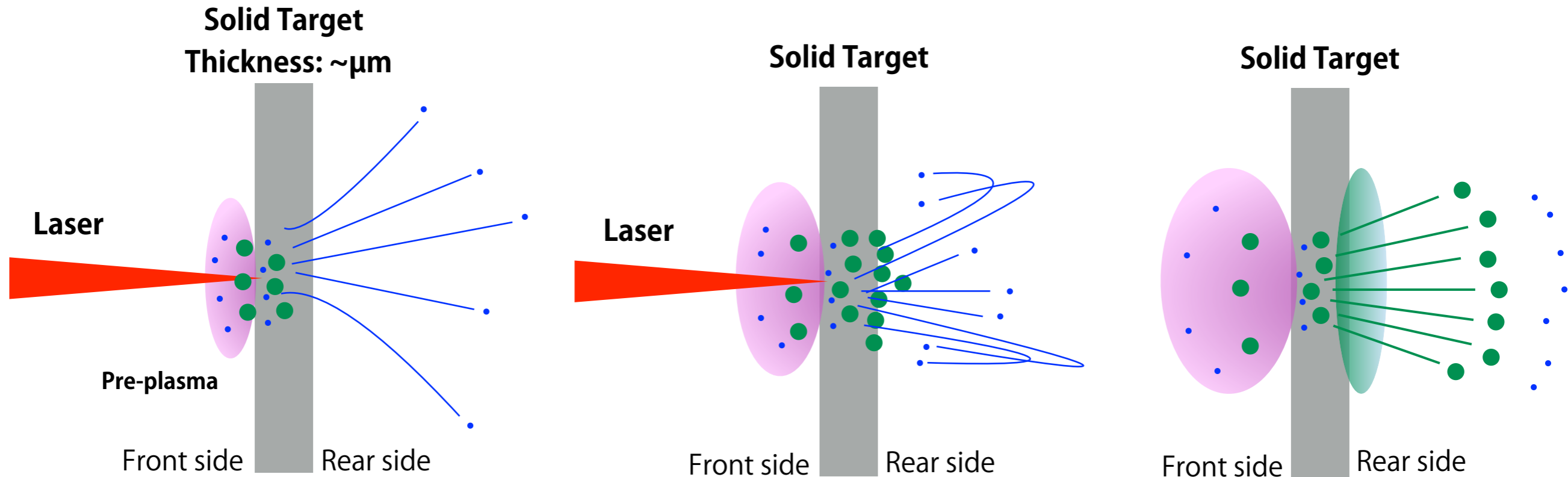
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# Laser-driven Ion Acceleration (Target Normal Sheath Acceleration\*)

- ion
- electron



## ① interaction between pre-plasma and main pulse

Electrons can be accelerated to the laser axis by the interaction. Then, solid target is positively charged.

## ② formation of sheath field

Some electron with lower energy can return to the rear surface region. The quasi-static sheath can be formed.

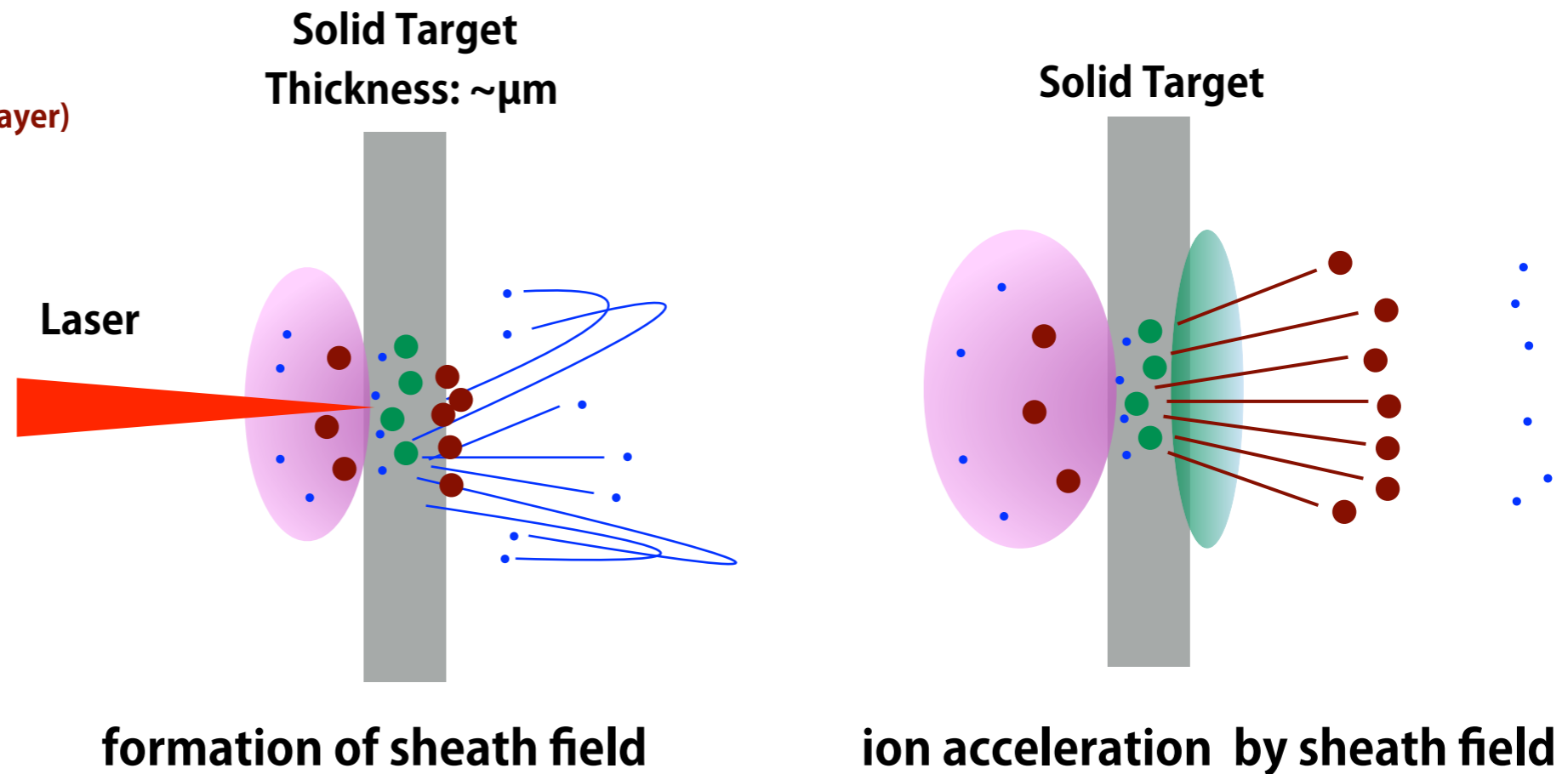
## ③ ion acceleration by sheath field

The quasi-static sheath field can accelerate ions to the target normal direction.

