Towards 10 GeV electron acceleration with 4-PW laser

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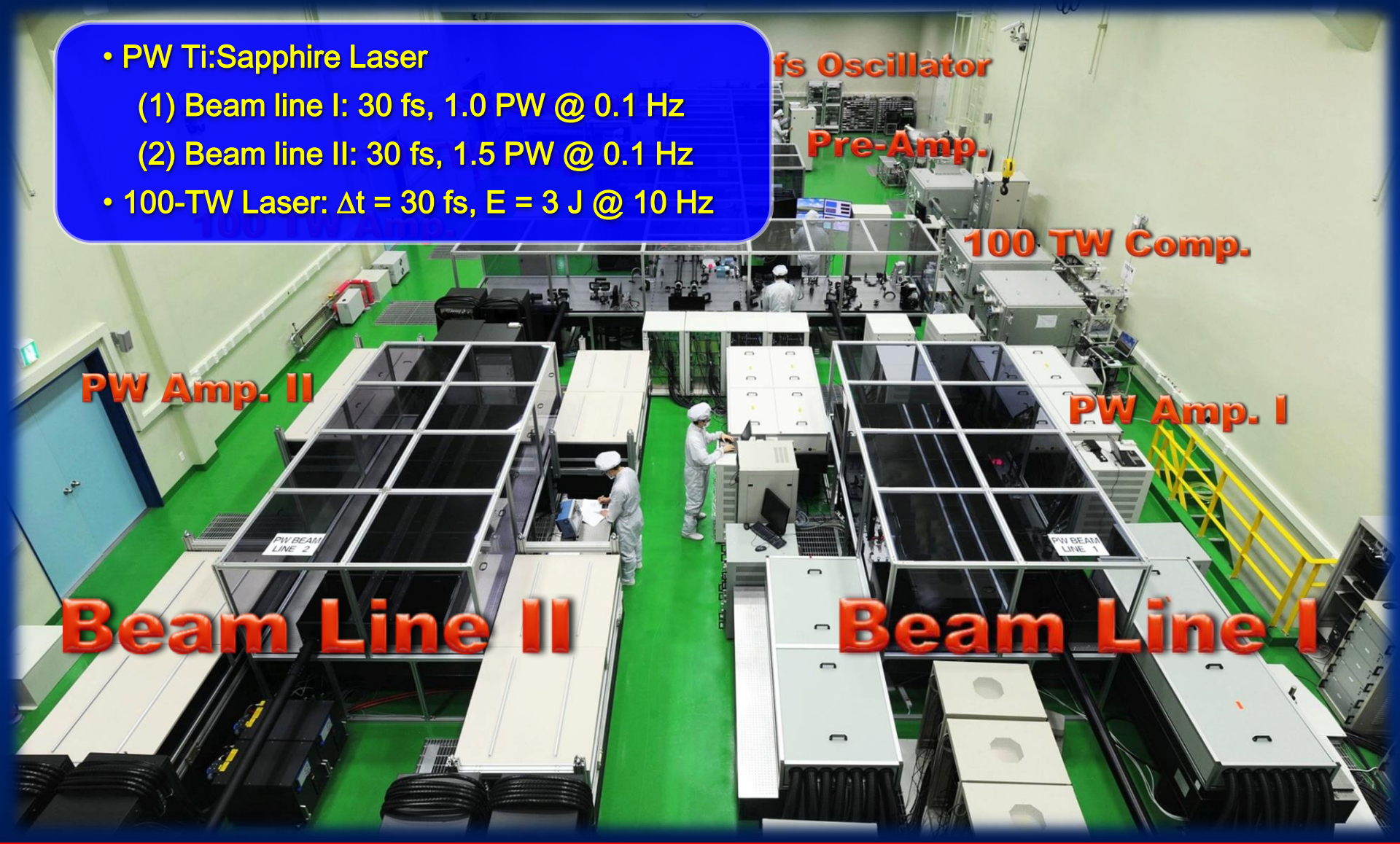
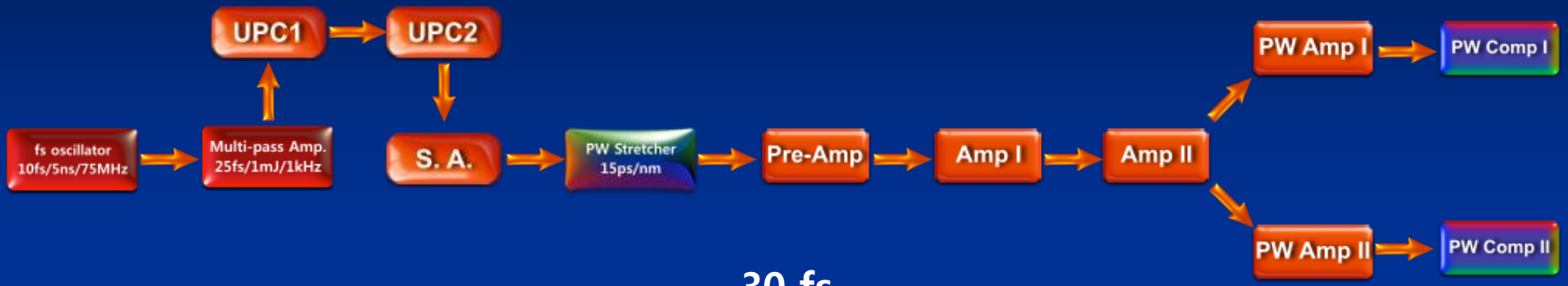
Overview

