Laser-driven Particle Acceleration with fs, PW Lasers at CoReLS

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Overview

1. Femtosecond PW Laser
2. Laser particle acceleration
   A. Laser wakefield electron acceleration
   B. Radiation pressure acceleration of protons

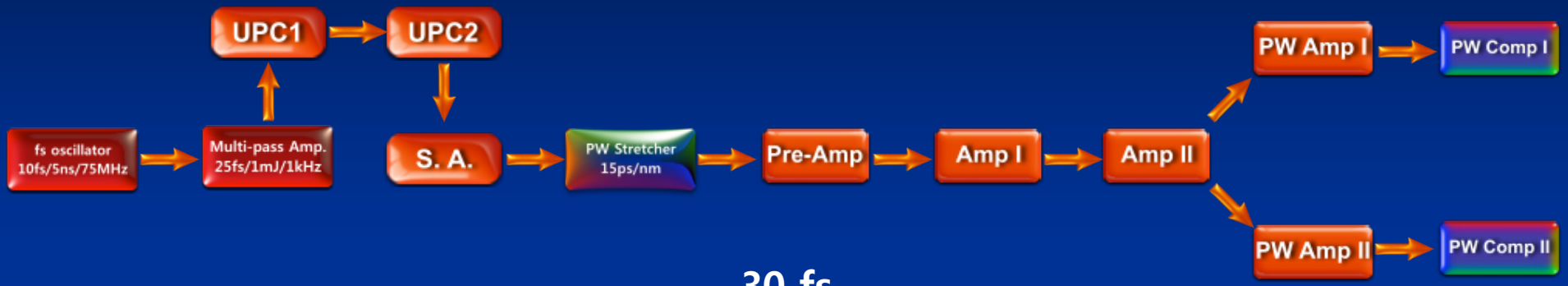
IBS Center for Relativistic Laser Science

GIST Ultrashort Quantum Beam Facility

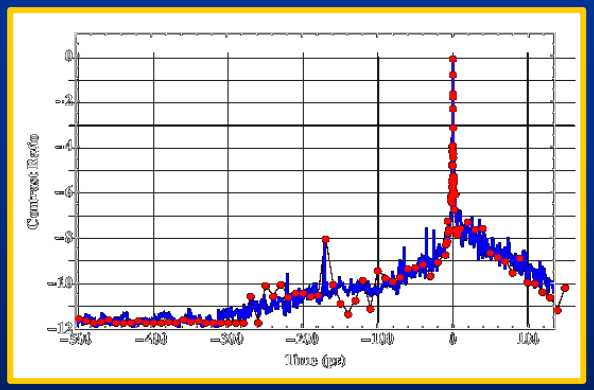
- PW Ti:Sapphire Laser
  - (1) Beam line I: 30 fs, 1.0 PW @ 0.1 Hz
  - (2) Beam line II: 30 fs, 1.5 PW @ 0.1 Hz
- 100-TW Laser: Δt = 30 fs, E = 3 J @ 10 Hz