\*S. C. Wilks, et. al., Physics of Plasmas (2001).

# Contamination layers on target surface degrade the acceleration performance

- ion (from target)
- electron
- ion (from contamination layer)



Contamination layers mainly consist of hydrocarbon. Especially proton (charge to mass ratio:1) prior to other ions could be accelerated which results in decrease of acceleration efficiency of heavy ions from target.

## Solution

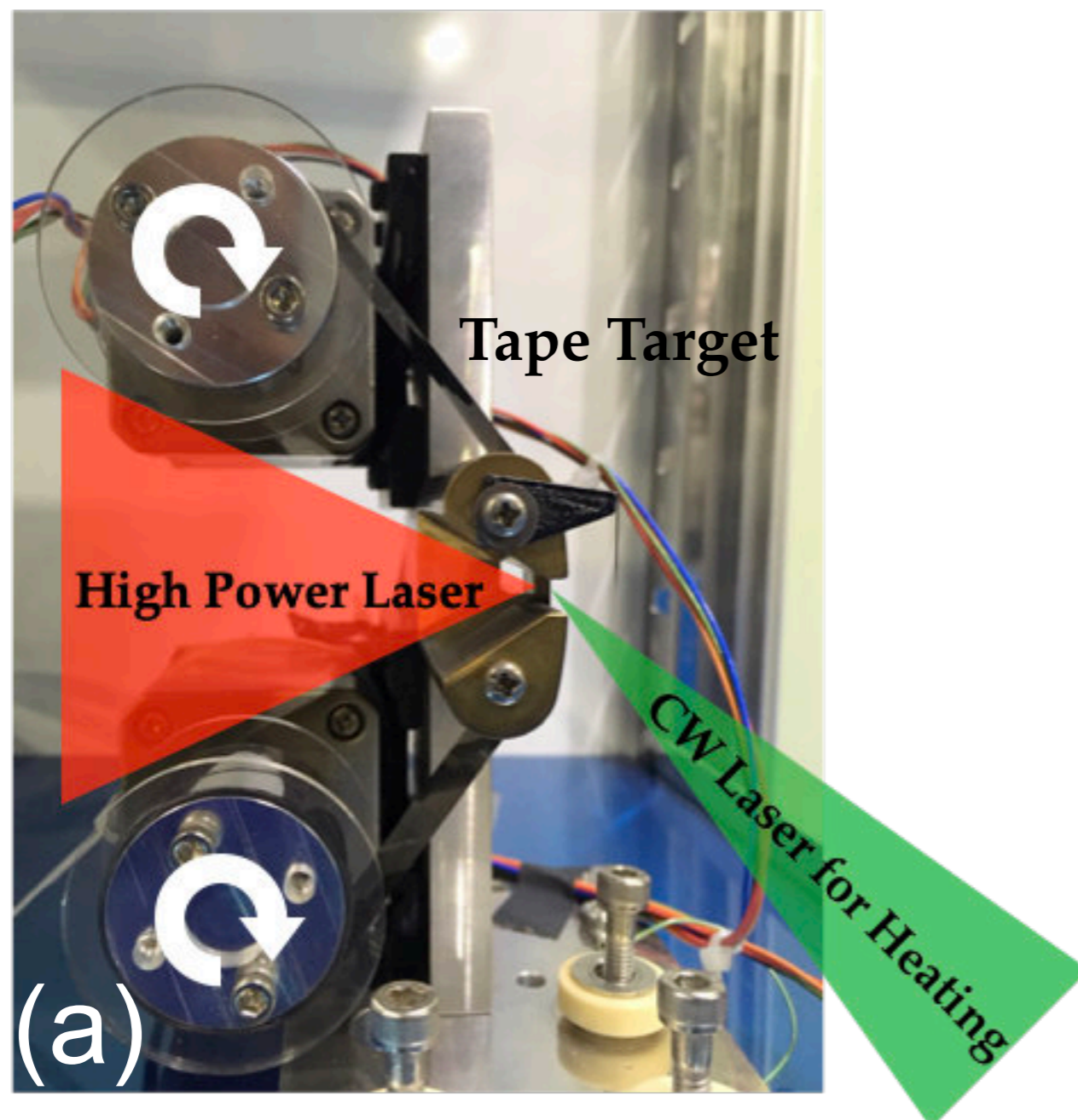
in-situ formation of contamination-free target

→ We propose a method as surface cleaning and modification using a CW laser which heats a tape film target with micrometer scale thickness.

