Laser Wakefield Acceleration with Optically Injected Electrons at the Naval Research Laboratory*

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Femtosecond Terawatt Lasers at NRL

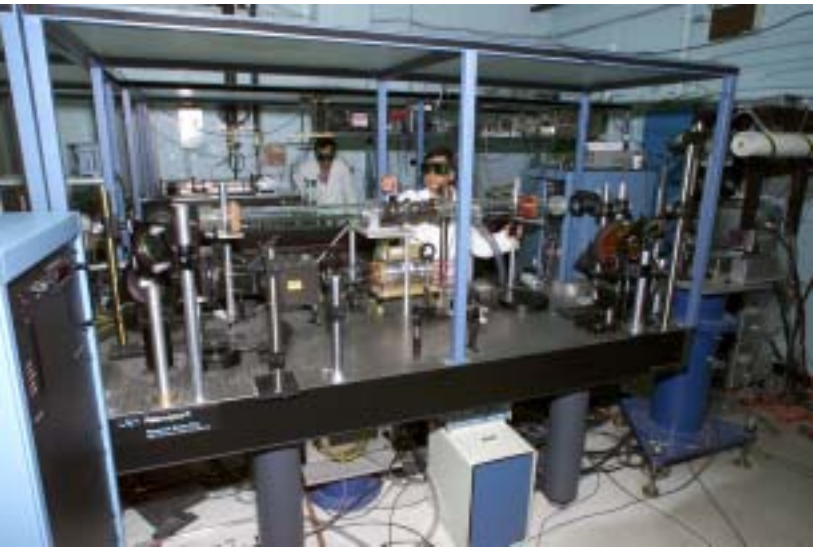
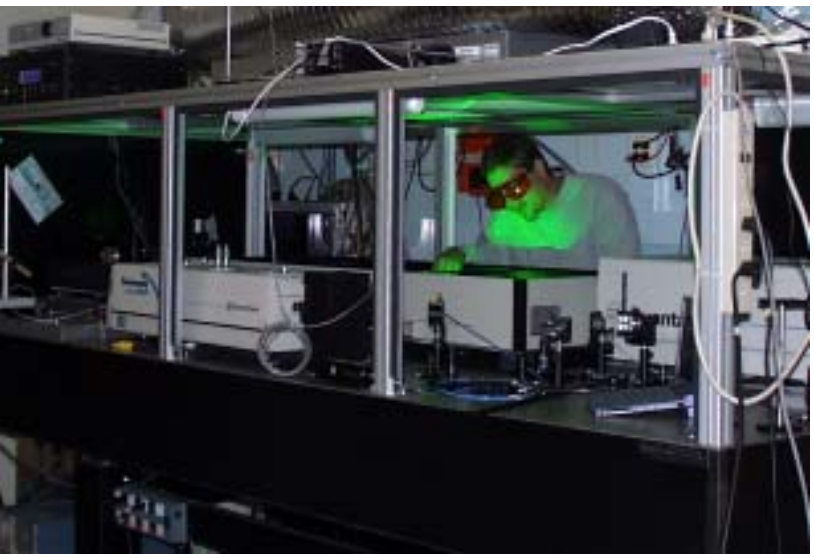


Table-Top Terawatt (T^3) Laser

Laser parameters:

Wavelength	1.05	μm
Pulse length	500	fsec
Pulse energy	>5	J
Rep-rate	15	min
Peak power	>10	TW
Beam diameter	7	cm

