ナノ空孔中におけるポジトロニウム消滅現象のポジトロニウムレーザー冷却に対する影響評価

Influence of Positronium Annihilation in Nano-vacancies on Positronium Laser Cooling

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Abstract

This work strives to establish the Bose-Einstein Condensate (BEC) of Positronium (Ps). With the recent evidence of laser cooling for Ps [1], the focal point of the present study is the investigation of 2P-Ps annihilation in nanocavities, vital for efficient Ps laser cooling and subsequent Ps-BEC realization. Our experimental setup, augmented with a 4K-GM cryocooler, allows for positron and laser irradiation on porous materials to allow for the determination of 2P-Ps annihilation rates. Systematically altering the cavity properties in terms of size, temperature, and composition, we aim to create a comprehensive model of the characteristics affecting Ps annihilation rates within the cavities. This model will guide the development of materials compatible with Ps laser cooling inside the nano-pores. The expected outcomes extend beyond improving Ps laser cooling techniques, potentially revealing novel Ps-matter interactions and advancing material and surface science. The study also anticipates implications for fundamental physics, especially in understanding the antimatter component of the universe and the development of new surface analysis methodologies using Ps.

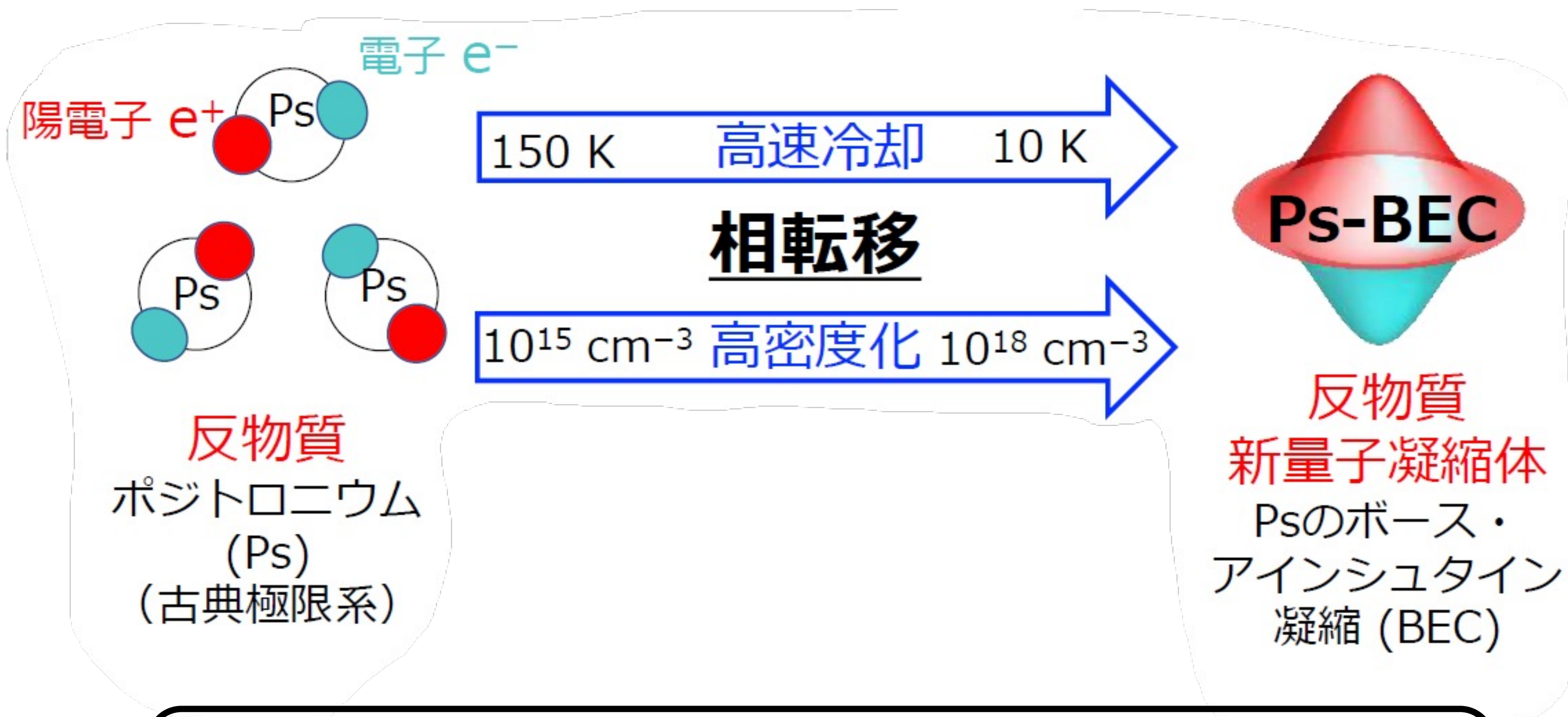

Fig. 1 The lifetime of Ps allows for ultrafast processes, as Ps, being a bound state of a particle and its antiparticle, annihilates into gamma rays after approximately 142 ns.

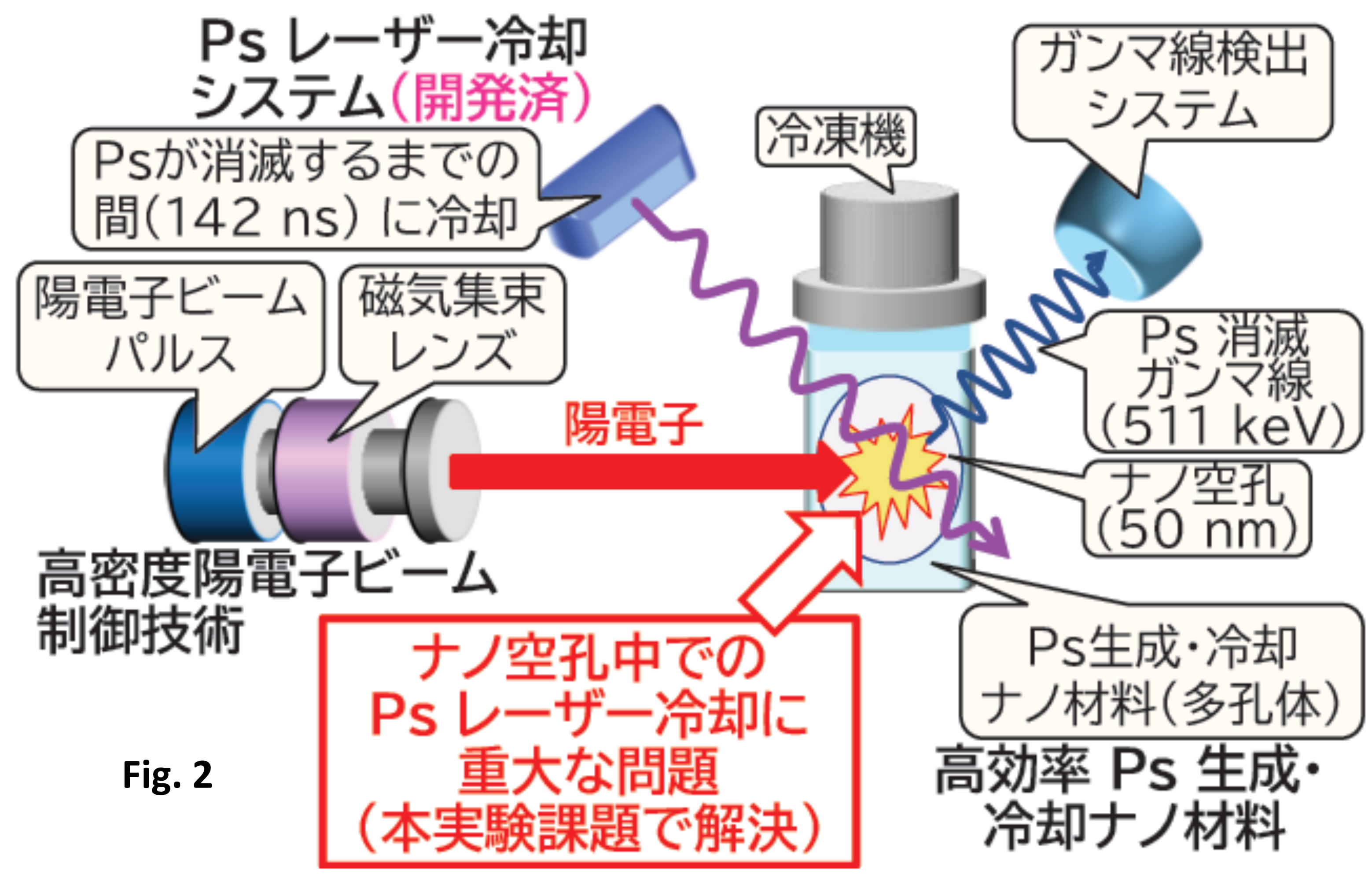

Fig. 2 Scheme for realizing Ps-BEC in this study. High-density positron beams are injected into the nanomaterial voids for efficient Ps production and cooling, achieving high-density Ps generation. BEC is realized through ultrafast cooling via a combination of thermal exchange (thermalization) with the void walls and laser cooling.

