Observation of quantum interference of Ps wave functions using single-layer graphene

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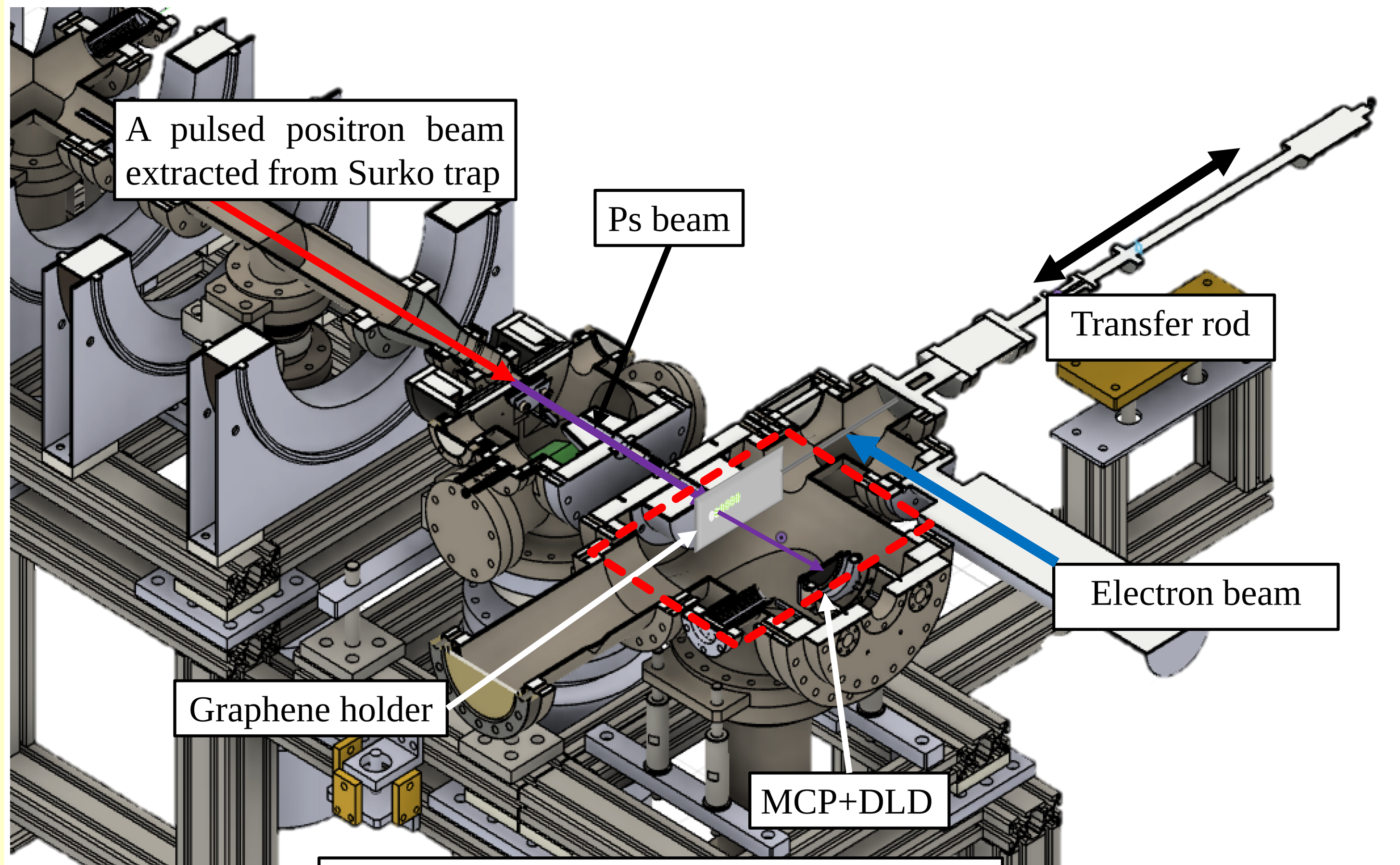
1. Outline of our research

We are conducting an experiment to observe Ps diffraction spots using an energy-tunable Ps beam [1] through a single-layer graphene. Before acquiring diffraction data, we observed the electron diffraction spots through the graphene and found that the diffraction spots became clearer after laser heating [2].