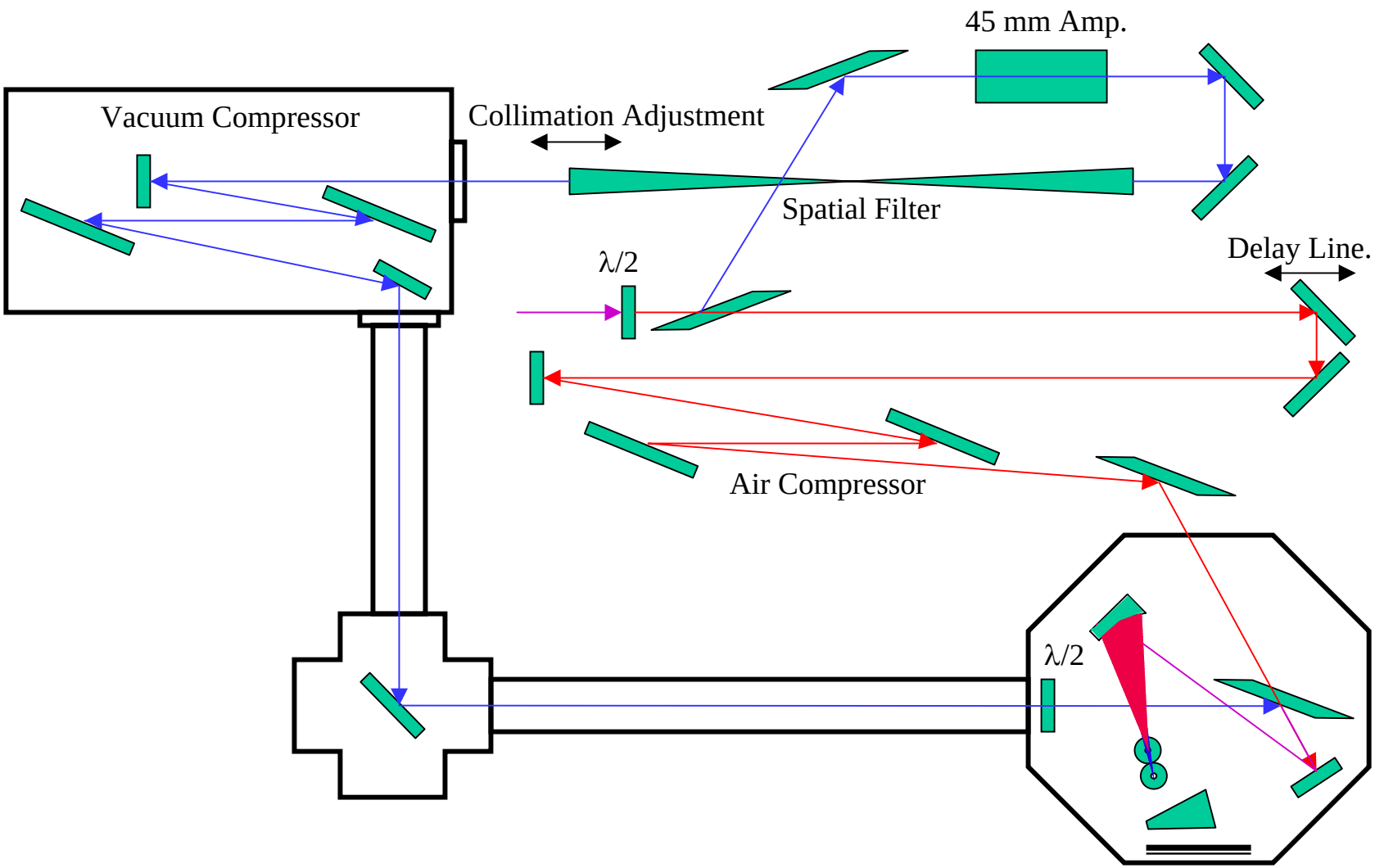


Ti:Sapphire Femto-second Laser (TFL)

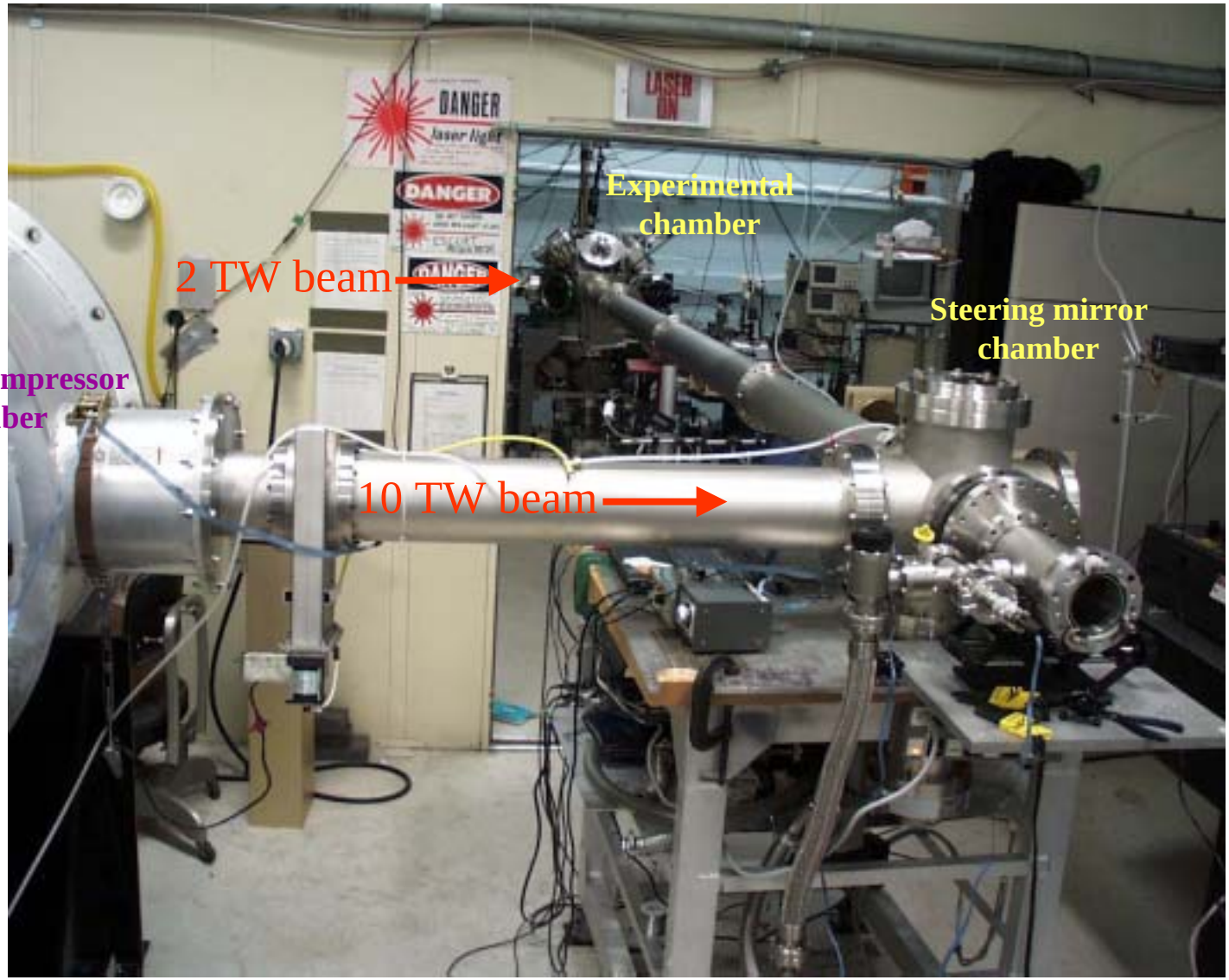
Laser parameters:

Wavelength	0.8	μm
Pulse length	50(40)	fsec
Pulse energy	>40(400)	mJ
Rep-rate	10	Hz
Peak power	>0.8(10)	TW
Beam diameter	7(40)	mm