PW Ti:Sapphire Laser

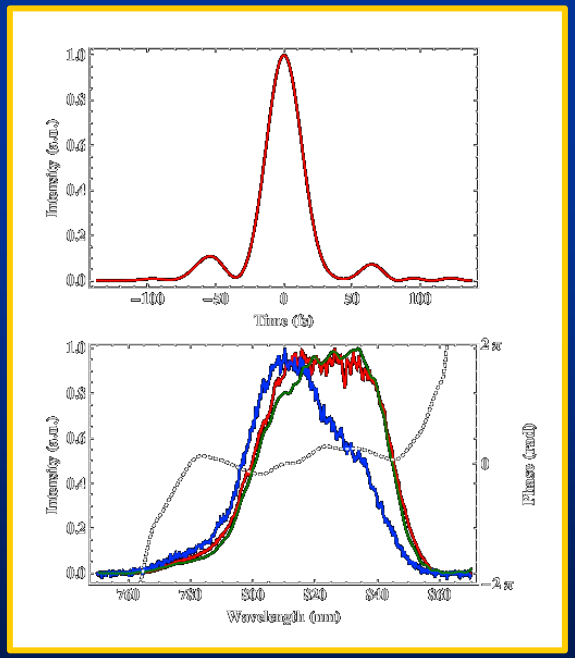
High contrast, 30 fs, 1.5 PW Laser



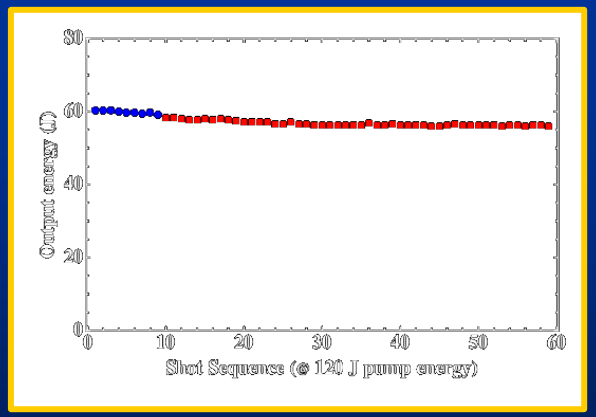
High contrast



30 fs



1.5 PW



1. Femtosecond PW Laser

2. Laser particle acceleration
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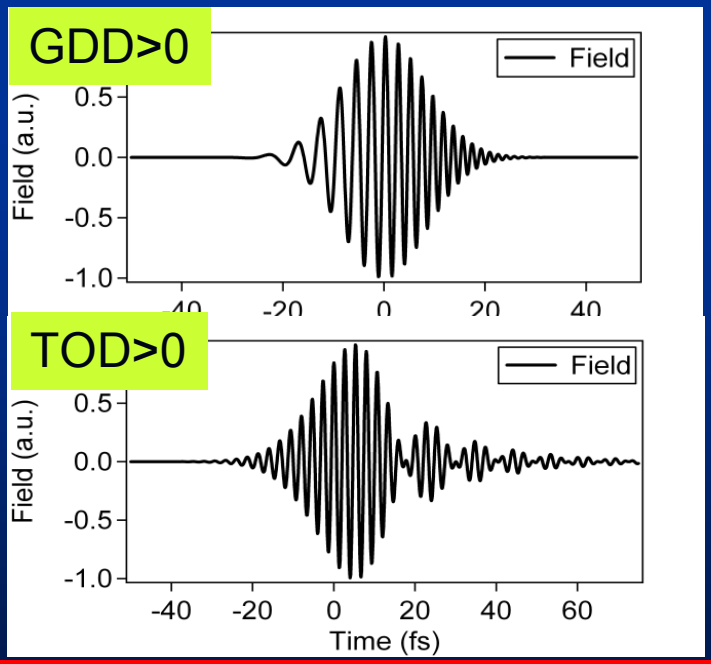
Coherent Control of Laser-Matter Interactions

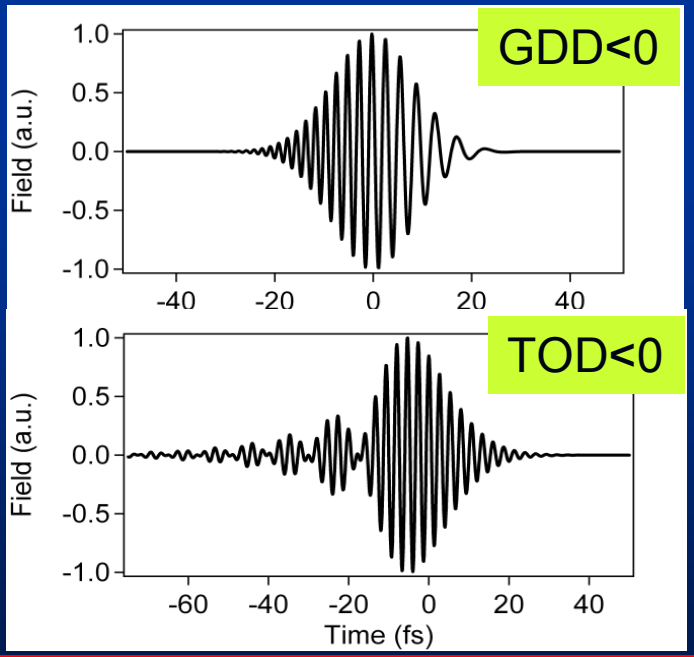
spectral phase:

$$\varphi(\omega) = \varphi_0 + \varphi_1 \frac{\omega-\omega_0}{1!} + \varphi_2 \frac{(\omega-\omega_0)^2}{2!} + \varphi_3 \frac{(\omega-\omega_0)^3}{3!} + \ldots$$

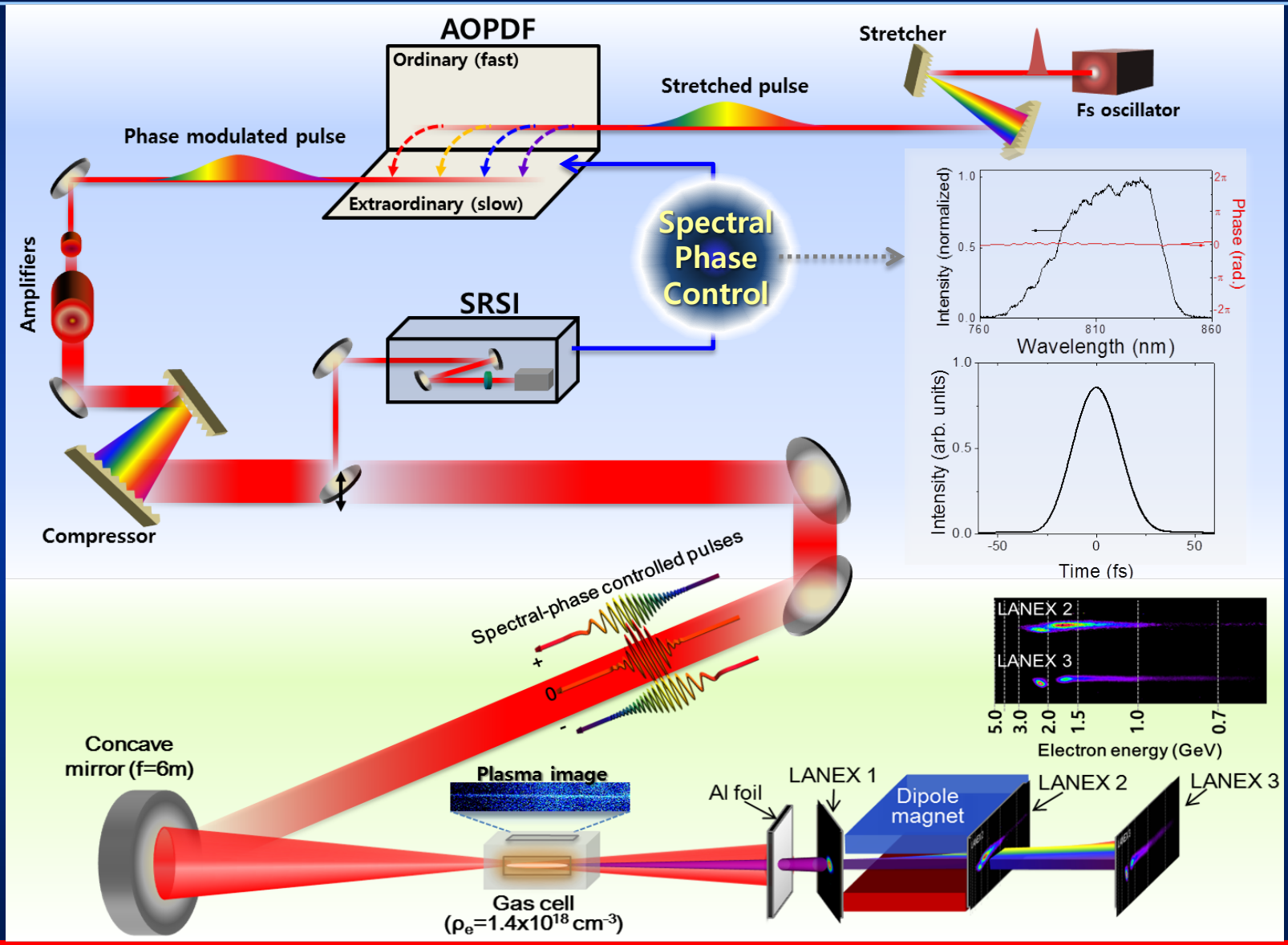
where $\varphi_2 = \left.\frac{d^2\varphi}{d\omega^2}\right|_{\omega=\omega_0}$ = group-delay dispersion (GDD) = linear chirp ,

