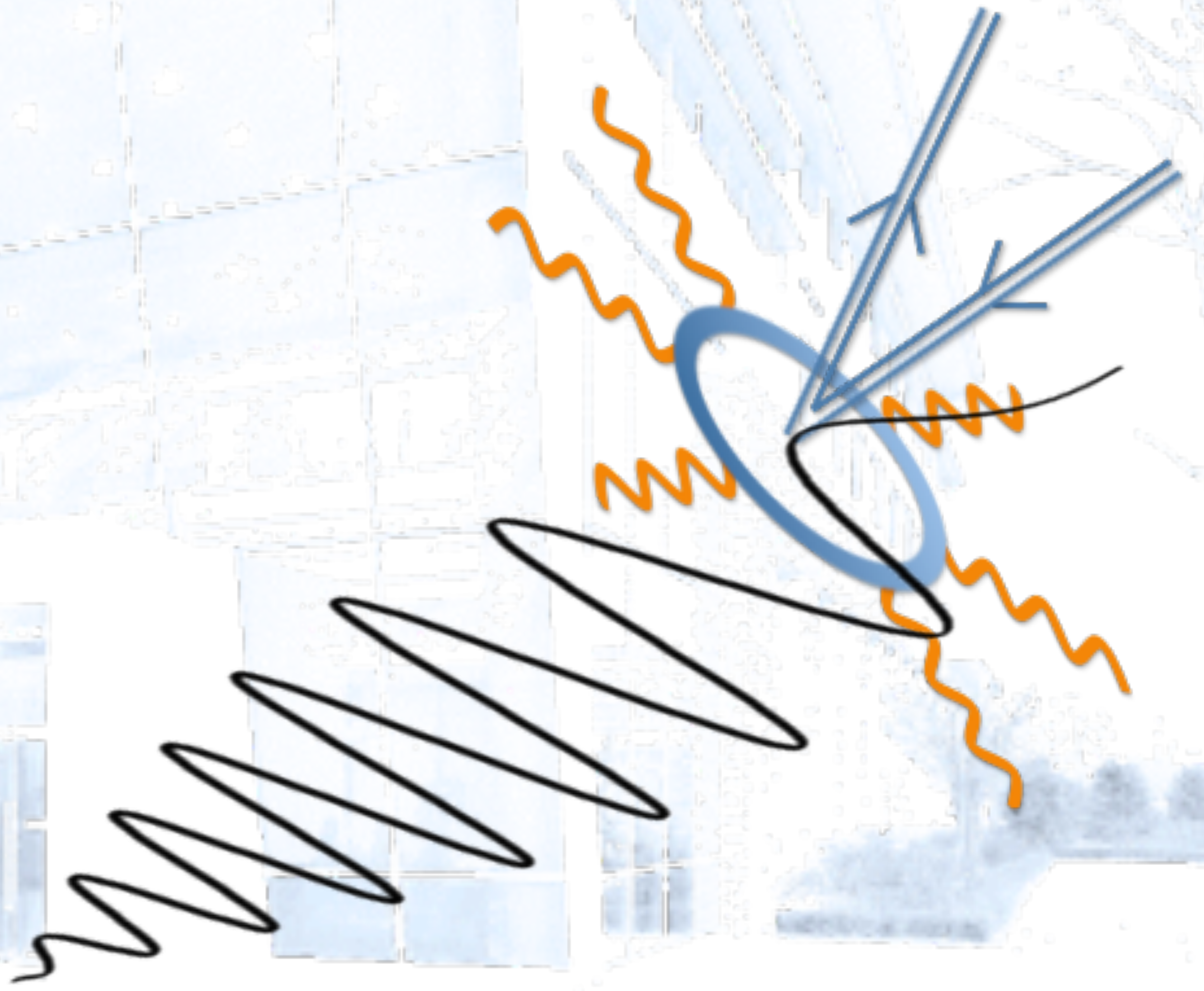
Activities potentially relevant to ALIC at CoReLS



Bjorn Manuel Hegelich,
CERN, March 27, 2019

Center for Relativistic Laser Science

Acknowledgements

Center for Relativistic Laser Science/Institute for Basic Science, Gwangju, South Korea:
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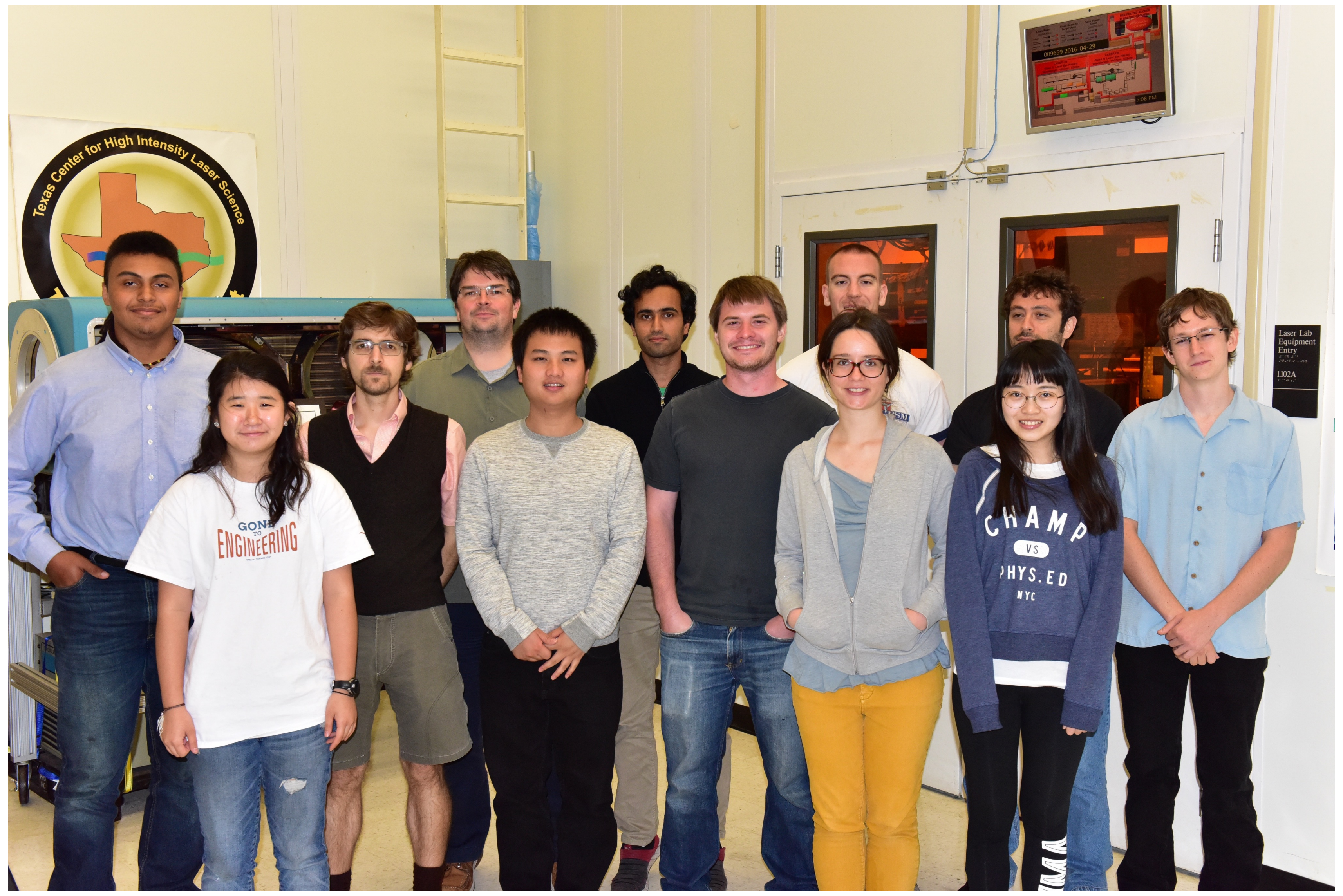
Collaborators:

UT group:

Dept. of Physics, University of Texas at Austin
O. Zhang Labun, L. Labun, G. Tiwari, L. Lisi, X. Jiao, S. Luedtke, R. Roycroft, E. McCary, R. Kupfer, B. Bowers

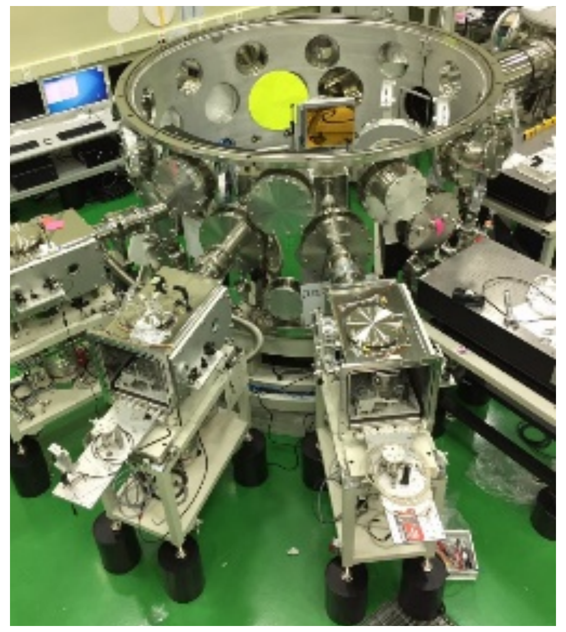


Laser Systems

- Petawatt System
  - 2 beam lines: 4PW + 1.5 PW, Ti:Sa
  - 80J (30J), 20fs, 0.1Hz
  - 3 experimental stations
- TW System
  - 150 TW, Ti:Sa
  - 5J, 30fs, 5Hz
  - 4 experimental stations
- Attosecond System
  - 2 beam lines
  - 1kHz, 25fs, 10mJ
  - 100kHz, 25fs, 25μJ
- High Average Power System (new development project)
  - mid-IR, kHz average power, >10 TW peak power