Ten Terawatt Two Beam T^3 Laser



T^3 Laser 10 TW Beam Line

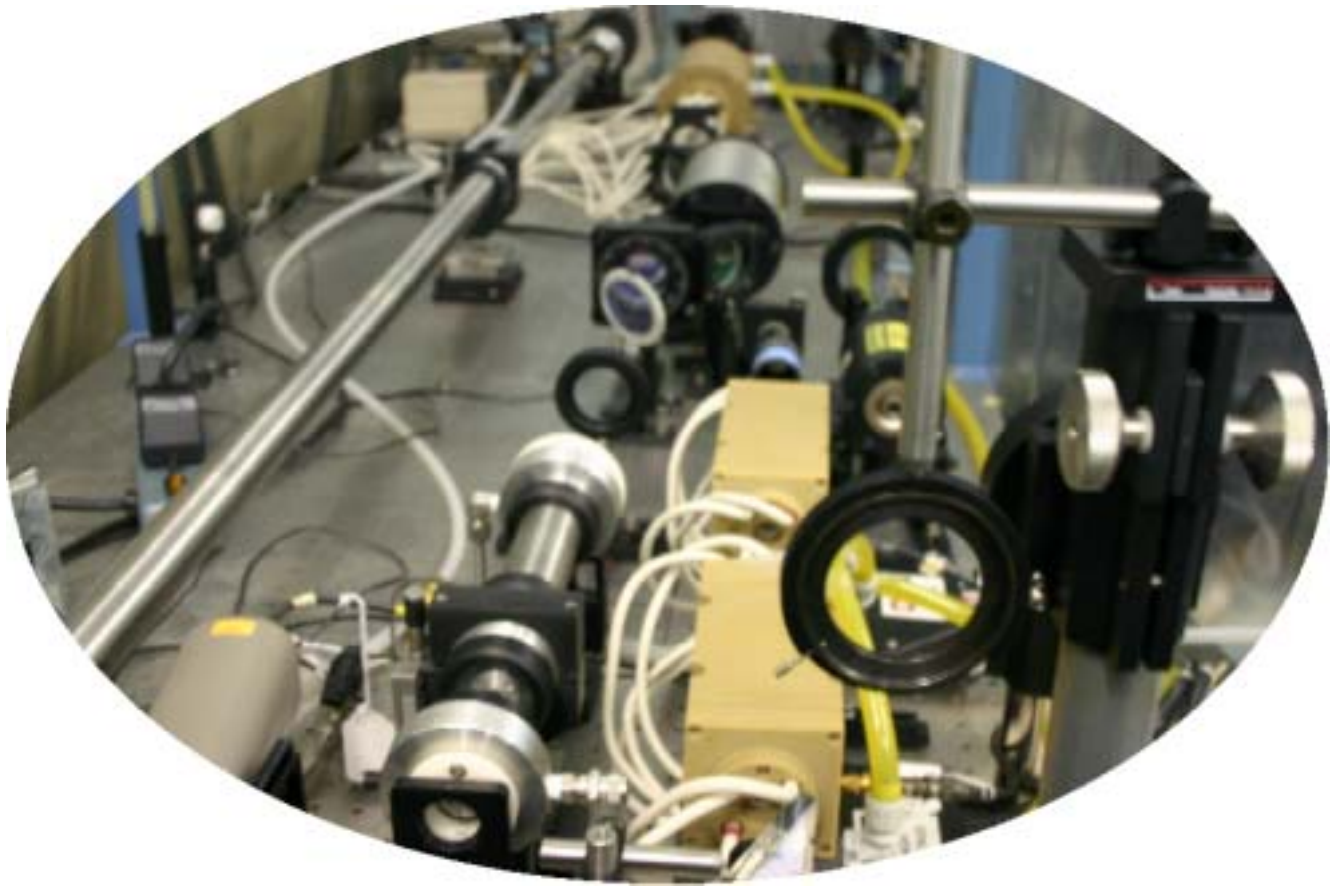


NRL T-cubed Laser Upgrade

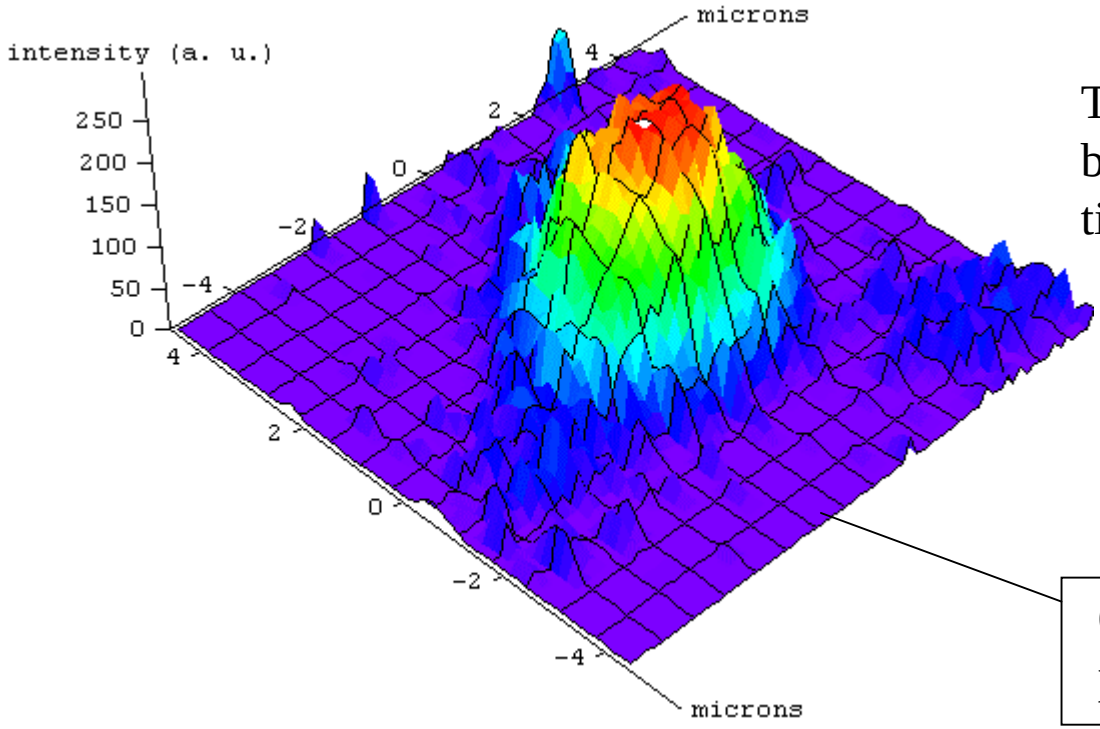
- Temperature stabilization.
  - New air conditioner unit was installed.
  - Temperature stability is 65±0.5°F.
- Amplifier cooling system upgrade.
  - Fire rate increased to 16 minutes between full power shots. Before upgrade was 20 minutes.
- Safety upgrade.
  - New automatic shutter unit.
  - Beam enclosure pipes.

NRL T-cubed Laser Upgrade

- Double pass of 9 mm amplifier.
  - Up to 15 J output before vacuum compressor.
  - All amplifiers operate at 75-80% of the maximum load.



T-cubed Laser Beam Focal Spot



The beam is focused by F#1.3 off-axis parabola (F.L.= 9cm, 45º).

The focal spot picture was taken by microscope camera with 36 times magnification.

90% of the Energy in spot size of 3 μm.

