Low Energy RHIC electron Cooling (LEReC)

High-power Fiber Laser System for LEReC

Zhi Zhao

DOE Review
Nov 16-17, 2016

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a passion for discovery

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Outline

- **Laser parameter review**

- **Laser progress report**

- **Laser control for beam operation**
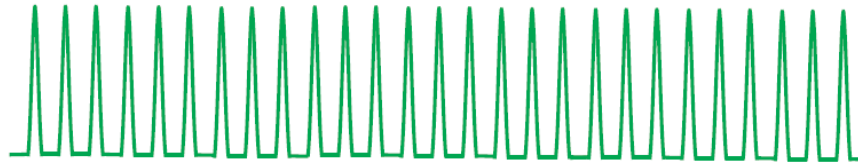
- **Conclusion**

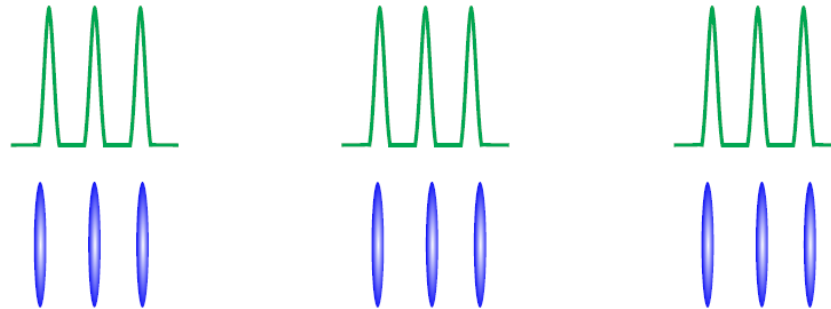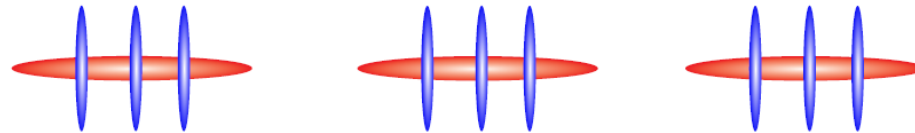# Laser Parameter Review

Laser Pulse Pattern for LEReC

Laser pulses
704 MHz

Laser bunch
Electron
9.1 MHz

Electron/Ion
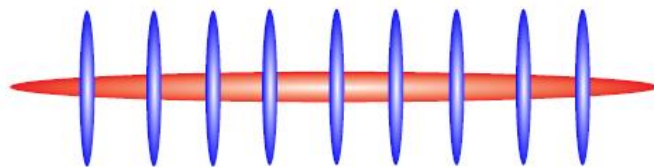9.1 MHz

Pulsed mode: 704 MHz, 9.1 MHz bunch rate, 10-30/bunch
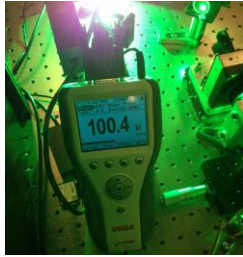
CW   mode: 704 MHz

Laser Energy & Power for LEReC

- **Electron bunch charge:**   130 pC   300 pC   120 pC

- **Laser energy (QE=1%):**   31 nJ   72 nJ   28 nJ

- **Repetition rate (MHz):**   9.1 x30 = 273   9.1x18 = 164   704

- **Green power on cathode:**   8.5 W   12 W   20 W

- **Green power from laser:**   8.5x3 =25.5 W   12x3=36 W   20*3 =60 W

A higher laser power capability, a factor of 2-3, would be needed
to achieve stable and reliable operation for beam experiment!
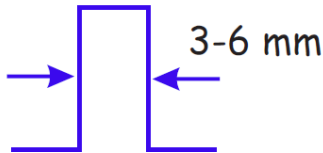
Laser Design Specifications
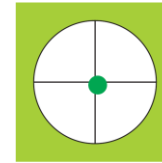
- **Green average power: 100 W**
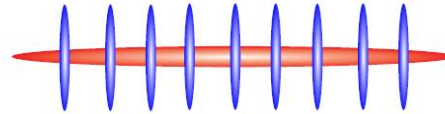
- **Spatial profile: M^2<1.2**

3-6 mm

- **"Flat-top" temporal profile**

80 ps

- **Timing jitter: 1 ps rms**

- **Point instability: 10 μm rms**

- **Stability & reliability**

power/jitter/spatio-temporal/position

Time (24/7)
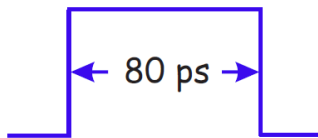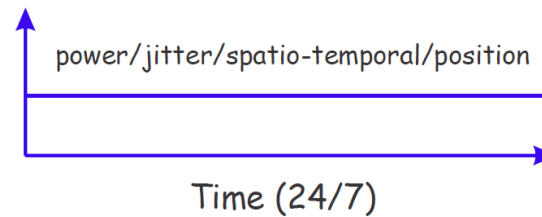
Laser Progress Report

Yb-doped Fiber Amplifier

Master oscillator power amplifier

Seed → Preamp → Amp → frequency doubling → green light
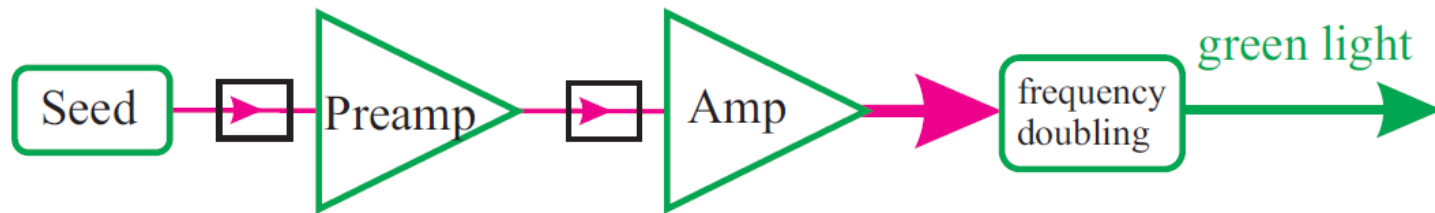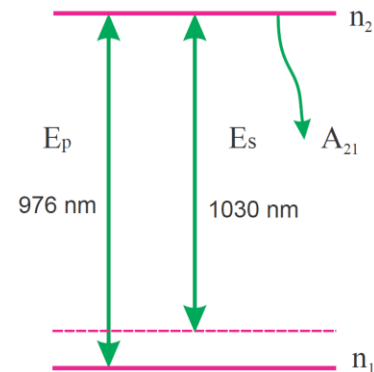
Advantages for fiber lasers

- High slope efficiency & average power

- Excellent thermal management

- Excellent spatial mode & point stability
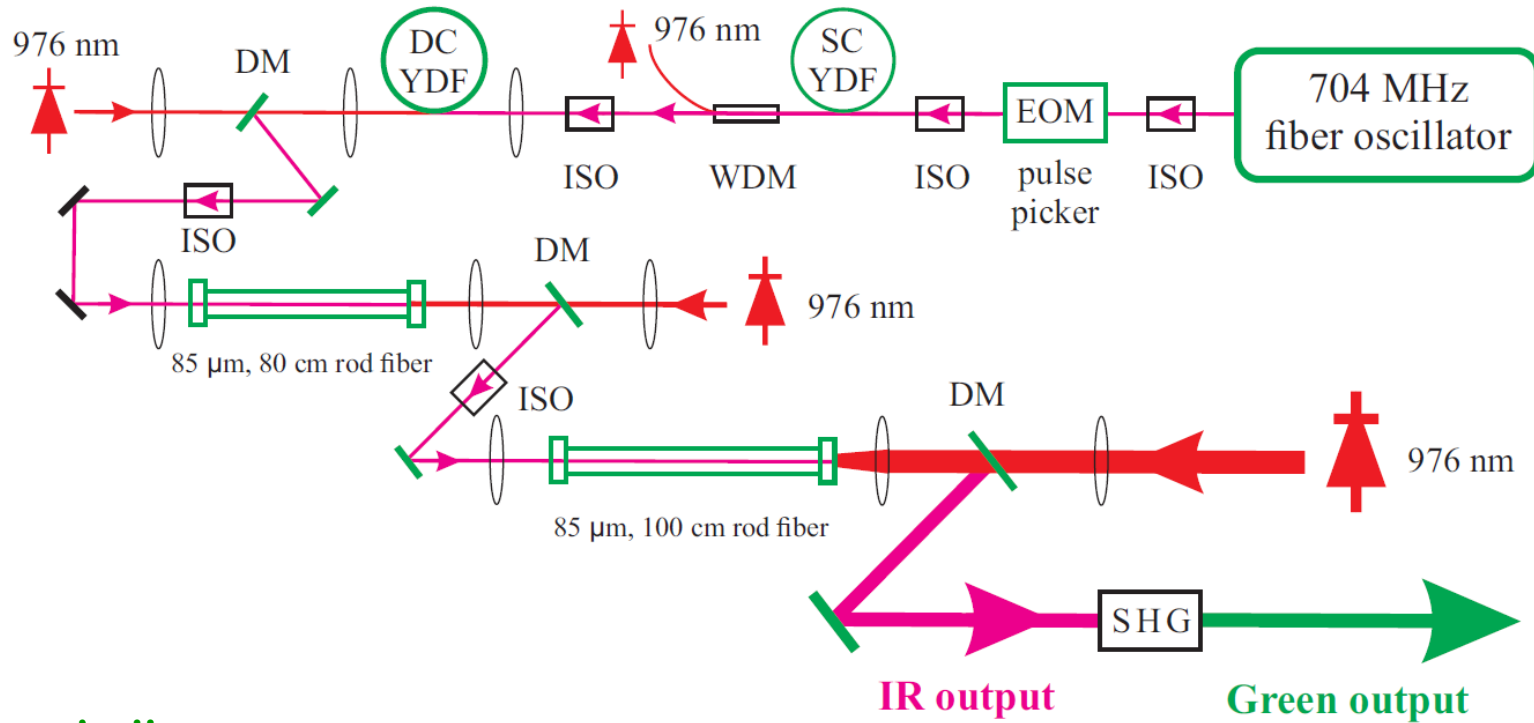
- Maintenance–free operation