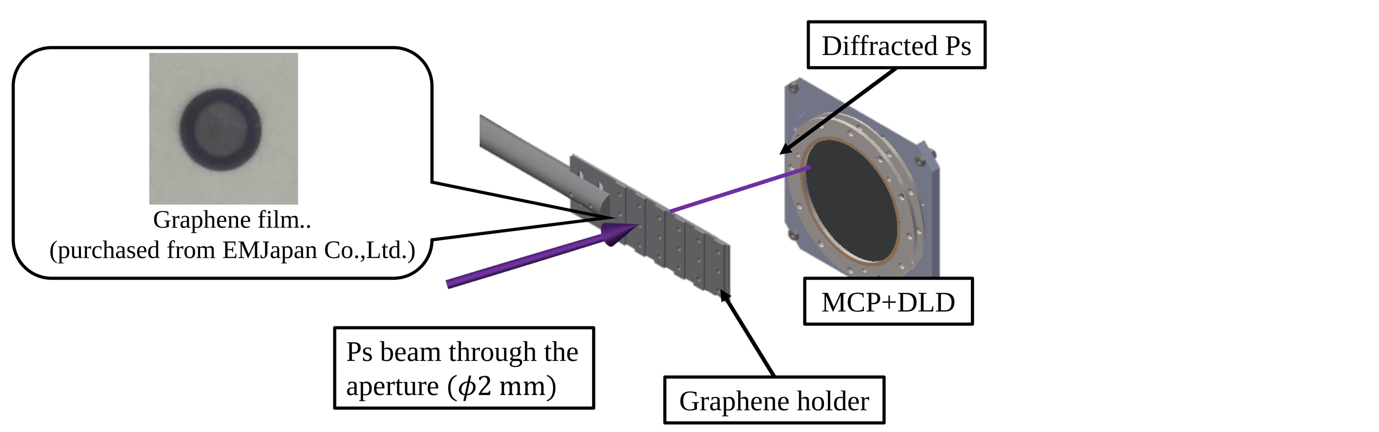
The Ps diffraction data was accumulated using a position sensitive detector composed of a micro-channel plate (MCP) and a delay-line anode. We integrated the two-dimensional profile in the angular direction and obtained a peak at a position corresponding to first-order diffraction.

2. Introduction

◆ High quality energy-tunable Ps beam



Cross-sectional view of our Ps beam line [1].



The graphene target and the detector.

A pulsed positron beam is injected into a Na deposited tungsten foil and Ps^- ions are emitted downstream. The Ps beam is produced by photodetachment after the ions are accelerated by an electric field.

◆Experiments using this Ps beam

We have already achieved the observation of motion-induced transition of Ps [3] and the measurement of binding energy between Ps and e^- [4] . In the present work, we try to **observe the interference of Ps wave functions**.

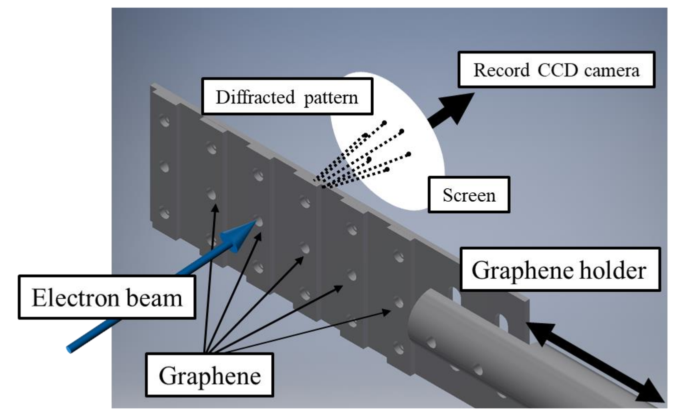
⮡ This will lead to:

- A new method of crystal structure analysis.
- Detail studies of the interaction between Ps and carbon atoms.