One square is 2 by 2 pixels of the camera

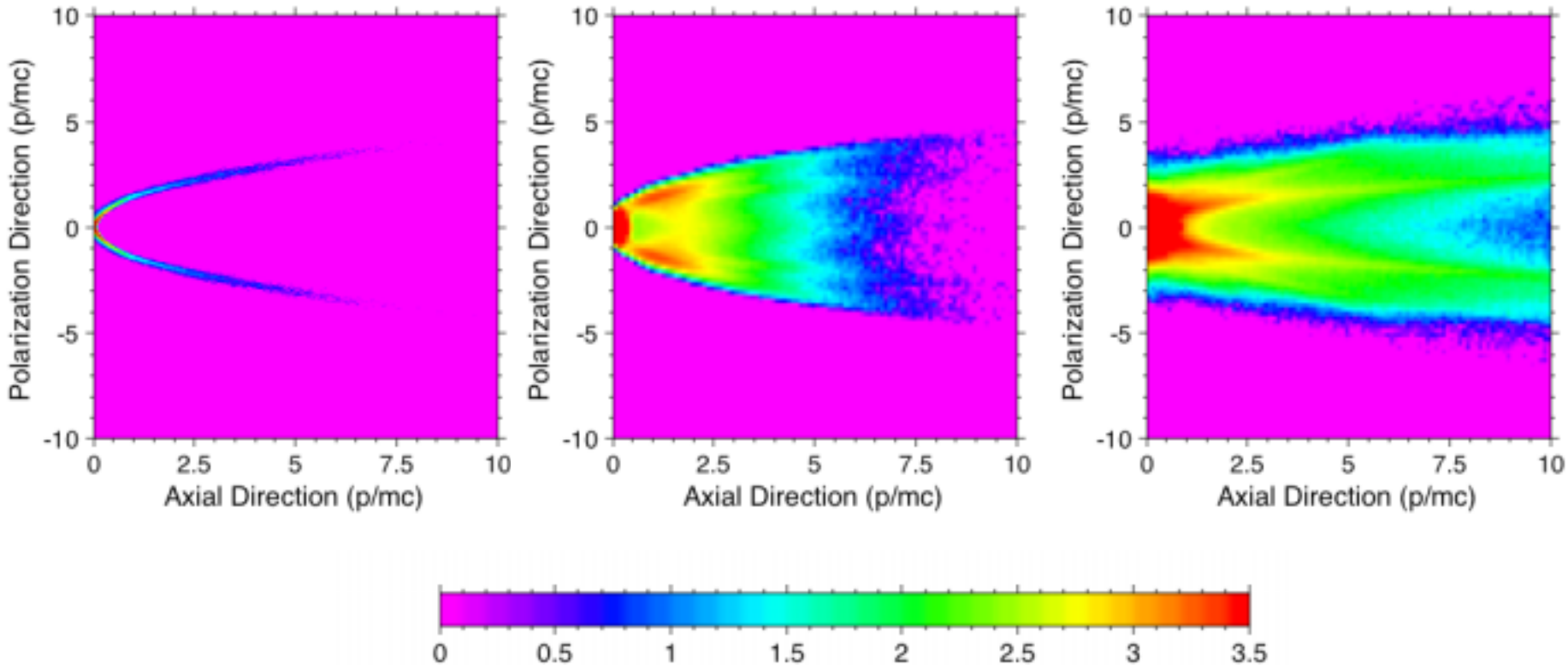
High Density LIPA

Gas = Nitrogen , Power = 10 TW , Spot Size Radius = 3 µm, Pulse Length = 400 fs

Momentum space from 2D PIC with atomic density = 1.1×10^{11} cm^{-3}

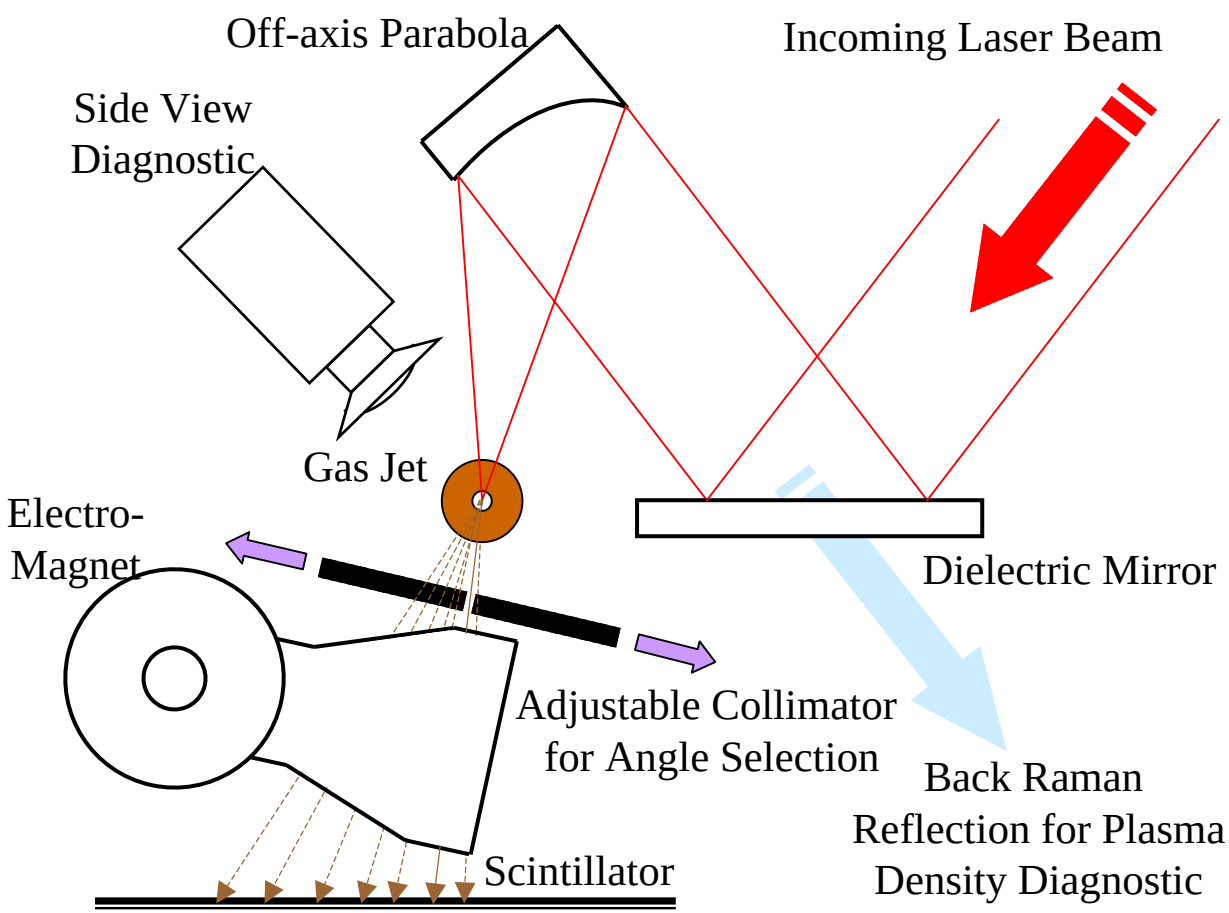
Momentum space from 3D PIC with atomic density = 1.1×10^{16} cm^{-3}