$\varphi_3 = \left.\frac{d^3\varphi}{d\omega^3}\right|_{\omega=\omega_0}$ = 3rd –order spectral phase (TOD) = quadratic chirp



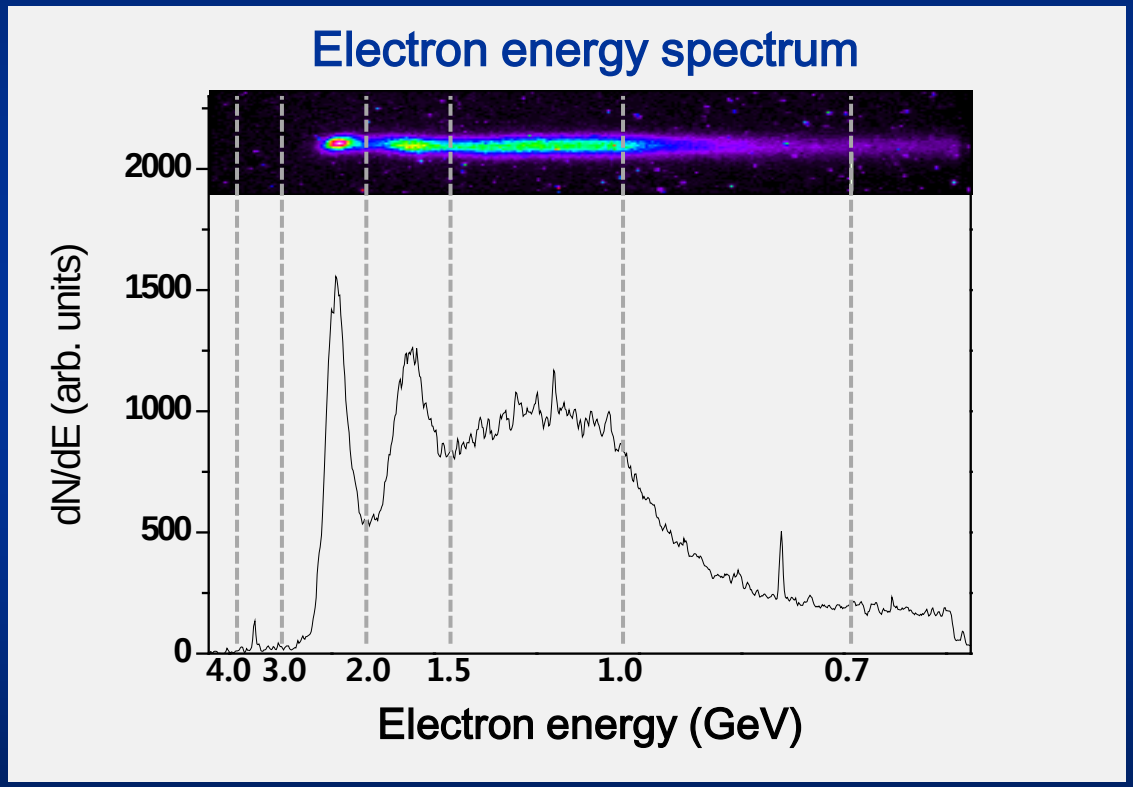


Coherent Control of LWFA

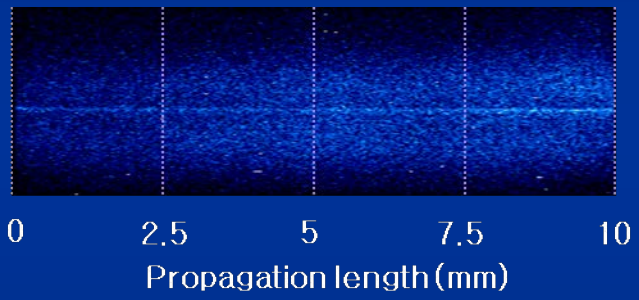


Electrons over 2 GeV from a 1-cm gas cell

Gas cell length = 10 mm
Positively chirped 61 fs
Intensity = 2×10^{19} W/cm^2 (a_0=3.1)