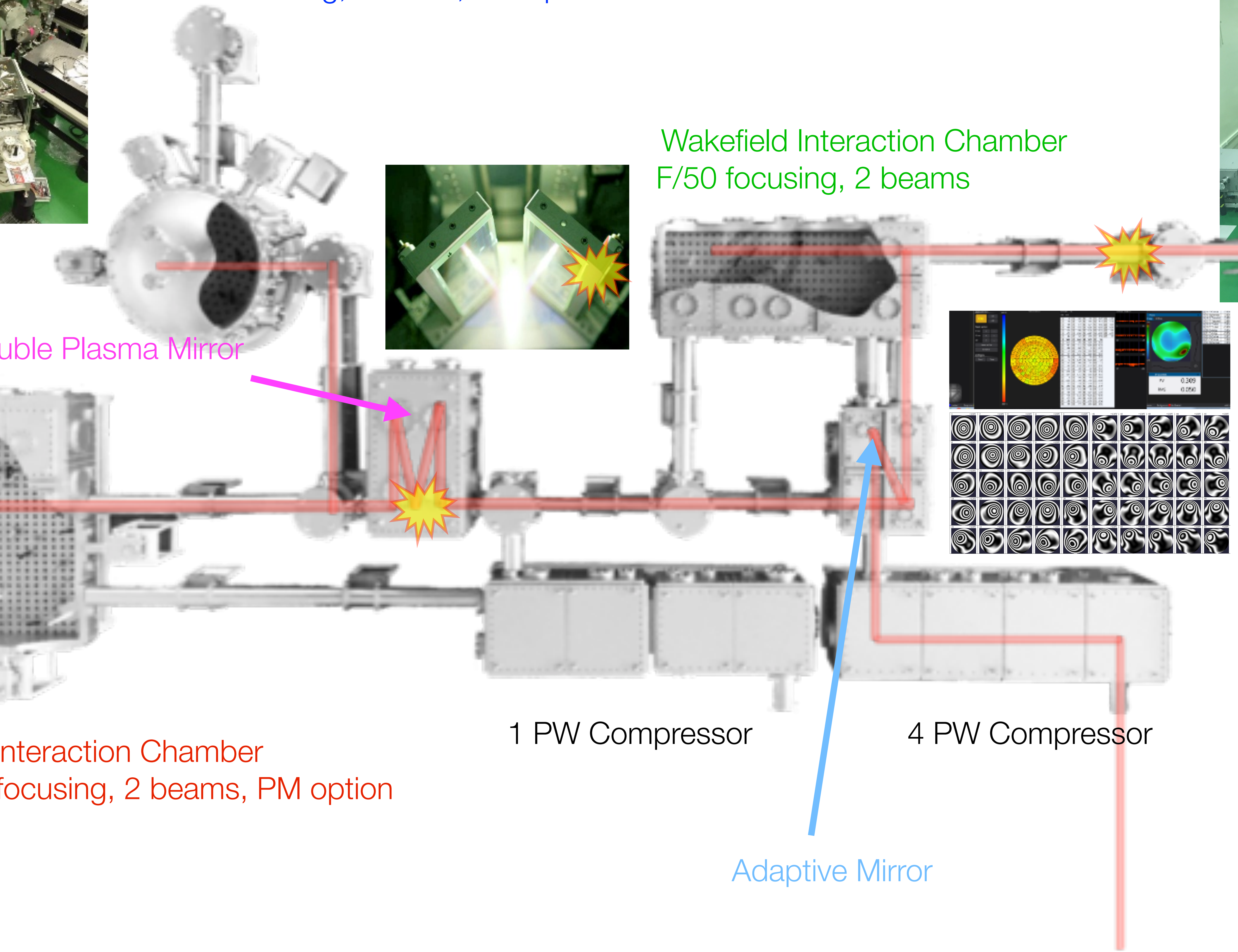
PW laser system

4PW compressor and target area



Solid Target Interaction Chamber
F/1 - F/5 focusing, 1 beam, PM option

Wakefield Interaction Chamber
F/50 focusing, 2 beams



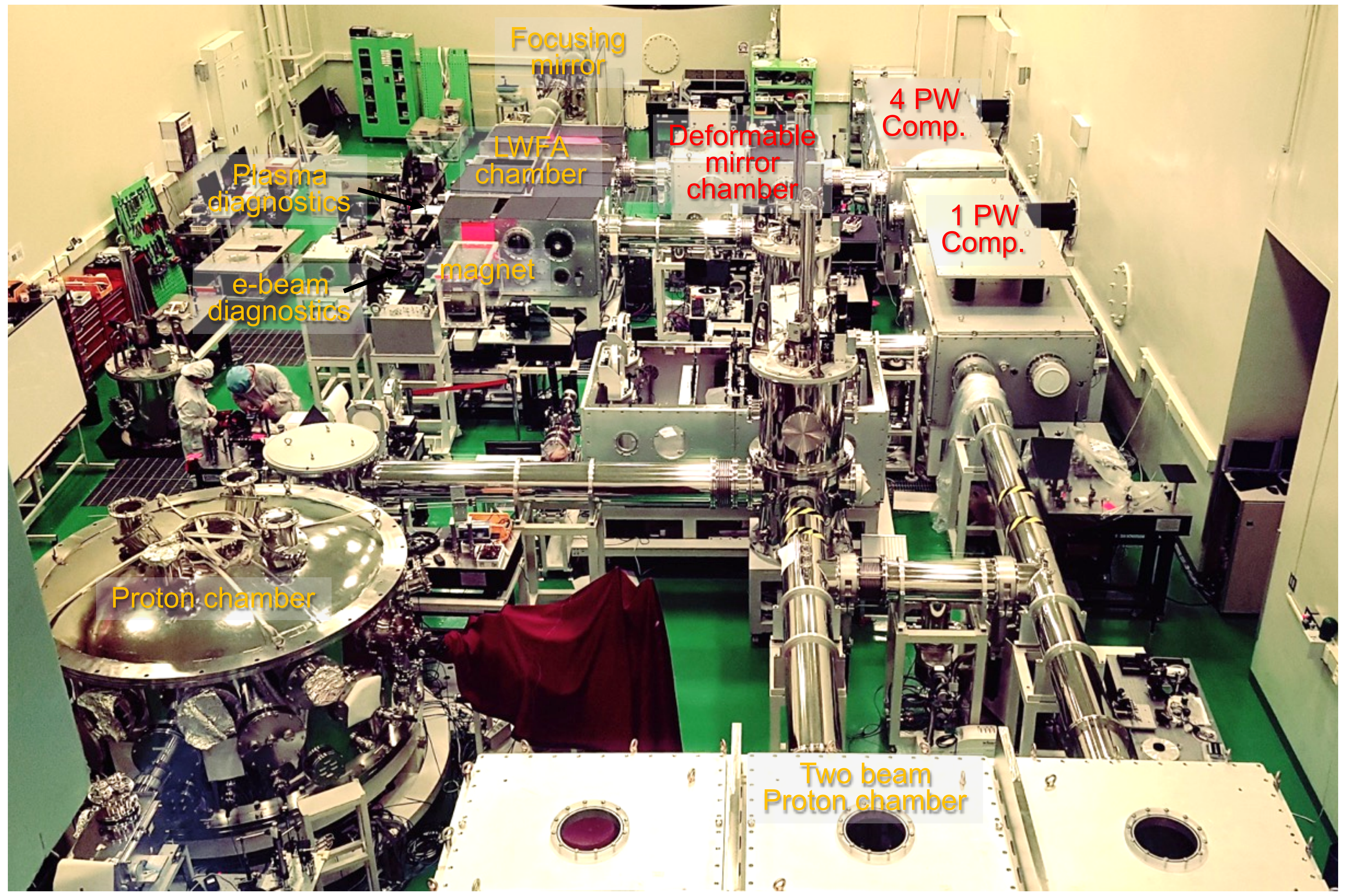
Double Plasma Mirror

High Field Interaction Chamber
F/1 - F/10 focusing, 2 beams, PM option

1 PW Compressor

4 PW Compressor

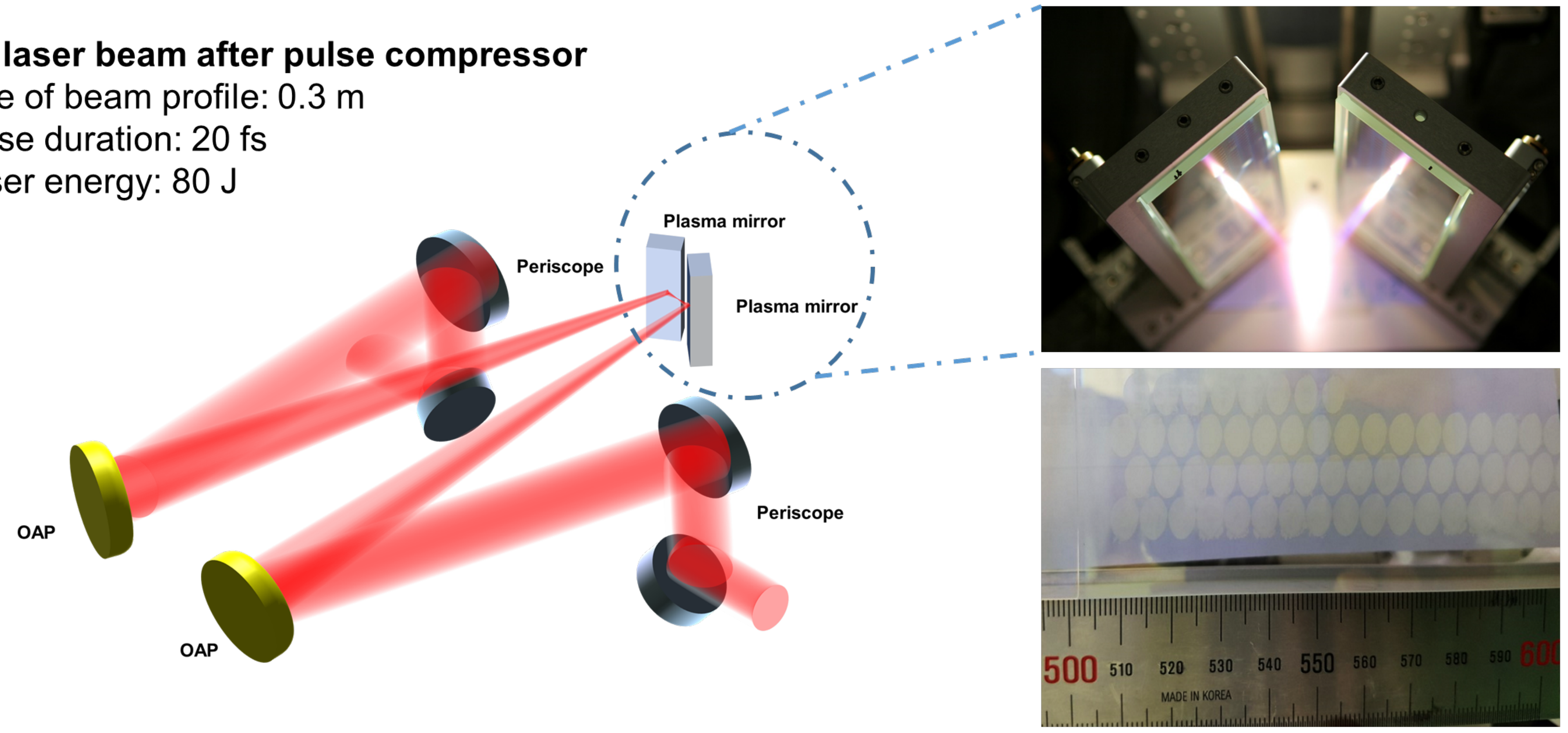
Adaptive Mirror

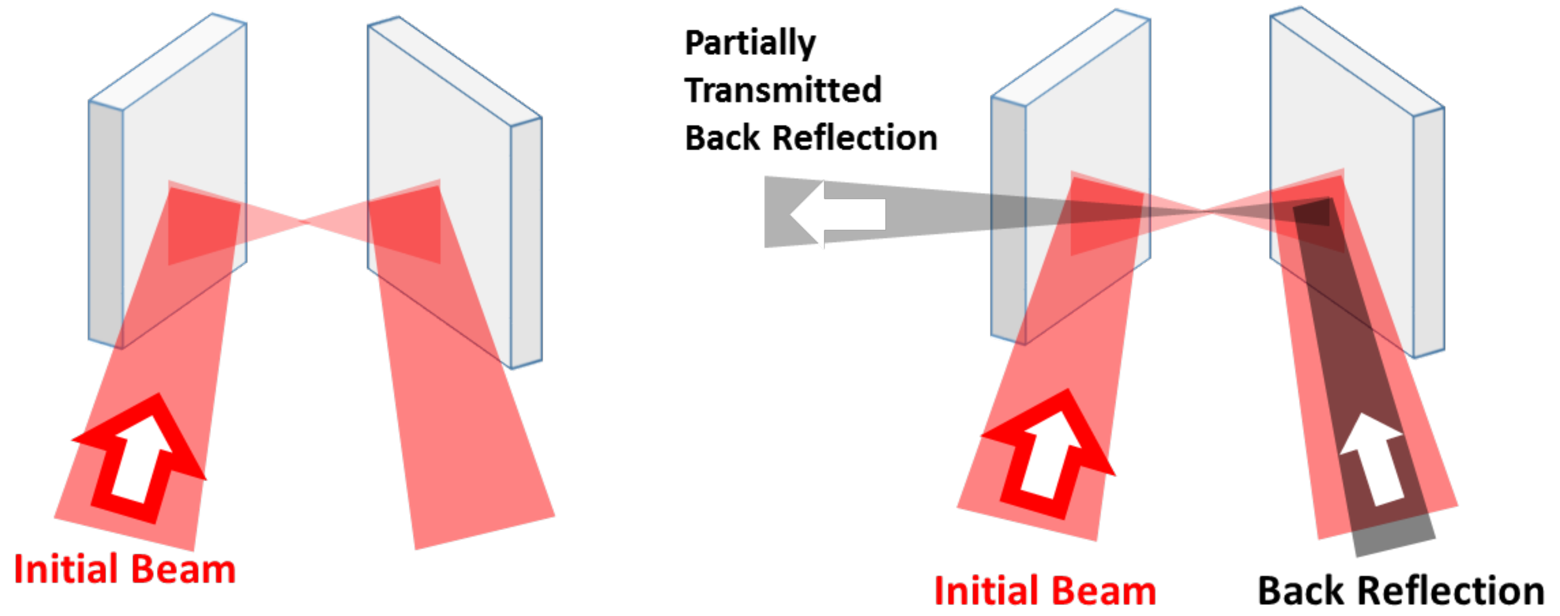


Implemented high rep-rate, recollimating double plasma mirror to shape pulse profile

Relativistic Quantum Photonics

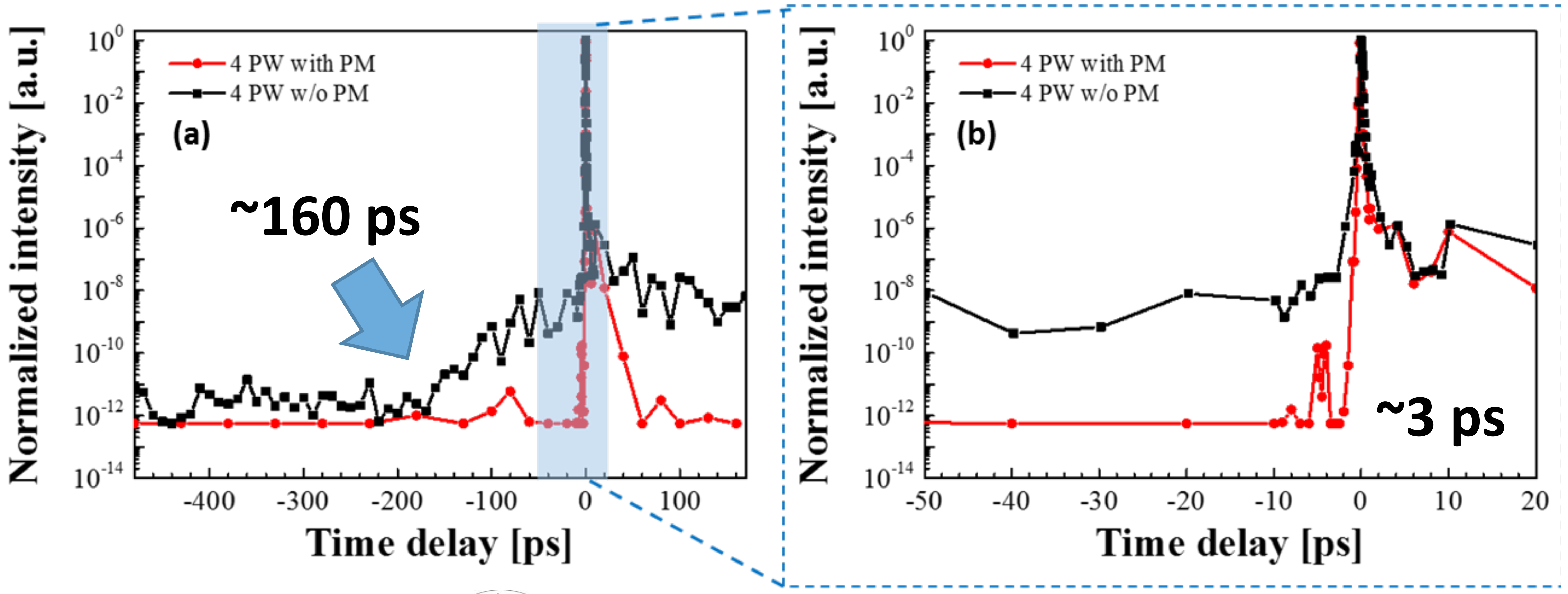
4 PW laser beam after pulse compressor
- Size of beam profile: 0.3 m
- Pulse duration: 20 fs
- Laser energy: 80 J