This work addresses some of the universe's mysteries--such as the formation of a matter-dominated universe, quantum properties of gravity, and the nature of dark energy and dark matter--which extend beyond the current understanding of particle physics. Central to our approach is the use of Bose-Einstein Condensation (BEC) of positronium (Ps), a simple atom made of an electron and its antiparticle, the positron (Figure 1). Achieving Ps-BEC requires creating Ps at ultra-high densities and cooling it rapidly, which can dramatically improve measurement accuracy and enable new experiments, such as gamma-ray lasers generated by self-annihilating Ps.

To achieve Ps-BEC, we employ a technique that involves laser cooling of Ps within nano-voids by rapidly alternating between the 1S and 2P energy states (Figures 2 and 3). The sample holder used in the most recent work is shown in Figure 4 with an alignment testing laser incident on the silica aerogel sample. Previous work has shown that this method is feasible and has led to significant progress toward realizing Ps-BEC [1], despite challenges such as the rapid annihilation of excited Ps in these environments.

By pioneering the use of Ps laser cooling technology in nano-voids, our project aims to overcome the biggest obstacles to realizing Ps-BEC and gamma-ray lasers. This breakthrough would not only open up new areas of research but also enhance our understanding of Ps-material interactions, offering insights into materials and surface science and potential new techniques for surface analysis.

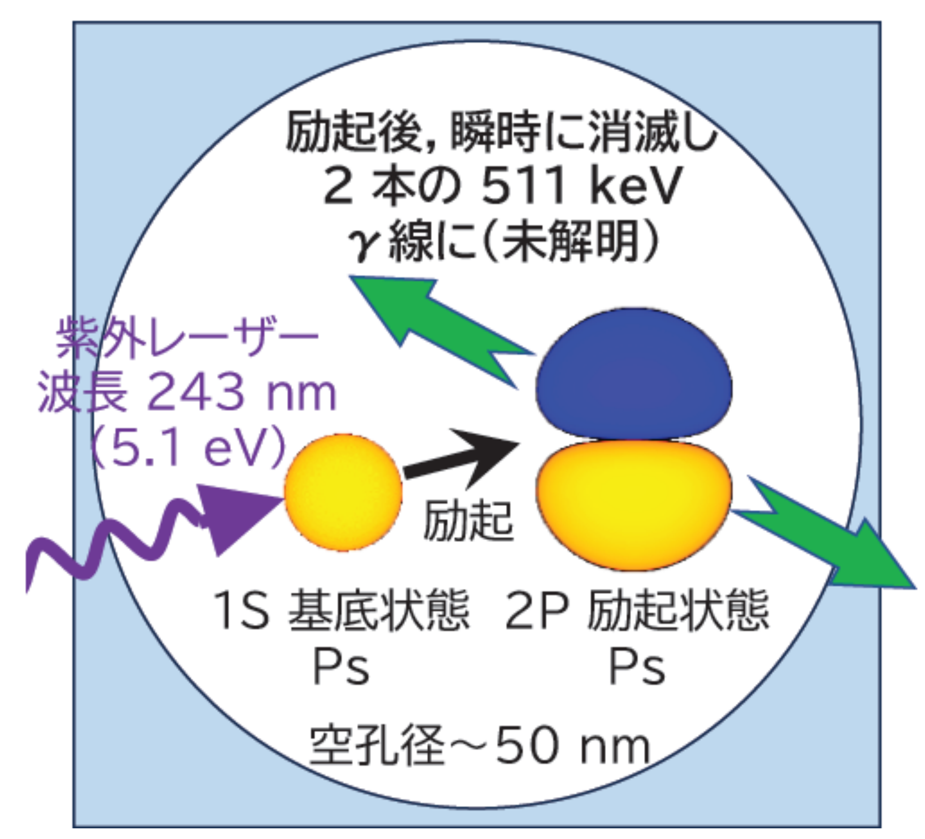

Fig. 3 Ps tends to annihilate immediately after excitation in the nano-voids, inhibiting laser cooling.