1. Femtosecond PW laser
2. Laser particle acceleration
   - A. LWFA with PW lasers
   - B. Gamma-ray generation

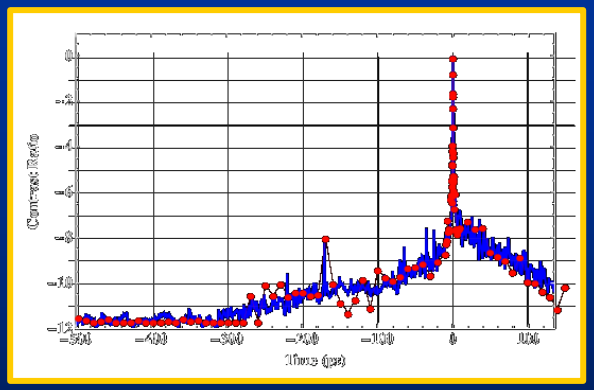
PW Ti:Sapphire Laser at CoReLS



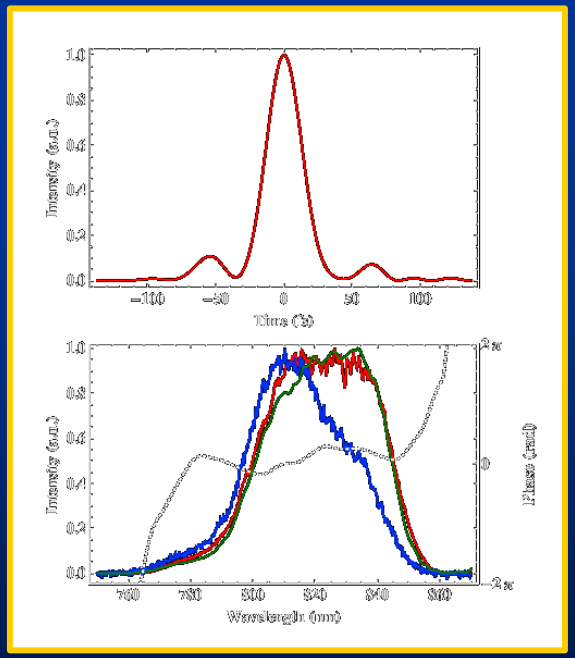
High contrast, 30 fs, 1.5 PW Laser



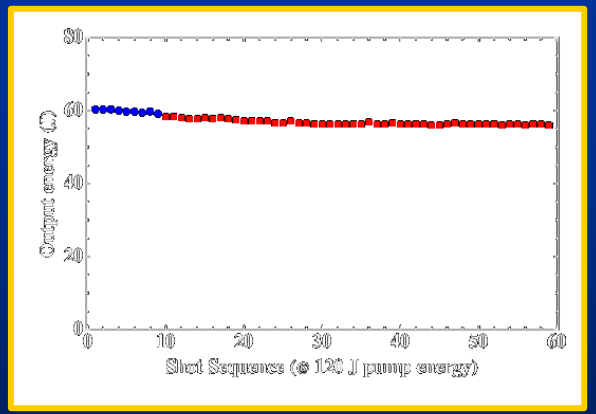
High contrast



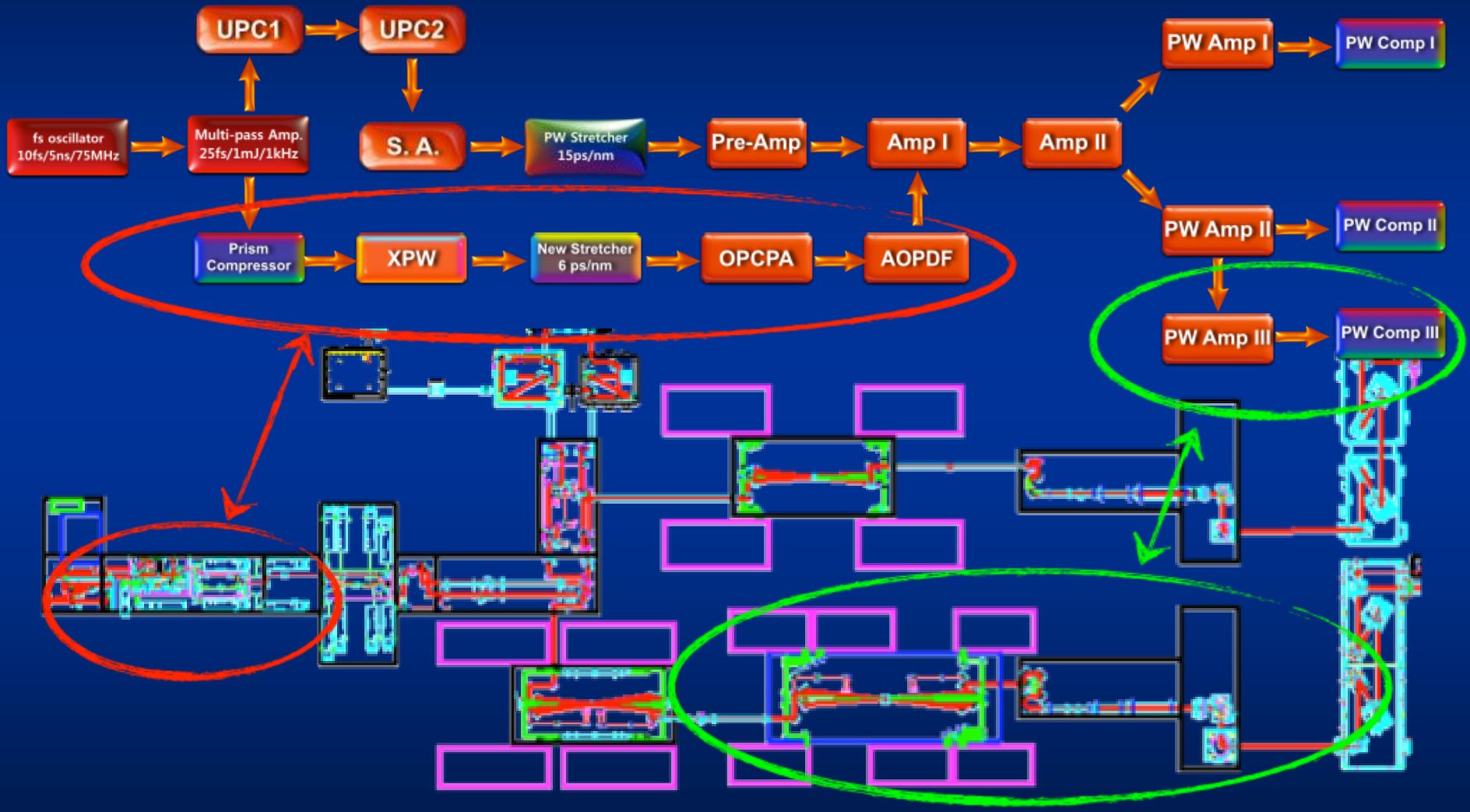