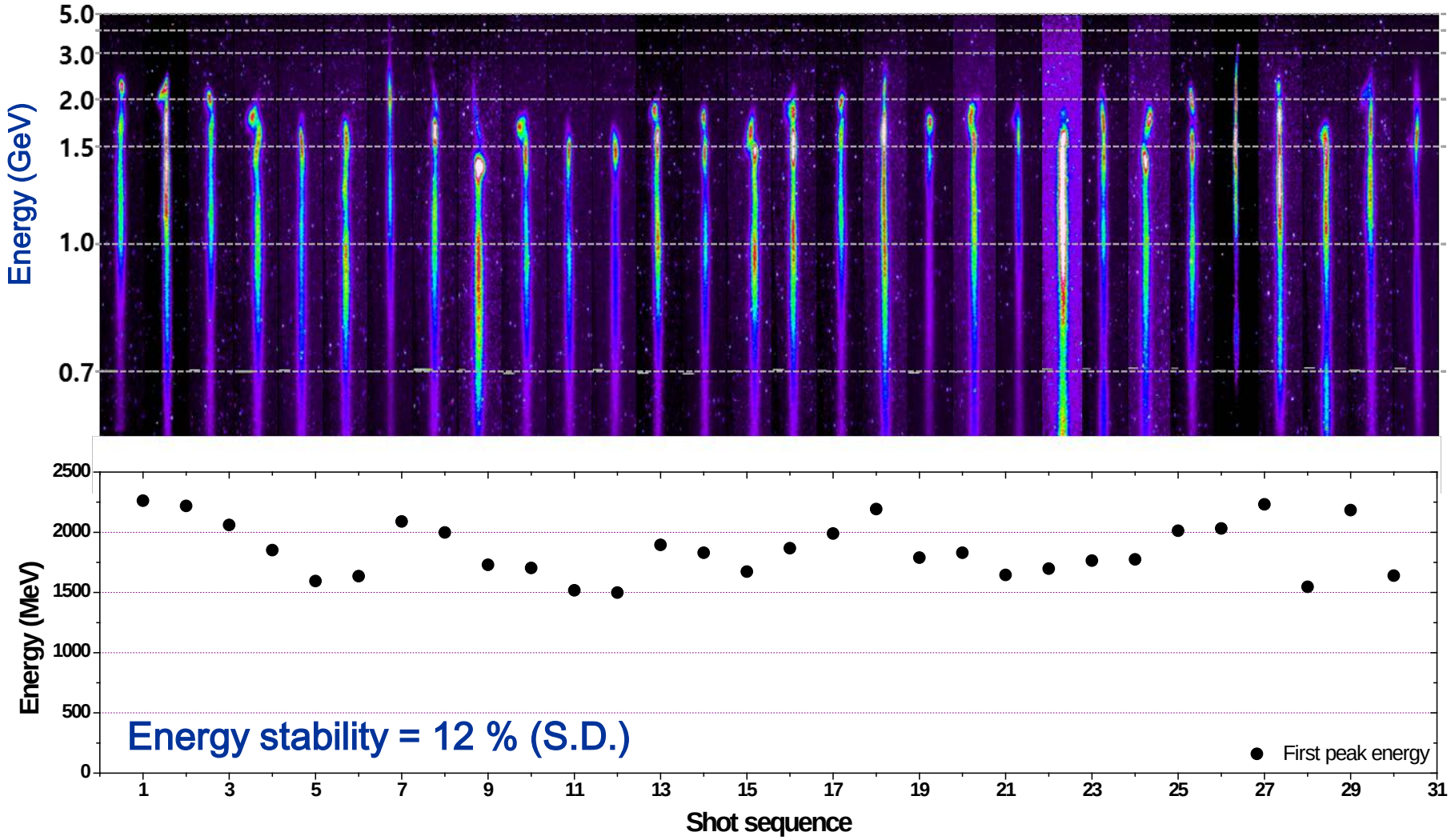
Top view (Thomson scattering)



