Multistage laser wakefield acceleration
driven by two laser pulses with different focal lengths

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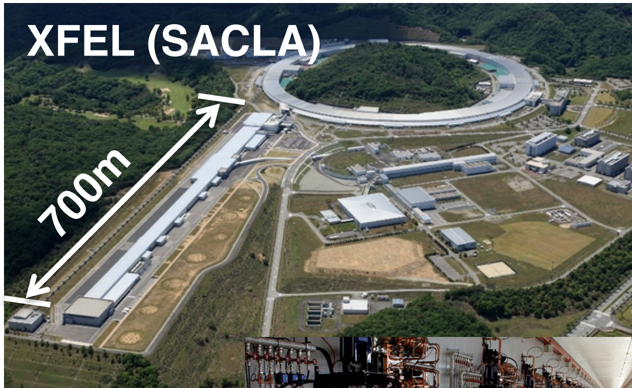
Outline

- Motivation
- Stable injector using plasma micro optics
- Multistage LWFA experiment
- Upgrading laser system for future exp.
- Summary

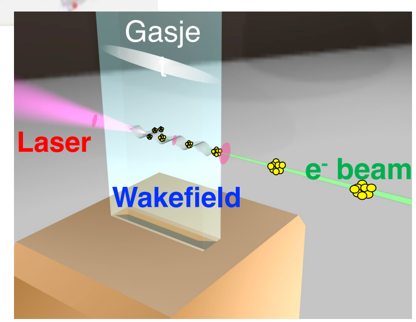
ImPACT Program towards the realization of compact XFEL system based on laser-driven accele



RF (C-band) accelerator

~ 50 MV/m

Conception of Mobile XFEL

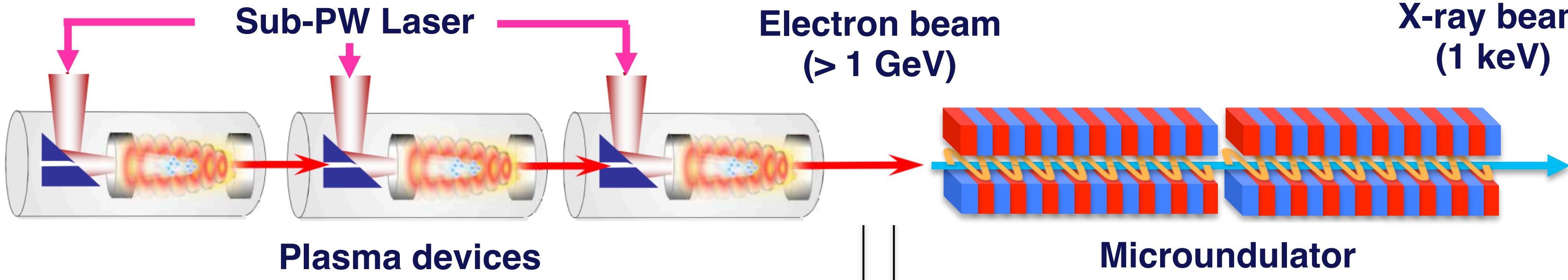


Laser wakefield accelerator

~100 GV/m

- XFEL enables atomic level analysis and has a lot of applications in material sciences, biology, advanced medicine and so on. However, XFEL facilities are currently existed at only two locations and large (ex. SACLA@Japan: ~700m).
- The goal of the ImPACT program is to establish basic technology for compact XFEL, which can be used for many applications such as ubiquitous equipment diagnosis, biological imaging, and quantum beam radiotherapy anytime anywhere.

ImPACT Program towards the realization of compact XFEL system based on laser-driven accele