30 fs



1.5 PW

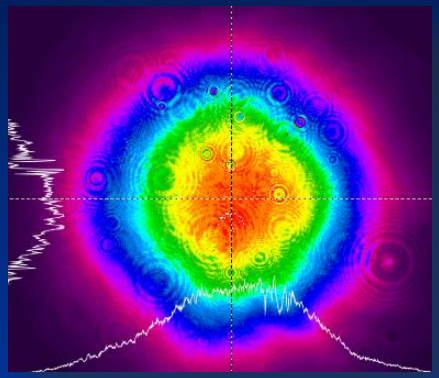


Upgrade: High Contrast, 20 fs, 4 PW Laser

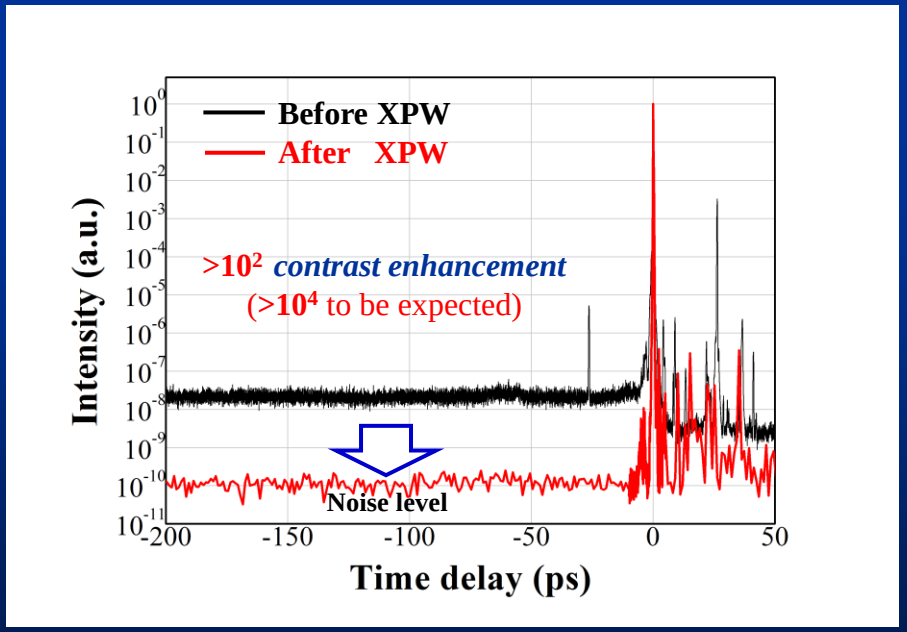


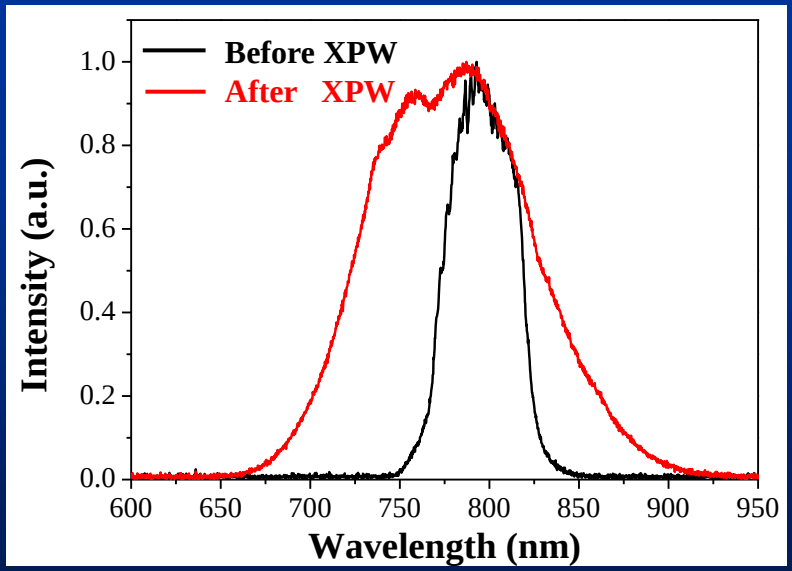
High contrast, broadband seed pulse by XPW

- Input pulse: 3 mJ, 25 fs
- Hollow-core fiber: 250-μm core, 20-cm long
- Energy after BaF_2 XPW: 500 μJ (16 %)