Smooth propagation over the whole medium length of 10 mm

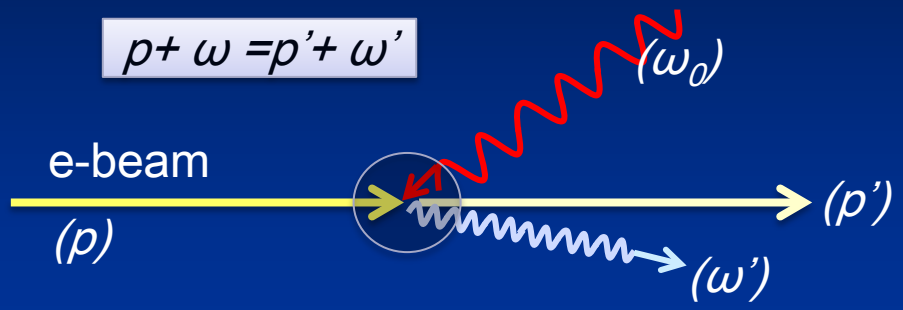
Electron energy > 2 GeV

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



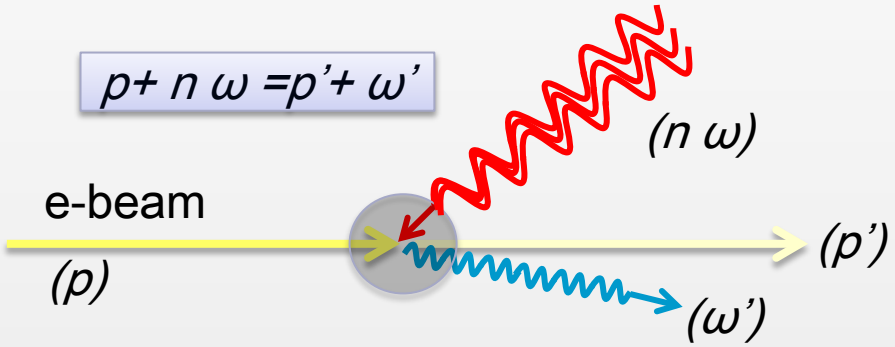
γ-ray generation from inverse Compton scattering

Inverse Compton scattering in the linear regime ($a_0 < 1$, $\gamma >> 1$)



$\omega'_{max} \approx 4\gamma^2 \omega_0$
$\approx$ 90 MeV with 2 GeV e-beam

Inverse Compton scattering in the nonlinear regime ($1 < a_0 < 2\gamma$, $\gamma >> 1$)

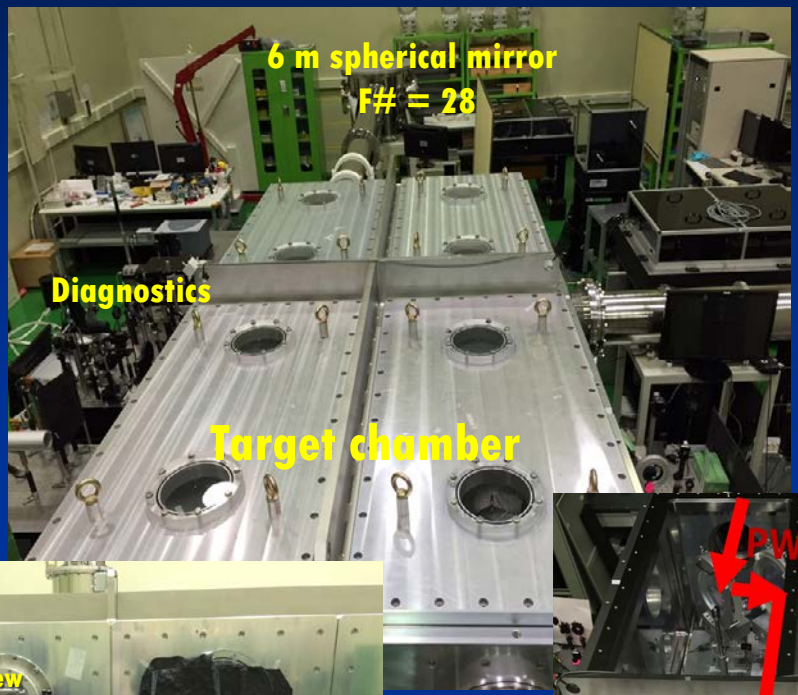


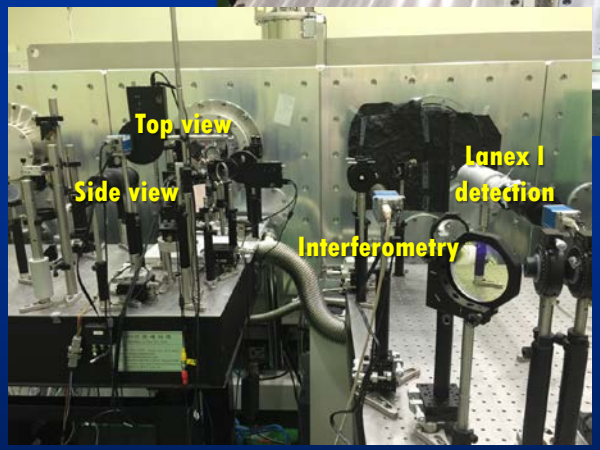
$\omega'_{max} \approx n\, 4\gamma^2 \omega_0 / a_0^2$

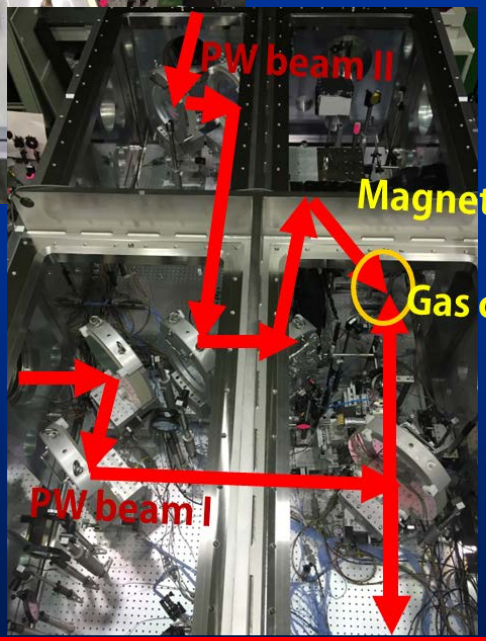
- Redshift of Compton edge (n=1)
- Broadening of spectrum
- Higher harmonic production