Energy structure

n_2

E_p E_s A_{21}

976 nm   1030 nm

n_1

Yb-doped fiber (YDF) will be used in the laser system.
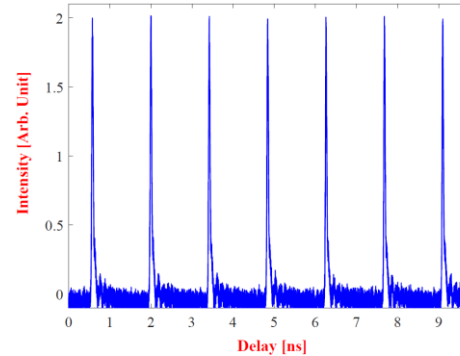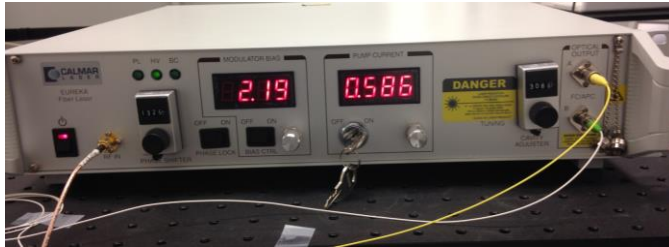
Fiber Laser System

Key challenges:

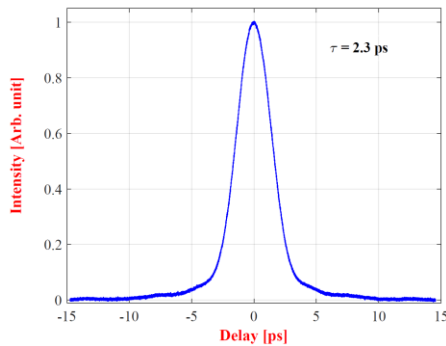- **Physical & technical limitations**

- **System engineering issues**

Mode-locked Fiber Oscillator (I)

- **High-harmonic mode-locked oscillator**

- **704 MHz (115th X 6.13MHz)**
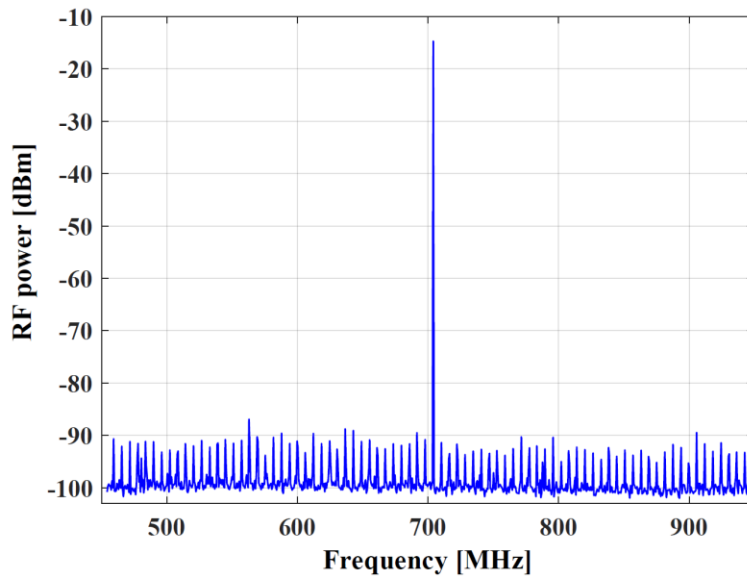

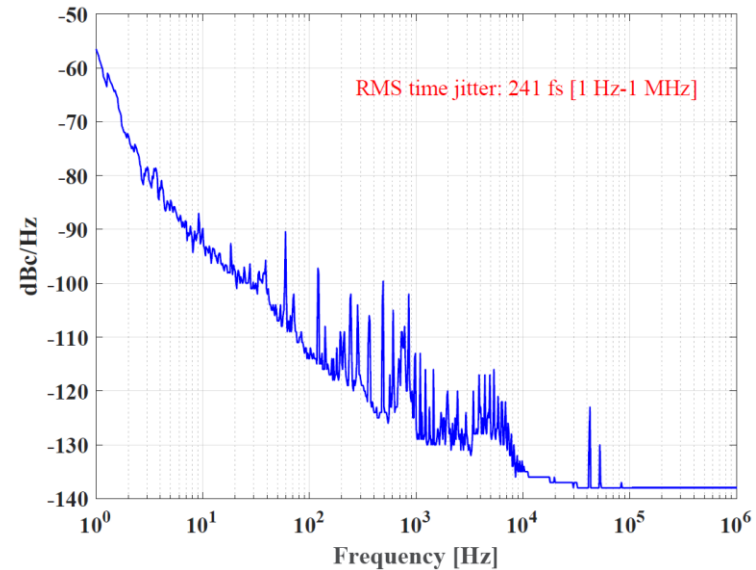

- **Pulse duration**

- **Optical spectrum**

$\tau = 2.3$ ps
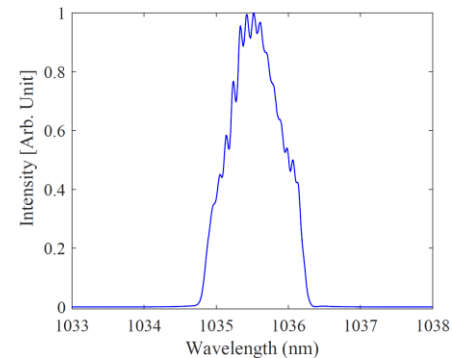
Time-bandwidth-product: 0.52

Mode-locked Fiber Oscillator (II)

- **RF spectrum measurement**

- **Phase noise measurement**

- **RF sideband suppression: < 70 dB**

- **RMS time jitter@704 MHz: 241 fs [1 Hz — 1 MHz]**
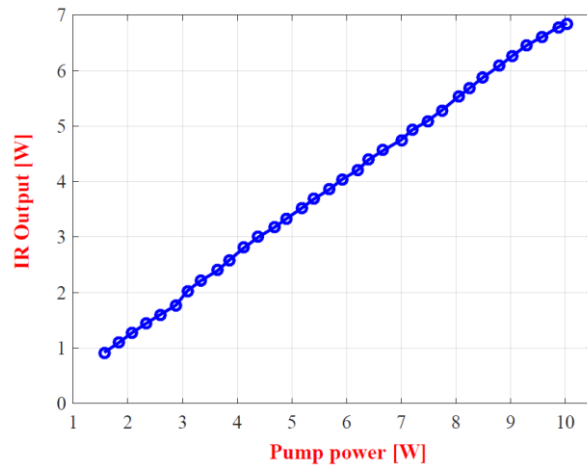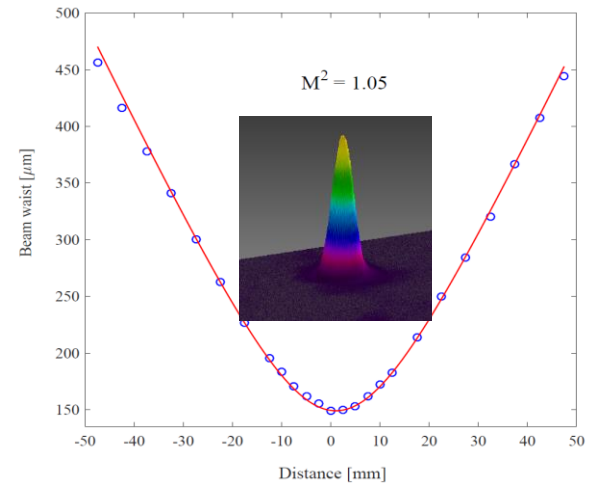
Specification for time jitter has been met.