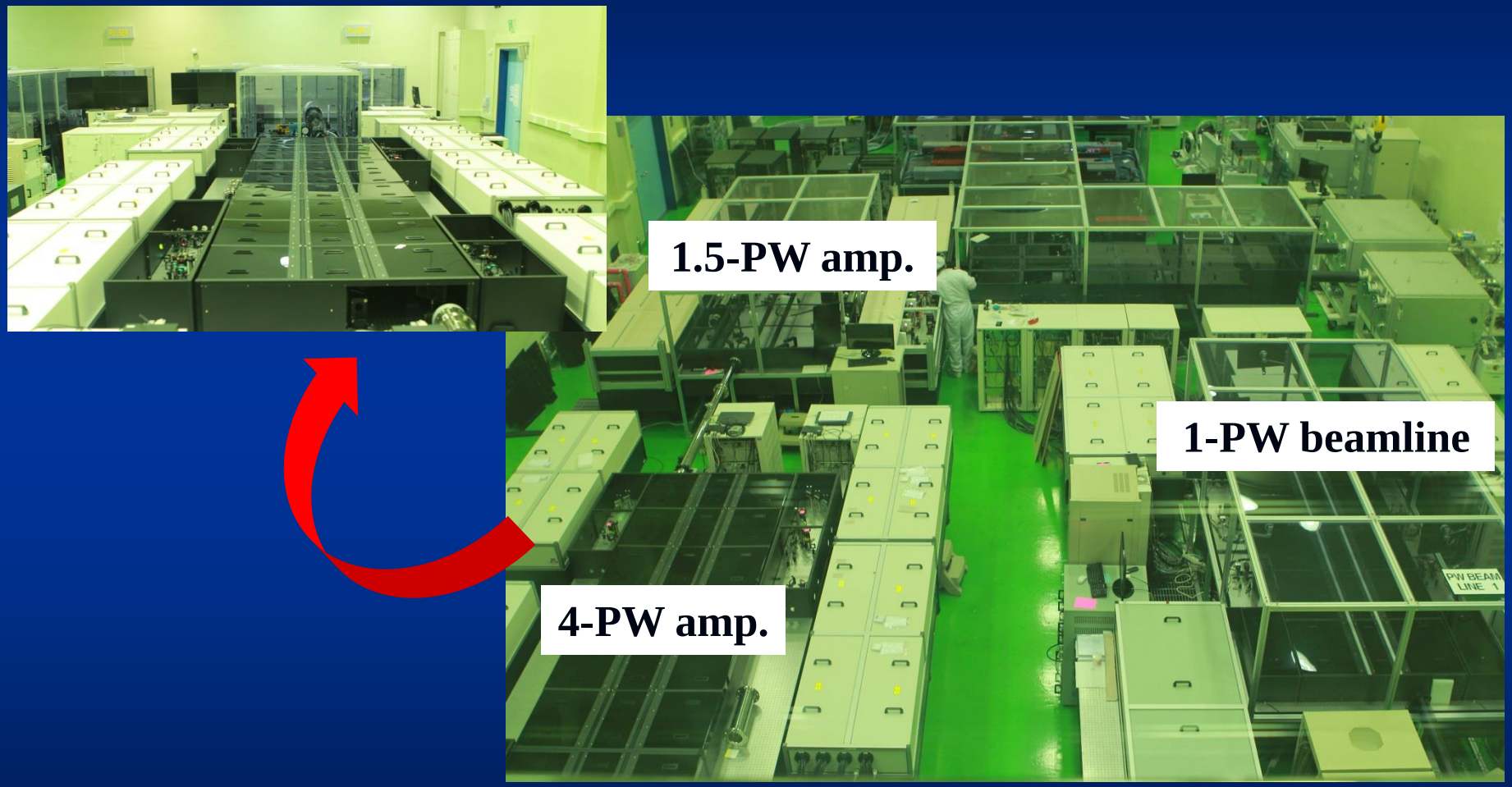


Beam profile after XPW



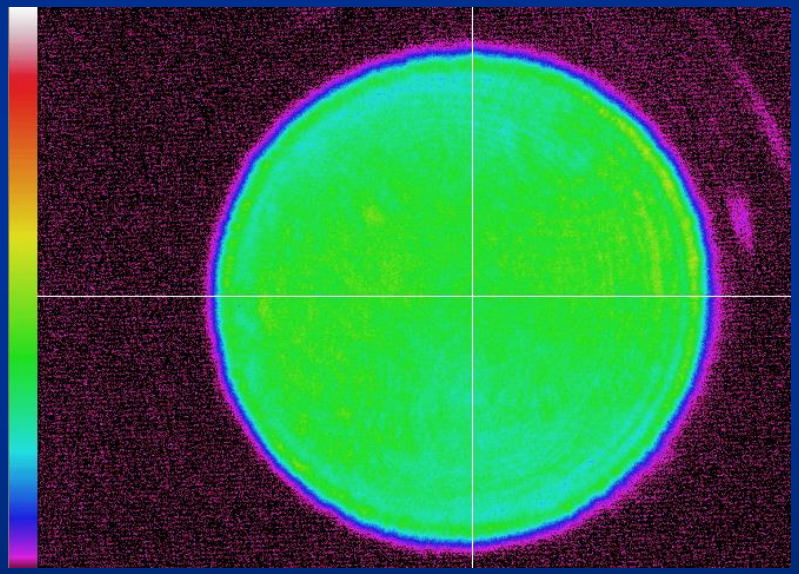


4-PW amplifier



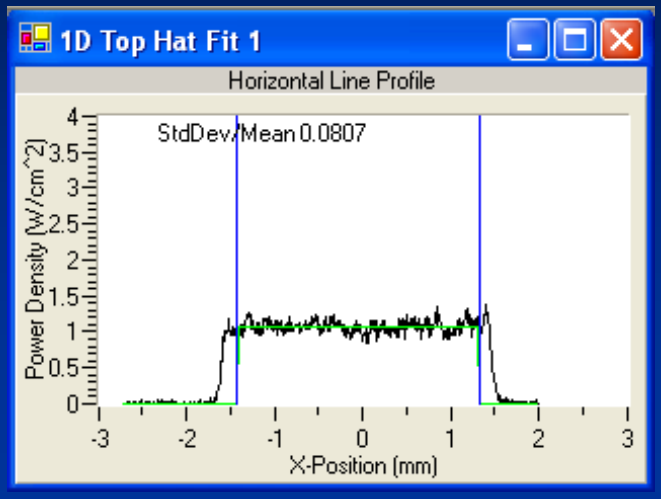
4-PW pump Laser

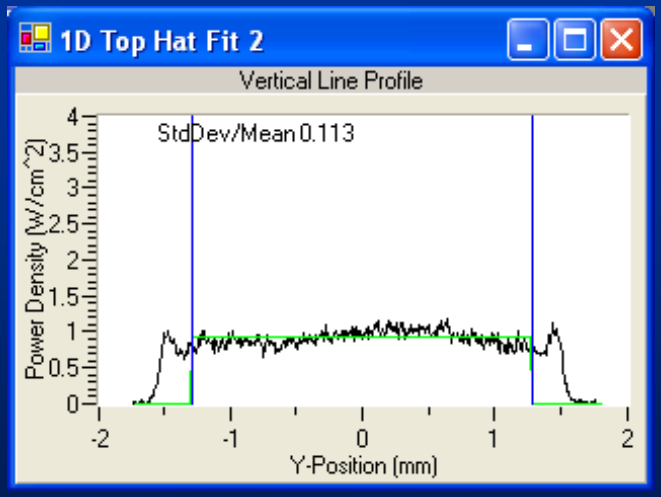
- Rep. rate: 0.1 Hz (Nd:glass laser)
- Total energy: 180 J (15 J x 12 beams)
- Pulse duration: 15 ns