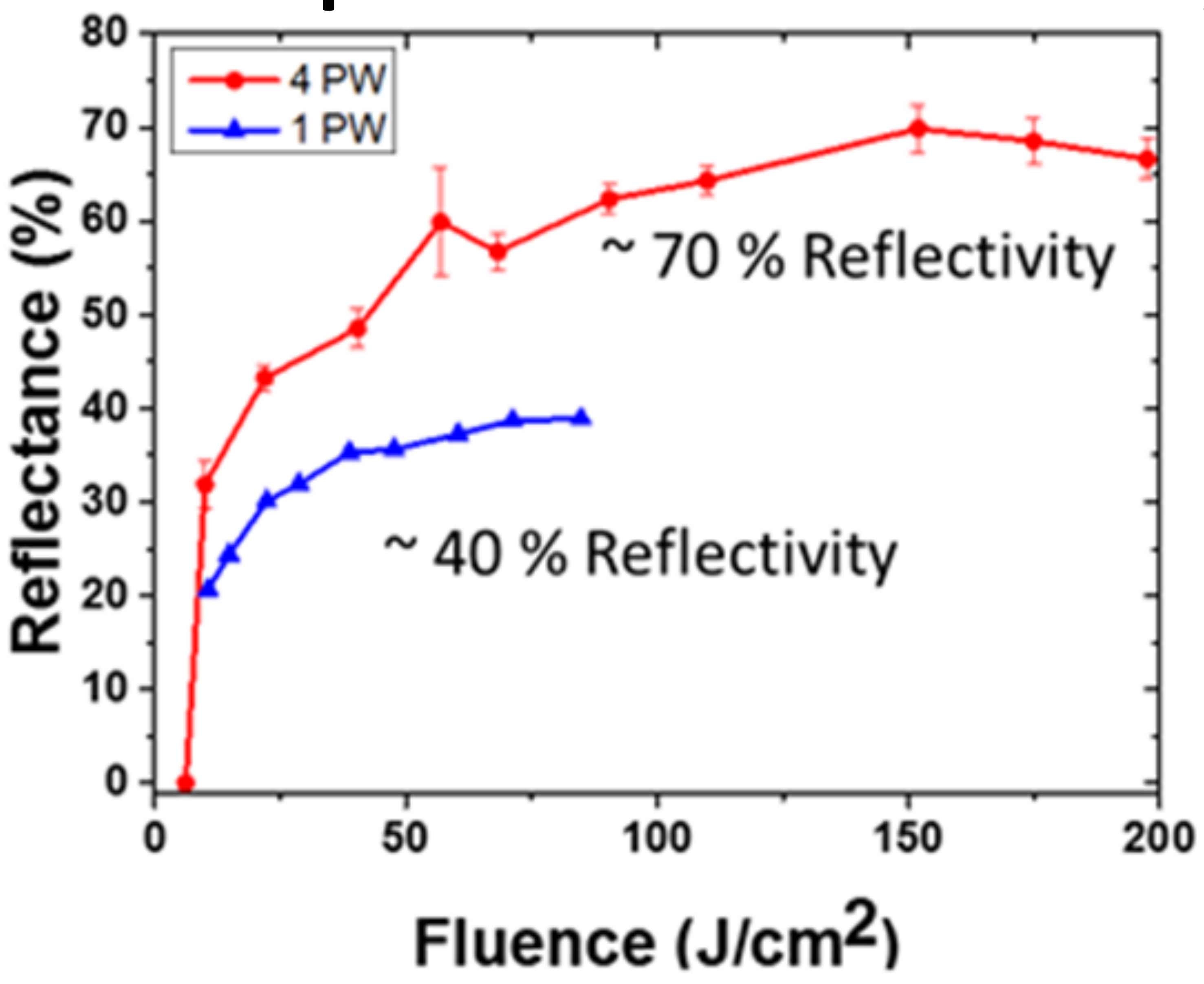


~800 shots per substrate pair

Contrast Ratio Measurement



Double plasma mirror efficiency

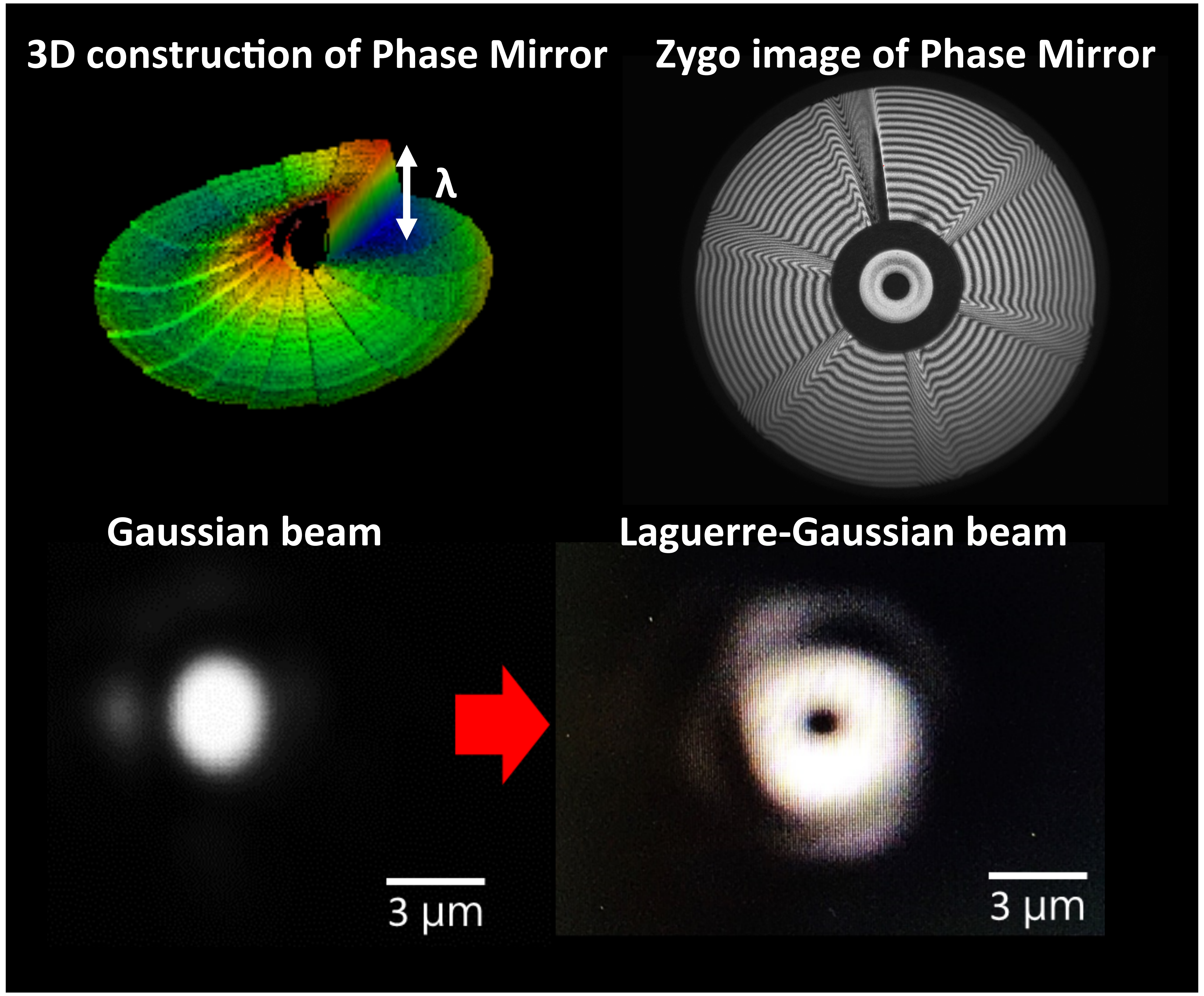


CoReLS Center for Relativistic Laser Science

B. M. Hegelich

Polarization and Focal Shape

- Half-wave plates and quarter wave-plates allow different polarizations:
  - p-polarized
  - s-polarized
  - circular polarized
  - elliptically polarized
- Phase plate allows LaGuerre-Gaussian Beam



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Selected Results in Laser Wakefield Acceleration LWFA

150 TW System

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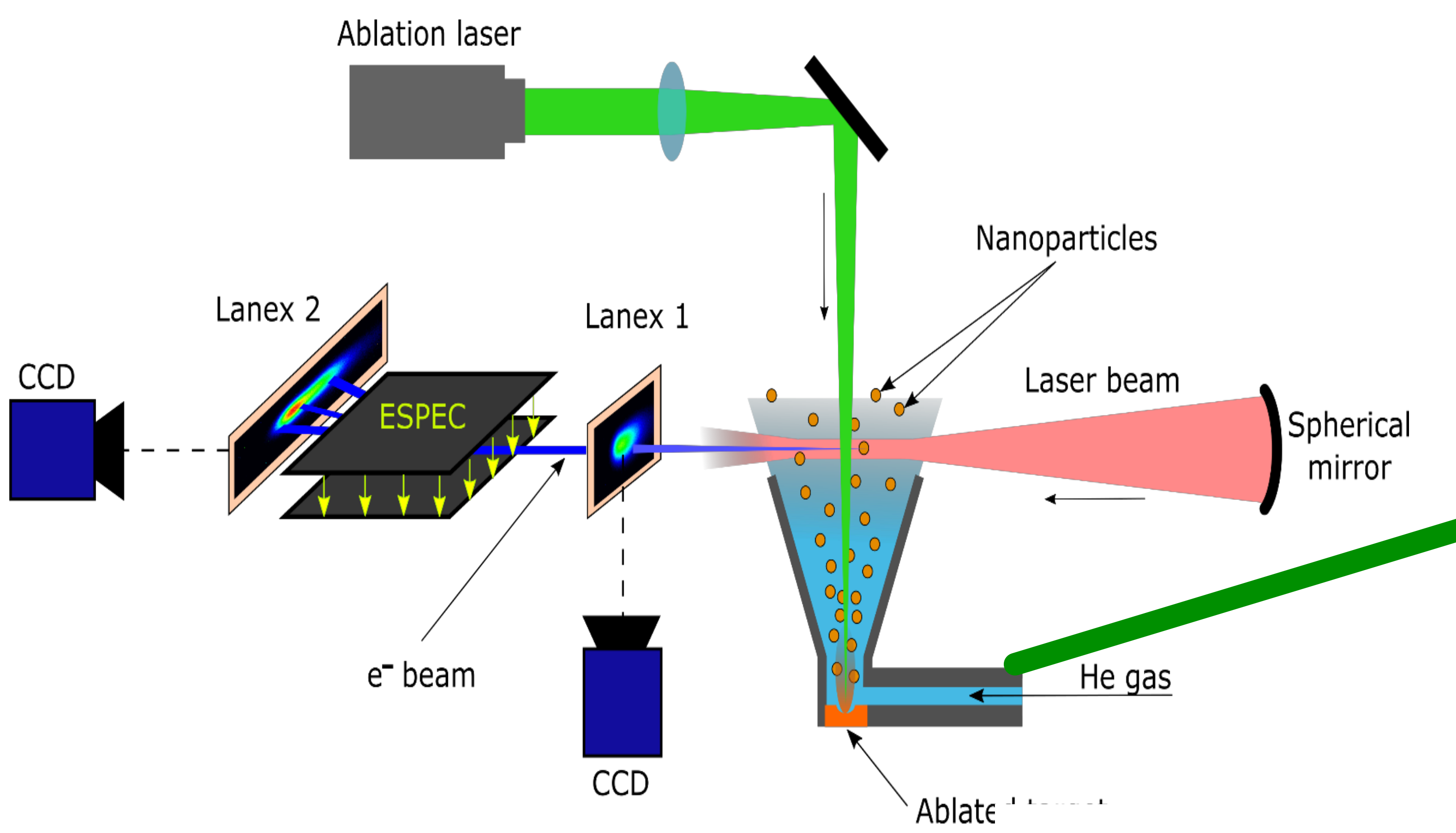
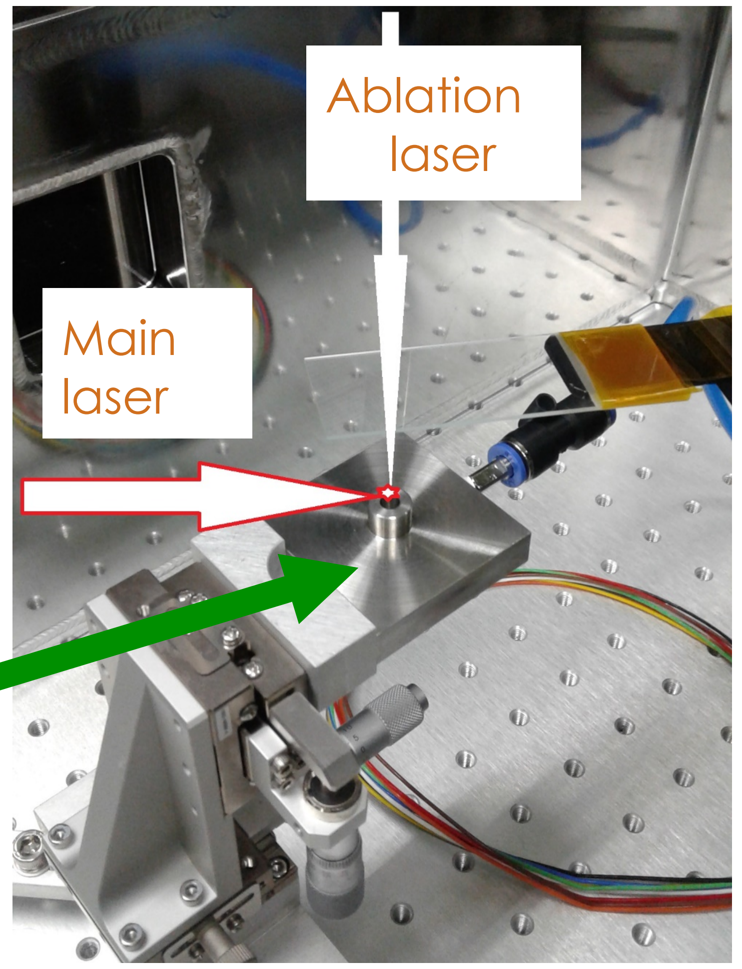
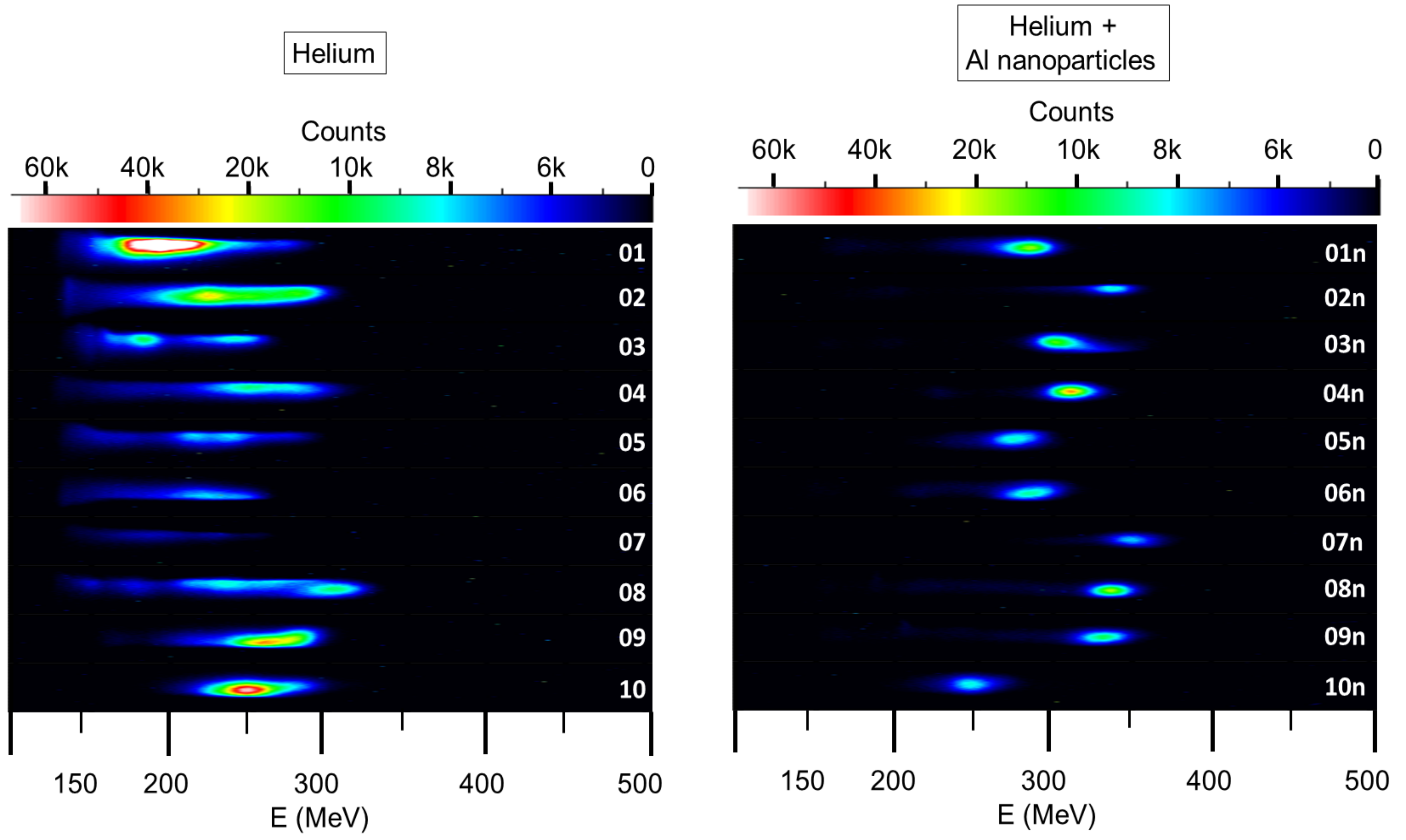
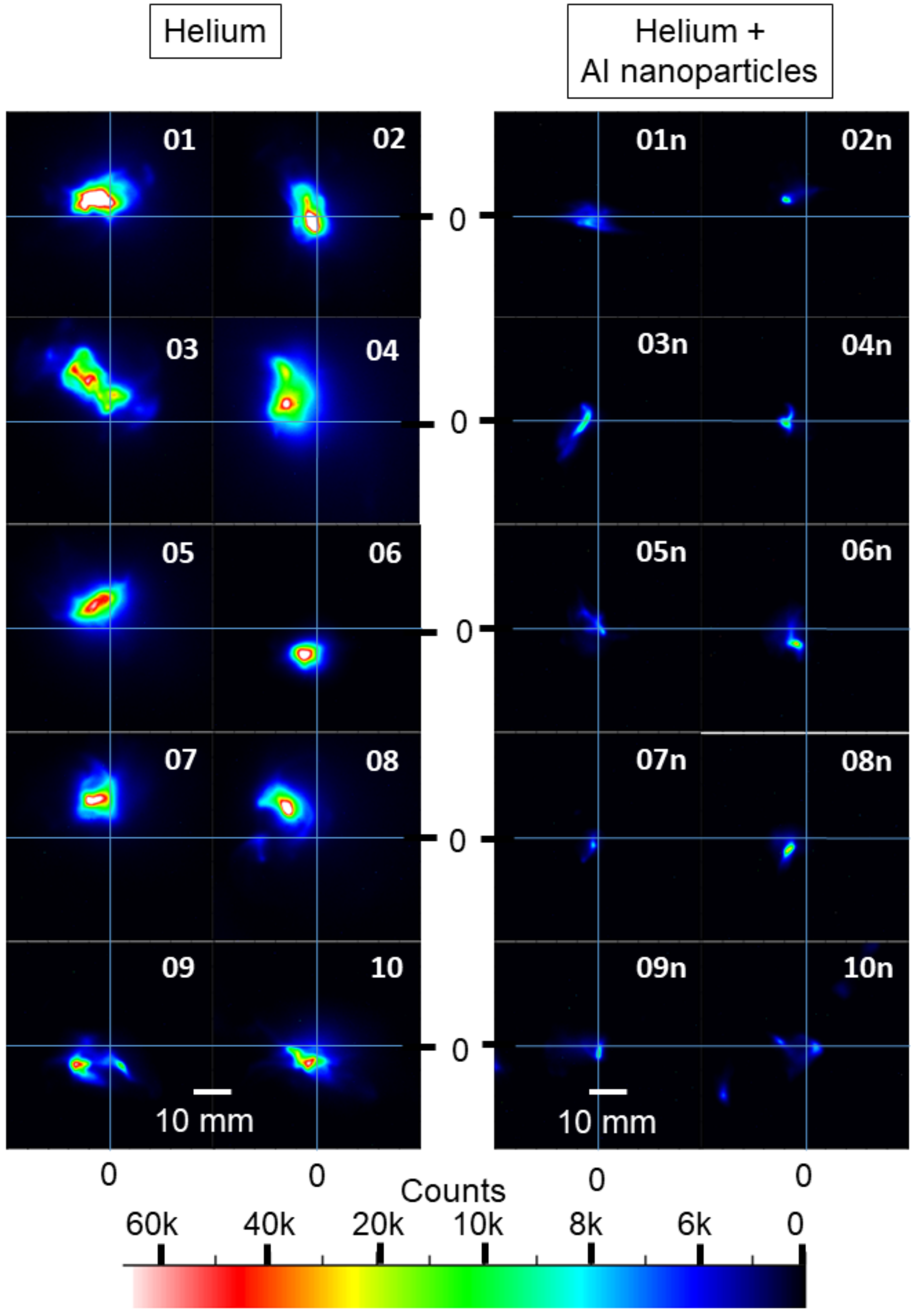
Nanoparticle-assisted electron injection in a laser wakefield accelerator : Experimental setup 100 TW