PCF Preamp II
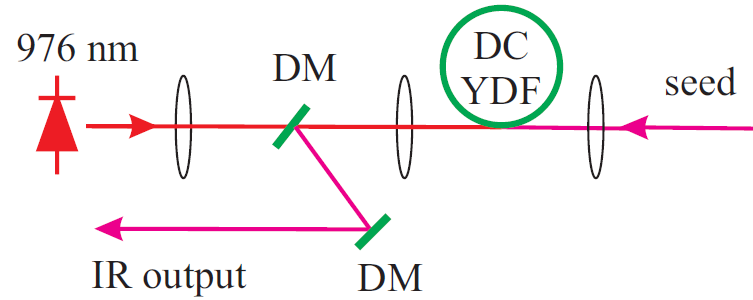
IR output from DC YDF preamp

M^2 value

$M^2 = 1.05$

Rod Fiber Preamp III
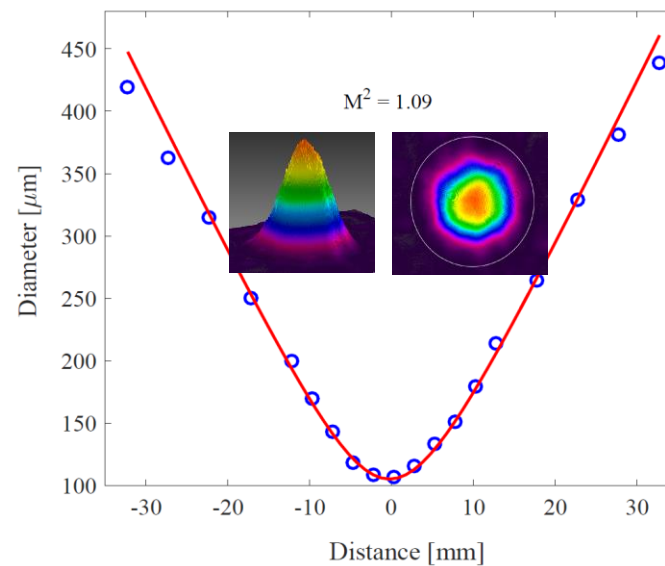

seed   85 μm, 80 cm rod fiber   DM   976 nm

DM   ISO   IR output
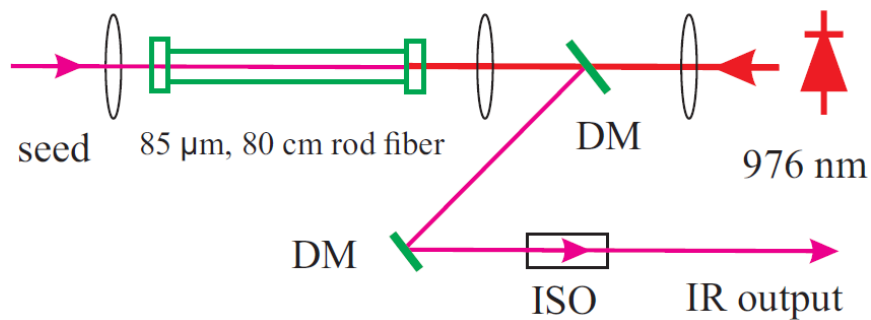
IR Output from rod preamp

M^2 value

$M^2 = 1.09$
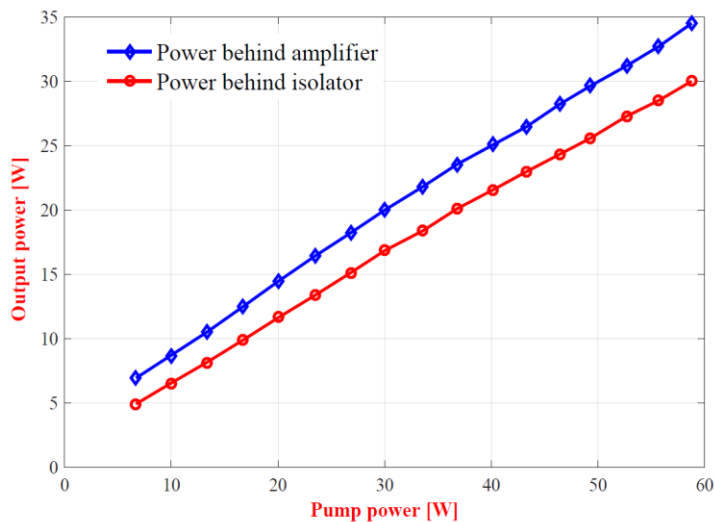
Main Rod Fiber Amplifier

seed   pump
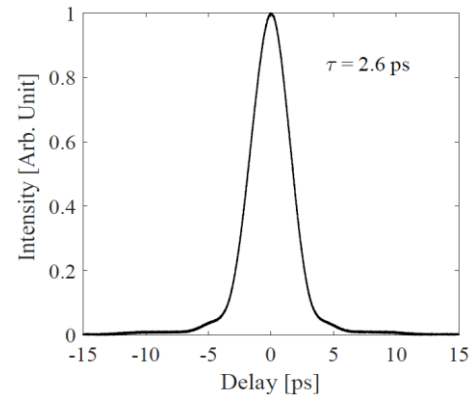
85 μm, 100 cm rod fiber
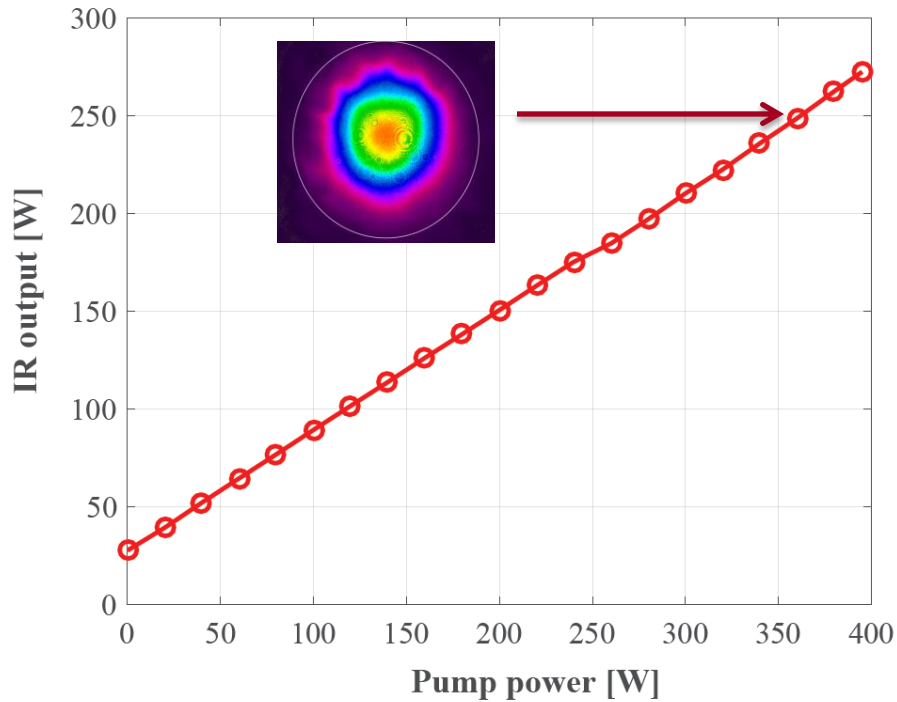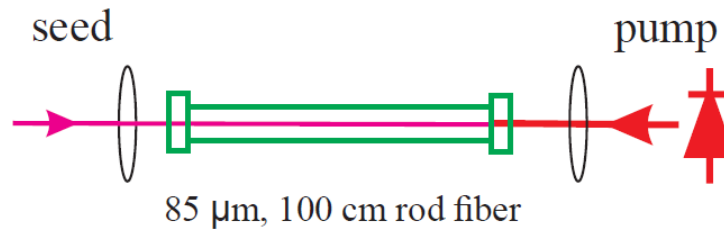
IR: Pulse Characterization
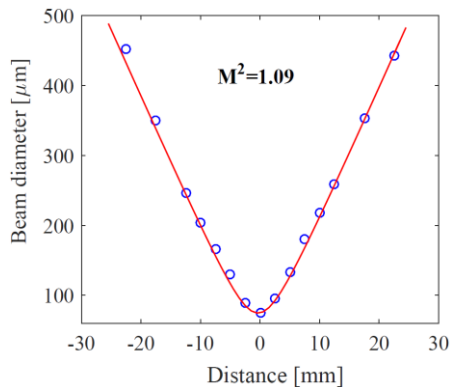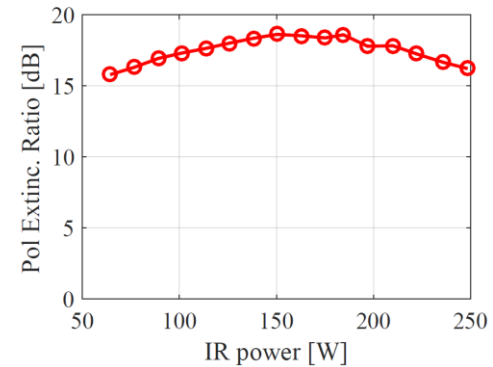
- **Optical spectrum**
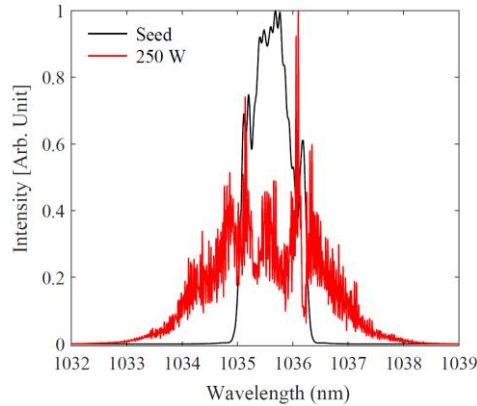
- **Pulse duration@250 W**