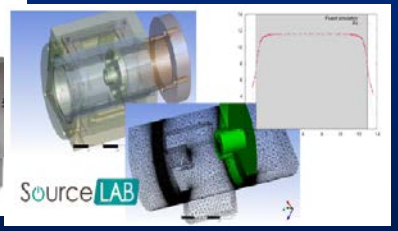
Exploring transition from linear to nonlinear Compton scattering (a_0 = 0.1 - 20)

Experimental setup for LWFA with PW lasers

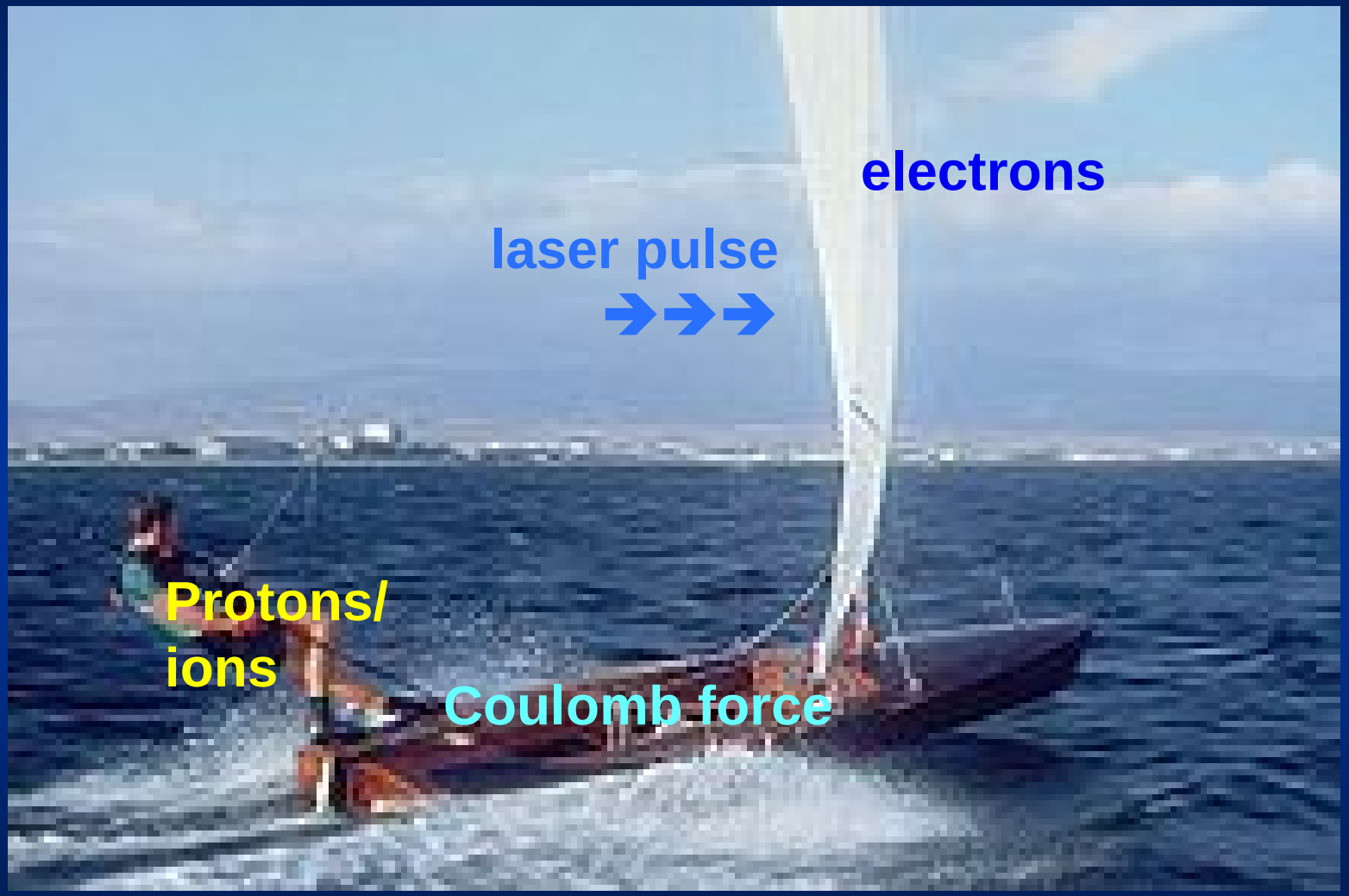




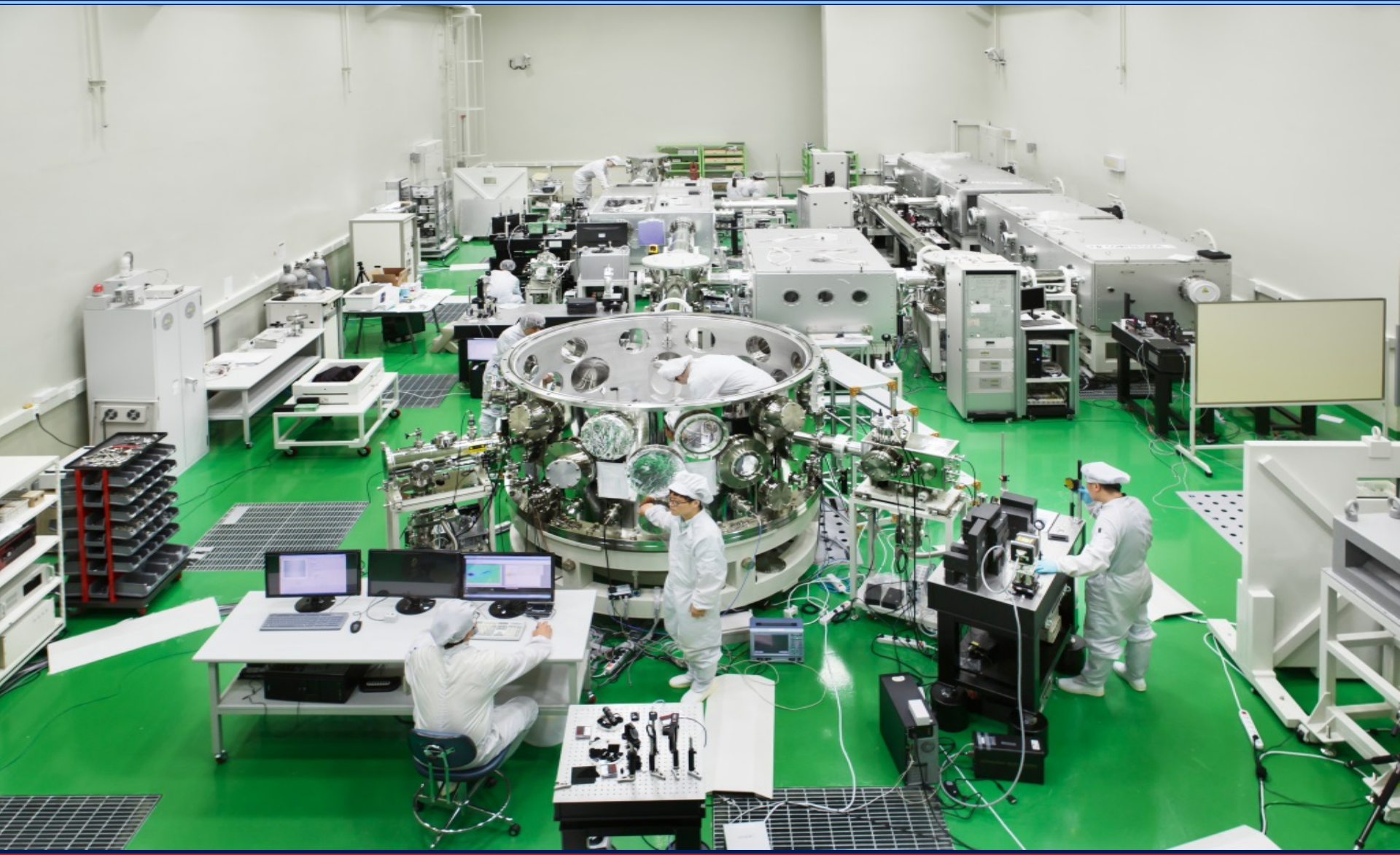




Radiation Pressure Acceleration: Light Sail



PW Laser Experimental Area

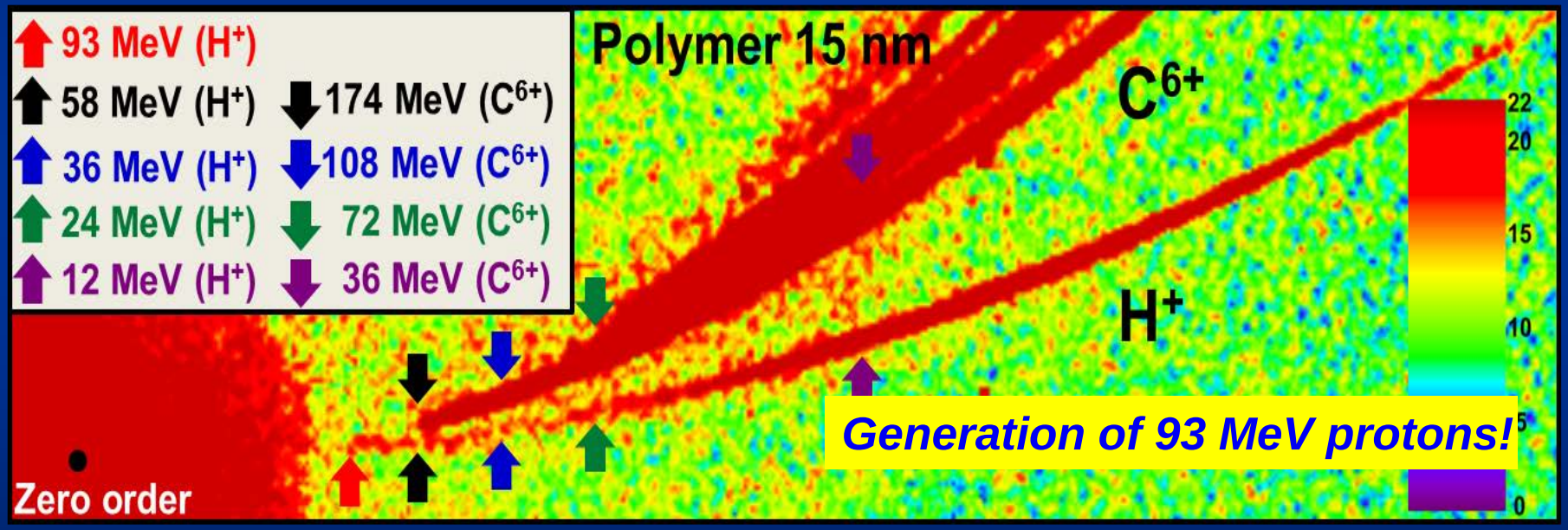


RPA with CP laser pulses: Experiment