- The hybrid gas target can generate supersonic gas jets doped with any kind of nanoparticles
- The density and size of nanoparticle controlled by the laser energy, pulse width and fluence
- ***Electron peak energy and energy spread greatly improved***
- ***Electron beam divergence decreased***





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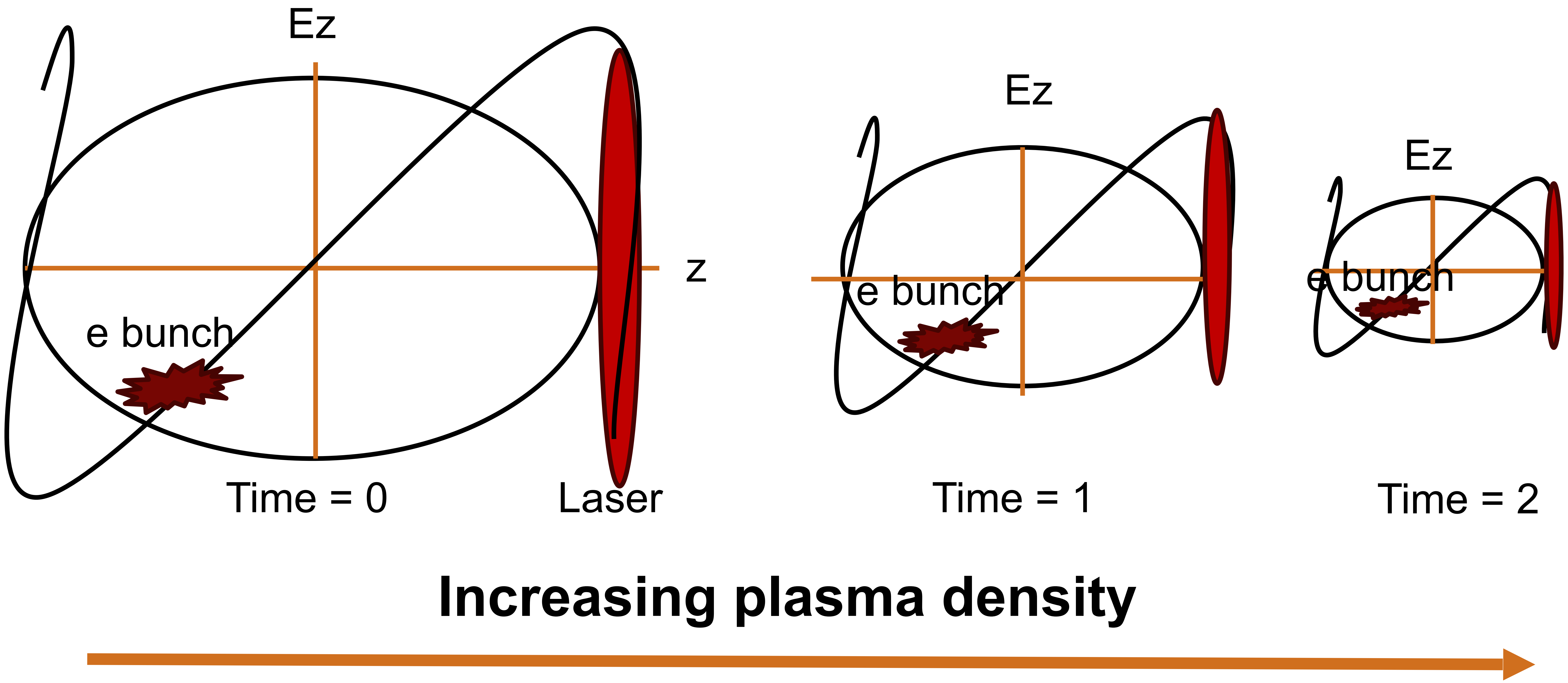
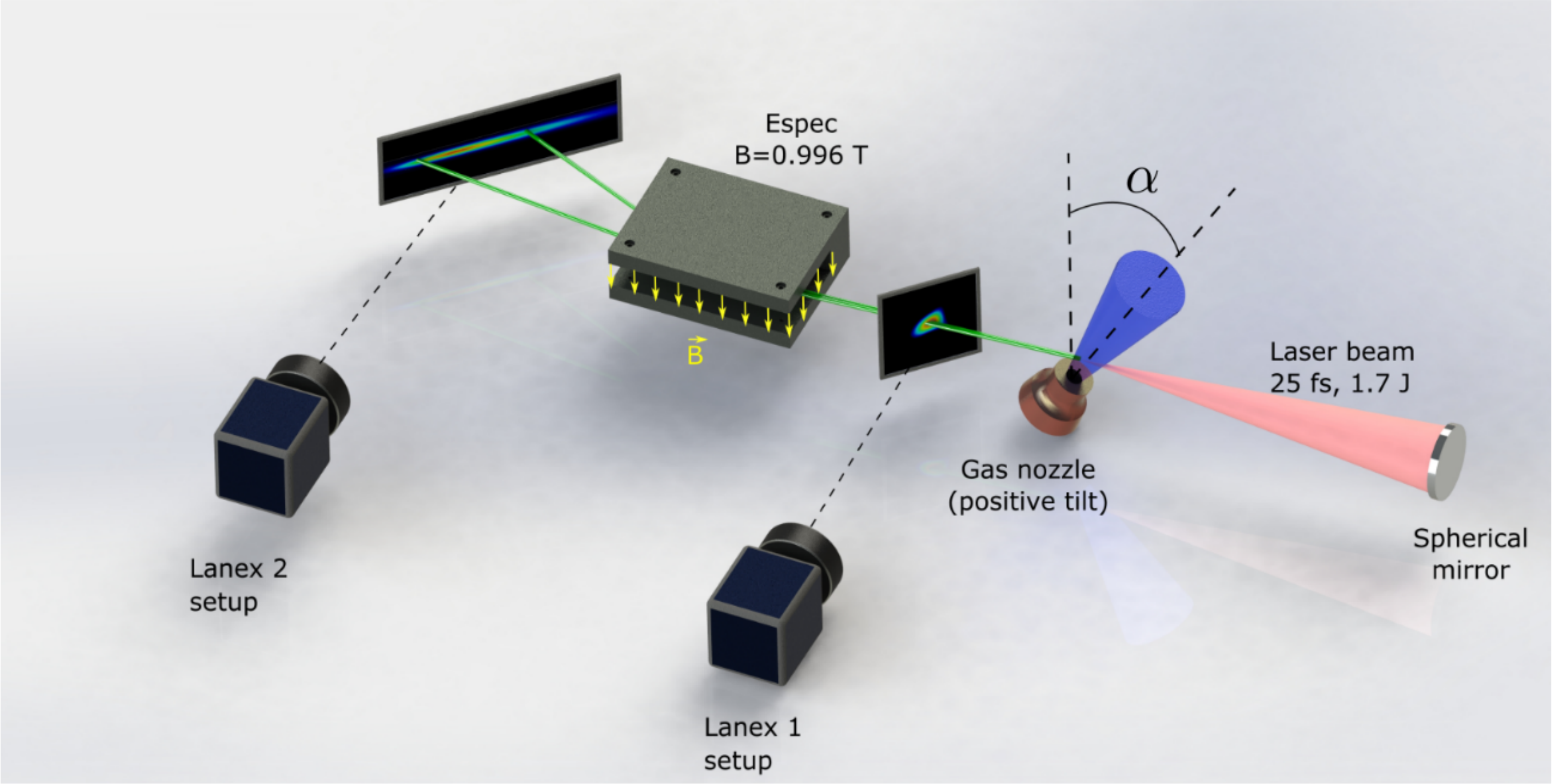
Laser wakefield acceleration in up-ramp plasma density profiles :