- **M^2 value@250 W**

- **Pol extinction ratio**

IR: Power Stability & Beam Point Stability

- **Laser power stability**
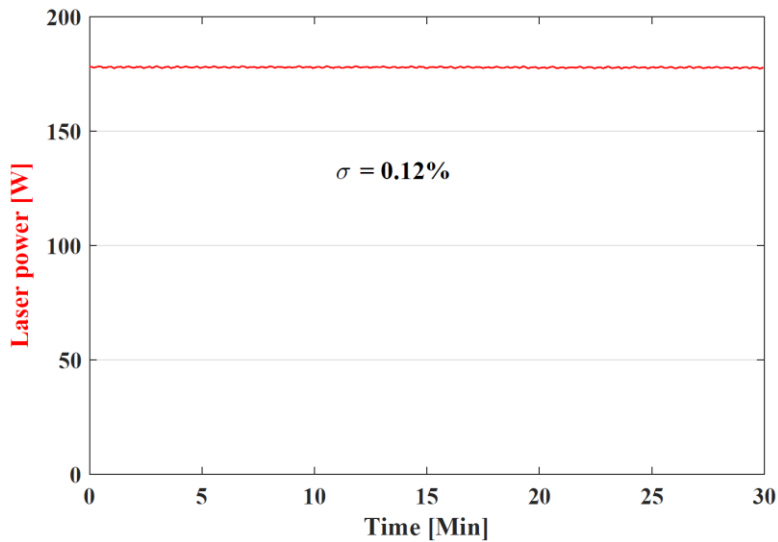
- **Laser beam point Stability**
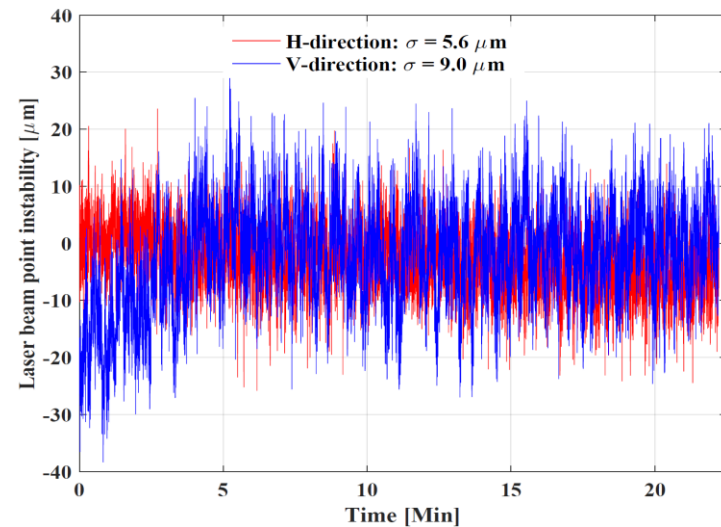
Measurements are done at 180 W.

Green Light Generation

Frequency doubling: noncritical phase matching
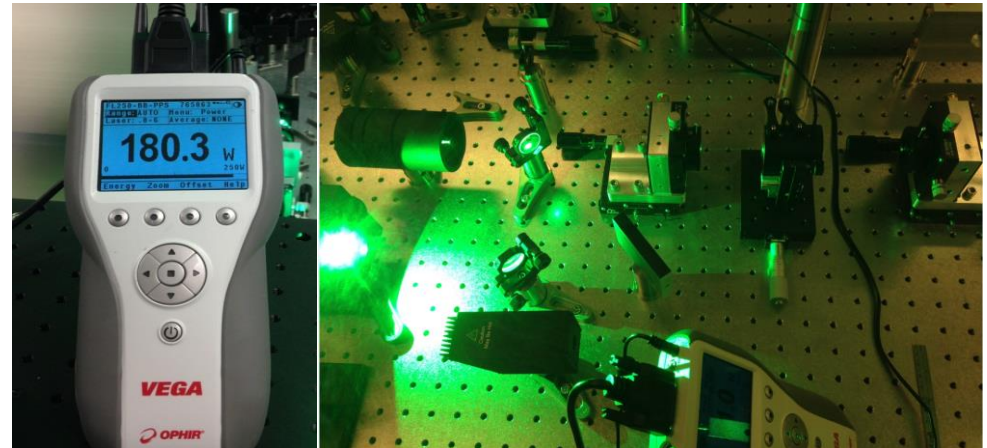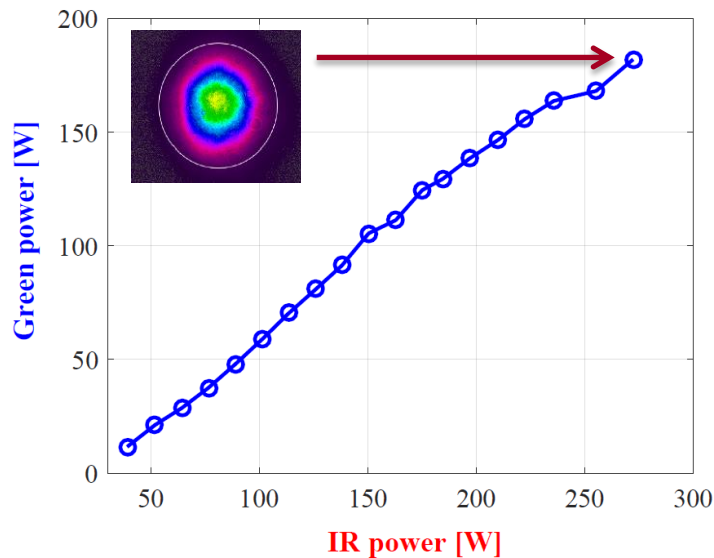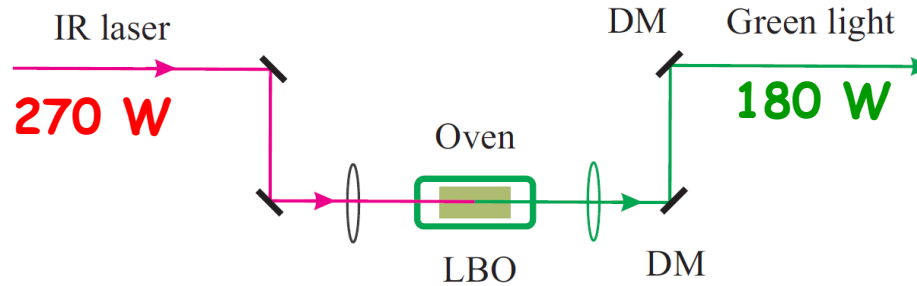
Highest average green power in the fiber-based laser!

Green Light: Pulse Characterization

- **Pulse duration@100W**

$\tau = 2.1$ ps
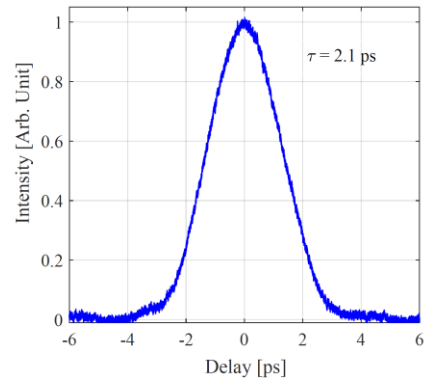
- **Autocorrelator for ps green light**

- **M^2 value@100W**

$M^2 = 1.08$

- **Power stability**

$\sigma = 0.5\%$
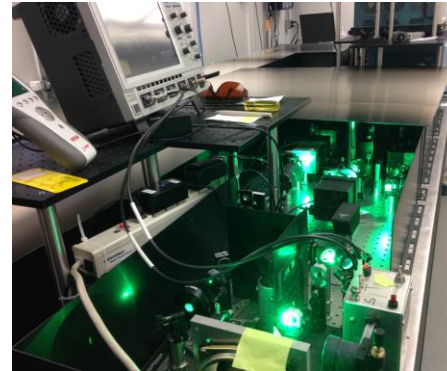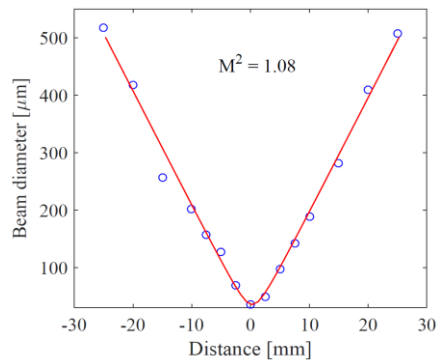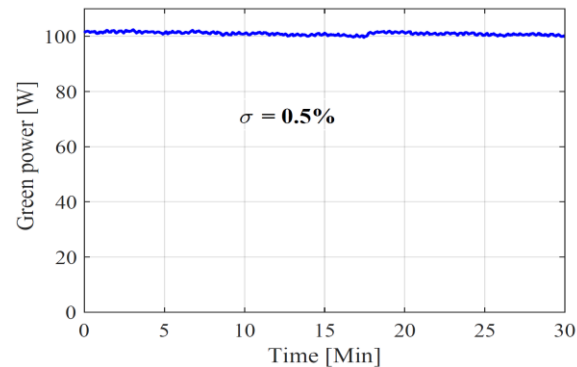
Specifications for laser power and spatial mode have been met.