Momentum space from 3D PIC with atomic density = 1.1×10^{18} cm^{-3}



2 + Log(simulation particles/m^{2}c^2)

NRL Electron Injector Experimental Setup



Experimental Parameters

Laser 10 TW (500 fs, 5 J)

Wavelength 1053 nm

Intensity on target ~10^{19} W/cm^2

Parabola F#2 (focused the beam to < 10 μm diameter)

Gas Jet N_2 ~10^{18} neutral density. Nozzle 0.5 mm output.

Magnet 5 cm sector, maximum field 2.5 kG

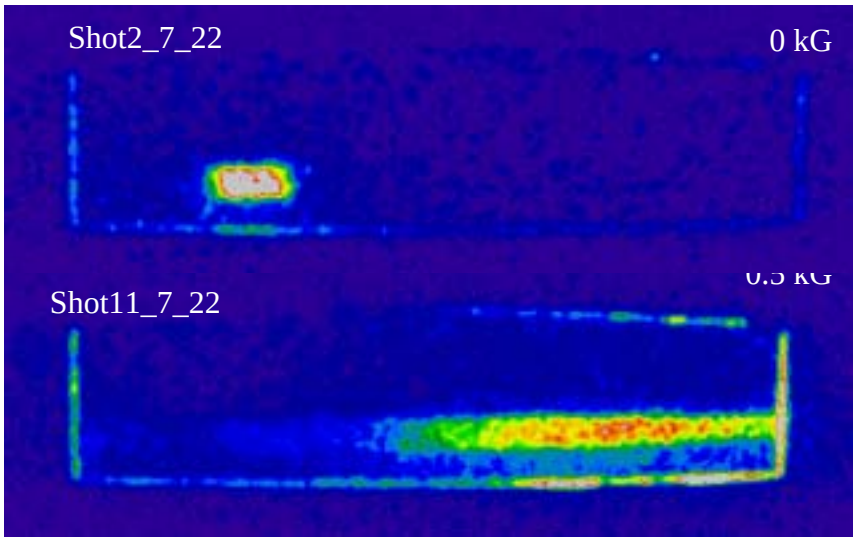
Scintillator 1 mm BC-400, covered by 40 μm of Al foil.

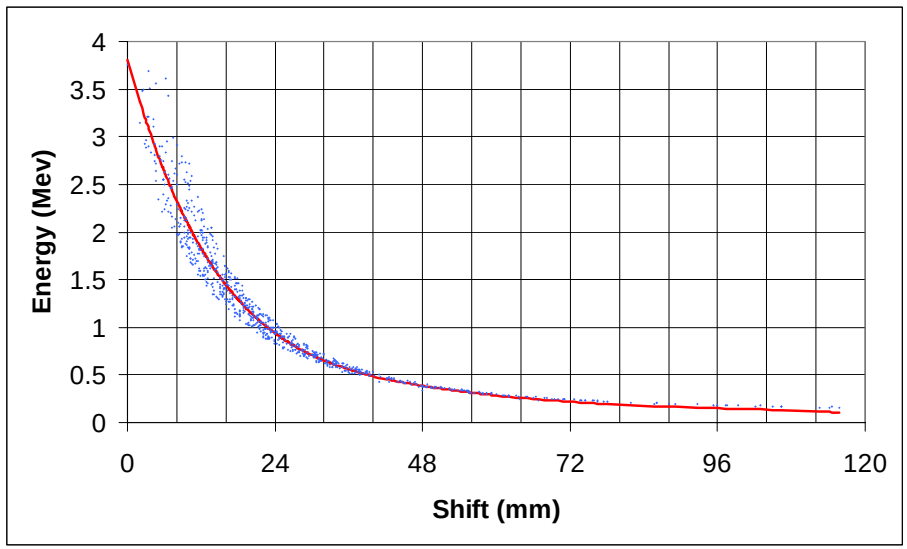
D. Kaganovich, APS-DPP (2003)

Electron Spectrometer Output and Calibration

Electron spectrometer output for 30 degrees setup without magnetic field (upper picture) and with 0.5 kG field (lower picture).

Electron spectrometer calibration for 20 to 30 degrees setup and 0.5 kG field. Simulated using CyberRay (D. Gordon).