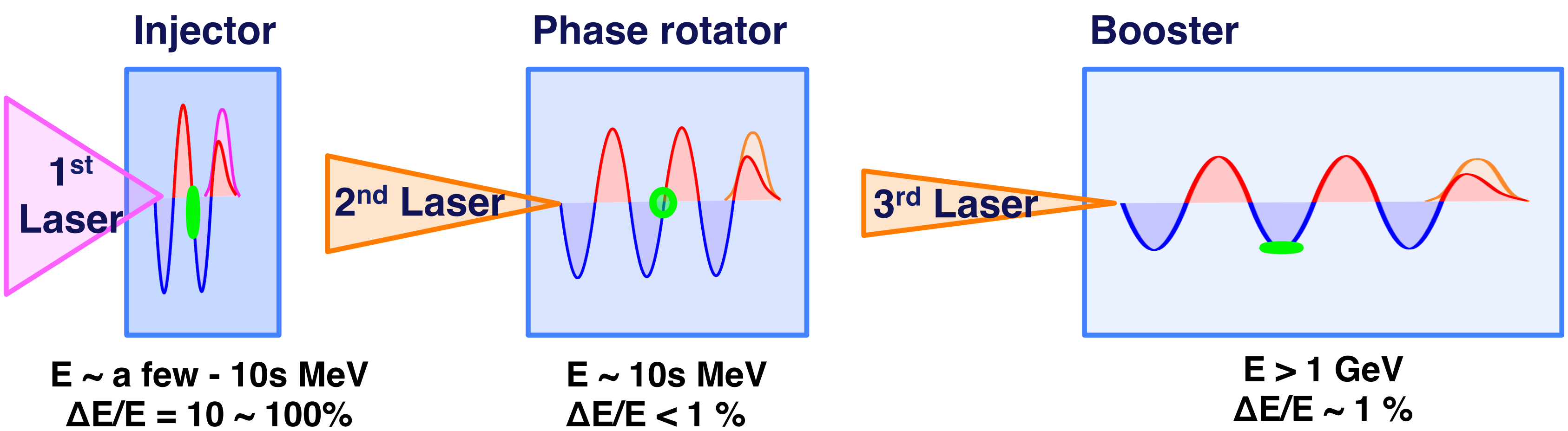
Laser acceleration technologies: Osaka Univ.
Beam monitoring and control: JAEA
Plasma device power source: Nagaoka Univ.

Development of microundulator: KEK

Highly stable GeV acceleration using LWFA

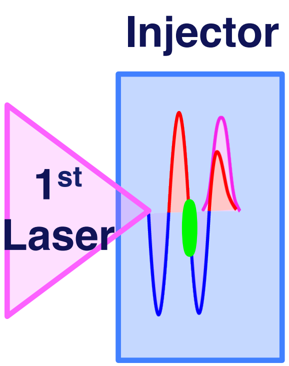
Length	**< 10 m**
Energy Gain	**> 1 GeV**
Energy spread	**< 1 %**
Emittance	**< 1 mm-mrad**
Bunch duration	**~ 10 fs**