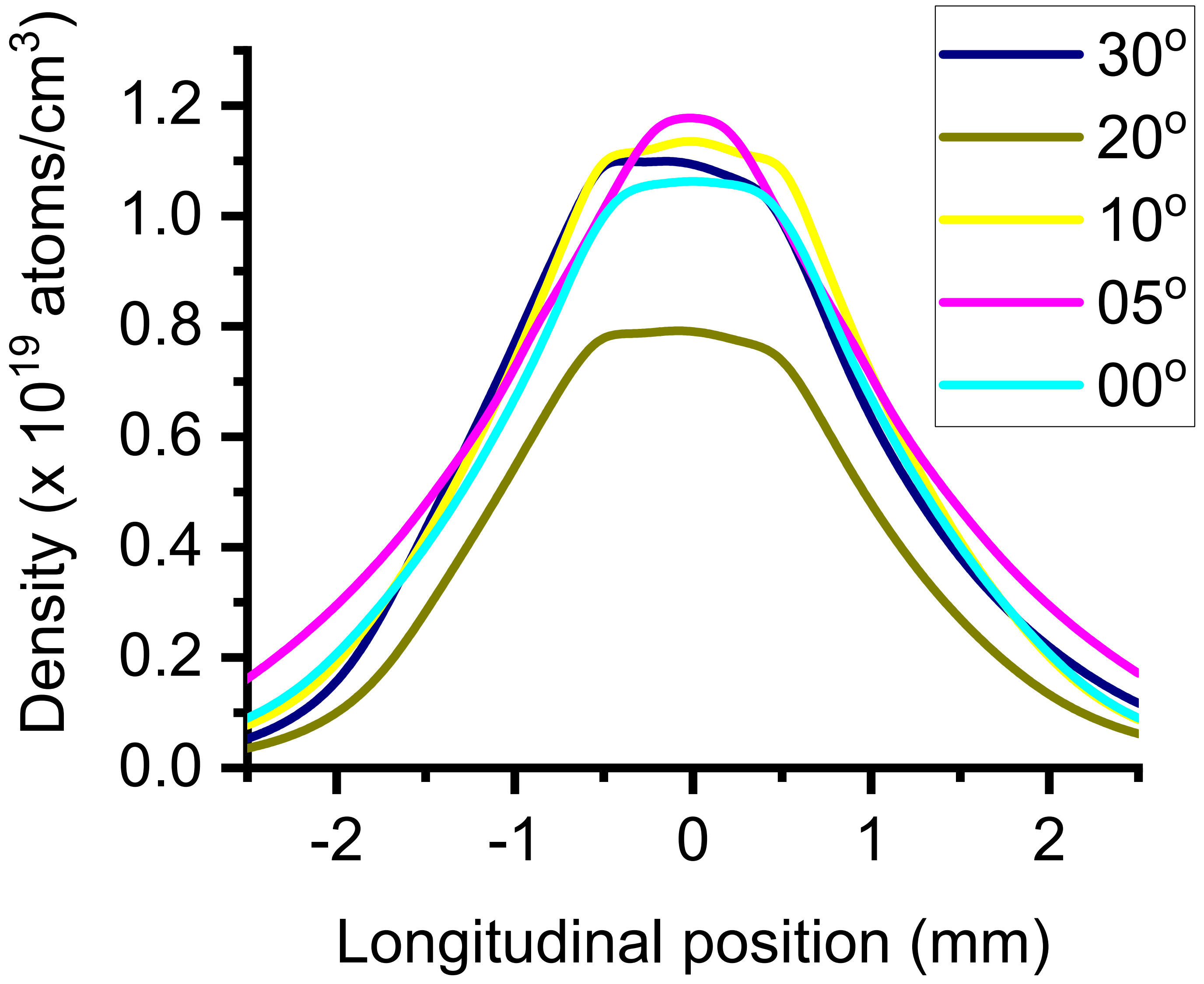
Dephasing-compensated LWFA

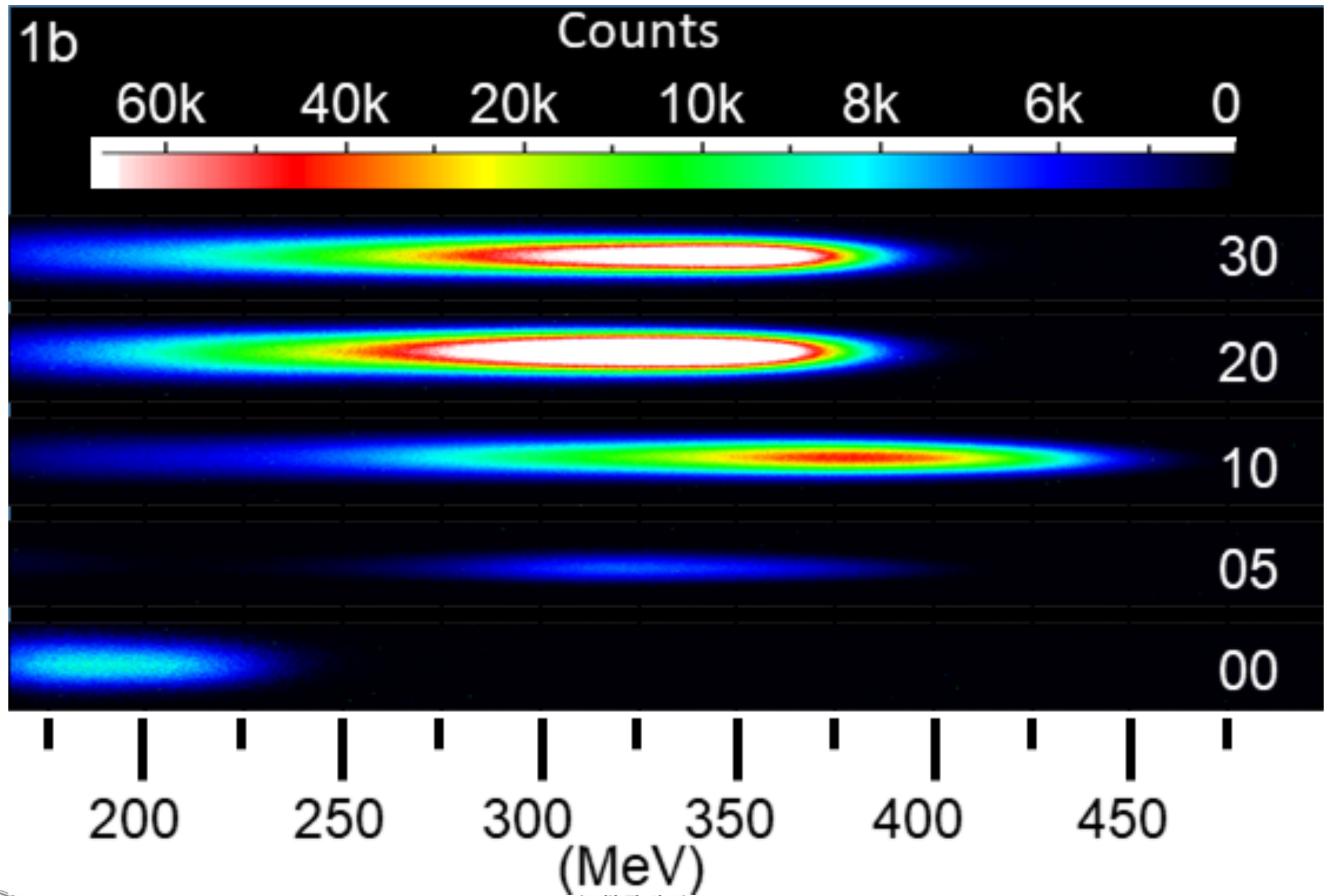


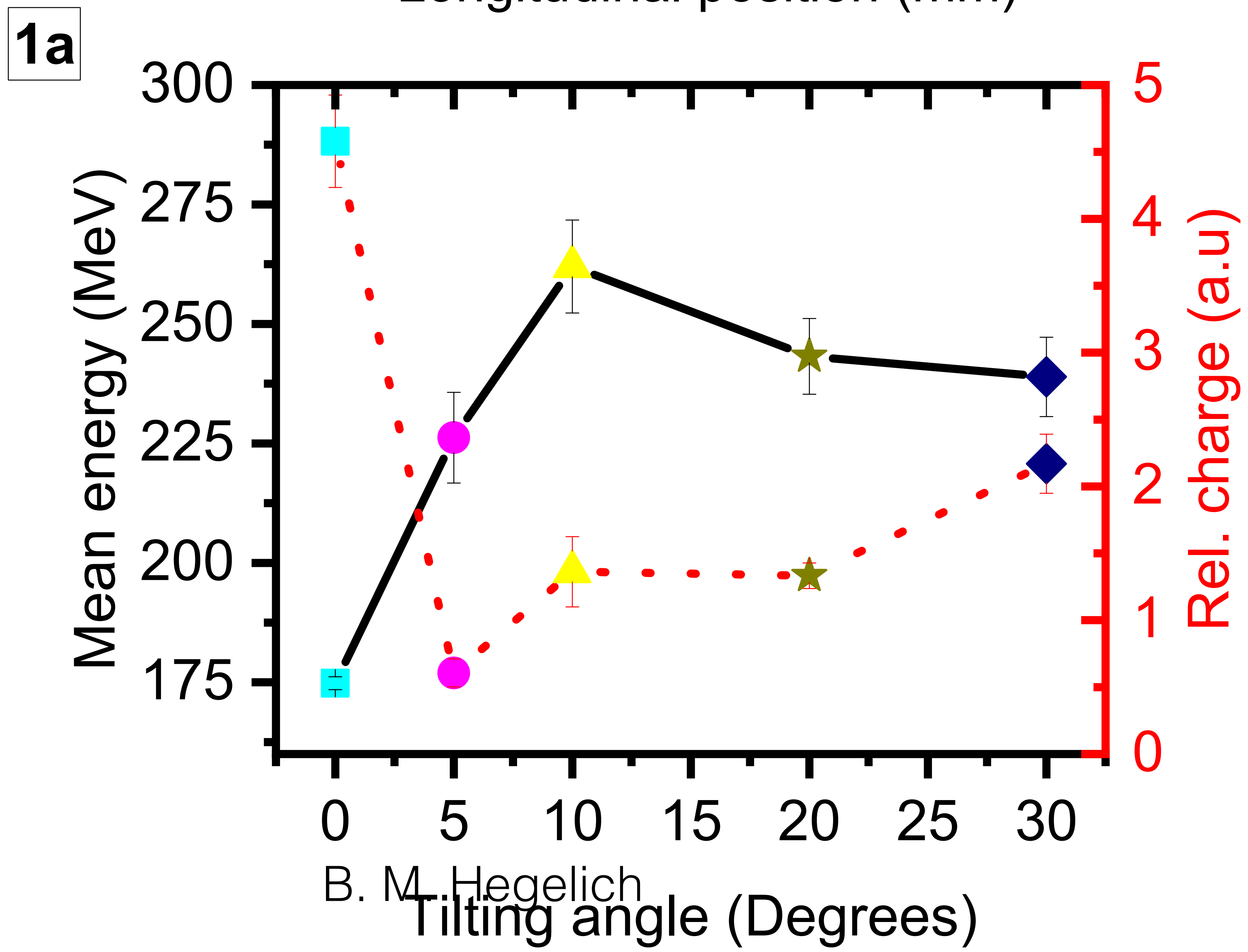
A plasma density gradient shrinks the bubble as the laser propagates thus the electron beam stays in the same place, relative to the back of the bubble.

Laser wakefield acceleration in up-ramp plasma density profiles : Experimental setupc@ 150 TW









- The gas density profile can be shaped by:
  - tilting the nozzle relative to the direction of propagation of the laser
  - changing the gas inlet pressure
  - varying the interaction zone above the outlet

Significant electron energy has been observed – 50% on average with a few shots above 100%

The divergence follows the energy trend and decreases significantly

B. M. Hegelich

Relativistic Quantum Photonics

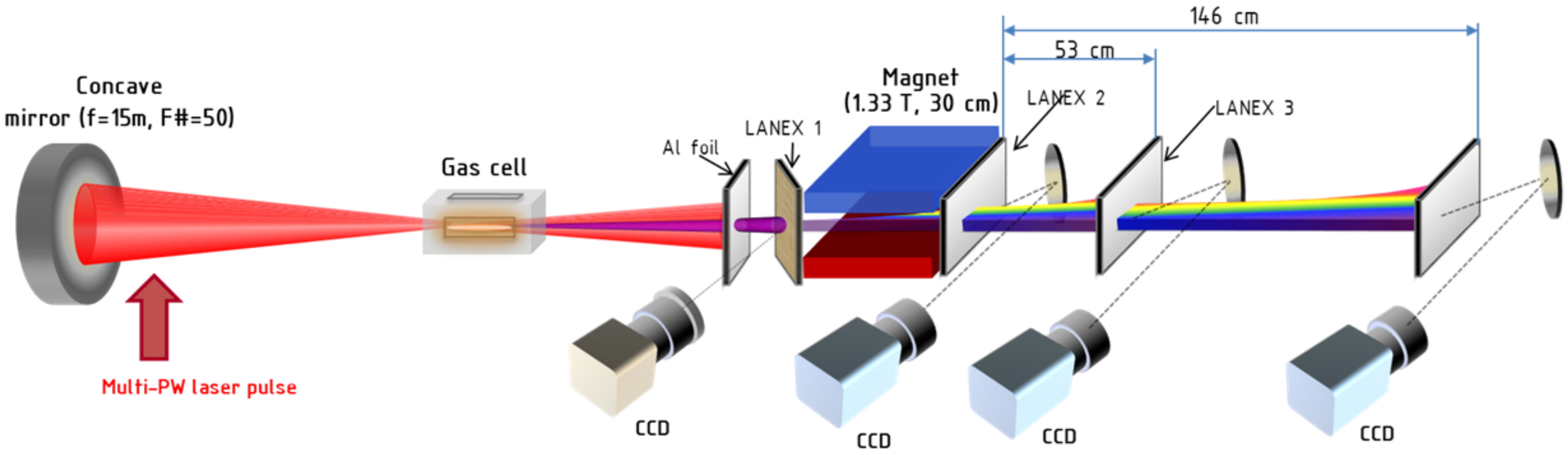
Selected Results in Laser Wakefield Acceleration LWFA

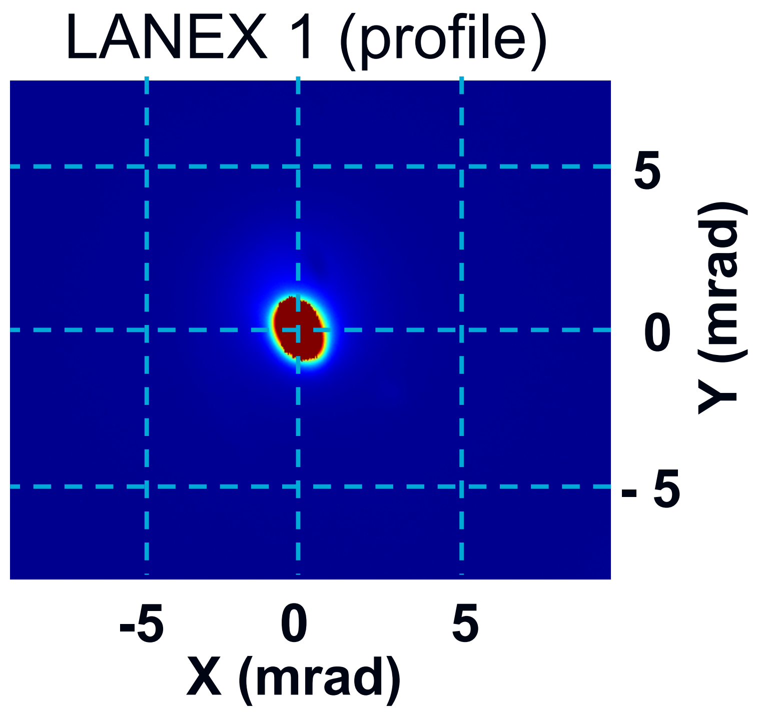
4 PW System

B. M. Hegelich

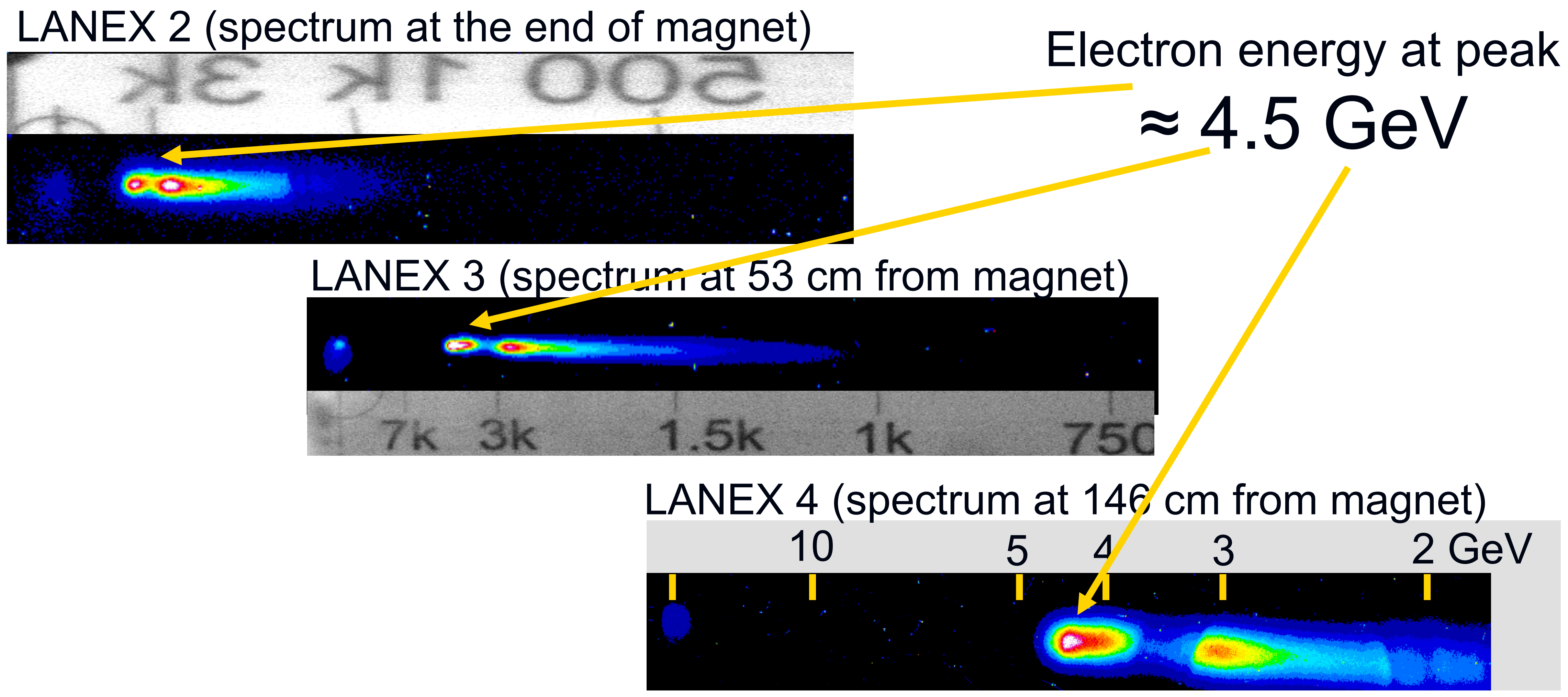
Wakefield Acceleration with 1 PW of a 4PW laser