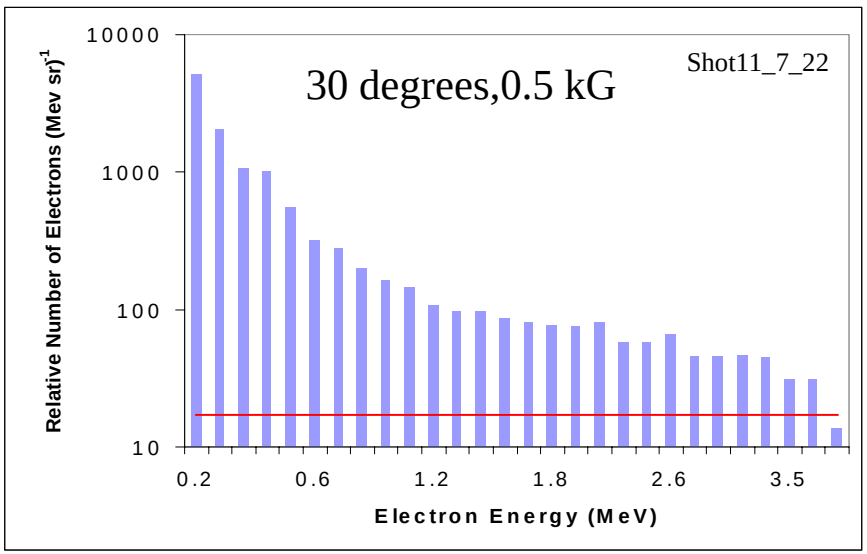


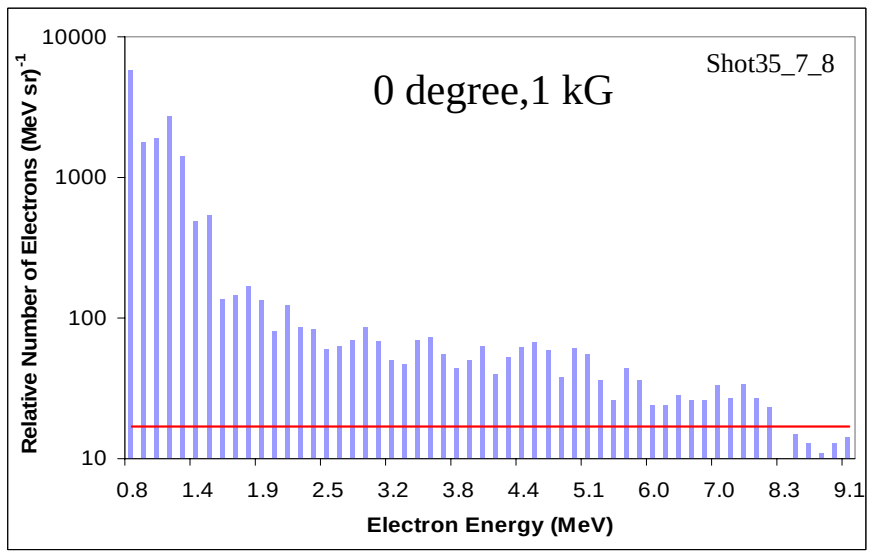
Experimental Electron Spectra

- Electrons at 30° has high energies as predicted by LIPA
- Electrons at 0° has much higher energies
  - — further acceleration in the plasma
  - — suitable for injection into 2nd stage acceleration
- High number of electrons detected, >10^5 in F/16 cone