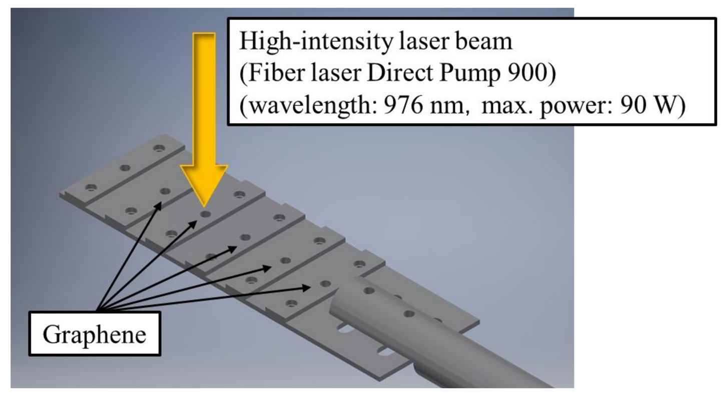
3. Experiments of electron diffraction

◆Purpose

In order to obtain sharp Ps diffraction spots, we tested heat treatment on the graphene by observing electron diffraction spots.



Setup of electron diffraction.



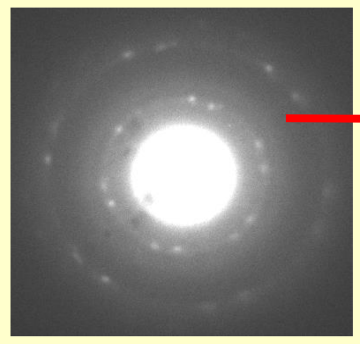
Configuration of the graphene holder for the laser heating.

◆ Experimental method

- Inject electron beam into the graphene at 6 keV in ultra high vacuum ($\sim 3 \times 10^{-8}$ Pa) and record diffraction spots by CCD camera (ATIK Cameras, Atik 420).
- Rotate the graphene holder and irradiate with the laser. Then, return the holder to the original position.

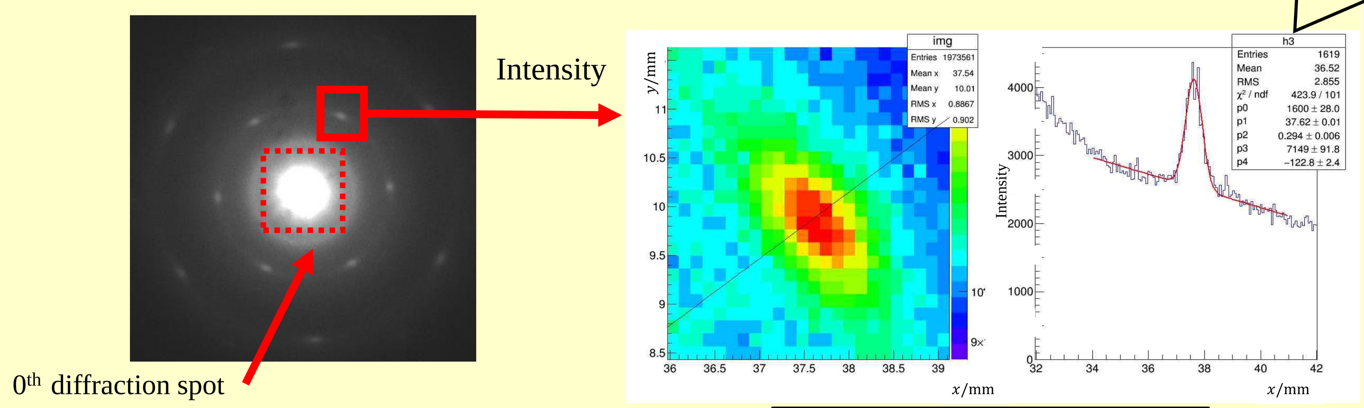
◆The change of diffraction spots by the laser heating

➢ Untreated



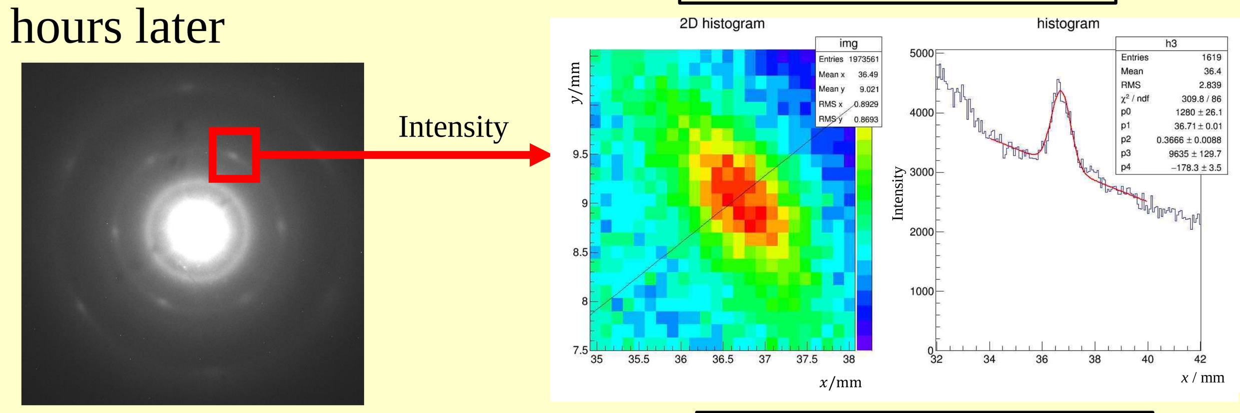
Diffraction spots seem to double.