Green Light: Beam Point Stability

- **Point stability@60 W**
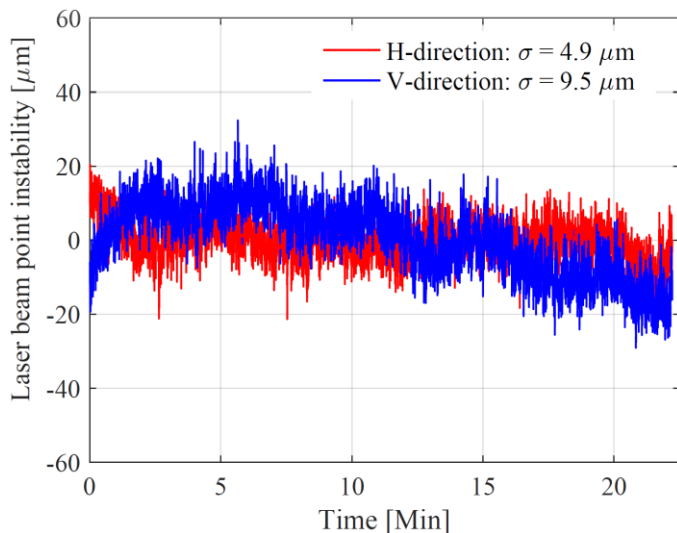
- **Point stability@100 W**
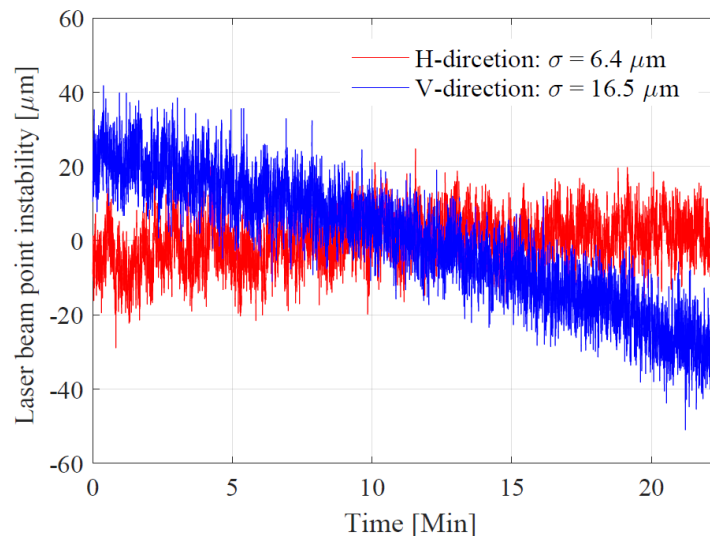
Specification for laser beam point stability has been met.

Fiber Laser System

Main amplifier
Preamp III
Preamp II
Preamp I

Oscillator

Frequency doubling

Diagnostics tools

Pump diode & 5x13x2ft^3 table in the RD room
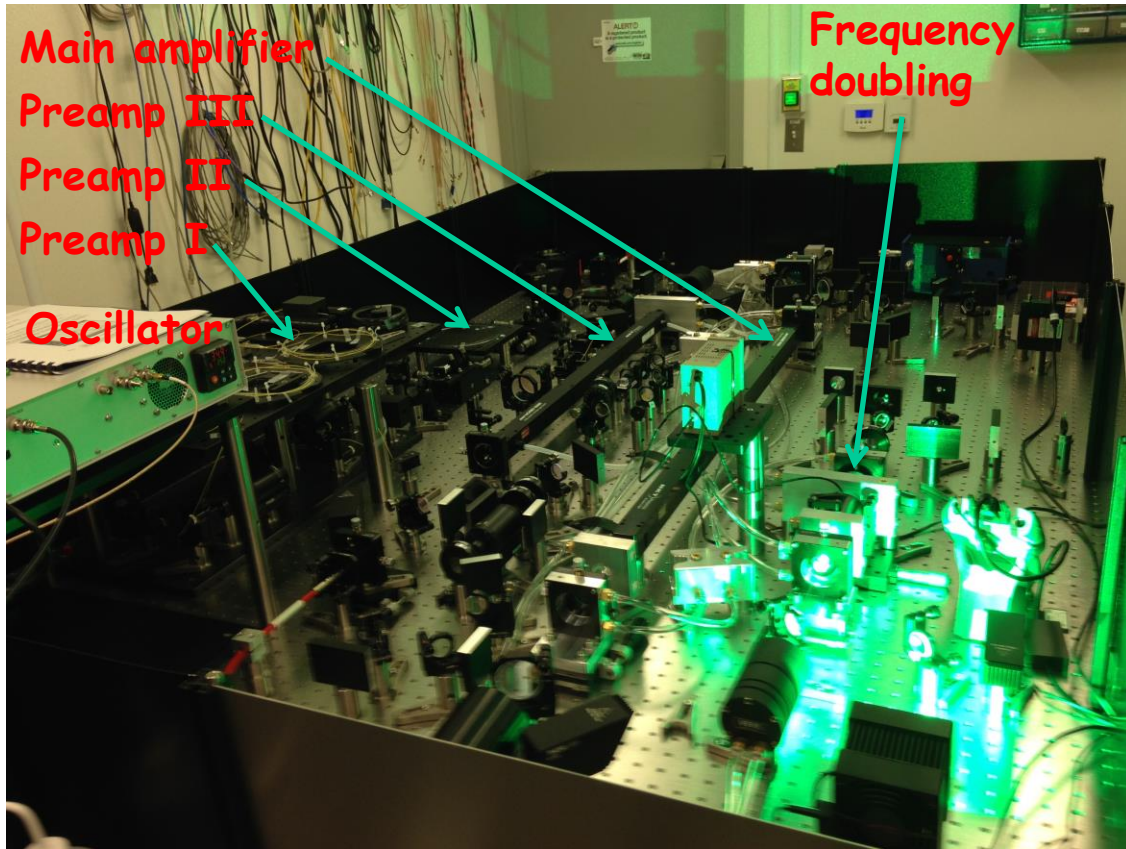
- **Diagnostic tools:** RF & optical spectrum analyzer, sampling oscilloscope, autocorrelators, CCD

- **Five chillers for temperature control**

- **Highest engineering standards**

Laser Control for Beam Operation

Layout of Laser Control for Beam Operation

SHG ← pulse picker2 ← High-power fiber amplifier ← pulse picker1 ← 704 MHz 1μm fiber oscillator

SHG → intensity control → temporal shaping → laser transport → spatial shaping → laser 1:1 imaging → DC gun
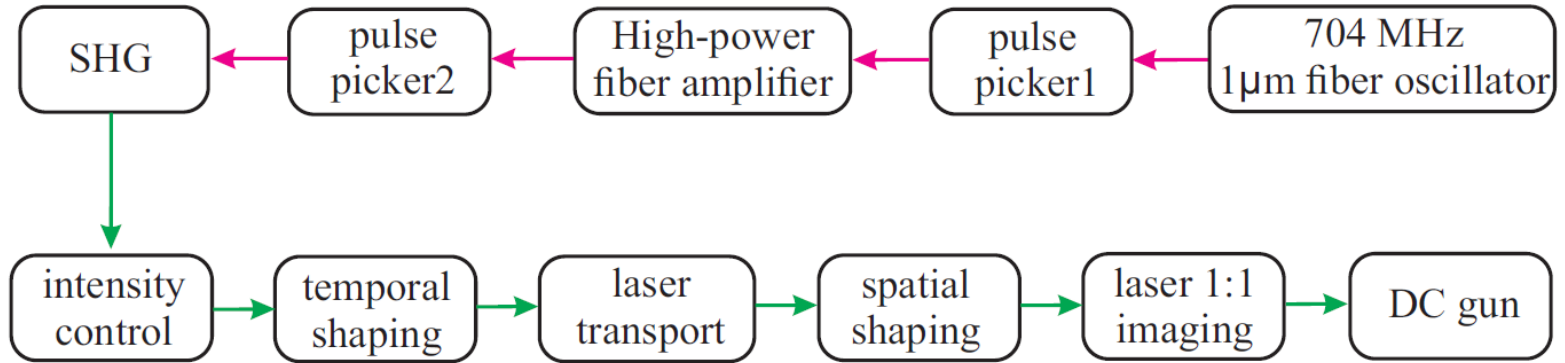
Key control