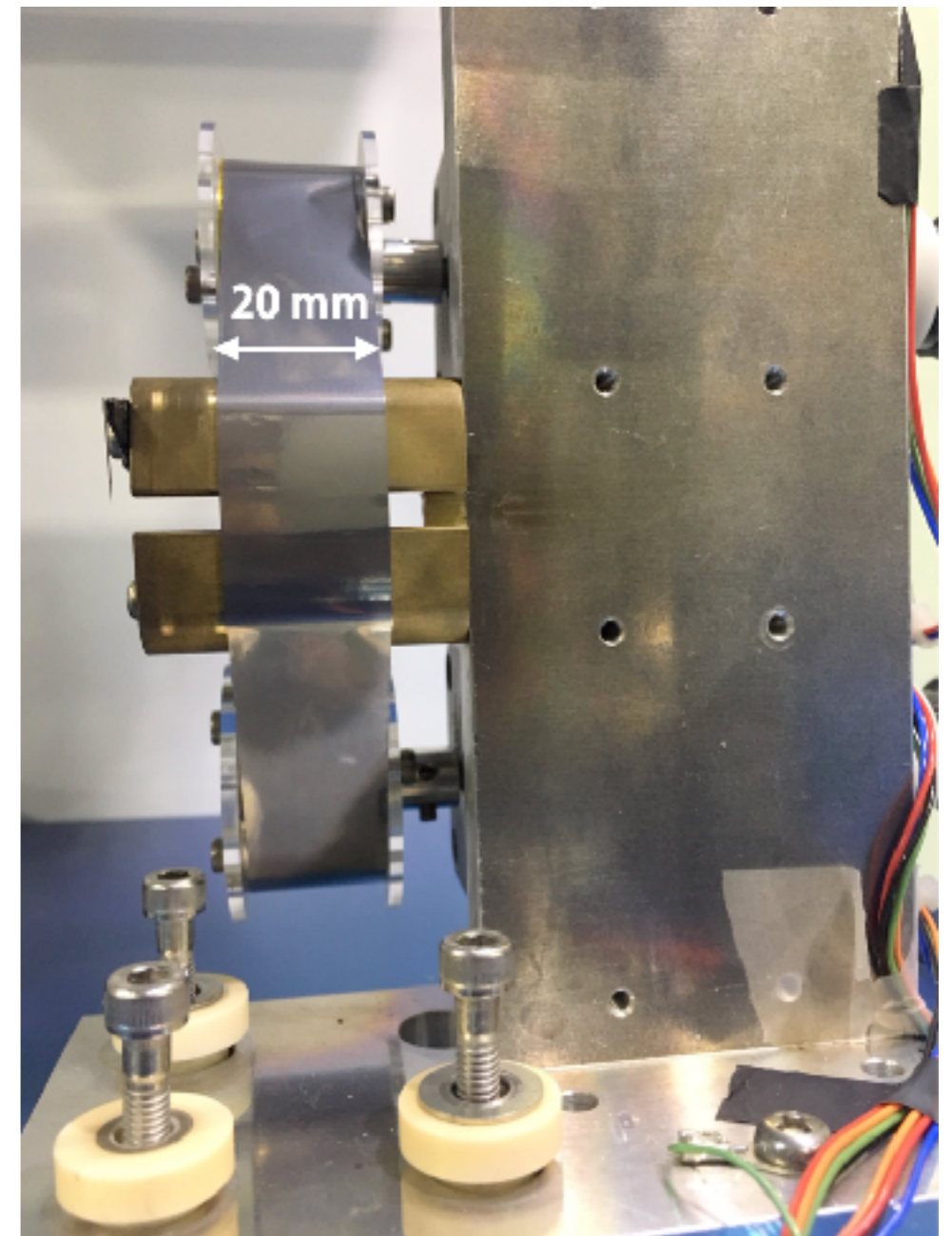
# Micrometer thick scale tape film target

After PW laser shot ( $\sim 10^{21}$  W/cm<sup>2</sup>) on target, several mm holes on the tape were observed. Therefore, a few cm distance is required for each shot.

Nevertheless, the target holder with stepper motors can supply a fresh target with  $> 0.1$  Hz.