Spatial profile of a Nd:glass laser

Top-Hat Beam Profile

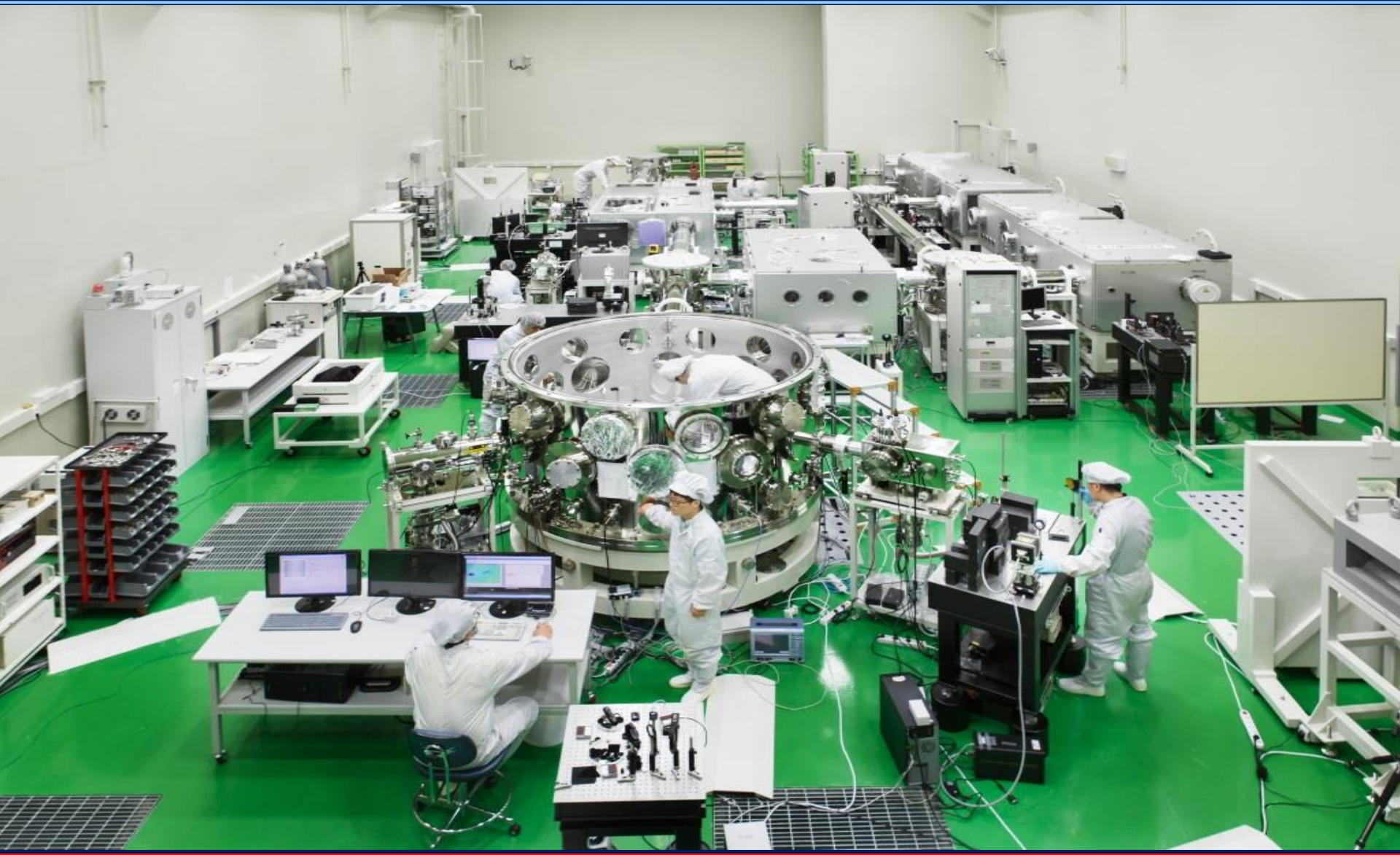




1. Femtosecond PW laser

2. Laser particle acceleration
   A. LWFA with PW lasers
   B. Gamma-ray generation

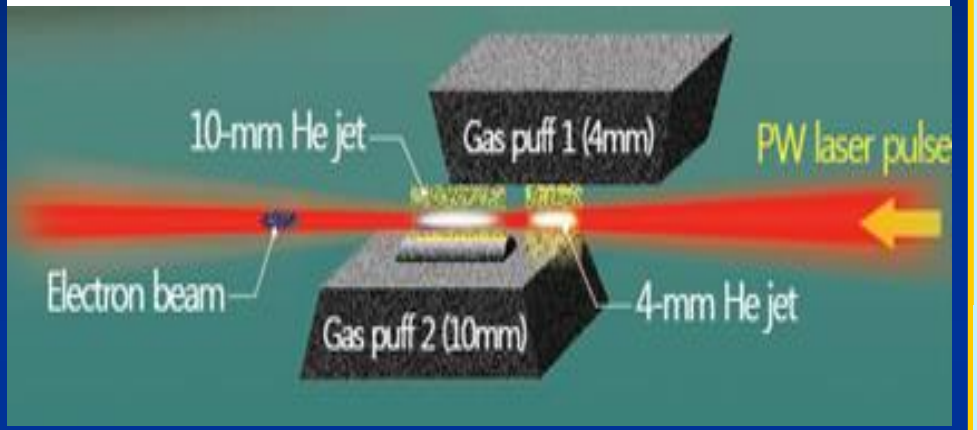
PW Laser Experimental Area (2)



Multi-GeV e-Beam Generation with Dual Gas Jets

Double-stage Gas jet

$d_e = 2x10^{18}$ cm^{-3} (4 mm) ; $d_e = 0.7x10^{18}$ cm^{-3} (10 mm)