- Pulse pickers

- Intensity control

- Spatiotemporal shaping

Key diagnostics

- Laser power and QE

- Laser spatial profile

- Point stability on cathode

Laser vs RF Phase Locking
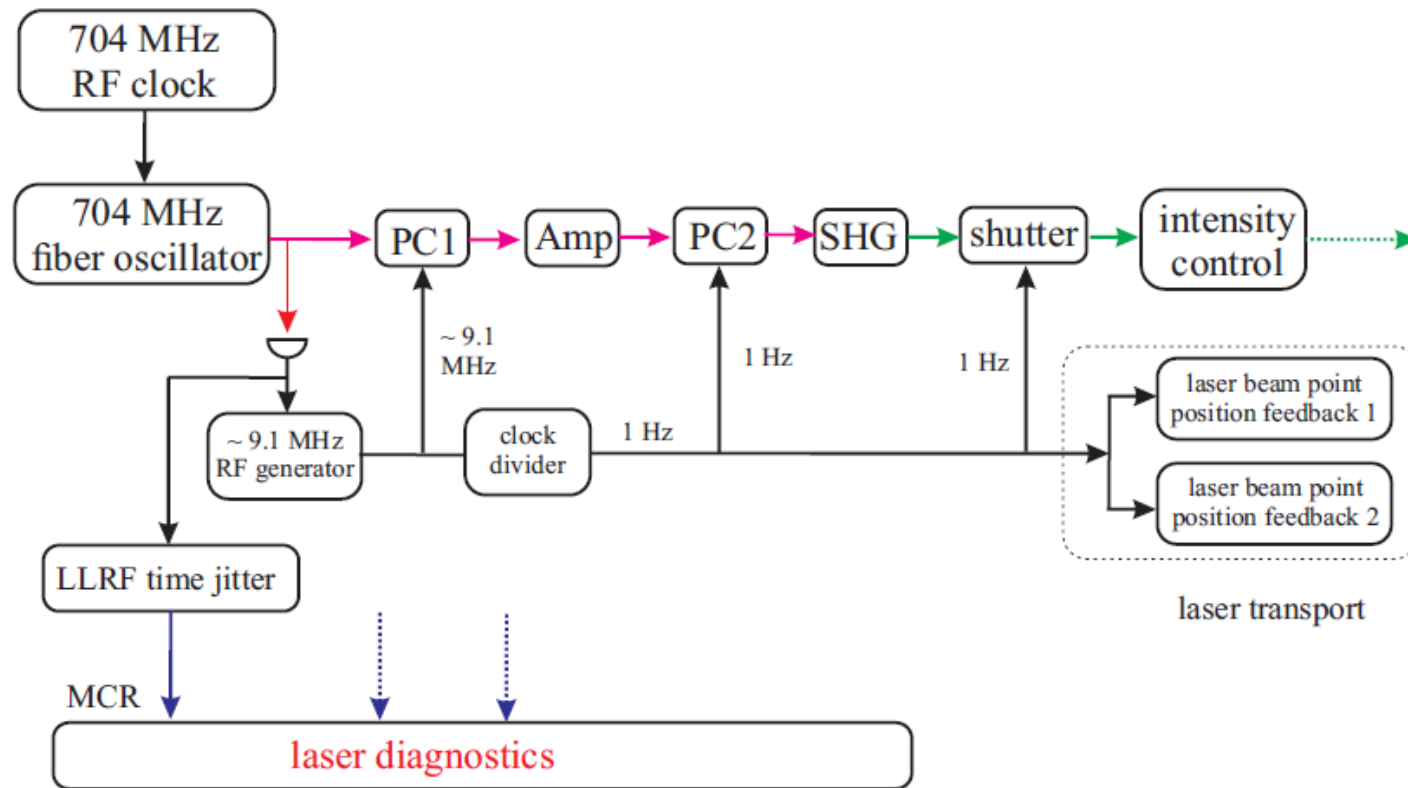
- **Both laser and RF cavities are locked to the same low-phase-noise RF signal generator;**

- **A feedback on RF phase is built to correct the phase slip between laser and RF cavities.**

Macro-bunch Generation: Pulse Picker1
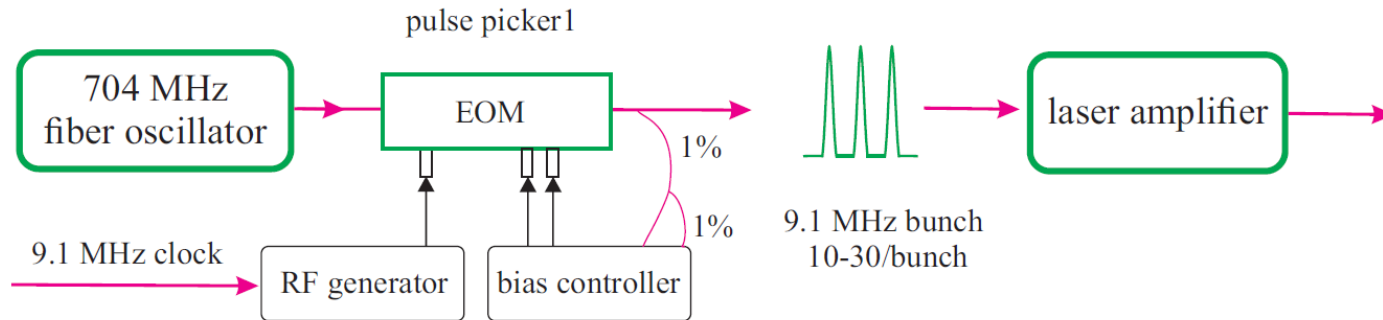
- **Mach—Zehnder intensity modulator**

- **Bias control for null locking with high extinction ratio: 45 dB**

- **RF on/off for activating pulse picker**
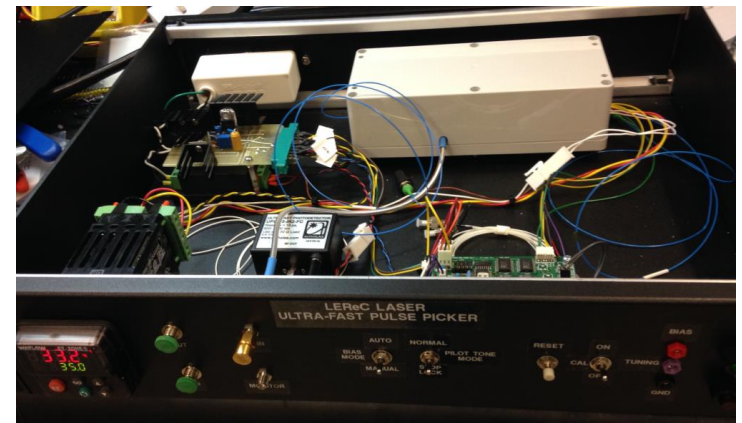
Pulse Picker 2

- **Bunch pickup for beam diagnostic**
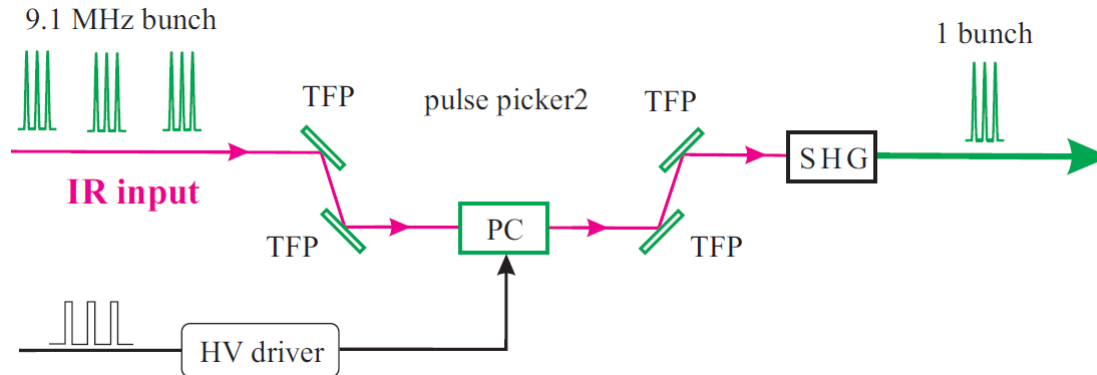
- **Three major requirements:**

1. **High extinction ratio:**

   1000:1@IR and 10^6:1@ green

2. **Fast switch time: ~ 5 ns**

3. **High average power: >100W**

Pockels Cell & driver
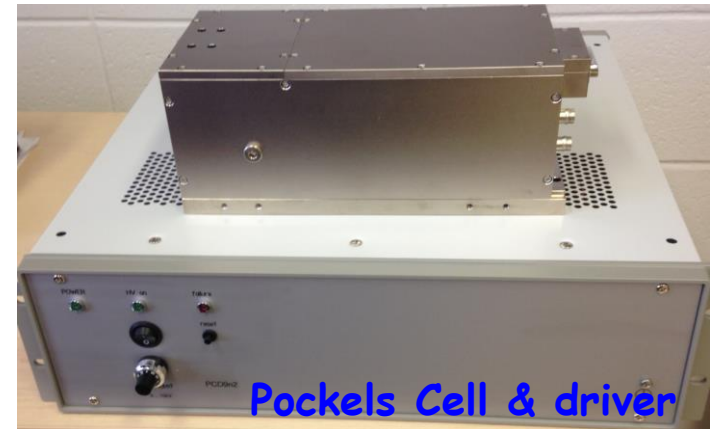
Fast shut-down for MPS in the pulsed mode