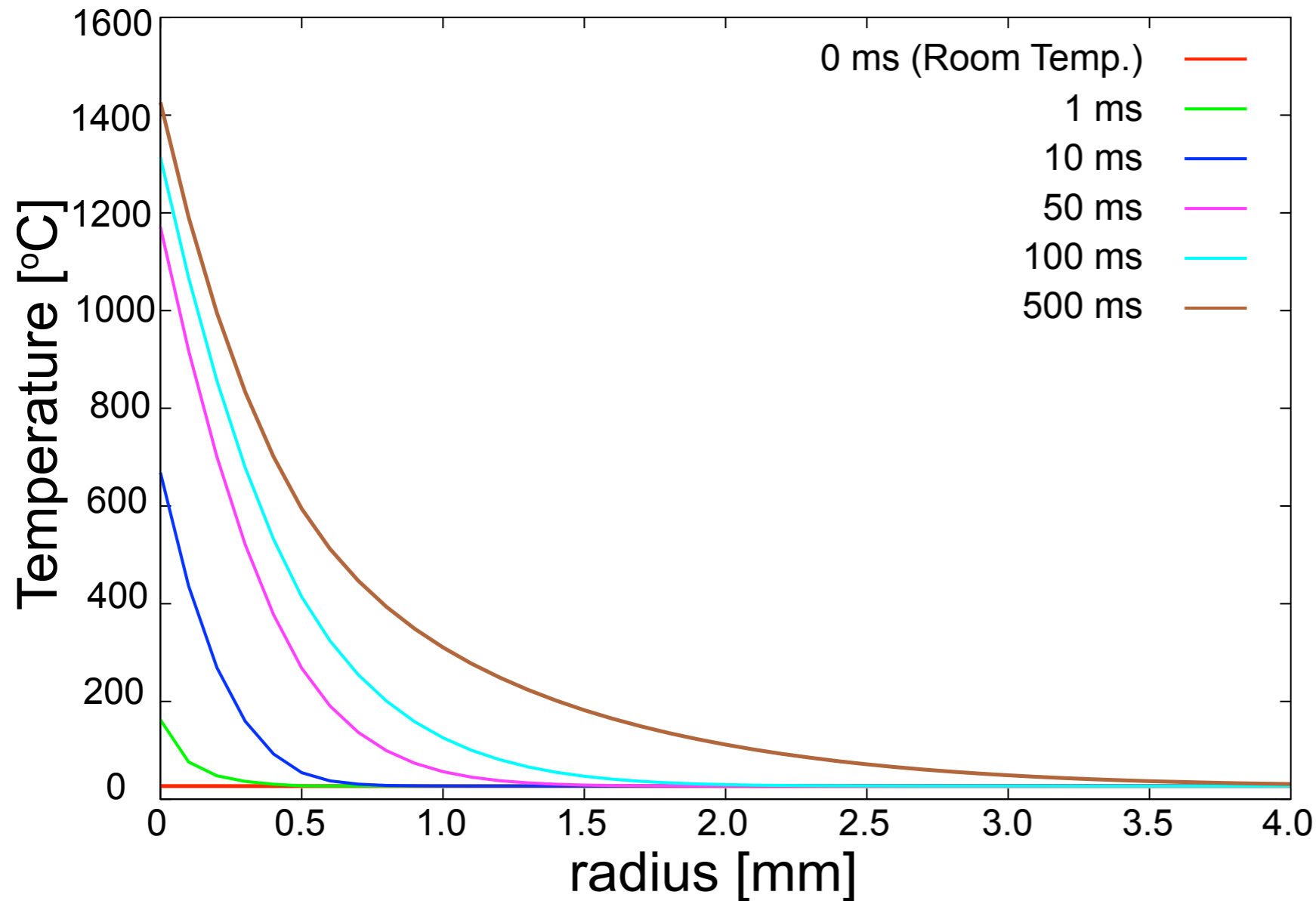


Side View



Rear View

# Time-dependent thermal heat transport simulation

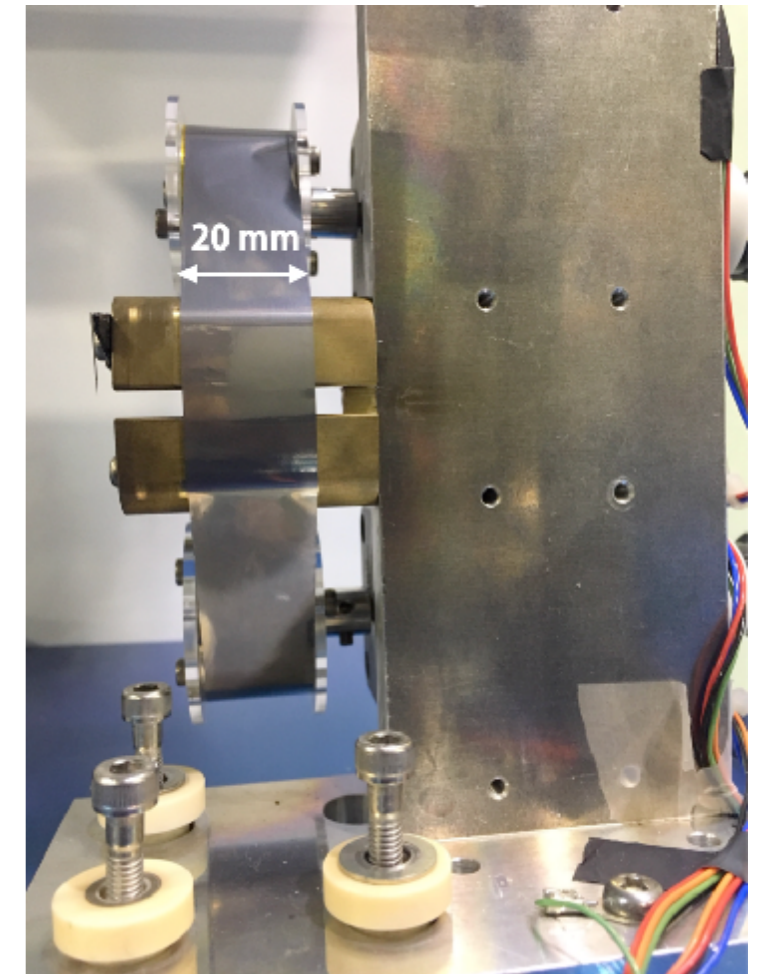
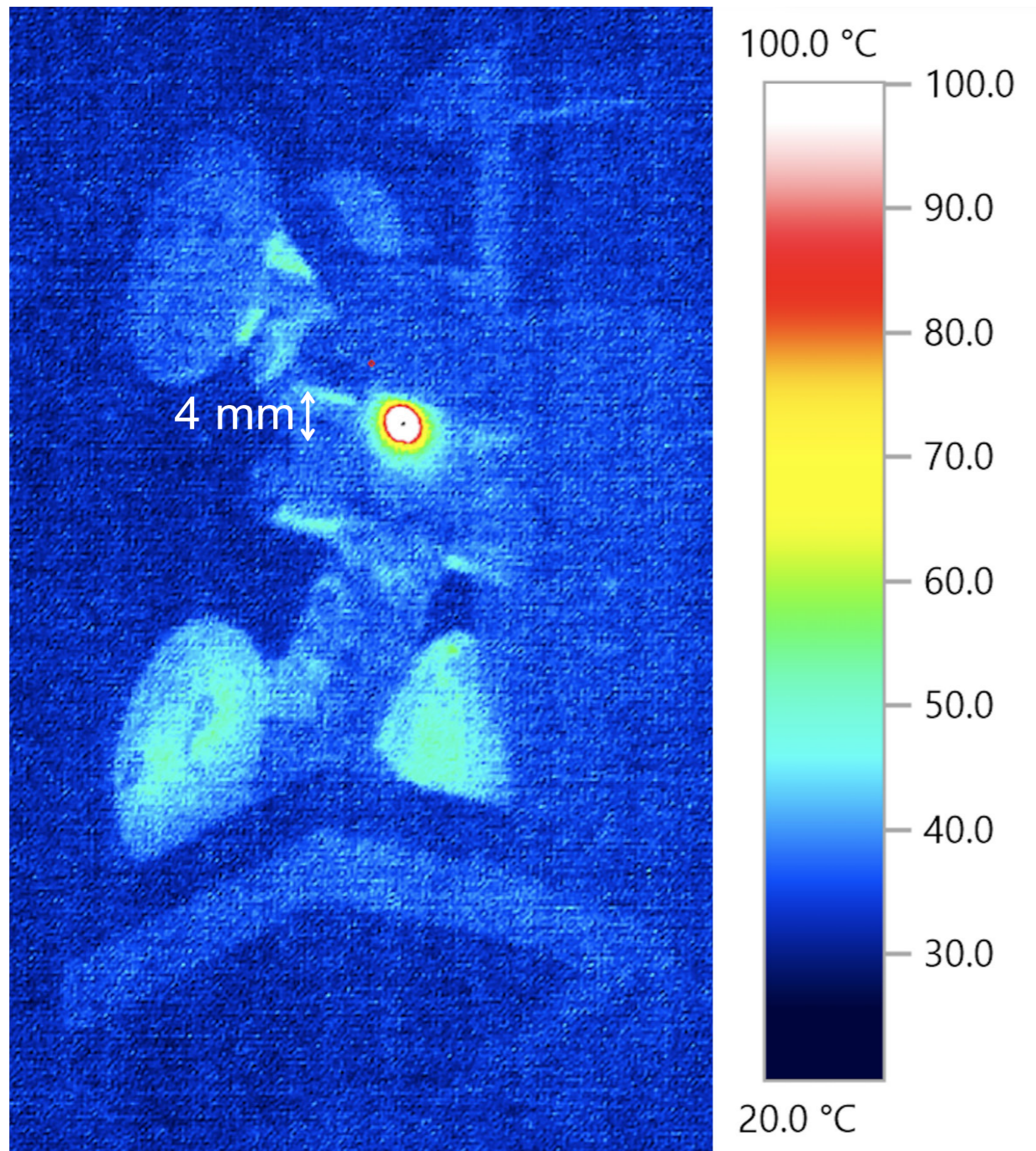


- Simulation condition**
- Laser size ( $D4 \sigma$ ): 1 mm
  - Laser Power: 1 W
  - Absorption of the laser to Ti: 50%
  - Target Materials: Ti
  - Target thickness: 5  $\mu\text{m}$

To confirm the measurement, we performed a time-dependent thermal heat transport simulation in polar coordinates with radial symmetric, including thermal conductivity and radiation.

The simulations indicated a localized region several mm in size with a temperature beyond 100 °C as well as a smaller region with a temperature beyond 1000 °C, showing good agreement with the IR thermography measurement.