➢ Immediately after laser heating (72 mW/cm² for 1 min.)



The peak becomes sharp!

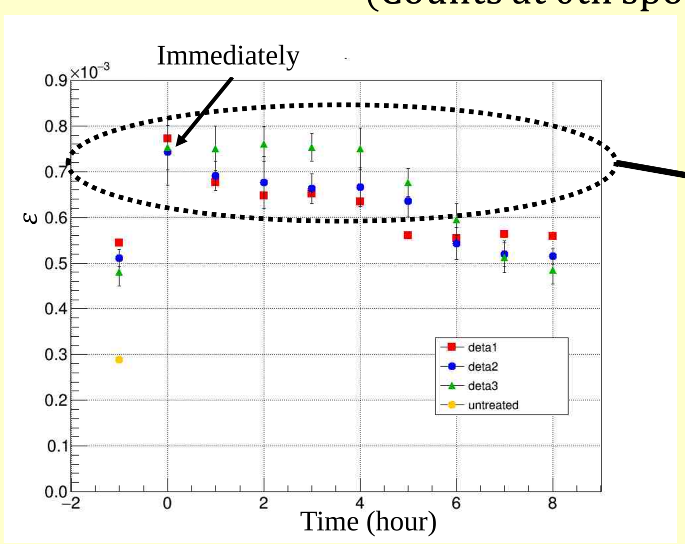
➢ 8 hours later



The peak becomes broader.

◆Investigate time dependence of ε

$$\varepsilon = \frac{\text{(Counts at 1st spot)}}{\text{(Counts at 0th spot)}}$$



ε increases 1.2-1.4 times after laser heating.

After heating, the graphene is contaminated gradually.

We need the laser heating every a few hours.

4. Experiments of Ps diffraction

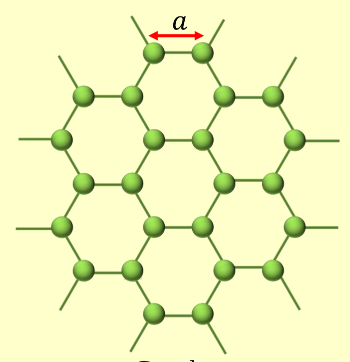
◆Estimation

We estimated the distances D_i(i=1, 2, 3) between diffraction spots and the beam center:

$$D_1 = \frac{\hbar K_1}{\sqrt{2m_{Ps}E_{Ps}}} \quad \text{(1st diffraction spots)}$$

$$D_2 = \frac{\hbar K_2}{\sqrt{2m_{Ps}E_{Ps}}} \quad \text{(2nd diffraction spots)}$$

$$D_3 = \frac{\hbar K_3}{\sqrt{2m_{Ps}E_{Ps}}} \quad \text{(3rd diffraction spots)}$$



where

E_{Ps}: Ps beam energy (3.3 keV)