Multistage laser wakefield acceleration for highly stable GeV acceleration



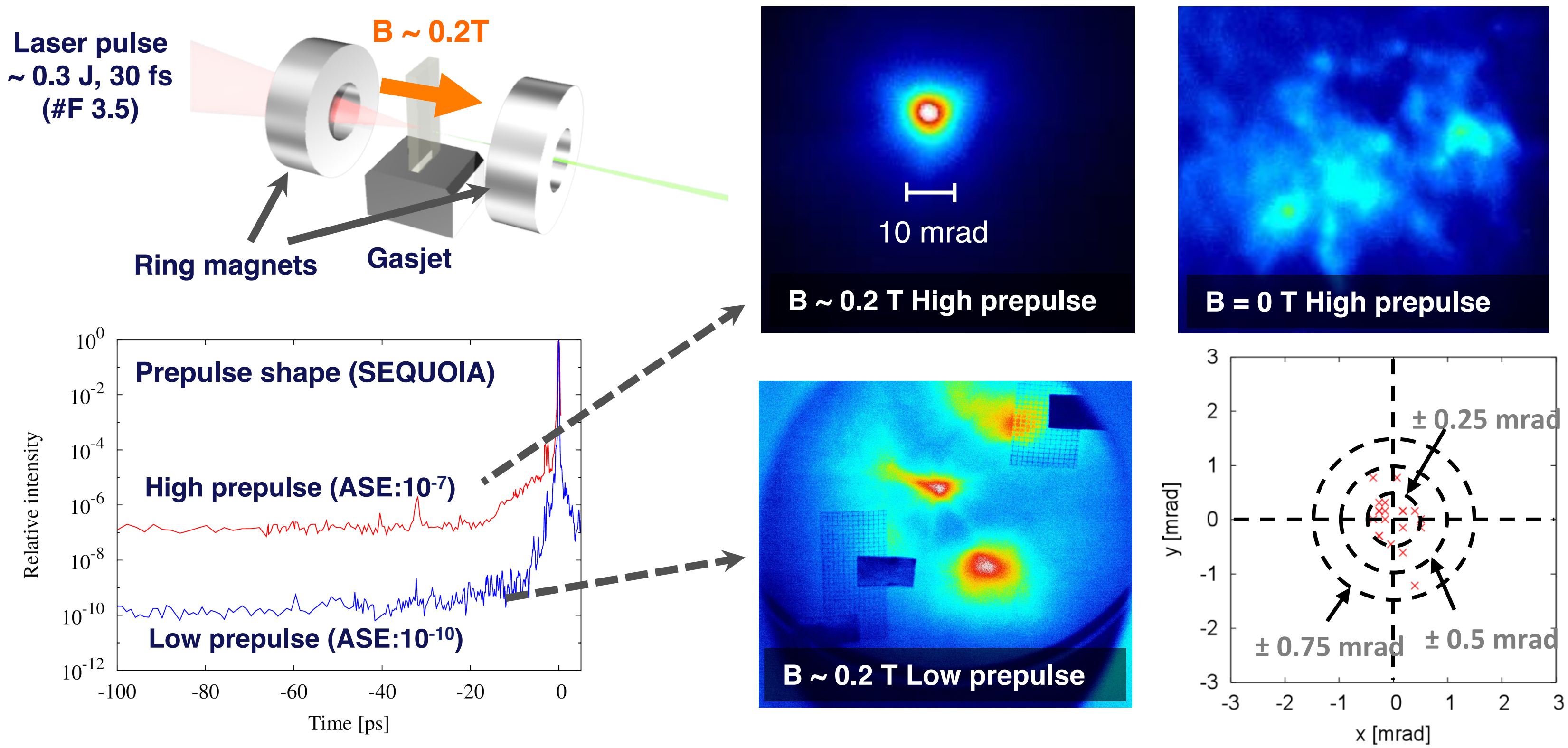
- **Injector, Phase rotator and Booster is separated for each function as conventional accelerator**
- **Each unit is driven by different laser pulse. That enables optimization of the laser parameters for each function**
  - Injector: $a_0 > 1$, short pulse duration for high density
  - Phase rotator/Booster: $a_0 < 1$, longer pulse duration, long focus length
- **Energy can be controlled by changing the timing between laser pulses and can be increased by adding more booster units.**

Stable injector using plasma micro optics



ΔE/E = 10 ~ 100%

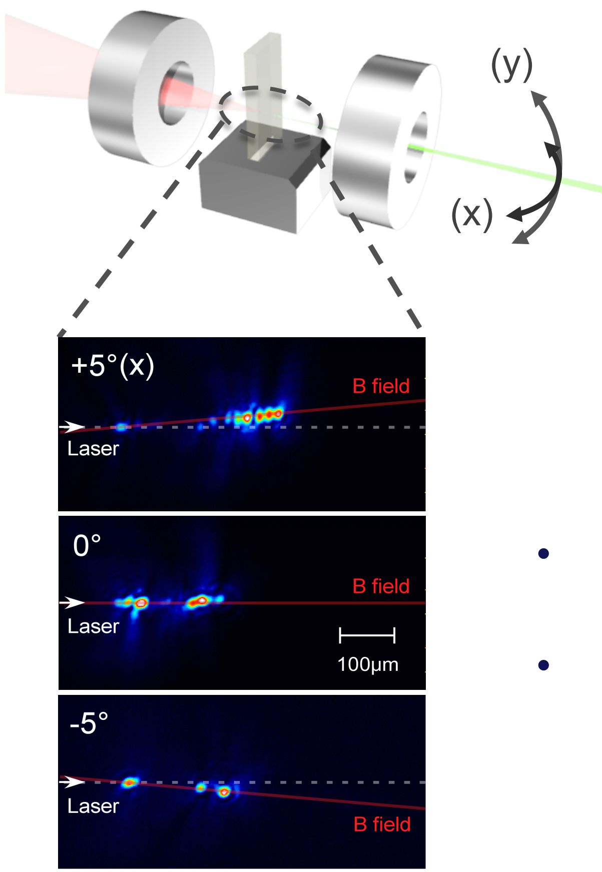
Stable steerable injector driven by short-focus laser pulse with plasma micro optics