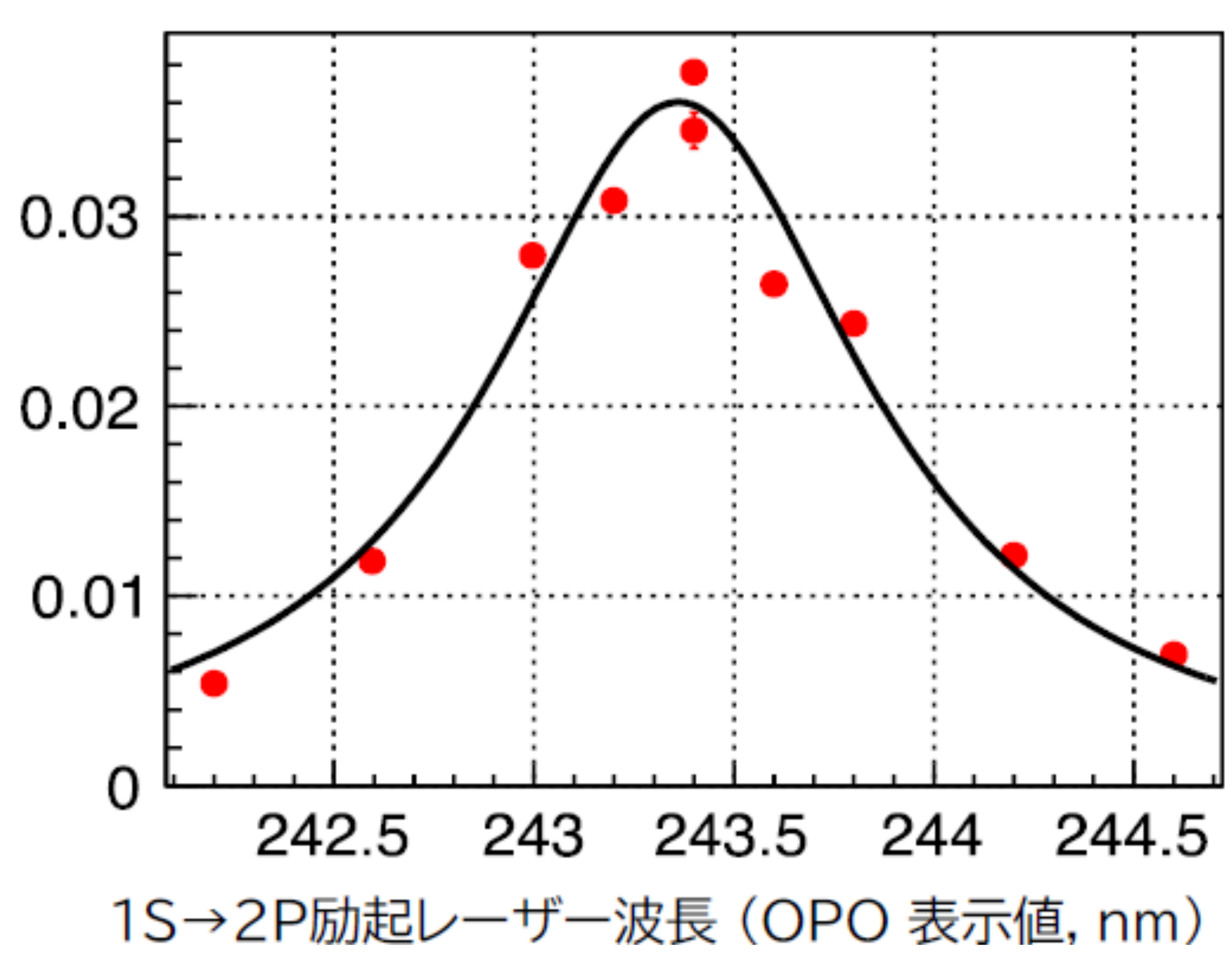

Fig. 5 The transition curve from 1S to 2P obtained in previous work. From the figure, the annihilation rate of 2P-Ps can be determined [2].