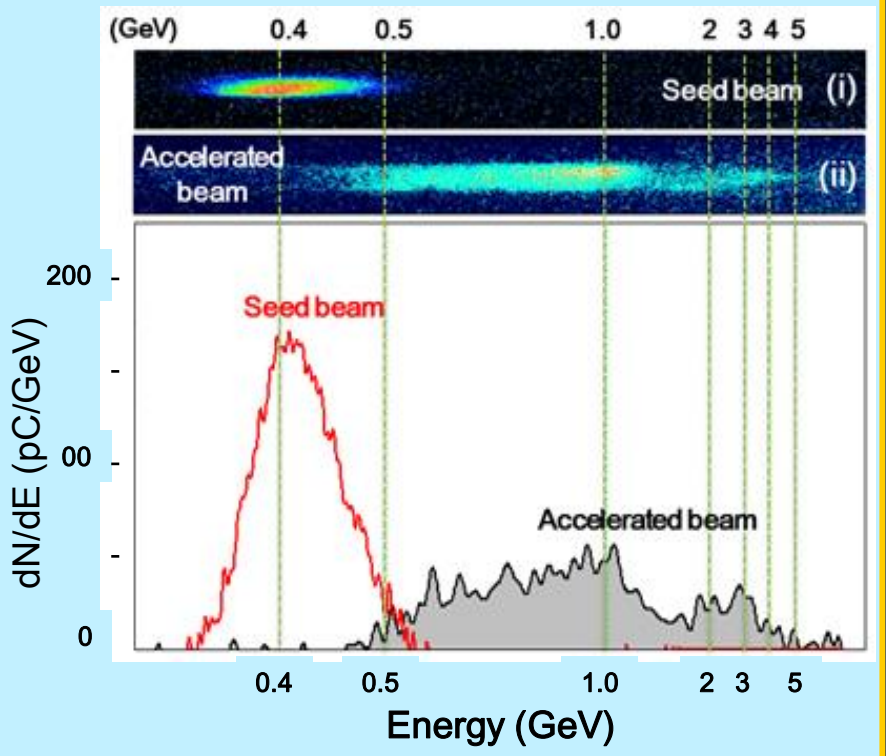


High-energy electron beam (>400 MeV) injected to the second gas jet

→ Investigation on multi-jet configuration with high energy electron injection

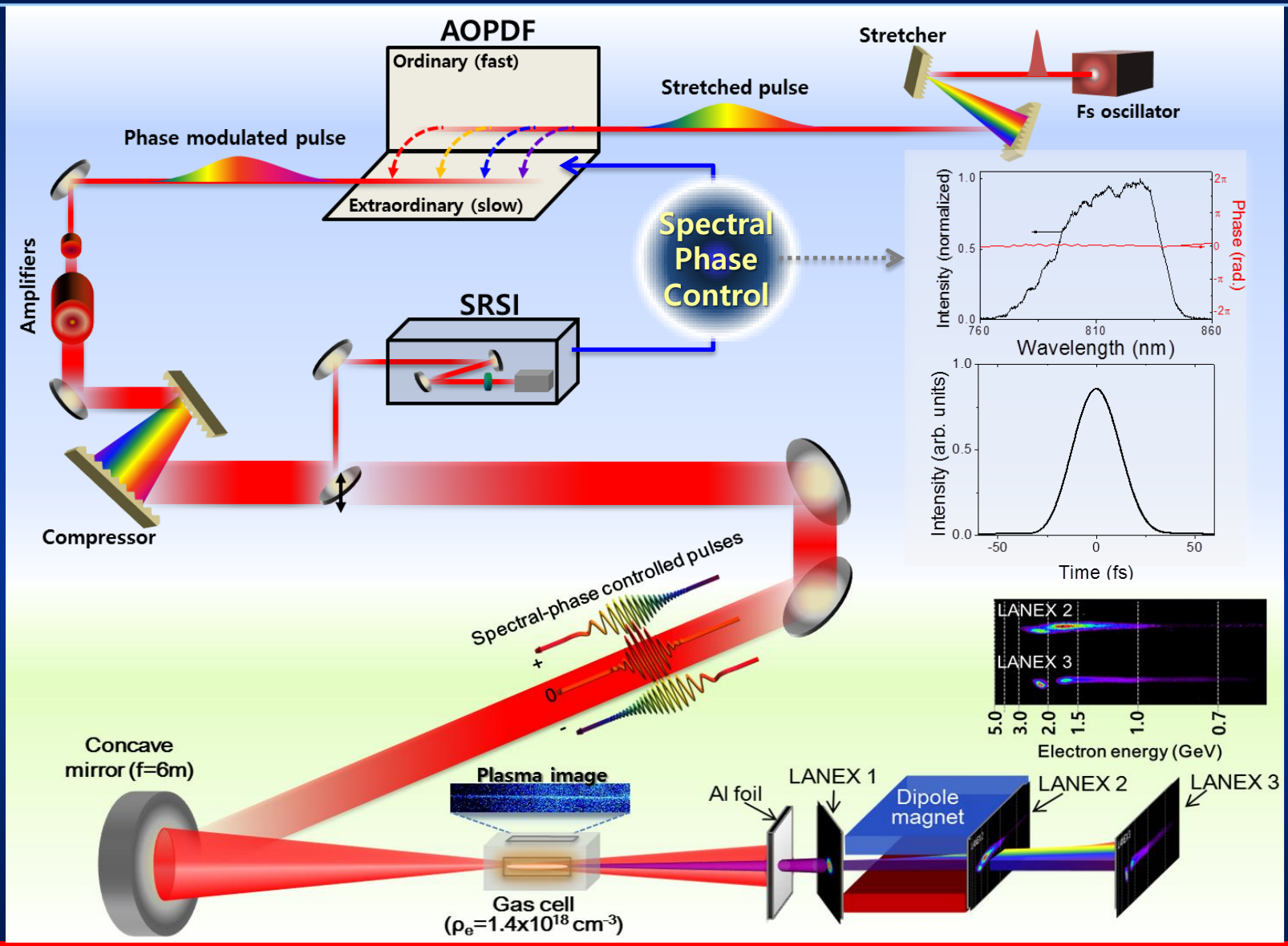
Charge of electron beam (4+10 mm):
~ 80 pC (> 0.5 GeV), ~10 pC (> 2 GeV)

Electron energy spectrum



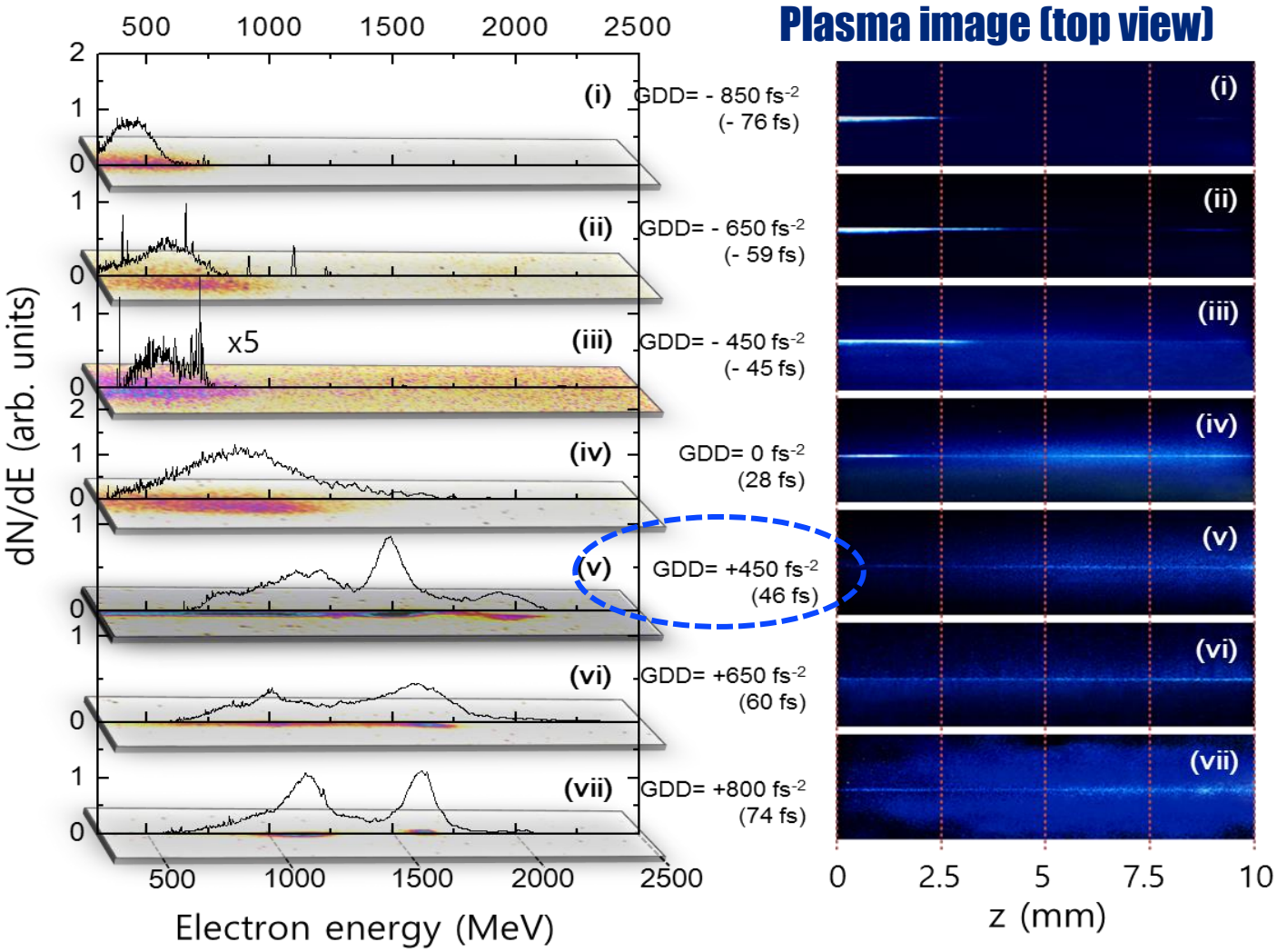
HT Kim et al., PRL (2013)