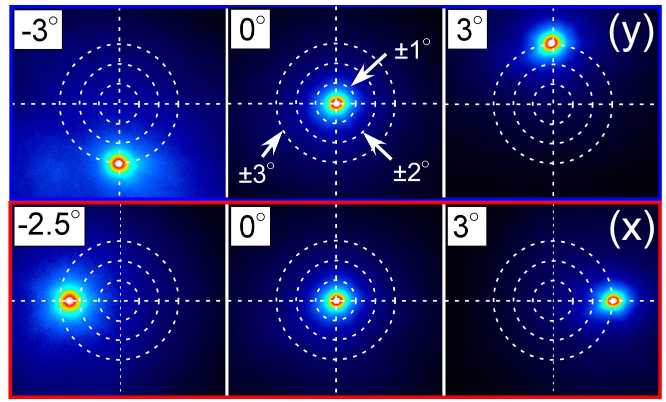
- **By applying external B field, high-quality electron beam with high charge(~ 2 nC), low divergence(~ 11 mrad) and stable pointing (< 0.5 mrad rms) can be generated.**
- The beam quality also depends on prepulse energy. That indicates the preplasma created by the prepulse acts as optics to main pulse and improves the main pulse's focusability (plasma micro optics).

T. Hosokai et al., Phys. Rev. Lett. (2006), N. Nakanii et al., Phys. Rev. ST-AB (2015)

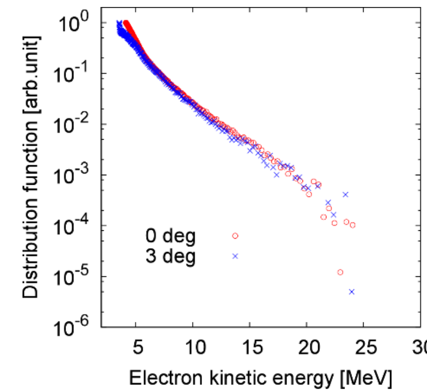
Stable steerable injector driven by short-focus laser pulse with plasma micro optics



Thomson scattering (Top view)