- Laser parameters :
  - 52 J on target, 25fs => 2PW
  - 50% in central spot => 1 PW
  - focal spot ≈ 50 μm (FWHM), + 30 fs (GDD +350 fs-2),
  - I ≈ 4.2 x 10^{19} W/cm^2, a_0 ≈ 4.5
- Gas medium :
  - He mixed with 1-% Ne,
  - 7-cm gas cell
  - plasma density ≈ 1.5 x 10^{18} elec./cc



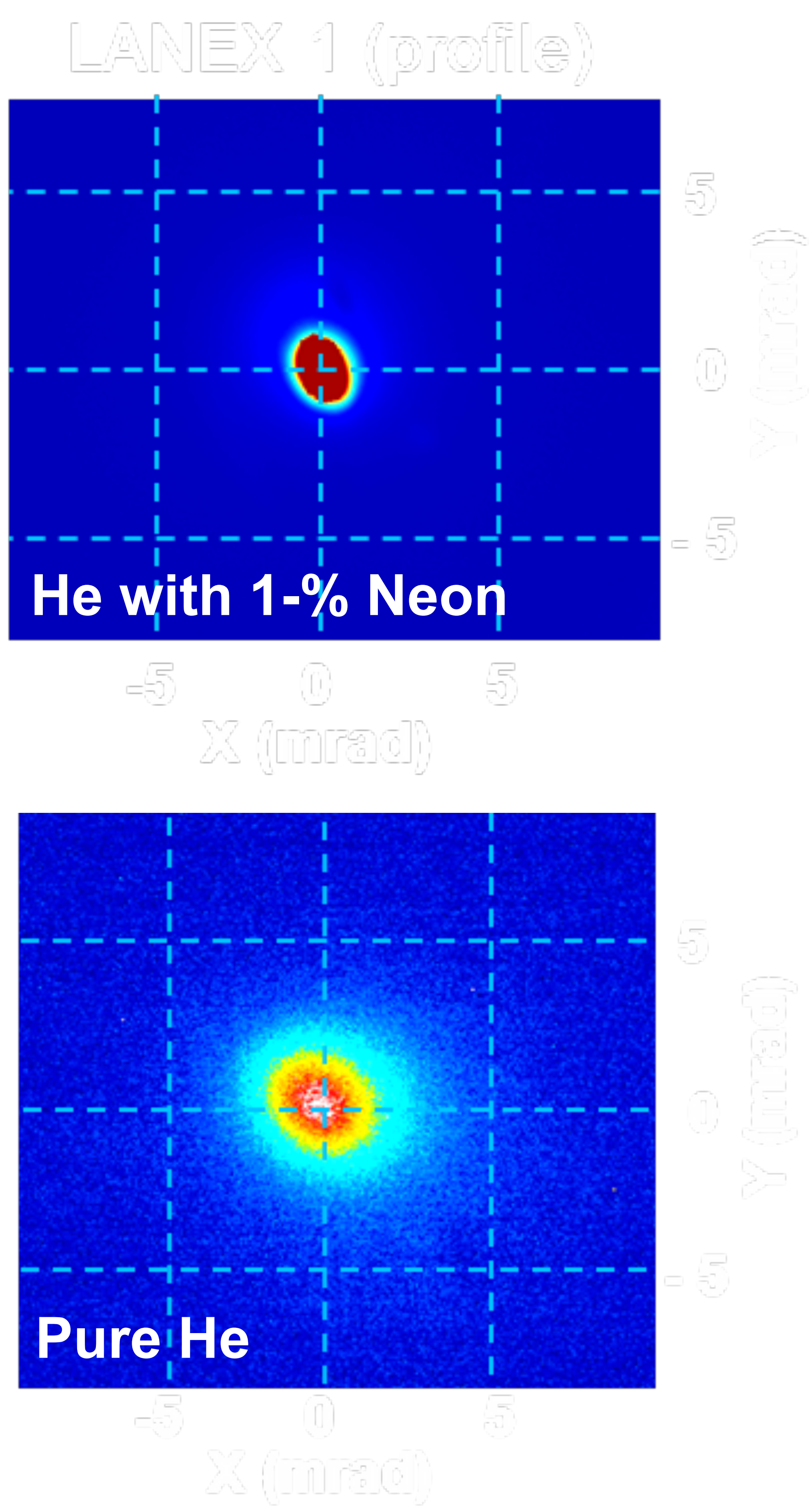


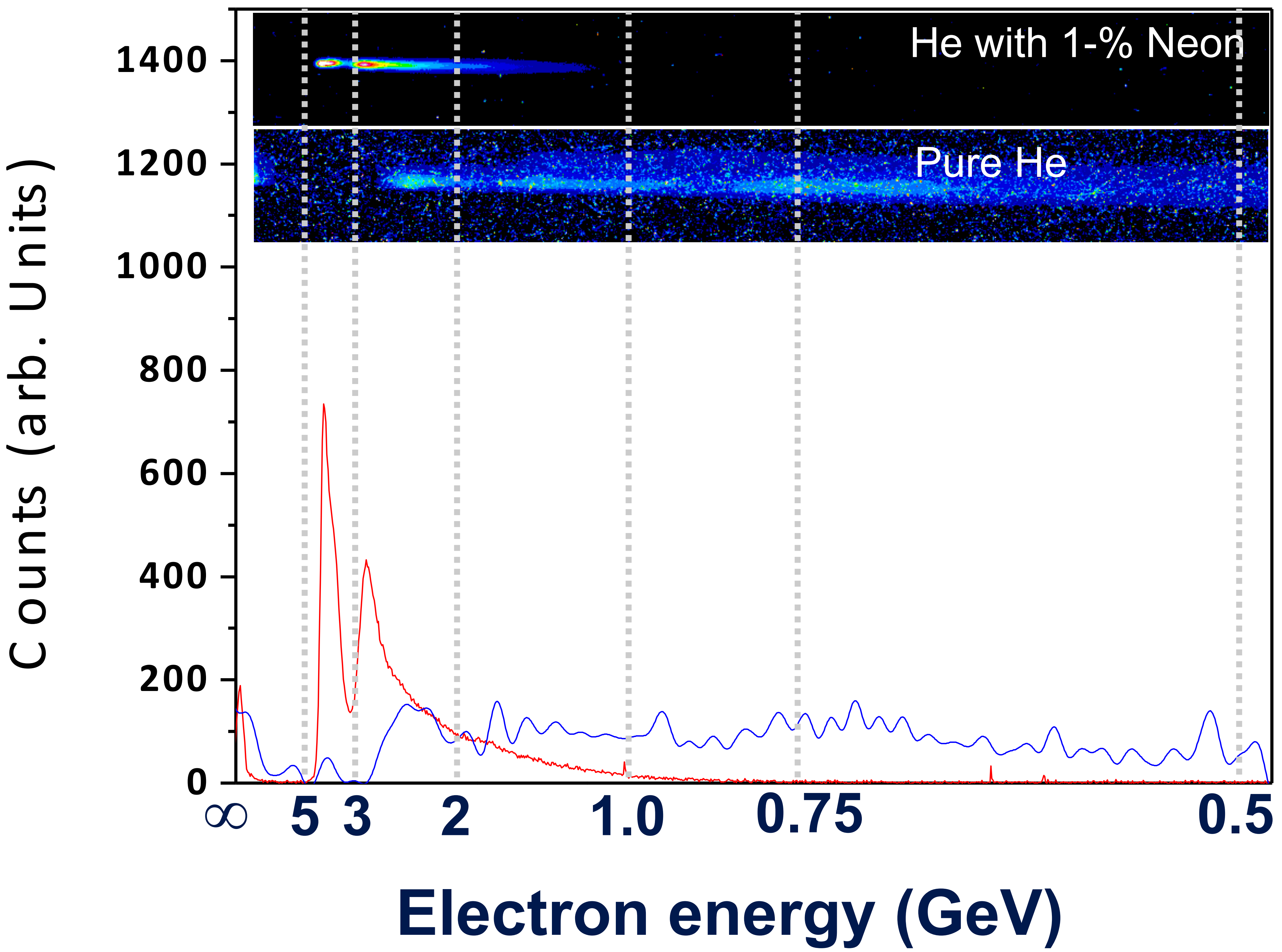
Deeply saturated
Divergence < 2 mrad
Total Charge > 1 nC