LWFA with structured PW laser pulses



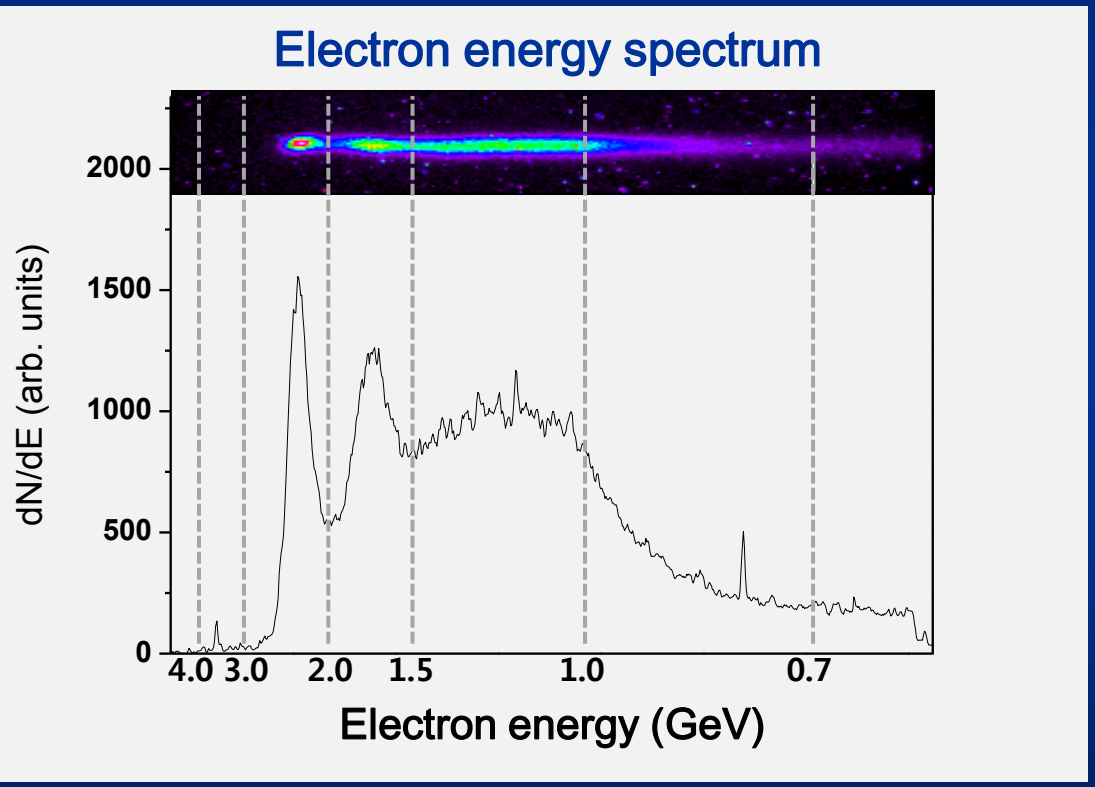
Control of spectral phase: GDD

26 J on target, focal spot ~ 35 micron, Ne ~ 1.4x10^{18} /cc, 10 mm cell length

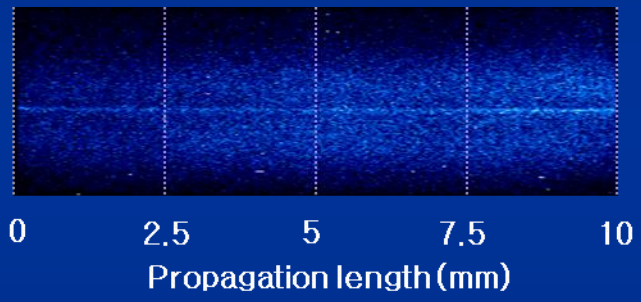


Electrons over 2 GeV from a 10-mm gas cell

Gas cell length = 10 mm
Positively chirped 61 fs
Intensity = 2×10^{19} W/cm^2 (a_0=3)



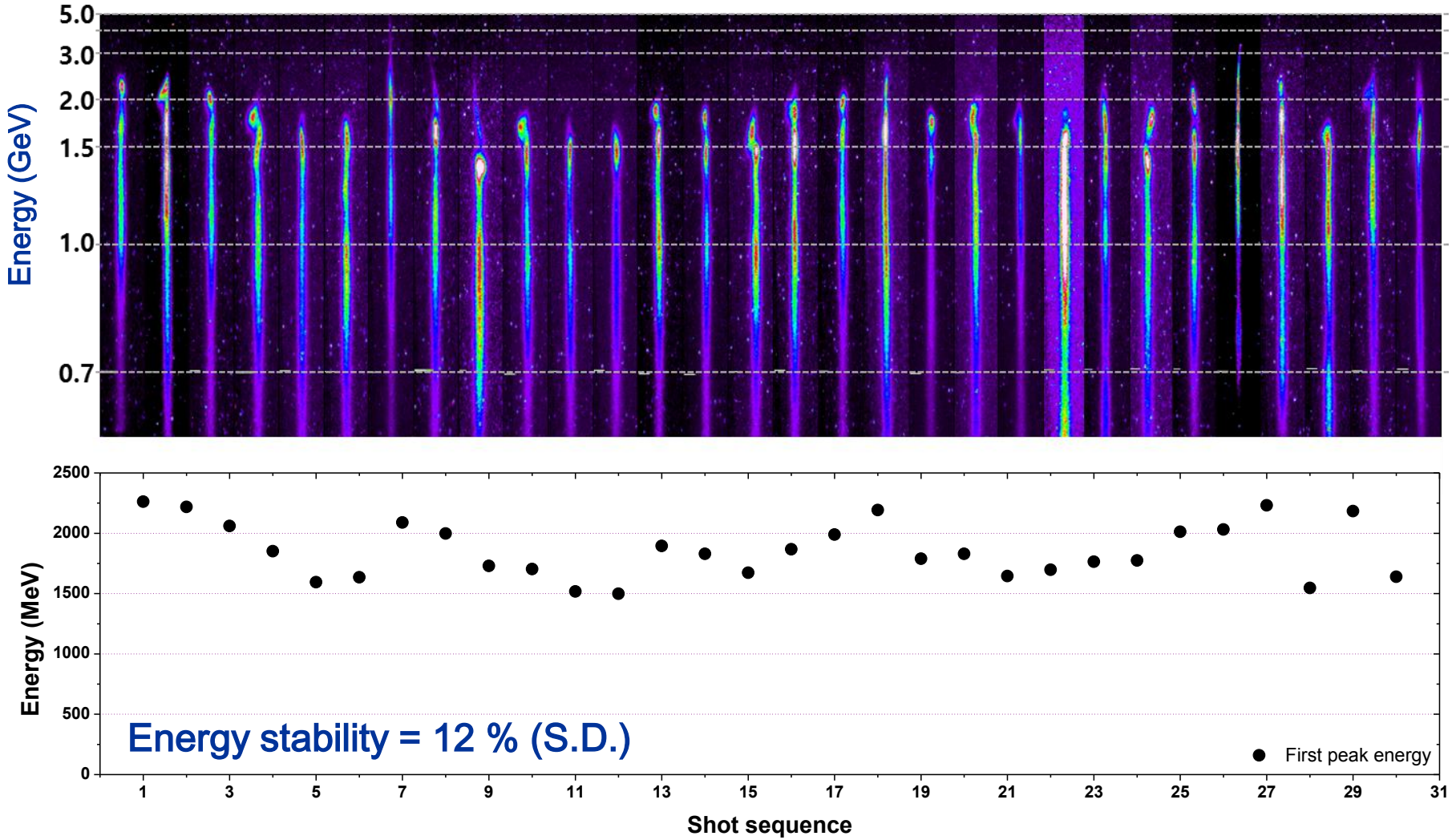
Top view (Thomson scattering)