Spatial distribution

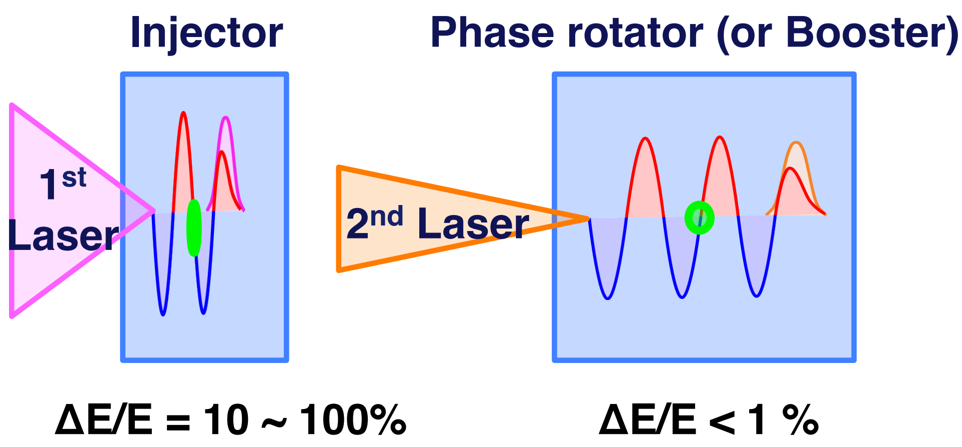


Energy spectrum

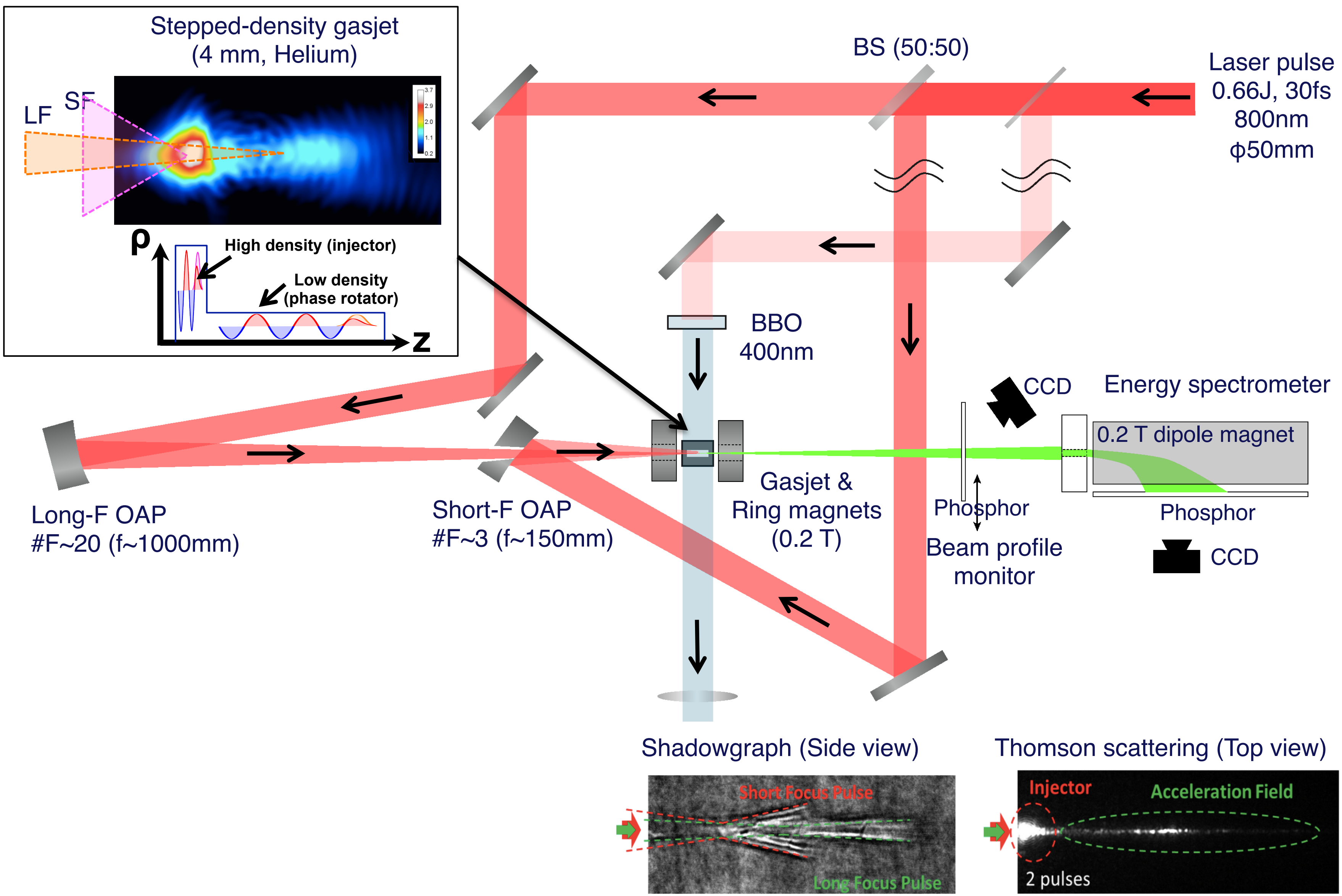
- **Electron beam can be steered freely by tilting magnetic field direction.**
- The electron beam exactly follows on the magnetic field direction without changing the beam quality and the energy spectrum.
- The plasma micro optics (magnetized preplasma) can guide main laser pulse to the magnetic field direction

N. Nakanii et al., Phys. Rev. ST-AB (2015)

Multistage LWFA experiment (two stages)