~ 10^{19} W/cm^2 laser intensity, ~10^{19} cm^{-3} plasma density

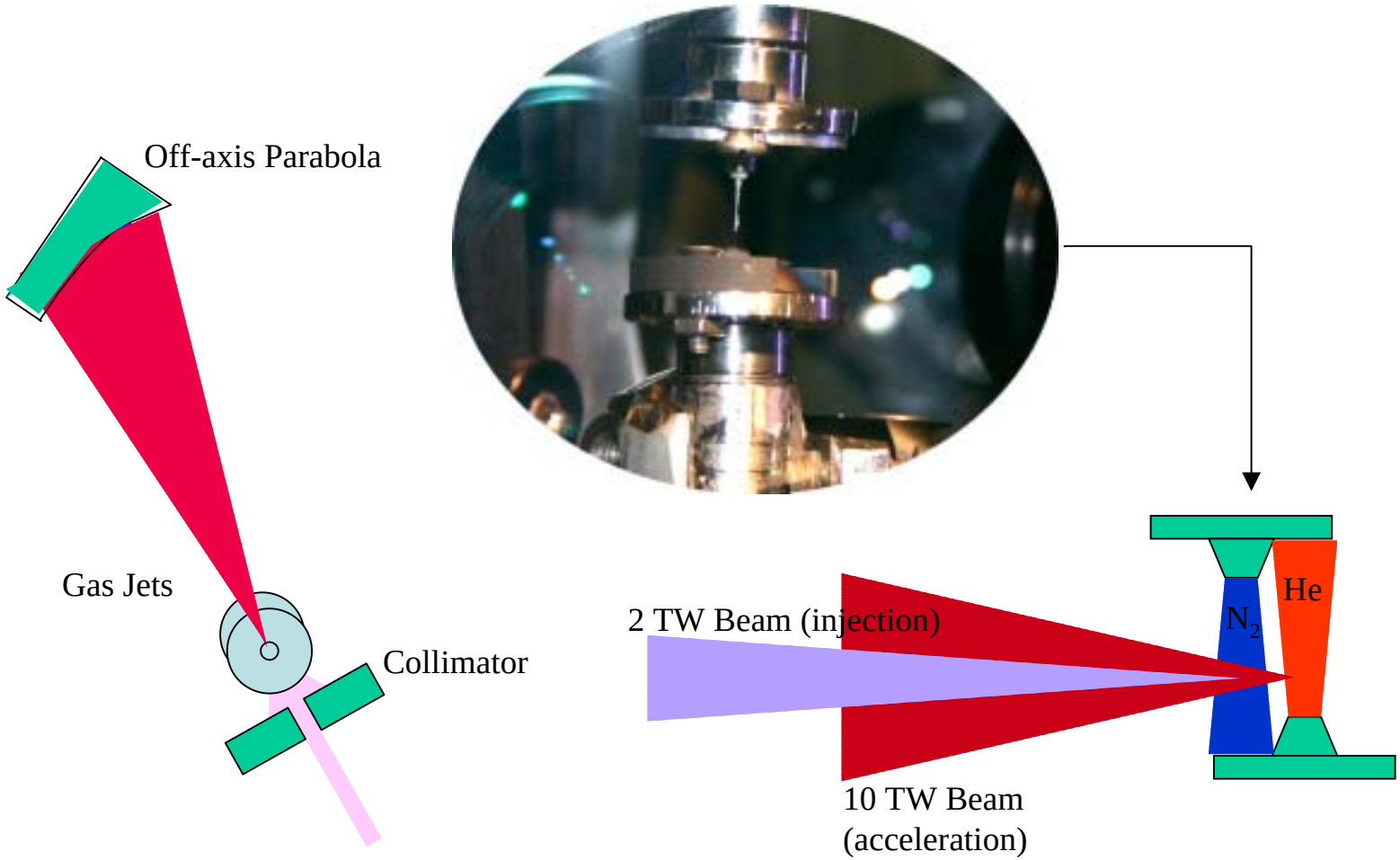
Detector noise level





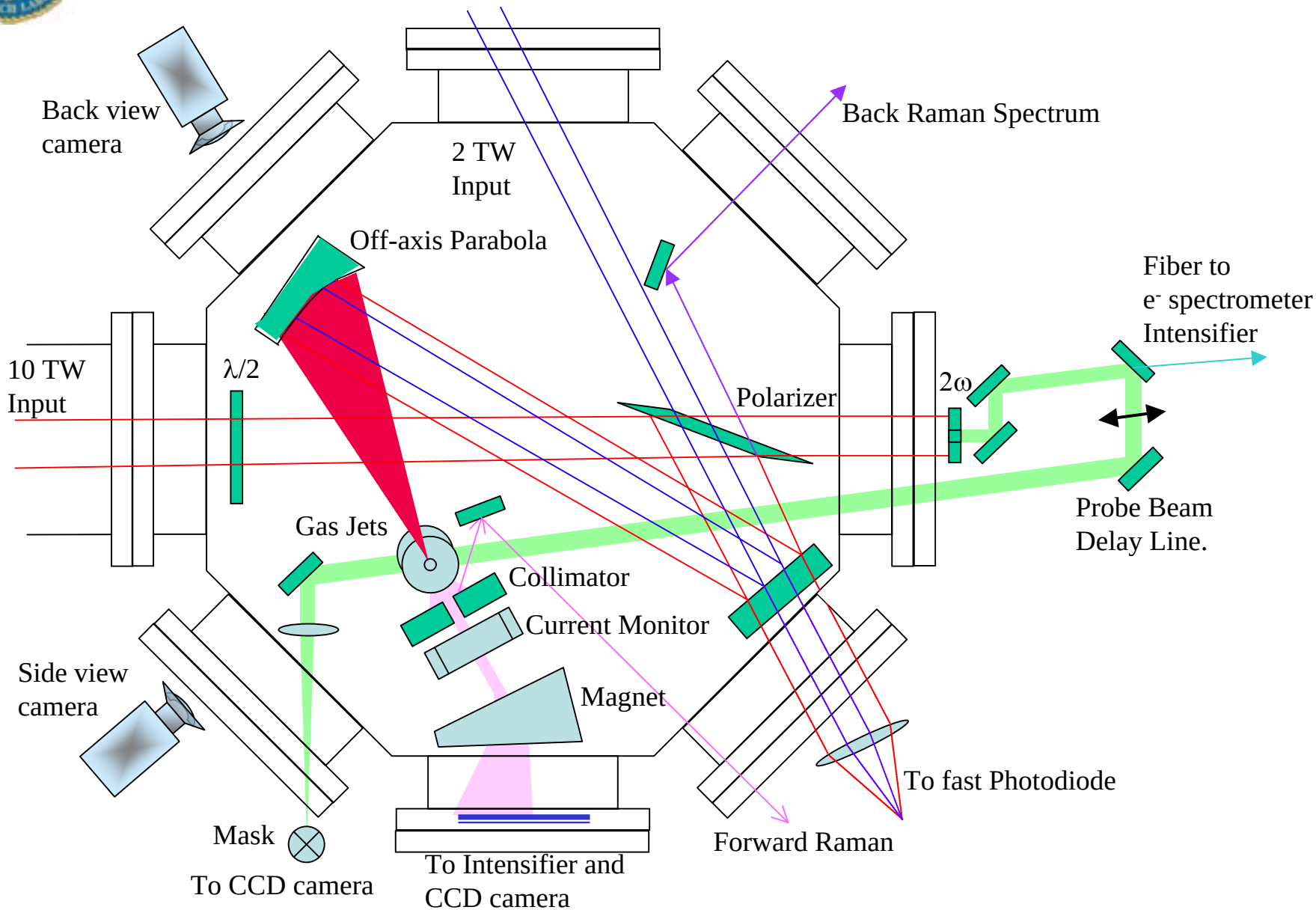
Staged Optical Injection and Laser Wakefield Acceleration