K_i: crystal momentum

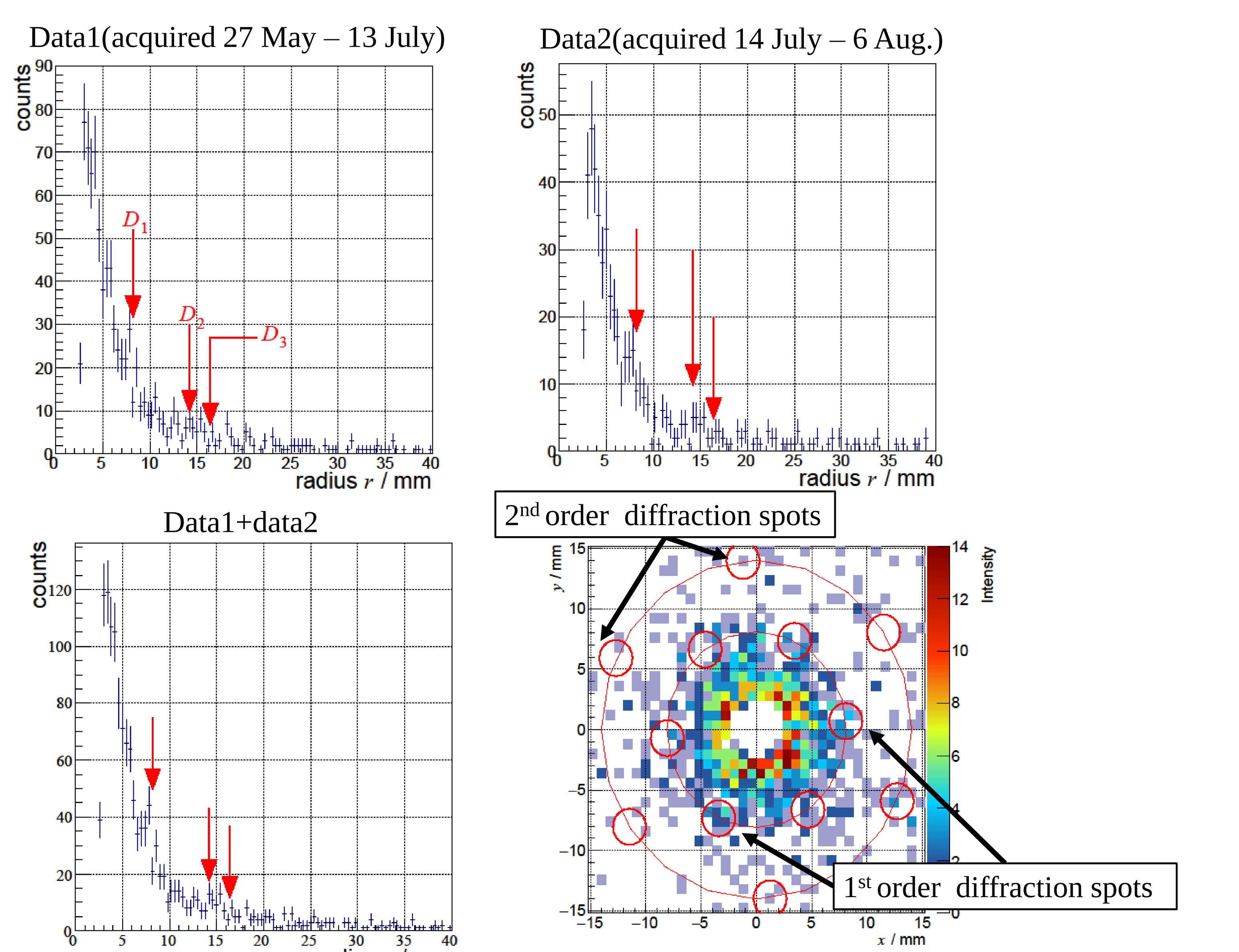
L : a distance between the graphene and the detector (MCP)

For the present experiment, $K_1 = \frac{4\pi}{3a}$, $K_2 = \frac{4\pi}{\sqrt{3}a}$ and $K_3 = \frac{8\pi}{3a}$.

➡ D_1 = 8.2 mm
D_2 = 14.2 mm
D_3 = 16.4 mm

◆Experiments and results

We injected the Ps beam (E_{Ps} = 3.3 keV) in the single-layer graphene cleaned by the laser heating. We acquired tha data for about 300 hours.



2-dimensional beam profile for data1+data2.

A peak corresponding to the first Ps diffraction spots was observed!!

◆Future prospects

We will accumulate more data to obtain clearer diffraction spots. We will also take data for different Ps energies.

5. Acknowledgements

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6. Reference

1. K. Michishio *et al.*, Rev. Sci. Instrum. **90**, 023305 (2019).
2. A. Niggas *et al.*, J. Chem. Phys. **153**, 014702 (2020).
3. Y. Nagata *et al.*, Phys. Rev. Lett. **124**, 173202 (2020).
4. K. Michishio, S. Kuma *et al.*, Phys. Rev. Lett. **125**, 063001 (2020).