No oscillating term in radiation pressure

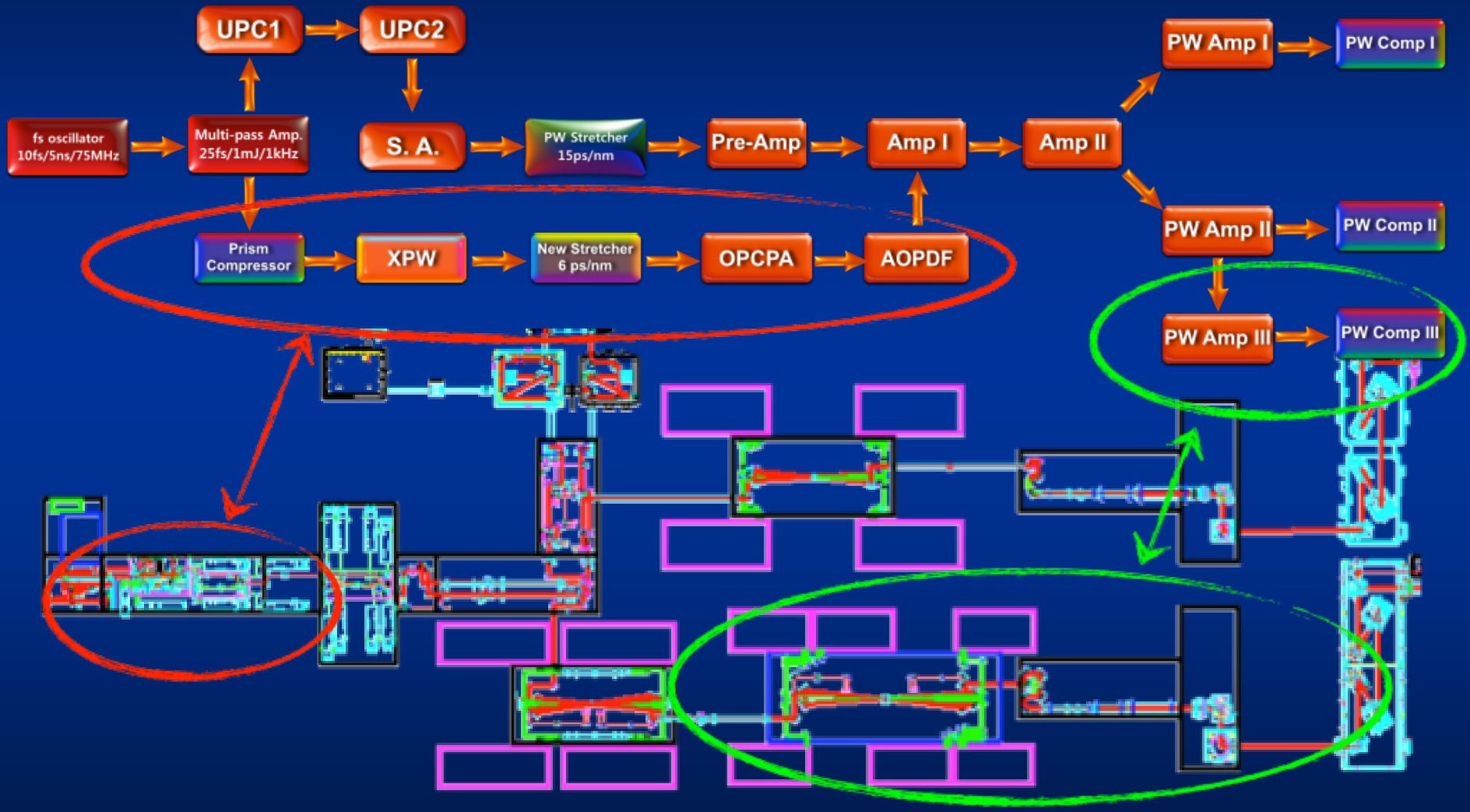
No $\vec{J} \times \vec{B}$ heating

Circular pol., 30fs, 6.1x10^{20} W/cm^2, 15 nm polymer



Proton and C^{6+} spectra measured with Thomson parabola

Upgrade: High Contrast, 20 fs, 4 PW Laser



Summary

1. Two PW laser beamlines, 1 PW and 1.5 PW at 30 fs, at CoReLS of IBS are operational for research on strong field science.
2. By applying the coherent control method to laser wafefield electron acceleration with PW lasers, stable 2-GeV electron beams were produced in a 1-cm gas cell of He.
3. With the application of circularly polarized laser pulses at an intensity of 6×10^{20} W/cm^2, proton energy reached 93 MeV mainly due to radiation pressure acceleration.
4. The 4 PW laser upgrade for increasing further the achievable laser intensity is being progressed.