# 5 $\mu\text{m}$ thick Ti was heated up to 1000 $^{\circ}\text{C}$ during CW laser irradiation.



**Ti Tape Target Holder**

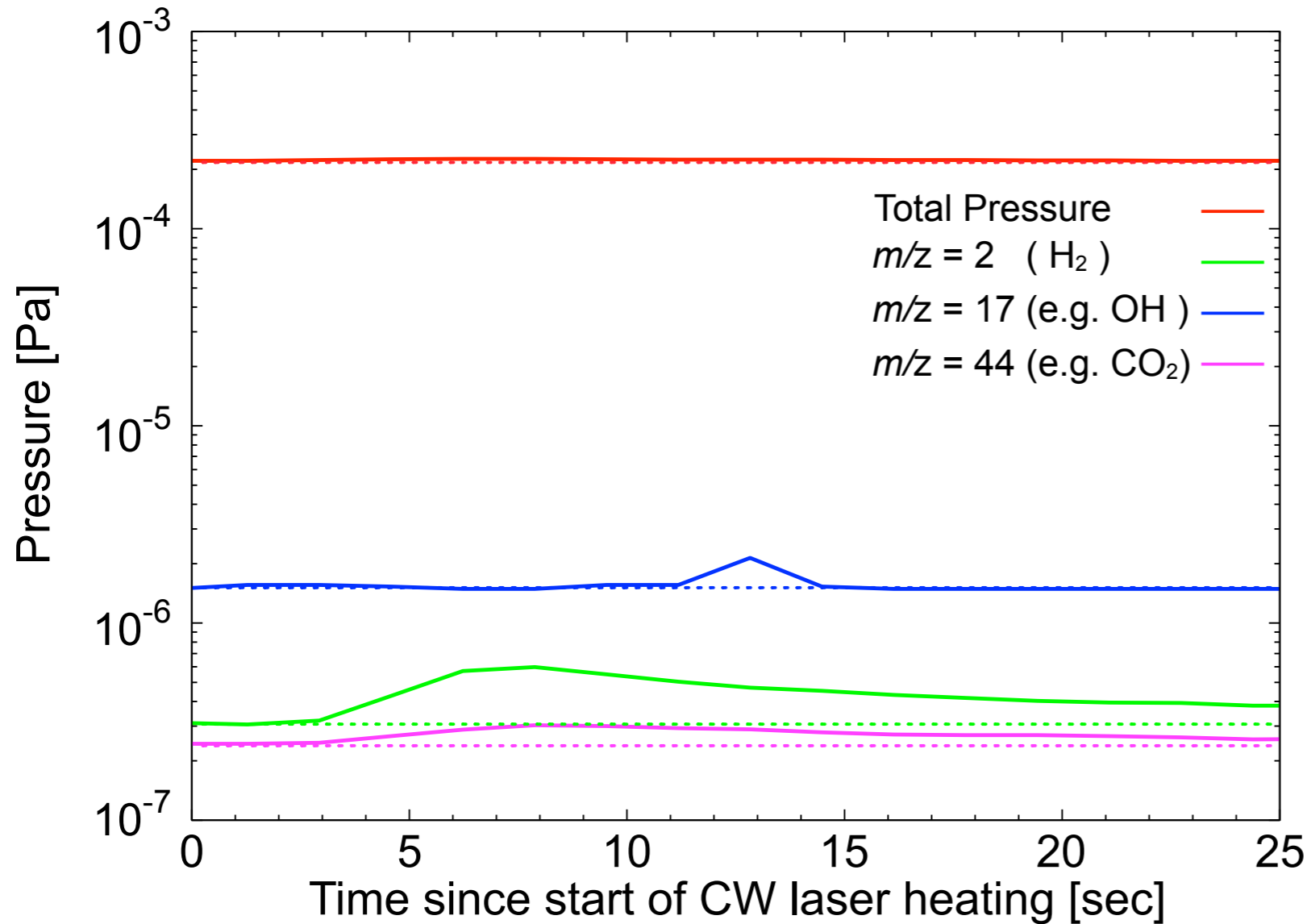
## Heating condition

- CW Laser wavelength: 532 nm
- CW Laser spot on target:  $\Phi \sim 1$  mm
- CW Laser Power: 1 W
- Target Material: Ti (Emissivity: 0.5)
- Target thickness: 5  $\mu\text{m}$

IR thermography shows CW laser heats Ti foil up to  $\sim 1000$   $^{\circ}\text{C}$  in the black point at the center of the white region.

(The melting points of Ti:  $\sim 1670$   $^{\circ}\text{C}$ ,  $\text{TiO}_2$ :  $\sim 1840$   $^{\circ}\text{C}$ )

# Quadrupole mass spectrometer measurement



## Heating condition for QMS

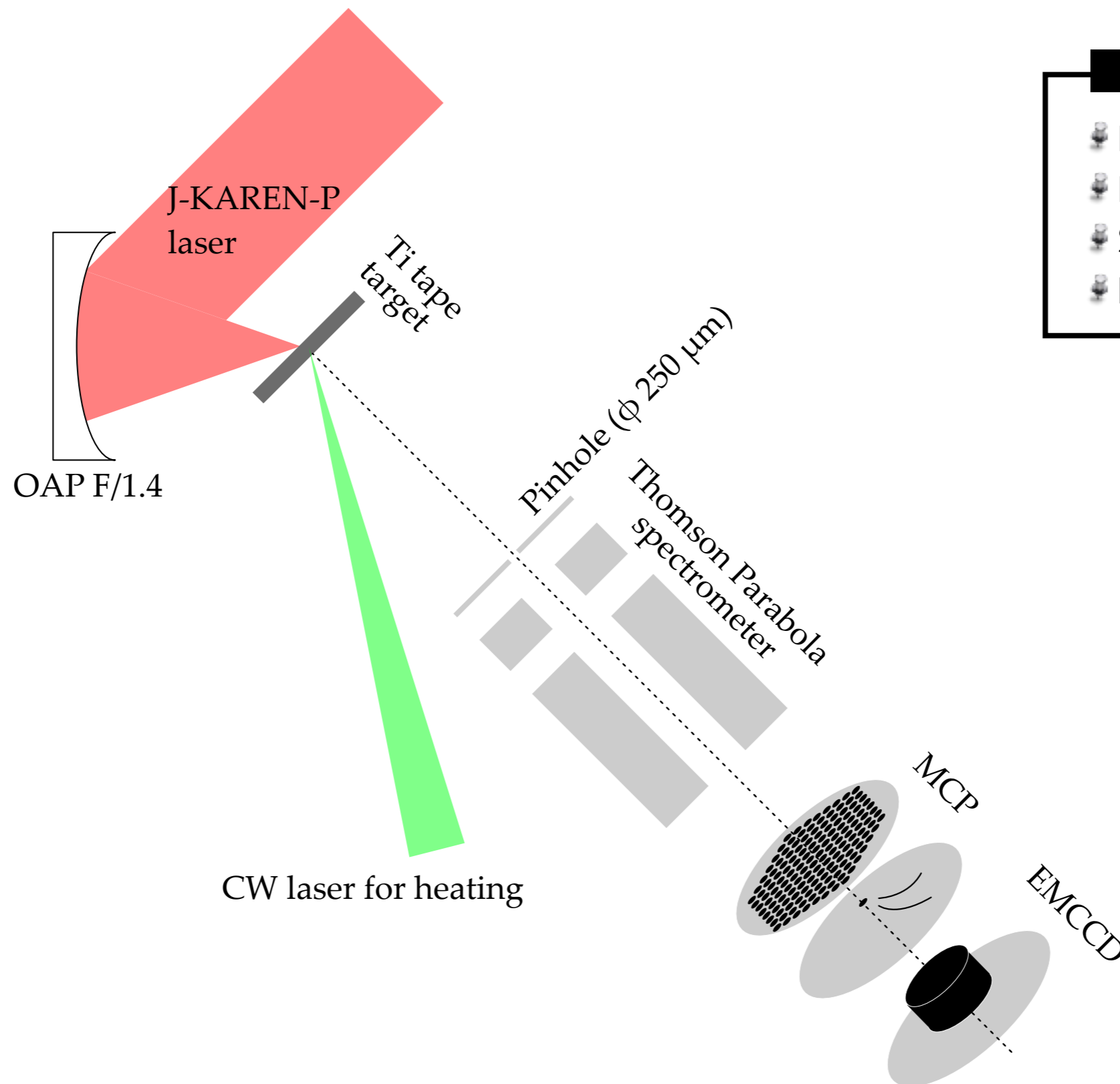
- CW Laser wavelength: 532 nm
- CW Laser spot on target:  $\Phi \sim 1$  mm
- CW Laser Power: 0.3 W
- Target thickness: 5  $\mu$ m