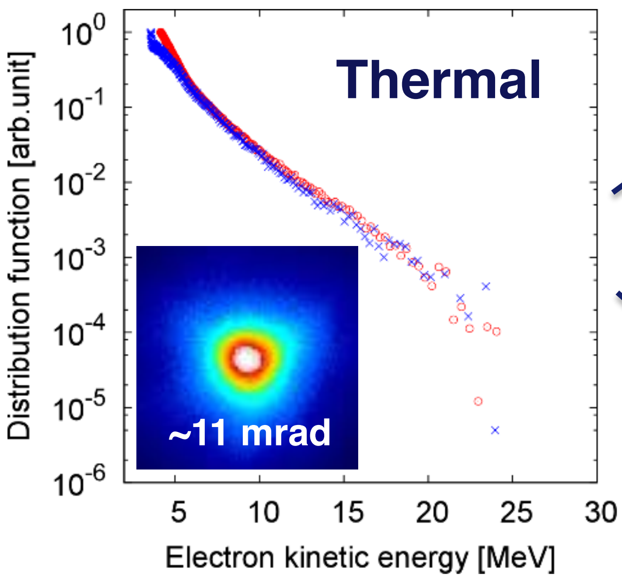


Multistage LWFA experimental setup

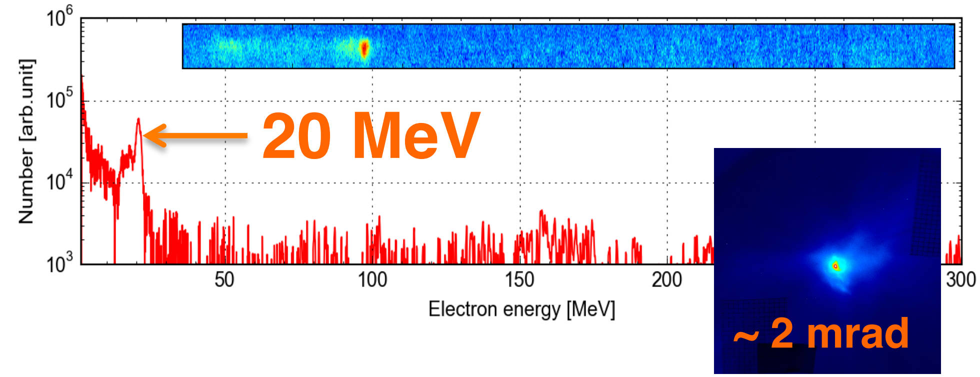


Quasi-monoenergetic electron beam with narrow energy spread is obtained by multistage LWFA

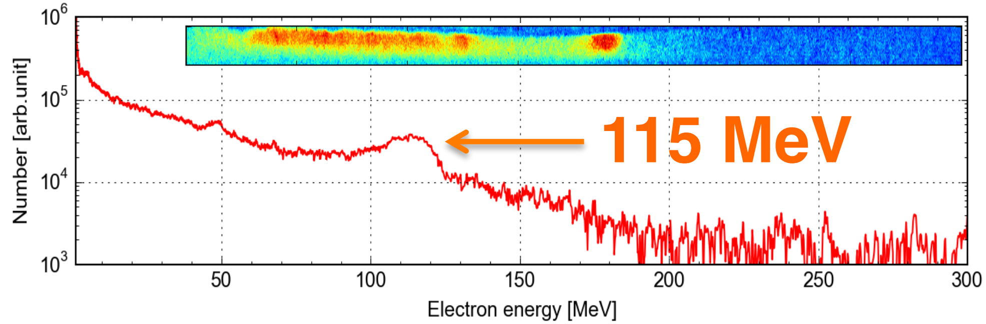
Short-focus pulse (Injector)



Both pulses (Δt ~ 300 fs)