Intensity Control
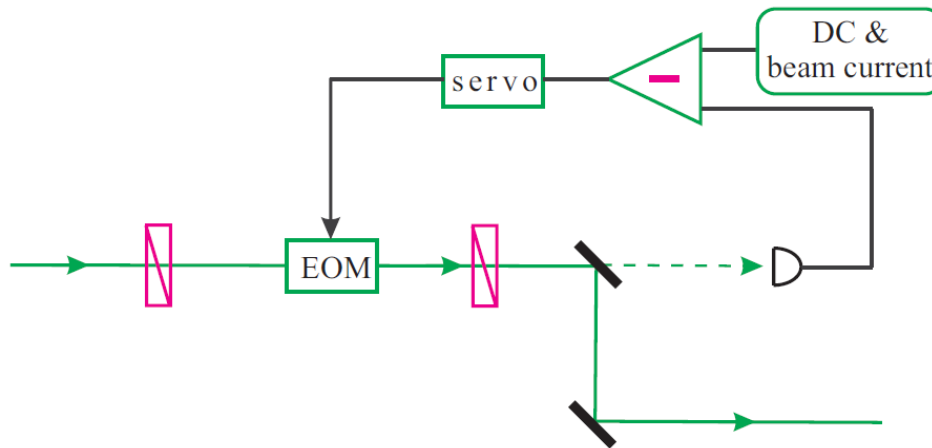
Three major functions:

- **Stabilizing green light intensity**

- **Stabilizing beam current**

- **1 μs rise time (EOM) for fast machine protection system**

To be commissioned during DC Gun Tests

Crystal Stack for Longitudinal Beam Shaping

YVO4 Crystal stack

Input pulses

Shaping pulses

BBO

PMT
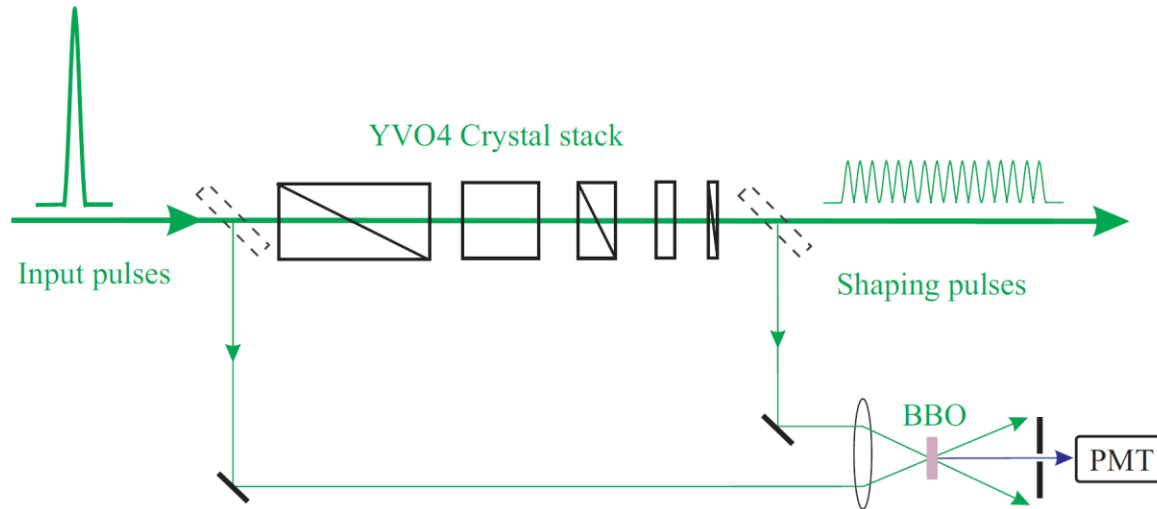
Specifications:

- Duration: 80 ps

- Rise & fall time: 2 ps

- Ripple modulation: 40%

Simulation
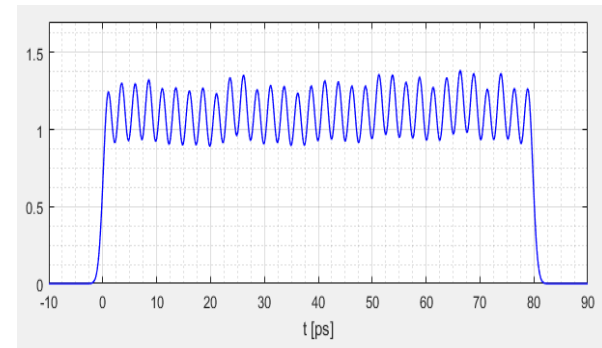
Free-space Laser Transport: Beam Optics

- **Laser beam transport**
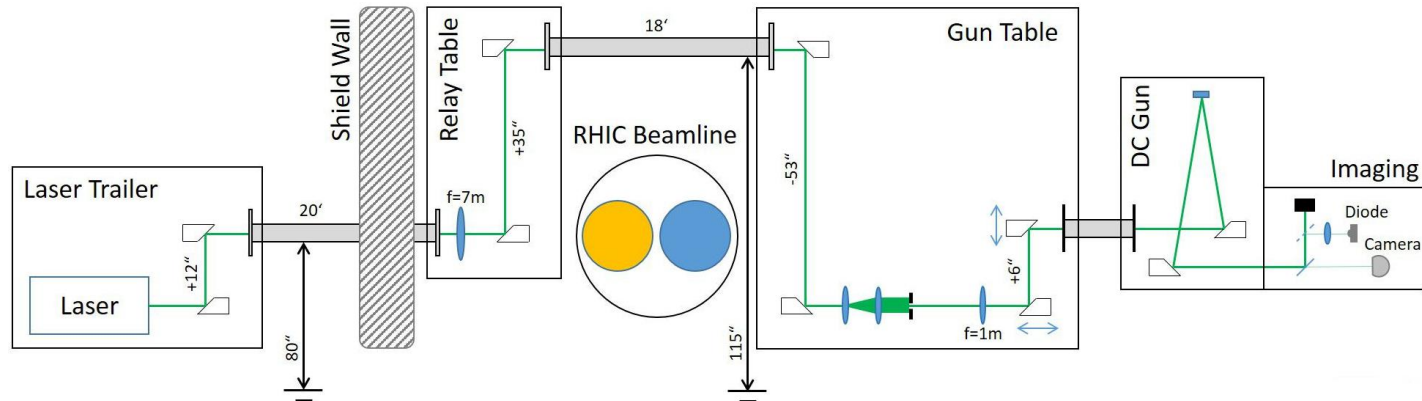
- **Laser beam optics: simulation (M^2 =1.1)**
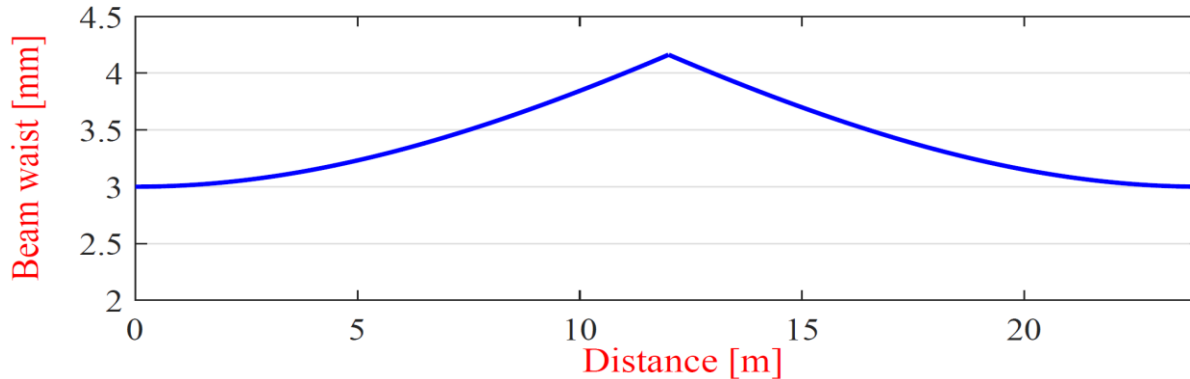
Laser Transport: Design & Engineering
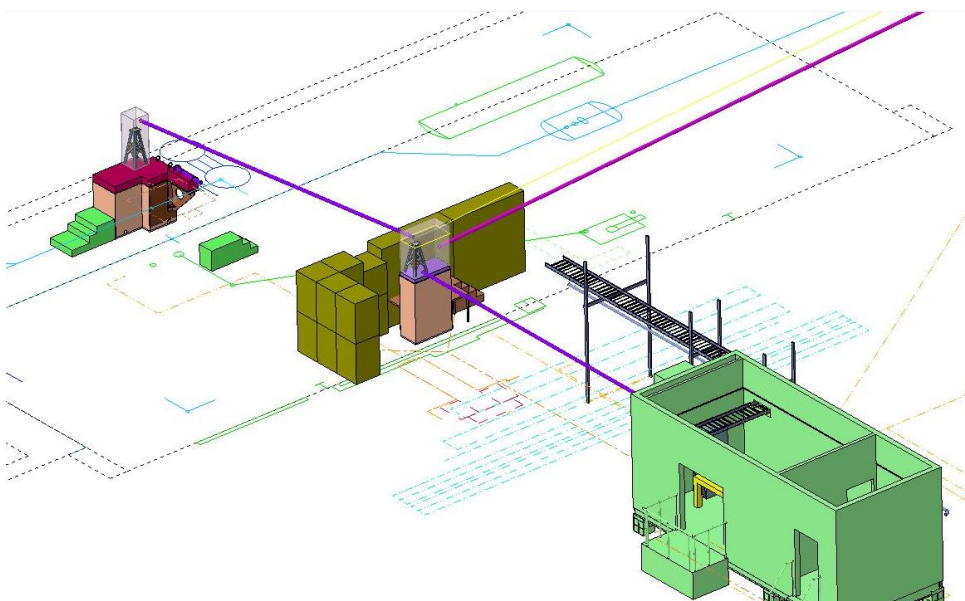
Laser table

Highest engineering standards:

- Vibration reduction in the laser room & tables;

- Vacuum pipes for the laser transport;

- Preventing any air flows by sealing laser boxes;

- Rigid mechanical mount and stands;

- Mirrors (R>99.97%), lens and view window (R<0.25%).