In order to confirm the desorption of the contaminants from the Ti tape by the CW laser heating, heating, we also used a quadrupole mass spectrometer (QMS) as a residual gas analyzer. For this we also used a quadrupole mass spectrometer (QMS) as a residual gas analyzer.

Emissions of hydrogen, hydrogen, hydroxide and carbon dioxide were observed after the CW laser heating began, providing supporting evidence that the technique can be used to desorb contaminants from the Ti tape.



# Ion-acceleration demonstration setup using a 5 $\mu\text{m}$ Ti tape

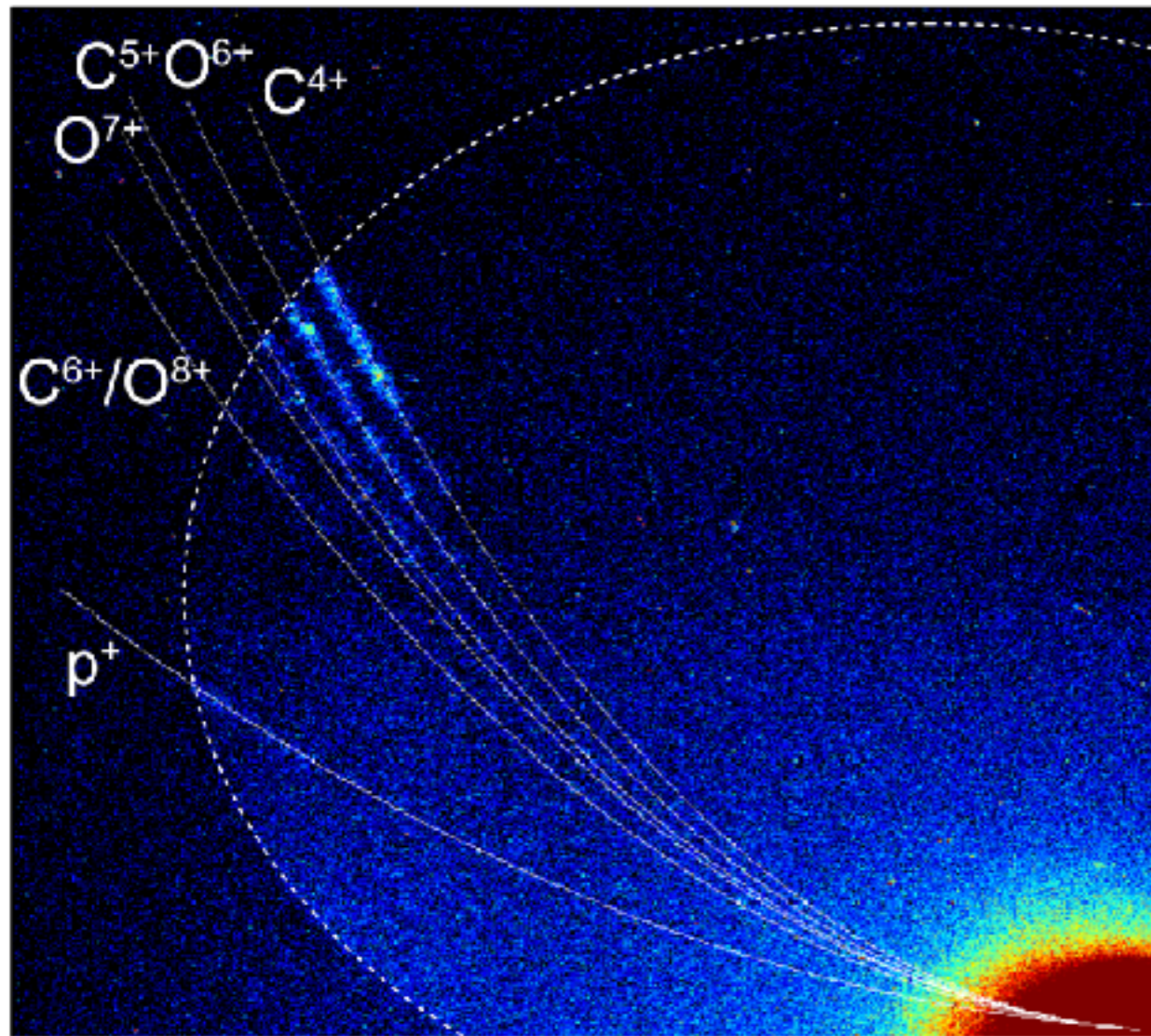


## J-KAREN\* Parameters

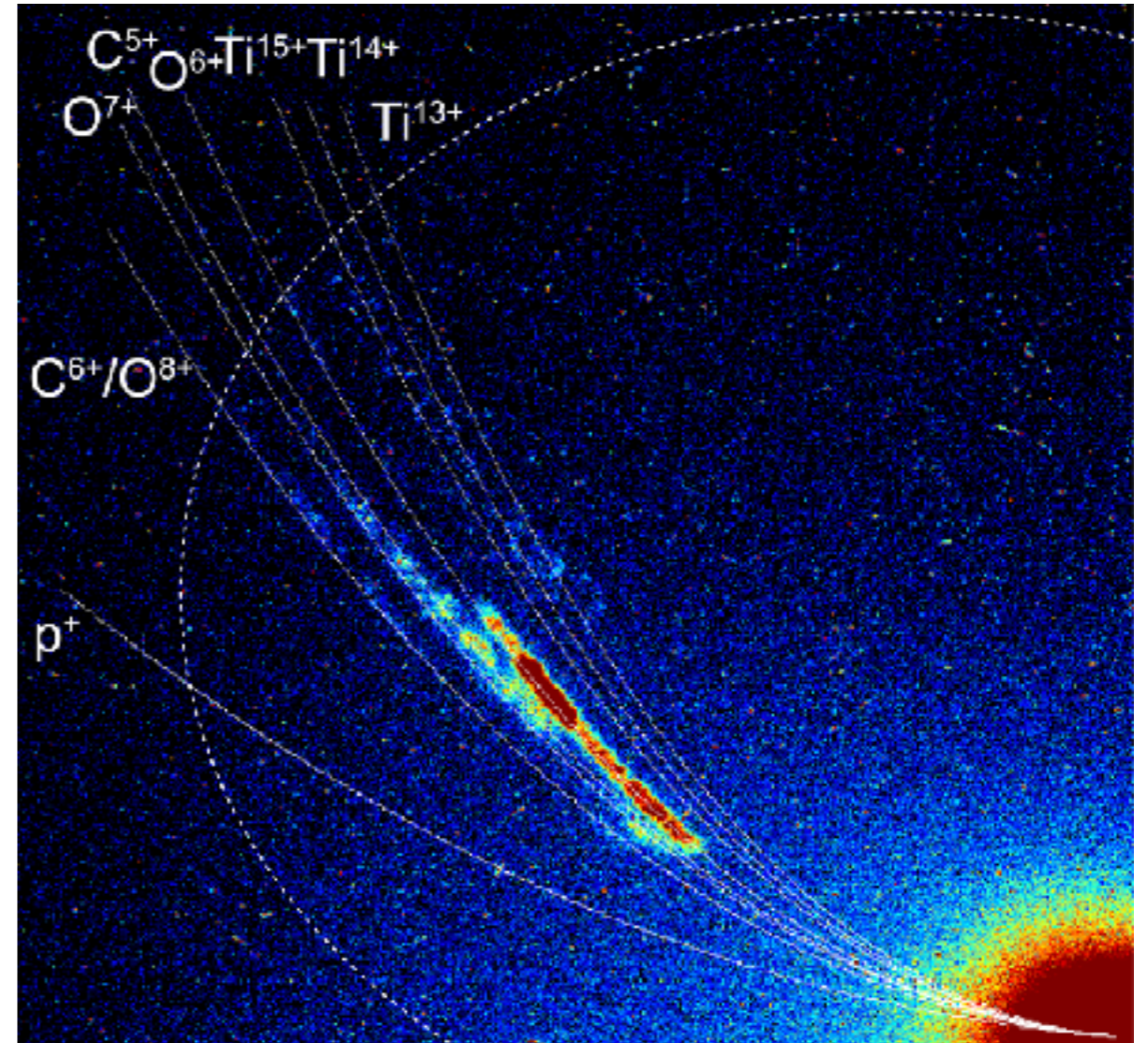
- Pulse Length: 40 fs (FWHM)
- Energy:  $\sim 10$  J
- Spot Size:  $1.5 \mu\text{m}$  (FWHM)
- Intensity:  $\sim 5 \times 10^{21}$  W/cm<sup>2</sup>

\*H. Kiriya, et. al., Optics Letters (2018).