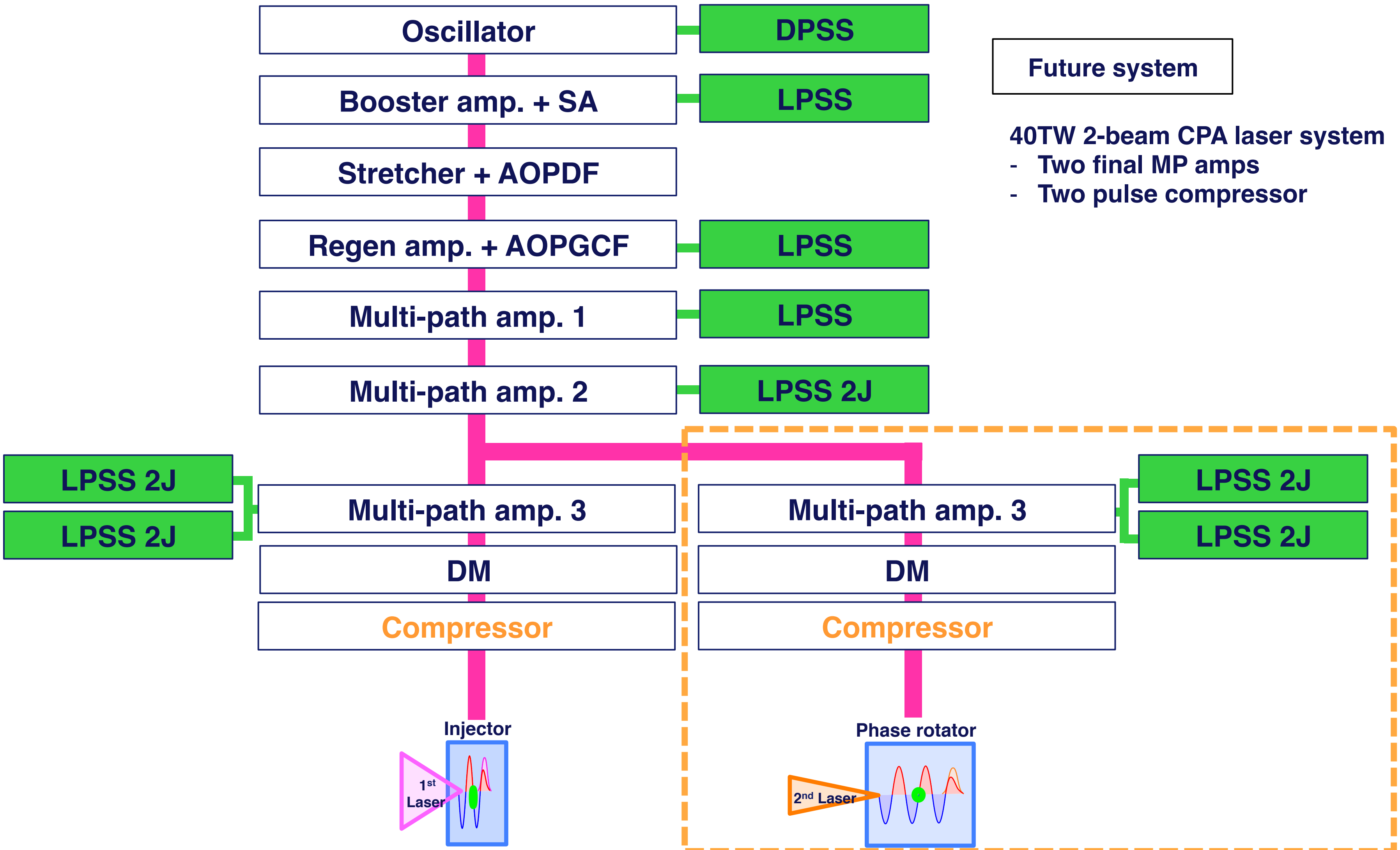
Both pulses (Δt ~ 33 fs)



- In the 2nd wakefield, the thermal energy spectrum of injector beam is modified to quasi-monoenergetic spectrum with narrow energy spread by phase rotation.
- By changing the injection timing, the electron can be accelerated in the 2nd wakefield. We obtained quasi-monoenergetic beam with peak at 115 MeV.

Upgrading laser system for future exp.