Relay & gun tables

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Laser Transport: Beam Stabilization

- **Laser decoupling from vacuum pipes**

- **Active laser beam stabilization**

laser relay box

actuator

vacuum pipe

lens:
f = 6 m

laser beam vertically
lifted by 40 inches

detector

vacuum pipe

laser transport

laser beam

actuator

DC gun

detector

closed-loop controller
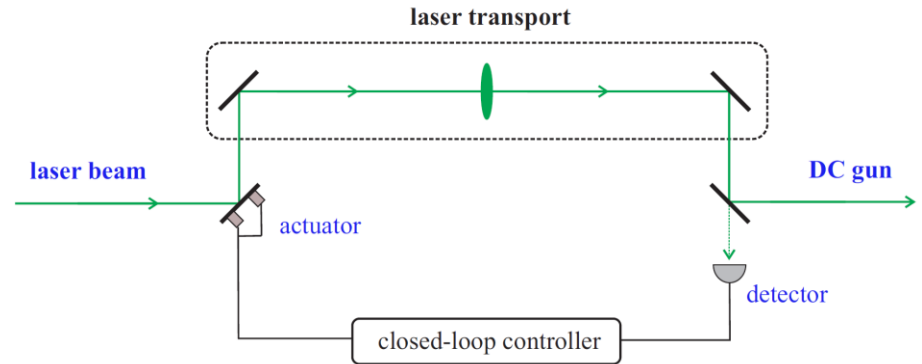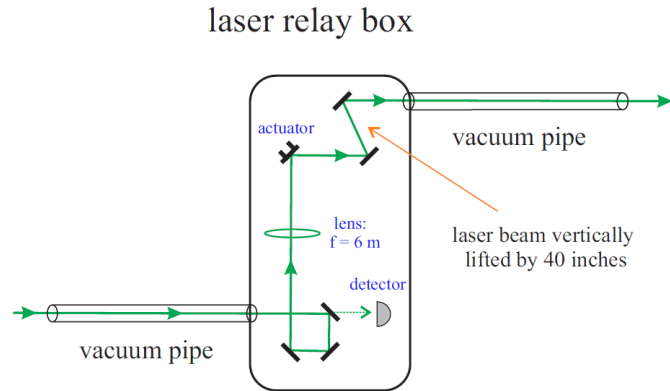
- **Target:**

1. **Correcting range:** **<2 mm**

2. **Vibration freq.:** **<500 Hz**

3. **Operation mode:** **cw & pulsed**

4. **Point instability:** **<10 μm**

Feedback OFF
Feedback ON

Amplitude [dB]

Frequency [Hz]
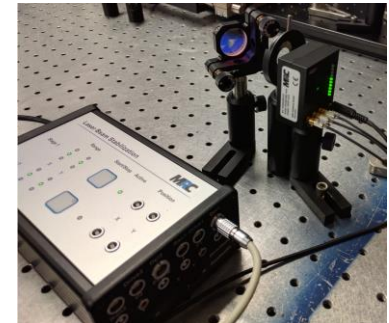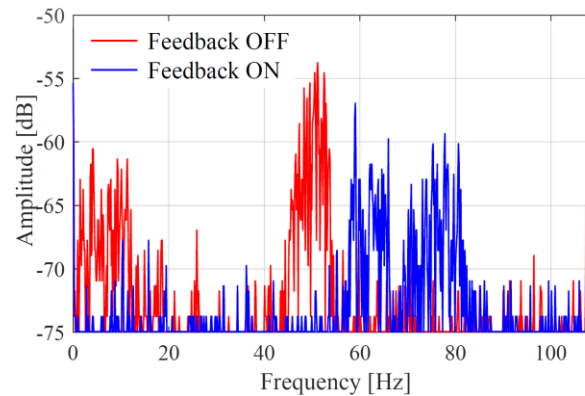
It is working!

Laser Spatial Shaping & Diagnostics

vertical translation

DC gun

PZT

from tunnel

PZT

pinhole

f = 75 cm

horizontal translation

4 mm

CCD & power meter

CCD & power meter
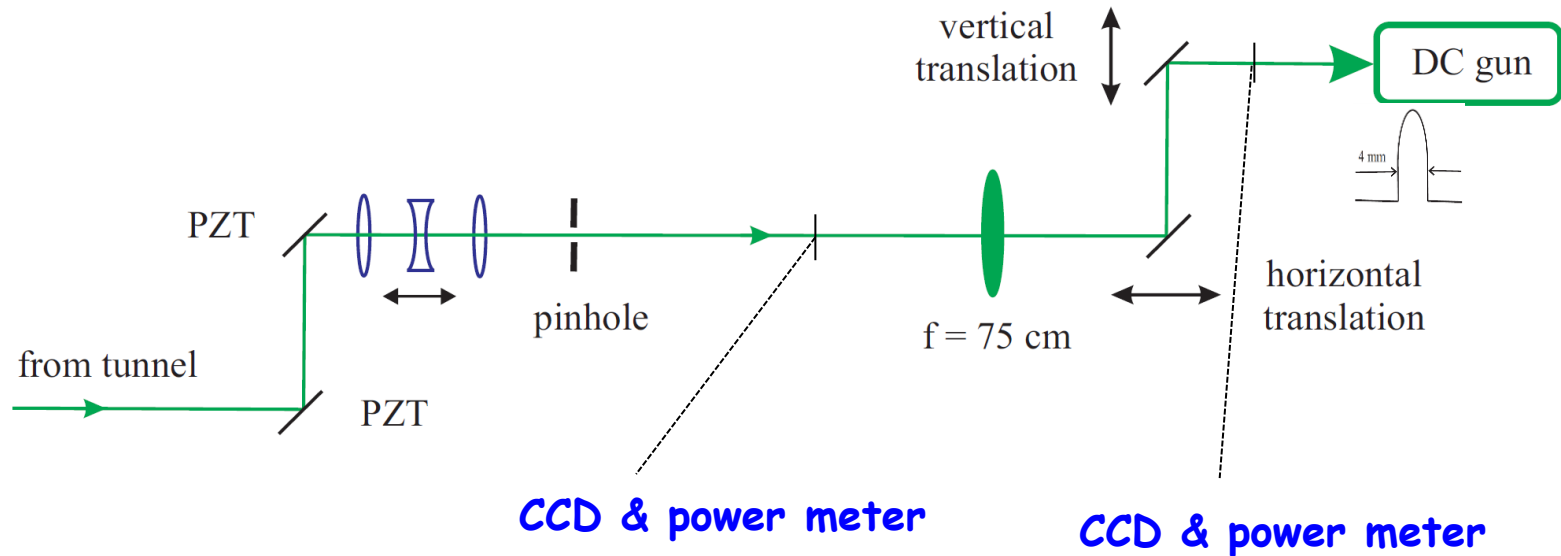
Laser control & diagnostics:

- **Spatial mode shaping and 1:1 imaging**

- **Motion control for beam optimizing & QE**

- **Laser power & spatial mode monitoring**

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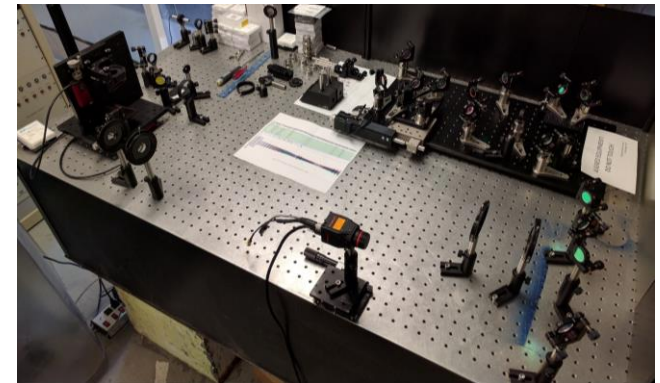
Conclusion

- **High-power fiber laser design specifications:** demonstrated

  Laser power (180W green, record in fiber laser), power stability (σ=0.5%), RMS time jitter (241 fs), excellent spatial mode (M^2<1.1), and laser point stability (σ<10 μm)

- **Laser control & transport:** to be done by December

  Pulse pickers, laser transport, spatiotemporal shaping, & diagnostics

- **Remaining laser topics:** during DC gun tests

  Intensity control, stability and reliability

- **Laser ready for beam operation:** December, 2016

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