Smooth propagation over the whole medium length of 10 mm

Electron energy > 2 GeV

Stability of electron beam from a single gas cell (30 shots)



LWFA over 10 GeV with 4 PW laser

With $L_{dp} < L_{pd}$ & $L_{acc} = L_{dp}$,

$$\Delta E[\mathrm{GeV}] \approx 1.7 \left(\frac{P[TW]}{100}\right)^{1/3} \left(\frac{10^{18}}{n_e[cm^{-3}]}\right)^{2/3} \left(\frac{0.8}{\lambda[\mu m]}\right)^{4/3}$$

W. Lu, Phys. Rev. ST Accel. Beams ('07)

Requirements for generating electron beams over 10 GeV

4 PW laser: Energy per pulse ≈ 90 J
Pulse duration ≈ 22 fs

Laser energy ≈ 90 J
Pulse duration ≈ 70 fs
Beam spot diameter ≈ 85 μm
Normalized vector potential ≈ 2
Medium density ≈ 2×10^{17} cm^{-3}
Medium length (L_{dp}) ≈ 20 cm

⇨ 12-GeV electron beam

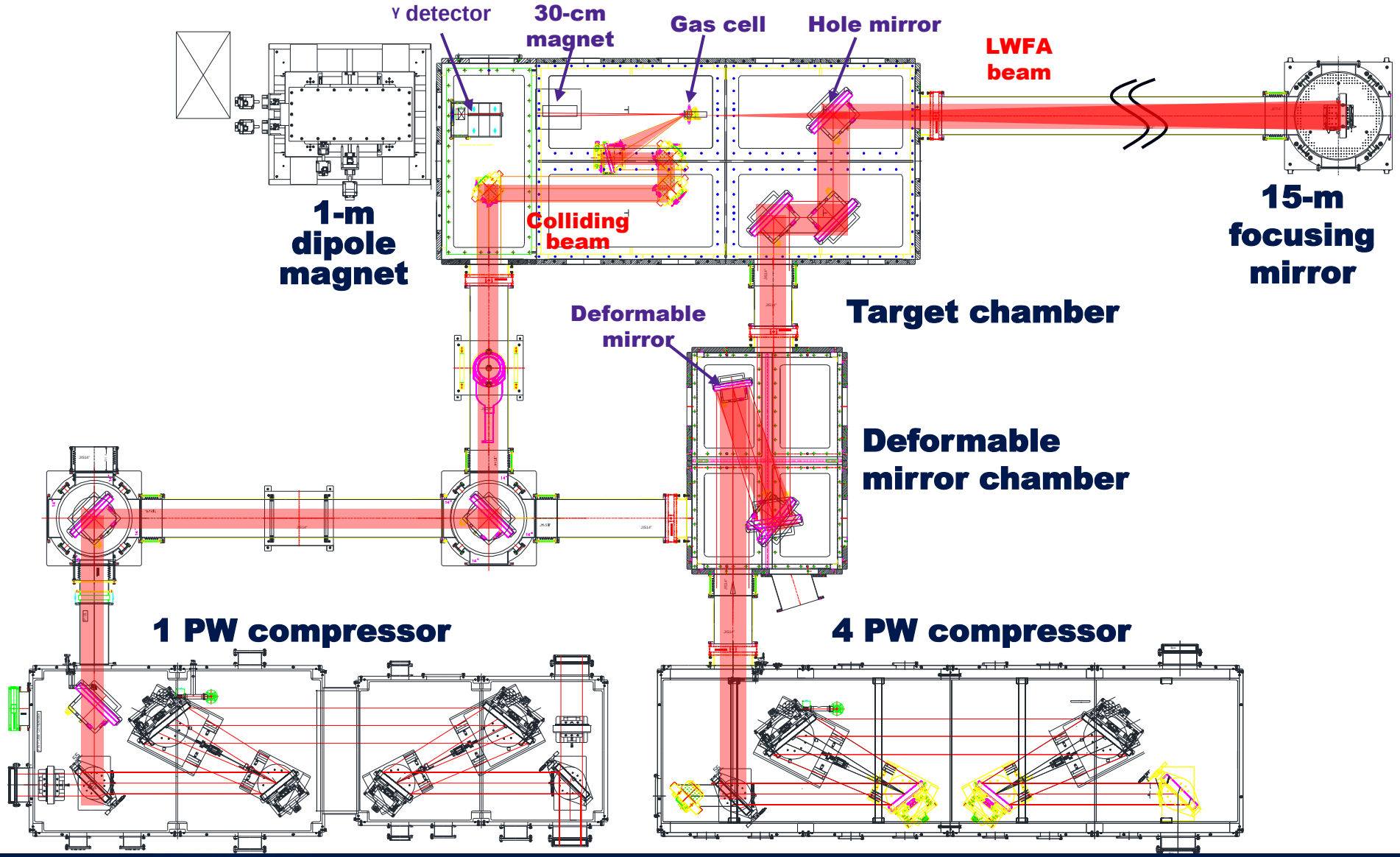
Technical Challenges

Self-injection in a low density medium
⇨ Dual gas medium

Self guiding in a 20-cm long medium
⇨ Plasma wave guide

LWFA with the 4 PW laser

- **Optical layout for 4 PW LWFA**



Summary

1. Two PW laser beamlines, **1 PW and 1.5 PW at 30 fs**, at CoReLS of IBS are operational for research on high field science.
2. **Laser wakefield acceleration** has been explored. With the two-stage acceleration 3-GeV electron beam was generated. Using the **coherent control** of LWFA process with PW laser pulses monoenergetic electron beam over 2 GeV was produced from a 1- cm gas cell.
3. After the **4 PW laser upgrade** we are expecting to generate electron beams over 10 GeV.
4. **Inverse Compton scattering** of PW laser pulses with multi-GeV electron beam are being prepared for multi-10 MeV γ-ray production.