Effect of ionization injection with Neon

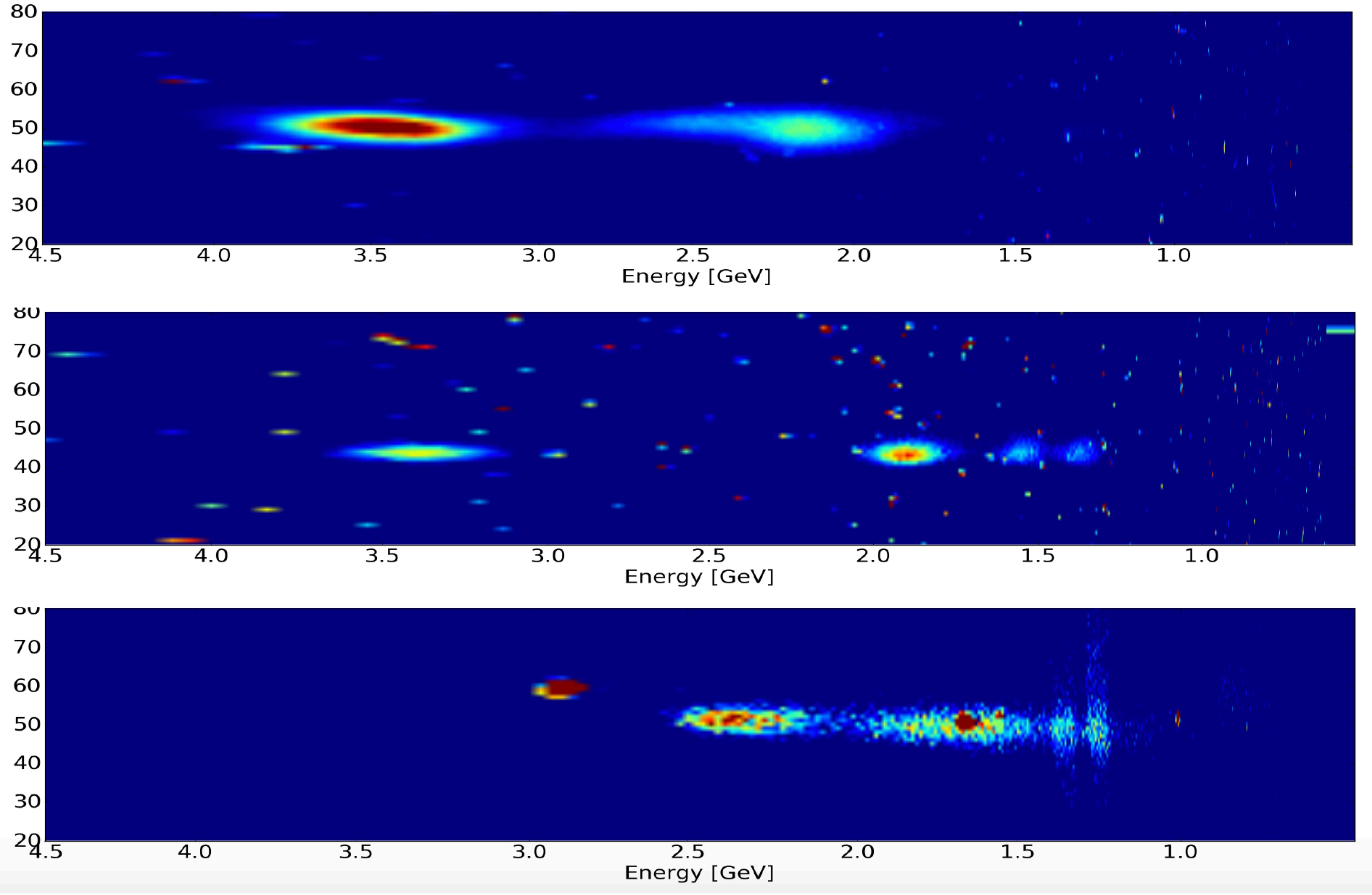
led by Dr. Hyung Taek Kim

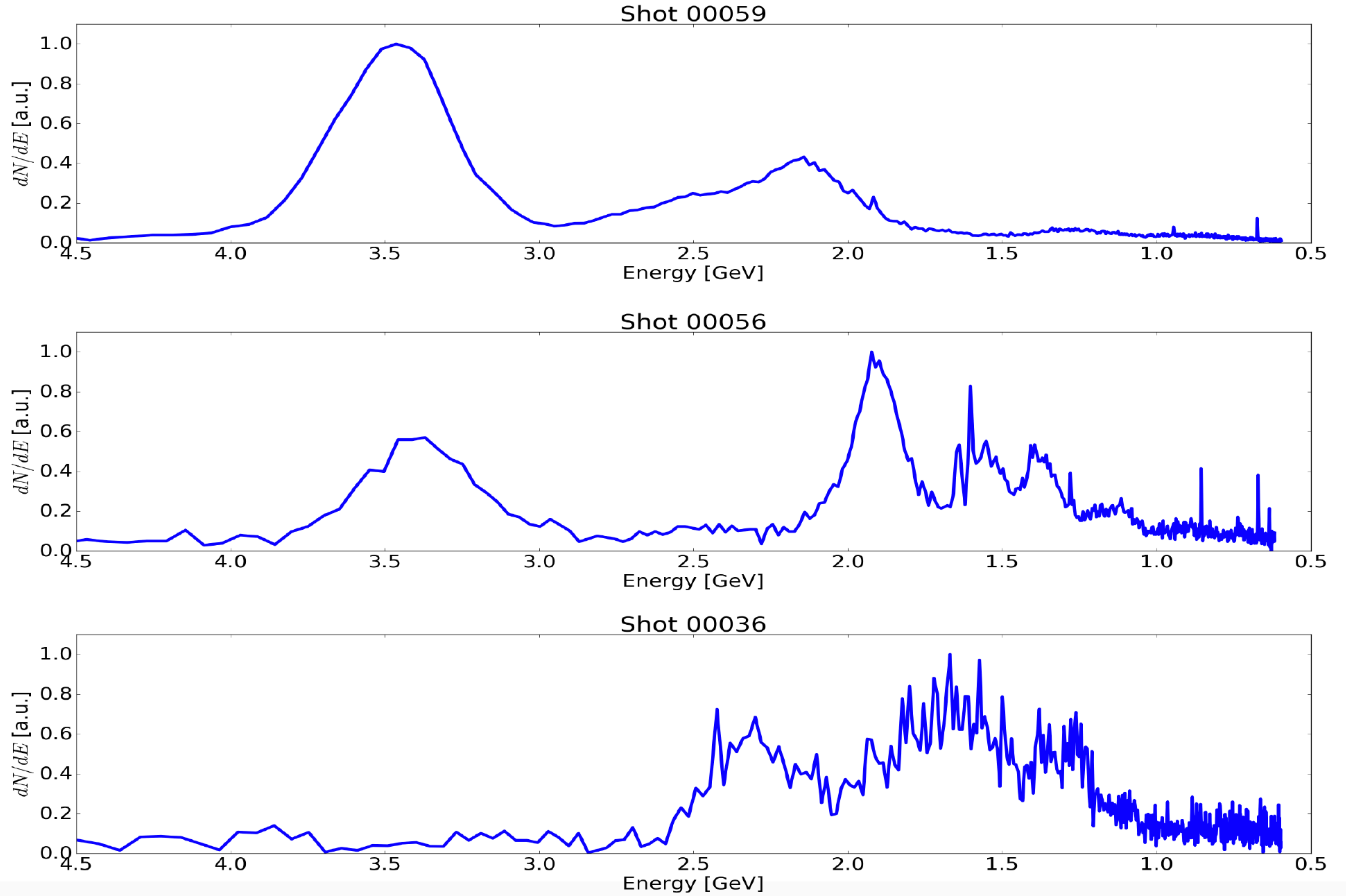




Energy fluctuations

Grad Stud. C. Hojbota





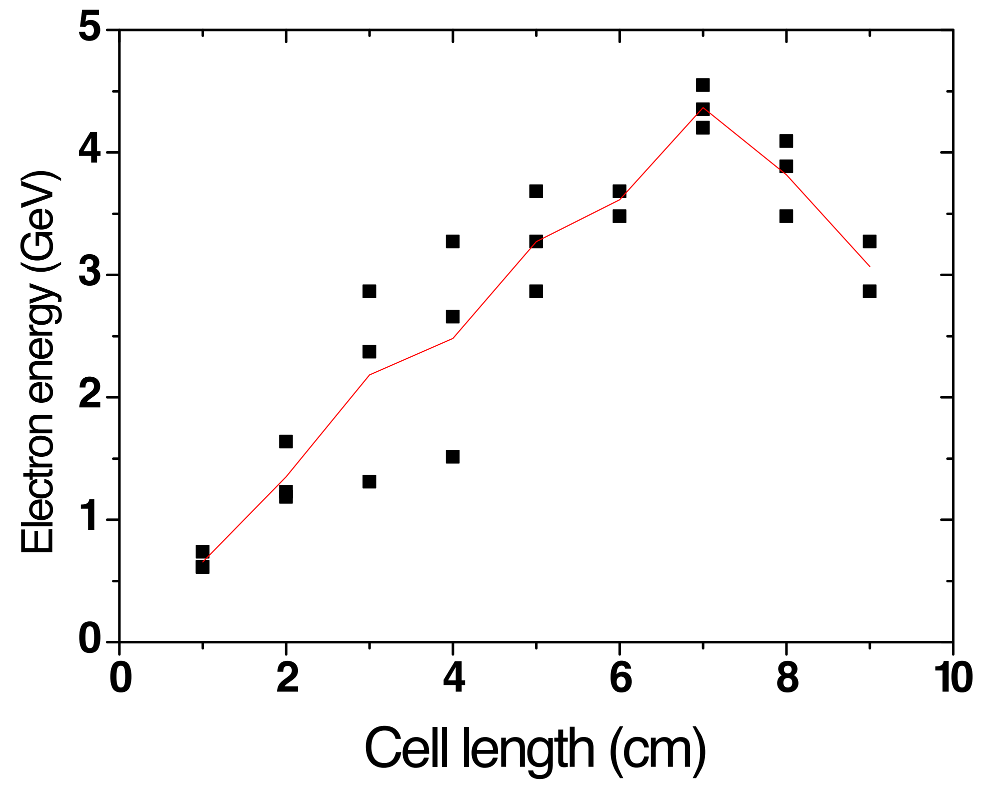
Electron beam pointing

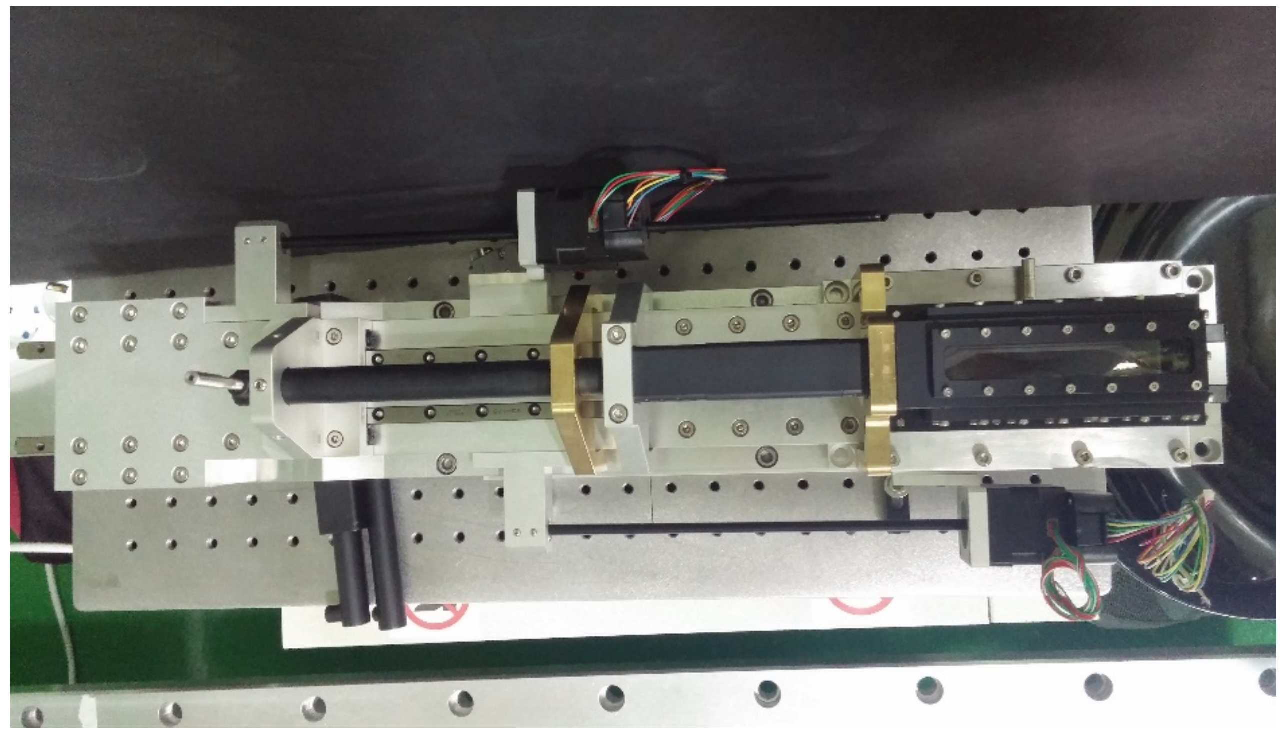
Grad Stud. C. Hojbota

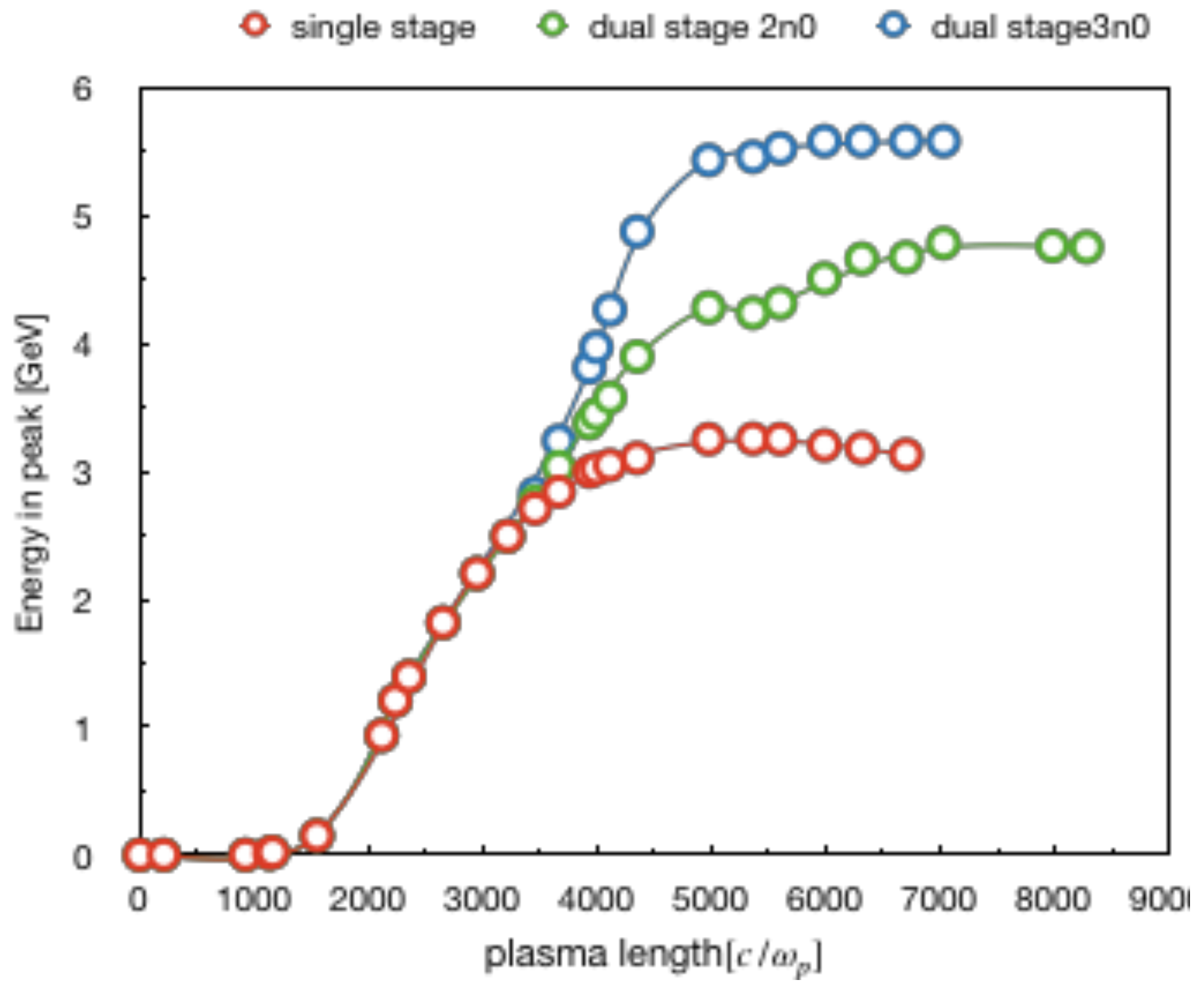
Future Directions

Laser-electron accelerator for Collision Experiments

- Laser parameters: 30 J, + 30 fs (GDD +350 fs-2)
- Medium: He mixed with 1% Ne in a gas cell; Ne≈ 1.5 x 10^{18} cm^{-3}
- The electron peak energy variation as a function of the gas cell length suggests that the dephasing length is reached at ~7 cm
- A staged gas target with tunable length and densities can achieve re-phasing of the electron bunch
- The density difference between stages is controlled
  - PIC simulations (with 30 J, 80 fs pulses) with step density-like density profile show that doubling the electron energy is possible
- Electron energy proportional to (Laser pulse energy)$^{1/3}$
- 100 J laser pulse could generate ~20 GeV electrons
- 600 J can reach ~30 GeV







Facility Requirements

- I~10^{19} W/cm^2 (a_0~2-4)
- Controlled spatial & temporal pulse profiles
  - True gaussian
  - Fourier limited pulses of variable length
- 50 GeV class particle detectors