# Thomson Parabola (TP) Spectrometer Results



without the CW laser heating

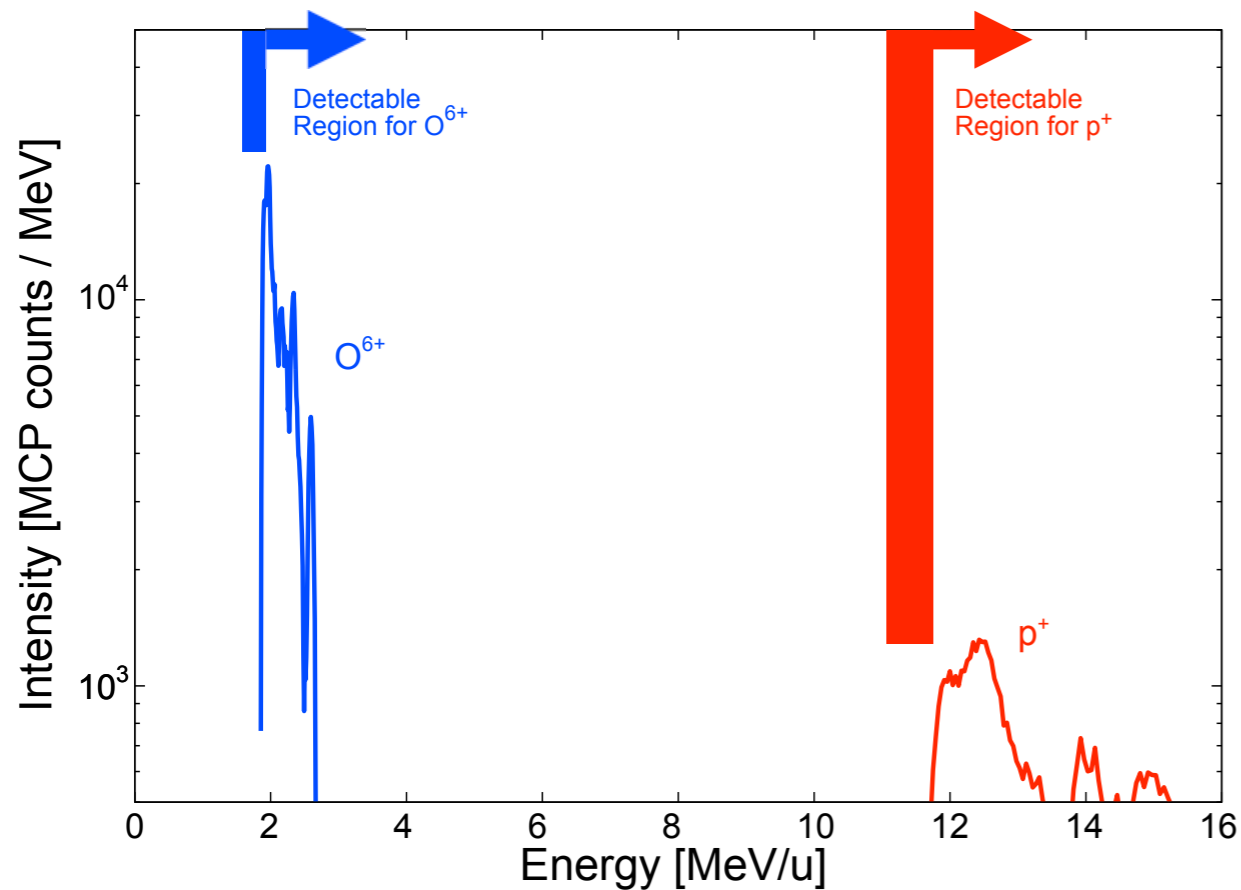


with the CW laser heating

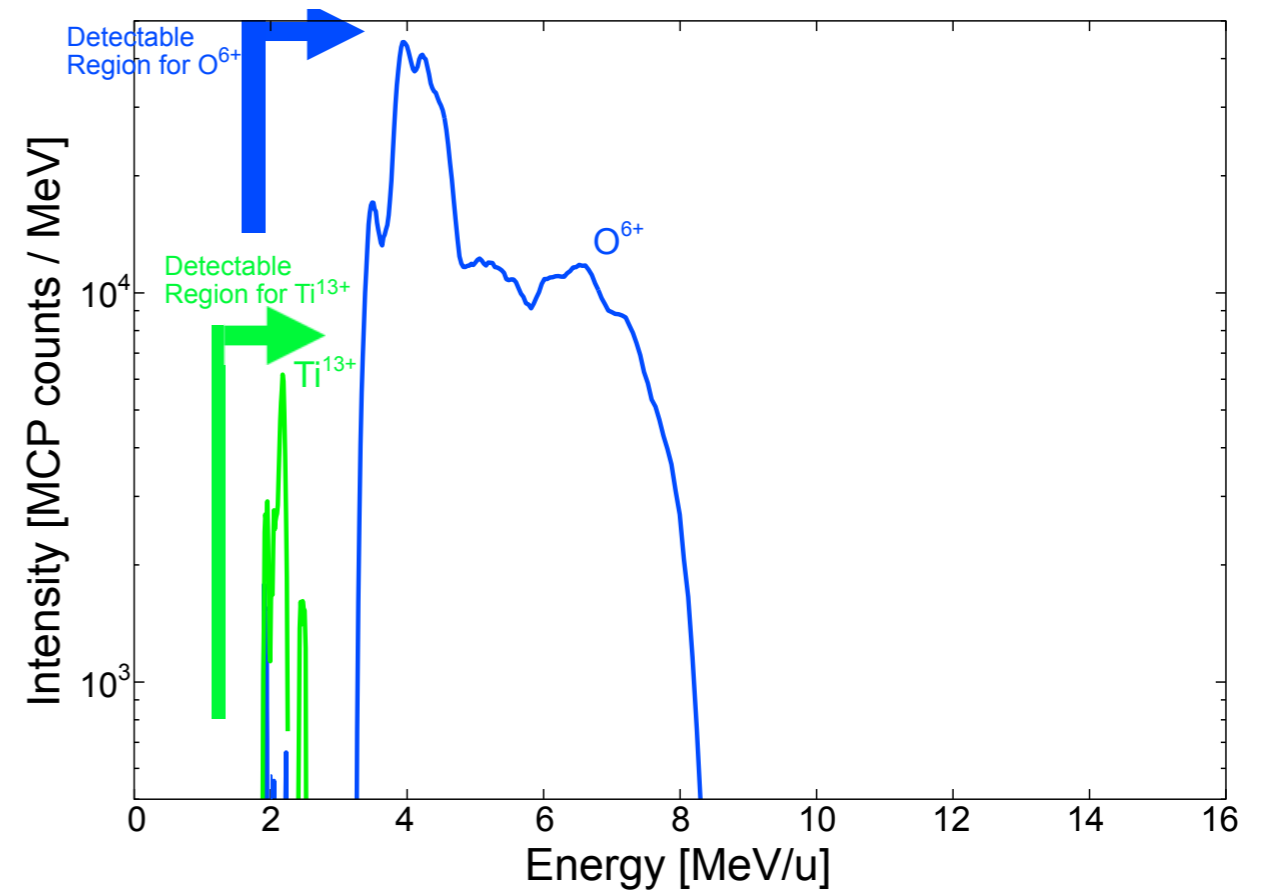
$C^{4+}$ ,  $O^{6+}$ ,  $C^{5+}$ ,  $O^{7+}$ ,  $C^{6+}/O^{8+}$  and proton were observed without the CW laser heating.

On the other hand,  $O^{6+}$ ,  $C^{5+}$ ,  $O^{7+}$  and  $C^{6+}/O^{8+}$  were observed, but no proton signal was visible above the background level with the heating. Signal consistent with Ti ions is also observed with the CW laser heating.

# Thomson Parabola (TP) Spectrometer Results



**without the CW laser heating**



**with the CW laser heating**

In the case without the heating, the proton beam has a typical thermal-like spectrum from the minimum detector cut-off of  $11.5 \pm 0.3$  MeV to a maximum cut-off of  $15.2 \pm 0.4$  MeV. A just-detectable oxygen beam is observed up to a maximum energy of  $2.6 \pm 0.1$  MeV/u.

On the other hand, the  $O^{6+}$  ions appear from  $3.3 \pm 0.1$  MeV/u to  $8.3 \pm 0.5$  MeV/u. The CW laser heating therefore not only increased the flux and energy of the  $O^{6+}$  ions, but also generated ions in a relatively narrow energy band ( $\Delta E \sim 5$  MeV/u).

# Summary\*

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- 🔍 The target surface treatment by a CW laser is proposed for laser-driven heavy ion acceleration. That has potential to supply contamination-free targets with high rep. rate.
- 🔍 Laser-driven ion acceleration using a 5  $\mu\text{m}$  Ti with CW laser heating was demonstrated for oxygen ion source.
- 🔍 A Thomson parabola spectrometer provided evidence that oxygen ions were preferentially accelerated compared to the case without the CW laser heating.
- 🔍 The experimental results indicate stable thin oxide layers on the surface of the Titanium foil can be accelerated when we apply the CW laser heating.