Advancing Laser Wakefield Acceleration: Toward a Compact Tabletop XUV Free-Electron Laser

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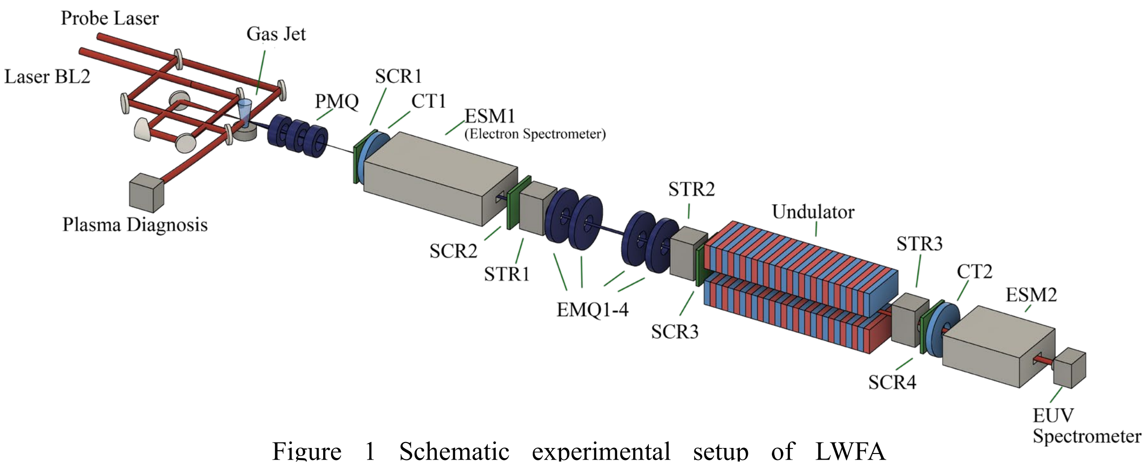

Figure 1 Schematic experimental setup of LWFA

To develop a stable laser wakefield acceleration (LWFA)-based accelerator [1] and demonstrate free-electron laser (FEL) generation, a novel LWFA platform was constructed at the RIKEN SPring-8 Center. Systematic experiments were carried out under the support of the ImPACT (2013–2018) and JST MIRAI (2017–present) programs. Although undulator radiation in the XUV spectral range, driven by LWFA electron beams, was successfully demonstrated in 2019, reproducibility was hampered by poor electron pointing stability and large energy fluctuations. To overcome these challenges, the quality of the accelerated electron beam was enhanced through the development of a shock injection scheme, which allows precise injection control and ensures stable plasma conditions. This advancement significantly improved both the reproducibility and stability of the LWFA electron beam. This presentation will outline the LWFA platform, detail the setup of the proof-of-concept experiments with a focus on key improvements, and discuss the results obtained.

The experiment was conducted at Laser Acceleration Platform LAPLACIAN (Laser Acceleration Platform as a Coordinated Innovative Anchor), a specialized facility designed for laser wakefield acceleration research (Fig. 1). This platform is located at the RIKEN SPring-8 Center. The laser system utilized in the platform is a custom-built Ti:Sapphire femtosecond laser system capable of delivering three laser beamlines with adjustable parameters, all synchronized with each other.

For the FEL experiment, beamline 2 was employed as the driver laser, providing a laser pulse energy of 0.8 J and a minimum pulse duration of 21 fs post-compression. A gold-coated off-axis parabola with a focal length of 1500 mm was used to focus the laser onto the gas target.

A stable laser wakefield accelerator relies on two key factors: a well-tailored, stable plasma (gas) density distribution and a stable drive laser with suitable parameters. Efforts have been made to enhance both plasma and laser stability [2, 3].

By ensuring precise injection control, stabilization of the laser wavefront, and optimal performance of the gas jet, as well as by optimizing phase rotation and beam loading, we can generate quasi-monoenergetic electron beams with an energy spread of less than 1%, energies approaching 400 MeV, pointing stability of less than 0.5 mrad, and energy stability of less than 6% (rms). Demonstration experiments by sending these beams into a mini-undulator have shown a FEL gain of 14 times in XUV range.

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References
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