Upgrading laser system to 40 TW 2 beams for optimization of pulse duration and 3-stage LWFA

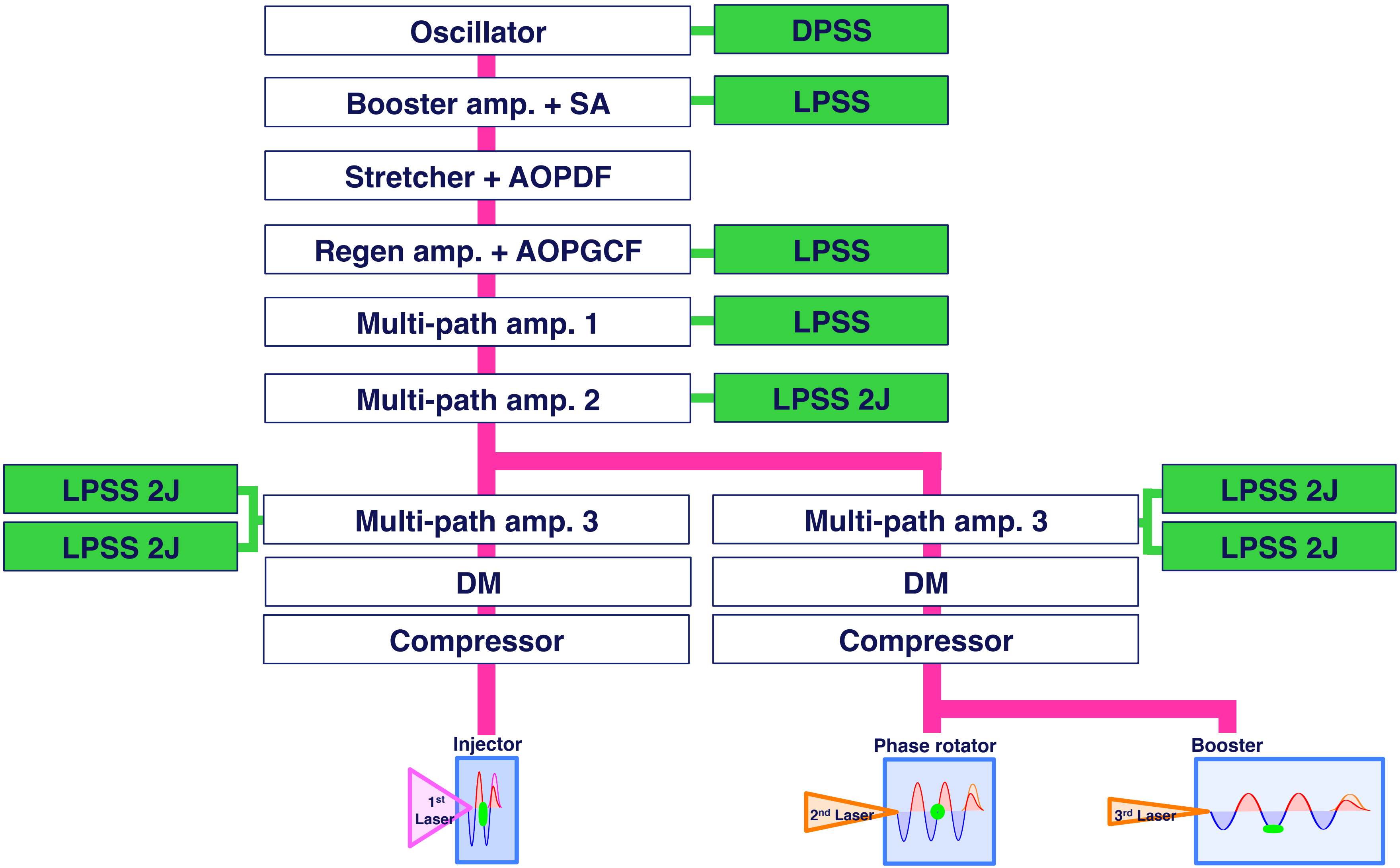


Future system

40TW 2-beam CPA laser system

- Two final MP amps
- Two pulse compressor

Upgrading laser system to 40 TW 2 beams for optimization of pulse duration and 3-stage LWFA



Summary

- High-quality steerable injector beam (divergence ~ 10 mrad, pointing < 0.5 mrad rms, charge ~ 2 nC) has been developed by using the plasma micro optics technique.

- We have demonstrated two-stage LWFA driven by two laser pulses with different focal lengths
  - Quasi-monoenergetic electron beam with narrow energy spread is obtained by phase rotation in the 2nd wakefield.
  - Electron can accelerate by changing the injection timing. We observed quasi-monoenegetic beam with 115 MeV peak.

- We are upgrading our laser system for improving the beam quality by optimization of pulse duration and for three-stage LWFA exp.