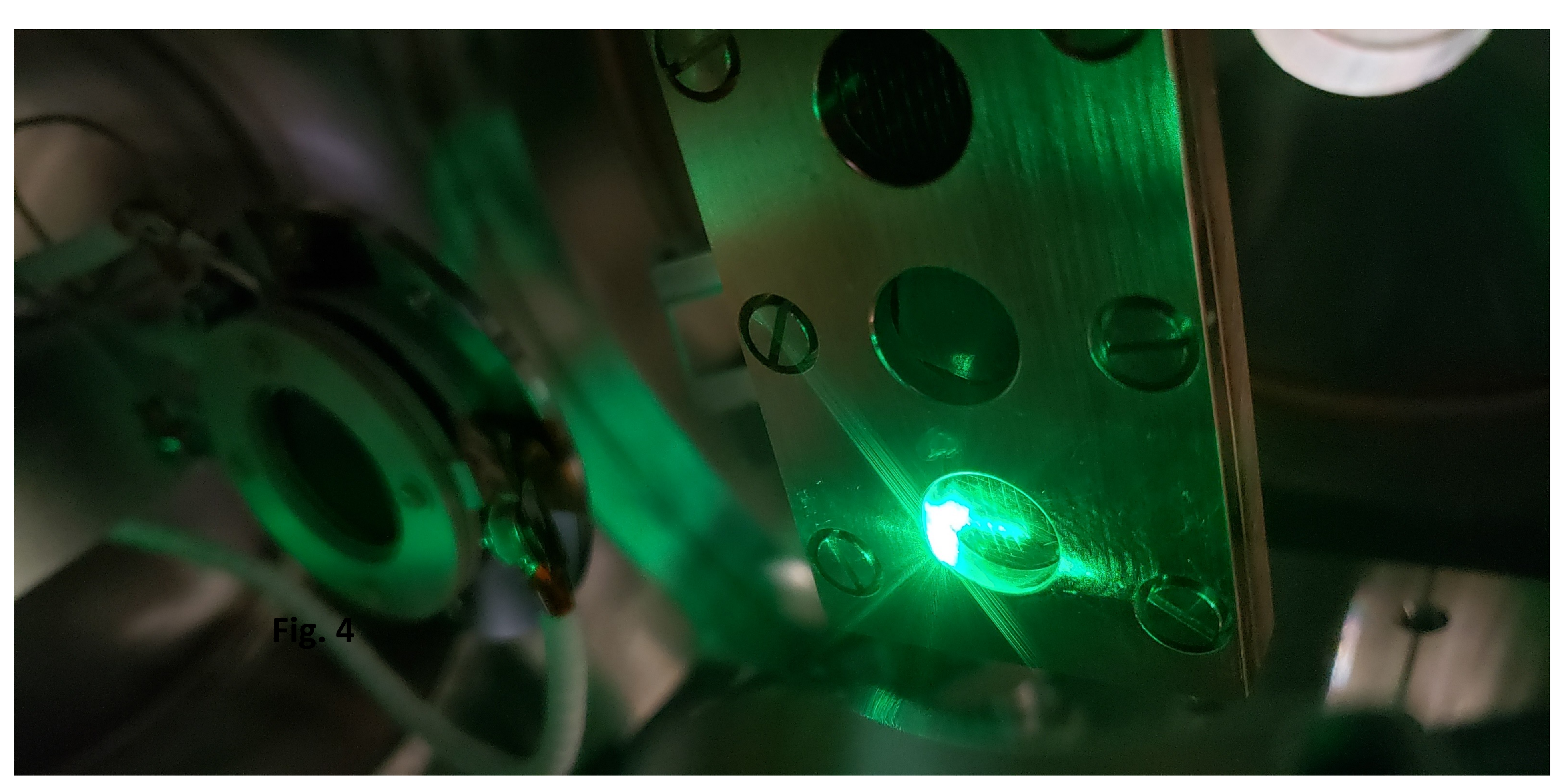

Fig. 4 Sample holder (attached to cryocooler) with the laser path incident on the silica aerogel sample (a laser pointer is . The actual laser profile used in the experiment is roughly circular.

References

[1] Shu, K., et al., Laser cooling of positronium. arXiv:2310.08761 (2023).
[2] PFACR 37 (2020) 201

Acknowledgements

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