- **Synchronized, collinear, two jet, two-beam (2TW/10TW) laser configuration**



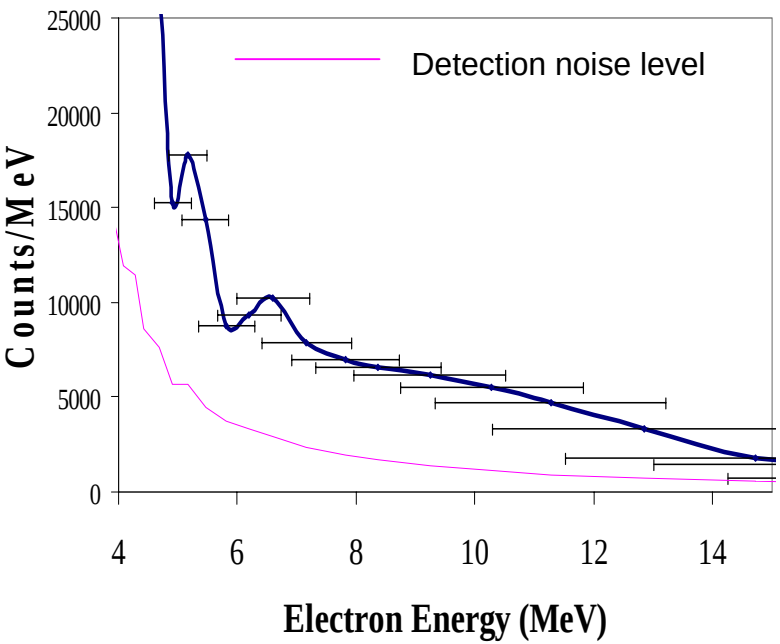
Top view **Side view**

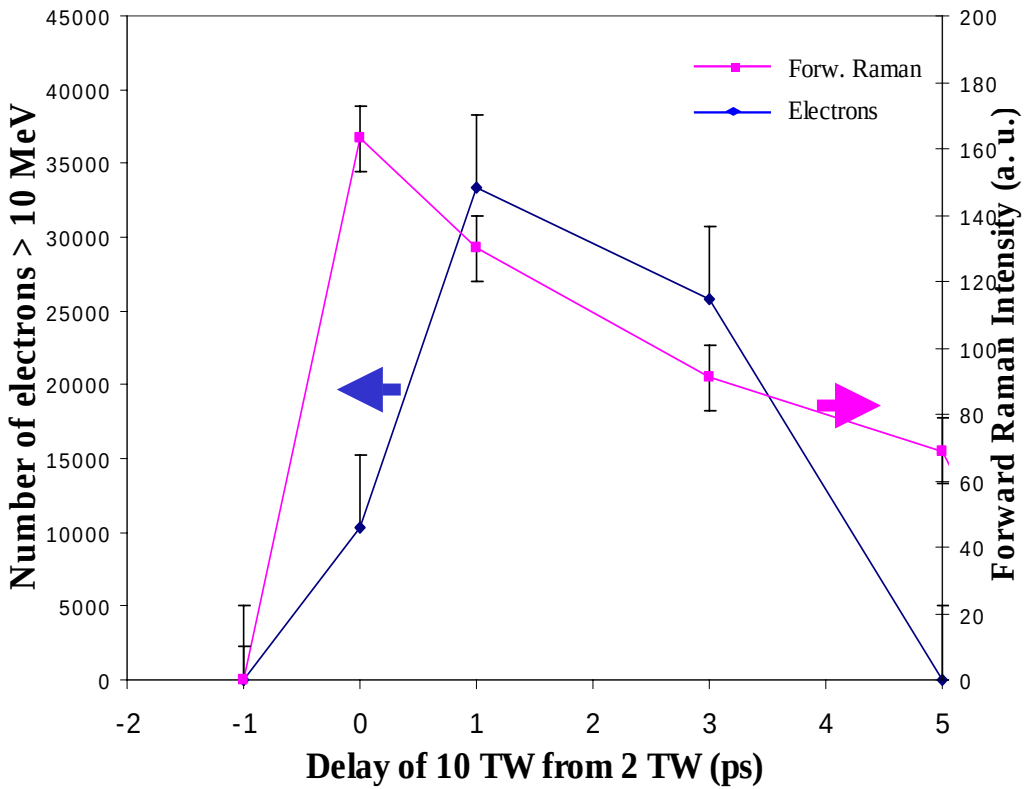
Two Laser Beams, Two Gas Jets Experiment.



First demonstration of staged optical injection/acceleration LWFA experiment

- **Injection electrons <0.5 MeV (high-density LIPA)**
- **Accelerated electrons >10 MeV**
- **Injection/Acceleration occurs only for time delays of <4 psec**
- **Delay of electrons from peak forward Raman signal shows:**
  - **Injection electrons not from background plasma**
  - **Slippage of injection electrons from laser pulse**

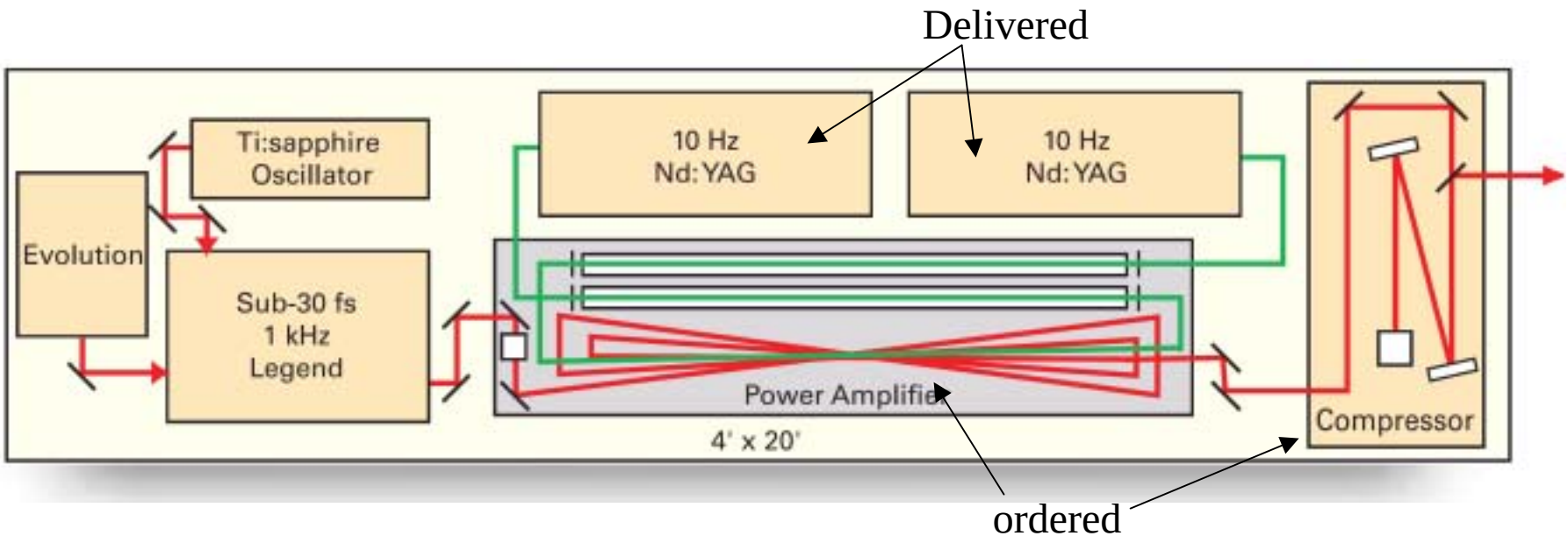




10 TW Ti:Sapphire Femtosecond Laser (TFL) Upgrade

Laser upgrade parameters:

Pulse energy: >400 mJ
Pulse length: 40 fsec
Peak power: 10 TW
Rep. rate: 10 Hz
Pump lasers: Two 1.2 J Nd:YAG lasers at 532 nm
Amplifier: 4-pass, 16 mm dia. Ti:Sapphire crystal



Summary

- **"High density LIPA" produces favorable injection electrons:**
  - **High energy electrons at 0° can simplify experimental setup**
  - **Electron energy > LIPA theory prediction $\Rightarrow$ injection + acceleration (agrees with simulation)**
  - **Large number of electrons, >10^5 in F/16 solid angle (acceptance of capillary)**
- **Injection-Acceleration experiment demonstrated and produced high energy electrons**
  - **>20 MeV were detected, corresponding to ~20 GeV/m accelerating field**
  - **Injection time window is < 4 ps**
  - **Injection energy ~ 150 keV**
- **Capillary chamber is ready and 10 TW, 10 Hz Ti:Sapphire Femtosecond Laser (TFL) upgrade in Aug., 2004 for Injection-Acceleration-Channel experiment**