Relativistic
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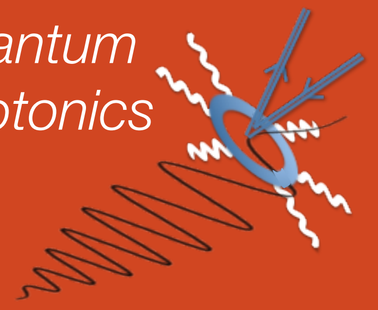
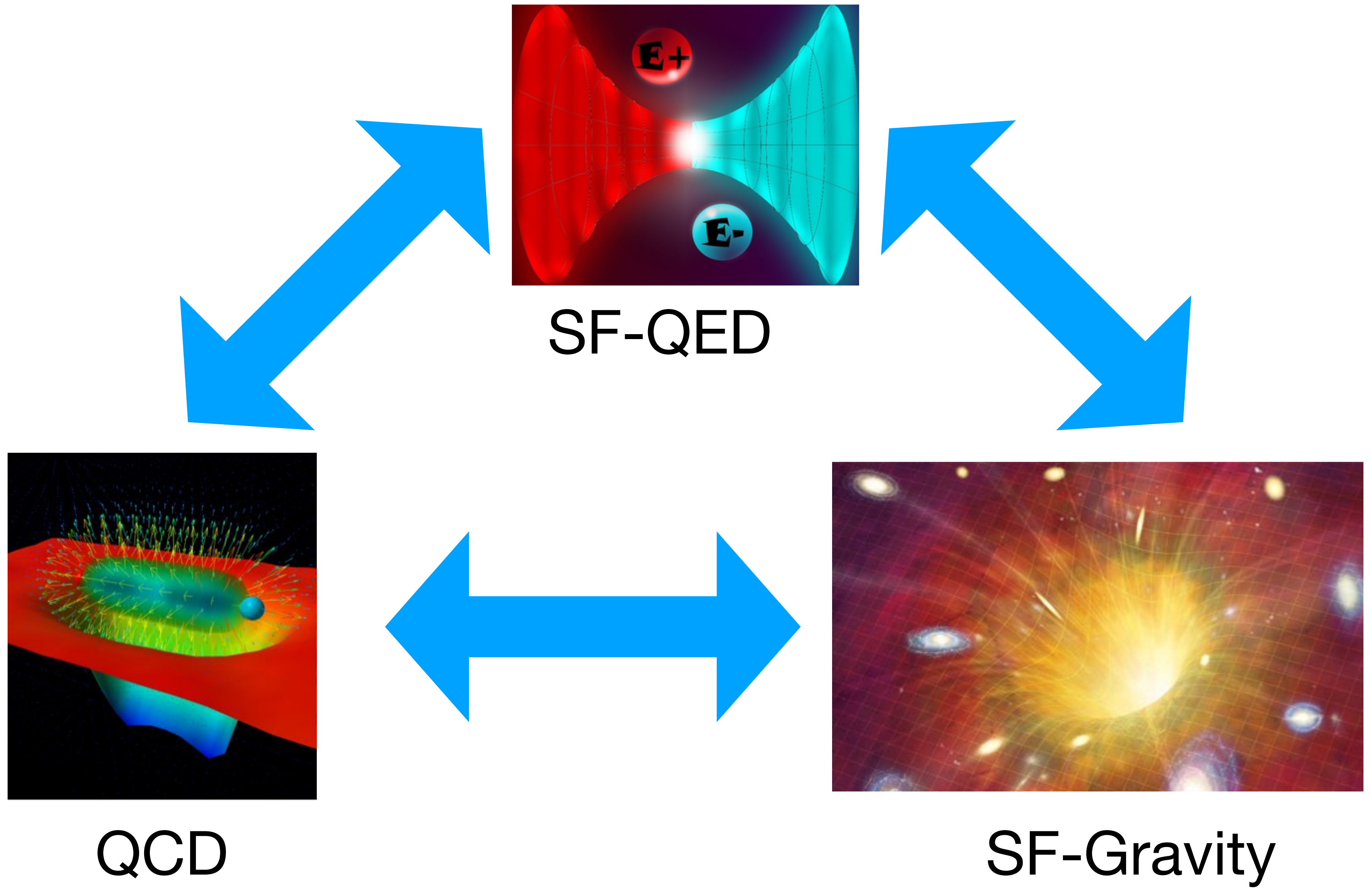
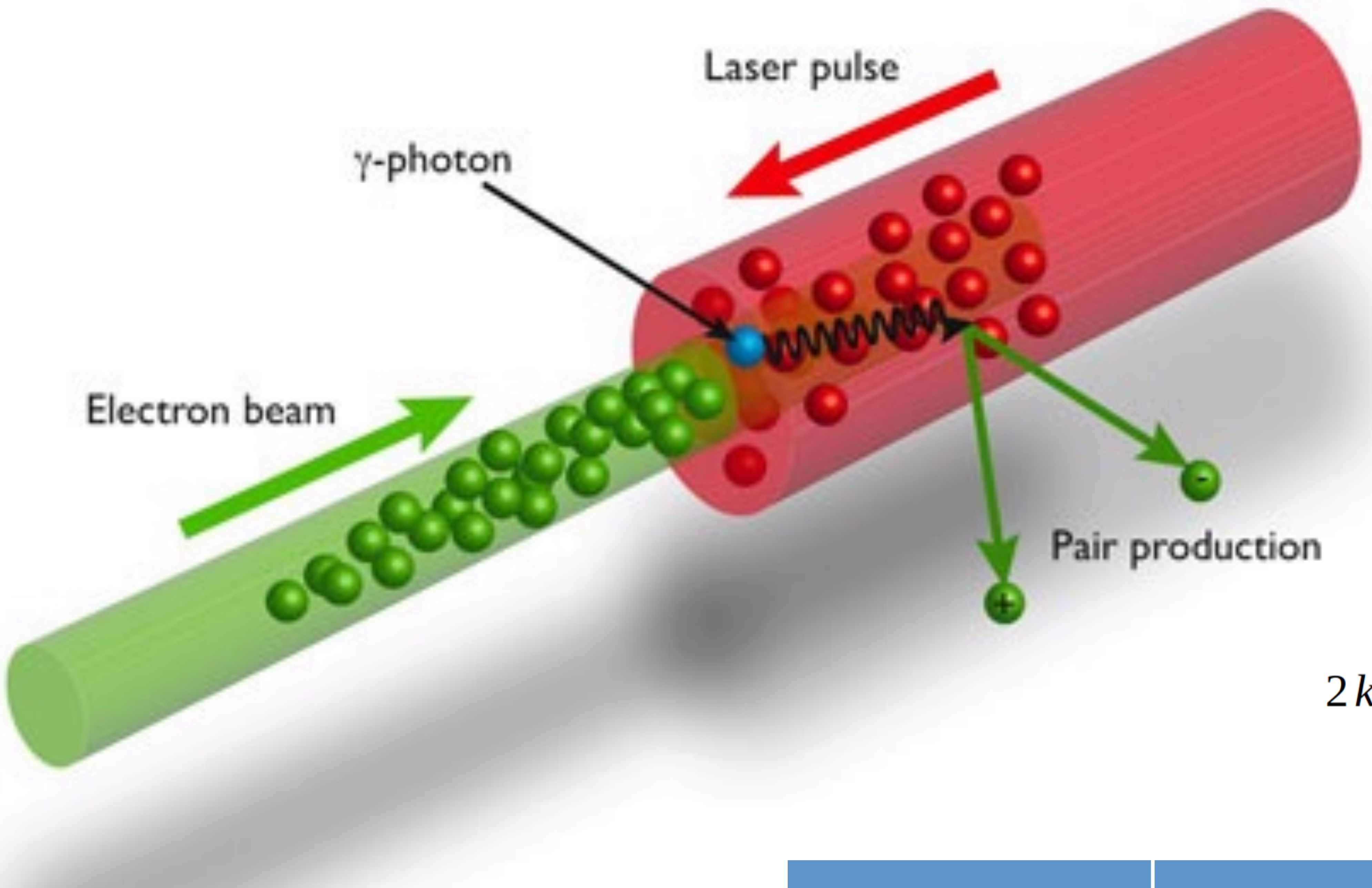
Physics Case
Strong Field - Quantum Field Theories

B. M. Hegelich

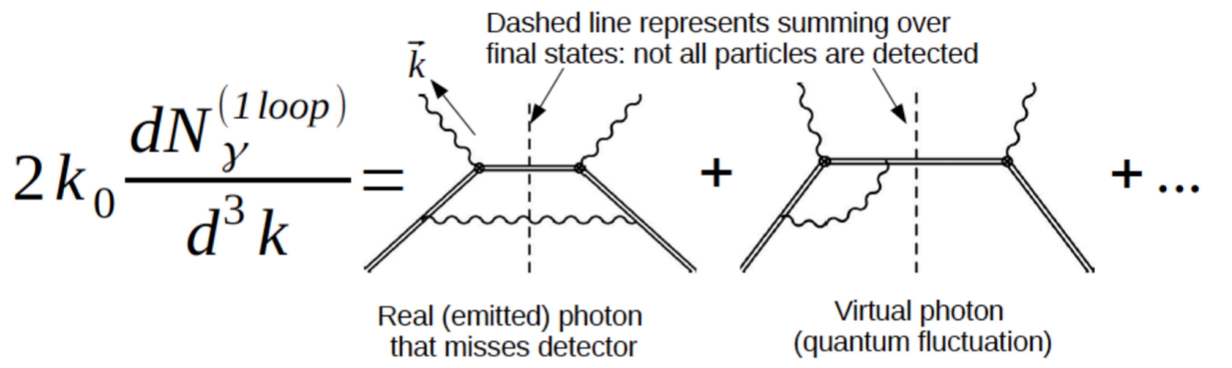


Testing Strong-Field Quantum Field Theories





our SF-EFT suggests 1-loop contribution significant at $\chi_e \sim 1$, 2-loop contribution to be important/dominant at $\chi_e \sim 20\text{-}60$



$$(i\partial\!\!\!/ - e A\!\!\!/_{\rm cl}(x) - m)\psi(x) = 0 \qquad a_0 = \frac{|eA|}{m} \gg 1$$

Typically solved by semiclassical approximation in leading order, tree level.

This semiclassical approximation becomes invalid at some point. Depending on model, when

$\chi_e = E/E_{crit} > 1$ up to $\chi_e\, \alpha^{2/3} > 1 \Rightarrow \chi_e > 1600$

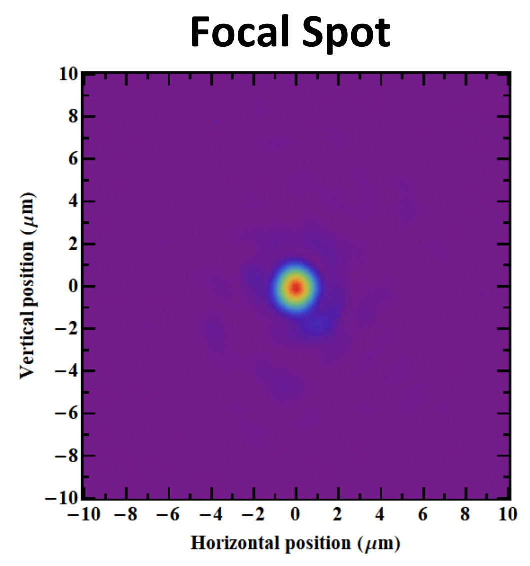
	E_{e-} [GeV]	a_0	χ_e
SLAC	42	<1	0.2
OPAL	30	600	130*
AWAKE-2	50	60	20
ALIC	300	600	>1600*

Relativistic Quantum Photonics

Summary CoReLS: Commissioned 4PW laser system for Advanced Acceleration and Extreme Field Studies

4PW Laser System

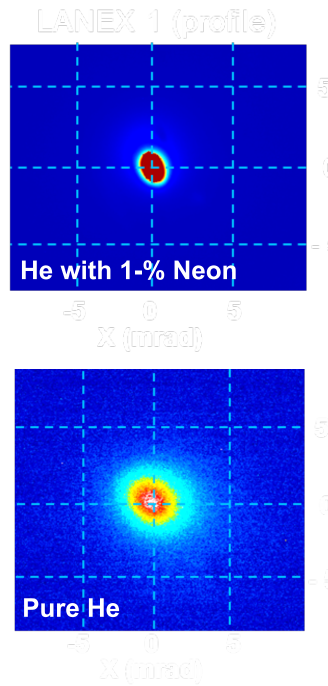
- Petawatt Laser System
  - 2 beam lines: 4PW + 1.5 PW, Ti:Sa
  - 80J (30J), 20fs, 0.1Hz
  - Intensity up to 10^{23} W/cm^2
- 3 experimental stations with permanent setups
  - Long Focus - Wakefield: electrons, betatron, Compton, muons, …
  - Short Focus - Solid Targets: Ions, neutrons, relativistic HHG, gammas
  - Short - Medium Focus - 2 multi-PW beams: ultrahigh intensity, RR, QED

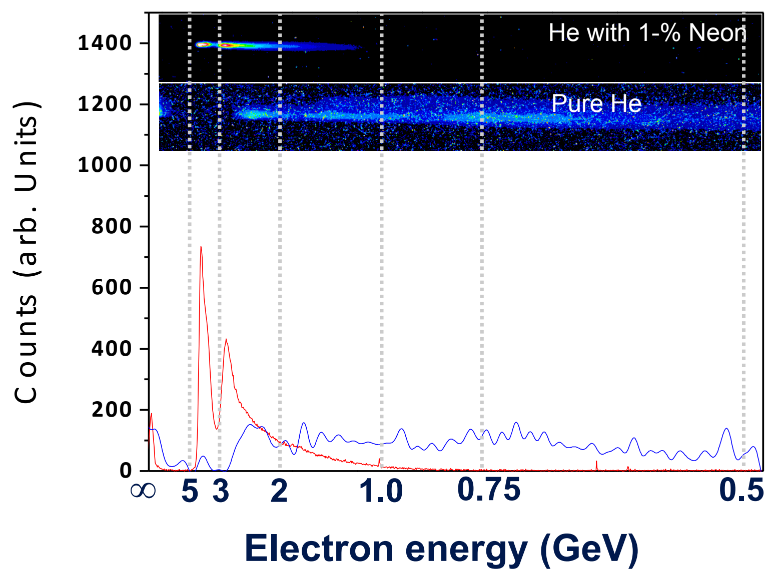


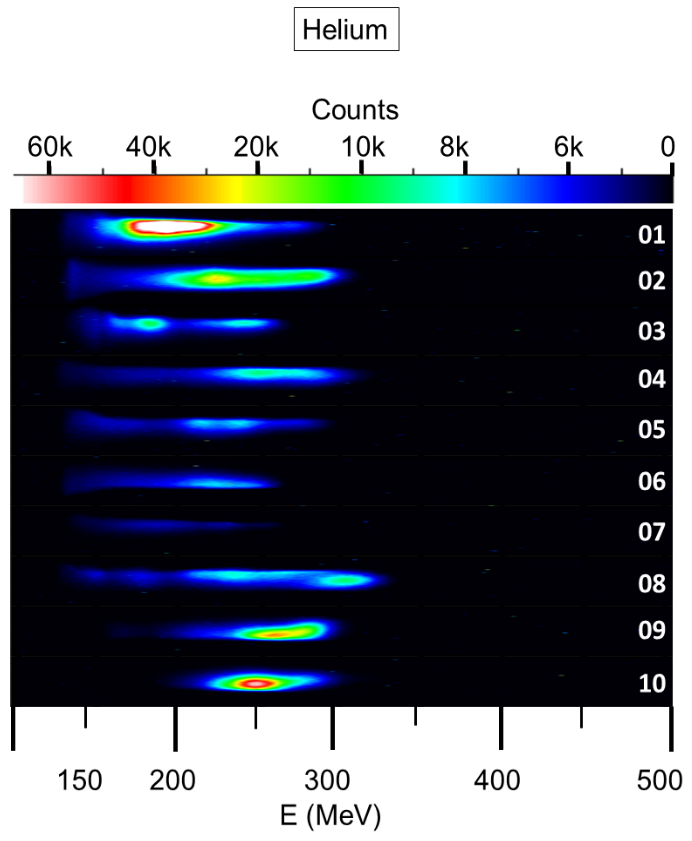
First Results

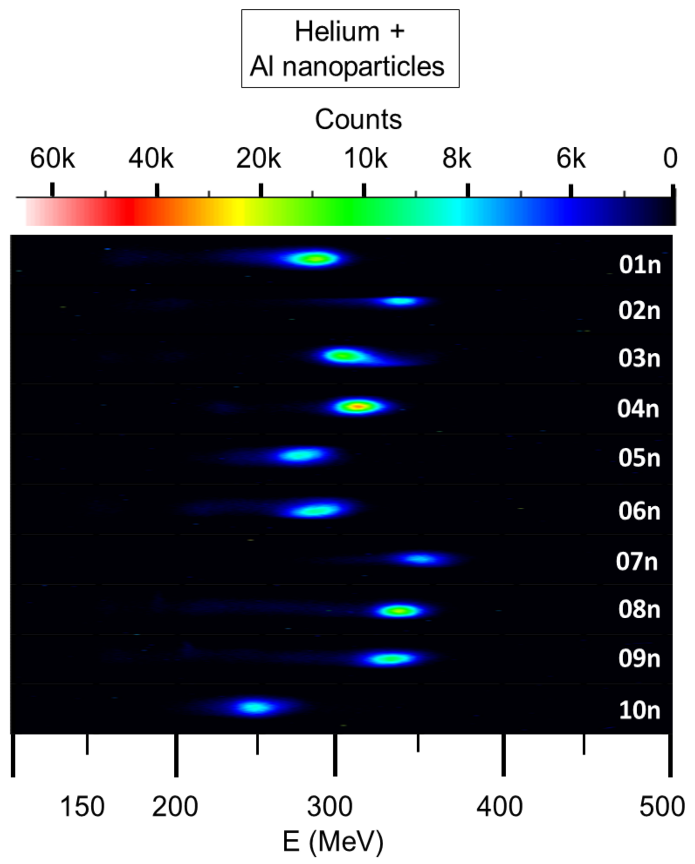
~5 GeV electrons

- First Results in LWFA
  - Electrons up to ~5 GeV
  - Nanoparticle injection: Improved energy, reduced dE/E, divergence
  - Upramp acceleration: Rephasing -> towards 30 GeV
- Opportunities for long term collaborations in Focus Areas
  - Particle & Photon Sources
  - Extreme Fields & non-perturbative QED
  - Laser & Diagnostic Development









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